COMPARISON OF COURTYARDS IN TRADITIONAL IRANIAN HOUSES IN DIFFERENT CLIMATES OF IRAN

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ETHICAL DECLARATION

I hereby declare that I am the sole author of this thesis and that I have conducted my work in accordance with academic rules and ethical behaviour at every stage from the planning of the thesis to its defence. I confirm that I have cited all ideas, information and findings that are not specific to my study, as required by the code of ethical behaviour, and that all statements not cited are my own.

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ABSTRACT

COMPARISON OF TRADITIONAL IRANIAN COURTYARD HOUSES IN DIFFERENT CLIMATES OF IRAN

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Master's Program in Architecture

Advisor: Asst. Prof. Dr. Athanasios Stasinopoulos

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Iran's diverse range of climates required people to adapt to climatic diversities by adjusting their houses' architectural designs. Courtyards have been a very important feature of Iranian architecture for centuries. Accordingly, traditional courtyards have been customized based on the needs of each region's climate to make them more compatible with their particular environment. In a traditional Iranian courtyard, dealing with the major environmental characteristics such as wind, sun, and energy to create a comfortable living environment that addresses the environmental features of the region is a crucial factor. The climatic adaptation of courtyard houses in Iran's different regions can shed light on the significance of climate in vernacular architecture and is worth paying attention to. Therefore, the present thesis studies the differences in the traditional courtyard in Iran's three climatic groups as these are specified by the Köppen–Geiger classification (arid, continental, temperate). Initially, the study introduces some influential examples of Iran's courtyard houses in arid (Yazd), continental (Tabriz), and temperate (Sari) climates, elaborating on and their

characteristics. Then the characteristics of each climate type are compared and discussed based on the design strategies proposed by the Climate Consultant [CC] software in order to understand to what extent those suggestions agree with the old practices. The results demonstrated a close agreement between the traditional courtyard houses in Yazd, Sari, and Tabriz and the CC design suggestions, optimizing the occupants' comfort time in a year.

Keywords: Climate, Comfort time, Environmental characteristics, Iran, Traditional Courtyard Houses.

ÖZET

İRAN'IN FARKLI İKLİMLERİNDEKİ GELENEKSEL İRAN AVLU EVLERİNİN KARŞILAŞTIRILMASI

Mousighichi**,** Pouya

Mimarlık Yüksek Lisans Programı

Tez Danışmanı: Dr. Öğr. Üyesi Athanasios Stasinopoulos

Ocak, 2023

İran'ın çeşitli iklimleri, insanların evlerinin mimari tasarımlarını ayarlayarak iklimsel farklılıklara uyum sağlamasını gerektirdi. Avlular, yüzyıllardır İran mimarisinin çok önemli bir özelliği olmuştur. Buna göre, geleneksel avlular, her bölgenin ikliminin ihtiyaçlarına göre özelleştirilerek, kendi çevreleriyle daha uyumlu hale getirildi. Geleneksel bir İran avlusunda, bölgenin çevresel özelliklerini ele alan rahat bir yaşam ortamı yaratmak için rüzgar, güneş ve enerji gibi başlıca çevresel özelliklerle uğraşmak çok önemli bir faktördür. Avlulu evlerin İran'ın farklı bölgelerindeki iklim adaptasyonu, yerel mimaride iklimin önemine ışık tutabilir ve dikkate değerdir. Bu nedenle, mevcut tez, İran'ın Köppen-Geiger sınıflandırması (kurak, karasal, ılıman) tarafından belirlenen üç iklim grubundaki geleneksel avludaki farklılıkları incelemektedir. Çalışmada öncelikle İran'ın kurak (Yezd), karasal (Tebriz) ve ılıman (Sari) iklimlerdeki etkili avlulu evlerinden bazı örnekler tanıtılmakta, özellikleri ve özellikleri üzerinde durulmaktadır. Daha sonra, bu önerilerin eski uygulamalarla ne ölçüde uyuştuğunu anlamak için, İklim Danışmanı [CC] yazılımı tarafından önerilen

tasarım stratejilerine dayalı olarak her bir iklim tipinin özellikleri karşılaştırılır ve tartışılır. Sonuçlar, Yazd, Sari ve Tebriz'deki geleneksel avlulu evler ile CC tasarım önerileri arasında yakın bir uyum olduğunu ve kullanıcıların bir yıl içinde konfor süresini optimize ettiğini gösterdi.

Anahtar Kelimeler: İklim, Konfor seviyesi, Çevresel özellikler, İran, Geleneksel Avlu evleri.

To all people who fled their homeland in pursuit of freedom and happiness…

ACKNOWLEDGMENTS

I would like to express my gratitude to my supervisor, Asst. Prof. Athanasios Stasinopoulos, this thesis would not have been possible without your input, insightful feedback, and supervision. And my mother and brother, I cannot forget to thank you for all the unconditional support throughout my life, I would never have been where I am without you two.

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CHAPTER 1: INTRODUCTION

1.1. Study context

Humans have always been eager to design spaces that fit their climatic, cultural, and social conditions (Nardi, 2019). However, due to the variable character of nature and the diversity of cultural and social backgrounds, there is hardly a single general formula for these spaces (Jiang et al., 2019). To put it another way, they had to make changes and adjustments to make their living conditions more comfortable in a variety of environmental and climatic situations and with diverse beliefs and cultures. As a result, the usage of environmental aspects in indigenous dwellings has long been recognized. Apart from the climate, building a suitable environment for human habitation necessitates consideration of beliefs and cultures to the extent that different structures are created under similar meteorological conditions (Valencia-Arias et al., 2021).

Traditional Iranian courtyard homes are good examples of vernacular architecture due to providing pleasant living spaces that are well-suited to their environment, society, and culture. In vernacular buildings, environmental sustainability components are common, and these considerations have influenced the design qualities for attaining comfort indoors (Afshar, 1964). Courtyards are a major architectural element for achieving this target, being enclosed areas that are generally open from the top, or in other words:

"An unroofed area that is completely or partially enclosed by walls or buildings, typically one forming part of a castle or house" (Lea and Runcie, 2002).

Furthermore, throughout the evolution of traditional courtyard house architecture in relation to each particular place and environment, several elements such as climate, renewable energy utilization, sustainable construction materials, and sociocultural conditions are taken into account. The climate in Iran varies greatly from region to region. Differentiating climatic circumstances have the greatest impact on building forms in Iran, which is why there are certain changes in the design of traditional Iranian courtyards based on their region.

The courtyard is an inseparable feature of traditional Iranian architecture, which, in addition to its cultural and religious significance, plays an important role in the utilization of renewable energies like sun and wind through their architectural design and orientations (Salavatian, 2022). The courtyard, in general, is in harmony with the

movements of the sun, where the southern side is the home of the shadow, and the northern side is the royal residence and the place of the sun. In addition to the daily function of each side, the organization and orientation of the summer and winter spaces were logically placed around the courtyard (Ranjbar Kermani, 2008). In architecture, the courtyards are utilized to provide a social center area in buildings for different events like weddings, religious events, etc. (Ghaffarianhoseini et al., 2015; Taleghani et al., 2015). Figure 1 depicts a few examples of courtyards in Iran's various climate zones, with Yazd and Kashan representing a hot and dry environment, Tabriz representing a cold and arid climate, and Kermanshah representing a warm and temperate climate. Figure 2 illustrates the geographical map of Iran.

Figure 1. Courtyard houses, Yazd (A), Tabriz (B), Kashan (C), Kermanshah (D) (Source: Maleki, 2021; Mirahmadi and Altan, 2018; Tripadvisor, 2019; Tripadvisor, 2022)

Figure 2. Geographical map of Iran (Source: Burningcompass, 2022)

There are various studies that have evaluate courtyards climatic adaptation in different eastern countries, by researchers from China (Xu et al., 2018), India (Gupta and Joshi, 2021), Saudi Arabia (Abuhussain et al., 2022), Tukey (Onur and Altuntas, 2022), and Iran (Teshnehdel et al., 2020) to name but a few. The evaluated criteria of most studies consist of layout of openings, green space connectedness (Taleghani et al., 2012), materials (Soflaei, Shokouhian, Abraveshdar, et al., 2017), layout proportions (Gupta and Joshi, 2021), geometric features (like the ratio of closed to open space, width to height ratio, and length to width ratio) (Zamani et al., 2018), and orientation (Soflaei et al., 2020).

Regarding the vernacular architecture's development and structure in different regions of Iran, it can be considered that the diverse characteristics of these climates

have significantly impacted the development of urban settlements as well as architectural structures. As a result, it is very important to determine the climatic regions of the country and its characteristics in a precise way to provide appropriate and coordinated approaches with the climate of each region.

1.2. Problem Statement

Iran has a diverse range of climates. In order for people to adapt to the climatic diversities, they needed to adjust their architectural styles. As a result, traditional courtyards have been modified based on the needs of each region to make them more compatible with their environment. In a traditional Iranian courtyard, employing environmental variables such as wind and sun to create a comfortable indoor living environment that addresses the environmental features of the region is a key factor. However, despite the benefits of courtyards according to the diverse climatic conditions in the past, today these structures have declined in popularity in Iran.

This study aims to examine the architectural characteristics of the traditional courtyard in Iran's three climatic groups based on Köppen–Geiger classification (arid, continental, temperate) (which are discussed in the next section) and identify relevant similarities and differences for a comparative evaluation of the role of climate as a design parameter.

1.3. Significance of Study

Courtyards in general provide various benefits regarding environmental, architectural, religious, socio-cultural, and psychological aspects which are extensively elaborated on the next section. This research considers the climatic factors in the evolution of traditional courtyards that are not being considered in Iran's architecture today. In this research general information about Iran includes the climate influence on the traditional courtyards. Unfortunately, in today's society, environmental considerations and their influence on the environment are not taken into account. Furthermore, architects must be inspired by traditional architecture due to its consideration of the environment in the design of buildings. In contrast to older settlements, newer settlements hardly take into account the environmental factors.

Therefore, this research will hopefully highlight the differences of available courtyard houses in Iran based on their climatic region and demonstrate the role of environment in the diversity of courtyard buildings.

1.4. Research Objectives

This work aims to explore the differences of courtyards in Iran as they were

developed by regional environmental parameters. An additional objective is to establish potential benefits that the courtyards might offer to contemporary buildings in the same climatic context.

Therefore, the primary purpose of this research is to understand the architectural factors of Iran's traditional courtyard houses in arid, continental, and temperate climates, and compare their differences.

1.5. Research questions

In brief, the current thesis's objectives are to answer the following questions according to the available literature on the given topic:

- What are the architectural factors of Iran's courtyard houses in arid continental, and temperate climate?
- What are the relative differences between the traditional courtyard houses in those climates of Iran?

1.6. Research Methodology

The present thesis utilizes a descriptive-analytical qualitative research method. At first, by reviewing the literature, the physical factors of the courtyards are identified (orientation, geometrical characteristic, materials, and dimensional ratios). Then, in order to investigate the difference between courtyards in various climates of Iran, the identified factors were compared between the existing examples of traditional courtyards in the three major climates (arid, temperate, and continental).

Furthermore, this study utilizes Climate Consultant [CC] software to identify the appropriate design strategies for modern houses in each climatic zone for creating comfortable living conditions for the occupants. Then it compares the suggested techniques with previously employed methods in traditional Iranian courtyards to overcome environmental harshness. Further explanations are provided in Section 3.2. All of the required data are extracted from various online sources. Figure 3 outlines the general framework of the research methodology.

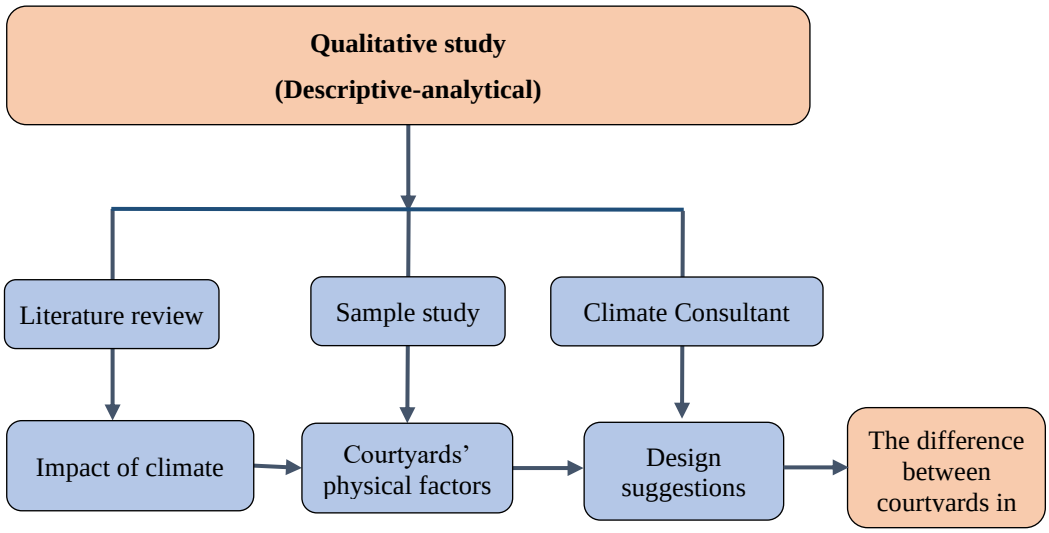


Figure 3. Research framework

1.7. Research limitations

Due to the range of study topic, the following limitations are present:

- There are several variations of Iran's climate but since the difference between the courtyard houses in adjacent climatic zones are not significant, we have chosen only three climate types (arid, continental, temperate) based on Köppen–Geiger classification to outline their differences.
- The Iranian traditional courtyards include also non-residential buildings, but due to the scope of the subject, they were excluded from the study.
- The CC proposed strategies refer to contemporary perceptions of comfort, which may differ from the ones in the past.

CHAPTER 2: BACKGROUND OF STUDY

2.1. Introduction

This section aims to offer an overview of Iran, its history, culture and climatic conditions. The climate is among the most significant factors that influence the design of vernacular dwellings, such as the usage of different parts of houses in different seasons. As a result, the topic of "climate" and its variations in Iran based on Köppen–Geiger climate classification will be studied in this section. Given the conditions in Iran, three climate groups namely "arid", "continental", and "temperate" will be considered. Further in this section, courtyards are described as architectural features, and their benefits, functions, and physical factors are discussed, with a greater attention on the impact of climate on them.

The main topics discussed in this section are:

- General information on Iran
- Culture
- Climate
- Courtyards
- The impact of culture on courtyards
- The impact of climate on courtyards
- Courtyard in Iran’s present architecture

2.2. Iran

Iran is located in Southwest Asia and shares borders with Turkmenistan, Afghanistan, Pakistan, Iraq, Turkey, Armenia, and Azerbaijan. Its area is 1648000 sq km and is located between 25° and 40° N and 44° and 63° E (Bahadori, 1973). Iran's border with its neighbors extends for a total distance of 4455 kilometers, according to recent estimations. Over half of that distance is bordering with water, with 650 kilometers on the southern Caspian shore and the remaining kilometers covering the northern parts of the Persian Gulf (Figure 2).

A part of the Iranian plateau, which is located in the middle of the wide and dry belt of Eurasia, forms the physical geography of Iran. The Alborz Mountain range separates the plateau of Central Iran from the alluvial regions of the Caspian Coast to the north. This range culminates at Damavand Mountain, which rises to a height of 5671 meters northeast of Tehran, and runs from the borders of Turkey and Armenia to Afghanistan's Hindu Kush (Ehlers, 1981). The Zagros Mountains range has impacted the area's

ecosystem, which cuts through western Iran. These two ranges and smaller ones in central Iran contribute to various climatic and environmental conditions.

2.2.1. Population

Iran had a population of about 10 million people in 1900 (then still named Persia), but in less than a century, it has increased by a factor of more than six. More than 60% of the population lives in urban areas; slightly less than 40% lives in rural areas; and the remainder is primarily made up of seasonal migrants. This country has traditionally had a higher share of urban residents than the rest of the world. For instance, in 1996, more over 60% of Iranians lived in towns, compared to 36% of people in underdeveloped countries and around 45% of people worldwide (Zandjani, 1998). Figure 4 depicts Iran's population growth throughout the years 1800 to 2017.

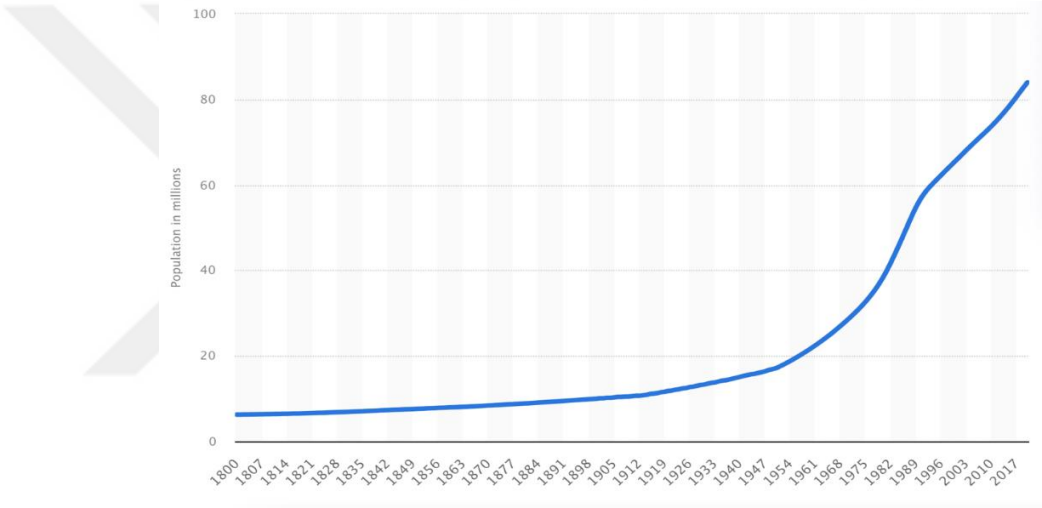


Figure 4. Iran's population (Source: Statista, 2022)

2.2.2. History

There are two distinct eras in the history of ancient Iran (Persia up till 1935): the time before the Aryans arrived and the time after they did. The pre-Islamic period and the Islamic period are further periods in the later era.

The existence of remnants of many ethnic groups' laws and civilizations during the Aryan era (a thousand-year BC) in this region is evidence of its ethnic diversity. All of these peoples descended from the Elamites. Depending on one's point of view, the Islamic era in Iran can be divided into a number of distinct periods. This period was one of the nation's most glorious and development-oriented periods, marked by the declaration of an official religion, the establishment of a powerful central government, the subjugation of regional warlords, resistance to foreign intrusion, a thriving economy, and rural and urban development, particularly in Esfahan and its magnificent

monumental architecture (Heidari, 2000).

A more detailed classification of Iran's chronology is presented in Table 1 (Daniel and Mahdi, 2006):

Table 1. Summary of Iran's history (4000 BC – Present)

ANCIENT IRAN, historically known as Persia	
ca. 4000 BC	Bronze Age settlements (Sialk, Hasanlu, Hessar).
2400–1600 BC	Elamite Kingdom.
ca. 728–550 BC	The Median Kingdom.
ACHAEMENID PERIOD (550–330 BC)	
ca. 550 BC	Cyrus the Great.
522–486 BC	Darius the Great.
331 BC	Alexander the Great defeats Darius III at Gaugamela.
SELEUCID AND PARTHIAN PERIOD (312 BC– AD 224)	
312–281 BC	Seleucus Nicator founds Seleucid Kingdom.
ca. 238 BC	Revolt of Arsaces, king of Parthia.
THE SASANID PERIOD (AD 224–651)	
AD 224	Ardashir defeats Parthians and founds Sasanid Dynasty.
AD 531–579	Khosrow I Anushirvan.
AD 637–642	Arab-Muslim armies defeat Sasanids at Qâdesiyeh and Nehâvand.
AD 651	Death of last Sasanid king.
CLASSICAL ISLAMIC PERIOD (AD 651–1040)	
AD 747	Abbasid Revolution in Khorâsân.
AD 874–999	Samanid Dynasty in eastern Iran.
AD 932–1055	Buyid Dynasty in Western Iran.
AD 994–1040	Ghaznavid Dynasty in eastern Iran.
TURKO-MONGOL PERIOD (AD 1040–1501)	
AD 1040	Battle of Dandânqân: Saljuq Turks in Khorâsân.
AD 1055	Saljuqs seizure Baghdad.
AD 1219	Start of Mongol invasion.
AD 1256–1349	Mongol Il-khanid Dynasty.
AD 1380–1393	Conquests of Timur (Tamerlane).

Table 1 (continued)

SAFAVID AND EARLY MODERN PERIOD (AD 1501–1797)	
AD 1501	Shah Esmâ'il establishes Safavid Kingdom.
AD 1587–1629	Shah 'Abbâs the Great.
AD 1722	Afghan attack and siege of Isfahan.
AD 1736–1747	Nâder Shah.
AD 1750–1779	Karim Khân Zand.
THE QÂJÂR PERIOD (AD 1797–1925)	
AD 1797	Âghâ Mohammad Shah establishes Qâjâr rule.
AD 1804–1813	First Russo-Persian War.
AD 1826–1828	Second Russo-Persian War.
AD 1921	Coup d'etat by Rezâ Khân and Ziâ-od-Din Tabâtabâi.
PAHLAVI IRAN (AD 1925–1979)	
AD 1925	Constituent Assembly chooses to inaugurate monarchy under Rezâ Shah Pahlavi.
AD 1962	Inauguration of the White Revolution.
AD 1967	Coronation of Mohammad-Rezâ Shah.
AD 1971	Celebration at Persepolis of 2,500 years of kingdom in Iran.
AD 1979	Mohammad-Rezâ Shah leaves Iran; Shâpur Bakhtiâr fails to inaugurate a transitional government.
THE ISLAMIC REPUBLIC (AD 1979 TO PRESENT)	
AD 1979	Âyatollâh Khomeini returns to Iran; Establishment of the Islamic Republic of Iran.
AD 1980–1988	Iran-Iraq War.
AD 1989	Choosing Âyatollâh Khamenei as Iran's supreme leader.

2.3. Culture

"Culture" has been a polysemous term for a very long time. Although Cicero had already used the phrase figuratively to refer to philosophy (Jahoda, 2012), the word's origins are in the Latin verb *colere*, which means "to cultivate" (Cobley, 2008). A racial, religious, or social group's traditional beliefs, social structures, and material characteristics are what Merriam-Webster defines as their culture today.

2.3.1. Culture and civilization in Iran

The region occupied by the modern country of Iran, previously was home to simple

semi agrarian cultures as early as 13,000 BC However, the plateau's conditions did not favor the growth of sophisticated agricultural cultures observed in other Fertile Crescent regions. That had to wait for the creation of an effective irrigation system, today known as the *kariz* or *qanât* system, at an indeterminate but late date because there were no big rivers to exploit. This is a network of underground channels to carry water by gravity fed from highland water tables to fields at lower elevations (Beaumont, 1971). Consequently, pastoralism, which encompasses the management and husbandry of cattle with the aim of securing sustenance, either through the exploitation of limited vegetation or through commercial interactions with trading communities, overshadowed agriculture as the predominant mode of subsistence in specific regions. These trading societies played a crucial role as providers of raw materials, such as metal, to the extensive urban centers of Mesopotamia and the Indus Valley. Furthermore, pastoralism often entailed a nomadic lifestyle, characterized by the periodic migration of the herd and the pastoral community in search of fresh grazing lands and water sources.

Only in the southwest, near the *Kârun* River, were the geographical conditions favorable for developing an early civilization. Although this region was essentially just an extension of the Mesopotamian plain and was influenced by the Mesopotamian civilization, it was eventually inhabited by a tribe known as the Elamites, who had clear ties to the plateau. They established a kingdom in 2700 BC, and between 1500 and 1100 BC, they rose to prominence, even managing to overthrow and sack Babylon briefly.

The Elamites established the earliest known civilization in the region of Iran, yet despite this, they were not ethnically "Iranian" because they spoke a distinct language that was unrelated to any other group of languages. People referring to themselves as Aryans (from a word that likely means "noble") and speaking Iranian languages first arrived on the Iranian plateau about the time that their (Elamites) empire was at its height. It is challenging to pinpoint and is subject to intense debate among experts on how these Iranians came to be separated from the closely similar Indo-Aryans (who migrated into the Indus Valley) and brought to the plateau. However, it is evident enough that Iranian tribes had made it to the Zagros by the start of the first millennium BC. The Assyrians attacked one of these tribal groups, the Medes, between 881 and 788 BC. The Medes finally formed a kingdom in response, with Ecbatana (modern Hamadân in the central Zagros) serving as its capital. The Medes joined forces with

Babylon under King Cyaxares (625–584 BC) to subjugate the Assyrians. They eventually pushed into Asia Minor (modern-day Turkey), where they negotiated a border along the Halys River following an unsuccessful conflict with the Lydians.

The Achaemenid kings expanded their realm from northern India to Egypt under the leadership of Darius the Great and Xerxes. In 330 BC, Alexander the Great marched through and overthrew the Achaemenid Empire. Shortly after, he passed away, leaving his generals and their heirs to build their sub-empires. At the start of the third century AD, the subdivision process resulted in the creation of the Sassanid Empire, which was wholly Persian. To the east, toward China and India, the Sassanians united all the lands.

The Arab Muslims who ascended from Saudi Arabia in 640 AD were another enormous conqueror. They gradually assimilated into the Iranian population, and in 750, a revolution that originated on Iranian land ensured the Persianization of the Islamic world through the establishment of the vast Abbassid Empire at Baghdad.

In the early sixteenth century, the Safavids, a developing religious movement, responded forcefully to the series of Mongol raids that began in the thirteenth century at a time of relative instability. As the Safavid Empire's capital, Isfahan was one of the most sophisticated cities, much ahead of most of Europe. Afghan and Qjr Turk invaders both arrived and adopted Persian culture. Iran first connected with European societies during the Qjr period (1899 to 1925). From the 1890s to the 1970s, a series of popular demonstrations against the throne occurred during the Qjr period. These demonstrations frequently involved religious leaders and persisted throughout the Pahlavi dynasty's rule (1925–1979). The Islamic Revolution of 1978–1979—hereafter referred to as "the Revolution"—was the culmination of these demonstrations (Menashri, 1990).

2.4. Climate

2.4.1. Definition of climate

Climate is described as "the regular pattern of meteorological conditions in a given place" in the Oxford English Dictionary. A logical and semantic definition of climate is "a time integration of the physical conditions of the atmospheric environment, unique to a specific geographical area," according to Koenigsberger et al. (1974). In this theory, time and place—both of which can produce an infinite number of climates—are two essential components. Additionally, these varieties could be changed by both natural and man-made factors.

An important environmental factor that affects people's life is the climate. A specific weather pattern's temperature, precipitation, amount of rain, humidity, and ventilation are all referred to as the climate (Szokolay, 1980).

2.4.2. Climatic classification

Precise delineation of the border for climatic zones is hazy, if not impossible. On the other hand, climate classification is crucial for an ideal approach to building design with climatic concerns and is closely related to the volume of data regarding climatic developments. A building's primary purpose is to provide its occupants with a secure and comfortable environment. To create a single, distinct climate zone, climate factors that support a certain method of heat dissipation from the human body and require the usage of particular specialized qualities in building design are grouped together (Heidari, 2000).

2.4.3. Iran's climatic classification

Most of Iran is located in a temperate region with latitude between 25- and 40-degrees north latitude. Iran has a high plateau with a majority of its territory rising beyond 475 meters above sea level. Although Iran is sandwiched between two sizable water basins (the Caspian Sea and the Persian Gulf), the effects of these basins are only felt in the immediate vicinity due to the Alborz and Zagros Mountain ranges (Figure 5) and their geographic location. Because of this, these enormous water basins rarely have an impact on controlling the temperature of the country's interior.

Iran is a vast country in terms of land area, which has led to a diverse climate that includes a wide range of temperatures from subtropical to subpolar. During the winter, high-pressure systems pass through Iran's western and southern areas. On the other side, low-pressure systems develop over warm waters like the Indian Ocean, the Persian Gulf, and the Caspian Sea. The Alborz and Zagros Mountain ranges and their locations, even though Iran has two significant water basins (the Caspian Sea and the Persian Gulf), confine the influence of these two basins to areas that are pretty close to them. Because of this, these enormous water basins rarely impact controlling the temperature of the country's interior.

Figure 5. The Alborz and Zagros Mountain ranges (Source: Worldatlas, 2022)

Undoubtedly, a mountainous region like Iran has a diverse spectrum of climatic conditions. Due to this, during the coldest winter months, the temperature difference between Iran's hottest and coldest regions may frequently reach more than 50 degrees Celsius (Modarres, 2006).

There are several climate categorization systems available. Iranian climatic zones were categorized by Hariry and Millany (1985) into eight distinct types, Kassmai (1992) grouped Iran into 12 separate categories, and UNFCCC (2017), has a climatological variety with three kinds of climate. Among those, the Koppen (1936) approach is the most widely accepted by pundits and scientists alike.

A number of scholars have utilized the Köppen technique to develop a climatic zoning map for Iran; the first one was released in 1965 by Ganji (1955), and it was created using data from 56 meteorological stations dispersed around the nation at the time of the study but with a short statistical period. A few years later, Adl (1960), using 66 meteorological stations dispersed over Iran, once more used the Köppen technique to split the nation. Although it differs from the preceding two maps in certain specifics, Javadi (1966) published another climate zoning of Iran using the Köppen method, which is entirely congruent with them in illustrating the overall structure of Iran's

climatic zones (Khalili et al., 1991).

The Köppen method was never used to pinpoint Iran's climate areas until 2008. In their book, Iran's climates using the Köppen technique, Masoudian and Kaviani (2008) published a map of Iran's climatic areas that, in contrast to the climatic maps of Ganji (1955), Adl (1960) and Javadi (1966), provides more significant specifics of the climatic regions of Iran.

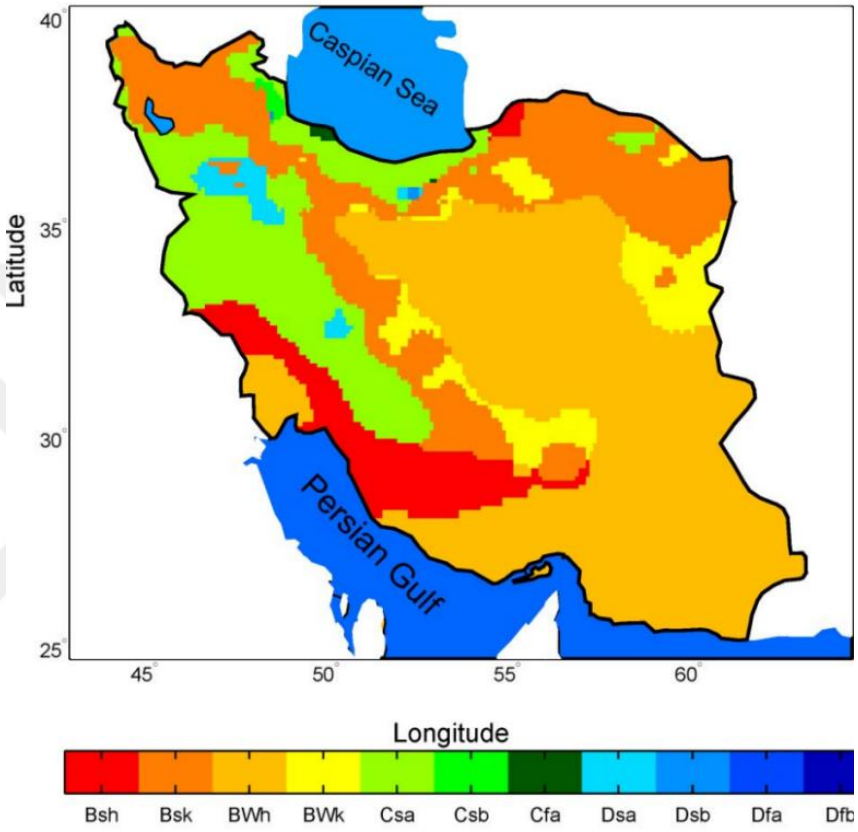


Figure 6. Köppen–Geiger climate classification map of Iran (Source: Raziei, 2017)

The produced climate map now shows more information about the country's climate zones thanks to the Köppen-Geiger method and the usage of numerous additional stations with a nearly regular distribution throughout the nation (Raziei, 2017). Therefore, although there are various classifications for Iran’s climate, a good way to achieve a basis for determining the country's climatic zones is the Köppen–Geiger climate classification (Figure 6). On the other hand, since the difference between traditional courtyard houses in the adjacent climatic zones are insignificant, this study has split Iran into three groups with nine distinct climatic zones (Table 2) to clearly underline these differences.

Table 2. The characteristics of Köppen–Geiger climate classification

Climate groups		Types	Description
1	Arid	BWh	Hot desert climate
2		BWk	Cold desert climate
3		BSh	Hot semi-arid climate
4		BSk	Cold semi-arid climate
5	Temperate	Csa	Hot-summer Mediterranean climate
6		Csb	Warm-summer Mediterranean climate
7		Cfa	Humid subtropical climate
8	Continental	Dsa	Mediterranean-influenced hot-summer humid continental climate
9		Dsb	Mediterranean-influenced warm-summer humid continental climate

2.4.4. Characteristics of Iran's climates

Every climatic zone has distinctive characteristics that reflect the particular circumstances of the area. These comprise the quantity of precipitation annually, the average wind speed, and the average monthly temperature. Each of these characteristics will be explored in relation to a particular city as a representative of its climatic zone in Iran. The current thesis has studied "Arid, BWh (Hot desert climate) - Temperate, Cfa (Humid subtropical climates) - Continental, Dsa (Mediterranean-influenced hot-summer humid continental climate)" which are further explained in part 3. In addition, as shown in figure 6, the selected climatic zones (BWh, Cfa, and Dsa) are the predominant climatic zones of the respective climatic groups to which they belong.

Group B: Arid climates

The desert climate or arid, is a dry climate sub-type in which there is a severe excess of evaporation over precipitation. Desert climates often have bare, rocky, or sandy surfaces that are dry and don't hold much rainwater, so what little rainfall they do get soon evaporates. Hot deserts climates have some variations:

- BWh; Hot desert climate

In this climate, clear skies and high pressure above lead to hot, arid conditions with intense sunlight. When the sun is at its strongest in the summer, sweltering heat rules, average temperatures during the hot months often range between 29 and 35 °C (84 and 95 °F), with noon readings of 43 to 46 °C (109 to 115 °F) being typical. Due to the high radiation loss under the clear skies, nighttime temperatures can fall to zero or below during the year's colder months. Under the cold subtype, temperatures do occasionally fall far below freezing. This desert is inhospitable to most species due to

the nearly constant high pressure, nearly permanent removal of low-pressure systems, dynamic fronts, and atmospheric disturbances, sinking air motion, dry atmosphere near the surface and above, and the exacerbated exposure to the sun where solar angles are always high.

- BWk; Cold desert climate

Summers in cold desert climates (BWk) are normally hot (or warm in some cases), dry, however, they are not typically as hot as summers in hot desert climates. Cold desert climates, as opposed to hot desert climates, typically have chilly, dry winters. In areas with this climate, snow usually falls in infrequent and small amounts. There is no more than 200mm of precipitation per year and a mean annual temperature of less than 18 °C in this climate.

- BSh; Hot semi-arid climate

These climates typically feature mild to cool summers and occasionally very hot winters with little or no precipitation. Hot, semi-arid climates are most frequently found around the edges of subtropical deserts. They typically have a Mediterranean-style precipitation pattern, with rainier winters and dry summers.

- BSk; Cold semi-arid climate

Cold semi-arid climates usually feature warm to hot dry summers, though their summers are typically not quite as hot as those of hot semi-arid climates. Areas with cold semi-arid climates typically have a cold and maybe even freezing winters, in contrast to hot semi-arid regions. Winter snowfall is common in these areas; however, it is significantly less than in places with more humid climates at similar latitudes. There are sometimes significant temperature differences between day and night, sometimes by as much as 20 °C (36 °F) or more, in regions with cold semi-arid climates, which tend to have higher elevations than regions with hot semi-arid climates.

Group C: Temperate climates

The coldest month in this type of climate has an average temperature between 0 °C (32 °F) and 18 °C (64.4 °F), and at least one month has an average temperature above 10 °C (50 °F). A location is considered to have a wet summer when more precipitation falls during the summer months than during the winter months, and a location is considered to have a dry summer when more precipitation falls during the winter months, for the distribution of precipitation in locations that both satisfy a dry summer and a dry winter.

- Cfa; Humid subtropical climate

A climate zone characterized by hot, humid summers and cold to mild winters is known as a humid subtropical climate. In this climate, the mean monthly temperature ranges from 0 °C (32 °F) to 18 °C (64 °F) in the coldest month to at least 22 °C (72 °F) in the warmest month. When monsoons are strong, rainfall frequently peaks in the summer. In contrast to Mediterranean climates, other regions have more regular or variable rainfall cycles, but they never have any reliably dry summer months. Due to the severe surface heating and great subtropical sun angle, thunderstorms that develop in the summertime produce the majority of the season's rainfall.

- Csa; Hot-summer Mediterranean climate

This subtype of the Mediterranean climate (Csa) is the most common form of the Mediterranean climate; therefore, it is also known as a "typical Mediterranean climate".

Regions with this type of Mediterranean climate see average monthly temperatures exceeding 22.0 °C (71.6 °F) in the warmest month and averaging between 18 and 3 °C (64 and 27 °F) or, in certain cases, between 18 and 0 °C (64 and 32 °F) in the coldest month. To avoid developing into a cold Mediterranean subtype, at least four months must average over 10 °C (50 °F). This type of Mediterranean climate is characterized by hot, occasionally extremely hot, dry summers and warm, wet winters. In many cases, the summers here can be quite similar to and close to the thresholds for the summers found in arid and semi-arid regions. Due to the proximity of a sizable body of water, summer high temperatures are typically not as extreme as those in arid or semiarid areas. This subtype's locations all experience wet, moderate winters. Some regions with a hot Mediterranean subtype, however, might actually have quite frigid winters with sporadic snowfall.

- Csb; Warm-summer Mediterranean climate

This subtype of the Mediterranean climate (Csb), which is also sometimes called the "Cool-summer Mediterranean climate," is less common and has warm (but not hot) and dry summers. Its warmest month never averages temperatures above 22 °C (72 °F), and its coldest month typically has average temperatures between 18 and 3 °C (64 and 27 °F) or, in some cases, between 18 and 0 °C (64 and 32 °F). Again, the average temperature must be above 10 °C (50 °F) for at least four months. The seasons are wet and can range from pleasant to frigid. In these regions, snow may occasionally fall. Even while it rains more frequently during the colder seasons, there are still plenty of

clear, sunny days.

Group D: Continental climates

Continental climates often have a significant annual variation in temperature (hot summers and cold winters). Precipitation in continental regions typically occurs in moderate amounts, mainly during the warmer months. Snow typically covers the ground for more than a month and makes up a percentage of the annual precipitation. In continental areas, summers can be stormy and frequently hot, although summer weather is generally more consistent than winter weather.

- Dsa; Mediterranean-influenced hot-summer humid continental climate
- Dsb; Mediterranean-influenced warm-summer humid continental climate

The coldest month average in these two climates is below 0 °C (32 °F) (or 3 °C (27 °F)), the warmest month average is above 22 °C (71.6 °F), and at least four months average above 10 °C (50 °F). The wettest month of winter receives at least three times as much precipitation as the driest month of summer in a Mediterranean-influenced hot-summer humid continental climate. In contrast, the driest month of summer receives less than 30 mm (1.2 in).

The difference between Dsa and Dsb climates is that Dsb has relatively cooler summers with more precipitation when compared to Dsa.

Within the framework of this thesis, a thorough examination was conducted to compare and contrast the traditional courtyard houses in Iran across three climatic categories, specifically arid (BWh), continental (Ds), and temperate (Cfa).

2.5. Courtyard

2.5.1. History of courtyards in Iran

A courtyard is a kind of room in a building without a roof; “An unroofed environment that is completely or partially surrounded by walls or buildings, normally one developing part of a large dwelling.” (Lea and Runcie, 2002). There are numerous variations of courtyard residences that have been created throughout the world. Looking back in time, the courtyard has been a revered building style (Bridson and Design, 2012). A courtyard is the essential characteristics of traditional courtyard homes. Its designation as a courtyard stems from the arrangement of the spaces constructed around it, particularly in the courtyards of large buildings, and the closure of such courtyards on four sides with rooms or at the very least with walls (Afshar, 1964). Various generic courtyard forms with one or two floors are illustrated in Figure 7.

The courtyard form has been used for more than 6000 years, according to the findings of ancient excavations in Iran's Qazvin province (Pirnia, 1990). The climate and culture of a particular region's inhabitants influence a courtyard's qualities; for instance, a courtyard may be used as an indoor garden or as the house's focal point. The Middle East's earliest cultures are listed as Sumer, Pharaonic Egypt, and Persia, and thousands of years of diverse courtyard dwelling and design have been chronicled (Bekleyen and Dalkiliccedil, 2011).

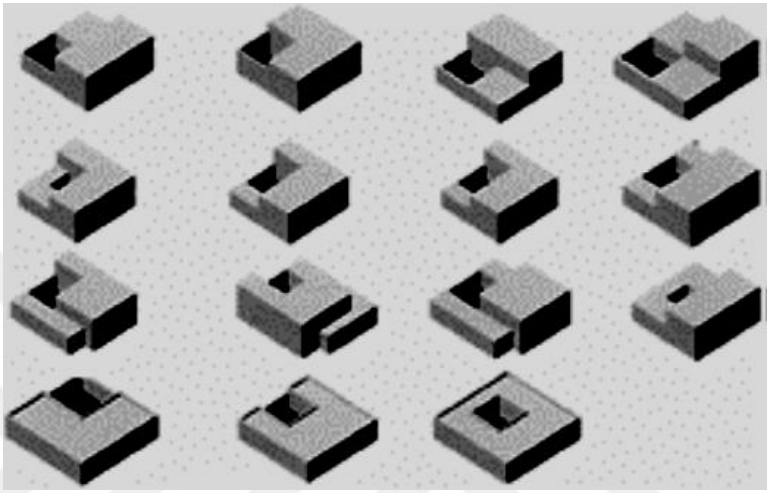


Figure 7. Different possible forms of the courtyard with one or two stories (Source: Edwards et al., 2006)

In both the pre-Islamic and Islamic eras of Iranian history, courtyards were one of the most important architectural elements. The enclosed pattern, which is considered the essential notion of Iranian architecture, has been used in dwellings, palaces, bazaars (marketplaces), and mosques, among other structures. According to Memarian and Brown (2003), the courtyard's continued popularity as a desirable form in Iranian architecture is shown by its widespread application in a variety of construction types. According to (Pirnia, 1990), Persepolis is one of the earliest surviving instances of a courtyard (in a non-residential architecture) in history. A re-construction of the spatial structure of Persepolis palace by archaeologists has been made, despite its state of disrepair, and they confirm that the buildings were arranged around the central courtyards.

2.5.2. Courtyard houses

Constructing a home suitable for a particular environment involves substantial expertise and knowledge. Developing technological skill and lifestyle knowledge go hand in hand. Especially when dealing with a traditional community, one must first comprehend the way of life in order to have a deeper understanding of architecture.

Building shelter has always been the choice for constructing a protected environment, both against the harshness of the climate and as a statement of a way of life, according to Rapoport (1969). This helps to explain why some people live in tents while others do in substantial mud structures in the same setting. Figure 8 explains an Iranian courtyard house example with its plan.

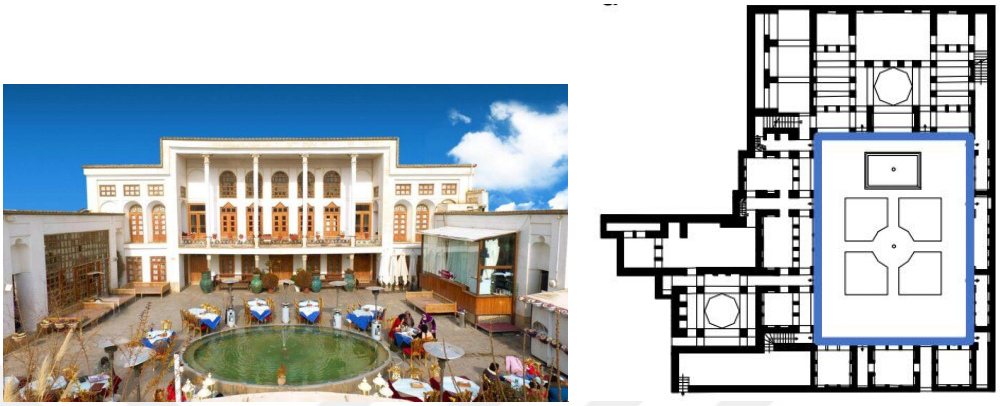


Figure 8. An Iranian courtyard house example (Source: Pinorest, 2022)

In reality, by taking into consideration the cultural, social, and climatic elements, a range of adaptation mechanisms have been used throughout the history of man's experience with living in different climatic settings to create comfortable conditions. Iranians who live in traditional homes have long made an effort to meet their heating, cooling, and lighting demands by utilizing available resources and techniques. The classic courtyards that we see today are the result of numerous iterations over a lengthy period of time to address their challenges and provide a comfortable living environment. The growth of these structures was impacted by changes in people's wants brought on by gradual changes in their society (Mohsen, 1978).

Iranian architecture has undergone significant alterations, especially since Islam changed significant cultural and social development in Iran. One of these architectural designs that had to evolve and adapt with the rise of Islam and the imposition of a new culture was the courtyard house. As a result, this part's other goal is to investigate how Islam shapes the living conditions of its adherents to meet the new cultural milieu.

2.5.3. Characteristics of Iranian courtyards in general

Aside from the literature mentioned earlier, there are many available studies covering various subjects regarding traditional courtyard houses in Iran and worldwide. Some scholars have stressed the importance of design changes, pointing out that the thermal condition of courtyards is substantially influenced by the amount of solar radiation and wind that enters the space. The effects of these parameters have

been evaluated using a courtyard's orientation and geometrical (IA Meir, 2000; Rajapaksha et al., 2003; Reynolds, 2002; Tablada et al., 2005). Al-Masri and Abu-Hijleh (2012) found that the thermal conditions inside a courtyard and its surroundings can be significantly influenced by the direction, size, and height of the walls around the courtyard. Heidari (2010) provided a design guideline for courtyards in the arid environment of Yazd based on the results of case studies on thermal comfort and airflow.

It was discovered that landscaping may increase humidity in the examined courtyards. Thermal comfort may be significantly impacted by a pond. For airflow patterns, the depth-to-width ratio is crucial. According to Ghaffarianhoseini et al. (2015), the orientation, height, and albedo of a walled enclosure, as well as the use of vegetation, are all architectural elements that can be used to make unshaded courtyards into thermally comfortable outdoor spaces. In Kashan, Iran's hot and arid region, Cho and Mohammadzadeh (2013) examined the natural ventilation systems in traditional courtyard homes.

Courtyards houses and vernacular architecture

Studies by Olgyay (1997) and Edwards et al. (2006) are crucial for understanding the patterns of courtyard houses. In their cross-cultural research, Edwards et al. (2006) includes a wide range of courtyard examples from around the world, with a focus on Middle Eastern architectural styles. Numerous research on vernacular architecture and courtyard homes have been conducted around the world (Knapp, 2012; Rabbat, 2017; Wilbaux et al., 2008). Additionally, numerous research works concentrating on Iran's vernacular architecture are available (Ghzelbash and Abolziya, 1984; Kheirabadi, 2000; Memarian, 1993a; Petruccioli and Pirani, 2002; Pirnia, 1990; Pope, 1965; Pope, 1971; Soltanzade, 2014).

Glassie (2000) examines the core ideas of evaluating and understanding vernacular architecture through the use of case studies from the United States, Europe, and Asia from a more general viewpoint on material culture and vernacular architecture. Carter and Cromley (2005) also provide a complete fundamental introduction to vernacular architectural studies, which is a useful resource. Rapoport (1976), who gives the practical methodological frameworks, studies the built environment of people in great detail.

Furthermore, Rapoport (1969) proposed a historical perspective on the vast array of prehistoric and rural structures in his overall research of the relationship between home

types and culture. Similar to Rapoport, Oliver and Shelter (1975), and Oliver (2007) explored the relationship between housing architectural form and culture. To put it another way, Oliver and Shelter (1975) looked into how beliefs and values affected vernacular architectural forms, while Oliver (2007) looked into how social and cultural elements influenced the development of vernacular architectural styles.

2.5.4. Courtyard physical features

Courtyards houses have been used in both urban residential structures and rural farmsteads as a spatial organizing concept to create a desirable living space. The courtyard's enclosed quality makes it an ideal alternative for a variety of objectives, including privacy, privacy, fortification and defense, protection against severe weather, and privacy.

One of the key underlying elements in the selection of courtyards is the climate. During various climatic and harsh weather circumstances, the courtyard serves as a "earthly paradise" (Jonas, 1980), providing physical comfort to the inhabitants while also meeting their cultural aspirations (Memarian and Brown, 2003). The greatest way to use environmental elements to lower the winter and summer heating and cooling loads is to build a courtyard. It can be said that the courtyard is not exclusive to a particular location or climatic zone when diverse climates in different areas, such as cold and mountainous climates (Tabriz), are taken into consideration. However, it was mostly utilized in dry areas like Yazd.

One of the characteristics of the courtyard design is its introversion, which significantly reduces the incursion of bothersome breezes. Additionally, the existence of a pond in this area has assisted in the evaporation of water, cooling the atmosphere, and reducing air dryness. In addition to being beautiful and relaxing, having nature beside the water is crucial for people's mental health as a biological phenomenon. By removing and reducing pollution, regulating light reflection, and modifying temperature, wind speed, and humidification, plants significantly contribute to the improvement of living circumstances.

2.5.5. Courtyard sociocultural features

The fact is that the courtyard, aside from being a proper alternative for environmental situations, was a responsive typology to the social-cultural aspects in space configuration of old cities. Courtyard houses were utilized to create harmony between culture and social perspective/structure rather than standing out (Al-Sabouni, 2017). Additionally, for the courtyards to be more suitable for the urban fabric, society,

tradition, and religion are known to be the most influential parameters. Since the major emphasis is on the family's position and private seclusion, the occupant's social standing is shown to the outside world to a minimum (Abass et al., 2016). In the eyes of Fathy (2010), the courtyard's value as a utilitarian feature can be summarized as following:

"*Yet, the courtyard is more than just an architectural device for obtaining privacy and protection. It is, like the dome, part of a microcosm that parallels the order of the universe itself.*"

Furthermore, the courtyard as an element of the urban layout brought together people of many socioeconomic groups and religions in a heterogeneous manner, but in a harmonious way that people created as an emergent phenomenon. Wealthy and poor, Muslim and Christian, were all intertwined in this form of habitation, which was unostentatious and tightly connected (Al-Sabouni, 2017). This spirit of neighborliness developed a life of tolerance, peace, and cohabitation, which resulted in the creation of long-term viable communities and societies.

2.5.6. Courtyard functions

Courtyards were frequently the main gathering locations for particular activities like gardening, cooking, dining, working, playing, sleeping, and in some cases even serving as animal kennels (Edwards et al., 2006). A courtyard serves a variety of purposes as an open area inside a home, including social, leisure, and microclimate (Isaac Meir, 2000). These courtyards can be manicured spaces for peaceful reflection, places to dry clothes, vents for toilet or cooking aromas, or spaces for a variety of household activities, depending on their size (Zwain and Bahauddin, 2017). Figure 9 portrays an example of Iranian feasting ceremony in a courtyard house.

Moreover, courtyard as a space can provide visual or acoustic protection. The courtyard geometry and its material makeup should be considered in the design stage in order to provide the highest level of thermal comfort possible (Isaac Meir, 2000). The courtyard can be used as a suitable location to promote a healthy, natural atmosphere. Trees, flowers, wind, water, and sunlight can all have a favorable impact on the body's five senses (Nam and Kim, 2021). Visual connection, transparency from indoor to outdoor, seclusion, and security enhance user experiences in courtyards (Lau and Yang, 2009).

Figure 9. An Iranian feasting in courtyard house (Source: Tebyan, 2018)

Natural lighting can significantly make a space feel larger and inviting, subsequently, by inviting sunlight, courtyards are bright open spaces that revitalize humans and plants alike (Zwain1a and Bahauddin1b, 2020).

Central gardens are a usual characteristic in courtyards; the bright environment is a perfect setting for sun-loving trees and plants. Courtyards also permit airflow without the security concerns of leaving windows or doors open. Spending a lot of times in indoor environments can be stressful. Courtyards offer a solution by creating a beautiful, private outdoor space that you can use to get some fresh air, talk to a neighbor, or even meditate. Courtyards are a prominent feature for many traditional houses, giving people a relaxing space to spend time (Huang et al., 2020).

In summary, courtyards have historically been used for many purposes including:

- Cooking
- Laundry
- Sleeping
- Working
- Playing
- Gardening
- Keeping animals.

2.5.7. Drawbacks of the Courtyard House

One of the key advantages of courtyard dwellings used to be their capacity to form a dense settlement fabric. However, in the case of Yazd, one can see that the settlement's extremely narrow streets and cul-de-sacs aren't the sole ways of mobility; doors between dwellings can also be utilized (Figure (2-8)) (Rapoport, 2007). This is dependent on a variety of social factors, including a high level of homogeneity (and often kin ties). As a result, it symbolizes a different set of culturally unique transitions in and use of the street system than, say, Isfahan, Cairo, or elsewhere (Rapoport, 2007).

A tightly maintained set of rules (whether of conduct, positions, space utilization, time organization, privacy, etc.) is also involved, which allows such systems to function but is becoming increasingly difficult to manage today. The underground courtyard houses of Matamata (Tunisia) and the Loess area of China appear to have their own set of rules. In both circumstances, the court is fully visible to onlookers and offers little privacy. As previously noted, privacy is most likely obtained by groups being homogeneous (perhaps related) and adhering to strict norms such as staying away from edges and not looking down (Figure 10).

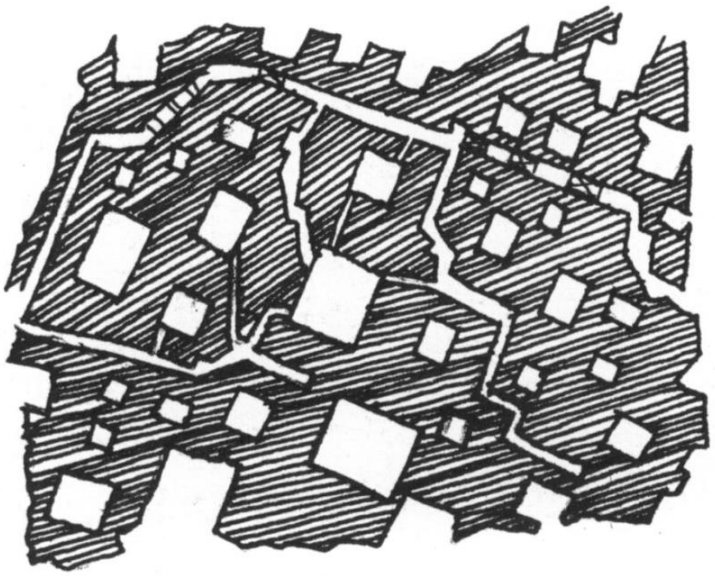


Figure 10. The urban fabric of traditional Iranian city (e.g., Yazd) (not to scale) (Source: Rapoport, 2016)

Additional to the density problems of courtyards in today's living settings is the growing emphasis on individual identity over group identity, as well as privatization (Baumgartner, 1988). The meanings offered by dwellings become increasingly significant when identities, social interactions, situations, and the like become more

varied, diversified, flexible, and dynamic (Rapoport, 2007).

Another potential issue is the ‘privatization’ of greenery. A Courtyard house can have almost as much greenery as a city's residential urban fabric, but this greenery would not be visible behind walls. On the other hand, greenery is also important for producing perceived qualities such as low density, high status, and current notions of high environmental quality (Figure 11) (Rapoport, 2007).

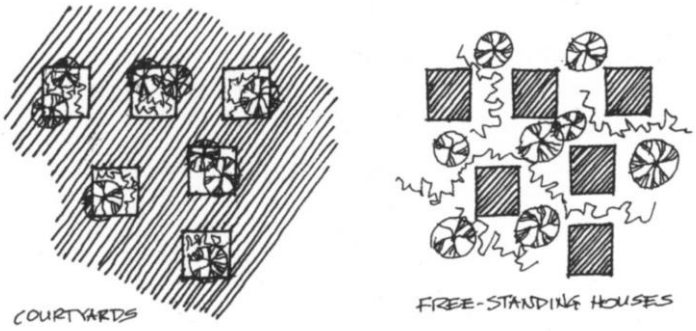


Figure 11. Urban fabric and greenery (Source: Rapoport, 2016)

As a result of what have been stated above, privacy and communication can be considered as important reasons for courtyards to be abandoned. Modern life has grown different needs in human social life that traditional courtyard cannot answer to and as usual people change their residential environment to feed those needs. Especially in Iran’s case, gradually, with the change in the socio-cultural system of the country, the high migration of people to the cities, the increase in the population of the cities and the lack of land, construction left the traditional typologies. In this way, some of the spaces that existed in a traditional house were removed in all of today's residential buildings, such as the courtyard, and only the main spaces such as the bedroom, living room, kitchen, and bathroom were designed. During this period, with the reduction of land area, the area of the yard also decreased. The change in socio-cultural factors have weakened humanity's interaction with nature and architecture. It should not be forgotten that as people's lives have changed, the value and attention given to green space and nature has waned to the point where environmental challenges have arisen over the world. It is more fitting than anything else that energy conservation and the environment are of considerable importance among current viewpoints, and that it relies on more integrated conservation measures, such as what atrium offers in terms of materials and energy conservation.

2.5.8. Benefits of the Courtyard House

Aside from the drawbacks and problems listed above, the courtyard has numerous

positive points. The following are some of the benefits:

- Environmental Benefit
- Architectural Benefit
- Religious Benefit
- Socio-cultural Benefit
- Psychological Benefits
- Security Benefits

Environmental Benefits

Due to their ability to moderate hot temperatures, channel breezes, and regulate the degree of humidity, courtyards have been dubbed "microclimate changers" (Saxon, 1986). Courtyards served as a source of airflow and thermal comfort for the dwelling. It can also help to reduce heat gain by acting efficiently with the features of self-shading and thermal lag when placed in the right location relative to the house and using the right material. Finally, especially in hot, arid countries, a courtyard serves as a cool air reservoir (Sthapak and Bandyopadhyay, 2014).

For example, one of traditional architecture's critical ways of providing thermal comfort for people in buildings, particularly in hot and dry areas, was to use wind energy for ventilation. This method has been used to save energy while maintaining sufficient thermal comfort for people in enclosed spaces (Al-Hemiddi and Al-Saud, 2001; Behbood et al., 2010).

In courtyard dwellings, wind energy serves two functions. One of them moves the air horizontally, between the courtyard's outdoor and inside areas. The second function is that the courtyard's air is refreshed. Warm air rises from the top of the courtyard throughout the night in hot and dry climates departs and is replaced by cooler air. During the day, cold air is pumped throughout the interior rooms (Al-Hemiddi and Al-Saud, 2001).

In cold climate zones, on the other hand, the building requires natural heating in the winter and natural illumination throughout the year. The northern block of a courtyard dwelling, which receives the highest amount of sun and light during winter, has the largest part of the building in a cold climate. In other words, receiving the highest amount of sun and light during winter by the northern block makes it one of the essential aspects of courtyard houses in cold regions. The southern block, on the other hand, gets the least quantity of sunlight. As a result, this block is the smallest in

courtyard structures since it only gets sun a few days a year. Because the eastern and western blocks get more sunlight than the southern block, they are bigger. In this region, the regions of the eastern and western blocks are usually equal in size. These are a few instances of how courtyard homes in cold areas affect the environment (Mänty and Pressman, 1988).

Architectural Benefits

In most buildings and dwellings, courtyards serve as a hub, connecting various spaces and functions. The courtyard's significance stems from its central location, which is surrounded by diverse landscape and tree components that play a vital part in our social and practical activities (IA Meir, 2000). Furthermore, it provides visual and acoustic comfort as well as climatic protection to the building. As a result, the geometry of the courtyard and the qualities of finishing materials should take precedence throughout the stage's design to provide a high level of thermal comfort (IA Meir, 2000).

Spiritual Benefits

The physical aspects of traditional courtyard dwellings were formed by Islamic ideology and traditional views, which were mirrored in the social laws and lifestyle of the Iran community. As a result, one of the most important goals of a traditional Iranian courtyard house is to provide seclusion for family life. As previously said, dwellings were designed in such a way that they faced the center courtyard with no view of the street or other nearby houses, providing comfortable privacy. Despite the fact that the central courtyard is an open area, it protects from prying eyes since it cannot be seen from the outside, such as neighbors (Figure 12) (Zein Alabidin, 2010). The courtyard creates a unique place with various benefits, including spatial and optical privacy, as well as an intimate world for tranquil and privacy settings.

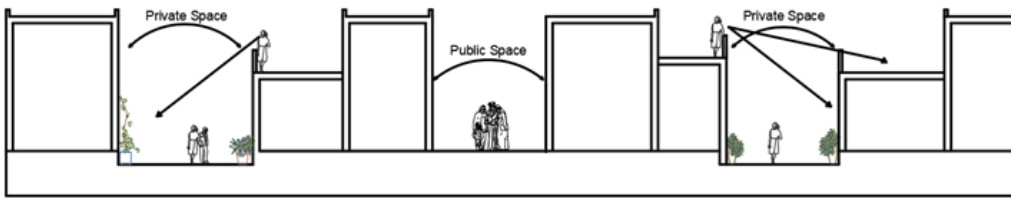


Figure 12. A section showing how courtyard provide privacy from the outside, such as neighbors (Source: Edwards et al., 2006)

Socio-cultural Benefits

The traditional Iranian culture was characterized by a sense of extended family, in which numerous families lived together and assisted one another. Typically, strong family and local connections are maintained via cooperation and support among community members (Zein Alabidin, 2010). The courtyard was built in a way that was compatible with the sort of civilization and cultural attitude that existed at the time. Aside from that, the courtyard serves as an extension of the home, giving outdoor space for the family to enjoy regularly or for social gatherings to commemorate specific occasions. Additionally, they contributed to the practice of social rituals in accordance with the social ties that prevailed in society. As a result, the courtyard has traditionally served as the focal point of daily life and social interaction. In the past, the courtyard served as a gathering spot for a variety of social gatherings, including:

- Private space: as it is a place for daily life activity (e.g., eating, sitting with family, cooking, workspace, sleeping) (Hatipoğlu and Mohammad, 2021).
- Communal space: religious rituals and wedding celebrations with folk music bands, as well as open space for entertaining intimate friends, such as monthly female parties, are examples of events for visitors and family (Zein Alabidin, 2010).
- Safe space: especially for kids to play within parent's close supervision (Lee and Park, 2015).

Psychological Benefits

We, as human beings, have a psychological need for connecting to nature. Studies have shown that seeing natural elements such as plants, trees, and water and interacting with them can have tremendous health benefits (Chawla, 2020). This is one more of the benefits of a courtyard. A courtyard in the middle of your house is a great way to introduce these natural elements into indoor environments that may not necessarily have access. Courtyards would typically incorporate a garden because they have access to sunlight and rain. Gardens could have small plants or large trees, depending on the size of the courtyard which interacting with them would reduce anxiety and stress (Abdelaal and Soebarto, 2018). Numerous courtyards include water features and consist of a pond and fountain; even, some courtyards encompass a swimming pool. The sound and sight of water are often calming and create an enjoyable and relaxing atmosphere (Qureshi et al., 2022).

Security Benefits

Traditional houses with courtyards offer a sense of seclusion and protection thanks to walls that are devoid of windows on the exterior and a design that blocks direct views from the street into the home (Soflaei, Shokouhian, and Zhu, 2017) and enhances security in troublesome times. It is common knowledge that the courtyard also serves as a safe play space for young preschool children, who can be watched over by their mother or another elderly person within the house (Vedhajanani and Rose, 2016).

Regarding the thorough study of the literature, the benefits of the courtyards are categorized in Table 3 to compare with the benefits of their present forms:

Table 3. Courtyard benefits

Environmental Benefits	**Architectural Benefits**	**Religious Benefits**	**Socio-cultural Benefits**	**Psychological Benefits**
Regulating humidity	Connecting indoor and outdoor	Private semi-open space	A place for religious rituals	Enjoyable environment
Natural airflow	Greenspace connection	Spatial privacy	Social gatherings	Relaxation
Thermal comfort	Visual aesthetic	Visual privacy	Safe space for kids' playing	Reducing anxiety and stress
Reduce heat gain	Acoustic			
Cool air reservoir				

2.6. The impact of culture on Iranian courtyards

Socio-cultural factors have had a role in the development of traditional Iranian courtyards. According to (Brown et al., 2006), the presence of several housing typologies in the same climatic zone demonstrates the influence of cultural variables on building design (Bonine, 1979; Mazumdar and Mazumdar, 1997). Haji Ghassemi (1999) contends that different qualities of Iranian dwellings are not just reflections of the religious ideas of solitude but are also traces of pre-Islamic architecture. Instead,

he argued that they are a reflection of Iranian culture as well as the feeling of seclusion valued by Islamic rules. Memarian and Brown (2003) investigated the influence of religious ideology on the spatial and formal structure of buildings. They claim that the significance of religion varies depending on local circumstances and customs. From the perspectives of the city's culture, religion, and tradition, Karimi and Hosseini (2012) analyzes the principles of creating residential dwellings. Othman et al. (2015) investigates Muslim households' privacy, and hospitality. They concluded that nations are impacted by cultural variables that are present in their place of residency (or origin). These issues influenced different aspects of the architectural styles and spaces used in Muslim dwellings. In the meanwhile, the following research on traditional dwellings and Islam can also be related: (Othman et al., 2014), (Omer, 2010), and (Mortada, 2003).

As stated by Mazumdar and Mazumdar (1997), Islamic beliefs regarding solitude and privacy, produced a clear delineation between the realms of the man's world and the realms of the woman's world, as well as between the public and the private worlds, the street, and the house. The amount of time spent outside the home was always limited in order to guarantee that women had the fewest possible interactions with men who were not members of the mahram (Memarian and Brown, 2003).

The courtyard houses offered a great amount of privacy to their occupants due to the rooms that faced inward toward the interior of the home. Because of the mandates and restrictions imposed by Islam, this aspect of Iran's traditional culture held a place of special significance for Muslim people (Kheirabadi, 2000). Controlling social contact between the sexes is central to Islamic religious heritage. Only men and women who are *"mahram"* to each other (i.e., who are not allowed to marry due of kinship) are permitted to interact freely and on a casual basis. There should be very little interaction between non-*mahram* people (those who are unrelated to each other, either by marriage or kinship) (Khatib-Chahidi, 2021).

Because of the high value placed on privacy inside the dwelling and the desire to keep female family members hidden from public view, it is reasonable to assume that stringent restrictions are maintained over entry and view from the outside. The architecture of Iranian homes was quite consistent in this regard. Although most of the buildings were just one story tall, the walls that surrounded them were rather high, and the front of the buildings facing the street was often blind, with the exception of a single, substantial door that indicated that people lived inside. When there was no other

option, openings were kept tiny and were positioned high up so that those walking by couldn't see inside (Memarian and Brown, 2003).

According to Memarian and Brown (1996), hospitality is a deeply ingrained component of Iranian culture, which has been impacted by Islamic beliefs to serve a dual purpose of maintaining the privacy of the inner residence while providing warmth and welcome to guests. These two necessities were harmonized differently for big and small courtyard houses. In big courtyard houses, this harmony was established by a distinct welcome chamber near the entrance. In some instances, the entry corridor opened immediately into the courtyard, with the reception room nearby. On the other hand, the entrance route led directly to the reception room in smaller courtyard houses, which was entered before reaching the courtyard.

From a general point of view, the courtyard house was divided into two distinct quarters, namely the *birun* and the *andarun*, a phenomenon discussed by (Mazumdar and Mazumdar, 1997), (Khatib-Chahidi, 2021), and (Memarian and Brown, 2003). *Birun* is a Persian word that translates to "outside," and it was originally a male-only portion of the home that was located near the main door. This was the place where the household males would entertain male guests who were not part of the immediate family, in other words, non-*mahram* male visitors and the reception rooms were to be found within this area. *Andarun*, which literally means "inside," was the name given to the family quarters, the majority of which were occupied by women. Although female guests were sometimes given the opportunity to be entertained in the reception rooms located inside the *birun*, they were far more likely to be sent to the *andarun*. In big residences, there may be distinct retinues of servants assigned to each area: female attendants assigned to the *andarun*, and male servants assigned to the *birun*.

2.7. The impact of climate on Iranian courtyards

Numerous academics have indicated that the primary cause for the emergence of courtyard dwelling in Iran was the climate (Ramezani and Hamidi, 2010). According to Brown et al. (2006), high thermal mass building materials, the presence of a basement and semi-open spaces, the use of wind catchers, and changes in the sectional profile of the courtyard are all methods that are used to keep comfort levels in Iranian courtyard houses even in hot climates. Additionally, some of the studies have investigated the existence of summer and winter rooms in Iranian courtyard houses, as well as the movement between rooms to achieve optimum thermal comfort on different days of the year and at different times of the day. Foruzanmehr (2012) has illustrated

how seasonal rooms function as climatic factors to give comfort, as well as how present occupants perceive them.

Heidari et al. (2000) discusses how to achieve thermal comfort in Iranian courtyard dwellings in the hot and dry climate by relocating to various spaces of the home during the day. Soflaee and Shokouhian (2007) focus on the long-term effects of courtyards as climatic elements in traditional Iranian architecture in hot-arid locations. The findings demonstrate that by using traditional architecture from hot-aired places, it is feasible to produce an environmentally and sustainably designed structure (Brown et al., 2006; Ragette, 2003). Continuing the climate effect on the difference of courtyard houses, Kottek et al. (2006) conducted research on the design requirements for courtyards in various climatic zones. In other words, the article examined the design requirements for courtyards in terms of shape and their impact on wind movement and illumination in various climatic zones. Ebadi et al. (2014) explored the role of courtyards in different climates to improve human comfort in terms of sustainability by characterizing and categorizing Iran's diverse climates and geographical locations, as well as comparing the nature and function of courtyards in different climatic zones. Rezazadeh Ardebili and Shafiei (2016) investigates and analyzes the vernacular approach and climatic design of traditional houses that have persisted in Iran for at least a century.

Nonetheless, the design and construction of the investigated buildings adapt to their climatic conditions and are contextually appropriate. (Taleghani et al., 2012) concentrate on the climatic impact(s) in hot-arid, snow-covered, temperate, and tropical regions. The most significant discoveries of their article are the various forms of courtyard structures, the natural components employed in them, and the placement of openings in various facades. Ebrahimi et al. (2013) examined the unique strategies used by architects in cold and dry environments to control energy use in vernacular structures. Their results demonstrate that, despite substantial similarities, this climate's traditional architects have used a variety of inventive and sustainable ways in the design and structure of buildings that are unique to this country in order to withstand the region's harsh climatic conditions.

2.8. Courtyard in Iran's present architecture

Modernization has had a negative impact on the existing Iranian house design. Iran has seen significant social, economic, and cultural transformations since the beginning of the twentieth century, which have affected several elements of Iranian society.

Architecture has evolved significantly as the physical manifestation of social activity. In Iran, the construction of modern homes started about 1961 (Haeri, 1997; SoltanZadeh, 2005). The period of transition began during the final years of the Qajar dynasty (AD 1925) and lasted until the beginning of the year 1961 (SoltanZadeh, 2005). Different architectural styles emerged throughout the transitional and modern eras as a result of new construction technology and other factors.

2.8.1. Transitional Period (the last years of the Qajar dynasty to 1961)

Urban areas lost their mixed-use social and economic activities during the transition era and became purely residential communities. Land plots were shrunk in size and geometrically formed, primarily in rectangular shapes. The spatial aspects of the dwellings were affected by the rectangular land. The constructed area had to be positioned in the northern and southern sections of the property, with the courtyard in the center, since the lots were thinner. When the home faced south, as it did in most cases, the primary two-story residential space was on the northern side, facing the sun, with the ground floor devoted to living areas and the first to guest rooms. In most cases, the other part had one story above ground and one below ground. The basement, below ground level, housed the kitchen and service spaces (Mirmoghtadaee, 2009; SoltanZadeh, 2005).

During this time period, the buildings received their very first electrical and mechanical systems respectively. As a direct result of this, the kitchen and service areas, which were often situated at a considerable distance from the primary living rooms, benefited from the addition of modern sanitary facilities and were able to be relocated closer to the primary living areas.

2.8.2. Contemporary Houses (1961 to Present)

In Iran's urban areas, the use of multi-story building types with a stairwell access system made up a significant portion of the local housing stock. Even if modern structures make living circumstances better by providing essential amenities such as appropriate sanitation, power, and so on, one of the negative influences of these buildings is that they circumvent the culture of the local population as well as the architectural and urban identity. It was unsettling to witness the replacement of the traditional courtyard houses with profitable houses based on technical innovation and deprived of any previous spatial codes. This occurred at the expense of human needs and values, which are the factors that should have guided design decisions. In addition, architects seldom raise probing questions about whether or not a shape is acceptable

given the social and cultural circumstances of a given time and place (Al-Jokhadar and Jabi, 2016).

During the modern era, the majority of traditional homes were abandoned, and their replacement with apartment complexes became more common. Due to the fact that families now had fewer people, the living rooms of each home in the new style of housing were smaller, and rather than having their own private courtyards, residents of the apartment building shared one yard amongst all of the families (Figure 2-12). The new construction code, which enables structures to fill 60% of a land lot while leaving 40% open space, has had a significant impact on home spatial arrangement as well as urban architecture. The center courtyard has been relocated to the front, and multi-story apartment complexes have replaced single-family homes as the most popular housing option (SoltanZadeh, 2005).

With the change in the architectural style during the modern era, the style and function of the courtyards also changed. In this way, the yard was removed from the essential elements of the building and changed to the parking area for the cars of the building's residents (Asadi et al., 2015). The courtyard is no longer located in the center of the house and has been moved to the southern part of the building (Figure 13). It only includes greenspace like small plants, and it no longer acts as a gathering space. Furthermore, paying attention to the courtyard landscape design increases the aesthetical value of the building (Eliaszadeh Moghadam et al., 2013).

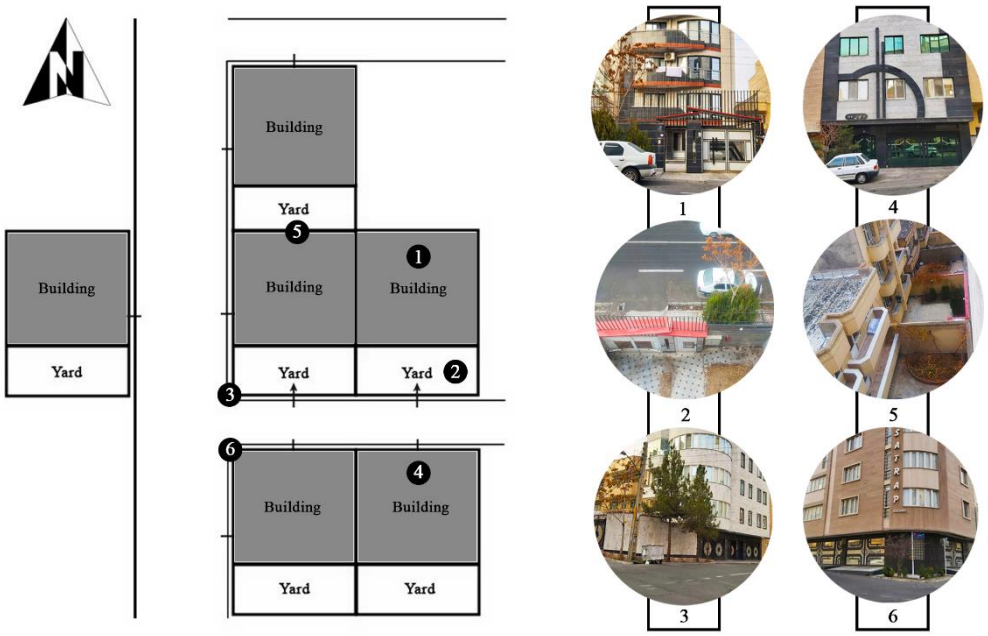


Figure 13. Simplified diagram of residential buildings with a shared courtyard in all Iran

2.9. Directions for future work: The effects of Islam and modernity on Iranian courtyards

This section contains certain brief observations about the past influence of Islam on the courtyard houses of Iran, as well as about the evolution of courtyards in the contemporary architecture of the country. There are major differences between pre-Islam and after Islam courtyard houses due to Islam's' religious ideologies (Memarian and Brown, 2003) which makes it an interesting topic for future studies. Additionally, the process of courtyard houses' evolution is of great importance since it is subjected to urban expansion and limited available open space in todays' urban life (Raith and Estaji, 2020). Therefore, both topics can be the focus of further research studies.

2.9.1. Islam culture impact

Aside from the impact of the environment on architecture, history and culture have also had a vital influence on its development. Iran has a long and rich history as an ancient civilization. Many dynasties have come and gone over Iran's lengthy history, and each has left its imprint on the country's architecture. Considering Islam as one of the most influential cultural factors affecting Iranian architecture, more attention should be concentrated on two general eras: before and after Islam (7^{th} century). In the seventh century (AD 637–642), Arab-Muslim armies defeated Sasanids at *Qâdesiyeh* and *Nehâvand*. After that, the culture of Islam influenced the architectural styles of structures (Alborzi et al., 2019). There are not many structures with courtyards which date to the pre-Islamic periods that have survived (e.g., Apadana Castle Shush, Bishapur palace, Haji abad house).

The main structural spaces of pre-Islamic periods' architecture were porch, *andarun, birun,* yards, and a room for praying to their god. The use of local materials and a focus on height to symbolize glory and power were other traits of this era's prestigious homes. Most of these structures are restricted since they have suffered significant alterations and destructions brought on by wars and natural disasters (Bonine, 1979).

It is demonstrated that the allocation of space within houses as well as the layout of entrance are directly influenced by the rules and practices of Islam's culture (Memarian and Ranjbar-Kermani, 2011). Islam culture places great importance on the concept of privacy, the separation of male and female social spheres, and the definition of domestic and private space—principles that conditioned the arrangement of space within the dwelling as well as the relationship between the house and the space outside

(Valibeigi et al., 2022); It was necessary to strike a balance between the need to protect residents, particularly women in the household, from being seen and the desire to maintain a sense of openness and transparency.

The management of sex-related social contact is fundamental to Islamic religious heritage. Only men and women who are ‘mahram’ to one another—that is, between whom marriage is prohibited due to kinship—are permitted to interact freely and informally. There should be little to no interaction between non-mahram individuals (those who are not linked to one another through marriage or kinship) (Khatib-Chahidi, 2021). The house was divided into two parts: the ‘*birun*’ (the male quarters), which was closer to the front door, and the ‘*andarun*’ (the female quarters), which was farther inside and out of sight. The *andarun* had high walls, or rooms with windows that only opened inward, creating space that was "protected" from non-*mahrams* (Milani, 2019).

The courtyard (both *birun* and *andarun*) itself had a strong impression of an earthly paradise, and it was formerly used as a retreat and the center of the house (Zhang, 2020). There was often a square or rectangular pool in front of the gardens' main pavilion. Prior to and in the early days of Islam, round pools were popular but were not utilized subsequently. Later, from a hexagon to a dodecahedron, these ponds assumed a regular and straightforward geometric shape (Soflaee and Shokouhian, 2007). Whether it was tiny or huge, pond was regarded as an essential component of many courtyard homes, which was typically in the middle of the yard, serves as a reminder of the significance and centrality of water in the forest. Its presence in the yard, along with a few potted plants next to the lush vegetation of the garden, served as an allegory of heaven that was common in traditional Iranian homes (Akbari et al., 2021).

2.9.2. Modernity

The cities’ densification following the industrial revolution in Iran (Ghadami and Newman, 2019) has increased the construction of apartment blocks, and traditional Iranian courtyard houses have gradually decreased (Mohammed et al., 2021). People’s desire to live in a modern environment and benefit from the greater security of apartments are other reasons for the decrease of Iranian courtyard houses (Gangwar and Kaur, 2020). The densification of cities and the tendency towards apartment living have naturally created shared courtyards like shared open spaces between people living in an apartment (Mirmoghtadaee, 2009). In addition to these shared apartment courtyards, balconies can be considered as a symbolic alternative to traditional private

courtyards, because they are open and private spaces for each household. The use of indoor plants, although small, can be seen as an answer to compensate for the lack of traditional courtyards in terms of nature connectedness (Kiyota and Oliver Selfridge, 2002).

The similarities of the traditional courtyards with the shared courtyards of today's apartments are that both are considered open spaces that separate indoors from outdoors, and green space can be seen in both types of yards. Indoor plants also resemble traditional courtyards regarding their common benefits (a summary of the courtyard houses' benefits is mentioned in Table 3). The environmental and psychological benefits of the central courtyard, which include regulating air humidity, reducing heat gain, relaxation, and reducing anxiety and stress, are also provided by indoor plants. Several studies have pointed to the psychological (Bringslimark et al., 2009; Deng and Deng, 2018) and environmental effects (Kim et al., 2020; Yoshimi and Altan, 2011) of indoor plants. Similarities in terms of their benefits are also identified between balconies used in apartments and traditional courtyards; Psychological benefits (enjoyable environment, relaxation and reducing anxiety and stress), architectural benefits (connecting indoor and outdoor, and green space connection) and environmental benefits (regulating humidity, natural airflow, and reducing heat gain) are common in both balconies and traditional courtyard.

The most similarity in terms of benefits is related to the similarity between the traditional courtyard and the shared courtyard of today's apartments, which are similar to each other in every respect (environmental, architectural, psychological and socio-cultural benefits) except for religious benefits (intimate and private semi-open space, spatial and visual privacy) due to the lack of shared courtyard's privacy. In addition to the increased cost of land occupied by courtyards, the fact is that some environmental benefits provided by the courtyards are nowadays given by new materials and technology that replace traditional methods. In summary, considering the impact of Islamic culture and modernity on Iran's traditional courtyard houses, these two aspects can be studied in the future to better understand the evolution of courtyard houses and their contemporary forms (Figure 14).

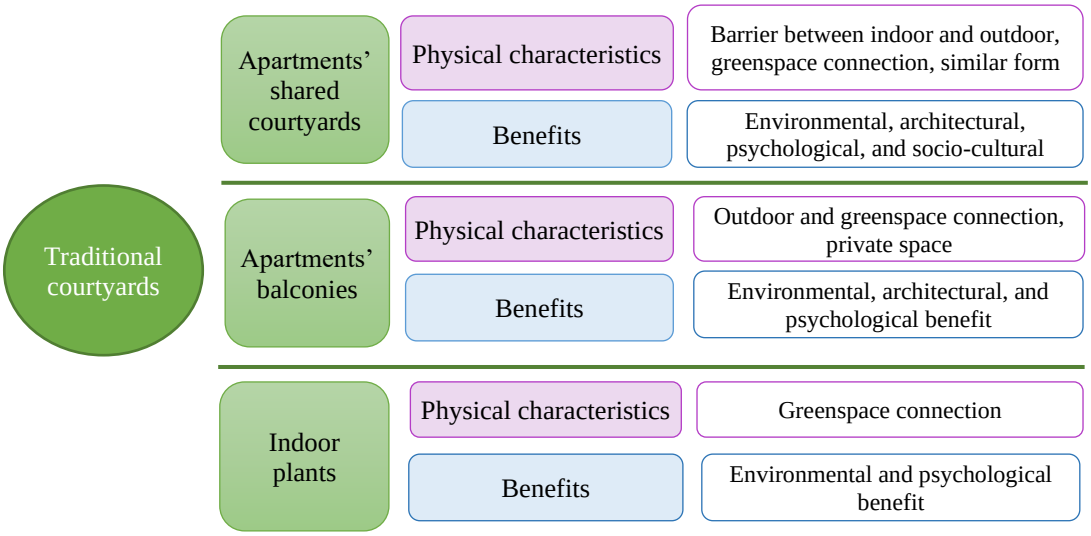


Figure 14. Contemporary alternatives of traditional courtyards

2.10. Summary

As mentioned in section "2.1.1. Iran's climatic classification", the Köppen-Geiger method, by using more stations with a quite regular distribution in the country, provided a more detailed map of Iran's climate zones (Raziei, 2017). Of the various classifications for Iran's climate, the current thesis is based on Köppen–Geiger climate classification that splits Iran into three general groups (arid, moderate, continental) (Figure 3).

In part 3, one city is chosen as a sample for each climate group and their courtyards are introduced. Later in part 4, the courtyards of each group are evaluated based on climate characteristics.

CHAPTER 3: ANALYSIS OF CASE STUDIES

3.1. Introduction

This study evaluates the link between traditional courtyard houses and climate in Iran. Initially, the courtyard houses of three major climates in Iran (arid, continental, and temperate) are discussed, then, the difference between courtyards in arid, continental, and temperate climates are examined.

In this chapter, study areas and study examples are explained.

3.2. Climatic characteristics of the selected areas

The locations that are taken as representatives of the selected three major climatic regions are as follows:

- Yazd in Yazd province for arid climate
- Tabriz in East Azerbaijan province for continental climate
- Sari in Mazandaran province for temperate climate (Figure 6).

Geographical data of the selected cities is given in table 4:

Table 4. Geographical situation of the selected cities

City	Latitude	Longitude	Altitude
Yazd	31°53′49″ N	54°22′02″ E	1216 m
Tabriz	38°04′47″ N	46°17′30″ E	1396 m
Sari	36°33′47″ N	53°03′36″ E	43 m

After discussing the climate characteristics of the selected areas and introducing their courtyard house examples, the climate characteristics of each group (arid climate, continental climate, temperate climate) will be combined with the physical factors of their courtyard houses in chapter 4. A comprehensive explanation of the three climates' characteristics is presented next:

3.2.1. Climatic characteristic comparison of Yazd, Tabriz, and Sari

Table 5 summarizes the basic climatic characteristics of the selected cities and their respective climatic zones extracted from Meteoblue website. Meteoblue is a weather forecasting service originating from the University of Basel in Switzerland. It was established as a spin-off company in 2006 with the purpose of catering to clients in the agriculture, solar, and wind power industries. The first row in Table 5 illustrates the monthly average precipitation, the second row portrays the monthly average temperature, and the third row indicates the wind rose diagram of the respective city. The chosen cities and their respective climates are as follows:

- Yazd - Arid, BWh (Hot desert climate)

- Tabriz - Continental, Dsa (Mediterranean-influenced hot-summer humid continental climate)
- Sari - Temperate, Cfa (Humid subtropical climates)

Precipitation: Yazd (A) as a city located in an arid climatic zone has the lowest level of precipitation among the three studied climatic zones with March being the wettest month with just 25 mm. On the other hand, there is nearly no perception during July, August, and September. Tabriz (B), on the other hand, as a city located in a continental climatic zone, has the highest rate of precipitation among the other two with May and August having over 50 mm of rain with a minimum 10 mm of precipitation in September. Finally, Sari (C) as a representative of the temperate climatic zone in Iran experiences its highest precipitation level in May with nearly 50 mm. Furthermore, the precipitation levels for Sari stay above 20 mm in 7 months of the year and fluctuate between 5 to 10 mm in the other 5 months.

Temperatures: The maximum temperature that each selected location that typically sees during each month of the year is depicted by the "mean daily maximum" (solid red line). The "mean daily minimum" (solid blue line) depicts the average temperature at night in a similar way. The dashed red and blue lines show the average maximum daytime temperature and minimum nighttime temperature for each month for the past 30 years. Among the three representative cities, Yazd (D) experiences the hottest summer with over 40 °C in its hottest daytime in July; on the other hand, Tabriz (E) has the coldest winter with below -10 °C in January. Sari (F), due to having a humid subtropical characteristic, experiences the lowest temperature fluctuation between day and night.

Wind: The wind rose of Tabriz (H) indicates that Tabriz mostly experiences its winds from a northeast direction for more than 1500 hours in a year with a speed between 12 to 19 km/h and it can be considered the windiest among the three. Additionally, Tabriz faces some harsh winds with a speed of 50 or 60 km/h. In Yazd, winds are mostly from the north, north-northeast, and south with each being over 1000 hours in a year. Finally, the winds in Sari (I) come mainly from west to southwest directions.

Table 5. Annual climatic summary of selected locations (Source: Meteoblue, 2022a; Meteoblue, 2022b; Meteoblue, 2022c)

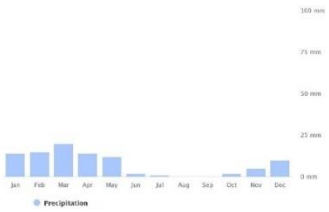
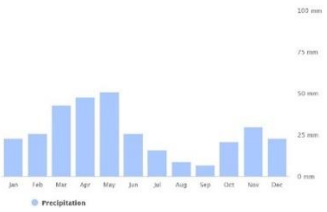
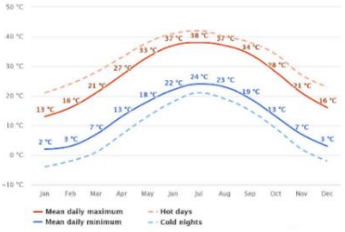
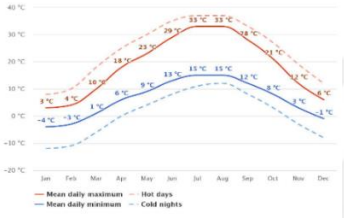
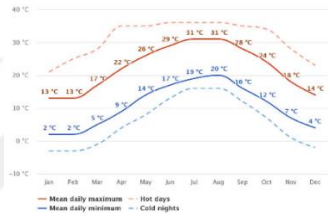
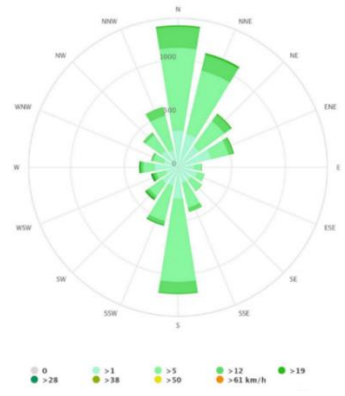
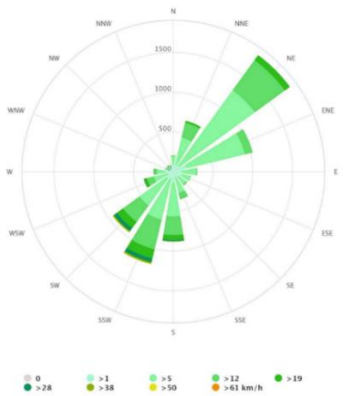
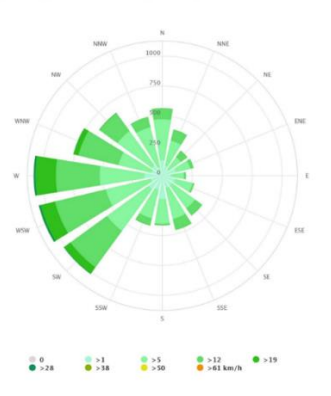
Yazd	**Tabriz**	**Sari**
		
Precipitation mm/month (A)	Precipitation mm/ month (B)	Precipitation mm/ month (C)
		
Monthly Mean temperatures (D)	Monthly Mean temperatures (E)	Monthly Mean temperatures (F)
		
Wind rose (G)	Wind rose (H)	Wind rose (I)

Table 6 briefly compares the data from Table 5 for the selected cities. Each row represents a city. The column “Climate type” indicates the climatic classification of each city and column “Precipitation” portrays the rainiest and driest days in a year with its respective month. Additionally, “temperature” depicts the coldest and the warmest day, respectively. The last column entitled “Wind” indicates the direction and speed of dominant winds.

Table 6. Brief climatic characteristic comparison of the selected cities

City	Climate type	Precipitation	temperature	Wind
Yazd	Arid, BWh	March: 7 rainy days Sep: 0 rainy days	Jan: 13 ℃ to 2 ℃ Jul: 38 ℃ to 24 ℃	North to south 19 - 28 km/h
Tabriz	Continental, Dsa	May: 16 rainy days Sep: 3 rainy days	Jan: 3 ℃ to -4 ℃ Jul: 33 ℃ to 15 ℃	Northeast to southwest < 19 km/h
Sari	Temperate, Cfa	March: 44 mm July and Aug: 4 mm	Jan: 13 ℃ to 2 ℃ Aug: 31 ℃ to 20 ℃	Southwest to northeast 19 - 28 km/h

3.2.2. Psychrometric chart comparison

A psychrometric chart presents graphically the air temperature and relative humidity in a given location combining monthly or daily data. The chart can assist the proper design according to the temperature-humidity combinations during the year. In this study such charts have been extracted from Climate Consultant software [CCS] that presents various types of climatic data for a large number of locations based on the EnergyPlus database. The software can produce the psychrometric chart of a location and also suggest design strategies, to increase the level of comfort experienced by occupants Table 7 shows the psychrometric charts of the three selected locations, presenting the graphical part with a list of suggested design strategies for achieving thermal comfort during a time period that is indicated as a percentage of the year duration. The CCS suggestions are used in this study as a guidance for studying their correlation with the traditional designs. In doing so, one should consider that the "thermal comfort" differs in time and cultures. Furthermore, CCS focuses mainly on comfort indoors but not so much on outdoors. Therefore, some discrepancies between contemporary could be interpreted as indications of that difference.

As it is suggested in Table 8, shading for windows is an important factor for designing a house in an arid climate (Yazd) to the point that considering a correct shading system for windows can increase the comfortable time in a house by up to 21% but this system for Sari and Tabriz is only 16% and 12% respectively. Yet it is not the one with the maximum effect; On the other hand, this parameter for Tabriz and Sari does not have the maximum effect and has 33% and 3%, respectively. It should be noted that in the Psychrometric chart (Table 7) evaporative cooling system consists of direct and two-stage evaporation cooling.

Furthermore, for Tabriz, as a representative of the continental climate in Iran,

thermal mass is one of the important designing parameters meaning that chosen materials for building should be able to absorb, store, and release heat, this parameter may thus enhance the annual comfort time by up to 21%. On the other hand, for Yazd and Sari, this rise in annual comfort time drops to 15% and 4%.

Among the suggested design parameters for Sari, internal heat gain and passive solar direct gain are relatively important factors, with a positive effect on comfort time throughout the year of about 24% and 28%, respectively. On the other hand, these parameters for Tabriz are 19% and 10%, and for Yazd, they are 19% and 17%. Furthermore, concerning other parameters, ventilation is the factor with the maximum effect on Sari, which increases the annual comfort time by up to 30%; for Yazd and Tabriz, this figure is only 10% and 12%, respectively.

Heating with humidification is by far the most important design factor to be considered in Tabriz dwellings, as it may extend the comfort time for residents by up to 52% per year; however, in Sari and Yazd, this number drops considerably to 28% and 21%, respectively.

Table 7. Climatic comparison of chosen locations through their psychrometric charts. (Source: CCS, 2022)

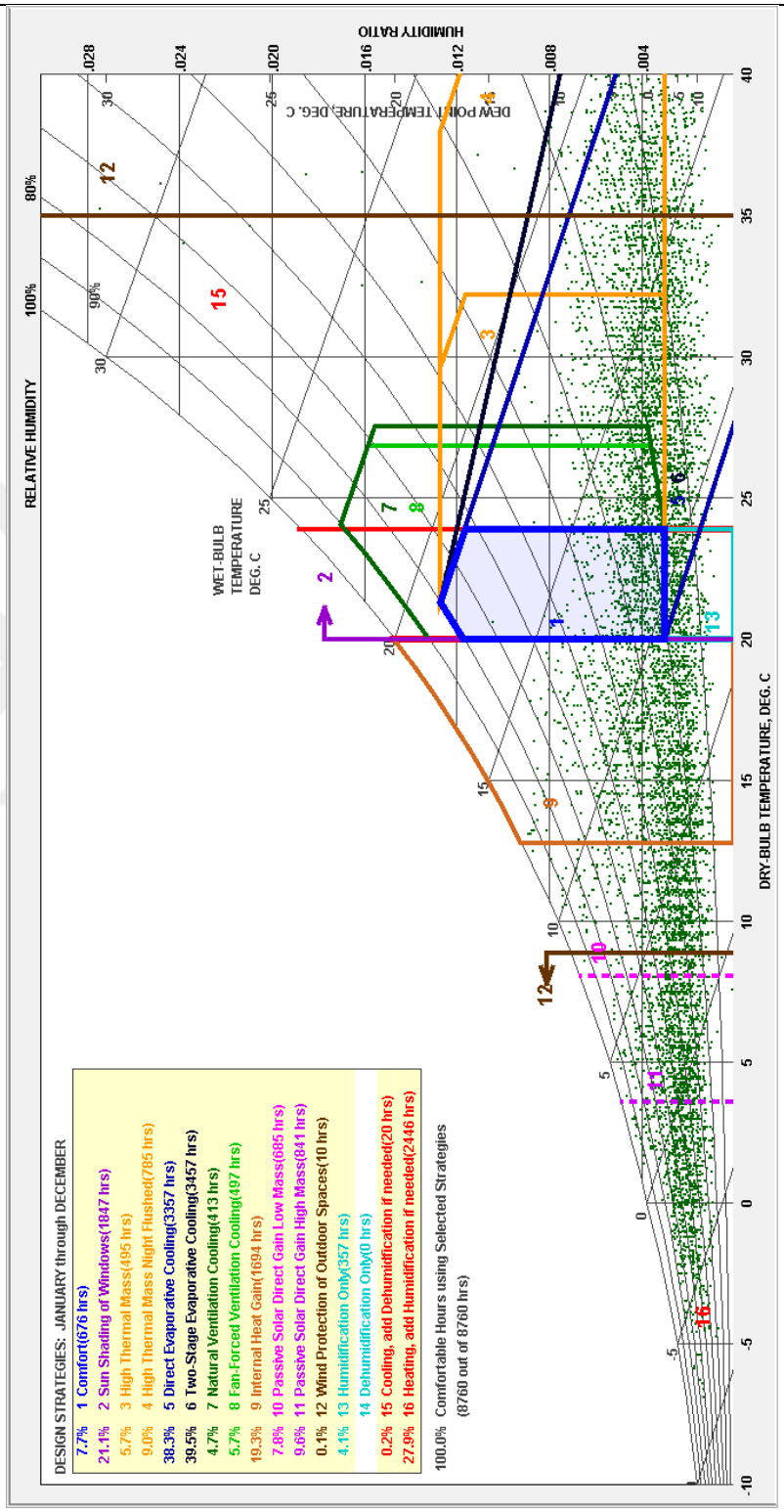
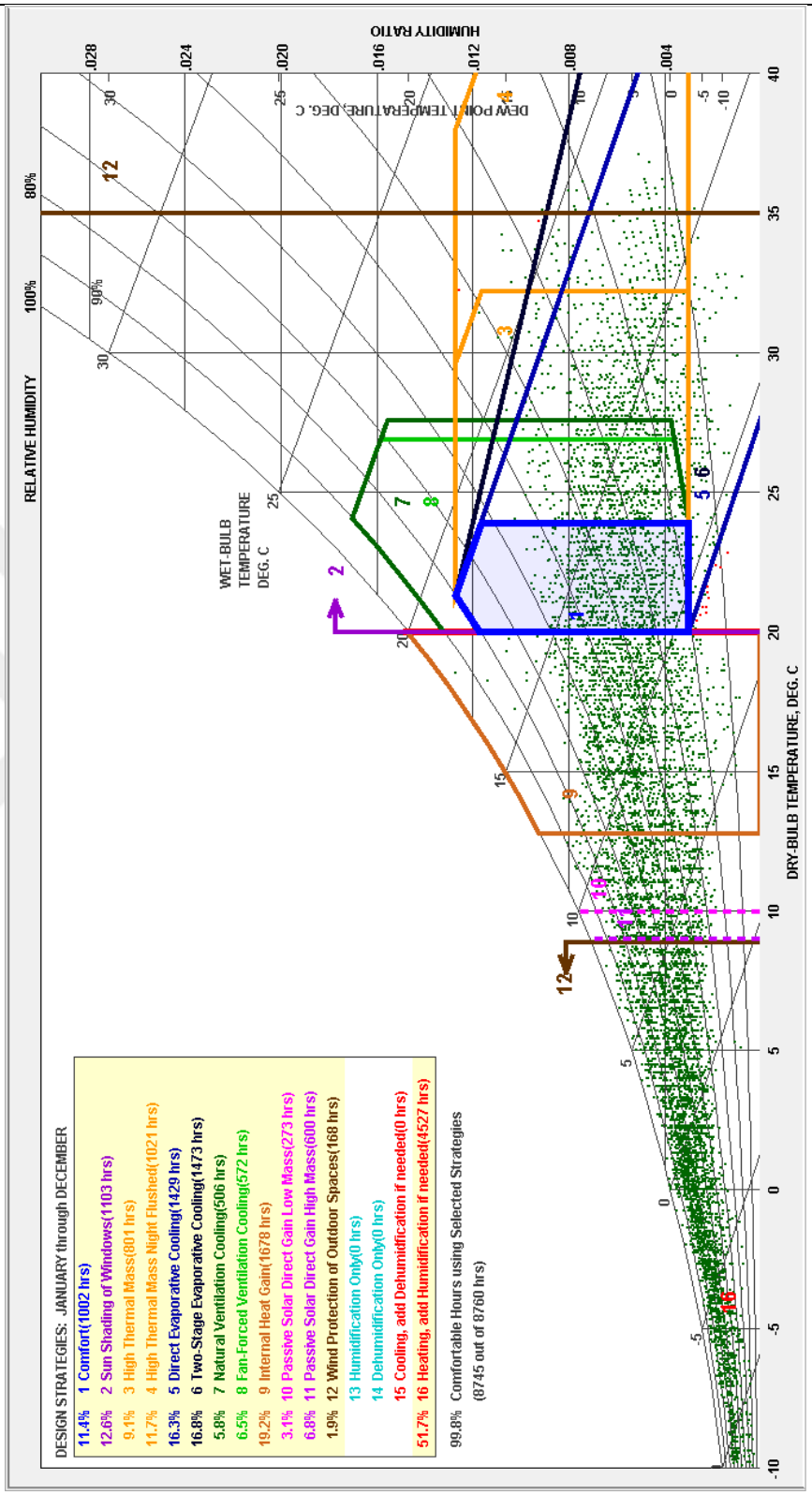
City	Chart
Yazd	 Despite the need for cooling system in nearly 78% of the time in a year the humidity stays low. Additionally, there is a need for heating system with humification for nearly 30% of the time through a year.

Table 7 (continued)

Tabriz	

The need for cooling with evaporation reduces to 33% for Tabriz with more need for heating systems with around 50% of a year. On the hand, similar to Yazd the city is nearly dry with low humidity rate.

Table 7 (continued)

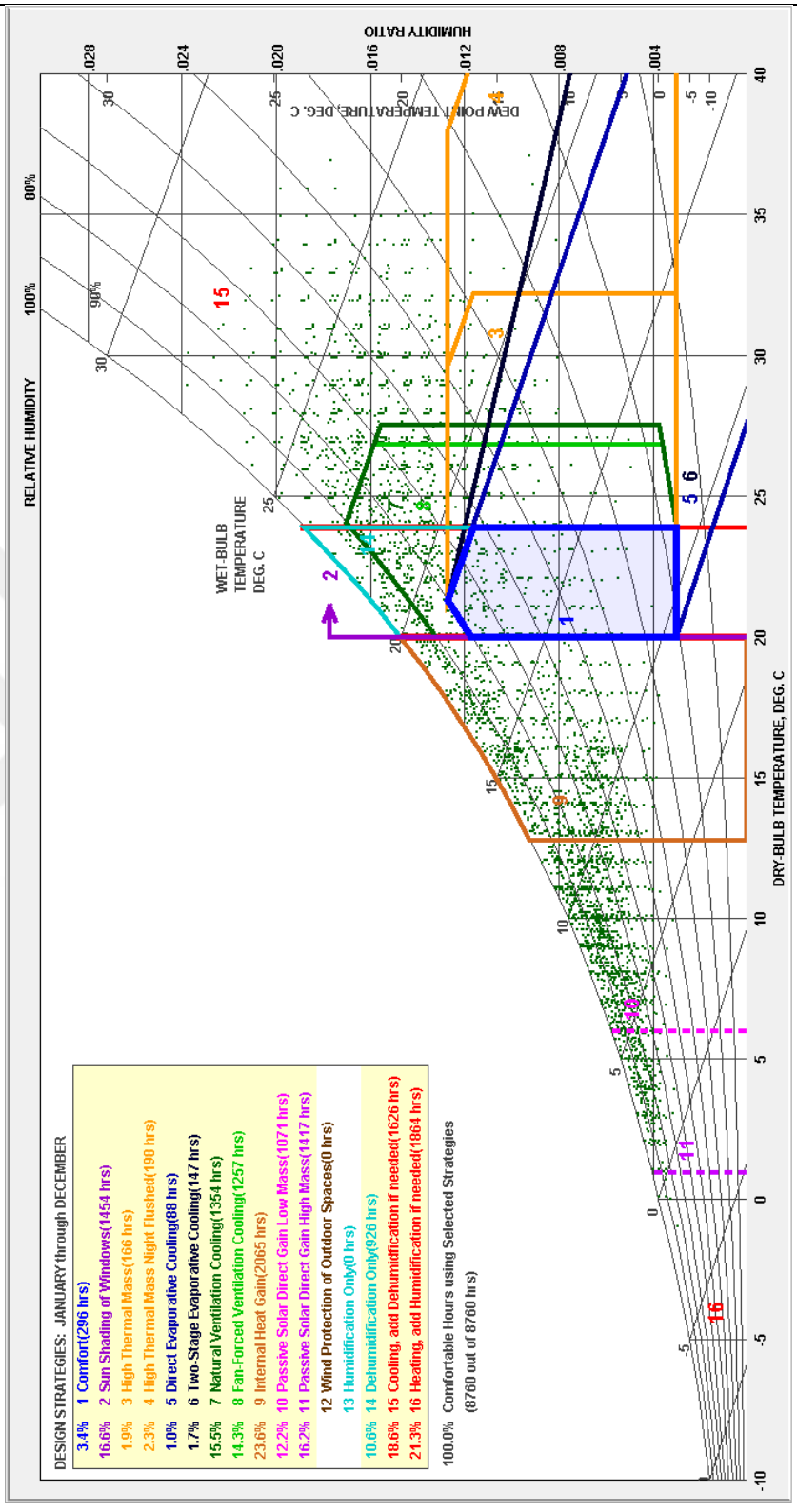
Sari	 In contrast to the two previous cities, Sari experiences high levels of humidity throughout a year. On the other hand, the natural heating and cooling can be more considered for creating comfortable living situation.

Table 8. Numerical summary of Climate Consultant design suggestions

Design Parameters	**Tabriz**	**Yazd**	**Sari**
Comfort	11.4%	7.7%	3.4%
Sun Shading of Windows	12.6%	21.1%	16.6%
Thermal mass	20.8%	14.7%	4.2%
Evaporative cooling	33.1%	**77.8%**	2.7%
Ventilation	12.3%	10.4%	**29.9%**
Internal Heat Gain	19.2%	19.3%	23.6%
Passive Solar Direct Gain	9.9%	17.4%	28.4%
Wind Protection of Outdoor Spaces	1.9%	0.1%	0.1%
Humidification Only	0.4%	4.1%	0.0%
Dehumidification Only	0.0%	0.0%	10.6%
Cooling, add Dehumidification if needed	0.0%	0.2%	18.5%
Heating, add Humidification if needed	**51.7%**	27.9%	21.3%

3.3. Examples of influential courtyard houses in different climates of Iran

This section includes architectural details of courtyard houses, selected among influential examples in the three locations. Although these examples do not represent the vast majority of Iranian courtyard houses regarding size, they demonstrate cases of elaborate materialization of generic courtyard typologies.

3.3.1. Examples of arid climate's influential courtyard houses (Yazd)

Five houses were selected as examples for arid climate in Yazd, which are introduced below.

- Rasoulian house
- Mahmoudi house
- Mortaz house
- Laryha house
- Golshan house

Yazd comprises many courtyard houses, which, the selected examples are among Yazd's prominent traditional courtyard houses; Raoulian house (Bemanian et al., 2010), Mahmoudi house (also known as Arabs' house) (Afshari Basir et al., 2017), Mortaz house (Hedayat et al., 2020), Laryha house (Bolouhari et al., 2020), and Golshan house (Rizi, 2022) have been studied and evaluate by many scholars and are located in the historical zone of the city (Figure 15).

Figure 15. Yazd courtyard house examples

- Rasoulian house:

Rasoulian house is one of the prominent buildings of the old desert city of Yazd. This desert city, among other cities in Iran, is one of the places where historic and traditional buildings have remained with minimal changes. Rasoulian House is located in Sahl Bin Ali neighborhood in the historical context of Yazd and belongs to the Qajar period. It is devoted to Yazd University. After renovations were carried out, it became a part of the Department of Architecture and Urban Planning of Yazd University (Radaei, 2020). The courtyard orientation is north-south and has walls on four sides (Ali Pourmand and Tabatabaei Malazi, 2016). The ratio of closed to open space is 2.57, length to width is 1.28, and length to height is 3.4 (Mahmoudi Zarandi, 2016). In Rasoulian house, brick tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of brick and clay (Bolouhari et al., 2020). Figure 16 illustrates the courtyard and plan of the Rasoulian house.

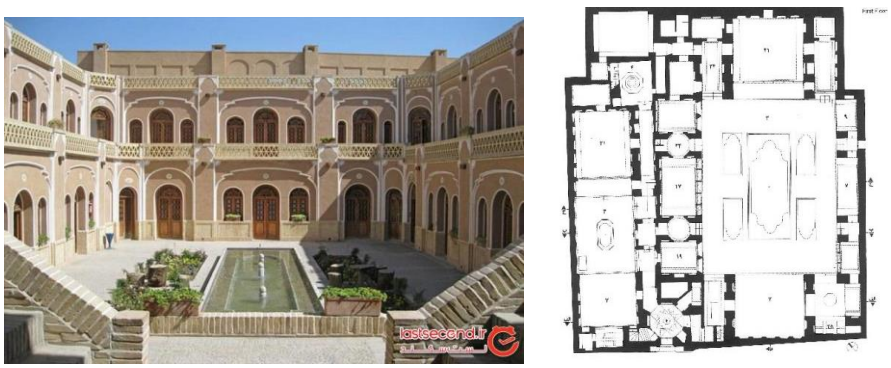


Figure 16. Picture and plan of Yazd courtyard house example - Rasoulian house (Source: Afshari Basir et al., 2017)

- Mahmoudi house

Mahmoudi house belongs to the Qajar period and is located in Yazd, Imam Khomeini St., Fahadan neighborhood. This house, which is also called the Bahreini Arabs, is approximately 130 years old and belonged to a family of merchants known as the Bahreini Arabs. Currently, the Mahmoudi house is owned by the cultural heritage of Yazd. The Mahmoudi house courtyard orientation is north-south and has walls on four sides. The ratio of closed to open space is 3.02, length to width is 1.51, and length to height is 4.27. In this house, window and door frames are made of wood and walls are made of clay, additionally, brick tiles are used for floor (Mahmoudi Zarandi, 2016). Figure 17 depicts the courtyard of the Mahmoudi house and and its plan plan.

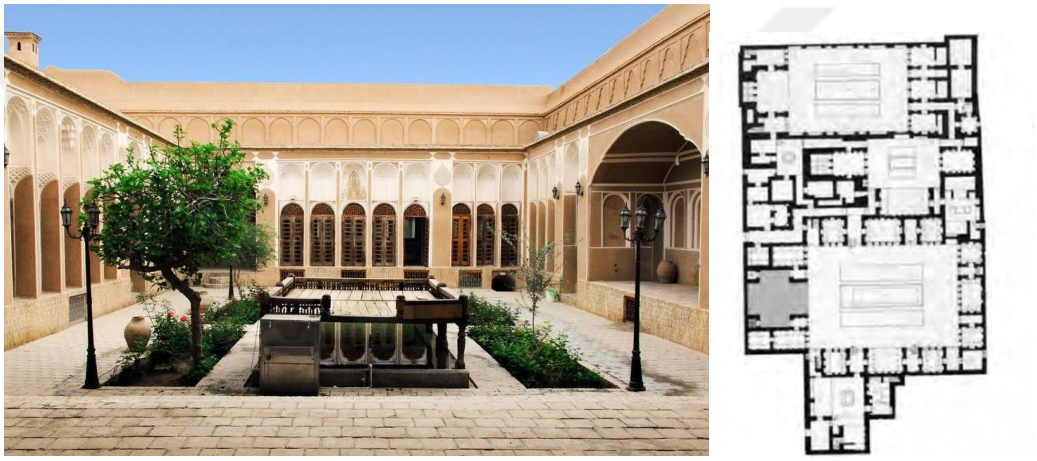


Figure 17. Picture and plan of Yazd courtyard house example - Mahmoudi house (Source: Mahmoudi Zarandi, 2016)

- Mortaz house

Mortaz house was built by Ali Shirazi in the Qajar dynasty and is situated on Mortaziun Street in Yazd. This house was devoted to the Department of Architecture and Urban Studies, Yazd University; and it is currently being used by the Department of Urban Studies (Afshari Basir et al., 2017). The courtyard of Mortaz house is oriented in the north-south direction and has walls on four sides. The ratio of closed to open space is 2.18, length to width is 1.48, and length to height is 3.35 (Mahmoudi Zarandi, 2016). Flooring material is brick tiles, openings' material is wood, and walls are made of brick and clay. Figure 18 indicates the plan of Mortaz house and its courtyard's picture.

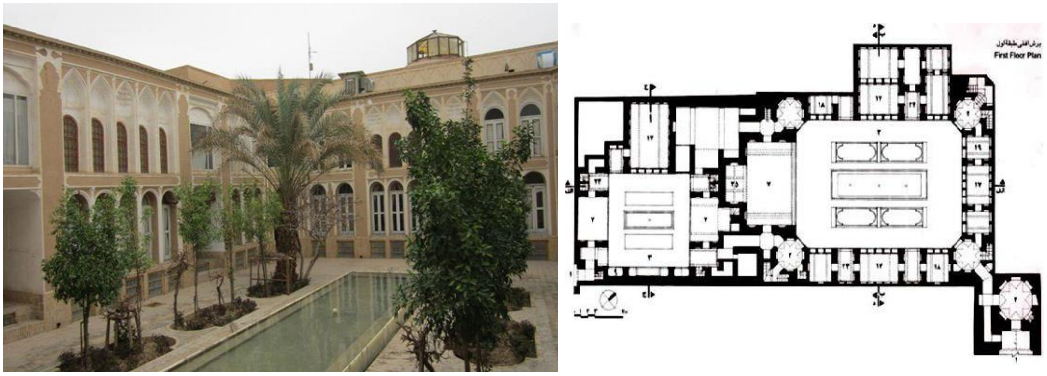


Figure 18. Picture and plan of Yazd courtyard house example - Mortaz house (Source: Hedayat et al., 2015)

- Laryha house

The Laryha House is considered one of the most valuable buildings in Yazd and belongs to the Qajar era. This historic house is named after the owner of the house, Haj Mohammad Ibrahim Lary. After many years and due to inheritance, the house of the Laryha became an abandoned building and suffered serious and extensive damages. Finally, with the efforts of Iran's Cultural Heritage Organization, this historical building was bought from its owner and restored. Parts of the house were placed under the control of the National Library and Records Organization to become the National Document Museum and establish an administrative branch there (Bolouhari et al., 2020). The courtyard orientation is approximately north-south and has walls on three sides. The ratio of closed to open space is 2.74, length to width is 1.68, and length to height is 4.75 (Mahmoudi Zarandi, 2016). In Laryha house, brick tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of clay (Bolouhari et al., 2020). Figure 19 illustrates Laryha house courtyard view and its plan.

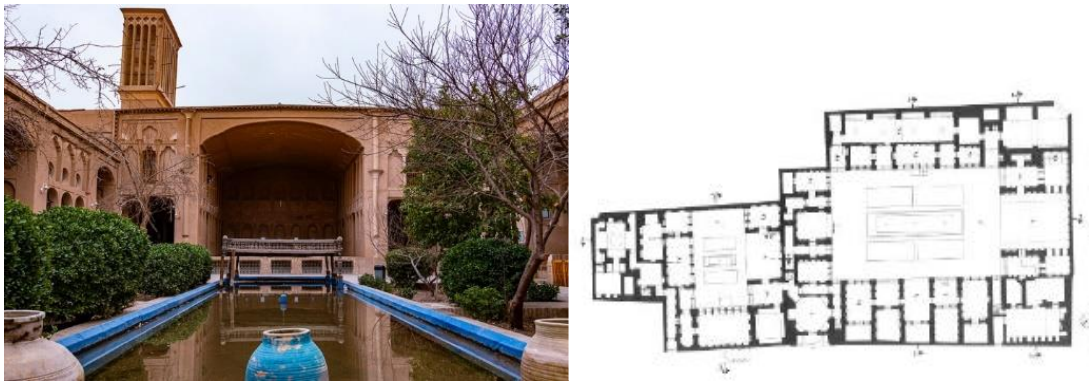


Figure 19. Picture and plan of Yazd courtyard house example - Laryha house

- Golshan house

Golshan house is located next to the Butchers gate alley, 10th Farvardin Street, Tal

neighborhood and dates back to Qajar period. The house was belonged to Haj Ali Akbar Mahalli Tali; but since he gave the building to his daughter, Bibi Fatima, and her husband, Haj Hossein Golshan, the building has been known as Golshan house. After renovation, the building has been changed to the Yazd Laleh Hotel (Afshari Basir et al., 2017). The courtyard is built on north-south direction and is fully enclosed from four sides. The ratio of closed to open space is 3.19, length to width is 1.31, and length to height is 4.57. In Golshan house, brick tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of brick and clay (Bolouhari et al., 2020). Figure 20 indicates the Golshan house courtyard picture and its plan.

Figure 20. Picture and plan of Yazd courtyard house example - Golshan house

3.3.2. Characteristics of arid climate's influential courtyard house examples (Yazd)

The main direction of Yazd courtyard house examples is north-south, their main geometrical characteristic is being four-sided, and the most used material for walls is clay, and bricks are used for the floor. The mean ratio of closed to open spaces is 2.74, lengths to width is 1.45, and lengths to height is 4.06. Table 9 summarizes the characteristics of courtyard houses examples for Yazd.

Table 9. Characteristics of Yazd courtyard houses

	Name	Courtyard main axis direction	Geometrical characteristic	Material		Proportions		
				Floor	Walls	Closed to open space	Lengths to width	Lengths to height
1	Rasoulian house	N-S		Brick	Brick and clay	2.57	1.28	3.4
2	Mahmoudi house	N-S		Brick	Clay	3.02	1.51	4.27
3	Mortaz house	N-S		Brick	Brick and clay	2.18	1.48	3.35
4	Laryha house	N-S		Brick	Clay	2.74	1.68	4.75
5	Golshan house	N-S		Brick	Brick and clay	3.19	1.31	4.57

3.3.3. Examples of continental climate's influential courtyard houses (Tabriz)

5 houses were selected as examples for continental climate in Tabriz, which are introduced below;

- Behnam house
- Salmasi house
- Rastgar house
- Khiabani house
- Alavi house

Tabriz include several prominent courtyard houses that Behnam house (Salehipour et al., 2021), Salmasi house (Fardanesh et al., 2022), Rastgar house (Balian Asl et al., 2014), Khiabani house (Moradi et al., 2018b), and Alavi house (Mansouri, 2018) are among them. All of the selected examples are located in the historical area of Tabriz (Figure 21).

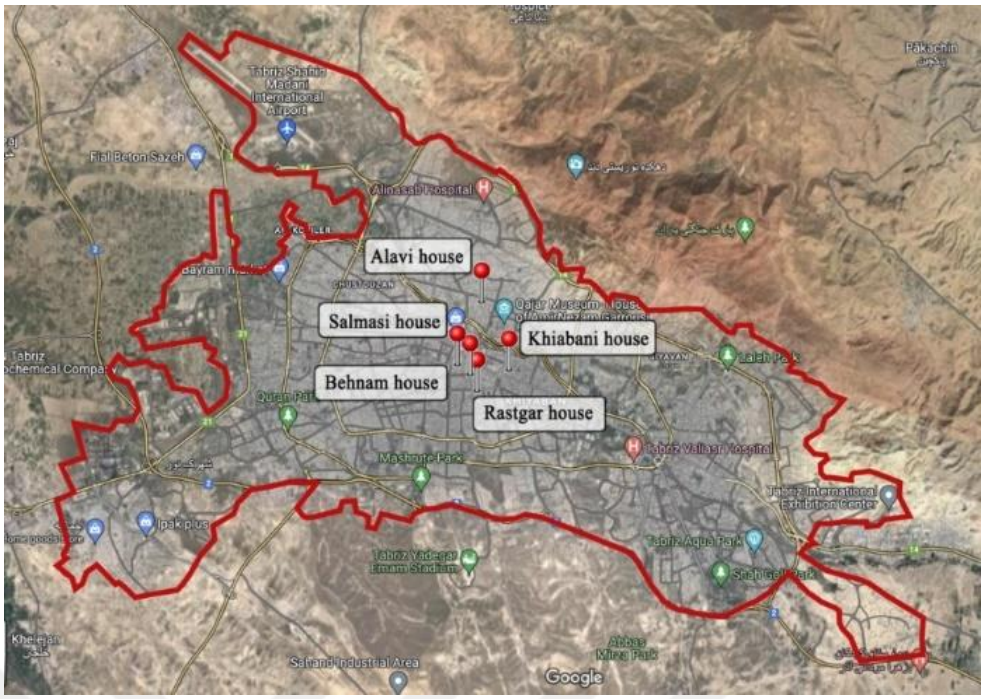


Figure 21. Tabriz courtyard house examples

- Behnam house

Behnam House (Figure 22), also known as Behnam Ganjei or Ghadki house, is a building related to the beginning years of the Qajar era and it was built as a residential house. This house was built on Maghsodieh street and near the Tabriz Grand Bazaar. Currently، the administrative department of Tabriz University of Islamic Arts is located in this building (Abdolhoseyni, 2011). The courtyard orientation is north-south and has walls on two sides facing each other. The ratio of closed to open space is 0.66, length to width is 1.49, and length to height is 3.9 (Moradi et al., 2018b). In Behnam house, brick and stone tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of brick and clay (Panahi et al., 2013).

Figure 22. Picture and plan of Tabriz courtyard house example - Behnam house

- Salmasi house

This house is one of the old and valuable houses of Tabriz, which dates back to the middle of the Qajar period. This house was the family home of Mr. Salmasi, a food merchant, which after about 120 years, was bought by the cultural heritage of Iran. After restoration, it has been put into use as a measurement museum. This museum is the only specialized measurement museum in Iran where measurement tools and instruments are kept (Fardanesh et al., 2022). The courtyard orientation is north-south and is enclosed from three sides. The ratio of closed to open space is 1.32, length to width is 1.66, and length to height is 3.4. Regarding materials, stone tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of brick and clay (Moradi et al., 2018b). Figure 23 illustrates the courtyard of Salmasi house and its plan.

Figure 23. Picture and plan of Tabriz courtyard house example - Salmasi house

- Rastgar house

The Rastgar house belongs to the first Pahlavi period and is located on South Artesh Street in Tabriz near Baghshomal intersection. This building has been called the “Shahriar Research Foundation” for more than a decade and has been devoted to the Persian Language and Literature Academy (Sattarzadeh and Balilan Asl, 2015). The Rastgar house’s courtyard orientation is north-south and is enclosed from two adjacent sides. The ratio of closed to open space is 0.71, length to width is 2.27, and length to height is 3.8 (Moradi et al., 2018b). In the Rastgar house, floor is made by stone tiles, window and door frames are wooden, and walls are made of brick. Figure 24 portrays the Rastgar house’s brick façade and its plan.

Figure 24. Picture and plan of Tabriz courtyard house example - Rastgar house

- Khiabani house

The Khiabani house (Figure 25) is a historical building in the center of Tabriz, where Sheikh Mohammad Khayabani lived the last 10-15 years of his life. This house, located in Shahid Beheshti square of Tabriz (former Mansour intersection), was built at the end of the Qajar period and the beginning of the Pahlavi period. Currently, this building is called “Sheikh Mohammad Khiabani Museum House”. The courtyard orientation of Khiabani house is north-south and has walls on two sides facing each other. The ratio of closed to open space is 0.98, length to width is 1.42, and length to height is 4.2. In Khiabani house, stone tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of brick and clay (Moradi et al., 2018b).

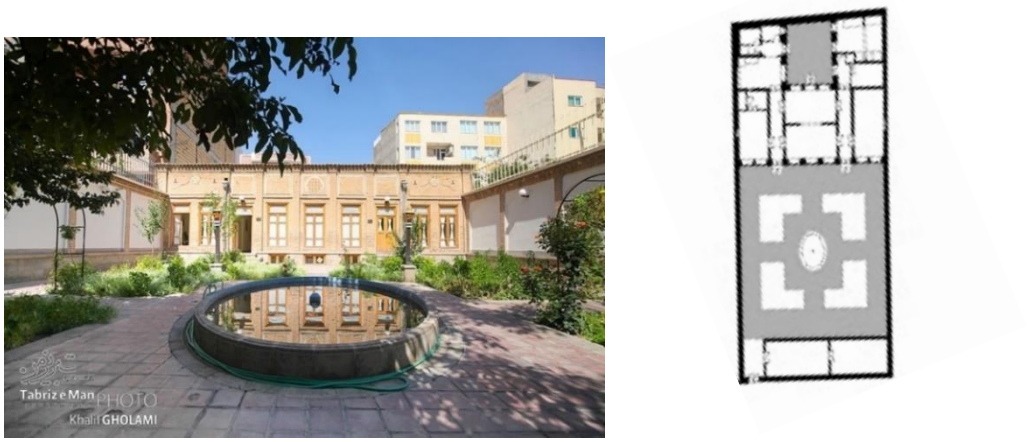
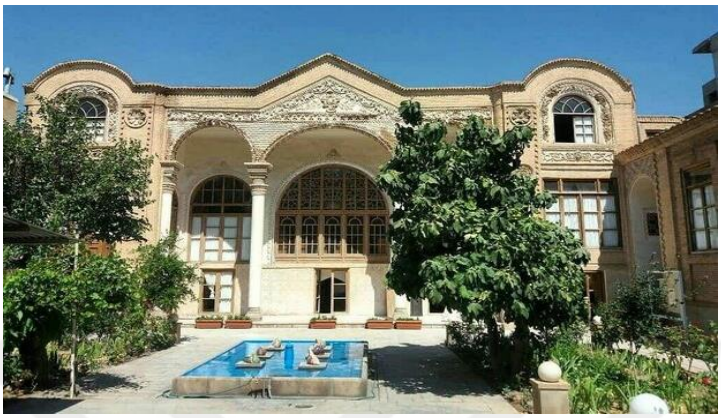


Figure 25. Picture and plan of Tabriz courtyard house example - Khiabani house

- Alavi house

The Alavi house dates back to the Qajar-Pahlavi period, which was bought and renovated by the East Azerbaijan Governorate and Cultural Heritage Organization about 30 years ago, and became the Pottery Museum and the venue for pottery classes

(Sattarzadeh and Balilan Asl, 2015). The courtyard of Alavi house is oriented in the east-west direction and has walls on two adjacent sides. The ratio of closed to open space is 1.27, length to width is 1.41, and length to height is 2.1. Flooring material is brick and stone tiles, openings' material is wood, and walls are made of brick and clay (Moradi et al., 2018b). Figure 26 indicates the Alavi house courtyard and its plan.



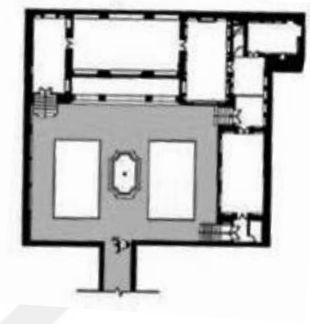


Figure 26. Picture and plan of Tabriz courtyard house example - Alavi house

3.3.4. Characteristics of continental climate's influential courtyard house examples (Tabriz)

Table 10. Characteristics of Tabriz courtyard

	Name	Courtyard main direction	Geometrical characteristic	Material		Proportions		
				Floor	Walls	Closed to open space	Lengths to width	Lengths to height
1	Behnam house	N-S		Brick and stone	Brick and clay	0.66	1.49	3.9
2	Rastgar house	N-S		Stone	Brick	0.71	2.27	3.8
3	Salmasi house	N-S		Stone	Brick and clay	1.32	1.66	3.4
4	Khiabani house	N-S		Stone	Brick and clay	0.98	1.42	4.2
5	Alavi house	E-W		Brick and stone	Brick and clay	1.27	1.41	2.1

The main direction of Tabriz courtyard house examples is north-south, their

prevailing geometrical characteristic is being two-sided, and the most used materials for walls are brick and clay, openings are made of wood, and stones are the most common material for floors. The mean ratio of closed to open spaces is 0.98, lengths to width is 1.65, and lengths to height is 3.48. Table 10 summarizes the mentioned characteristics of the courtyard houses examples for Tabriz.

3.3.5. Examples of temperate climate's influential courtyard houses (Sari)

3 houses were selected as examples for temperate climate in Sari, which are introduced below;

- Fazeli house
- Kolbadi house
- Ramadani house

Among the most important courtyard houses of Sari are Kolbadi, Fazeli, and Ramdani houses which are located in the traditional tissue of Sari (BEManian and SaREM, 2015). Figure 27 illustrates the geographical locations of considered courtyard house examples for Sari.

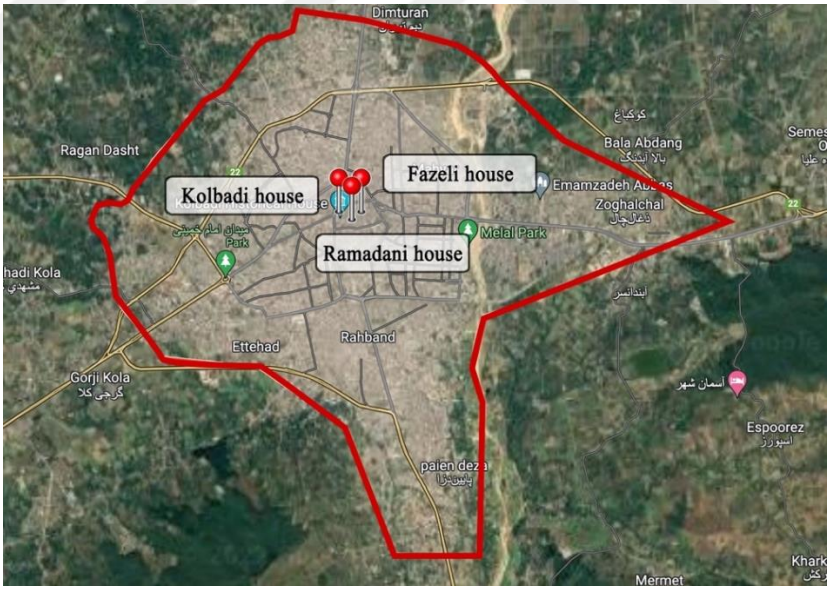


Figure 27. Sari courtyard house examples

- Fazeli house

This building was built in the Qajar and Pahlavi periods and was the Fazli family's residence. The restoration and reconstruction project started when the building was about to be destroyed. About a decade ago, the Fazli house went opened to the public without any specific use (BEManian and SaREM, 2015; Mehri and Zabihi, 2021). The courtyard orientation of Fazli house is east-west and has walls on three sides. The ratio

of closed to open space is 1.56, length to width is 1.17, and length to height is 3.25. In Fazeli house, brick tiles are used for floor and woods for openings (window and door frames), additionally, walls are made of brick and wood (Rezaighadi et al., 2022). Figure 28 shows the picture and plan of the Fazeli house in Sari.

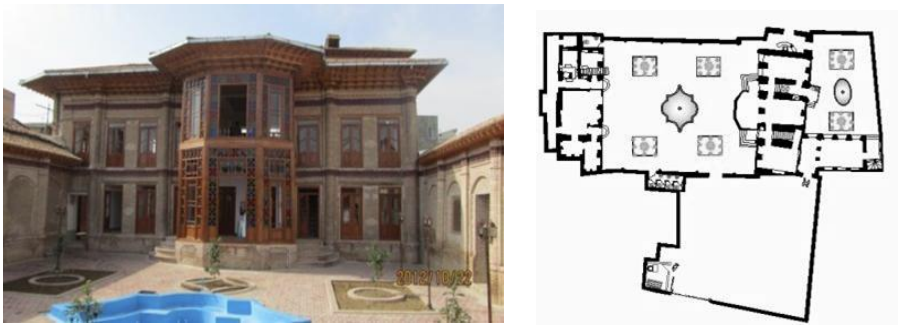


Figure 28. Picture and plan of Sari courtyard house example - Fazeli house

- Kolbadi house

The Kalbadi house (Figure 29) dates back to the late Qajar period and is located in Sari. The house of Kalbadi was built about one hundred and thirty years ago by the order of Sardar Jalil and named after his grandson Manouchehrkhan Kalbadi. After the death of Manouchehrkhan Kalbadi, this building was devoted to the Cultural Heritage Organization (BEManian and SaREM, 2015; Mehri and Zabihi, 2021). The courtyard of Kolbadi house is oriented in the north-south direction and has walls on three sides. The ratio of closed to open space is 2.74, length to width is 1.08, and length to height is 4.1. Flooring material is brick tiles, openings' material is wood, and walls are made of brick and wood (Rezaighadi et al., 2022).

Figure 29. Picture and plan of Sari courtyard house example - Kolbadi house

- Ramadani house

The Ramdani house is located in the neighborhood of Ab Anbar Nou, in Sari, and is one of the beautiful buildings left from the Qajar era. The cultural heritage organization of Mazandaran province renovated this building about two decades ago. Today, this building is no longer privately owned and belongs to the cultural heritage

and tourism organization of Mazandaran province (BEManian and SaREM, 2015; Mehri and Zabihi, 2021). The courtyard orientation is east-west and has walls on three sides. The ratio of closed to open space is 0.61, length to width is 2.06, and length to height is 3.9. In Ramadani house, brick tiles are used for floor, the window and door frames are wooden, and walls are made of brick (Rezaighadi et al., 2022). Figure 30 illustrates the picture and plan of Ramadani house.

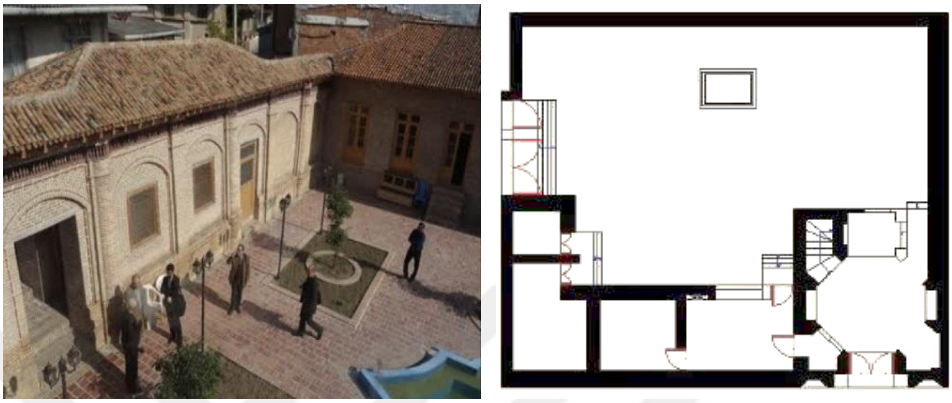


Figure 30. Picture and plan of Sari courtyard house example - Ramadani house

3.3.6. Characteristics of temperate climate's influential courtyard house examples (Sari)

Sari courtyard house examples are directed mainly on east-west axis. The common geometrical characteristics among the study examples is being three-sided. The mean ratio of closed to open spaces is 1.63, lengths to width is 1.43, and lengths to height is 3.75 Regarding the materials, brick and wood are the most common materials for walls, brick for floors, and wood for openings. Table 11 illustrates a summary of characteristics of selected courtyard house examples in Sari.

Table 11. Characteristics of Sari courtyard houses

Name	Courtyard main direction	Geometrical characteristic	Material			Proportions		
			Floor	Walls	Openings	Closed to open	Lengths to width	Lengths to height
1 Fazeli house	E-W		Brick	Brick and wood	Wood	1.56	1.17	3.25
2 Kolbadi house	N-S		Brick	Brick and wood	Wood	2.74	1.08	4.1
3 Ramadani house	E-W		Brick	Brick	Wood	0.61	2.06	3.9

CHAPTER 4: FINDINGS

4.1. The findings of the courtyard house examples

This chapter correlates the architectural features described above with the corresponding environmental parameters exploring the role of climate in that dialogue.

4.2. The impacts of Iran's major climates on traditional courtyard houses

The degree of enclosure of central courtyards in arid region is higher than in other regions, as shown in table 12. Arid climate's courtyards are fully closed from 4 sides, but temperate climate's courtyards are mostly open form one side, and continental climate's courtyards are regularly open from two sides. The main axis of arid and continental climates' courtyards is directed north-south which is different from the ones in temperate climate (east-west).

Table 12. Comparison of courtyards characteristics in Iran's

Climate	**Courtyard main direction**	**Geometrical characteristic**	**Material**		**Proportions**		
			Floor	**Walls**	**Closed to open space**	**Lengths to width**	**Lengths to height**
Arid climate	N-S	 Closed from 4 sides	Brick	Brick and clay	2.74	1.45	4.06
Continental climate	N-S	 Closed from 2 sides	Stone	Brick and clay	0.98	1.65	3.48
Temperate climate	E-W	 Closed from 3 sides	Brick	Brick and wood	1.63	1.43	3.75

There are a lot of similarities between the used materials in the three climates' courtyards; all of the three climates' courtyards use wooden doors and windows, given the lack of other options in the past. Brick and clay are used for walls of arid and continental climates' courtyards, and brick and wood are used for temperate climate's courtyard walls. Regarding the flooring of the courtyards, brick is common in arid and temperate climates and stone is common is continental climate.

The courtyards' close-to-open space proportion is different in all climates; the arid

climate has the highest mean (2.74) and the continental climate has the lowest mean (0.98). The ratio of lengths to width does not vary significantly, and as for the ratio of lengths to heights, arid climate has the highest mean (4.06).

These characteristics have climatic origins which are separately explained for each of Iran's climates in the next sections.

4.3. The relation between the physical features of courtyards and climatic characteristics in arid climates like Yazd

Yazd's predominant influencing environmental factor is the wind; hence it is important to design the architectural spaces to minimize the impact of hard winds while maximizing the benefits of favorable breezes for the internal ventilation of buildings (Jasim et al., 2021).

Sand is another feature that emphasizes the significance of the winds because it is carried by the wind obviously affecting the life of the locals. Only 14.4 km/h of wind speed is needed in a sand storm to raise the dust off the ground, however most significant dust storms have wind speeds significantly higher than this (Zarei et al., 2018). In Yazd, a significant amount of the year's wind is directed from the north to the south, typically ranging between 19 and 28 km/h (Figures 16 to 20), which are the primary sources of the sand and dust storms in the area.

These storms can be considered as one of the reasons for avoiding the construction of residential space on the south-eastern side of the yard (Figure 17). In order to take advantage of favorable climatic conditions like solar energy or favorable breezes and to avoid unpleasant ones like sandstorms (Figure 31), the central yard in Yazd houses must be in close contact with their surrounding environment (Figure 31), and Table 9 indicates that, except for the Laryha house, which is enclosed from 3 sides, other courtyard house examples (Rasoulian, Mahmoudi, Mortaz, and Golshan houses) are fully closed from 4 sides. However, CCS (Table 8) suggests that wind protection from outdoor spaces in Yazd buildings, only improves the comfort time for occupants by up to 0.1% in a year. Due to the fact that sandstorms have no influence on the thermal comfort of the indoor environment, CCS does not regard wind protection as an effective parameter for indoor thermal comfort.

Figure 31. Sandstorm in Yazd (Source: Sputniknews, 2018)

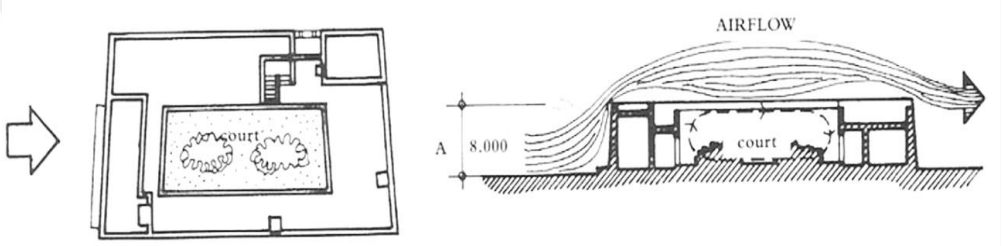


Figure 32. How courtyard prevent sandstorm (Source: Dragons Rabbit Sandroosters, 2022)

In the compact urban texture of historic towns such as Yazd, the house is usually bounded either by neighboring dwellings or by narrow streets. Openings to the exterior spaces were avoided for privacy concerns and access could be tricky. As a result, the home was completely inward-looking, and the courtyard was transformed into a little garden with a pool that served as a cool area in the spring and summer. CCS suggestions indicate that only humidification causes a 4.1% increase in the comfort time throughout the year (Table 8). In fulfilling this goal, by enhancing evaporation and supplying humidity, the water in the pool absorbs the air heat and lessens its aridity, which is provided in all of the Yazd courtyard house examples.

It has been shown that courtyards can give thermal comfort in arid areas without the aid of mechanical cooling systems (Figure 33) (Akbari and Teshnehdel, 2018; Soflaei, Shokouhian, Abraveshdar, et al., 2017), or at least they can significantly lower the amount of energy used by mechanical cooling systems (Foruzanmehr, 2017).

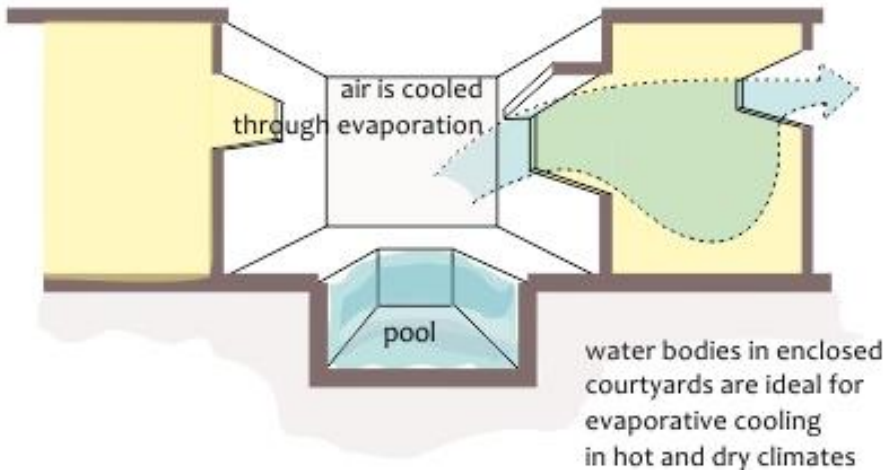


Figure 33. Courtyard pool's cooling mechanism (Source: Oxycom, 2022)

In order to take full advantage of the winter sun, the southern and northern facades should contain glass to gain maximum passive heating, which can increase the comfort time for residents by up to 17.4% in a year but should include overhangs to full shade in summer. Additionally, louvered openings that promote natural cross ventilation were used in several of Yazd's traditional courtyard, such as Mahmoudi house (Figure 17), and according to the CCS design suggestions, sun shading of windows will raise the comfort time during 21.1% of the year (Table 8). Therefore, seasonal rooms, private spaces, and reception areas were arranged around various courtyard areas, connecting these various places (Memarian and Brown, 2003); The summer living rooms are situated on the southern side of the courtyard, which receive natural ventilation from the wind catcher and is sheltered in the summer. According to CCS design suggestions (Table 8) ventilation can promote comfort time during up to 10.4% of the year. The courtyard's northernmost section houses the winter chambers, which receive warmth from the sun during the winter (Muhaisen and Gadi, 2006).

Evaporative cooling has been utilized to cool down living environments; porous clay vessels filled with water that is placed beneath an air inlet provide cooling when the air passes through them. Iranian architecture traditionally employed evaporative cooling using wet rags in combination with a wind tower to provide cooling in arid climate's buildings (Figure 34), which according to the CCS design suggestions, evaporative cooling can increase the comfort time by up to 77.8% in a year (Table 8).

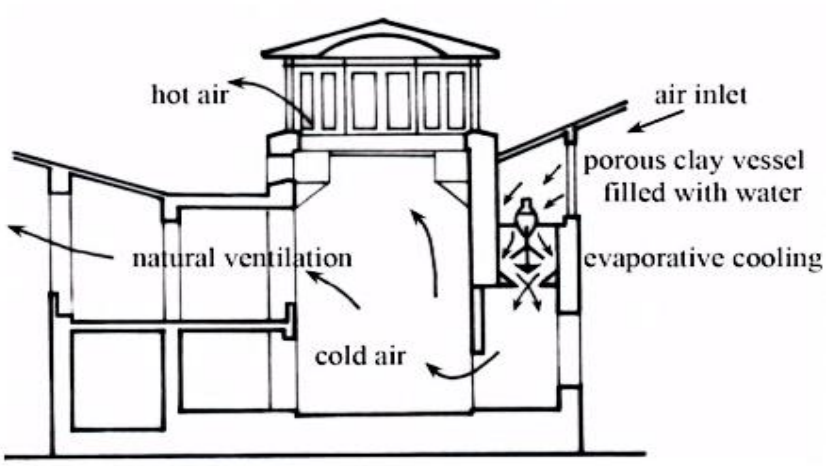


Figure 34. Wind catcher natural cooling mechanism (Source: Oxycom, 2022)

In general, the building materials used in this climatic zone are selected for their low heat conductivity and high resistance properties in order to minimize and delay the transfer of heat, thereby promoting thermal comfort (Toros, 2009). The soil, which is the most plentiful natural resource in the area, was converted into clay and used as the primary material of building and courtyard walls. This locally obtained material, which is recyclable, robust, and climate-compatible, doesn't disrupt the environment's natural cycle and permits construction with the least amount of environmental harm and waste (Asbagh, 2022). Due to excavating the ground in order to create a lower courtyard, the majority of the materials were obtained from the construction site itself, saving money on transportation and energy. Additionally, thick clay walls trap heat throughout the day and release it into the interior spaces at night. The opposite happens at night, modifying the temperature variations during the day.

Clay tiles were frequently used to pave the courtyards of homes in hot-arid climate zones (Table 9) since they tend to absorb less heat when exposed to the sun than stone slabs or mosaic, which makes the daily heat bearable. However, the bricks helped to retain some of the heat from the day throughout the night, when the air was cooler, preventing the yard area from freezing due to heat emittance to the night sky, which can improve the comfort time in a year up to 14.7% (Table 8).

Due to the scarcity of wood in this climate location, only the doors, windows, and occasionally the porch columns were made of it. Wood cannot transfer heat to the inside during the night because of its extremely low heat absorption, and it also cannot do the opposite during the day. As a result, its use as the main walls did not comply with the climatic needs of buildings in these areas, and it was excluded from the regional architecture (Ghazizadeh, 2014).

Table 13 presents a comparison between the design strategies recommended by the CCS and the techniques used in the design of Yazd's traditional courtyard dwellings in order to provide residents with a pleasant living environment. As can be seen in Table 13, most of the suggestions that have been proposed have indeed been taken into account in the design of the courtyard house.

Table 13. Climate Consultant suggestions' fulfilment in traditional courtyards of Yazd

Design Parameters for Yazd		
Comfort	7.7%	No design strategies were identified
Sun Shading of Windows	21.1%	The southern and northern facades that contain glass, include overhangs to full shade in summer.
Thermal mass	14.7%	Floors with bricks, help to retain the heat from the day and throughout the night, when the air was cooler, preventing the yard area from freezing due to heat emittance to the night sky.
Evaporative cooling	77.8%	Using wet rags with wind catcher provide evaporative cooling.
Ventilation	10.4%	Summer rooms are situated on the courtyard's southern side to receive natural ventilation from the wind catcher.
Internal Heat Gain	19.3%	Using materials with high thermal mass, using seasonal rooms, Building orientation
Passive Solar Direct Gain	17.4%	The southern and northern facades should contain glass to gain maximum passive heating in winter.
Wind Protection of Outdoor Spaces	0.1%	Enclosed courtyard from 4 sides and narrow streets.
Humidification Only	4.1%	Including pool in the courtyard to enhance evaporation and supply humidity.
Dehumidification Only	0.0%	No design strategies were identified
Cooling, add Dehumidification if needed	0.2%	No design strategies were identified
Heating, add Humidification if needed	27.9%	Using fireplace

4.4. The relation between the physical features of courtyards and climatic characteristics in continental climates like Tabriz

In comparison to dry locations, central courtyard enclosure in continental regions is less common (Table 12). In accordance with CCS design suggestions (Table 8), to take advantage of the solar heat during cold months, winter rooms in cold places are

situated on the south side of the courtyard and are wider and larger than other areas, which can increase comfort time for occupants up to 9.9% in a year (Table 8); however, these openings should be overhang to fully shade in summer and raise the comfort time in a year up to 12.6%. Due of the brief summer, the south side of these homes is less frequently used. If there are any, the spaces on the east and west front are also utilized as service areas, including a storage room, and restroom (Moradi et al., 2018b).

The quality of thermal comfort will be decreased due to the rise of the courtyard walls, especially in the south, which will cause extensive shadows on the courtyard's adjacent surfaces. It will also lower the quantity of heat storage in the courtyards during the cold seasons (Moradi et al., 2018a). The case study findings showed that the average length to height ratio in courtyards in continental climates is 3.48 (Table 12), indicating that all walls (especially south ones) should be relatively short compared to the courtyard lengths to reduce casting shadows and obstructing sunlight from reaching inside the courtyard. Additionally, the example analysis for the continental climate area showed that the most common style of courtyard is one that is closed on two sides (Table 10), highlighting the necessity for more sunlight-welcoming courtyards.

It was common for courtyard houses in this climatic zone to have small courtyards with large and thick walls to create passive heating through the cold months of the year. Although the courtyard's short, surrounding walls block the direct wind, they also restrict sunlight, which decrease the buildup of heat in the fabric and surfaces of the courtyard.

Studies on the wind speed in the city of Tabriz indicate that most of the time the wind speed is higher than 19 km/h and the north-east to the south-west directions are the dominant wind direction (Table 10). It is important to examine how central courtyards affect wind flow direction, especially during the colder months of the year. Moradi et al. (2018a) suggest that courtyards in Tabriz with dimensional proportions similar to square, can be more efficient in comparison to the ones with a wide north-south orientation in terms of reducing the wind speed, which the CCS design suggestions estimated increase in comfort time in a year of up to 1.9% (Table 8).

In the summer, wind can be used as a positive factor that can be taken into consideration for the purposes of natural ventilation. In the winter, due to the extreme cold in the area, the acceleration of the wind and penetration of the wind flow inside the courtyards are not desirable.

While the garden's floor gets some low-angle sun during the winter, the courtyards surrounding it and the walls facing north, east, and west remain in the shade. Despite being exposed to the wind, open areas are warmer than those that are enclosed (Xu and Peng, 2020).

Small openings are used selectively in this environment to limit heat transfer between the inside and outside of the building. The awning must be used if the windows are large. Therefore, to take advantage of sunlight as much as possible, openings on the southern walls of the house were designed to be broader and wider; on the other hand, there was no opening on the northern facade of the house, which was exposed to the cold winds.

The utilized materials for construction in traditional courtyard houses in cold and mountainous climatic zones are local. Therefore, it is necessary to use materials with high thermal capacity and resistance to be able to keep the internal environment warm (Kurmus and Mohajerani, 2021) and act as an insulation (Psychometric chart’s design suggestions). CCS (Table 8) suggests that thermal mass increases the thermal comfort by up to 20.8%. To prevent humidity, the courtyard walls are made of brick and clay, and the flooring is made of stone (Table 10).

The structure's flat roof in cold climates and the heavy snowfall meant that the roof needed to be built to withstand the weight of the snowfall. Native trees that can withstand weight and cold climate, such walnut and Populus nigra, were utilized to construct the roofs. In order to support the weight of the roof and stop heat loss, strong walls were also used. Additionally, wooden window frames were typical since wood has a low rate of heat transmission and a long lifespan.

As can be observed in Table 14, Traditional courtyards in Tabriz were able to satisfy the CCS's suggested points to a large extent, but not entirely. For instance, the most important recommendation that the CCS had for the homes in this climatic zone was to install a heating system that also provided the necessary humidification; the used wood fireplace was able to satisfy the mentioned point as a heating system but was not able to create the needed humidity.

Table 14. Climate Consultant suggestions' fulfilment in traditional courtyards of Tabriz

Design Parameters for Tabriz		
Comfort	11.4%	No design strategies were identified
Sun Shading of Windows	12.6%	The openings of rooms situated on the south side of the courtyard should be overhang to fully shade in summer.
Thermal mass	20.8%	Using materials like brick with high thermal capacity and resistance to be able to keep the internal environment warm.
Evaporative cooling	33.1%	No design strategies were identified
Ventilation	12.3%	No design strategies were identified
Internal Heat Gain	19.2%	No design strategies were identified
Passive Solar Direct Gain	9.9%	Winter rooms in cold places are situated on the south side of the courtyard and are wider and larger than other areas. All walls (especially south ones) should be relatively short compared to the courtyard lengths to reduce casting shadows and obstructing sunlight from reaching courtyard.
Wind Protection of Outdoor Spaces	1.9%	Openings on the southern walls should be wider, but there should be no opening on the northern facade of the house.
Humidification Only	0.4%	No design strategies were identified
Dehumidification Only	0.0%	No design strategies were identified
Cooling, add Dehumidification if needed	0.0%	No design strategies were identified
Heating, add Humidification if needed	51.7%	Wood fireplace without humidification system

4.5. The relation between the physical features of courtyards and climatic characteristics in temperate climates like Sari

In this climate zone, the goal of architecture is to control and reduce indoor humidity and temperature. These goals are achieved by applying strategies to create shading by using window overhangs and retractable sunshades reduce the amount of heat that enters the house (16.6% increase in comfort time in a year), and by exploiting natural airflow inside the home through leveraging prevailing winds and local breezes (Roshan et al., 2019), which according to the CCS suggestions, ventilation can raise the comfort by up to 29.9% of the time in a year (Table 8).

Most homes in temperate climates have regular geometrically shaped courtyards

that are often east-west oriented (Table 11) to maximize the use of the prevailing western winds. Additionally, there are two quarters for the winter and summer. In order to receive more sunlight and make the room warmer naturally during the winter, people shifted to the northeast side of the house and faced southwest. They relocated to the southwest throughout the summer because there was less sun exposure there and more introduction of the pleasant wind's fresh air (Baboli et al., 2015). Also, in order to minimize heat gain, incorporating bushes, trees, and ivy-covered walls, especially on the western side is common.

Residents' living quarters are situated in the shallow plan of the northern portion of the building site. The optimal way to catch the desired wind flow is through courtyard's shallow designs. In order to dehumidify the interior areas, shallow design helps ventilation and solar heat absorption, which will 18.5% increase the comfort time in a year (Table 8). The majority of the time, windows and doors are positioned on the yard's northern and southern sides (mostly southern sides), which promotes good air circulation. Additionally, to provide cross ventilation, western façade openings should be minimized or eliminated. More windows on the south walls encourage the access of winter sun.

The local resources were utilized to obtain the building materials for the courtyard dwellings that were designed for this environment. In this area, wood was widely used as the primary building and finishing material. Brick was another locally available material used in the main construction and finishings, as well as for floor covering and apertures (Table 12). Due to the high amount of precipitation in winter (Table 5), roofs made of locally produced fired clay tile extend beyond the facades on all sides (Baboli et al., 2015).

Porches and patios provide passive cooling. The porch was built in the courtyard as a protection from humidity, because, as previously mentioned, humidity control is one of the most important purposes of courtyard residences in this area. The porch served many functions and was also the most noticeable and commonplace space because it was semi-open and in a conspicuous point of the facade. Due to the stable weather and little temperature difference from May to October (Table 5), a variety of activities including cleaning, cooking, living, dining, and even sleeping were done in porches (Miryousefi, 2010). As they connected the internal space to the outside, porches that were at least 2 to 2.5 meters wide stretched the length of the building and offered air circulation. Additionally, because of the sun's vertical rays hitting the roof, the porch

on the south side of the building was able to enjoy a lovely shade throughout the summer.

Table 15. Climate Consultant suggestions' fulfilment in traditional courtyards of Sari

Design Parameters for Sari		
Comfort	3.4%	No design strategies were identified
Sun Shading of Windows	16.6%	Using window overhangs and retractable sunshades.
Thermal mass	4.2%	No design strategies were identified
Evaporative cooling	2.7%	No design strategies were identified
Ventilation	29.9%	Utilizing natural airflow inside the home by leveraging prevailing winds and local breezes. Courtyard's east-west orientation maximizes the use of the prevailing western winds. Openings are positioned on the yard's northern and southern sides which promotes good air circulation.
Internal Heat Gain	23.6%	No design strategies were identified
Passive Solar Direct Gain	28.4%	Using the proper orientation
Wind Protection of Outdoor Spaces	0.1%	No design strategies were identified
Humidification Only	0.0%	No design strategies were identified
Dehumidification Only	10.6%	No design strategies were identified
Cooling, add Dehumidification if needed	18.5%	To dehumidify the interior areas, shallow design helps ventilation and solar heat absorption. Porches and patios provide passive cooling and dehumidification
Heating, add Humidification if needed	21.3%	No design strategies were identified

Additionally, the sun's lower angles in winter increase heat absorption by the facades (Miryousefi, 2010). The principal rooms were on the second floor because of the rain and heat gain by the sun and were protected from the rain by porches surrounding the structure (Table 11), or at least in the south and east (Khotbehsara et al., 2018). The porch shields the main part of the structure from summer heat by opening on two or three sides, particularly the south and east. The main porch, which doubles as the living space, is therefore wider and higher than the other spaces, providing a better view and ventilation (Memarian, 1993; Miryousefi, 2010; Rezazadeh and Medi, 2017).

The courtyard homes were constructed separately and apart from one another because of the urban layout (Figure 8) and the necessity for wind to provide enough

ventilation. Since they had high walls on all four sides, they had multiple openings to enhance ventilation (Baghaiepoor et al., 2019).

The strategies that are used in the design of traditional courtyard houses in Sari are outlined in Table 15 along with the proposed design points that were provided by the CCS. Regarding this table, several aspects of the design are not taken into consideration. In spite of this, the most crucial ones, ventilation and cooling, with any necessary dehumidification, are used, which may increase the annual comfort time by up to 50 % in a year.

4.6. Summary

In the present part (4), the findings of the study were demonstrated; additionally, the impacts of Iran's major climates on traditional courtyard houses, and the relation between the physical features of courtyards and climatic characteristics in arid, continental, and temperate climates presented. Furthermore, regarding Figure 35, each bar indicates the percentage of the total time that the respective design strategy is effective in its considered climatic zone. Accordingly, in Tabriz city's traditional courtyard houses, the most important and effective CCS suggestion is "heating, ass humidification if needed", As for Sari city's traditional courtyard houses, "ventilation" is the most effective design suggestion. Finally for Yazd city's traditional courtyard houses, "evaporating cooling" is considered the most important factor.

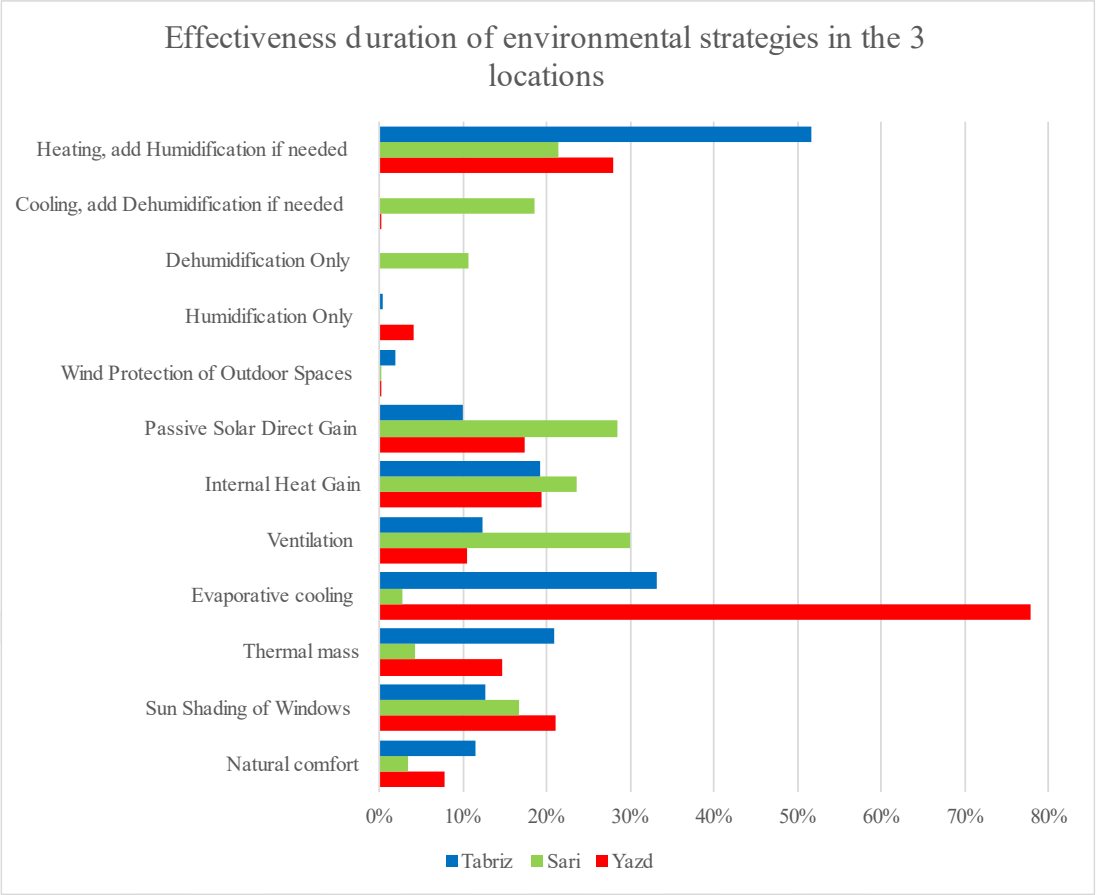


Figure 35. Schematic presentation of conclusions on the agreement of CCS suggestions in Yazd, Tabriz, and Sari (Source: CCS, 2022)

CHAPTER 5: DISCUSSION AND CONCLUSIONS

5.1 Overview

The current thesis evaluated the impacts of climate on the design Iran's traditional courtyard houses. Although Iran has different climate types, in order for people to adapt to these climatic diversities, they modified their architectural styles to make them more compatible with their environment. Therefore, the courtyards, which are inseparable features of traditional Iranian architecture, have been utilized differently in each climate. Despite the availability of different climatic classifications for Iran, the Köppen–Geiger classification was selected for Iran's climatic groups, which indicated three major climates: arid, continental, and temperate.

Thus, the main goals of the current thesis were to study the architectural factors in each climate and then compare them. In this regard, part 1 outlined a brief overview of the thesis, the problem statement, objectives, and methodology.

In part 2, by reviewing the literature on Iran's climates, courtyard houses, and the relationship between them, the physical factors and benefits of the traditional courtyard houses were identified.

Part 3 assessed Iran's climatic characteristics and utilized CCS design suggestions for each climate. Afterward, the selected courtyard house samples of each climate were introduced, and their climatic adaptations were analyzed.

Finally, in part 4, in order to investigate the difference between courtyards in various climates of Iran, the identified factors were compared between the existing examples of traditional courtyards in three climates. In addition, the climatic adaptations of each courtyard's characteristics were compared to the suggestions of CCS, and the level of these suggestions' fulfillment was discussed. CCS is extensively being used by architects and researchers to understand local climates; recent studies have used it to evaluate Iran's diverse climates (Farivar and Agharabi, 2021; Khalili, 2021).

5.2 Findings

The results demonstrated that the level of enclosure of courtyards in arid climate (closed from four sides) is higher than in other regions, which is also demonstrated in previous research, recommending a high wall enclosure to block the sand storms and create more sustainable courtyards in arid climate (Hasehzadeh Haseh et al., 2018). The main direction of arid and continental climates' courtyards is north-south which

is different from the ones in temperate climate (east-west) (Salavatian, 2022; Yazdi et al., 2021).

All of the three climates' courtyards use wooden doors and windows. The widespread usage of wood for openings is also pointed out in previous research (Nabavi and Ahmad, 2016; Nabavi et al., 2013); which is supposed to be due to its availability all over Iran (Ghobadian, 2015). Brick-clay are used for walls of arid and continental climates' courtyards, and brick and wood are used for temperate climates' courtyard walls. Regarding the flooring of the courtyards, brick is common in arid and temperate climates and stone is common is continental climate; which are chosen based on their heat conductivity to adapt to each climate's characteristics, but also were dependent on the locally available materials (Izadpanahi et al., 2021).

The "close to open space proportion" is highest in arid climate and lowest in continental climate. As indicated in previous studies, the reason for the low "close to open space proportion" in continental climate is to invite natural daylighting as much as possible (Mansouri, 2018). There are not noticeable differences in terms of the "length to width ratio", but regarding the "lengths to height ratio", arid climate's courtyard houses have the highest mean (Table 12), which as previously stated, is mainly due to avoid sand storms (Hasehzadeh Haseh et al., 2018).

Furthermore, the results of each climate's examples are discussed in the 4.3, 4.4, 4.5 sections according to the Climate Consultant's design suggestions (Table 8) to understand to what extent those suggestions were fulfilled. The overall results demonstrated that in Yazd traditional courtyard houses, most of the suggestions are used, and therefore, occupants will benefit from the optimum comfort time throughout a year. On the other hand, in Tabriz's traditional courtyard houses, despite fulfilling the wide range of suggestions the heating system was lacking humidification. Furthermore, in Tabriz, the main focus was on providing passive solar direct gain, and after that, sun shading of windows, thermal mass, and wind protection of outdoor spaces. Regarding traditional courtyard houses of Sari, ventilation and cooling with dehumidification are fully provided, and sun shading of windows is used to some extent. Since the "comfort, internal heat gain, and dehumidification only" design strategies cannot be applied to the Yazd, Tabriz, and Sari cities' traditional courtyard houses, these factors are considered as neutral suggestions (Table 16). Regarding Table 16 the green check mark and red x mark indicate the agreement and non-agreement, respectively, with the respective design strategy. On the other hand, the

neutral orange circle represents design strategies that are not applicable.

Table 16. Climate Consultant suggestions' overall fulfilment

Design Parameters for Yazd	**Yazd**	**Tabriz**	**Sari**
Comfort	○	○	○
Sun Shading of Windows	✓	✓	✓
Thermal mass	✓	✓	✗
Evaporative cooling	✓	✗	✗
Ventilation	✓	✗	✓
Internal Heat Gain	○	○	○
Passive Solar Direct Gain	✓	✓	✗
Wind Protection of Outdoor Spaces	✓	✓	✗
Humidification Only	✓	✗	✗
Dehumidification Only	○	○	○
Cooling, add Dehumidification if needed	✗	✗	✓
Heating, add Humidification if needed	✗	✓	✗

As can be seen in Table 16 the number of agreements with the suggested design parameters differs depending on the climatic zone. Yazd as a city located in the arid climate is the one with the highest number of agreements with the suggested design parameters and this number decreases for Tabriz and Sari. It should be noted that the CCS only accounts for the parameters that impact internal thermal conditions and fails to consider other environmental factors, such as the occurrence of sandstorms, which is a critical concern in Yazd. Consequently, it can be inferred that CCS is not a comprehensive tool for evaluating all relevant design parameters and factors.

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