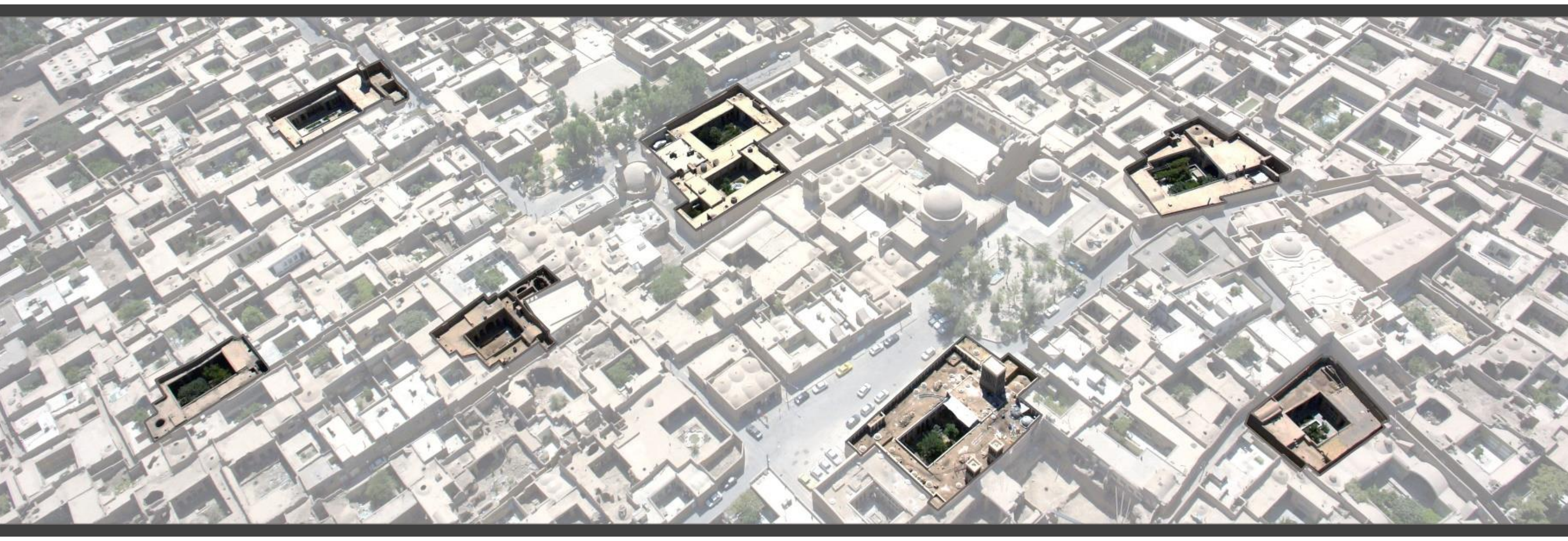
FROM HERITAGE TO SUSTAINABLE DESIGN
FOCUS ON TRADITIONAL HOUSING ARCHITECTURE IN IRAN



Analyzes and Recommendations for Sustainable Design
in Hot and Arid Region

Case Study: Traditional and Contemporary Housing Architecture in Yazd, Iran

O. Univ. Prof. DDI Wolfgang Winter
Univ. Prof. Mag. Arch. Francoise-Helene Jourda
Dr. Mohammad Hassan Talebian

Student: Afsaneh Soltani

Vienna University of Technology
Institute of Architecture and Design
Department for Spatial and Sustainable Design

CONTENTS

Abstract

Iran's traditional architecture has been admired by architects regarding its aesthetic values and wise architectural and structural solutions, but very rarely is it discussed why this architecture is not used any longer, or how it can be adapted to contemporary living and architecture standards, specifically in contribution to its environmental considerations.

In recent decades, energy crisis, depletion of natural resources and environment pollution have been challenging issues especially in fossil-fuel dependent countries like Iran and more specifically in hot and arid regions with a challenging climate.

At present one important trend in response to these emerging problems is to assist architects and designers by providing them guidelines for a more sustainable approach in architectural design specifically developing countries of Iran, where sustainability is a new debate and normally misused or misunderstood with very high-tech architectures or smart buildings that require high grey energy to be constructed and advanced technologies to operate.

In Iran, with thousands of years of architectural background and a huge legacy of traditional architecture, while the traditional architects did not have access to high technological solutions, they tried to find very simple but efficient local low-tech solutions for a more environment-friendly architecture to deal with the sever climatic conditions of hot and arid desert area.

These solutions were used, upgraded and passed from one generation to the next till the reformations of the 20th century in Iran, while different reasons caused these simple sustainable solutions in Iran's traditional architecture to become abandoned. This resulted in a contemporary architecture that follows global style all over the country, regardless of huge climatic and contextual differences in the country that covers a wide range of climates including cold mountains in the west, moderate climate of the Caspian sea area in North, very hot and humid gulf side areas in the South near the Persian Gulf as well as the very extensive area of hot and humid central deserts.

This dissertation focuses on the lessons and inspirations from sustainable Iranian traditional housing solutions in hot and arid region, and assess them according to modern architectural design criteria to see which solutions can be used again, which ones must be changed and which ones cannot be utilized any longer.

By implementation of empirical research, four successive phases are defined for the project:

- Selection of comprehensive case studies
- Defining the relevant evaluation system,
- Evaluation of case studies in terms of environmental sustainability
- Conclusion and recommendations

The research is fulfilled by using mixed (qualitative and quantitative) method through an inductive approach.

For the beginning, this project starts to discuss if traditional architecture in Iran was sustainable or not. In order to get to a more accurate discussion, contemporary architecture is also evaluated. Therefore case studies from among both traditional as well as contemporary types of housings are selected.

In order to avoid subjective evaluation and to do the evaluation in a more scientific way, the major challenge is to find the right baseline for evaluation of sustainability in the selected case studies. Since Iran does not yet have any sustainability evaluation system for buildings, the probable choice is to select among the existing evaluation systems worldwide.

This research first discusses the practical solutions to evaluate sustainability in houses, and then goes through a brief review of the existing national and international evaluation systems in the world, and the sub-categories they use for evaluation, all of which share lots of similarities and all claim to have the capacity to be used internationally. According to the climatic similarities between Iran and the US, the author finally selected LEED evaluation system as one of the oldest, simplest and most user-friendly and widely internationally used evaluation systems.

Nevertheless due to the limitations of using an evaluation system for both traditional and contemporary housings in their very different contexts, and due to the emphasis in existing evaluation systems such as LEED that encourage the users to use specific housing equipment or appliances for achievement of higher credits, this dissertation draws a proper evaluation system that works parallel with LEED in a critical viewpoint in order to define solutions that are adaptable at the architectural design stage.

The evaluation topics defined finally, focus on five major features of architectural sustainability including:

- Water
- Energy
- Ground and Land Use
- Material
- Health and Wellbeing.

In each category, contemporary and traditional case studies are investigated and evaluated to find out which is more sustainable; the traditional or contemporary housing and to learn the sustainable strategies adapted in each group.

It should be noted that although sustainability includes social, cultural and economic aspects too, but according to the author's field of study, this research only focuses on environment-based factors of sustainability.

After evaluating the old and new housings, this dissertation will provide recommendations and general guidelines in the five mentioned categories (Water, Energy, Ground and Land Use, Material and Resources, Health and Wellbeing) on basis of sustainable traditional architectural solutions in hot and arid region to be adapted by the contemporary architects at the early stages of their architectural design for houses in the region.

The social and cultural correspondence as well as climatic and environmental similarities between hot and arid region of Iran and the neighboring countries in the region, the outcome of this research can be developed to inspire the designers and architects who aim to design houses in those regions too.

Keywords

Environmental sustainability, traditional architecture, Iran, hot and arid region, Sustainability Evaluation, Contemporary housing design

Chapter 1. Description of the Research Problem

1.1. Iran

Iran is a large country with an area of 1,648,195 km² located in the Middle East. According to the most recent Iranian National Census in 2011, more than 75 Million people live in urban and rural regions inside the borders of Iran (SCI 2012).

Figure 1, Iran's location and area in comparison to Austria, drawn by author, on base of google maps

As one of the oldest countries in the world, Iran has been home to civilizations with ancient roots (Elke Pahl-Weber 2013, 110).

Archaeological excavations have revealed remaining of the pre-history period in Iran as old as Paleolithic era; such as primary tools and weapons in Bakhtiari Mountains in southeastern Iran and rock paintings in Lorestan area dating back to 15000 BC.

Various findings dating back to Mesolithic and Neolithic periods also confirm the agricultural and livestock-dependent living of the people in Iran during the following (Mesolithic and Neolithic) pre-history periods (Marzban 2007, 26)

Tappe Zagheh is one of the first agricultural settlements in Iran (Malek Shahmirzadi 1993) constituting of important properties belonging to late 8th to mid-6th millennium BC. The residential units in this village follow specific patterns that are in harmony with the climatic characteristics of the area, such as the rural fabric's orientation for preventing the hot desert winds, and adaption of local building material like rammed earth or adobe (Pirnia and Memarian, Styles of Iranian Architecture 2008, 41).

During the late 4th millennium BC, the Elamite Empire was founded in Southeastern Iran who possessed a perfect civilization (Marzban 2007, 27). The Elamite Empire succeeded to achieve a high position in culture and history of the near East that lasted for more than two thousand years (Hintz 1992). They adapted Susa as their capital city and established all the required urban elements such as governmental citadel as well as the Choghazanbil ziggurat temple, built with adobe and covered with burnt bricks. Their architectural remainings in

Haft Tappeh in Khuzestan, Iran is an evidence of their advanced knowledge of building techniques, with rectangular plans and vaulted roofs (Pirnia and Memarian, Styles of Iranian Architecture 2008, 44).

Later, the original Iranian empire, the Achaemenid (550-330 BC) became the largest empire in the world (Elke Pahl-Weber 2013, 110) that ruled over extensive territories from India and central Asia to North Africa, Balkan and Greece peninsula (Safa 1977).

At present, Iran is bordered by Iraq and Turkey to the west; by Armenia, Azerbaijan and Turkmenistan to the north; and by Afghanistan and Pakistan to the east. Iran's southern border is a coastline of 2,440 km on the Persian Gulf and the sea of Oman. A part of Iran's northern border is also coast, with 740 km along the Caspian Sea (Sabetghadam 2006).

Figure 2, Iran borders, provinces and neighbors, drawn by author, on base of google maps *i. Iran's Climatic Conditions*

The Iranian plateau is located in an arid region of the world (Figure 3) (Ghobadian 1994, 34). A large part of this great plateau encompasses the present country of Iran, an immense area with a variety of climates.

Mountains from the north, east, south, and west surround the central Iranian plateau. With an area of about 320,000 km², the central Iranian plateau includes the Lout and Salt deserts (Badi'ee 1988).

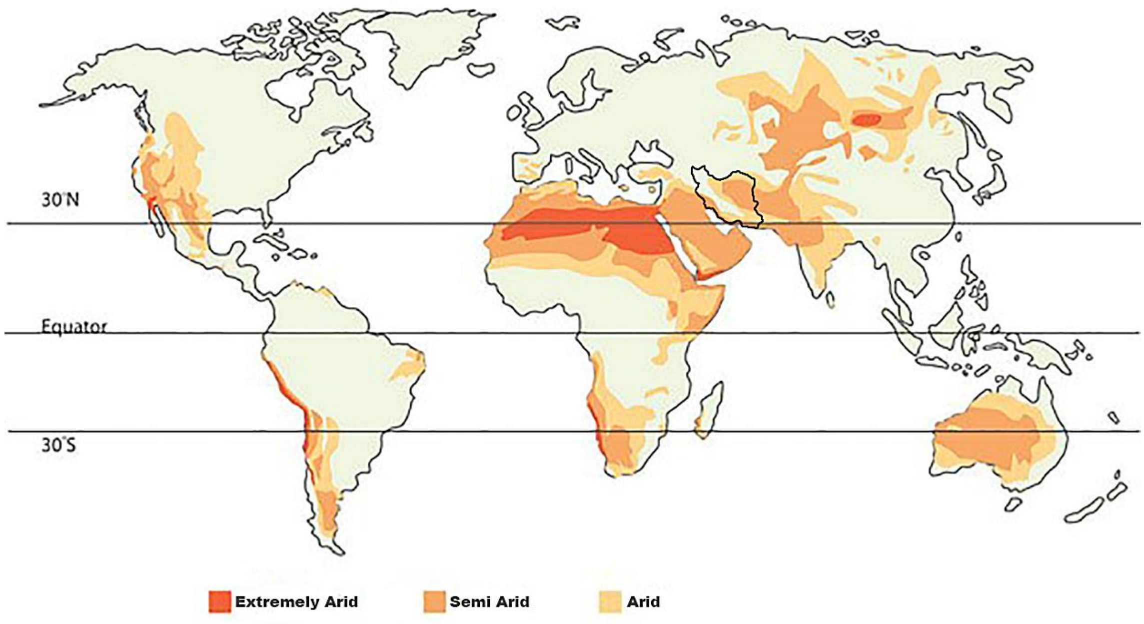


Figure 3, Distribution of arid land and location of Iran plateau. Image from: (Nature 2011)

Iran has a great geographic variety, from the Kavir desert to the Zagros Mountains in Western Iran or the Alborz mountain range with the 5,671 meter Damavand peak (Elke Pahl-Weber 2013, 110).

Some 65% of Iran's territory is arid or hyper arid, and approximately 85% has an arid, semi-arid or hyper arid environment. Like many of the neighboring countries in the region, a large area of the country is covered by desert areas with severe climatic conditions (Badripour 2004)

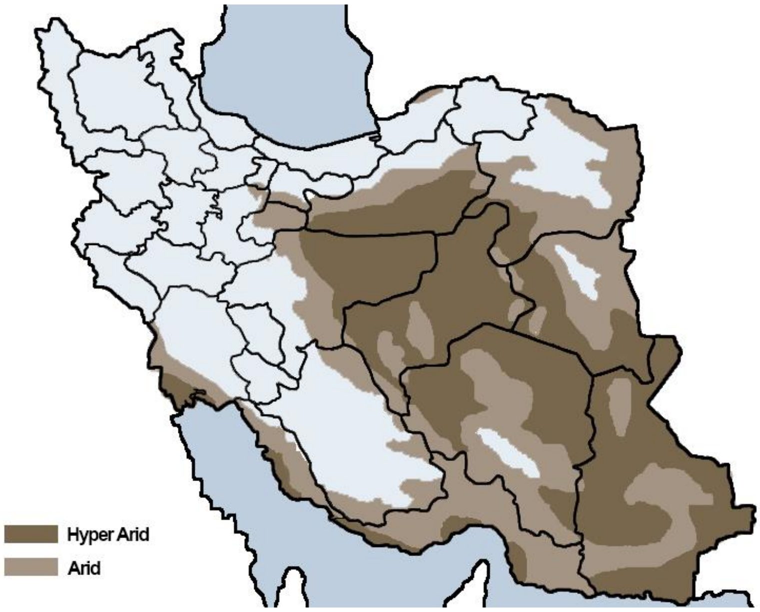


Figure 4, Distribution of arid and hyper arid areas of Iran, drawing by author on basis of FAO map

Also in its climatic classification for Iran, FAO profiles (Badripour 2004) define the Irano-Turanian zone as the largest climatic zone in Iran that covers approximately 90% of the country. This climatic zone includes the most arid part of the central Iranian plateau, the Subdesertic zone, with annual precipitation below 100 mm, average temperature in January between 4 ºC (north) and 10 ºC (south) and the average temperature in July being between 29 and 34 ºC, containing the towns of Yazd, Bam and Zabol.

The towns in this zone have at least three summer months of total drought extending up to nine months in the most arid regions. Relative humidity in winter between 80% and 55% (central desert) falling in summer to below 40% and down to 20%.

These severe climatic conditions create a real challenge for the inhabitants of this sub-desert zone. Due to the constrained natural resources in this area, achieving the comfort conditions for living in houses requires specific strategies adapted by house designers. (ibid)

ii. Architectural Trends in Iranian Cities

As Ehlers and Floor describe: “Before 1920, the Iranian cities were characterized by features that are considered to be typical for the “traditional” city. In the traditional world, every element, from architectural scale to the whole city, was made on the basis of local patterns that involve cultural, social and environmental aspects of vernacular architecture and urbanism” (Ehlers and Floor 1993, 251). These traditional cities have survived over centuries by considering local and environmental criteria.

After 1920, this continued process was ended with the modernization of the country. As researchers describe, the reforms that initiated during the 1930's changed not only the cultural patterns of urban life in Iran and the economic structure of the country, but even the spatial organization of the cities (ibid). Darab Diba, an Iranian architect, believes that "after this period, architecture [in Iran] was modernized in a new way: socio-political planning under the authoritative rule of government with the aid of westerners." (Diba and Dehbashi 2004).

Modern Iranian architects and city planners largely imitated and imported western patterns and styles in both urban planning and architectural scale projects. They rarely attempted for localizing them. This trend is still in progress.

iii. Sustainability Approach in Iran and the Neighboring Countries

Sustainability as a whole in Iran has recently become the center of debate and discussion. Even here, the designers rely on sustainability criteria defined by developed countries. In this regard, the evaluation systems of western countries are followed without consideration of local and vernacular features of environmental sustainability.

In a general view, the image of sustainable building in Middle Eastern countries like Iran, that have recently begun to consider sustainability, is a smart city in the heart of the desert, or high-tech constructions that have low energy requirements or zero carbon distribution, with attached green spaces on the facades or roofs, bearing equipment to provide the building with renewable energy (Figure 5).

Figure 5, Bahrain trade tower.
Image from: https://www.flickr.com

These are the typical buildings or cities that have been constructed by neighboring countries, spending large amounts of resources to build them. These buildings are mostly considered as examples of sustainable buildings for architects in the region. This confirms how often the term sustainability is misunderstood or misused, specifically in oil based countries like Iran, who believe that they are able to spend large amounts of cheap fossil fuel energies to build high-tech or smart buildings. Although these buildings may low energy consumption after usage, but they consume huge amounts of energy and resources during construction process, that results in resource depletion and environmental pollutions.

iv. Iranian Authorities for Architectural Urban Design Regulations

There are several organizations and authorities in Iran[1] whose duty is to prepare instructions for urban planning and construction, institute design regulations, and control and supervise building constructions in Iran. One such authority is *The Ministry of Roads and Urban Development.*

One of the duties of The Ministry of Roads and Urban Development (BHRC 2013) is the codification of *National Building Code* (Office for Codification and Development of National Building Codes 2005).

Volume 19 of these codes discusses energy saving in buildings (Ahmadi et al. 2009) and offers some practical instructions for reduction of energy exchange and therefore reduction of energy consumption in different types of building functions by application of insulation panels on the building envelope. The suggested solutions and details in this booklet are largely duplicated from developed countries' building codes that can be implemented with existing technologies in Iran.

Other organizations, such as Renewable Energy Organization of Iran, have also made some surveys on renewable and passive energies such as wind and solar power (SANA 1995), but research is still in its primary stages and is usually replicated from western research and experience.

v. Lack of National Sustainability Evaluation Tool in Iran

Despite the recent efforts of authorities and private organizations in Iran to develop resource and environmental policies, the building construction sector still suffers from the lack of a comprehensive national system for the standardization and assessment of sustainability. This leads engineers and authorities to implement the rules and regulations used by developed countries.

According to Figure 6, international rating systems for sustainability, such as LEED and BREEAM, are used in many countries around the world. This map shows that Iran follows the LEED system.

[1] Iran Construction Engineering Organization, Municipality, Iranian Fuel Conservation Organization, Iran Energy Efficiency Organization, Renewable Energy Organization of Iran

Figure 6, rating systems for sustainability around the world. Source: (Pearce 2012, 152)

Although these assessment systems claim that they are applicable on the international scale, one of the main objectives of sustainability is the utilization and consideration of local natural resources and settings, and this requires each region with its different climatic, environmental, social, and economic characteristics to implement its own rating system.

vi. Existing Challenges of Sustainability Debate in Iran

Two major challenges become apparent while discussing sustainable design in Iran:

The first is the lack of a national sustainability rating system that considers the existing local and vernacular potentials in Iran's traditional architecture and historical cities.

The second is the scale of research conducted on sustainability in Iran. A review of previous research on sustainability in Iran reveals that there are two major categories of research:

a. General descriptions of the benefits of historical architecture that include a large emphasis on aesthetic features and general descriptions of environment-adaptive features of Iranian traditional architecture and cities. These surveys are too general, without sufficient empirical analysis. The following description is an example of such Iranian researchers' attitude toward sustainable features of Iranian architecture. It is more akin to a beautiful poem than an architectural analysis:

"*The traditional city is very similar to a cactus in a desert. It has a very hard skin and is completely closed. Consequently, people spend their lives inside this skin. All spaces are well protected against dusty winds and they are shaped to use cool wind in the summer and sun in the winter. The urban fabric is dense. Alleys with tall walls and a zigzagging form do not let the wind blow easily…*" (Ahmadkhani Maleki 2011)

b. Detailed analysis of the small case studies, including measurement of energy performance of one or more historical buildings by architectural simulation tools and assessing them using western evaluation systems (Figure 7).

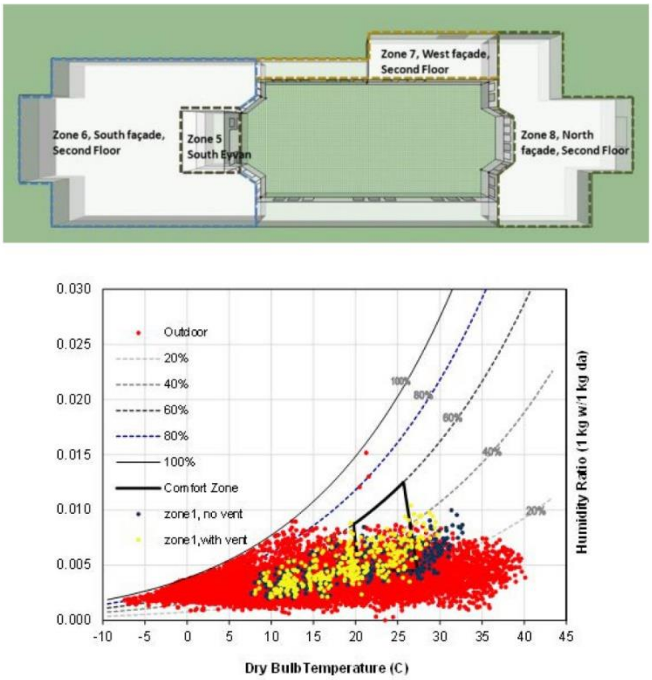


Figure 7: Simulation of Brojerdi-ha house in Kashan and its thermal results. Image from (IBPSA 2015)

After this brief discussion, it is observed that practical studies are missing between the two previously mentioned scales of research. Studies are either too wide and general or too focused and restrictive.

Research between these two scales is required in order to implement general and detailed studies by identifying structures and criteria that can be helpful in specific, practical projects.

1.2. Summary of the Research Problems

After the previous discussions, the following research problems are set as the main focuses of this dissertation:

1. The severe conditions of the subdesertic areas in Iran require adaption of specific strategies for creation of comfort conditions for the inhabitants, without depletion of the rare resources in the region.
2. Since the 1920s dramatic changes in Iran, contemporary architecture uses western patterns of design and construction methods for buildings without adaption of these patterns with the local climatic conditions.
3. The sustainability approach in building is a new debate in the oil-dependent countries like Iran and other neighboring countries. The term sustainability is majorly misused for high-tech, low-energy dependent buildings that consume large quantities of resources in their construction phase.
4. Contemporary authorities in Iran do not offer any specific rules for contemporary building design in contribution to environmentally friendly architecture.

1.3. Research Field

This dissertation focuses on housing design at Architectural scale in Iran's Hot and Arid Region. A parallel dissertation investigates the same subject at the neighborhood scale (by Hossein Abbasimehr).

The well-preserved historical city of Yazd as a sample that generates sufficient knowledge of Iranian traditional housing in hot and rid region is selected as the case study.

The LEED system has been adapted as the main tool to define the baseline for assessment of the case studies regarding environmental sustainability.

Analyzes are made on several houses (architectural scale) in Yazd that are selected from among both historical and contemporary houses from various areas in Yazd to be compared.

1.4. Target Group, Objectives and Aims of the Research

This research aims at the designers and architects who wish to design districts, houses and residential projects in hot and arid regions of Iran. However due to socio-cultural and environmental similarities between Iran and the neighboring countries in the region such as Saudi Arabia, Iraq or Arab Emirates… who share the same climatic conditions with sub-desert area in Iran, the outcome of this research can be developed to inspire the designers and architects who aim to design houses in those countries too.

While as will be discussed in Chapter 3, Figure 36, investigations imply that the urban and architectural design strategies and decisions taken at the primary stages may have more influence on the environment than the construction stage.

The ultimate concern of this dissertation is to provide contemporary architects and designers with general knowledge of the local traditions of housing architecture in the hot and arid region of Iran in order to create more environmentally sustainable housing.

Therefore the following objectives are defined for this dissertation:

1. The first objective of this research is to show that the modern approach to urban and architectural design that raised after the abandonment of the traditional system in recent century and does not consider local and traditional systems and values, is not a sustainable design approach. The traditional systems and values used in the past possessed more sustainability features, which have the ability to be adapted to and utilized in contemporary living.
   This is achieved by evaluation of both traditional and contemporary houses by means of a proper sustainability evaluation tool. The attempt for finding the right evaluation tool in this research can be considered as an introduction to more extensive research on the development of Iranian evaluation systems of sustainability.

2. Ultimately, this dissertation intends on defining and addressing helpful sustainability solutions, derived from Iranian traditional architecture and city design, to adapt to modern life in hot and arid regions of Iran. In other words, this research aims to inspire from traditional architecture and to identify some features of sustainability on basis of Iranian traditional architecture patterns and values.

1.5. Research Question

Therefore this research aims at the following research questions:

1. Which is more environmentally sustainable, the traditional or the contemporary housing design in the hot and arid region of Iran?
2. If the Iranian traditional architecture reveals sustainability features, what are its sustainable features that can be adapted again in contemporary architectural design? And how can we suggest general recommendations as the main aim of this research?

In order to answer the first question, the following questions must be replied in advance:

- When and why did the traditional architecture in the hot and arid region in Iran, surviving over centuries, discontinue?
- What is the right evaluation tool to assess the degree of sustainability in both traditional and contemporary housing architecture in Iran hot and arid region?

For answering the second question, the sustainability features in both traditional and contemporary architecture must be compared and analyzed. The results will be demonstrated in form of architectural illustrations, small sketches and schematic drawings, including general design recommendations as the conclusion for this research.

1.6. Methodology and Approach

This dissertation begins in Chapter 1 by short discussion of the different aspects of the research problem: the conditions of the sub-desert area in Iran that needs adaption of extra design strategies due to the severe climatic conditions and lack of required resources. Then the author makes a review to show that the contemporary architecture in Iran, that has abandoned the local and traditional patterns in recent decades, does not offer any specific strategies for sustainable design in this arid zone.

In the following, this chapter raises the research question to define terms of ultimate thesis of the research. The final aim of this dissertation is to show that it is possible to elicit design strategies from the traditional architecture in Iran to recommend to contemporary housing designers and architects.

Therefore the practical objectives that can help achieve this aim are discussed: to show when and why the traditional and local patterns of architecture in Iran ceased and then to find the right tool for evaluation of the degree of sustainability in both traditional and contemporary architecture to elucidate which is more sustainable and in what aspects?

This Chapter is majorly made by adaption of library research.

Chapter 2 (State of the Art) discusses the probable projects or researches that have already been made on this topic. Many architects and researchers have already been discussing the sustainable aspects of the Iranian traditional architecture, but rarely do they discuss why these traditional aspects are abandoned. Therefor the author of this research claim that this is a novel approach that has ever been made in contribution to assessment of the traditional architecture in comparison to contemporary architecture by applying the modern sustainability evaluation tools. This Chapter is also mostly made by aid of library research.

Chapter 3 (General Context) gives a review on the general debates that are necessary for the start of the work including the general definitions of sustainability and the contribution of local patterns to sustainability as well as the role the cities play in this regard. Then the author attempts to elucidate when and why the development of traditional architecture in Iran ceased.

This chapter gets aid from timeline graphs to give a deeper insight of the important events in Iran that dramatically changed the hundreds of years of traditions in architecture and construction. This Chapter is also mostly made by adaption of library research.

Chapter 4 (Sustainability Evaluation Tool) aims at finding the proper sustainability evaluation tool for this research. In contribution to sustainable architecture, there are various environmental assessment systems and tools worldwide that focus on two main objectives at the same time:

- Reduction of environmental impact
- Improvement of quality of living and working space

These systems and tools try to reach these objectives by:

- Helping designers to improve their designs
- Evaluating and certifying the actual performance of the buildings

The two challenges in this dissertation are:

- Lack of sustainability evaluation system in Iran
- Evaluation of historical houses (in their original context) with modern systems

This chapter therefore makes a short review on existing evaluation systems worldwide and then extracts an outline out of them to establish a simple but comprehensive tool to evaluate the rate of sustainability in the selected case studies.

According to the similarities of approach in different evaluation systems in the world, this research focuses on LEED (Leadership in Energy and Environmental Design, developed by US Green Building Council since 1994) as one of the most used system in the world and tries to extract the headlines but not their grading system, because these evaluation systems target at a minimum of points, earned by the buildings, through variety of possibilities for better environmental performance of the buildings, to certify them by earned points, which is not the aim of this dissertation.

Although these evaluation systems claim that they are internationally compatible, but one of the main concepts of sustainability is locality. It means that the more common climatic factors, the less need for changing and adapting the rules.

Hence the main reason to choose this system is that the climatic conditions in Iran are more similar to US than Europe, UK or Japan.

LEED is established in the United States and is applicable in Iran due to the similarity of the conditions of central deserts of Iran and the central-west semiarid steppes of the USA.

Therefore, by choosing from among different evaluation systems in the world, this research focuses on LEED (Leadership in Energy and Environmental Design, developed by US Green Building Council since 1994) as one of the oldest and most used systems in the world. However, this dissertation extracts the central feature from LEED and adapts its properties to important, local characteristics of Iranian deserts. It then develops its own evaluation system. We do not use LEED's grading system, because such evaluation systems target at a minimum of points, earned by buildings, through variety of possibilities such as additional mechanical equipment or specific certified building materials, etc., to certify them by earned points. In contrast, this dissertation aims at architectural/urban strategies taken at the design stage, such as orientation, proportions of spaces, forms, and divisions of spaces.

Resources other than sustainability certifications are also taken into consideration in this stage in order to get to a better evaluation tool to evaluate both historical and contemporary housings in the hot and arid region of Iran.

It should be noted that although sustainability includes social, cultural, economic aspects too, but according to the author's field of study, this research only focuses on environment-based factors.

Finally the provided evaluation system evaluates the case studies in the following features:

1. Water
2. Energy
3. Ground and Land Use

4. Material and Resources
5. Health and Wellbeing

Several sub category items are defined under these five main categories by learning from items of LEED and also by considering traditional Iranian architecture and city design strengths and opportunities.

It must be taken into consideration that it is not possible to apply all LEED items into Iranian case studies; some of them are irrelevant to Iranian architecture characteristics. Therefore, some additional evaluation points are defined on the basis of Iranian's specific architecture and local criteria. These are added to points derived from LEED. The final evaluation, thus, includes a combination.

However, this dissertation does not claim to define a national sustainability evaluation system for Iran because this would require the cooperation of several experts from various engineering fields and many organizations at the national scale.

Again qualitative method is used in this phase through visual analysis such as analyzing architectural plan and section and 3D drawings, as well as quantitative methods such as measurements and calculations of the areas and spaces.

Chapter 5 of the dissertation (Selection of Case Studies) discusses finding the right case studies that can provide proper and efficient data for this project.

According to the very extensive borders of the hot and arid region in Iran, in order to define a limited frame for the project, the world heritage city of Yazd is selected as the case study according to its valuable traditional architecture and very well preserved and still lively urban texture of the historical zone, and also its climatic conditions which makes this historical city a good representative of historical Iranian cities in hot and arid region. Then the results would have the capacity to be developed for regions with the same climatic conditions, in Iran or even in the neighboring countries.

For case study selection, the author first finds the best categorization of traditional housing in Yazd.

Investigations show that major remaining historical houses in Yazd belong to two different periods: 13^{th} to 15^{th} cent. AD, and 16^{th} to 20^{th} cent. AD. Most of the well preserved houses belong to the latter period. These houses also reveal an evolved pattern of the former houses in terms of climatic design strategies and concepts. Therefor this dissertation chooses its case studies from among the historical houses of 16^{th} to 20^{th} cent. AD.

Investigations show that the main organizing element in these houses is the central courtyard, which is the main element of the microclimate. Main other features of these courtyard houses are the same. Therefore this dissertation selects three historical houses in Yazd with:

- One central courtyard (Tehrani house),
- Several central courtyards (Lari house),
- Two-story central courtyard (Oloumi house).

In order to get to a better understanding of the potentials, strengths or weaknesses in these traditional housings, three contemporary houses in Yazd are selected as the case studies as well. As mentioned before, the contemporary architecture design rules and regulations is uniform in Iran. Therefore the contemporary houses designed by architects, share common design strategies and these three samples cover the major types of contemporary housings in Yazd, Iran i.e.

- Single family house with a courtyard in South i.e. 40% of the land area.
- Multi-level midrise apartments each level containing one or several independent residential units, with a shared spaces e.g. staircases, rooftop, and sometimes spaces for public use of residents like swimming pool, fitness hall etc. A shared courtyard lays in the South (40% of the land area), and each unit must be provided by its own private parking and small storage space in ground floor or basement.
- Residential complexes with several blocks. Each block includes several independent residential unit. In a city at the scale of Yazd, these residential complexes are also midrise buildings, not high-rise. The blocks are located in a shared open air area, with vegetation and car parking, and sometimes sports ground or supporting functions such as laundry, kindergarten, bakery for more populated complexes.

  The three contemporary selected case studies in this dissertation are Atlassi single family house, Mir Hosseini multilevel apartment, and Sima Gostar 122 unit residential complex.

Therefore these selected case studies are the representatives of the different types of historical and contemporary housing in Yazd.

For data collection on traditional houses, qualitative methods such as on site observation and photography is beneficial to get a better understanding of the situation specially while trying to find an original view of the historical remaining.

Also quantitative methods such as mapping and architectural measurements will also conduct to a deeper understanding of the architectural sustainable solutions that the ancient architects applied.

For the contemporary housings, again both qualitative and quantitative methods are used for data collection, analysis and conclusion which lead to a micro-scale understanding of the rate of contribution of these contemporary buildings in environmental aspects of sustainability.

This chapter is made by observation and field research and application of analytical methods.

Chapter 6 (Evaluation of Case Studies) goes through assessment of case studies under the five mentioned categories in Chapter 4: Water (W), Energy (E), Ground and Land use (GL), Material and Resources (MR), Health and Wellbeing (HW).

In each category, first a short introduction of the probable traditional or contemporary related approaches are discussed. Then the case studies are evaluated in subcategories. The results of each part is shortly mentioned and highlighted at the end of each subcategory evaluation.

As discussed before, LEED criteria are also taken into account, as a standard baseline, when useful.

This is a simple but comprehensive way to easily demonstrate which houses operate in a more sustainable way, the traditional or contemporary houses, and what these sustainable features are.

The final chapter (Chapter 8: Recommendations) makes some recommendations for designing a sustainable contemporary architecture, inspiring from traditional sustainable solutions.

The evaluation of different historical and contemporary case studies using this combined system demonstrates that in the majority of evaluation categories, historical case studies yield better results regarding sustainability criteria.

Where traditional architecture reveals environmental sustainability advantages, these considerations will be presented as recommendations, not only as guideline notes, but also with the aid of small architectural sketches, in order to give the audience a better understanding and impact of what the author has achieved during this dissertation.

Some of these sketches are very general and schematic, not exact and detailed. They present general ideas for designers to gain inspiration from, to make their own design for their own specific cases.

Where the traditional architecture shows disadvantage e.g. in case of earthquake, the author tries to provide the designers with some replacing corrections and improvements form previous studies.

Finally, some recommendations and solutions in the five mentioned categories (Water, Energy, Ground and Land Use, Material and Resources, Health and Wellbeing) are suggested on the basis of these historical patterns of sustainability, adapting them to contemporary living standards.

Both chapters 6 and 7 are made by adaption of comparative investigations as well as analytical methods by using quantitative and qualitative methods.

This chapter makes a short review on the most outstanding efforts already made by architects for adaption of Iranian traditional architecture's strategies of hot and arid region to use them in contemporary design either in the framework of constructed projects or published theoretical guidelines.

Regarding evaluation of traditional buildings in terms of environmental sustainability, this dissertation has a novel approach in evaluating and comparing the traditional and contemporary existing houses with modern evaluation systems for sustainability.

In other words, no attempt for evaluation of traditional aspects of Iranian architecture by modern evaluation systems has ever been made on Iranian architecture in such a scale. The majority of previously made investigations aim at introduction of the environment-friendly aspects of this architecture, but lack of an integrate assessment on this traditional architecture to find out its weaknesses or strength is apparent.

There are however instances in this regard i.e. the investigations already made on limited features in one single building, such as Simulation of Brojerdi-ha house in Kashan and its thermal performance (see Chapter 1, Figure 7).

For the first time, this dissertation evaluates the traditional aspects of Iranian architecture in hot and arid region in comparison with the contemporary architecture by application of a modern evaluation systems for assessment of sustainability (LEED evaluation system).

Regarding the adaption of features of traditional architecture in contemporary era, there have been various approaches in Iran in recent century.

During the past decades, the economic crisis in fuel consumption, when debates for optimization of energy was raised seriously in Iran (Memarian, Theoretical Principles of Iranian Architecture 2007, 26) by the increase of public awareness of the energy and environmental issues, e.g. the depletion of resources and environment pollution in the region, sustainability has become a topic of debate amongst Iranian architects and designers.

As Memarian describes: "Although several books and articles on climatic features of Iranian local architecture have been published in Iran during the past four decades, thousands of buildings have been built without any consideration towards the climatic conditions of their location during the same period. These buildings follow the western architectural features that are responsive to neither the climatic and cultural conditions in Iran, nor the seismic hazards in the region.

Lack of a united management system for coordination of research and implementation that guarantees the accomplishments of the buildings due to the specific climatic and environmental conditions in each region is the main reason for this inconsistency.

It seems that as long as the country possesses abundant cheap petroleum products, this irresponsible attitude towards construction of high energy dependent buildings that are not designed in harmony with environment and climate continues in Iran goes on.

Meanwhile national authorities and organizations have published rules and regulations regarding energy saving in buildings, such as "Iran National Building Codes: Booklet 19: Energy Saving in Buildings", but such references are placed unused in library shelves, according to lack of legal obligations for their implementation." (Memarian, Theoretical Principles of Iranian Architecture 2007, 50)

Following is a short review of the background of such researches, including the most significant of them, in Iran.

2.1. Academic researches on adaption of climatic solutions of Iran's traditional architecture in contemporary architecture

After publication of Olgay's book in 1963 "Design with Climate" (Olgay 1963), a number of books about climate and architecture were published in Iran during 1970s (Memarian, Theoretical Principles of Iranian Architecture 2007, 24). The authors of these books investigated the formal and spatial logic grounds that lay beyond the local architecture and urban fabric in various climatic zones in Iran in confrontation with the climatic issues and conditions (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002, 59)

In 1974, the book "Architecture in Hot and Semi-Arid Climate in Dezful and Shushtar" (Rahimieh and Robubi 1974) was published (in Persian language) in Iran. The authors in this book investigated the influence of hot and humid climate on local architecture of the two towns of Dezful and Shushtar in South of Iran (Memarian, Theoretical Principles of Iranian Architecture 2007, 25).

Afterwards until early 1980s no other book in this regard was published. In 1981 another book titled "Urban Structures in Hot and Arid Climate" by Mahmoud Tavassoli was published in Persian too (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002). This book has had an important influence on the attitude towards Iranian architecture since then. At that time, the architecture education system in Iran suffered from lack of architecture books that introduce and investigate the local Iranian architecture.

Until the mid-90s, several investigations were made on climatic oriented architectural design in Iran. Although their results have hardly been used in practice due to lack of related compulsory construction codes in Iran, but these investigations have succeeded to motivate the academics to draw public attention among architects towards the existence of the technical sustainable solution in Iranian traditional architecture.

These researches have been mostly sponsored by the former Iran Ministry of Housing and Urban Development.

One of such researches was undertaken in at the beginning of the 21st century in Iran as part of a broader research undertaken by the Technical Office for Research and Education at Shahid Beheshti University in Tehran, Iran, being sponsored by Iran Ministry of Housing and Urban Development.

The major focus of this research was to codify the principles for design of mosques in Iran. One part of the research aiming at improvement of contemporary architecture of mosques to be compatible with climatic conditions in Iran and to benefit from natural resources passively was published in the framework of a book in 2008 as a reference for architecture students and professors: "Architectural Design Principal Compatible with Climatic Conditions of Iran, with Focus on Mosque Design, by M. Tahbaz and Sh. Djalalian (Tahbaz and Djalilian 2008).

This book starts by proposing a new climatic division for Iran and makes a categorization to address the climatic zone that each city of Iran is placed in. For each of the five defined climatic categories, firstly the climatic conditions is introduced, and the climatic needs for achieving the comfort conditions in buildings is investigated, and for this, the solutions suggested by the local architecture in the region is studied and at the end of each chapter, for that specific climate, instructions for designing the mosques in that climatic zone is recommended.

The authors of the book believe that due to the similarities of architectural patterns of mosques and houses in hot and arid region, the recommendations of this research can be applied in housing design too.

The following graphic shows the research structure applied in this book:

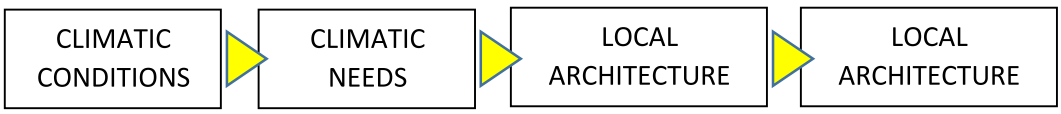


Figure 8, the four successive stages for study of each climatic zone in the book, Source: (Tahbaz and Djalilian 2008, 5)

The recommended design criteria for each climatic zone involve with general design features, architectural characteristics of open air space, semi open space, closed space, building envelope and construction methods.

2.2. Trends for adaption of traditional patterns into modern Iranian architecture

Besides the researches on climatic aspects of traditional architecture in Iran, that made sparkles for adaption of the traditional architecture and local construction solutions into modern architecture at least among the scholars and academics in Iran, another flow that raised during the past decades in Iran, aiming at revitalization of Iranian traditional architecture's values in modern design, was established during 1970s.

The 1973 wake of the oil crisis made some western critics turn from formal concerns in architecture towards environmentalism[2], and even anti-building ambitions (Westbrook 2014, 386). Meanwhile Iran experienced a very different context due to its booming economy aiming at accompanying the infrastructural reforms by regional identity, in extensive industrial, cultural, civic and governmental projects with the cooperation of western architects such as Louis Kahn (Emami 2011). The Iran government therefore, seeking to refine Iran's urban policies, sponsored several international architectural congresses[3] and competitions during 1970s[4], exploring the relation between regional cultures and international construction techniques (Westbrook 2014, 387).

The first congress "The Interaction between Tradition and Technology" in Iran was held in the historical city of Isfahan[5] in 1970 (Westbrook 2014, 389). The congress explored the possibility of a viable regional architecture counter posed to the "international" modern architectural design that was dominant in Europe, the United States and increasingly the Third World (Cantacuzino and Browner 1976).

The main topics of the congress were about tradition, technology and the possibility of combining traditional architecture with modern construction technologies (Westbrook 2014, 390) and the debates included a wide range of architectural views including the neo-traditionalism of Nader Ardalan (Ardalan, The Structure of Traditional Architecture and

---

[2] The codification of the modern movement made by the older generation of The Congrès Internationaux d'Architecture Moderne (CIAM) in 1930s was associated by critics in 1950s and 1960s (Pedret 2013). Contemporary culture was to be reconnected to tradition not through historicism, but through a rediscovery of what Van Eyck termed the "archaic principles of human nature", and significantly, an emphasis on "habitat" rather than "dwelling" (Tzonis and Lefaivre 2012).

[3] There were three major architectural Congresses in Iran in the decade before the Islamic Revolution: 1970, "The Interaction between Tradition and Technology", Isfahan; 1974, "Towards a Quality of Life", Persepolis, and in 1976, "Architecture and Identity", Ramsar, a special "Women in Architecture" conference. A fourth congress was planned for 1978, but does not appear to have taken place (Westbrook 2014, 386)

[4]Supported by the queen Farah Diba, the former architecture student at Beaux Arts, Paris.

5 Invited international participants to the 1970 congress included: A. Ali (Morocco), Y. Ashihara (Japan), G. Candilis and O. Zavaroni (France), A. Damian and M. Nicalescu (Romania), Buckminster Fuller, P. Will, Jr., P. Rudolph and L. I. Kahn (USA), M. l Hosseinoff (USSR Azerbaijan), A. Kuran (Turkey), M. Mistry and I. M. Kadri (India), J. Moravec (Czechoslovakia), L. Quaroni (Italy), L. Blanco Soler (Spain), and O. M. Ungers (Germany). Gropius, Mies and Neutra were invited to the conference, but died before it took place. Iranian delegates included M. Foroughi, the secretary K. Diba, S. Afkhami, H. Seyhoun and N. Ardalan (Farhad and Bakhtiar 1972, 19)

Urban Design in Iran, Preliminary Studies, 1970) to Paul Rudolph's criticism of Ardalan and Louis Kahn (Westbrook 2014, 392).

This congress emerged the discrepancy between an appeal to the social and aesthetic unity of traditional settlements proposed by traditionalists such as Kamran Diba and Nader Ardalan supported by O. M. Ungers' call for collective consensus on the form and function of social habitat on one side and the urbanization crisis by migration of large numbers of villagers to the Iranian cities and the need for provision of mass housing to accommodate displaced villagers on the other side (Bakhtiar and Farhad 1972, 87). This became the main focus of the second congress "Towards a Quality of Life"[6] in 1974 taking place in the 2500 year former capital of Iran; Persepolis, where the issue of tradition was again there in the background of the congress discussions (Westbrook 2014, 395).

As Nigel Westbrook in his paper "The Regionalist Debate in the Context of the 1970s Architectural Forums in Iran" (Westbrook 2014, 396) concludes: "The respective positions at the 1970 and 1974 congresses were later accommodated in the Persepolis Declaration written by nominated conference delegates[7], and presented as a Shelter Bill of Rights by the Iran delegates to the United Nations (UN) Conference on Human Settlements in Vancouver in 1976 (HABITAT 1976). This document, which reprises a central theme of the later CIAM congresses and Team 10 discussions (Pedret 2013, 81), balances a call for architects to learn from the organic unity of the traditional village structure, while calling for greater political control of citizens over their social and physical environment (Habitat 1976, 14)."

Inspirations from such congresses accelerated the new architectural trend in Iran established by the intellectual architects in 1960s and 1970s aiming at a modern architecture with local and historical tendencies (Bani Masoud 2009, 243) and searched its path parallel with the existing modern architecture that was affected by the major European modern architects and architectural styles.

In this regard some architects, like Nader Ardalan, were influenced by the mystic thoughts of contemporary traditionalist philosophers who made a division between the two worlds of tradition and modernity, and tried to create an eastern modernity on basis of Iranian traditions, intuition as well as Islamic believes.

In 1973, Nader Ardalan and Laleh Bakhtiar published their impressive book in English "The Sense of Unity: The Sufi Tradition in Architecture" (Ardalan and Bakhtiar, The

---

[6] Invited delegates to this second conference included Josep Luis Sert, the former president of CIAM, Buckminster Fuller, Moshe Safdie, Balkrishnan Doshi, Jaap Bakema, Dolf Schnebli and Kenzo Tange (Westbrook 2014, 396). Safdie, Balkrishnan Doshi, Jaap Bakema, Dolf Schnebli and Kenzo Tange.

[7] Josep Lluis Sert, Moshe Safdie, Balkrishnan Doshi, Georges Candilis, and Nader Ardalan

Sense of unity, The Sufi Tradition in Persian architecture 1973) which was an architectural interpretation of the traditional Iranian philosophy (Bani Masoud 2009, 247).

This book is mentioned as the first and foremost book on Iranian architecture theory, but the authors of this book seem to relate every aspect of Iranian traditional architecture to philosophy, theosophy and mysticism, ignoring the structural or climatic responsive role of many elements and features of the Iranian architecture.

Figures 9 and 10 show Iran Center for Management Studies (in association with Harvard Business School) in Tehran, designed by Nader Ardalan Iran (1972-75). He aims to integrate this architectural project with a contemporary interpretation of the classic Persian Garden (*Pardis*) and the traditional school (*Madrasa*) using the Iranian traditional construction material, brick (Ardalan Associates, LLC 2015).

The overall project is rather a modern physical reading of the Iranian traditional forms and spatial organization than revitalizing the technical grounds beyond these traditional elements, but it is truly successful in transferring a sense of being Iranian and being modern at the same time to the observer, and this, is a brand new pattern in traditional architecture of Iran, used simultaneously by some other architects like K. Diba and A. Saremi too.

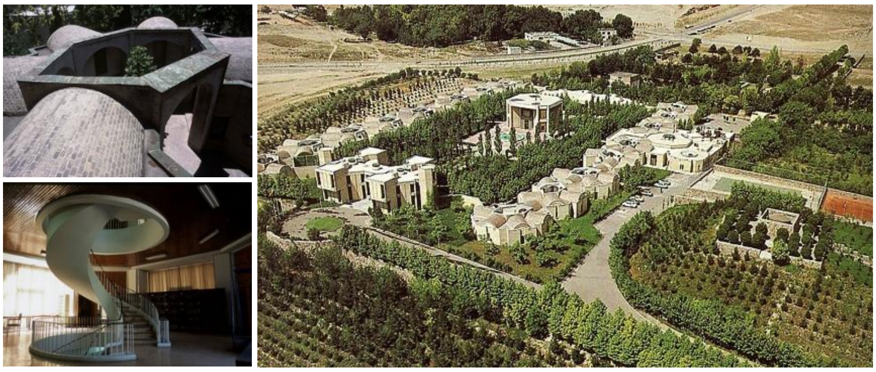


Figure 9, Iran Center for Management Studies in association with Harvard Business School, Tehran, Iran, (1972-75), Nader Ardalan, Founding Partner Mandala Collaborative (Naqsh 2012)

Figure 10, comparison of the main axis of the project with the Persian gardens, Left: Iran Center for Management Studies by Ardalan, right: Fin garden in Kerman, Iran, Source: Imam Sadeq Uni. official website (ISU)

This ambition for creating a purely Iranian architecture that is also modern is traced in the works of a group of Iranian modern architecture pioneers during the second Pahlavi era (1940-1977).

Although the first generation of modern architects in Iran, many of which were non-Iranians, symbolically used the elements of Iranian architecture in their contemporary projects (like the brick building of the Museum of Ancient Iran designed by the French architect Andre Godard in the early 20th century, influenced by Sassanid vaults particularly the Eyvān-e-Kasrā at Ctesiphon), but the latter generation who were Iranian architects educated in Iran as well as Europe or the US were more involved with defining an interpretation of the traditional architecture's features into their modern projects.

Figure 11, Museum of Ancient Iran designed by Andre Godard, Source: (Parinoush 2008)

These designers are rather influenced by the cultural values of the Iranian traditional architecture, tightly integrated with the religious and cultural traditions e.g. *Mahramiyyat* (privacy in spaces).

Most of their fascinating projects which were implemented either in the second Pahlavi period (like Dolatabadi house by H. Seyhoun or Tehran Museum of Contemporary Art by K. Diba) or after the Islamic revolution (Jolfa Residential Complex by A. A. Saremi and colleagues 1987-1989) still seem to be revitalizing the forms and spatial organization of Iranian local architecture e.g. central courtyards and vaulted roofs, domes or wind-catchers, as formal representatives of the original Iranian architecture's cultural identity than making a contemporary interpretation of the technical logic that lays beyond the traditional architecture such as climatic factors or structural grounds regarding environmental sustainability.

However it must be mentioned that they were majorly successful in creating a brand new design style that transfers a "modern Iranian" sense to the audience and their works, like Tehran Museum of Contemporary Art by K. T. Diba, have been welcomed by the public.

The author believes that this success is partially indebted to the architect's attention towards the context of the project, including the physical as well as cultural context of the place where the project is implemented.

Figure 12, Tehran Museum of Contemporary Arts, architect K. Diba, Source: (K. Diba 2014)

Other tendencies towards modern revitalization of traditional architecture are traced in the works of architects that have a semi-post-modern attitude. Such attitude is observed in Dezful Cultural Center, in Khuzestan, designed by Farhad Ahmadi (1987-1992) for instance. The architect collects symbols of Iranian architecture and unites their modern formal translation together, regardless of the context of the project. Many elements in this project do not even belong to the local architecture of Dezful such as the wind catchers.

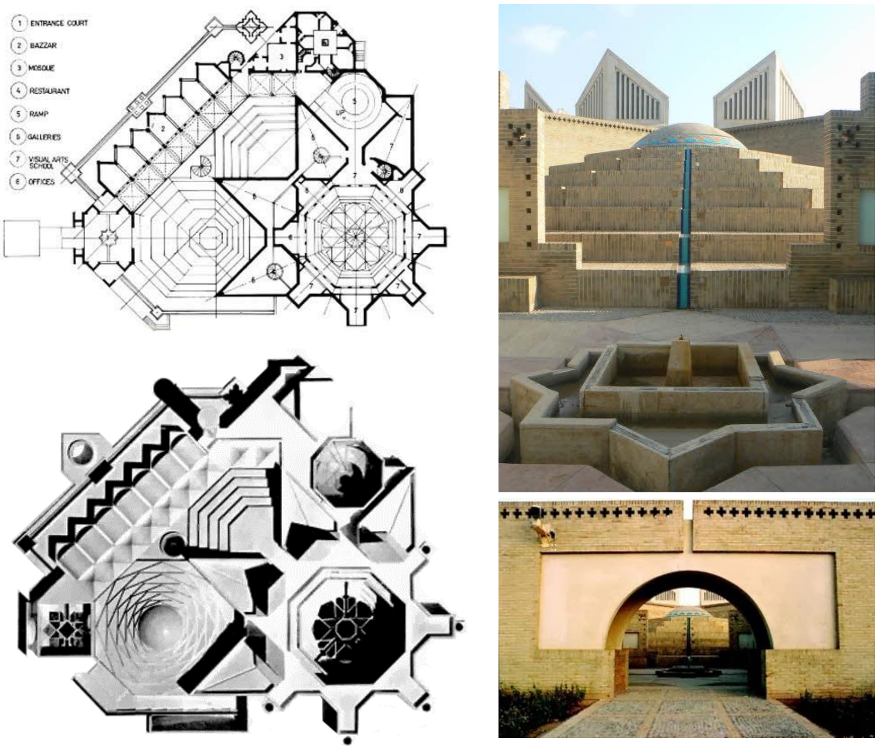


Figure 13, Plan, model and photos for Dezful Cultural Center, designed by Farhad Ahmadi (1987-1992), Source: (Arel 2016)

The most significant project from this period that adapts the environmentally sustainable features of the Iranian traditional architecture in a modern design is the Aga-Khan Award winning project (1986) "Shushtar New Town" conducted by Kamran Diba (DAZ Consulting Engineers) during 1970s, a new development near the ancient city of Shushtar in the hot and arid region in Southwest of Iran, Khuzestan province.

This exemplary small town belongs to the 70's, when there were no specific design trends in the country reflecting a sustainable attitude. After the dramatic changes in Iran during 1980s (the 1979 Islamic revolution and the eight year war) many Iranian architects of this generation left the country. This project will be reviewed in the following section in this chapter.

After the decline of architectural activities due to revolution and the eight year war during 1980s, the next decades until present time, witnessed various trends and flows among Iranian architects including a wide spectrum from pure traditionalism (in religious architecture) to exclusive advocating to the western patterns such as high-tech etc. (see (Bani Masoud 2009, 338))

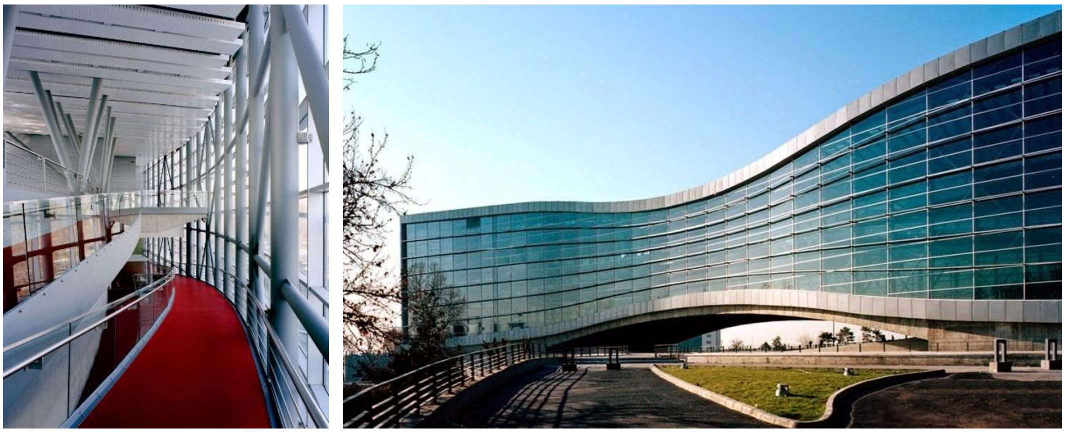


Figure 14, Mellat Park Cineplex in Tehran, Reza Daneshmir, Catherine Spiridonoff, Source: http://www.pardismellat.com/

2.3. Energy efficient design with inspirations from Iranian traditional architecture's patterns

In recent years, by cooperation of European countries, projects for improvement of energy operation of houses in Iran has been undertaken. One of the most recent instance of such projects is the 35 ha Housing Area in Hashtgerd New Town, Alborz province that targets the design of passive solar design in houses, and makes advantage of the traditional patterns of Iranian architecture in hot and arid region of Hashtgerd.

The Young Cities Project (Schäfer 2011) is an Iranian-German Research Initiative in the framework of the research program “Future Megacities” of the German Federal Ministry for Education and Research (BMBF), led by the Technische Universität Berlin (TU Berlin) and the Building and Housing Research Centre of Iran (BHRC) (Mir Moghtada, Weber and Seelig 2009). This project aims at elaborating solutions and strategies for a sustainable, energy-efficient development of new urban developments in Iran as a contribution to a significant CO_2 reduction (Schäfer, 2011), by realizing sustainable and energy-efficient housing settlements in semi-arid regions, explored within the case study of Hashtgerd New Town (Mir Moghtada, Weber and Seelig 2009).

A total of five pilot projects were defined to be implemented in Hashtgerd New Town in Alborz province, Iran from 2005 to 2013 (Mir Moghtada, Weber and Seelig 2009) in order to examine different strategies and solutions for energy efficient urban planning. The following pilot projects are elaborated at different spatial levels:

- The 35 ha Housing Area
- The New Quality residential building
- Three New Generation buildings for residential, office and educational uses (Schäfer 2011)

i. The 35 ha Housing Area

The 35 ha Housing Area as one of the main research sub-projects of the Youmg Cities in Hashtgerd New Town, aims at the production of the following outcome:

- Criteria and objectives for energy-efficient and resilient urban development in Hashtgerd New Town and other semi-arid regions on the neighborhood scale.
- Appropriate planning and design strategies tested on the basis of pilot projects, including their evaluation according to the project goals.
- Policies for urban planning and design for climate change in Iran that might result in adapted or new planning (S. Seelig 2011, 547)

Figure 19 describes the various aspects of design that are considered in 35 ha Housing Area project including architecture, transport and mobility, urban form, urban planning, environmental assessment, climate, energy, water, landscape and awareness rising.

Figure 15, Design features for the 35 ha Housing Area project in Hashtgerd New Town, Source: website for Embassy of Germany in Tehran, (DBT 2010), *©TU Berlin*

ii. Inspiration from the traditional Iranian architecture

One major characteristic of the 35 ha Housing Area project that is interesting to be mentioned here is that it investigates the main characteristics of the traditional Iranian cities and their climatic advantages which form the underlying spatial rationale of the urban design in hot and arid region of Iran (S. Seelig 2011, 550) in order to adapt them, as the main concept of the design, to modern living norms.

The following characteristics found throughout the region of "Islamic Urbanism" (Ehlers, et al. 1994) form the basic principles for the 35 ha area's urban design, though being adapted to contemporary needs e.g. concerning path dimensions and building sizes:

- The access system in the historic city with a clear spatial hierarchy from public to private spheres
- The introverted courtyard house that combines privacy, social interaction and protection against climate and provides light in the interior

- The compact, attached housing arrangement that minimizes the amount of exposed surfaces (reducing cooling and heating demand) providing thermal comfort by creating external spaces sheltered from direct sunlight
- Narrow lanes bordered by high walls in the densely built traditional city structure that create well-shaded spaces during hot summer afternoons and protect inhabitants against harmful winds
- The proximity of land uses, though functionally separated by the access network, that provides an appropriate amount of privacy and easy accessibility of services at the same time (Manzoor 1989) (Kheirabadi 2000).

The project also mentions the introverted pattern and the central courtyard as a very effective feature in traditional Iranian architecture in hot and dry region as Sebastian Seelig explains (S. Seelig 2011, 553):

“Energy demand is also significantly influenced by housing types (Santamournis 2006). The courtyard house supports ventilation and permits natural cooling (Fathy, Shearer and Sultan 1986), while reducing direct exposure to the sun.

At the same time its introverted building form reduces the amount of exposed surfaces. The courtyard house is also culturally sensitive because it creates private and introverted spaces in dense urban form, which is why it is the prevailing housing type in the traditional Islamic city.” The urban design for the 35 ha Housing Area makes use of these potentials by introducing a contemporary interpretation of the courtyard house.

Figure 16, 3D presentation of the design for one part of the 35 ha Housing Area project in Hashtgerd, Iran, Source: website for Embassy of Germany in Tehran, (DBT 2010), *©TU Berlin*

In a "research by design" process the typology based on a modular space system was developed, offering a large variety of dwelling sizes and qualities *(Pahl-Weber, Wolpert and Wehage 2013)*

The project proposing two to three storey stacked courtyard house buildings with widths of between six and fifteen meters.

The majority of plots have a north–south orientation and are between 20 to 35 meters deep so as to maximize energetic potentials. In order to increase solar radiation for energy production, the building volumes have terraces and niches in the upper floors.

The dominant vertical organization of the building volumes provides sun for every residential unit.

The orientation of the living zones within the units around the courtyard combines the need of privacy with microclimatic advantages (Seelig, Wehage and Pahl-Weber 2011).

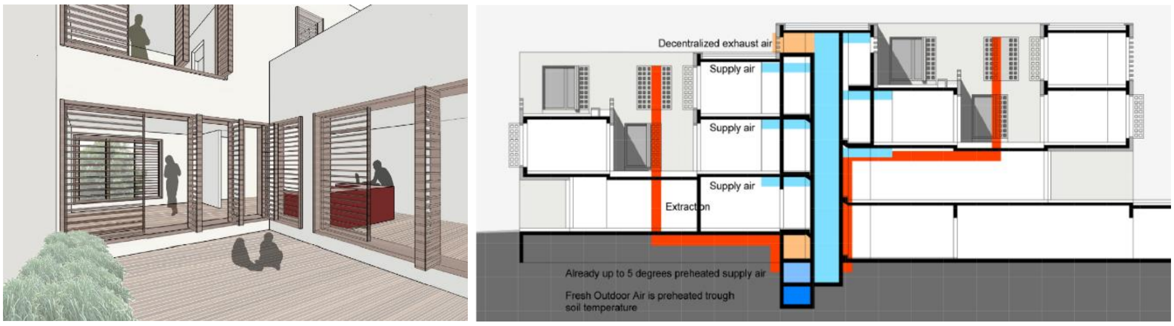


Figure 17, Private courtyard in Energy-Efficient-Home (left) and heat recovery in buildings (right), Source (Pahl-Weber, Wolpert and Wehage 2013) ©TU Berlin

Following photos show the opening of New Quality Housing Project as the first constructed phase of the 35 ha Housing Area in 2010 (Hosseini 2010).

Figure 18, Residential buildings in 35ha Housing Area project, Hashtgerd New Town, Source: BHRC website, (Hosseini 2010)

As mentioned before, one of the most significant projects in Iran that has succeeded in understanding the traditional technical solutions of Iranian traditional architecture and adapting them in contemporary architecture is Shushtar-Now in Khuzestan, Iran by Kamran Tabatabaei Diba.
Following is a review of this project:

2.4. Shushtar New Town (Shushtar-Now)

The ancient city of Shushtar is located in the hot and arid region in Southwest of Iran, Khuzestan province.

Figure 19, Locatio of Khuzestan province in Iran (left) and location of Shushtar town in Khuzestan province (capital city Ahwaz) (right), map by author, base from www.maphill.com

The historical background of this town dates back to 4000-3000 BC, one of the oldest fortress cities in Iran, the home for valuable mud-brick architecture from the Islamic period which are characterized for their specific brickwork façade ornamentations (Soltani and Abbasimehr 2013).

Figure 20, Historical buildings in Shushtar, source: Official website for Shushtar World Heritage Site, www.shushtarchtb.ir, accessed online 05.06.2013

Lack of rain in this hot and arid region makes it necessary to irrigate the lands with a system of dams and canals (DAZ Architects 1986, 4) and Shushtar is best known for its historical hydraulic system consisting of dams, tunnels, ancillary canals and watermills which is inscribed in World Heritage List of UNESCO in 2009 (SHHS 2009).

In 1973, the Karoun Agro-Industries Corporation decided to build a satellite town to house the employees of a sugar cane processing nearby (DAZ Architects 1986, 41) and *Shushtar-Now* was designed close to the historic town of Shushtar for 30,000 inhabitants (ibid, 57) conducting by Kamran Diba who supervised the construction of the phase 1 of the town consisting of two storey residential houses with several units around a small common central courtyard. After 1979 Islamic revolution in Iran, construction of the rest of the project was abandoned.

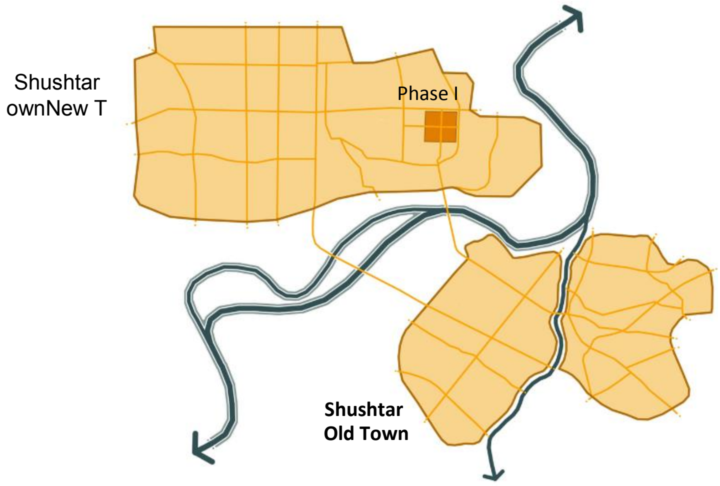


Figure 21, Location of Shushtar New Town and old town, and the seasonal rivers, Graphic by author (Soltani and Abbasimehr 2013)

i. Design Features

The architecture team (DAZ) and Kamran Diba explain in their technical report for Aga Khan Award, their approach to adapt the valuable patterns of traditional architecture to modern life:

- INTROVERT PATTERN; The design of New Shushtar follows the pattern of traditional Iranian architecture which is introverted, taking its forms from climatic constraints, available local technology and the country's culture (1986 award book, p 161)

- URBAN LAYOUT; The new settlement retraces the patterns of the old one, articulating compact segments of differentiated living units around a pedestrian spine, along which it distributes gardens, squares, bazaars, resting places and other public activities (DAZ 1986, 57).

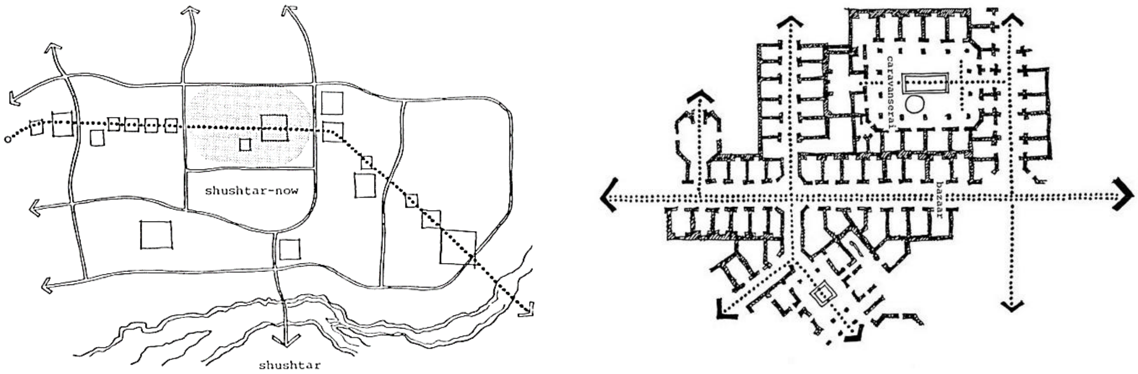


Figure 22, urban functions layout, Shushtar New Town (left) and an Iranian Islamic city (right), Source: (DAZ 1986)

- URBAN STRUCTURE; Adaption of the Iranian city structure in Islamic period is apparent in residential part (Phase I) of the new town.

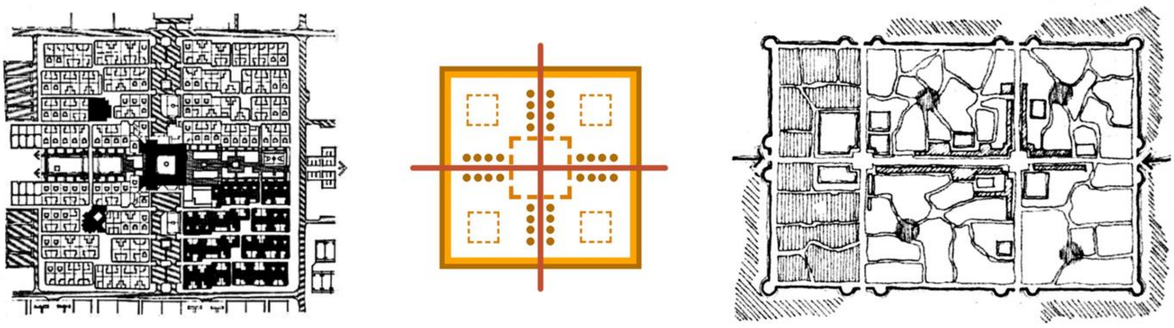


Figure 23, Common urban structure, Shushtar New Town (left) and an Iranian Islamic city (right), Source: (Soltani and Abbasimehr 2013)

- DENSITY; The phase 1 of Shushtar includes an area of 10.4 hectares designed for 4200 residents. This results in a density of more than 400 persons per hectares. The predicted local facilities in Phase I matches is the criteria of sustainability (compact city with mixed use).

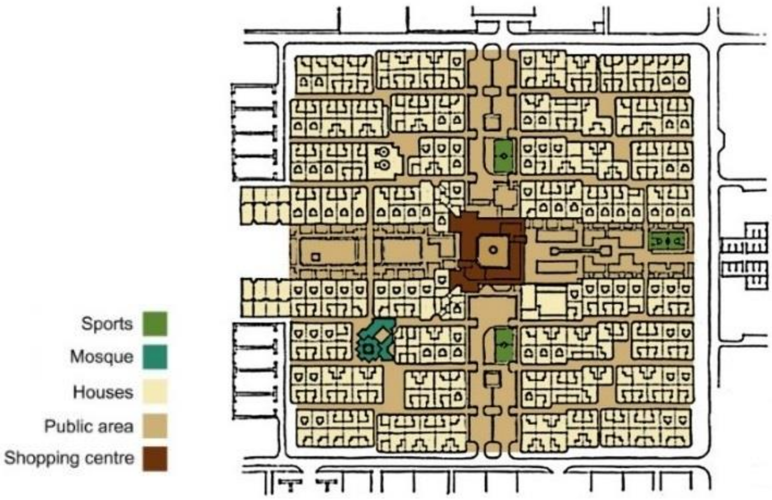


Figure 24, Density and distribution of urban services in phase 1, Shushtar New Town, Source: (Soltani and Abbasimehr 2013)

- PASSAGEWAYS; Most of the inner passageways in phase 1 are narrow and on an east-west axis. Thus houses face either South or North, which is an orientation that helps the shading.

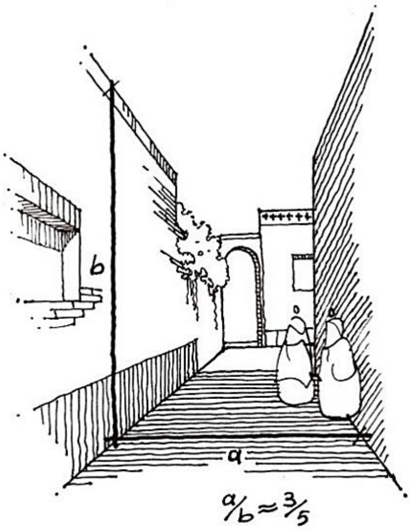


Figure 25, Right: Proportion of a sample passageway in Phase 1, the proportion of the dimensions of Width: Height is 3:5, drawing by Hossein Abbasimehr (Soltani and Abbasimehr 2013)

The non-linear layout of the passageways in relation to the climate closely follows the local customs and architectural tradition. The local access in residential part are indirect and designed for pedestrians with limitation for cars (only emergency cars). This strategy provides some secure spaces especially in expansions spaces for social connections as neighborhood centers.

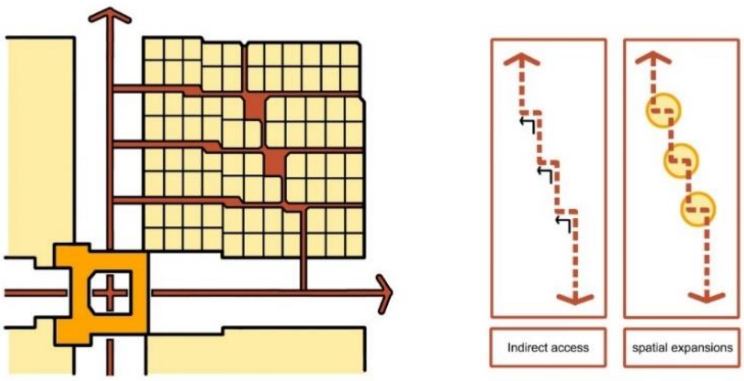
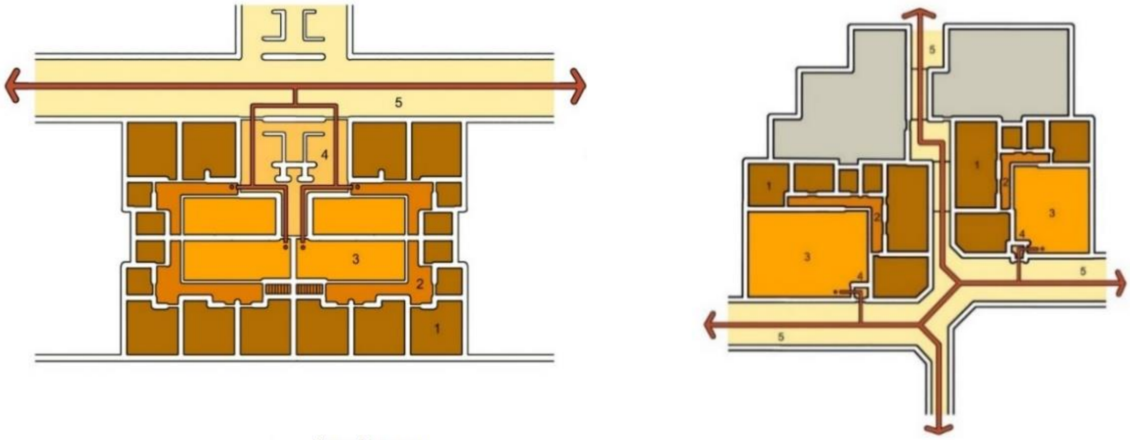
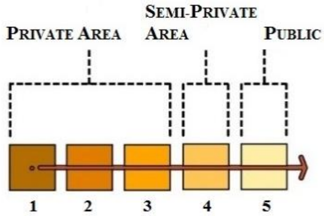


Figure 26, Phase I, non-linear passageways, Graphics by author (Soltani and Abbasimehr 2013)

- SPATIAL HIERARCHY IN HOUSES; There is a specific hierarchy from inner spaces in houses to public area, modeled from traditional patterns of Iranian architecture, from closed spaces to semi-open space (Eivan) and then the open space. The vestibule (Hashti) plays the role of a vision and circulation filter for connection of outer passageway into the house.





1. Inner spaces
2. Iwan
3. Courtyard
4. Hashti
5. Passageway

Figure 27, two different types of housing near in phase I and their spatial hierarchy in houses in phase 1 (figure 11), Graphic by author (Soltani and Abbasimehr 2013)

- PRIVACY DIVISIONS; At the architectural scale, there is a privacy zoning in locating the private and public areas. In the traditional Iranian architecture it is common that the house includes two courtyards. These courtyards are called *Andarouni* and *Birouni* in Persian. *Andarouni* is the private spaces for the use of the family and the *Birouni* part is built for guests and public communications.

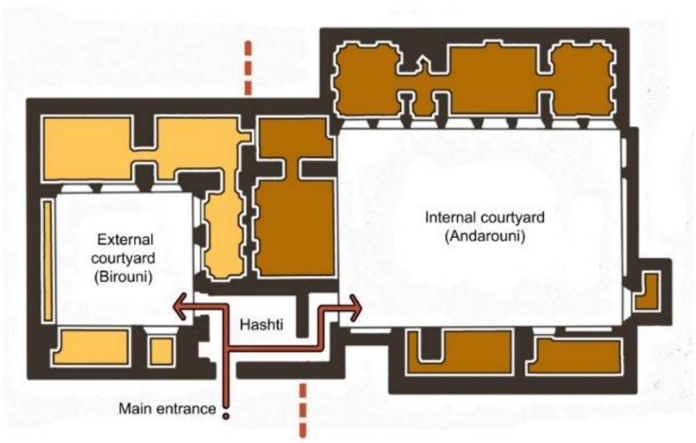


Figure 28, Mojahed traditional house in Yazd, privacy divisions, Graphic by author (Soltani and Abbasimehr 2013)

Shushtar-Now housing types reveal zoning patterns similar to traditional houses in hot and arid zone but in a simplified way: one of the rooms owns a separate access to public space for the use of non-family-members.

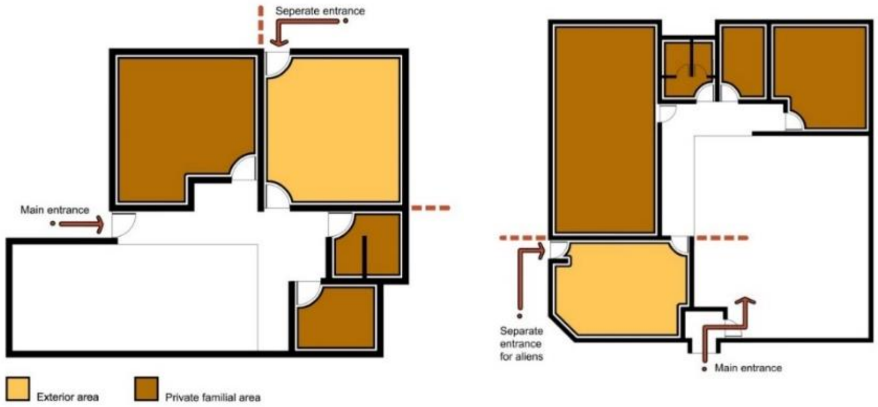


Figure 29, two types of Shushtar now houses, privacy divisions adapted from Irnian traditional architecture, Graphic by author (Soltani and Abbasimehr 2013)

- NATURAL VENTILATION; Orientation of the houses towards the fresh north wind with their central courtyards exclusively open to the wind, modeled from the traditional architectural patterns in the hot and arid region that balances the excessive summer heat and lack of air flow (DAZ Architects 1986, 13)

Decorative brickwork grilles beneath the windows, on the roof parapets, and the entry arcades also provide ventilation (award book 1986, p 165)

Figure 30, Shushtar New Town, central courtyards and brickwork grilles assisting in better air ventilation, Source: (DAZ 1986), *©Kamran Adle*

- SHADING; The planning concept is one of a close-textured city so that the buildings themselves shade, as much as possible, traffic and living spaces. Streets, paved in insulating bricks, are deep and narrow.

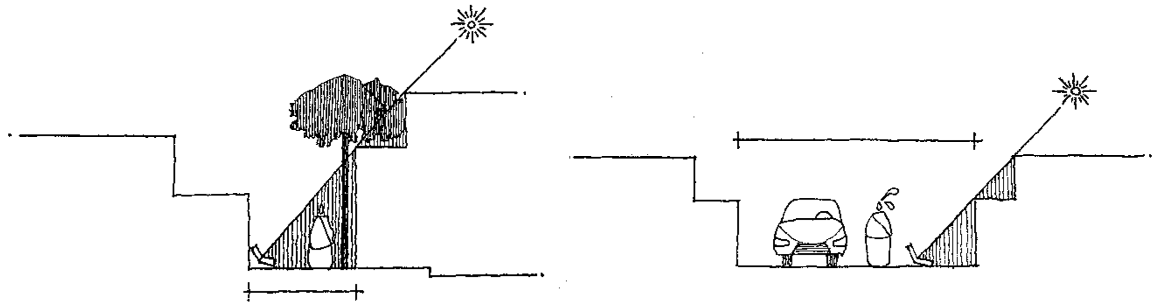


Figure 31, Comparison of two access systems: Shshtar-Now/ preservation of private pedestrian space Graphic by Hossein Abbasimehr on basis of (DAZ 1986)

- COOLING STRATEGIES AT ARCHITECTURAL SCALE; Thick walls, small windows on the shady side of the house, usually facing a small inner courtyard. Entry from the street is usually through a small protected space, between the street and the entry door, which provides a cool space for people walking down the street to meet and talk. The flat rooftops are accessible by steps for evening sleeps. The parapet walls surrounding the roof are often perforated for ventilation using brick grilles, high enough to provide shading, though not enough to give privacy from neighbors (DAZ Architects 1986, 6).

- LOCAL MATERIALS AND CONSTRUCTION TECHNOLOGIES; Traditional Construction methods were used by the local contractor who used local materials and mostly local, unskilled labor.

Load-bearing walls are built of locally made bricks and footings are of concrete. Roof frames are with steel beams.

Wall finishings are mostly of brick. Streets are paved in patterned brick with tile borders.

Figure 32, Local material in Phase 1, Source: (DAZ 1986), *©Kamran Adle*

The elegant brickworks frames the pedestrian street designed at a human and inviting scale. The streets are primarily for pedestrians and act as outdoor extensions of the homes where neighbors may interact in a peaceful atmosphere (DAZ Architects 1986, 41).

SUMMARY

After the raise of the second generation of modern architects in Iran in early 1970s, various approaches for application of the features of traditional architecture into modern architectural design started in Iran including:

1. Remarkable researches and published books on climatic design in architecture that raised attentions towards the climatic-responsive strategies in traditional architecture. Although these samples could open a path for the academics and architecture students, but the results were not applied into modern architecture in practice due to lack of an efficient system for coordination of research and implementation that guarantees the accomplishments of the buildings due to the specific results found on basis of these mentioned researches.

2. The series of international architecture congresses and competitions being held in Iran since 1970s, seeking to refine Iranian traditional urban and architectural policies by exploring the relationship between regional cultures and international construction techniques.
These debates brought up the neo-traditionalist approaches by a group of Iranian architects, being supported by western post-modern and environmentalists.

3. Thirdly are the implemented projects of the modern architects with trends towards traditional Iranian architecture, since 1970s till present.
The only outstanding project that can be mentioned as a successful investigation of the technical values of traditional Iranian architecture and then adaption of them in a modern architecture is the Shushtar New Town by K. T. Diba.
Other architects are either too much involved with the mystic characteristics of Iranian traditional architecture, like Nader Ardalan, or totally concerned with cultural or aesthetic values or interpretation of the meanings laid beyond the traditional architecture.
The projects built by these two groups are mostly symbolic and formal interpretation of the traditional elements in a modern language, by adapting the traditional organization or geometry missing technical rationalization.
However, in such projects, when the contextual features (including the urban context or cultural context) are taken into consideration, the outcome is successful in transferring a sense of modern-Iranian architecture to the public like the cases of Tehran Contemporary Museum of Art by Kamran Diba or Center for Management by Nader Ardalan.
But ignoring the contextual considerations in such projects, results in an eclectic adaption of irrelevant symbols of Iranian architecture, and the project fails in achieving public acceptance, like in Dezful Cultural Center by Farhad Ahmadi.

4. The latest activities that pay attention to the Iranian traditional architecture in their contemporary projects are the energy-efficient projects in Iran implemented by cooperation of European partners, like Hashtgerd New Town. These projects focus majorly on energy saving strategies while environmental sustainability covers a broader spectrum of features than energy saving in buildings. Other sustainability features have remained further more ignored.

CONCLUSION

This dissertation has a novel approach in evaluation of Iranian traditional architecture in terms of environmental sustainability by application of a modern assessment tool (LEED).

Since 1970s various debates on understanding the hidden values of Iranian traditional architecture and adapting them into modern design has been raised from different points of view. The outcome of adapting them in modern architecture has been, in most cases, a modern formal repetition of the Iranian architecture's elements. Such architectures have a modern but Iranian impression on the audience, but miss the right technical performance of the adapted traditional elements.

This dissertation aims to focus on technical solutions in traditional architecture, and reuse or upgrading of their sustainability features in Iranian modern architecture.

3.1. Sustainability; General Definitions

i. Sustainable development, a local concept

Today, sustainability is a global concept, and it is known to every region and country in the world. Meanwhile, as Emmanuel declares, there are many definitions of sustainable development (Emmanuel 2015, P337). There are different interpretations of this concept. In the following part, some of the different definitions of sustainability are presented: As argued in DETR report (2000):

"Sustainable development is about ensuring a better quality of life for everyone, now and for generations to come, through:

- Social progress which recognizes the needs of everyone
- Effective protection of the environment
- Prudent use of natural resources
- Maintenance of high and stable levels of economic growth and employment (DETR 2000).

Chaharbaghi & Willis show the different aspects of sustainability in different professions (Figure 33) (Chaharbaghi 1999, 41-48)

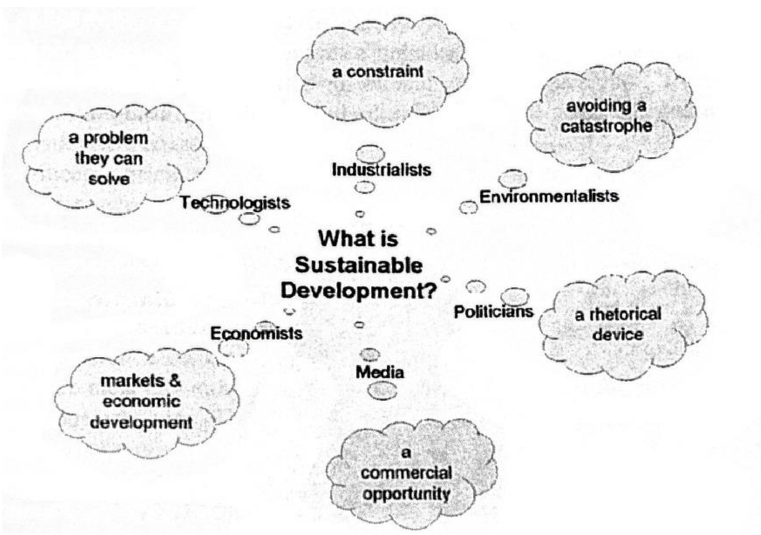


Figure 33: Different aspects of sustainability. Image from: sustainable buildings p337

As Pearce defines "sustainable design and construction has a focus on reducing or eliminating environmental problems and issues associated with built facilities and construction activities while maximizing the potential benefits to society and the economy" (Pearce 2012, 7).

According to the above definitions and in spite of the similarities and common issues in different definitions for sustainability, each emphasizes different aspects of sustainability. Most of these definitions are defined on the basis of subjective viewpoints and focuses.

It seems that the reason for the variety of definitions for sustainability is the generality and extensive borders of the concept. Sustainable development encompasses a large scope of phenomena and involves many elements, such as social and cultural features, economy, environmental issues and climatic conditions of human societies. Each definition of sustainability focuses on specific features of this concept.

In addition, because of the relationship between the concept of sustainability and the environment and socio-cultural conditions in different regions, this concept can be defined with different meanings in different countries and regions.

So it seems that sustainability is a relative phenomenon and its meaning is different for different nations and regions. As Guy expresses:

"There is a paradox for defining sustainability. For example a timber structure doesn't need the energy that goes into smelting aluminum. On the other hand, aluminum structure can easily be recycled, while timber cannot" (Guy and Moore 2005, 6).

So how can we agree on which construction is more sustainable, timber or aluminum?

Maybe the answer is that each can be considered as a sustainable solution in its own specific, relevant environment, where the other one cannot be used in the same context as a sustainable solution.

The following example shows the relativity and locality of sustainability, highlighting it as a context-dependent issue.

In climates such as the hot and arid region of Iran, one of the main problems at the city scale is the harsh solar radiation, inspiring the question of how to protect the city and passageways and make shaded areas for more comfort. While Europe, in contrast, benefits from more solar radiation. Either using sunlight or escaping from it is related to the climatic and environmental conditions of each region and country.

As Pearce describes "each national context has resulted in a variety of approaches to sustainability for the built environment and actions to move toward sustainability have evolved to meet the specific needs of the people of each nation and the conditions in which they live" (Pearce 2012, 24).

So it is important to define a local definition of sustainability in a country such as Iran, with its unique environmental, social and cultural context.

The aim of this research is to introduce some special and local aspects of sustainability that can support further research, which aims to define a local definition of sustainability and its criteria for the hot and arid region of Iran.

Nonetheless, before reaching that aim, this research benefits from the most accepted and general definitions in the world. According to Jenks, “the most commonly cited definition of sustainable development has been drawn from the Brundtland report (Jenks 2000, 3):

“*Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs*” (WCED 1987, 16).

The Brundtland Report emphasized a variety of actions needed to achieve the goals of sustainable development. To achieve its stated goals, the report emphasized three fundamental components for sustainable development: environmental protection, social equity and economic growth (Pearce 2012, 23).

As Jenks states, "those three categories (economy, society and environment) are three pillars of sustainable development" (Figure 34) (Jenks M. 2005, p1).

This research focuses on the environmental aspects of sustainability because of the reasons that will be explained in the next part.

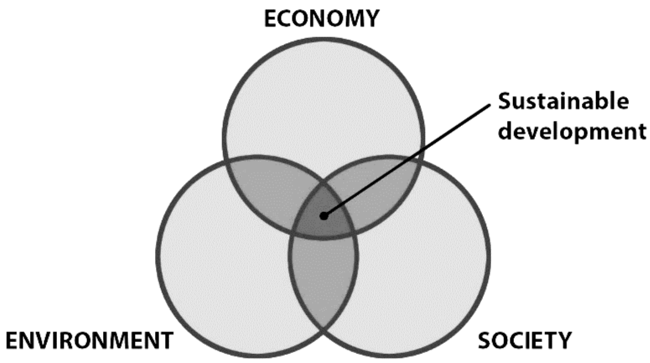


Figure 34: Three pillars of sustainable development. Image from: (Emmanuel 2015, 338)

ii. The Role of Cities

According to the study of the Brundtland report (Brundtland 1987), the world of the 21st century is a large urban world: in 2003, about 48% of the world’s population lived in urban areas and the predictions are that by 2030, 61% of the population will be urban (Jenks M. 2005, 1).

In this urban world, construction is one of the largest industries (Pearce 2012, p1). A great amount of energy is consumed by construction activities, mainly the operation of buildings. For example, in the United States, more than 68% of the total energy is consumed by buildings and transportation systems (Figure 35) (Pearce 2012, p1).

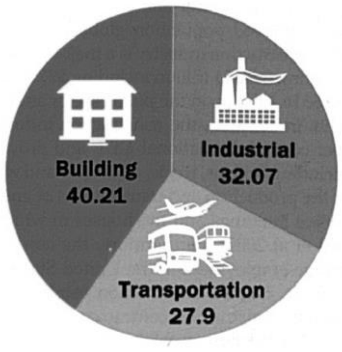


Figure 35: Energy use by sector of the economy in the United States. Image from: (Annie R. Pearce 2012, 2)

Due to the important role of urban activities and buildings in energy consumption and their effect on environment, decisions and strategies in the urban and architectural scales are important for sustainability. On other hand, decisions that have a primary effect on the performance of buildings are taken in the first steps of the design and management of the building (Figure 36) (Pearce 2012, p1).

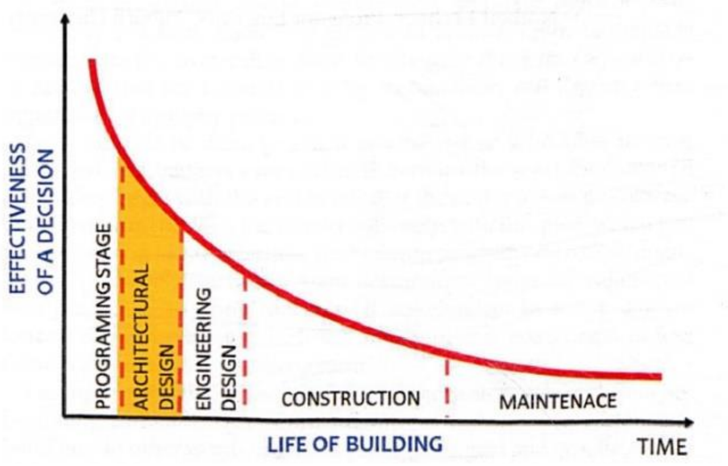


Figure 36: The change in the effectiveness of a decision over the life of a building. Image from: (Pearce 2012, 21)

This means that the urban and architectural design strategies and decisions taken at the primary stages may have more influence on the environment than the construction stage. Hence, urban and architectural design and strategies play an important role in environmental sustainability.

Urban design and architecture influence the economy, society, and environment. As Jenks explains, “the cities must be economically viable, socially equitable and contribute to environmental protection” (Jenks M. 2005, 1).

Without a doubt ,there is an interconnected relationship between economic, social, and environmental features of the communities on one side and urban decisions on the other side. But development of cities and their constructions has the most profound effect on environment. As Baycan states, "the environmental problems especially in the third world associated with rapid urbanization include specific problem manifestations such as:

a. Pollution from urban wastes (municipal and industrial wastewater, storm water drainage, municipal solid wastes, hazardous wastes, and ambient as well as indoor air pollution

b. Urban transport externalities (increasing motorization, poor traffic management, insufficient bicycle paths and walkways, etc.)

c. Resource management issues (unsustainable patterns of resource consumption include depletion and degradation of water supplies, inappropriate land development, inefficient urban fuel consumption and loss of natural and cultural heritage)

d. Environmental hazards (urban areas are subjected to natural hazards: severe storms, floods, earthquakes, volcanic eruptions, wildfires, etc.) (Baycan 2008, 132).

After defining and explaining the issue, this dissertation aims to find sustainable strategies for contemporary architecture and city design by drawing upon local and traditional strategies for inspiration.

Considering the strong environmental effect of city planning and architectural design, and also according to the author's field of study, this research focuses on environmental aspects of sustainability.

Of course it is very difficult to make definite borders for different aspects of sustainability i.e. environmental, social and economic items in analyzes, while there is a very close relationship in these three categories of sustainability, and some factors of analysis may affect or contribute to all three of them. For example, a compact urban texture with connected buildings can reduce environmental effects by minimizing fossil fuel energy consumption by reducing the external walls' energy exchange. From another point of view, these shared walls can develop social communications between neighbors. These further social connections can have the benefit of forming a united local community, but they can also cause social interferences between neighbors. Economic exchanges in society may also be an influential factor. Analyzing social benefits or problems of this exemplary case needs different social experts.

This dissertation concentrates on environmental aspects of sustainability and does not intervene with its social or economic features.

3.2. Contemporary Architecture in Iran; Discontinuity of the Traditional Architecture

i. Iranian Traditional Architecture

Traditional architecture of Iran, known as Islamic architecture, reveals an integrate unity in principles (Beheshti 2015). These traditional patterns have had a continuing unity in concept, design and construction throughout history. But dramatic changes happened in Iran's architecture in contemporary era. Sometimes these changes happen faster due to special events e.g. nationalization of oil industry (1951), land reformations (the White Revolution) in Pahlavi era, the Islamic revolution (1979), war with Iraq (1980-88) etc.

In this part, the features of this traditional Iranian architecture and the grounds that resulted in cease of this continuous system are discussed.

Ehlers and Floor describe the Iranian traditional city: (Ehlers and Floor 1993, 251) "Iranian traditional urbanism and architecture owes its form to the climatic constraints, the locally available technology, and the prevailing customs and culture."

Kamran Diba, in his investigations on Iranian traditional architecture (DAZ 1986, 23), describes the following features as some characteristics of this traditional system:

- Introverted architecture:
  - Preservation from sunlight
  - Preservation of the familial core; traditional and religious privacy
- Human scale
- Narrow streets preserving from the heat and sunlight
- Open meeting spaces in each small neighborhood
- Spatial transitions
- Generating a communal sense.

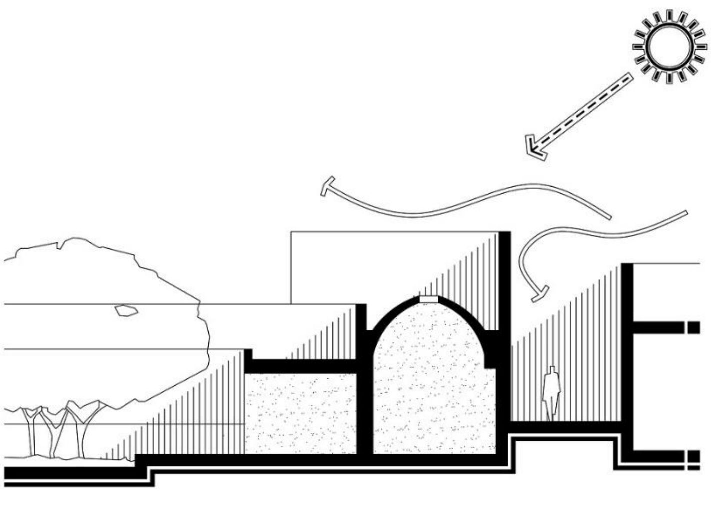


Figure 37, narrow passageways with high walls for preventing the passengers from abundant sun radiation. This proportion of passageway in addition to indirect path of passageways also prevents from desert sandstorms, drawing by author

Pirnia (1922- 1997), the father of Iranian traditional architecture, enumerates five principles for the Iranian traditional cities and architecture (Pirnia and Memarian, Styles of Iranian Architecture 2008, 26-35):

- Humanism: attention to human needs, human behavior and human scale
- Avoiding idleness: minimizing non-functional decorative elements and materials
- Durability**:** paying attention to building statics and the application of the best techniques and most persistent materials
- Self-sufficiency: using local materials and techniques
- Introversion-ism: attention to social, cultural and climatic principles

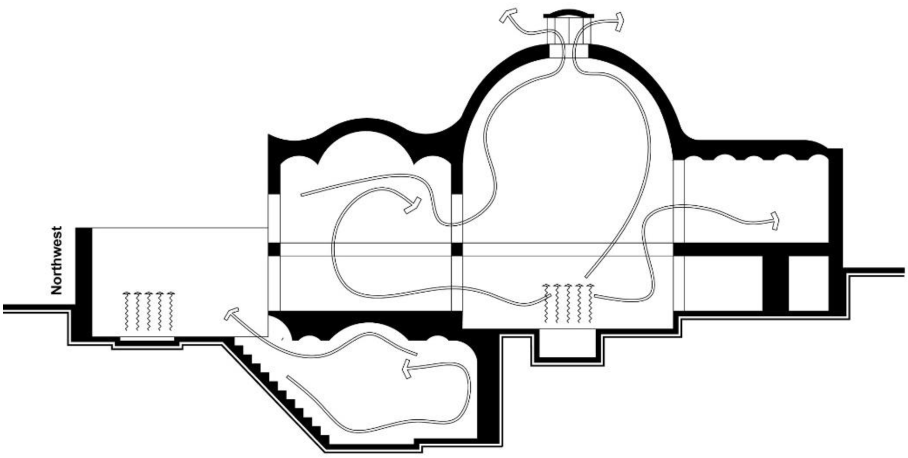


Figure 38, Section for Aal-e Yssin Houe in Kashan, mudbrick buildings with high vaultd roofs and domes that aid better air circulation inside the building, and adaption of strategies to cool down the air temperature by evaporising it through small water pools and vegetation, drawing by author

Another research adds two more aesthetic principles to these features stated by Pirnia (Mirrazavi 2009):

- Homogeneous proportions
- Symmetry and anti-symmetry

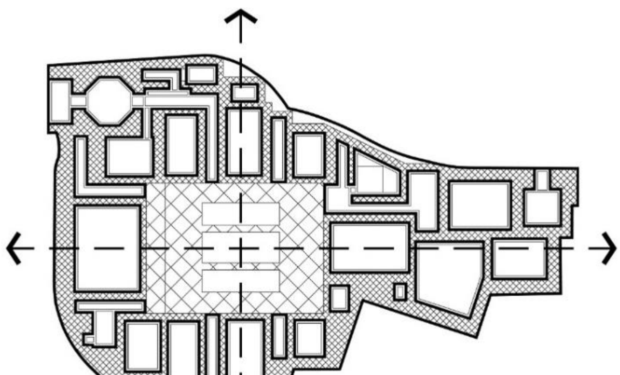


Figure 39, plan for Mashrouteh house, organic form of land in the organic shaped city turns into a very symmetrical geometry inside the courtyard, drawing by author, base plan (Haji-Qassemi, Harirchi and Qelichkhani 2005, 168)

Many of the above mentioned features share common characteristics with other traditional architecture around the world.

Specific climatic conditions in Iran's hot and arid regions, which has its own environmental challenges—lack of natural resources such as water and high aridity, in combination with the cultural characteristics of the inhabitants as well as the thousands of years of architectural and urban background in the Persian plateau—results in a specific sort of living. Throughout history, people in this region have learnt to adapt their life and buildings to this condition.

Most of the mentioned features in the previous part have climatic and environmental influences, and this expresses the vital role that the environment plays on the definitions and features of architecture and urban style in a special region.

As mentioned in the introduction chapter, the main aim of this dissertation is to redefine some design strategies from traditional Iranian city and architectural features that have the capability to be adapted and used in contemporary architectural and urban design.

These lessons and inspirations can be further developed to lead to Iranian sustainability criteria for contemporary life.

This effort will be discussed and developed in the following chapters, but now some of these features will be explained in more detail.

ii. Structure and pattern of Iranian city and architecture in the hot arid region

Structure

The traditional Iranian desert city includes the Friday Mosque in its center, with its high minarets as landmarks. Around this, the grand bazaar with vaulted roofs forms the central spine of the city. In addition, public baths, madrasas, *Serais*, mosques, and cisterns are located in almost every city center.

The residential areas surround these public structures.

Narrow passageways often link the bazaar (the commercial parts of the traditional cities) on the one side to the houses on the other. These passageways are only used for local access by the residents of each neighborhood house and are dead-ended. (Figure 39) (Ehlers and Floor 1993, 251-252).

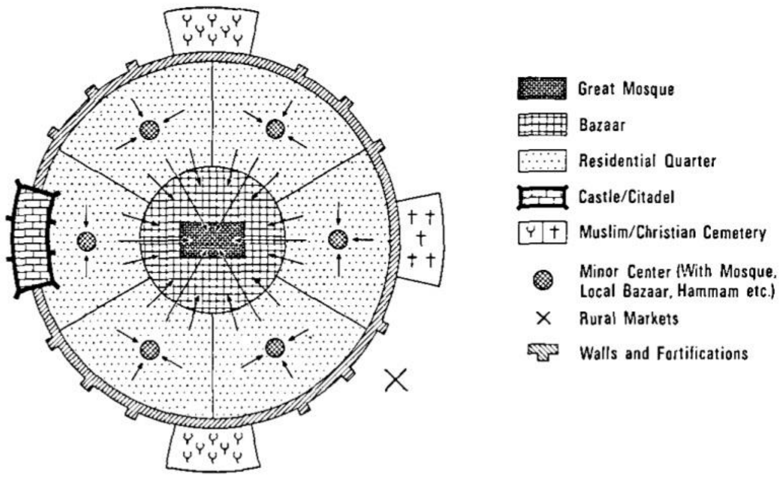


Figure 40: Model of a traditional Islamic city. Image from: (Ehlers and Floor 1993, 252)

Organization

The main center of the city, including the bazaar and other urban facilities, usually has a linear form and the residential districts are branched from this main axis.

In some cities such as Isfahan, the grand mosque is located at a plaza or square (as a public urban space). This square is connected to the main bazaar and its urban facilities (Figure 13).

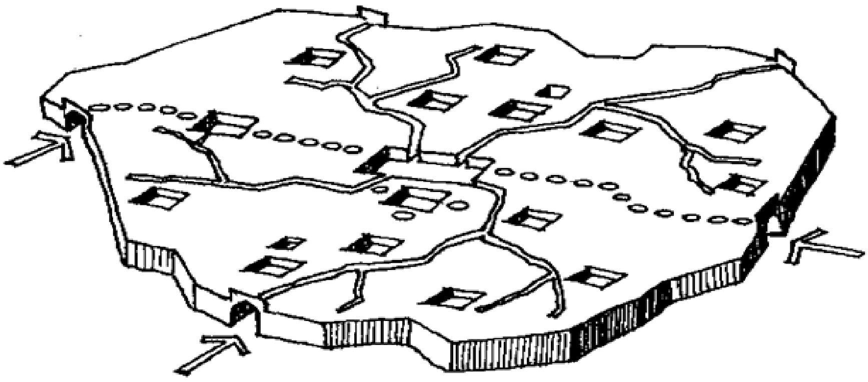


Figure 41: Big square and main bazaar as the main center and axis of the Iranian traditional city. Graphic by Hossein Abbasimehr

Residential districts are located around this main spine of the city (the grand bazaar), with a hierarchy of access from the main city center to the private houses.

Urban fabric

The buildings in the Iranian city are connected together in a compact, interwoven urban fabric. This is one of the most important features of the city for surviving in a desert climate. Common walls between neighbors reduce the energy exchange and waste through external walls (Figures 41 and 42).[8]

Figure 42: Urban texture of historical zone of Yazd. Image from: Image from: (YCHHTO 2013)

[8] As figures 13 and 14 show, the Iranian city appears like a united body that is formed from joining a large number of buildings with maximum connection between them. This feature increases the area of common walls between the buildings and with sharing heat and coldness through the common walls the amount of energy consumption will be reduced. This important feature is analyzed in chapter 6.

Passageways are narrow and non-straight in order to provide more shading and protect the residential areas against frequent sand storms in cities such as Yazd.

The skyline of these desert cities is mostly a straight, low horizontal line. Only the mosques' domes and minarets in some parts break this skyline (Figure 43).

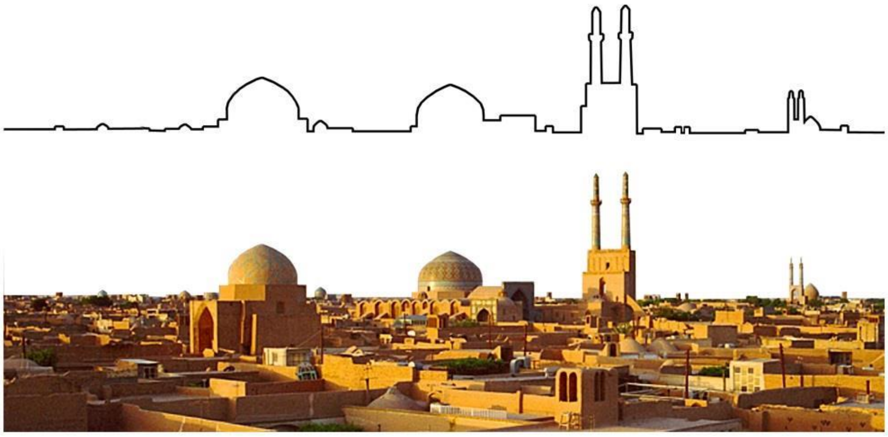


Figure 43: sky line of Yazd. Image from: http://fotografia.islamoriente.com/ accessed online: 11/11/2014

Hierarchy of facilities distribution

Traditional Iranian historical cities follow a pattern of hierarchy in the distribution of facilities from the urban scale to district and neighborhood scales. In the center of each district, there are several local facilities, such as retail shops on a small bazaar, public bathhouses, cisterns and a small mosque. These facilities are for supplying the daily needs of the inhabitants. For further urban services, people use the main bazaar's facilities, which connect different parts of the city as a central spine (Figure 44).

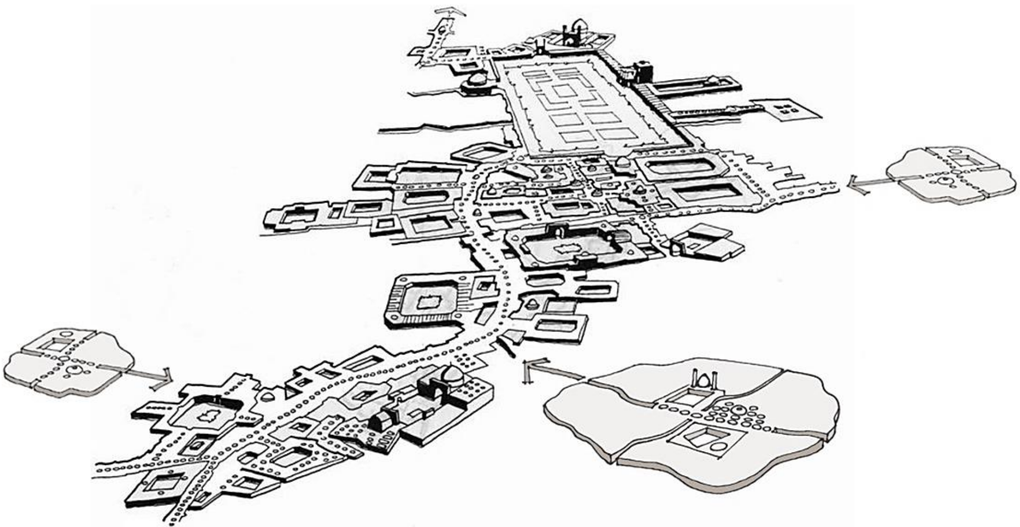


Figure 44: districts facilities that are connected to the main spine of the city. Drawing by Hossein Abbasimehr in (Ahari and Habibi 2001)

City fortress

The previously mentioned structure of the city is surrounded by a continued fortification that organizes an introverted city. Only a few gates around the city fortifications connect the inner parts to the outside, which is usually a desert (Figure 44).

This introverted organization, comprising of high thick adobe walls, protects the city from the threats of enemies and also sand storms (Figure 45).

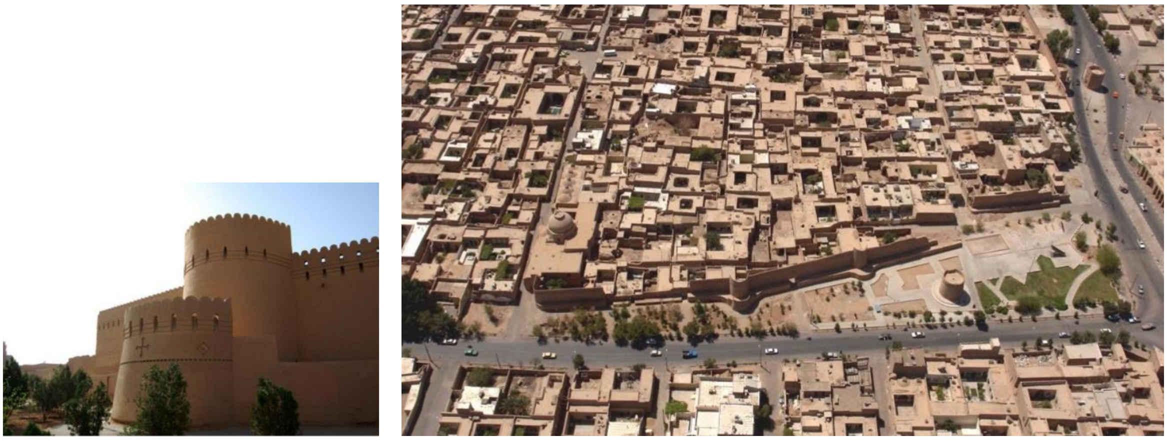


Figure 45: One part of Yazd's fortification. Image from (YCHHTO 2013)

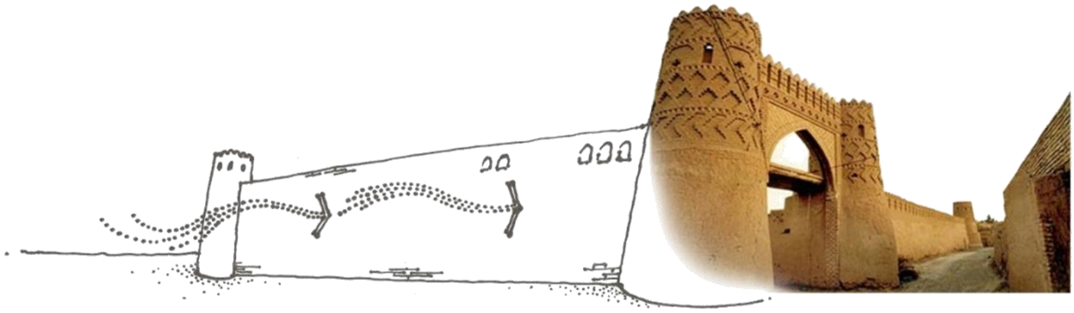


Figure 46: Usual fortification and gates around the historical cities. Graphic by Hosein Abbasimehr, base image from (Aftab News 2013)

Architectural scale

At the architectural scale, the ancient pattern of organization (central courtyard) is used in different facilities such as mosques, caravanserais, madrasas (religious schools), and houses. The courtyard pattern has been used for 8000 years in Iran (Memarian, Introduction to the Residential Architecture of Iran 1996, 16).

This pattern produces an introverted organization. All the living spaces are arranged around one or several central courtyards (Figure 47).

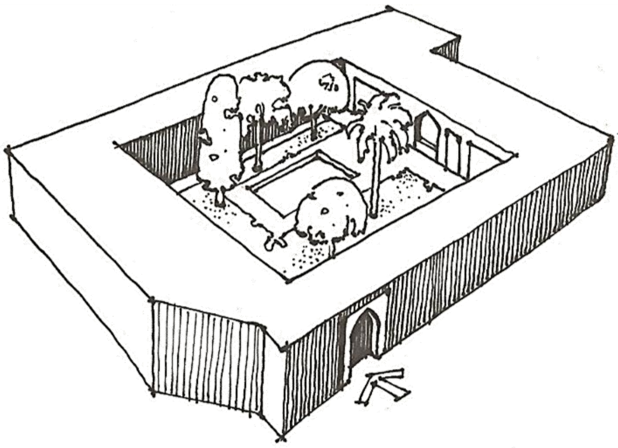


Figure 47: Central courtyard in the Iranian architecture. Graphic by Hossein Abbasimehr

According to this pattern, the building doesn't have any view toward the outside and only one simple entrance provides access from the outside to the internal parts of the building.

This is a beneficial organization regarding the climatic conditions of the hot and arid region. This introverted courtyard system, with its elements such as a wind catcher (traditional architectural element to create natural ventilation in buildings), water pool, and vegetation, creates a microclimate system that provides the inhabitants with comfort zone conditions.

This introverted system, which is closed to outside, helps create a controlled climatic system in the central courtyards against the severe conditions of exterior deserts. Inside the houses, there is a policy for organizing the living spaces around the courtyard. Major larger rooms are located at the center of each side of the courtyard, and secondary spaces are located at two sides of them. The corners accommodate the service spaces which do not need natural lighting (Figure 48).

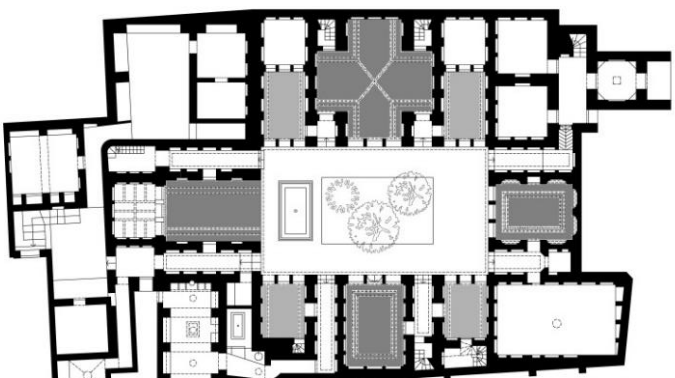


Figure 48: Distribution of the main and secondary spaces around the courtyard (Tehraniha house in Yazd)
Base image from: (Haji-Qassemi, Harirchi and Qelichkhani 2005, 34)

Larger traditional houses contain two or more courtyards. These courtyards are divided into one courtyard for guests and form the so-called external part of the house (*Birouni*), and the other courtyard(s) is for the private family use, so called Internal or *Andarouni*. In aristocratic houses, there were also other courtyards for the servants' living spaces or stables for keeping horses (DAZ 1986).

An entrance called *Hashti,* comprises of a small waiting and communication space with an octagon plan and an indirect corridor; this gives access from the outside to the courtyard. This strategy creates more privacy for the living spaces in the house, because it obstructs any view from the outside to the inside (Figure 49).

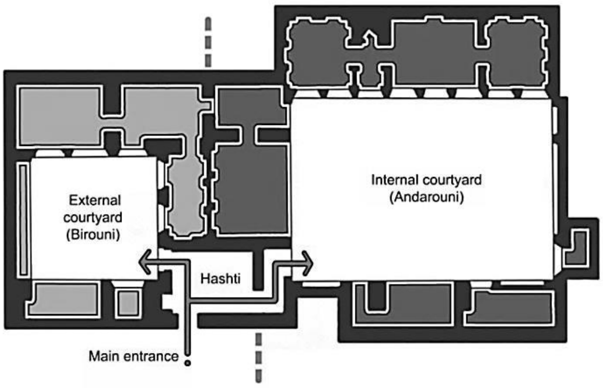


Figure 49: Hashti in Mojahed traditional house in Yazd. Source: (Soltani and Abbasimehr 2013)

This research claims that this system of architecture and urbanism has several advantages to respond to the socio-cultural and environmental context of the hot and arid region. That's why it has survived for thousands of years. This is built from features that are marked by local sustainability.

As Samizay argues, this traditional system and its features in the cities like Yazd, over the years responded to the forces of the environment which guaranteed its sustainability in harsh conditions (Samizay 2012, 127).

In order to prove this claim, these features will be analyzed and assessed with sustainability evaluation systems in the following chapters. Before this, some features of the contemporary system of city design and architecture, and how and why this contemporary architecture ignored the traditional system in the past decades will be explained in the following.

iii. Cease of the traditional system

As Diba argues, the traditional system of architecture and urbanism has survived until beginning of modern life in Iran. With the rule of the Pahlavi dynasty (1925-1979), architecture was modernized in a new way. Socio-political planning under the authoritative rule of the government, aided by westerners, was the style of the period (Diba and Dehbashi 2004, 32).

Ehlers also mentions that the reforms initiated during 30s changed not only the cultural patterns of urban life in Iran and the economic structure of the country, but even the spatial organization (Ehlers and Floor 1993, 251)

Figure 50 shows the spatial alternations, with the new wide car-scaled streets and boulevards that cut the traditional city structure and added a new meaning of spatial organization, with its new forms and elements taken from European cities, such as squares and straight passageways.

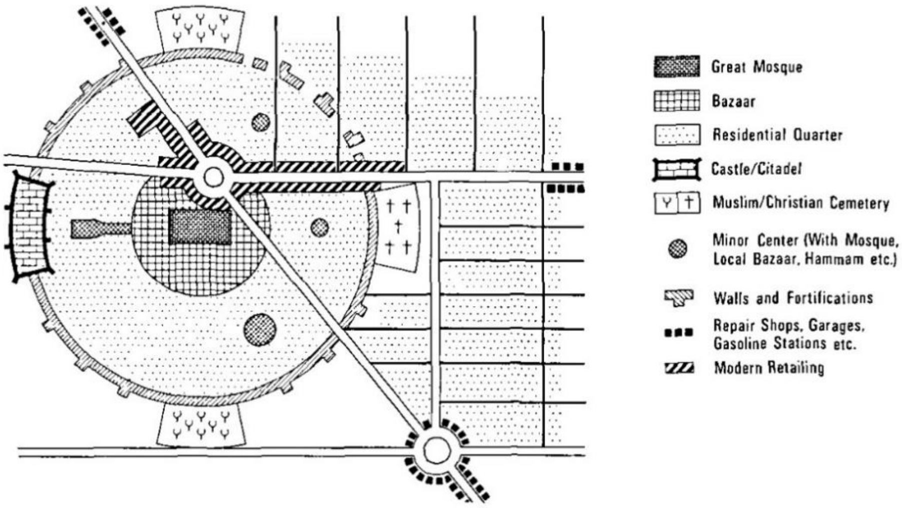


Figure 50: Model of a modernized Islamic city. Image from: (Ehlers and Floor 1993, 264)

A comparison between Figures 40 and 50 illustrates the spatial changes in the Iranian cities and the clumsy transfer of the old city to a modern city. The city was developed without consideration of the existing structures. Many of the important traditional buildings and urban spaces such as urban plazas and bazaars, as well as single buildings such as bathhouses and houses, were destroyed from the addition of new streets and facilities (Figure 51).

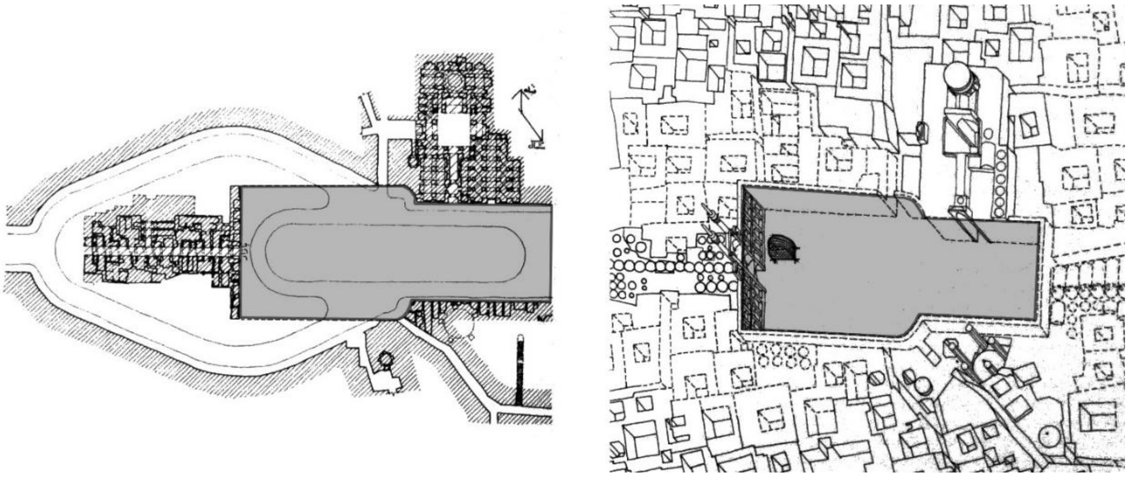


Figure 51: Amir-Chakhmagh square changes by modernizing city and new streets and squares (Right: traditional original square. Left: contemporary changes by adding new streets with different form and destroying the Old Square and bazaar). Source: (Tavassoli and Bonyadi, Urban Space Design 1 1992, 16-17)

As mentioned before, a definition of new organizations in modern cities and therefore new building facilities such as banks, hospitals, universities etc. have imposed a new structure to large cities. These new definitions mostly formed on the basis of a grid organization defined by a network of streets. This urban grid pattern was imposed onto the ancient city pattern, a mostly a centralized pattern (with the Friday mosque in the center). This means that these contemporary changes took place while neglecting the former characteristics and organization of the traditional city.

Many features of traditional cities, as explained before, are created for adaptation to climatic and environmental conditions. Features such as the orientation of the urban fabric, narrow and indirect passageways that prevent sun light in hot summer, and compact and connected urban fabric are direct examples of this conscientious building. These features are missing in modern urban organization, which was imitated from the west.

This blind imitation of western patterns defines a city with cars as the dominant feature of modern living.

The previous traditional hierarchy of passageways, starting from the grand bazaar and ending at neighborhood centers, was replaced by street grids, which cut the urban fabric, neglecting the hierarchy and privacy of the previous passageways. They cut the whole urban fabric and let the streets pass through all parts of the city, from across the bazaar to residential districts. This new pattern misses a logical connection with the former urban structure, functions and passageways (Figure 52).

Figure 52: Confrontation of traditional urban texture of Yazd with new structure and its streets. Image from (YCHHTO 2013)

All changes in the socio-cultural and spatial condition of the cities were misdirected trends, from a sustainable city, with its original and vernacular architectural and urban design system, towards an imported western system and style of urban design, which ignores the local values and sustainability potentials.

Contemporary Iranian architecture does not share any features with the traditional and local architecture. Its rules originate in contemporary international design styles and is largely homogeneous across differing climates in the country (from cold mountains in the west to a moderate climate in the north on the coasts of the Caspian sea, to the hot and arid central deserts of Iran, and the hot and humid climate along the coasts of the Persian Gulf). The local, traditional architecture in each region is left ignored.

Following, are some of the major grounds to see how and why the hundreds of years of continuous chain of traditional architecture was broken in recent century.

iv. Modernization in Iran

According to architecture historians, the first sparkles of modernization in Iran began in Qajar era (1785-1925 AD) as a result of increasing communications with Europe. This caused transformations in Iran’s traditional architecture (Diba and Dehbashi 2004, 31).

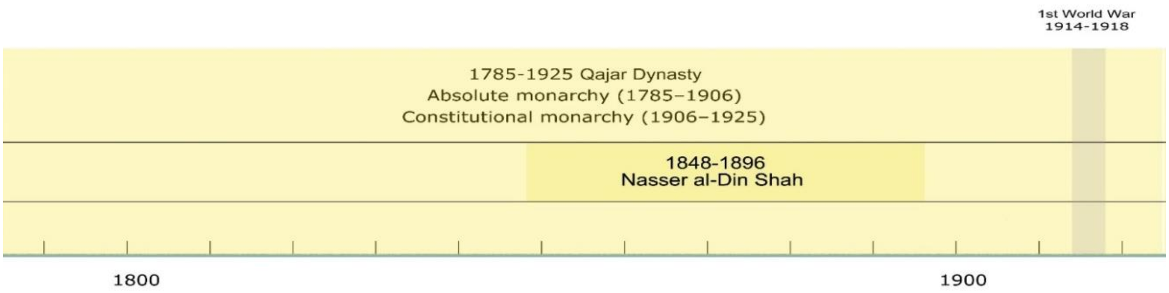


Figure 53, timeline for Qajar period in Iran, drawing by author

It happened as a result of the reforms enacted by the princesses and authorities and those who pursued the rational rule of law as well as the development of public education and welfare with economic independence as their real aim (ibid?).

Nasser al-Din Shah (1848-1896)

Briefly, the following reasons in Qajar period, specifically during the long monarchy of Nasser al-Din Shah (about 50 years) who was interested in travelling to Europe, laid the groundwork for the appearance of a new architecture in Iran since the second half of the 19th century:

- Education of Iranian students in European sponsored by the government.
- Presence of European and mostly French architects in Iran.
- Penetration of Western modernity into Iran that happened mostly through travels to Europe, translation of texts and activities of educational organizations.

These, influenced all aspects of daily life, culture, art, etc. including buildings and architecture which was mostly a non-conscious adaption of the western civilization, majorly a copy of Iranians' observations.

The outcome was therefore a mixture of the European technology with Iranian traditional architecture. Architecture with western tendencies began from royal palaces and then enfolded the urban design in Iran (Bani Masoud 2009).

New construction technologies brought about the opportunity for building new dimensions of buildings and construction patterns such as multilevel palaces, which totally reveal an extroverted non-Iranian architectural pattern.

Figure 54, Shams-ol-Emareh, Qajar Palace in Tehran, Source: Source: (Iran Review 2016)

First Pahlavi (Reza Shah 1925-41)

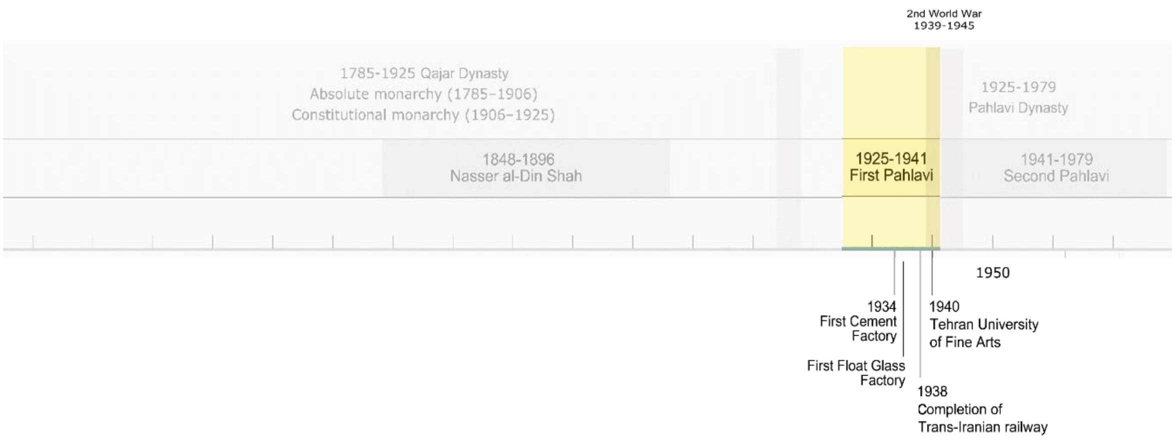


Figure 55, timeline for First Pahlavi period in Iran, drawing by author

By the decline of the Qajar dynasty after Nasser al-Din Shah's rule and after the First World War, this dynasty was replaced by the Pahlavi dynasty in 1925.

During the first period of Pahlavi dynasty, two decades of Reza Shah’s rule (1925-1941), Iran experienced dramatic developments. Industrialization of the country started**.**

This was in conjunction with a marked Europeanisation of social behavior. Education, the economy, and culture all figured on the agenda of Reza Shah under the influence of the West.

The government played an active role in the execution of civil projects. Roads and rail networks were constructed**.**

Western architects were invited to design new buildings such as factories, governmental offices, universities and hospitals for the first time, and the reconstruction plans were executed with great speed. As a result, the traditional design of many cities changed significantly.

For providing the required building materials to implement civil projects at a higher pace, factories such as cement and float glass were set up by the aid of Europeans.

In different years according to the political relations of Iran with Britain, Germany or France, different types of contemporary European architecture specially the Neo-Classic style was designed and implemented in Iran (Ayatollahi 2002, 292), (Diba and Dehbashi 2004, 32).

The return of the architects who were educated at the École des Beaux Arts in Paris (Wilber 1996, 349-351) and establishment of the School of Fine Arts at Tehran University (Diba and Dehbashi 2004, 33) brought up a new trend in Iran's architecture (Ayatollahi, p 292). The traditional pedagogy in architecture that passed the talents from master to trainee from one generation to the next was discontinued and replaced by education of architects along with the lines of European architecture universities.

The architecture of the first Pahlavi period can be divided into 3 major categories, which originated from different existing social flows at the time, with tendencies towards continuation of traditional (Islamic) architecture, western architecture or Iranian ancient architecture:

1. The architecture, which used traditional Islamic architecture of Iran, and was indeed a Continuation of the Late Qajar Architecture (Bani Masoud 2009).
2. Modern architecture, with a sense of being Iranian: the early-Modern architecture which was mostly designed by the foreign architects or the Iranian architects educated in Europe, who were influenced by the Wien style, and early German expressionism, and also the French Art Nouveau (Bani Masoud 2009). These architects usually tried to remain loyal to the principals of the Modern architecture, with a sense of being Iranian.
3. The third orientation was a combination of European Neo-classic architecture with the elements and motifs belonging to ancient Iran (Bani Masoud 2009). These architects tried to revitalize the principles of the Great Persian Empire.

Second Pahlavi (Mohammad Reza Shah, the son 1941-79)

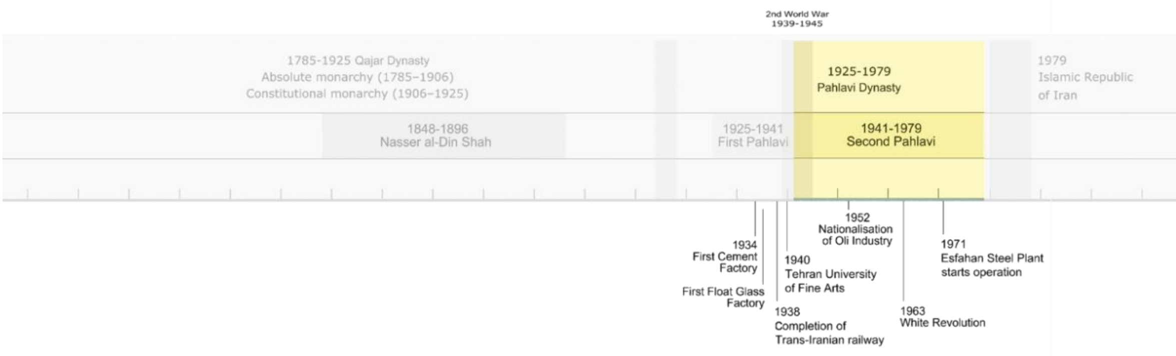


Figure 56, timeline for Second Pahlavi period in Iran, drawing by author

The second Pahlavi period was influenced with Mohammad Reza Shah's attitude. He was educated in Switzerland and instilled with new Western values, and sought to shape the image of Iran.

The decline in architecture and urban development projects in the first decade after the World War II was followed by nationalization of Oil industry in 1951. The emphasis on rapid development sometimes resulted in hurried and uncalculated import of western solutions for solving the urban and civil issues of Iranian cities (Diba and Dehbashi 2004, 33) (Ardalan, Architecture viii. Pahlavi, after World War II 1996).

From the architectural point of view, development of the School of Modernism and the International Style in Architecture was the major characteristic of this period.

This process, which occurred in the design of some structures from 1953 to 1963, was then applied to almost all buildings. During this period (1941-1979) numerous governmental and commercial buildings were erected and many residences were built without consideration for local characteristics or climatic conditions in Tehran and in other cities like Tabriz, Yazd, Mashhad and Kashan (Diba and Dehbashi 2004, 33).

The two flows of architecture in this period were:

1. Following the international style that was imitated all over the world, with multi-level to high rise buildings of concrete structure or steel and glass facades.

2. Modern Architecture, with a Sense of being Iranian, implemented by new generation of educated architects who knew values of Iranian traditional architecture and were committed to use them in their design. The outcome of their work was a modern Iranian architecture.

In addition, the following factors, specifically in the past decades, caused dramatic changes in traditional patterns of construction in Iran:

- The urban population has been growing up in Iran in recent years according to different factors such as better job, education and living opportunities in larger cities like Yazd. This has resulted in ascending request for cheaper and more rapid construction and has therefore changed the appearance of architecture.

The following graphs show the urban population growth in recent decades.

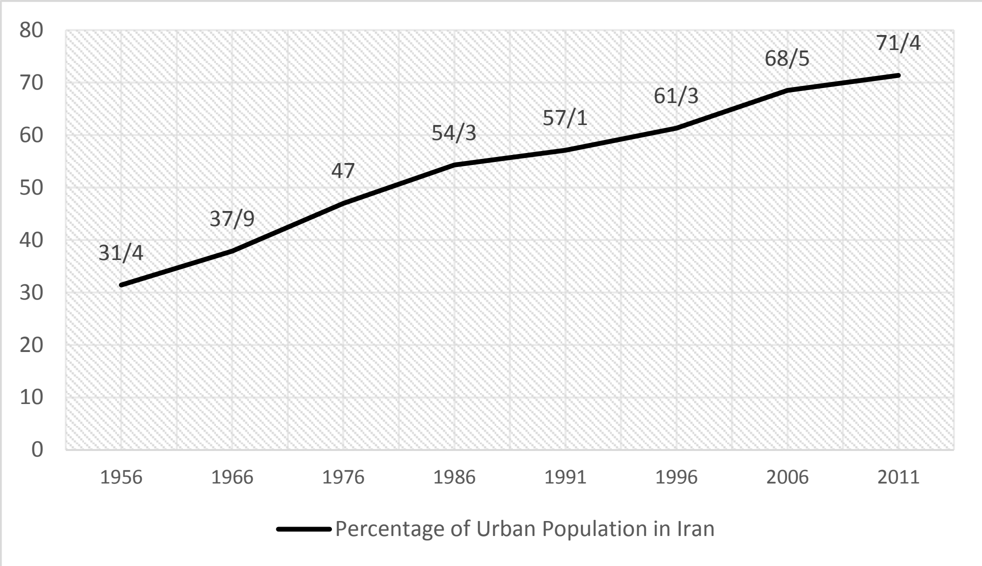


Chart 1, Percentage of urban population in Iran (1956- 2011), Source: (Statstical Center of Iran 2012)

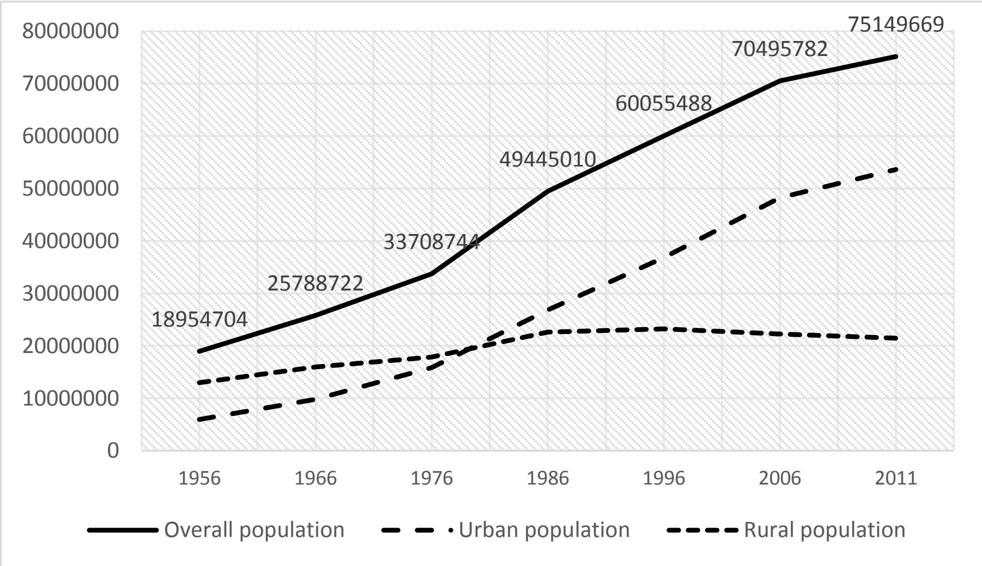


Chart 2, Population of Urban and rural areas in Iran (1956-2011) Source: (Statstical Center of Iran 2012)

Due to expansion of cities and population growth and migration to cities from rural areas, building and housing development has become a growing profit-making business in recent decades. Investigators at different scales have had the possibility to enter this business. This led to cheaper, faster mass housing construction which resulted in uniform structures regardless of climate and context (Diba and Dehbashi 2004, 33) unlike the traditional architecture.

Chart 3. Average price of residential land per m² in 1000 IR. Rials in Yazd (1993-2015), Source *(Statistical Center of Iran 2016)*

Modernization of the society especially the women's start for education and work totally changed the texture of the traditional Iranian families. In Iranian traditional families, children did not live in their own house after getting married, but stayed in their parents' large houses with many rooms. Different generations lived together in different rooms of a traditional house around central courtyard.
But in modern Iran, young generations leave their parents and live more independently. This also caused an emerging demand for small affordable hoses for young small families and made the traditional large houses more abandoned.

The following table shows the mean number of family members (ibid) which is now at an average rate of 3-4 persons per family. This also demonstrates the increasing demand for independent affordable housing especially in larger cities with more expensive lands.

Year	1956	1966	1976	1986	1991	1996	2006	2011
Person	4.8	5	5	5.1	5.2	4.8	4	3.5

Table 1, Average number of persons per family in urban and rural families, (SCI 2012)

Table 2 shows the mean age of the Iran population from 1956 to 2011 (SCI 2012). This shows that Iran has a young population.
Therefore there is a high demand for small affordable housing when the young generation's request for independent living is increasing.

Year	1956	1966	1976	1986	1991	1996	2006	2011
Mean Age	23.7	22.2	22.4	21.7	21.6	24.03	27.97	29.8

Table 2, Mean age of population in Iran, (SCI 2012).

SUMMARY

Briefly, the following facts caused the discontinuity in the hundreds of years of traditional architecture in Iran 20th century.

- Development of communication with Europe, westernization and Europeanization
- Industrialization
- New building materials
- Western Architects in Iran
- Education of Architects
- Development of the School of Modernism and the International Style in Architecture
- Oil Income

In addition, the following features has also resulted in increasing demand for construction of small, rapid housing

- rapid growth of population of larger cities
- transformation of definitions of family
- transformation of living style of the youth

3.3. Building Design in Iran, Regulations and Authorities

In modern era, simultaneously with the graduation of architects and separation of the design process from construction in Iran, different national and regional organizations have been responsible for establishing principles for integrate design rules and regulations at a national scale.

Following, is a short review of the most important authorities in this area in Iran to see how they contribute in making and controlling the design and construction in the country, and to see if they have any tendency or attention for sustainability or environmental considerations.

i. Architecture and Construction Institutions and Legislators in Iran

Ministry of Roads and Urban Development

The Ministry of Housing and Development was established in 1968 in Pahlavi era (MRUD 2010). In 2011 Ministry of Roads and Urban Development was established by merging the Ministry of Housing and Urban Development and the Ministry of Roads and Transportation. This ministry consists of different departments including acoustics, architecture, housing and building systems, building installation, building materials and products, concrete technology, economic and social research, engineering services, environmental and energy design, fire, geotechnical department, Iran strong motion network, seismology engineering, structural engineering and polymer department (Office for Codification and Development of National Building Codes 2005).

National Building Codes

National Building Codes are a compilation of rules and regulations that must be observed in building constructions. These rules have been established for the provision of safety and comfort.

National Building Codes are formulated according to the available technologies in Iran and have proved their usefulness in different fields. In recent years, before the formulation of National Building Codes, some codes had been adopted from other countries which were then localized, according to the conditions prevalent in different regions of the country. However, as the number of buildings and construction increased, there was a need to formulate codes which could be designed specifically for different regions in Iran (Office for Codification and Development of National Building Codes 2005).

Due to occurrence of earthquakes in recent years, low service life of buildings, constant need for maintenance, etc. proved that traditional construction of buildings is not effective any more. Therefore, formulation of National Building Codes is regarded as a top priority in the country (RHUD 2013).

The 22 booklets of Iran national building codes and their dates of edition (Iran National Building Regulations 2010).

Vol.	Title	1st Edition	2nd Edition	3rd Edition	4th Edition
1	Definitions	2013			
2	Administration	2005			
3	Building Fire Protection	2001	2013		
4	General Building Requirements	2008			
5	Building Materials & Products	1990	2003	2010	
6	Design Loads for Buildings	2001	2006		
7	Foundations	1990	2009	20013	
8	Masonry Buildings	2005			
9	Design and Construction of Concrete Structures	1989	2006	2009	
10	Design and Construction of Steel Structures	1989	2005	2009	
11	Industrialized Construction	2004			
12	Safety and Precautions in Construction	1993	2001	2006	2013
13	Electrical Installations	1993	2003		
14	Mechanical Systems	2001	2012		
15	Elevators and Escalators	2001	2008		
16	Plumbing systems	1993	2003	2012	
17	Natural Gas Piping	2002	2008	2010	
18	Acoustics and sound Control	2001	2011		
19	Energy Conservation	1991	2002	2010	
20	Signs and symbols	2005			
21	Passive Defense	2012			
22	Care and Maintenance	2013			

Table 3, list of booklets for Iran national building codes published by Iran Ministry of Roads and Urban Development

Booklet 19: Energy Conservation

The Booklet 19 of the Iran national building codes is a 90 page book written by a group of engineers and building professionals of the National Building Codes Professional Committee in Ministry of Roads and Urban Development (previously Ministry of Housing and Urban Development) and Building and Housing Research Center (BHRC). It was published for the first time in 1991 and has been updated in 2002 and 2010 (Ahmadi, et al. 2002) Chapter 2 describes the general rules for design and among the required documents to obtain a building permit, it asks for physical characteristics of heat insulator (materials and systems).

Generally this booklet introduces specific building physics calculations and construction detailing for better insulation of the building envelope by application of chemical insulation panels in the exterior shells.

This booklet also teaches calculations for better utilization of solar energy due to building function and location.

Other instructions include mechanical installations as well as lighting and electrical systems and equipment.

This is almost the only official reference that has been largely developed and encouraged to be used by architects and engineers, but energy considerations in this book is not yet mandatory to be implemented in buildings.

Iran Construction Engineering Organization (IRCEO 2011)

ICEO is a Non-Governmental Organization established in 1995, aiming to assist more effective contribution of engineers of different orders into construction industry.

This organization focuses on education of graduated engineers and creating the opportunity for them to update their knowledge in different courses or workshops.

This NGO also issues professional certifications for engineers in each province, and confirms the license for professional working permit through periodical examinations on design or construction supervision. Hence, every single building needs to be confirmed from the very early design stages, by an authorized engineer in the same province, who is a licensed member of ICEO.

This organization comprises of various professional groups such as architecture, urban planning, civil engineering, mechanical engineering, electronic engineering, cartography and traffic engineering.

Municipality

The Municipality in each province together with the ICEO have the duty to supervise and control the design for the buildings and to verify them after they are built and issue the license to confirm that they have the necessary standards and are habitable.

Only some small detailing such as usage of insulation panels for roofs or double glazed windows are the obligatory rules asked by the municipality in some cities in Iran for receiving the certificate for the building.

ii. Other energy related organizations and authorities in Iran

There are other organizations in Iran that are responsible to conduct the right consumption of energy and reduction of environmental pollutions in different industries in the country. Although these organizations are not in direct relation with building and construction, but their policies may influence building industry due to the high share of this sector in energy consumption. Following is a short introduction of these authorities:

Iranian Fuel Conservation Organization (IFCO)

The National Iranian Oil Company (NIOC) established the Iranian Fuel Conservation Organization (IFCO) in 2000 as a subsidiary branch with mission to regiment the fuel consumption in different sectors through review and survey of the current trend of consumption, and to execute nationwide conservation measures.

The energy conservation policies of this organization focus on wise energy consumption and cooperation in the reduction of greenhouse gas emission.

The IFCO uses the three methods of rulemaking (regulations, rules and standards, and practical systems), support (tax exemption, subsidization, and technological improvement) and information (labeling, education, advertisement) (Nasrollahi 2009, 58).

Iran Energy Efficiency Organization (IEEO)

Established in 1995, administers the plans of Energy Affairs deputy of Ministry of Energy to promote a culture of energy conservation and productivity, and to encourage participation from the private sector.

It has a record of energy auditing in factories in various industries, a collection of measuring instruments, experienced staff, modern laboratories for the formulation of energy consumption standards (for household appliances and industrial elements), a collection of information, books and professional publications related to energy management, and it organizes national and international seminars and training courses (Nasrollahi 2009, 58-59).

Renewable Energy Organization of Iran (SUNA)

In 2000, the Energy Deputy of the Iranian Ministry of Energy established the Renewable Energy Organization of Iran (SUNA) with the mission to investigate and promote the use of renewable energies over primary energies. This organization is divided into the sub organization of solar, biomass, geothermal and wind energy) (Nasrollahi 2009, 59).

SUMMARY

The main policies of construction activities in Iran are defined by the Ministry of Roads and Urban Development.
Construction Engineering Organization together with the Municipalities in each province have the task to take care of the right implementation of the policies made by this ministry.
In recent decades policies for reduction of energy consumption in buildings have been one of the main focuses of these authorities and many courses and workshops are presented to educate the engineers.
Due to high share of construction industry in energy consumption, other organizations such as Iranian Fuel Conservation Organization (established by The National Iranian Oil Company) and Iran Energy Efficiency Organization (established by Iran Ministry of Energy) are also now eager to assist the construction industry to reduce the energy consumption in building sector.
However, these activities are still at the stage of guidelines and encouraging policies, and have not yet reached a real implementation or mandatory points in construction activities.

Note. Although Booklet 19 issued by the Ministry of Roads and Urban Development discusses practical guidelines for reduction of energy consumption in buildings, but only very primitive solutions such as application of double glazed windows or layers of heat insulation for roofs have been mandatory for houses in the last few years.

CHAPTER 4. SUSTAINABILITY EVALUATION TOOL

In this chapter, the existing evaluation systems for assessing the rate of sustainability in buildings are discussed first and then the proper evaluation system for defining baselines for the assessment of the degree of sustainability in selected case studies in hot and arid region of Yazd, Iran will be selected.

The facing challenges are:

- At the moment, there are no specific evaluation systems for assessment of sustainability of buildings in Iran. Therefor the most relevant evaluation system among the existing systems in the world must be selected.

- The existing evaluation systems mostly originate from regions that have very different climatic conditions from the hot and arid region in Iran. Therefore the selected evaluation system must be adapted to the Iranian climatic and architectural conditions.

- To find the strategies out of the evaluation system, with which both traditional as well as contemporary systems could be evaluated.

- To evaluate the traditional buildings (here older than 120 years) in their original context - that does not really exist now- as it was at the time they were built. Even their original social context has dramatically changed.

4.1 Evaluation

Evaluation of environmental sustainability covers a wide range of features that are in close relation to economic and social aspects of sustainability. Although sustainability at first glance, brings to mind a wide range of meanings, concepts and contents, but as architects, after all, we have to find a practical tool to assess and evaluate the performance of buildings in relation to sustainability. This is not a new question, and has, during past decades, been a challenge for researchers to measure and evaluate sustainability in buildings and cities. As mentioned previously, this dissertation focuses on environmental aspects of sustainability.

As Pearce et al. discuss the sustainability evaluation and assessment in 2020 in their book (Annie R. Pearce 2012): 180, "specific challenges abound with regard to measuring the sustainability of the built environment and the products, services and organizations associated with it. At the foundation of the problem is the lack of a widely accepted operational definition of the construct of sustainability. As a context-dependent attribute, the sustainability of a system or artefact will be affected by different factors in different situations. It will also necessarily involve different factors and considerations for different types of products or systems. Thus, there is no 'one size fits all' approach to evaluating sustainability."

Some professionals like Edwards and Hyett imply that the alternative visions of how we might best live in harmony with nature can be adequately expressed through an energy-rating model (Brian Edwards 2001): 18.

Harry Gordon concurs from a US perspective when he argues that the 'LEED (Leadership in Energy and Environmental Design) standards, issued in 2000, are creating a common understanding of what it means to build green (Gordon 2000:34). [9]

Farmer and Guy (Graham Farmer 2005) in part A of the book "Sustainable Architectures" (Simon Guy 2005) state "physical performance has become a critical issue in several contemporary models of sustainable architecture. The main outcome of the global focus for sustainability[10] in terms of building production has been a continuing emphasis on improving physical performance generally and the efficient use of energy in particular."

---

[9] Employing similar logic, Paul Hawken, Amory Lovins and Hunter Lovins, in their very influential book Natural Capitalism, argue that consumers will automatically embrace radical resource efficiency once they understand that they can reduce consumption 'without diminishing the quantity or quality of services that people want' (Hawken, Lovins and Lovins 1999, 176).

[10] Although the concept of sustainable development as it developed through the 1980s and 1990s shifted the environmental debate in architecture beyond a narrow focus on energy efficiency, the 1987 Bruntland Report, the Earth Summit of 1992 and the subsequent Kyoto Protocol of 1997 have tended to be instrumental in framing the environmental 'problem' in the mainly macro-physical terms of greenhouse gas emissions and ozone layer depletion.

These few arguments show how far architects and designers have tried to figure out a tool to measure sustainability in the built environment.

4.2 Environmental Assessment Methods

Following from these assumptions is the belief that the ‘greenness’ of a building can effectively be predefined or assessed through the use of objective technical analysis such as life-cycle analysis, ecological footprint analysis or environmental assessment methods. Of these methods, the environmental assessment methods (EAMs) in particular have come to be viewed as a key way of both modelling and categorizing the environmental performance of a building, and during the last decades several different environmental rating schemes have been developed throughout the world. (Graham Farmer 2005)

4.3 Existing Rating Systems for Environmental Sustainability in Buildings

As Pearce et al. describe in chapter 4 “Green Rating Systems” of their book “Sustainable Buildings and Infrastructure”, at the scale of whole buildings, various rating systems have been developed around the world to evaluate capital project sustainability. Most green building rating systems include explicit performance thresholds that buildings must meet in order to be certified. They also typically come with guidelines that help project teams meet or exceed those performance thresholds.
Most of the green building rating systems on the market today were developed in a particular country to serve the specific needs of that country’s buildings. However, many of these tools have been applied across multiple countries to meet the demand for green building ratings in countries that do not yet have their own rating system. (Annie R. Pearce 2012, 151-152).

In the UK the Building Research Establishment (BRE) developed its own environmental assessment method (BREEAM) in 1990, claimed to be “the world’s most widely used means of reviewing and improving the environmental performance of buildings”. (Graham Farmer 2005).

Since then many other national and international evaluation systems were launched and developed one after the other.

The following figure shows the green building rating systems, mapped by country of origin and initial application.

Figure 57, Green building rating systems by country of origin, source: (Annie R. Pearce 2012, 152)

As observed in Figure 43, some of the rating systems such as BREEAM and LEED have been widely applied in countries outside their country of origin.

Following, is a short introduction to the rating systems originating in specific countries as Pearce describes:

- **Building Research Establishment Environmental Assessment Method (BREEAM)**

One of the first assessment methods to be developed for evaluating project sustainability. Developed in the United Kingdom, specific versions of this rating system exists for the UK, Europe and the Gulf, and it has also been adapted for use in other contexts to take into account environmental weightings; local codes, standards and building methods; and important local environmental issues.

- **Comprehensive Assessment System for Building Environment Efficiency (CASBEE)**

Developed by the Japan Sustainable Building Consortium and Japan Green Building Council in conjunction with several other Japanese government agencies in 2002.

- **Green Globes**

Initially developed in Canada, modelled after the BREEAM rating system as an offshoot of the BREEAM Canada in 2000

- **GreenStar Australia**

Developed by the Green Building Council of Australia (GBCA) based on British BREEAM system and the North American LEED system.

- **GreenStar New Zealand**

Launched in New Zealand in 2007, based heavily on the Australian version of Green Star

- **Leadership in Energy and Environmental Design (LEED)**

Developed by US Green Building Council (USGBC) since 1994, and has been applied to projects in the United States and beyond.

- **MOHURD 3 Star Rating System (China)**

A voluntary, context-specific rating system developed in 2008 developed by the Ministry of Housing, Urban and rural Development to encourage the development of green buildings beyond what has already occurred due to use of international rating systems such as LEED.

- **South Korea Green Building Certification System (GBCS)**

Development and implementation of the green building rating system GBCS beginning in 2001, one of Korea’s initiatives as part of the effort for comprehensive environmental action plans to achieve the goals of sustainability in the construction industry

The two international rating systems are also as follows:

- **Sustainable Building Challenge (International Rating Standard)**

Managed by the International Initiative for a Sustainable Built Environment (IISBE), this program began as the Green Building Challenge in 1996, and is a continuing program to feature high-performance buildings worldwide and examine their performance at World Sustainable Building conferences.

- **Living Building Challenge (International Rating Standard)**

Developed by the International Living building Institute for rating built facilities in terms of the degree to which they restore the natural and social environment and function effectively as contributors to, not parasites of, the context in which they are built.

In addition to the national and international rating systems described above, many other local and regional building rating systems have also evolved over time specifically at the level of residential construction.

The performance areas comprising each of these national or international evaluation systems discussed previously are as follows:

Sustainable Building Certificates		
BREEAM	Energy Management Health and wellbeing Transport Water	Materials Waste Land use Pollution Ecology
CASBEE	**Environmental Quality** Indoor environment Quality of service Outdoor environment on site	**Environmental Load** Energy Resource and materials Off-site environment
Green Globes		
Green Star Australia **Green Star New Zealand**	Energy Emissions Transport Material Water	Land use and ecology Indoor environmental quality Management innovation
LEED	Sustainable sites Water efficiency Energy and atmosphere Materials and resources Indoor environmental quality Innovation in design	
MOHURD	Land saving Energy saving Water saving Material saving Indoor environment Operations	
GBCS	Land use and commuter transportation Energy resources consumption and environmental loads Ecological environment Indoor environment quality	
Sustainable Building Challenge	Site selection, project planning and urban design Energy and resource consumption Environmental loadings Indoor environmental quality Service quality Social and economic aspects Cultural and perceptual aspects	
Living Building Challenge	Site Water Energy Health	Materials Equity Beauty

Table 4, national and international evaluation systems for sustainability, and their performance areas

As demonstrated in Table 4, all the national and international evaluation systems share almost the same features for evaluation such as building's approach towards site, energy, water, material, health etc.

CONCLUSION

Selection of Evaluation Tool

Due to similarities of approach in different evaluation systems in the world, amongst all, this dissertation chooses the LEED[11] (USGBC 2013) evaluation system (developed by US Green Building Council since 1994) regarding its wide range of utilization worldwide and in the Middle East (see Figure 57).

Although most of the evaluation systems claim that they are internationally compatible, but one of the main concepts of sustainability is locality. This means that the more common climatic factors between the system and the target case study, the less requirement to change and adapt the rules when we want to utilize the rating system in a new geographic region.

However the main reason to choose this system is the climatic similarities of its origin, the United States, to Iran's hot and arid region in comparison to other evaluating systems that originate from the cold and humid climate in Europe or climatic conditions of the far eastern countries like Japan with too much rain and humidity (see Figure 58).

Note: As mentioned before, due to the limitations of the existing evaluation systems in terms of architectural design, this dissertation does not aim to evaluate and certify the case studies by the evaluation systems. It tries to evaluate the houses in different categories (water, energy, site, material…) and show how architectural design affects the performance of the buildings.

To do this task in a more scientific way, parallel with the evaluation, the LEED rules will be mentioned too.

[11] Leadership in Energy and Environmental Design

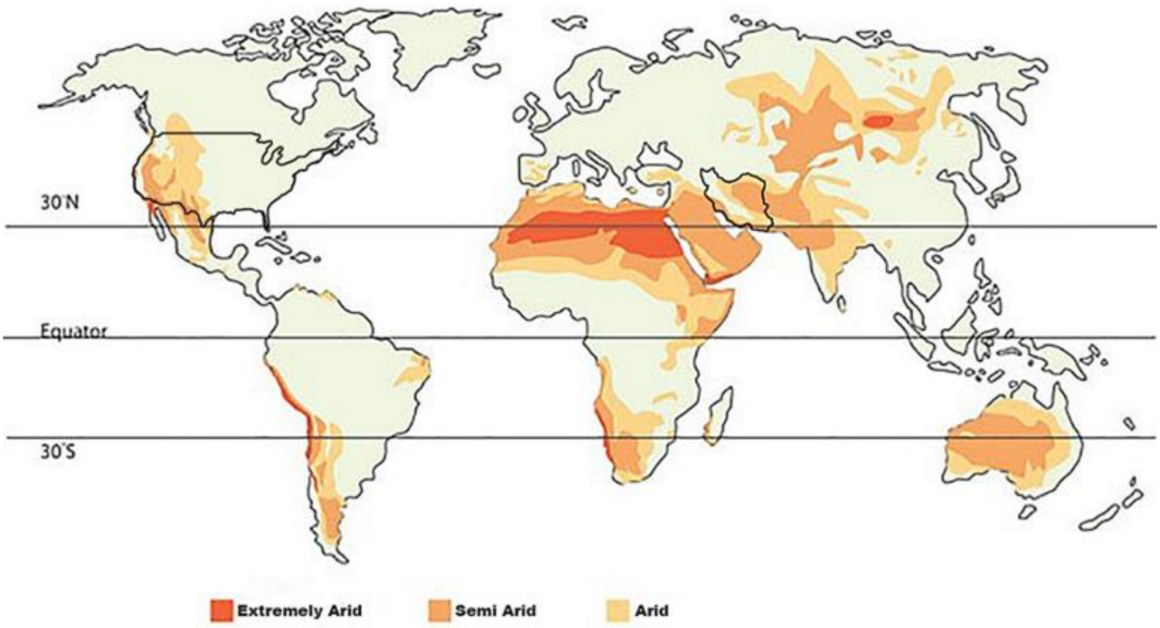


Figure 58, Distribution of arid land and location of Iran and the USA. Image from: (Nature 2011)

LEED rating system was initially modeled after the BREEAM system (Annie R. Pearce 2012): 159). Among all the existing tools described previously, LEED rating system is one of the most well-known systems worldwide. This system was launched by the United States Green Building Council, and has been applied to projects in the United Sates and many other countries. It has been applied across multiple countries worldwide as a base for making new national evaluation systems (Annie R. Pearce 2012, 160).

Briefly LEED system follows three goals:

- Improving overall energy performance and reduction of greenhouse gas emission
- Supporting energy efficiency efforts by over time monitoring
- Sustaining the home energy performance by training the occupants.

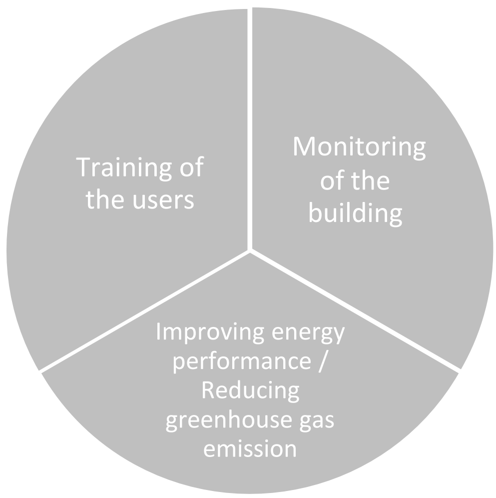


Figure 59. The three main LEED strategies for energy and atmosphere, graphic by author

For defining a practical evaluation system, LEED for Homes sets up 8 categories of evaluation. In each category, prerequisites and credits are defined. Each house can obtain up to a maximum of points from each category if the house follows certain standards or design rules defined by LEED. Finally the certifications will be issued due to the sum of points achieved by the house (home or midrise).

LEED has four levels of certification:
Certified: 40 to 49 points,
Silver: 50 to 59 points,
Gold: 60 to 79 points,
Platinum: 80 to 110.

The LEED rating system consists of a series of performance goals and requirements in the following six categories[12] (Annie R. Pearce 2012): p 160

1. Sustainable Sites, covering issues related to the location of the project site, impacts to the site during construction, site amenities and impacts resulting from building operations.

2. Water efficiency, deals with water consumption and waste-water generation by the building in operation.

3. Energy and atmosphere, addresses all aspects of the building's energy performance, energy source(s) and atmospheric impacts.

4. Materials and resources, pertains to the sources and types of materials used on the project, the amount of waste generated and the degree to which the project makes use of existing buildings.

5. Indoor environmental quality, covers aspects of the building's indoor environmental ranging from ventilation to air quality to daylight and views.

6. Innovation in design, rewards the project for going beyond the minimum credit requirements and for using a LEED accredited professional.

The newest version of the US LEED rating system, released in 2009, attempts to accomplish this goal via a system of region-specific credit requirements applied to buildings based on location. The following table shows the evolution of approach to this issue over the multiple versions of the LEED rating system. (Annie R. Pearce 2012) :181

Version	Launch	Approach to Context Specificity
LEED v1	1998	Somewhat prescriptive; limited building types – application guides proposed as mechanism for customization
LEED v2.0, 2.1 and 2.2	2001 ff	More performance-based; most credits converted; additional application guides developed; additional core rating systems developed for homes, neighborhood development, existing buildings, core and shell, and commercial interiors
LEED 2009	2009	Regional priority credits introduced; credit point values changed to reflect new weightings for relative importance of environmental issues (USGBC 2008)

Table 5, Context specificity and the LEED rating system, source (Annie R. Pearce 2012)*:181*

[12] LEED in its booklet for evaluation of home/midrise building defines the following eight categories:

1. Location and Transportation (LT)
2. Sustainable Sites (SS)
3. Water Efficiency (WE)
4. Energy and Atmosphere (EA)
5. Materials and Resources (MR)
6. Indoor Environmental Quality (EQ)
7. Innovation (IN)
8. Regional Priority (RP)

Since this dissertation focuses on architectural scale, and works parallel with another dissertation by Hossein Abbasimehr with focus on urban scale, this dissertation selects the categories 2 to 6, and makes the evaluation upon these criteria.

LEED rating system applies to a wide variety of project types, including new commercial construction and major renovations, existing buildings, commercial interiors, building cores and shells, residential construction and neighborhood development. The following table shows the LEED v4 checklist for home design and construction and shows a brief review to the prerequisites and credits with the points in each category.

Y	?	N	Credit	Integrative Process	2
0	0	0	**Location and Transportation**		**15**
Y			Prerequisite	Floodplain Avoidance	Required
PERFORMANCE PATH					
			Credit	LEED for Neighborhood Development Location	15
PRESCRIPTIVE PATH					
			Credit	Site Selection	8
			Credit	Compact Development	3
			Credit	Community Resources	2
			Credit	Access to Transit	2
0	0	0	**Sustainable Sites**		**7**
Y			Prerequisite	Construction Activity Pollution Prevention	Required
Y			Prerequisite	No Invasive Plants	Required
			Credit	Heat Island Reduction	2
			Credit	Rainwater Management	3
			Credit	Non-Toxic Pest Control	2
0	0	0	**Water Efficiency**		**12**
Y			Prerequisite	Water Metering	Required
PERFORMANCE PATH					
			Credit	Total Water Use	12
PRESCRIPTIVE PATH					
			Credit	Indoor Water Use	6
			Credit	Outdoor Water Use	4
0	0	0	**Energy and Atmosphere**		**37**
Y			Prerequisite	Minimum Energy Performance	Required
Y			Prerequisite	Energy Metering	Required
Y			Prerequisite	Education of the Homeowner, Tenant or Building Manager	Required
			Credit	Annual Energy Use	30
			Credit	Efficient Hot Water Distribution	5
			Credit	Advanced Utility Tracking	2
0	0	0	**Materials and Resources**		**9**
Y			Prerequisite	Certified Tropical Wood	Required
Y			Prerequisite	Durability Management	Required
			Credit	Durability Management Verification	1
			Credit	Environmentally Preferable Products	5
			Credit	Construction Waste Management	3

0	**0**	**0**	**Indoor Environmental Quality**		**18**
Y			Prerequisite	Ventilation	Required
Y			Prerequisite	Combustion Venting	Required
Y			Prerequisite	Garage Pollutant Protection	Required
Y			Prerequisite	Radon-Resistant Construction	Required
Y			Prerequisite	Air Filtering	Required
Y			Prerequisite	Environmental Tobacco Smoke	Required
Y			Prerequisite	Compartmentalization	Required
			Credit	Enhanced Ventilation	3
			Credit	Contaminant Control	2
			Credit	Balancing of Heating and Cooling Distribution Systems	3
			Credit	Enhanced Compartmentalization	3
			Credit	Enhanced Combustion Venting	2
			Credit	Enhanced Garage Pollutant Protection	1
			Credit	Low Emitting Products	3
			Credit	No Environmental Tobacco Smoke	1
0	**0**	**0**	**Innovation**		**6**
Y			Prerequisite	Preliminary Rating	Required
			Credit	Innovation	5
			Credit	LEED AP Homes	1
0	**0**	**0**	**Regional Priority**		**4**
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
			Credit	Regional Priority: Specific Credit	1
0	**0**	**0**	**TOTALS**	**Possible Points**	**110**

Table 6, LEED v4 for Homes Design and Construction Checklist, Source (USGBC 2014)

Following is a brief introduction to LEED in mentioned categories. Due to extensive guidelines published and updated by LEED periodical, the author tries to extract parts of LEED which are applicable for this dissertation.

1. SUSTAINABLE SITES

Prerequisite

For the Sustainable Sites (SS) category, LEED proposes the pathway in figure 32. The prerequisites aim at: (USGBC 2014, 20-25)

- Reduction of pollution of the construction activities by controlling soil erosion, waterway sedimentation, and airborne dust.
- Prevent the introduction of invasive plant species through landscaping

The major points are given to the following strategies:

Heat Island Reduction

At least 50% of hardscapes and roofs (excluding the common roads serving multiple buildings) on the project site are shading (by trees) (AND/OR) non-absorptive materials (light-colored, high-albedo materials or vegetation-covered hardscapes) by using paving materials with a Solar Reflector (SR) of at least 0.28, installing vegetated roofing, using open or engineered grass pavers…

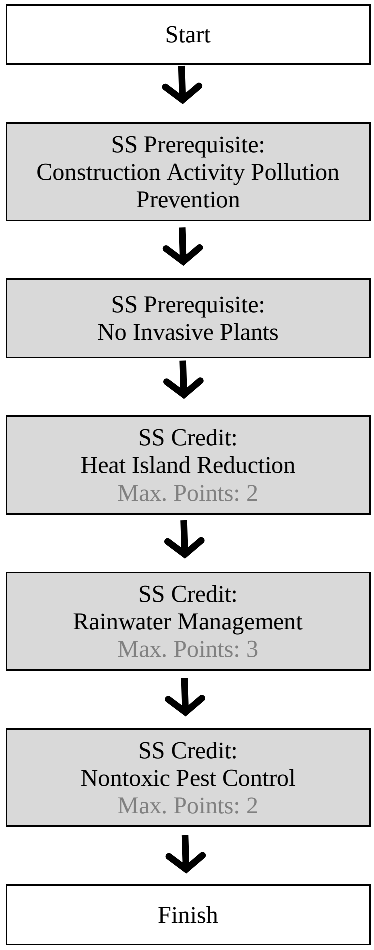


Figure 60, LEED v4 homes, Pathway through Sustainable Sites (SS) Category

Rainwater Management

To reduce rainwater runoff volume from the site through strategies such as minimizing the amount of storm-water that leaves the site Using Low Impact Development (LID) techniques such as native or adapted plant material, installation of vegetated roof, permeable paving or permanent infiltration/collection features (that can handle 100% of the run off from a two-year, 24 hour storm)

Nontoxic Pest Control

This is to minimize pest problems and risk of exposure to pesticides. The strategies aim at usage of termite control systems, treated cellulosic structural materials… and have some recommendations for below-grade walls, slabs, structural elements, the external cracks and entry points, and the minimum distance between the plantings and the building.

2. WATER EFFICIENCY

Water Efficiency category in LEED for homes and midrise aims at water consumption reduction through high-efficiency fixtures and efficient landscaping practices.

Prerequisite

The prerequisites propose monitoring and benchmarking water use over time to support water efficiency efforts. This prerequisite asks for installation of a water meter for the whole house in single family houses, and a water meter or sub-meter for each unit or the entire building in multifamily housings

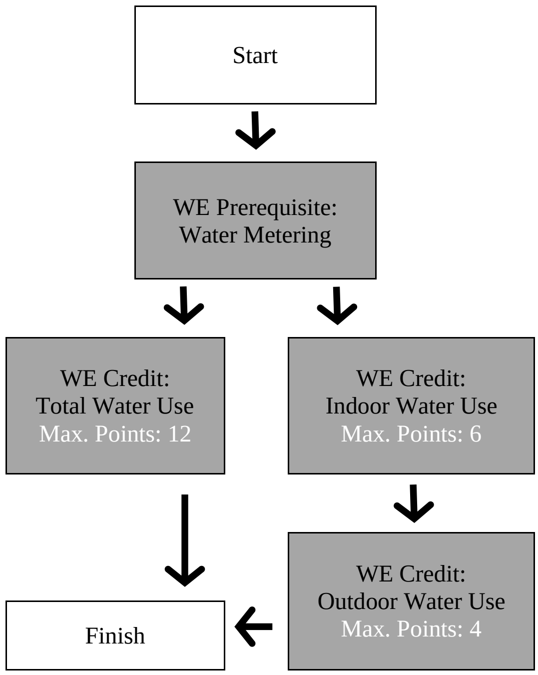


Figure 61, LEED v4 homes, Pathway through Water efficiency (WE) Category

Credits

The major credits for Water Efficiency (WE) category in LEED has some baseline standards for Total, indoor and outdoor water consumption, such as maximum indoor water pressure, or some technical strategies for reduction of landscape water use; such as smart scheduling technology, usage of captured, reclaimed or treated water.

Another requirement for reduction of outdoor water consumption reduction is to reduce the landscape area planted to turf grass by landscaping with plants that are native or adapted to the region.

Turf grass area		Native or adapted plant area	Points
< 60%	AND	> 25%	1
< 40%	AND	> 50%	2
< 20%	AND	> 75%	3
< 5%	AND	> 75%	4

Table 7, LEED WE Credit for outdoor water use, points for reducing turf grass and increasing native plantings, as percentage of total landscape area (USGBC 2013, 31)

3. ENERGY and ATMOSPHERE

For this part LEED has different credits applied for homes or midrise (or both types of) houses (USGBC 2013, 32).

Prerequisite

The prerequisite that applies to both homes and midrise houses, aims at the following strategies for Energy and Atmosphere:

- Improving overall energy performance and reduction of greenhouse gas emission
- Supporting energy efficiency efforts by over time monitoring
- Sustaining the home energy performance by training the occupants.

Going through the details for credits, this part of LEED mainly emphasizes on the performance and efficiency of the home appliances, installed equipment (for heating, cooling, humidity, ventilation …), fixtures, and duct runs (USGBC 2013, 33-37).

Credits

For the main credits (29 for homes and 30 for midrise) also the main emphasis is on improving the energy performance of the house through improvement of HVAC equipment, decreasing conditioned floor area, increasing the efficiency of hot water distribution (considering the pipe length, volume, circulation pumps…) and monitoring of energy and water use.

Home

For "Homes" LEED adds some credits such as maximizing opportunities for solar design (Photovoltaic- Ready design, or Solar Direct Hot Water- Ready design), HVAC Start Up Credentialing.

For homes also some points for improving energy efficiency by designing more impact living spaces, maximizing opportunities for solar design, avoiding air leakage, efficient envelope insulation, maximizing energy performance of windows (considering the Window-to-Floor-Area or Solar Heat Gain Coefficient in different climate zones), efficient Space Heating and Cooling Equipment, minimizing Heating and Cooling Distribution System by limiting the thermal bridges and leaks, improving the water heater efficiency, high efficiency lighting, installation of high efficiency home appliances, installation and operation of renewable electricity generation systems (USGBC 2013, 38-66).

The main references and baselines for rating and evaluation of many of these items are the protocols, guidelines and checklists of USGBC (United States Green Building Council), ENERGY STAR for Homes (ENERGY STAR Qualified Homes 2011), HERS Index

Target Procedure for National Program Requirements[13], and ASHRAE[14]. In many parts, LEED asks the users to use a USGBC approved equivalent standard for projects outside the United States which is quite confusing. Many parts are mechanical equipment based, not architectural based.

The following image shows the step by step process in LEED for calculation of the credits for homes and mid-rise houses.

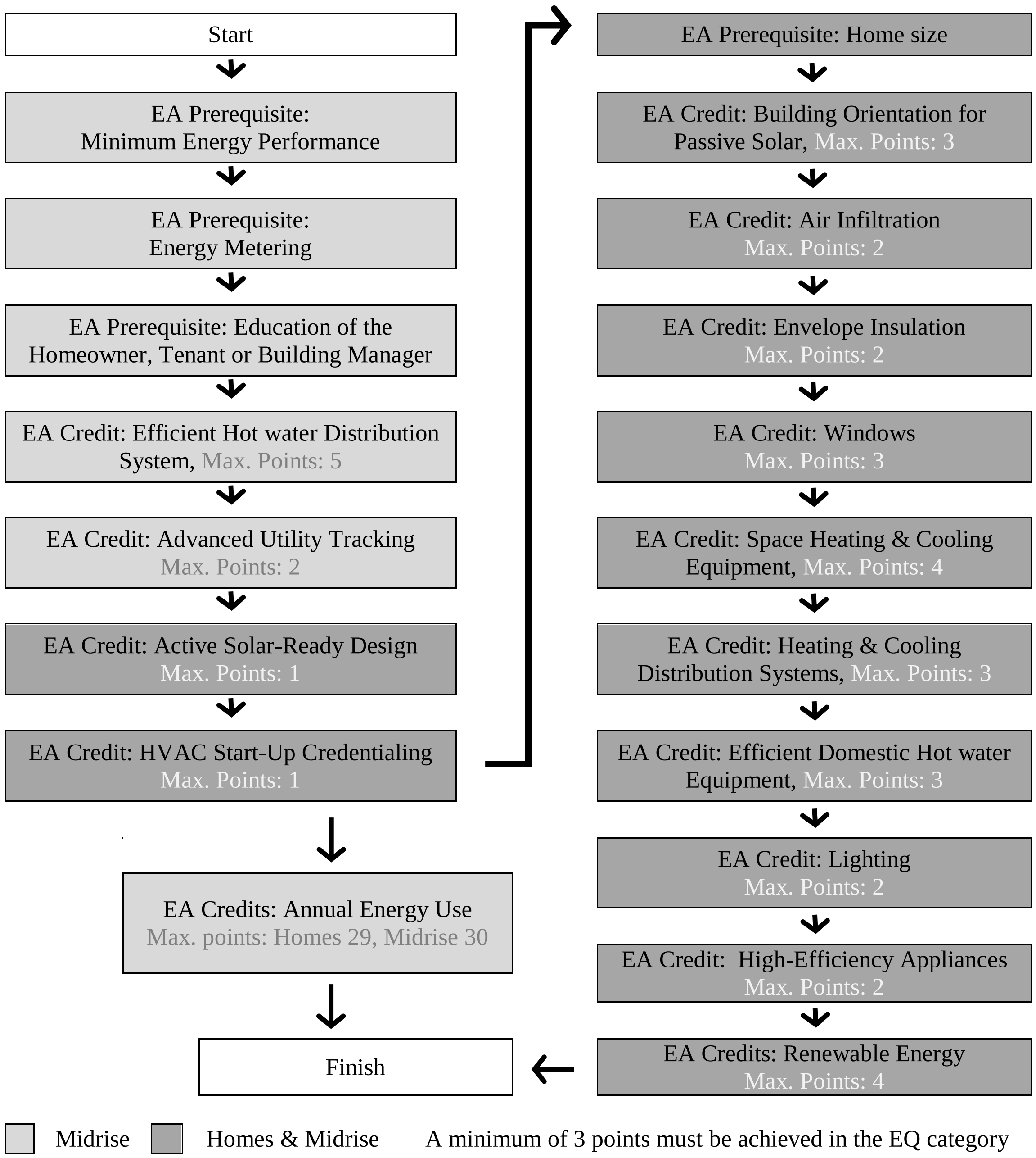


Figure 62, LEED steps for calculation of the credits of Energy and Atmosphere chapter in home and/or midrise houses. *Source* (USGBC 2013, 32)

[13]http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/V3HERS_IndexTargetProcedure.pdf accessed online on 22.08.2014

[14] https://www.ashrae.org/ accessed online on 21.08.2014

4. MATERIAL and RESOURCE

In Materials and Resources category (USGBC 2013, 66-75), LEED expresses two prerequisites for homes and midrise residential:

The first one emphasizes on usage of certified tropical wood, which is not really too functional in desert buildings, while wood is a rare material in desert areas and therefor it is not used as a building material.

The next prerequisite focuses on promotion of durability and performance of the building enclosure and its components and systems through appropriate design, materials selection and construction practices and has some recommendations for the interior moisture control measure for homes.

Likewise in its credit parts for MR category, LEED also gives 1 point for the durability management verification (through appropriate design, material selection, and construction practices).

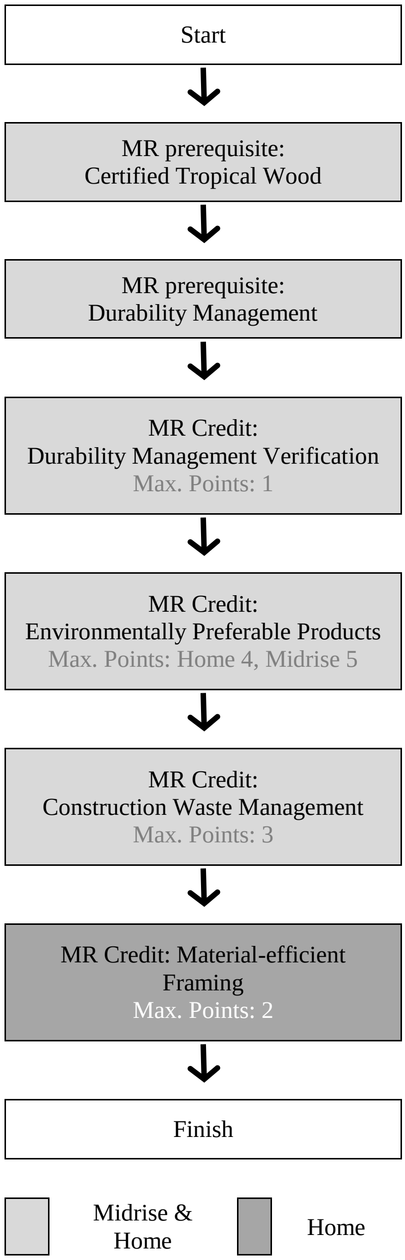


Figure 63, LEED v4 homes, Pathway through Material and Resource (MR) Category

Environmentally Preferable Materials

Aiming to increase demand for products or building materials that minimize material consumption through recycled and recyclable content, reclamation or overall reduced life-cycle materials.
There are 2 Options for earning points:

Option 1, locally extracted, processed and manufactured materials for framing, aggregate for concrete and foundation, drywall or interior sheathing. The distance for the material production from the project site is maximum 100 miles (160 km), and 50% of building component must meet the criteria.

(AND/OR) Option 2, environmentally preferable products

- at least 25% of the product is reclaimed material
- the product contains at least 25% postconsumer or 50% pre-consumer content

- certified wood products
- Bio-based products with specific standard
- concrete with at least 30%fly ash or slag as cement substitute and 50% recycled content or reclaimed aggregates OR 90% recycled content or reclaimed aggregate
- products purchased from a manufacturer with Extended Producer Responsibility

Each of the compliant building components (flooring, floor covering, insulation, sheathing, framing etc.) can earn points from only one of the above mentioned items in Option 2.

5. HEALTH AND WELLBEING

For this part, LEED proposes guidelines for prerequisites and credits for INDOOR ENVIRONMENTAL QUALITY. The main focus of LEED in this category is to define standards to protect occupants' health inside the houses.

Prerequisites

In this part LEED introduces some standards for ventilation and for reduction of occupants exposure to combustion gases, garage pollutants, radon gas, particulate matter from the air supply systems, environmental tobacco smoke and indoor pollutants.

Credits

Again the credits in EQ category go to the same intents as for prerequisites. This part defines some guidelines that mostly relate to the mechanical equipment in the house for better performance in the following categories:

- Ventilation
- Contaminant control
- Balancing of heating and cooling distribution systems
- Enhanced compartmentalization
- Combustion venting
- Enhanced garage pollutant protection
- Low emitting products
- No environmental tobacco smoke

As mentioned before, this part mostly defines baselines for mechanical equipment in the house and has little to do with the architectural design of the house.

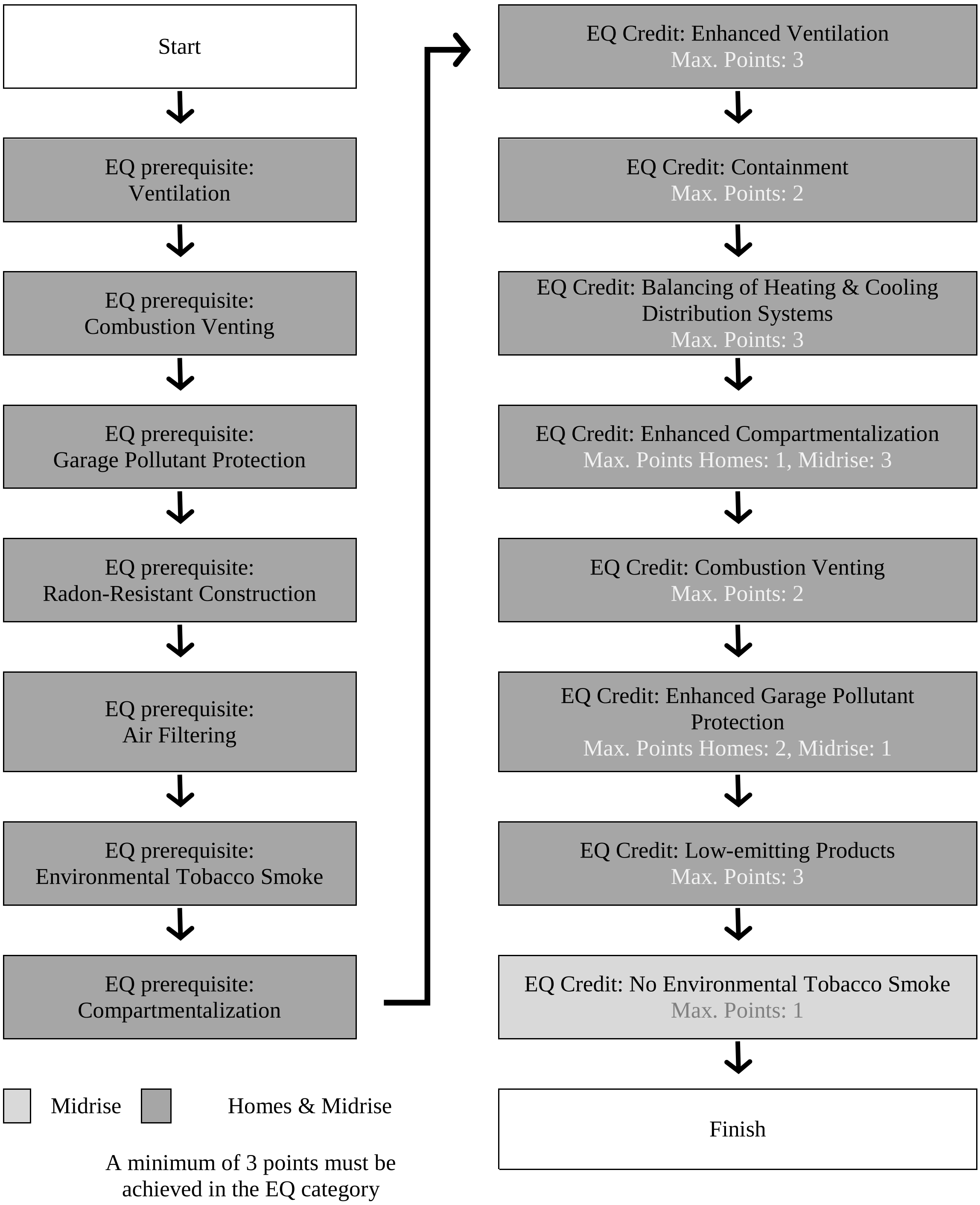


Figure 64, LEED v4 homes, Pathway through ENVIRONMENTAL QUALITY (EQ) Category

Other References

One interesting book on practical evaluation of environmental sustainability that was reviewed in this dissertation is "Strategies for Sustainable Architecture". Paola Sassi in this book also makes much the same division as LEED and other evaluation systems make in order to evaluate the selected case studies. Sassi then makes a wide range of strategies for sustainable design that are used to create the final table for evaluation of the case studies in this dissertation (Sassi 2006).

Following is a brief overview of the sustainable architecture FEATURES and STRATEGIES considered by this book:

Site and land use
Compact cities
Reducing transport impacts
In harmony with nature
Local food production

Community
Community participation
Housing for all
Training and employment
Enhancing the quality of life
Promoting sustainability

Health and wellbeing
Comfort
Insensible agents of disease
Identity and independence
Restorative environments

Energy
Minimizing energy needs
Using energy efficiently
'Green' energy sources

Water
Minimizing need and maximizing efficiency
Alternative water sources
Reducing the use of mains drains

Material
Design for longevity
Waste as a resource
Avoiding resources depletion
Minimizing manufacturing impact
Materials and energy

SUMMARY and CONCLUSION

In this chapter, the author focuses on finding out the features that are important to assess how far an architectural design (residential) is sustainable.

For this purpose, the author first tries to choose the most relevant sustainability evaluation system among the existing (LEED), and then has a glance to its categories.

As mentioned before, this dissertation does not aim to issue credits or certify sample houses by existing evaluation systems and certifications but tries to learn and extract features from these systems to find out how sustainability comes along with specific strategies in architectural design.

While LEED evaluation system makes a much ascertained way to go through evaluation, but in giving points, many of its parts focus on improving performance of mechanical equipment that improves overall performance of the building (in terms of energy, water, wellbeing….) and reduces its emissions and environmental pollution.

Therefor the main reason to overview these existing evaluation tools and systems is to find out features of architectural design that affect sustainability levels in houses.

The following three aspects of sustainability evaluation is taken into consideration:

1. The existing evaluation tools worldwide for sustainability performance in houses.

These evaluation systems evaluate buildings in different categories and issue certifications for the building due to the credits achieved by the buildings.

2. Other references for definition of the rate of sustainability in buildings.

Since this research does not aim at certification of buildings in terms of sustainability performance, but aims at finding out how architectural design strategies improve the sustainable performance of building, parallel with overviewing the sustainability tools (item 1), the author tries to learn from the practical experiences in architectural design projects that improve the sustainable performance of buildings.

3. Important features in performance of buildings in hot and arid region.

After all, since the case studies are located in hot and arid climatic zone, some features of the evaluation tool are removed, added or replaced with more important features due to climatic priority

The final outcome of this chapter is to bring out different features to evaluate the rate of sustainability in houses and show how far architectural design can affect the performance of the buildings.

After all, the author proposes the following table of sustainability features and the related strategies for each category to be surveyed in the sample houses in Yazd, Iran.

SUSTAINABLE DESIGN		
FEATURES		STRATEGIES
1. WATER	W1. Passive Water Supply System	Use passive water systems, Minimize the energy for providing water
	W2. Alternative Water Sources	Qanāts, Cisterns
2. ENERGY	E1. ‘Green’ Energy Sources	Wind and sun
	E2. Minimizing Energy Needs	Optimal shading in summer and winter; Natural heating; greatest solar gain in winter; Best natural ventilation and passive cooling
	E3. Minimizing Energy Exchange	Geothermal heating; Glazing; Compact neighborhood; Thermal mass;
3. GROUND & LAND-USE	GL1. Land Use (footprint)	Open, semi open and closed spaces
	GL2. Effective Green Area	Location of vegetation in the house
	GL3. Avoid Deforestation	Avoid resource depletion: forest ecosystems and deforestation
4. MATERIAL	MR1. Plentiful Material	Local materials: adobe, mud brick
	MR2. Low Emitting Materials	Earthen construction materials, e.g. clay, cob, adobe, and unfired clay bricks
5. HEALTH & WELL-BEING	HW1. Safety	Earthquake
	HW2. Comfort	Identity and independence: accessible and lifetime homes; Sound insulation
	HW3. Health	Access to fresh air; Purifying air with plants;

Table 8, proposed features of sustainability retrieved from different sources for evaluation of case studies

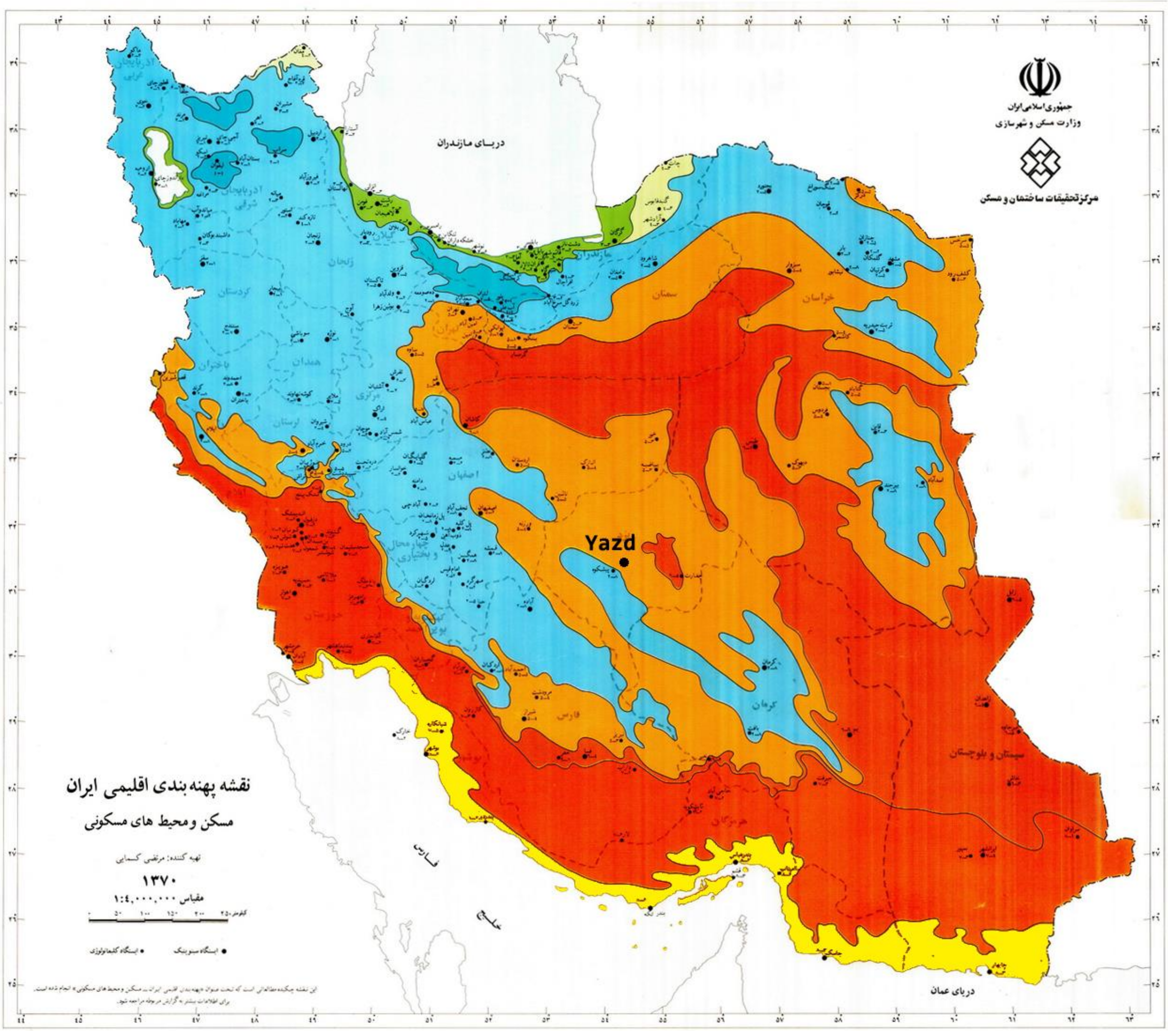


Figure 65, Map of climatic zones of Iran, by Morteza Kasmaei, 1991, hot and arid to semi-arid area in orange and red (Kasmaiee, Map of Climatic Zones of Iran 1991)

Within the extensive borders of the hot and (semi) arid region in Iran (the orange and red colors on the above map), the city of Yazd serves as the focus of this dissertation and is the target city of this research due to the following considerations:

- The historical city of Yazd is still standing as an integrated living organism, responding to modern living norms, while still maintaining its traditional elements. In contrast, many other historical cities in Iran have undertaken radical physical changes toward modernization in recent decades.
- Yazd is home to a large collection of architecture and urban elements from different time periods in a harmonious relationship with climatic conditions (UNESCO 2007).
- Considering that the geographical location of Yazd is near the central deserts of Iran, this city sets a good example that may be extended to other desert cities, even in

neighboring countries. It has a challenging desert climate, and its architecture has created enough elements in response to these environmental and climatic extremes during history.

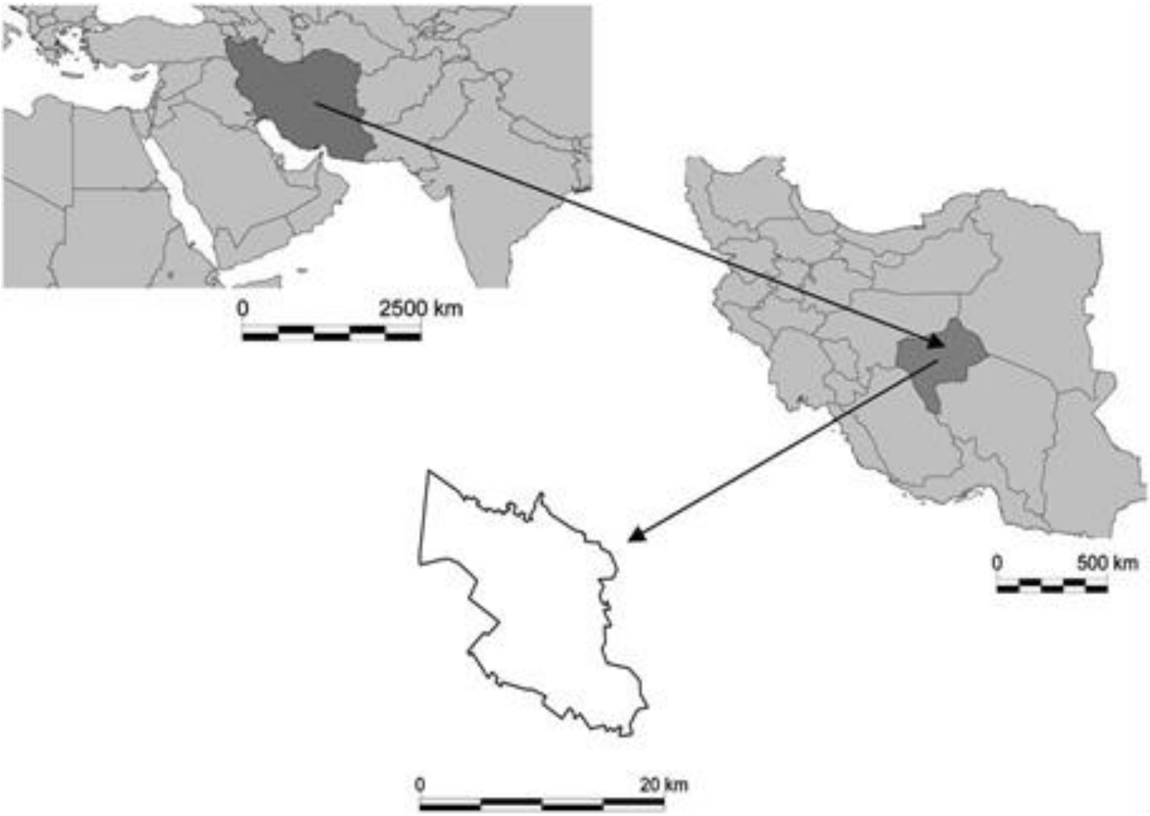


Figure 66, City of Yazd, Yazd province, Iran, source (Zangeneh Shahraki, et al. 2011, 523)

5.2. Case Study Buildings

This dissertation focuses on a selection of case studies that provide enough input for understanding the design strategies for the climatic conditions in Yazd.

Therefore, the author first attempts to specify a typology of houses centered on the climatic and environmental oriented approaches, and then select case studies from among every type.

For making a better assessment of sustainable criteria in traditional case studies, case studies from contemporary architecture in Iran will be selected as well.

The approach of selecting contemporary case studies aims to provide data from among all types of contemporary residential buildings in Yazd. One house type from each category is chosen, as the other houses within each category share the same noteworthy features.

5.3. Building Functions

In terms of building function and usage, traditional buildings in Yazd once served a variety of usages such as the following:

Function	Persian Name	Short description
Bath-house	*Hammam, Garmāba*	Public bath
Bazar	*Bāzār*	A unified, self-contained building complex of shops, passageways, and caravanserais, interspersed with squares, religious buildings, bathhouses, and other public institutions.
Caravanserai	*Kārvān-sarā*	A building that served as the inn of the Orient, providing accommodation for commercial, pilgrim, postal, and especially official travelers.
Castel	*Qal'eh*	tower, castle, or fortress
Cistern	*Āb-anbār*	Water reservoir with roofed underground access to Qanat water stream
City Fortress	*Arg, Ark*	the inner fortress or citadel of a walled city
Garden	*Baaq*	Garden including local trees and water pools and a building
House (Mansion)	*Khāneh*	a complete unit for one or more families to live in
Ice pit/ Ice container	*Yaḵčāl/ Yaḵdān*	A building for storing blocks of ice or, very rarely, compressed snow, which are collected in the winter for use in the summer.
Madrasa	*Madreseh*	Religious school + living rooms for students
Mosques	*Masjed*	A place for saying gods prayer 3 times a day
Plaza	*Meydān*	An open air square, usually used for gathering
Qanat	*Qanāt,Kārēz*	earliest irrigation system in Iran
Shrine	*Emam-zadeh*	shrine believed to be the tomb of a descendent of a Shiʿite Imam
Tek-yeh	*Tek-yeh, Hosayniya*	Buildings specifically designed to serve as venues for Moḥarram ceremonies commemorating the martyrdom of Ḥosayn b. ʿAli.
Tomb	*Boqʿa*	The mausoleum of a sacred or revered personage, sometimes taken to include additional structures adjoining the tomb or the open space surrounding it.
Water Mill	*Āsīāb, Āsīā*	Traditionally powered mills, principally watermills (āsīāb) to process corns to produce flour for the staple in the Iranian diet, bread
Zoroastrians (Fire)Temple	*Ma'bad-e Zartoshtian*	The holy place for Zoroastrians to worship and keep the holy fire

Table 9, traditional building types in Yazd due to function

Some of these mentioned types of buildings, such as cisterns or ice pits, have specific forms, spaces, and elements designed for their specific function. Popular types of spaces designated for people's daily living, such as houses, mosques, and madrasas, have many common patterns in response to climatic conditions.

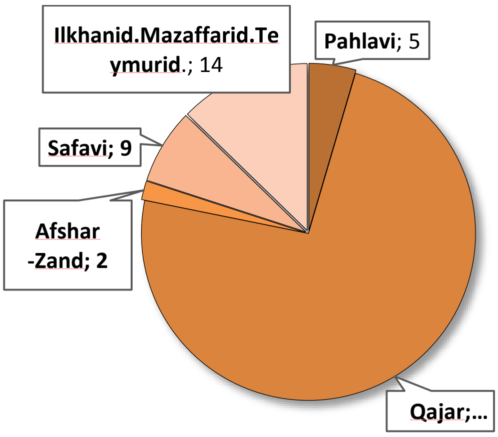
This research focuses on housing function as the most important function in daily living, and therefore the most complete patterns to achieve sustainability.

Finally, investigations will be undertaken to choose a reasonable selection of efficient case studies from among the existing historical houses in Yazd.

5.4. Study on Types and Categories of Historical Houses in Yazd

As mentioned before, in order to select case studies that aim to provide sufficient input and resources for the typical traditional architecture, the author first searches for a typology of houses centered on climatic design considerations.

A categorization of the 110 existing historical houses registered on the National Heritage List (YCHHTO 2013) reveals the following information:



Achaemenian	533 - 330 BCE	
Seleucidian	330 - 247 BCE	
Parthian	247 BC. - 224 AD	
Sassanid	224 - 651 CE	
Arab Invasion	645 CE	
Omavian and Abbasian	749 - 932 CE	
Saffarian	866 - 903 CE	
Samanian	819 - 999 CE	
Al Bouyeh	945 - 1055 CE	
Qaznavian	977 - 1186 CE	
Seljukian	1038 - 1194 CE	
Kharazmshahian	1077 - 1231 CE	
Mongol invasion to Iran	1220 CE	
Eilkhanian	1256 - 1353 CE	14
Mozaffarian	1314 - 1393 CE	
Teymurids	1370 - 1506 CE	
Turkamens	1380 - 1468 CE	
Safavid	1501 - 1732 CE	9
Afsharian	1734 - 1796 CE	2
Zandian	1750 - 1794 CE	
Qajar	1779 - 1924 CE	80
Pahlavi	1924 - 1979 CE	5
The Islamic Revolution	1979 CE	

Table 10 and Chart 4, number of 110 historical houses in Yazd due to date of construction, source (YCHHTO 2013)

The investigation demonstrates that most of the existing historical houses in Yazd date back to the Qajar period (18th – 20th century AD). The oldest existing house in Yazd dates back to the 13th century AD.

Investigations on architectural design of these historical houses reveal two major types of layout in:

- Houses belonging to 13th to 15th century AD (Ilkhanid, Mozaffarid and Teymurid dynasties)
- Houses belonging to 16th to 20th centuries AD (Safavid- Qajar dynasty)

This division matches the different historical layers of the urban fabric in Yazd as well. As Tavassoli mentions in his book (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002, 27), in the urban fabric of Yazd, three major zones are distinguishable:

- Historical core of the city dating back to pre-15th century
- Historical urban fabric including the city before the beginning of Pahlavi era in 1920.
- Outer contemporary urban fabric

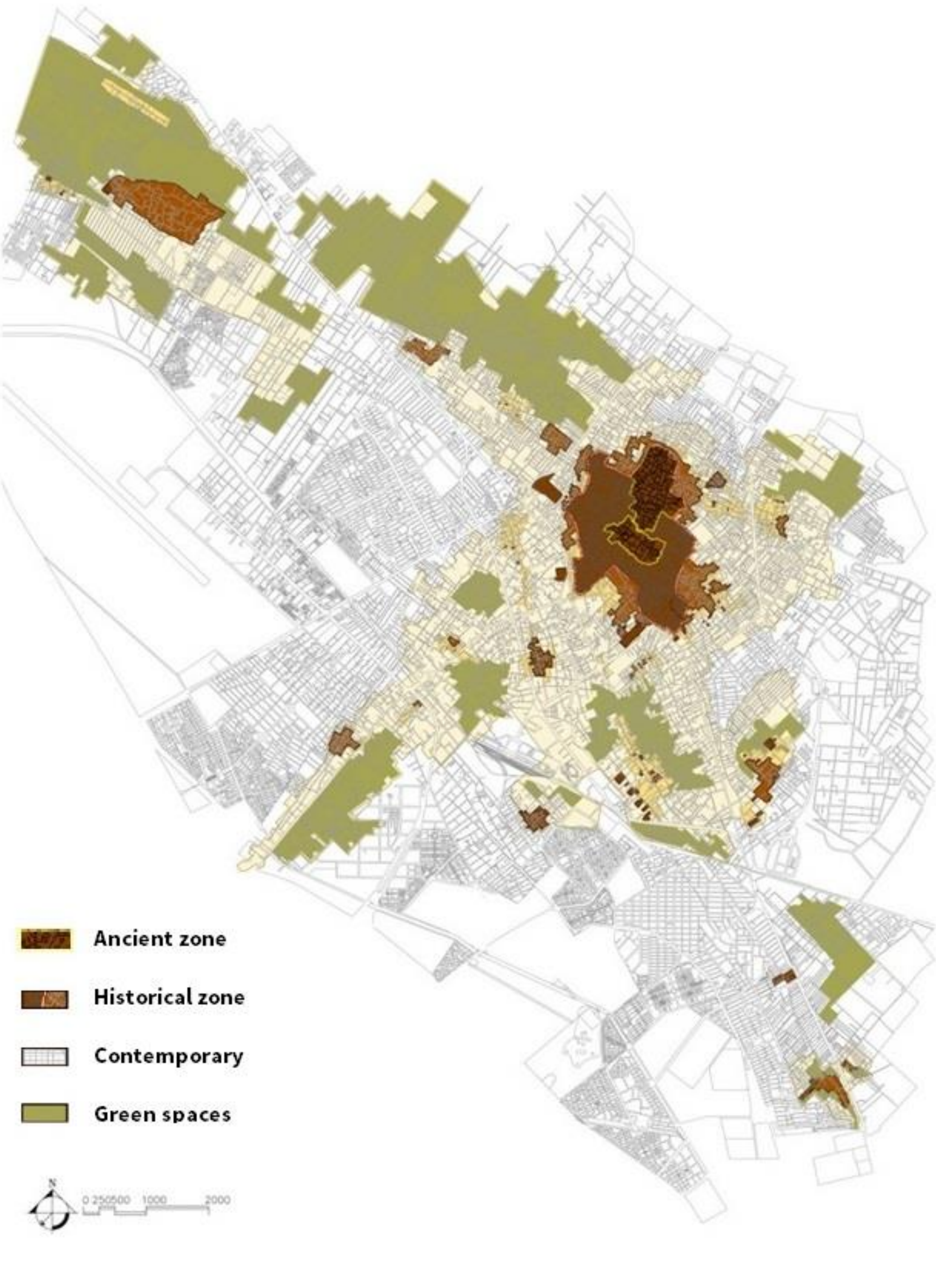


Figure 67, City of Yazd and its historical and contemporary zones. Source: (YCHHTO 2013)

i. 13th to 15th Century AD

The city of Yazd has a unique position in Iran in terms of number of buildings dating back to pre-Safavid period (Khademzadeh, Oloumi and Alvandian 2008, 201).

The historical houses in Yazd that date back to Ilkhanid, Mozaffarid and Teymurid dynasties share architectural design similarities. These are mud-brick houses with central courtyards. However many of these 600 to 800 year old houses in Yazd are in poor condition and have been abandoned and destructed. Some are the residents of Afghan migrants or low-income families. Following are some samples of these historical houses in Yazd.

Karimi House

The Karimi house in Yazd dates back to the Mozaffarid era (14th century AD). It is located in the Abolmaali district, with a Northeast to Southwest orientation at 26° due Southwest.

This house consists of a small courtyard and a high Eivan on the southwest side of the courtyard. This high eivan connects the house to the southern garden. Other rooms are located around these two spaces. Two one-level high Eivans on the Northeast and Northwest also support the back spaces with fresh air.

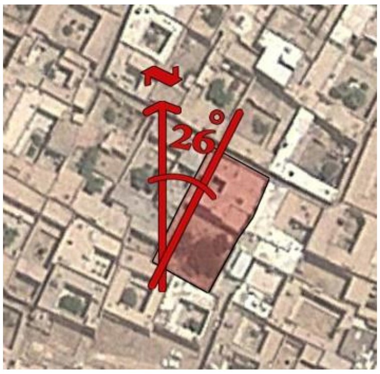


Figure 68, orientation of Karimi house on the aerial map

Figure 69, left to right: central courtyard, southern high Eivan, southern garden, Karimi house present situation, source: (YCHHTO 2013)

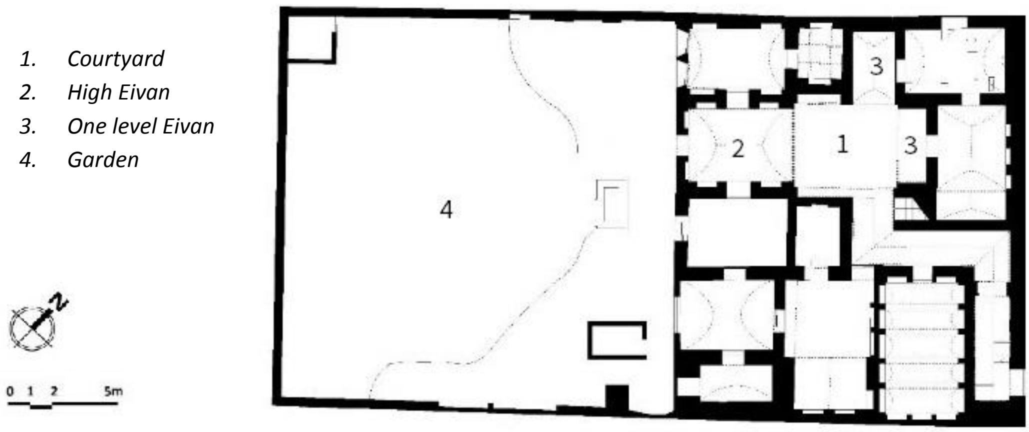


Figure 70, Karimi house ground floor plan, source: (YCHHTO 2013)

As illustrated in the plan, the *Eivan* plays an efficient role due to its location between the open and closed spaces, as well as its dimensions. The following section (figure…) also shows how this system of a central courtyard, *Eivan,* and garden creates a system of natural ventilation in the Karimi house.

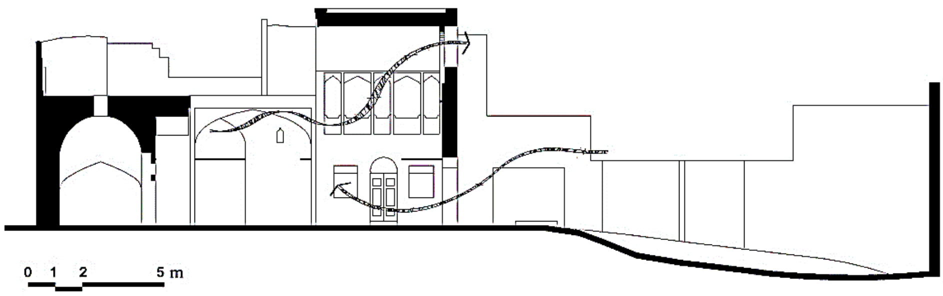


Figure 71, Karimi house section, the openings for better circulation of fresh air, base section from (YCHHTO 2013)

Momtaz House

The Momtaz house in the Abolmaali district of Yazd also dates back to the Mozaffarid era (14th century AD) and follows the common layout of the Mozaffarid houses in Yazd. Eivan serves as the main space of the house, distinguished by its dimensions and height. The following figures outline this house.

Figure 72, orientation of Momtaz house 24° due southwest

Figure 73, Momtaz house, Yazd, source (YCHHTO 2013)

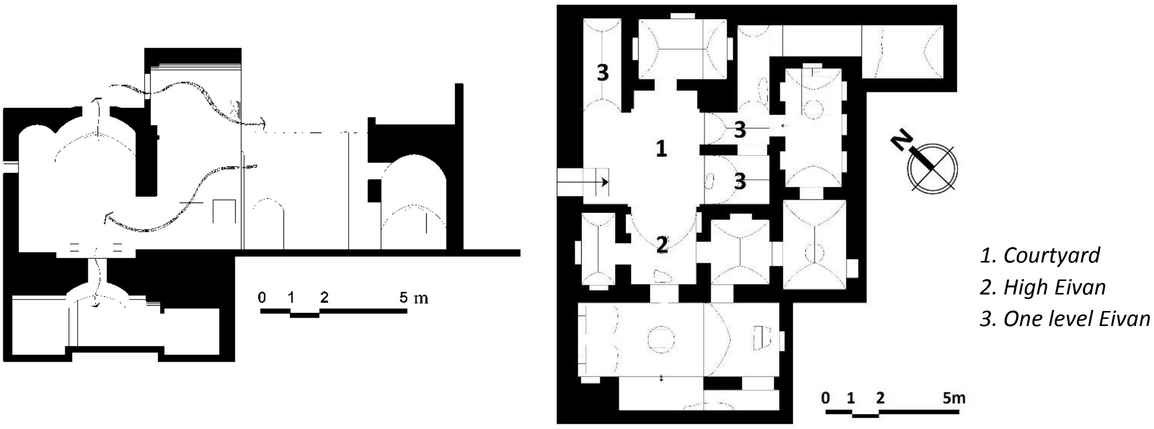


Figure 74, Momtaz house, plan and section, source (YCHHTO 2013)

This system, comprising of a high Eivan facing a small central courtyard, as the focal point for organizing the spaces of the house, is a typical characteristic of the 600 to 800 year old houses in Yazd.

The following are more examples of this spatial order.

Hosseinyan House

One of the oldest houses in Yazd (Kateb 1965) is the Hosseinyan house, and it is a part of a larger complex in the Fahadan district.

Figure 75, Hosseinyan house, source: (YCHHTO 2013)

The 15 meter high *Eivan* (Khademzadeh, Oloumi and Alvandian 2008) is located in the Northern side of the courtyard.

Figure 76, Hosseinian house in Yazd, Northern Eivan; source: (YCHHTO 2013)

SUMMARY

A short review of the plan and arrangement of spaces in these houses reveals that the major spatial concept in these mud-brick houses, which are mostly oriented towards Qibla (Southwest), is a small central courtyard with a very high vaulted roof Eivan that is open on its side facing the courtyard.

This Eivan, mostly located in the south and facing north, plays the role of circulating the air into the house.

Other spaces are located around this central element (Eivan) and are connected to it with openings that are supplied with fresh air ventilation. Sometimes rooms around the courtyard have direct access to the air.

Schematic plan in figure 60 shows how the high Eivans in Ilkhanid, Mozaffarid and Teymurid houses in Yazd organizes the other spaces in the house.

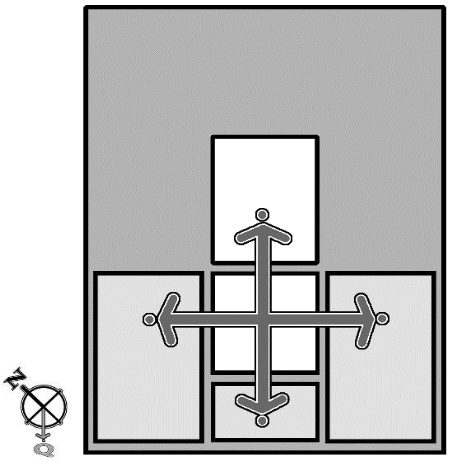


Figure 77, two types of spatial arrangement in ancient houses in Yazd, drawing by author

ii. 16th to 20th Centuries AD (Safavid- Qajar Dynasty)

One division of typology of these houses in Yazd is implied by Memarian. He distinguishes two major categories:

A. Houses with one central courtyard
B. Hoses with multiple inner courtyards

Due to this division, houses with one courtyard are again divided into sub-categories according to the number of rooms on the southern side of the courtyard (Memarian, Introduction to the Residential Architecture of Iran 1996, 296).
Other typologies can additionally be identified for these houses. Due to the presence and importance of the inner courtyard in these houses as an organizing element, one of the divisions is due to the layout of the spaces around central courtyard. The rooms can lie on one, two, three, or four sides of the central courtyard. This actually depends on the size of the land where the house is built.

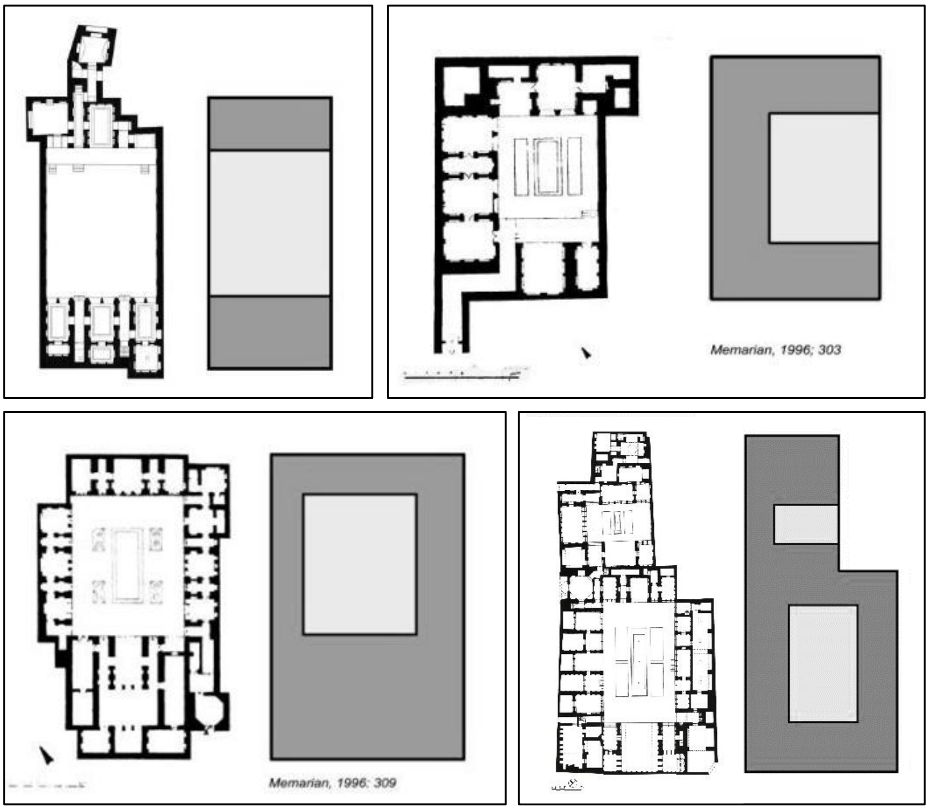


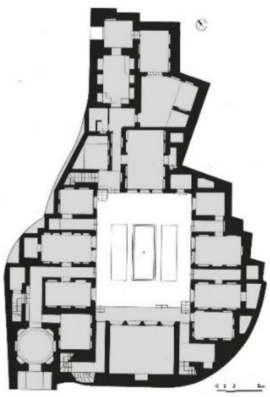
Figure 78, Categorizations of houses in Yazd due to mass and void spaces, source (Memarian, Introduction to the Residential Architecture of Iran 1996) and author

As mentioned above, different typological divisions can be made due to the interaction of the central courtyards and the surrounding rooms. But the important point to note is that all of these organizational types of houses follow the same design patterns, largely based on climatic considerations.

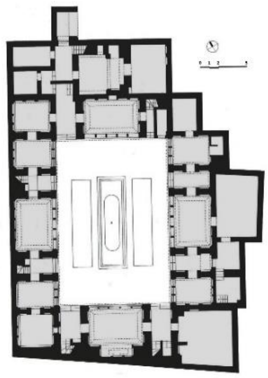
At a broad glance, the central courtyard is the main element that is common in all these houses. Some of these houses, such as Mashrouteh, Shafipour, Semsar, have only one courtyard that organizes the whole ensemble. Others have a main courtyard and some additional courtyards to provide access to natural light and fresh air for the back spaces, such as the Akhavan Sigari or Rohanian houses. The following are some samples of houses in Yazd.

1. Houses with One Central Courtyard as the Main Organizing Element

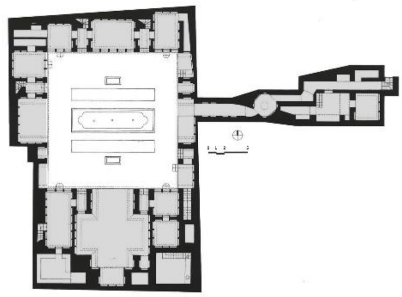
Below are some samples of Yazd traditional houses (16th-20th cent. AD) with one central courtyard:



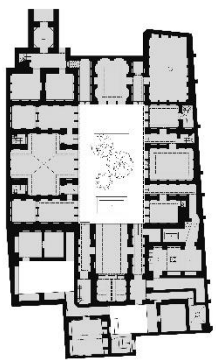
Mashrouteh



Shafipour

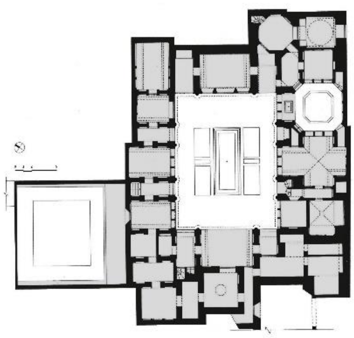


Semsār



Tehrāni

Akhavān Sigāri



Rohāniān

Figure 79, some historical houses in Yazd with one main courtyards, source: (Haji-Qassemi, Harirchi and Qelichkhani 2005)

2. Houses with Multiple Courtyards as Organizing Elements

These houses are a combination of two or more houses (normally belonging to different family members) or houses with *Andarouni* (inner spaces for the private use of family members) and *Birouni* (exterior spaces for non-family-member guests). Each zone therefore has its own courtyard, due to cultural and religious privacy in Iran.

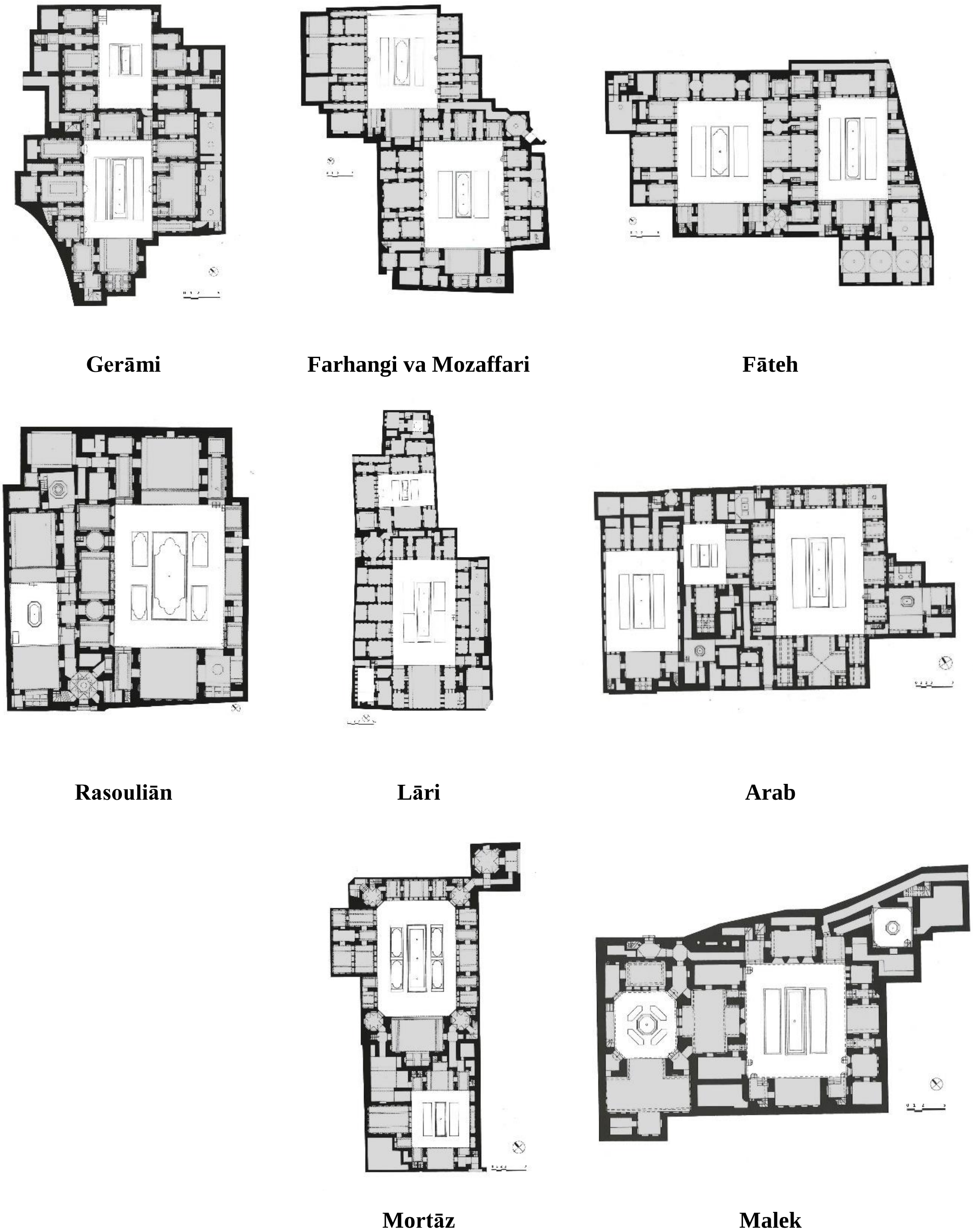


Figure 80, samples of historical houses in Yazd with several courtyards, source (Haji-Qassemi, Harirchi and Qelichkhani 2005)

3. Houses with Two Level Courtyards (Godal-Baqche)

These courtyards provide multilevel open space on different floors. Typically, they are more common in the city of Kashan, but they exist in Yazd as well. An example of such a house in Yazd is the Oloumi house.

Although they can be a subcategory of type 1 or 2, due to important advantages gained from this kind of multi-level courtyard, they are mentioned here as a separate category.

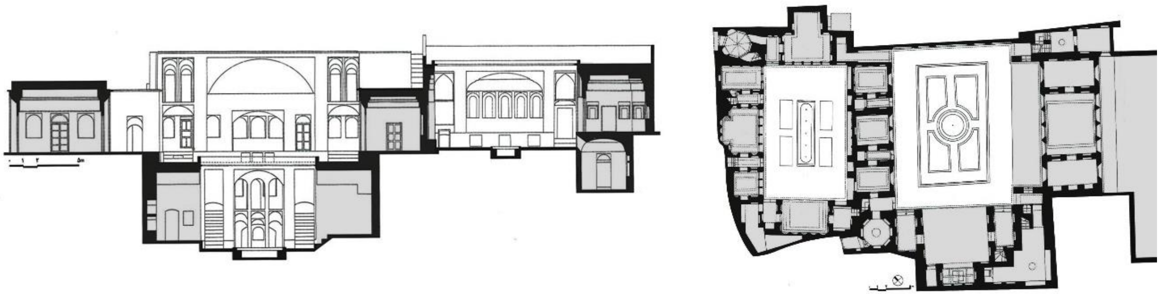


Figure 81, plan and section of Oloumi house with two level courtyard, Section and plan differ on scale, source: (Haji-Qassemi, Harirchi and Qelichkhani 2005, 104-111)

Common Design Concept

All three defined categories of houses mentioned previously (houses with one or several courtyards or with a two story courtyard), share similarities in plan layout.

As mentioned before, central courtyard serves a primary role of organizing the other spaces. This role of ordering spaces with a central courtyard in latter historical periods (Safavid to Qajar) is so strong that even in unplanned lands, a symmetric central courtyard outlines a mostly symmetric geometry that may be perceived from an observer inside the house and courtyard (Figure 82).

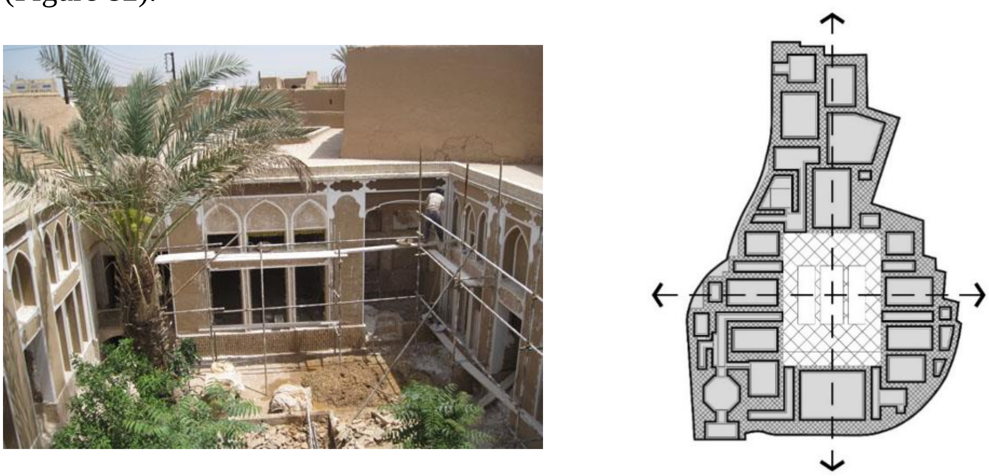


Figure 82, Mashrouteh house, Yazd, schematic plan by author, base plan (Haji-Qassemi, Harirchi and Qelichkhani 2005, 168), Photo from (YCHHTO 2013)

Thus, the symmetric organizational role of the central courtyard as the main ordering element in the house is sharply observed, even in houses with unplanned land.

This once again demonstrates the importance of the central courtyard in these historical houses in Yazd as the main element in the house.

RESULT

In spite of different approaches in defining typology for historical houses in Yazd, this research chooses categorization of houses regarding types of central courtyards, according to the importance of central courtyard as the main element in organization of the house.

A closer look at the plans of the historical sample houses reveals interesting common organizational principles of spaces around the courtyard.

This common pattern is due to climatic conditions in Yazd:

- The main orientation of the house and courtyard is due Southwest (Yazd Ron)
- Winter spaces face the sun and are located on the Northeast and Northwest sides of courtyard
- Summer spaces face opposite the sun, located on the Southeast and Southwest sides of courtyard. Summer space includes an open Eivan, mostly with one or two wind catchers at the back or beside Eivan.
- Corners are usually used for functions that do not need much natural light or access to fresh air

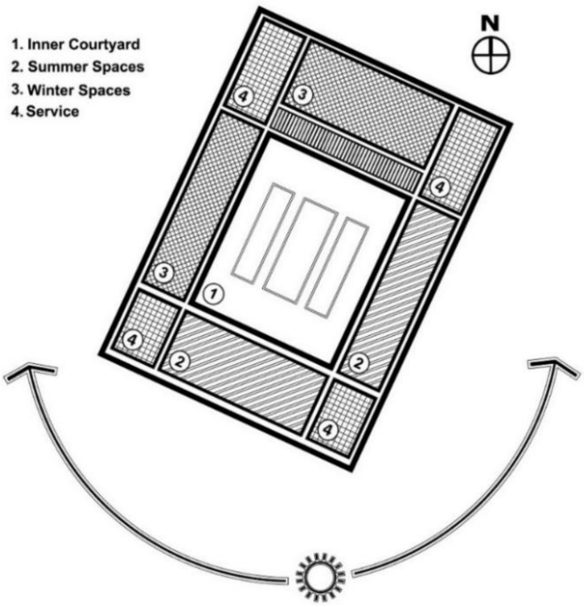


Figure 83, common layout of historical houses in Yazd being organized by central courtyard upon climatic considerations, drawing by author

This seasonal usage of space in these traditional houses with central courtyards leads to better performance of the microclimate (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002, 102) (see Chapter E1.B, page 108). This common pattern in these so-called "four season houses" in Yazd are oriented due southwest. The inhabitants use the sun-facing spaces in the Northeast and Northwest in cold winter times and benefit from exposure to the sun's rays. In summer time, they live in the Southeast and Southwest spaces, which are oriented opposite to the sun.

Figure 84, aerial view of the historical urban fabric in Yazd: courtyards are mostly oriented due southwest, image from (YCHHTO 2013)

The following figure illustrates the allocation of spaces around the central courtyard for winter or summer spaces in three historical houses in Yazd. The service spaces such as kitchen, bath, etc. are located on the corners, where the central courtyard does not provide sufficient natural light or ventilation.

Figure 85, Left to right: plans of Oloumi, Tehrani and Lari houses in Yazd, with their due Southwest orientation, central courtyards and location of winter and summer spaces around the central courtyard, drawing by author

REVIEW

In historical houses from 13th to 15th cen. AD, the high Eivān is the main organizing element in the house due to its function, height, and dimensions. It operates together with a small central courtyard in front, and sometimes a small garden in the back (Khademzadeh, Oloumi and Alvandian 2008, 210). This is in response to climatic conditions. The high Eivān conducts fresh air or wind from outside upper air in cooperation with the central courtyard. Other spaces are designed around this focal element.

Later in 16th to 20th century architecture, wind catchers were invented and included in the house as a more advanced form of the earlier high Eivans. Their function was to catch and conduct wind and to provide the house with passive ventilation.

In this period, central courtyards become the main element in the house and organize the surrounding spaces (Khademzadeh, Oloumi and Alvandian 2008, 278).

For a selection of case studies among historical houses, this research focuses on historical houses dating back to the latter period (16th – 20th cen. AD) because of the following:

- The former houses (13th – 15th cen. AD) have mostly changed during next periods or are in poor condition. Thus, finding the original designs of most of these houses is not possible.
- The more important reason is that this pattern uses a high Eivan to catch the wind and circulate it through the rooms in the former houses. Later this becomes the base point for the advent of wind catchers in next centuries (16th - 20th Cen. AD; Safavid and Qajar period).

The significance of this is that the former houses demonstrate an elementary design approach toward climatic considerations that evolves and improves in latter periods. Therefore, the latter period housings are richer in terms of spatial qualities and development of architectural elements considering the climate.

RESULT

The selection of case studies from the Safavid to Qajar period houses will provide more efficient data in contribution to climatic design approaches and environmental sustainability.

5.5. Selected Case Studies

i. Historical Case Studies

The 16th to 20th centuries AD houses share common spatial patterns, therefore only one sample case study per each category is selected in this dissertation. Three sample houses are selected. Each house is a typical representation of one of the types of houses defined previously.

They are selected from among mostly well-preserved historical houses in Yazd, many of which are registered in the national heritage list and now serve public functions for the sake of better preservation. The selected historical case studies in this dissertation are

- **Lari house**; with one wind catcher and different central courtyards (*Andaruni*: private zone, and *Biruni*: public zone in the house).
- **Oloumi house**; with two-level central courtyard (sunken courtyard)
- **Tehrani house**, with one wind catcher and one central courtyard, serving as a private hotel and a museum at present.

Lari House

Lari house is located in the Fahadan district in the historical zone of Yazd. The Youzdaran passageway provides the access to the house.

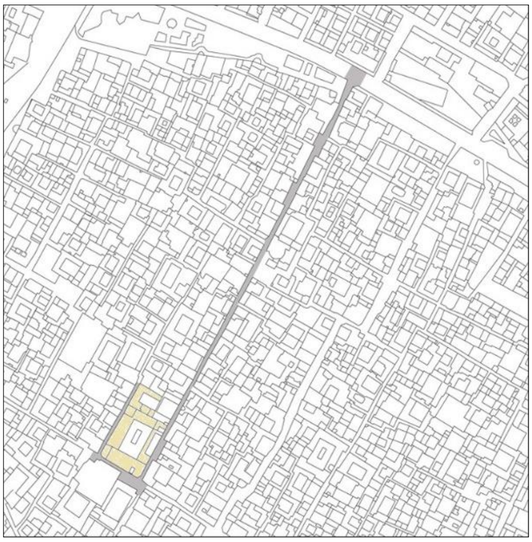


Figure 86, Lariha location and access in Fahadan historical district urban fabric, drawing by author, base map (YCHHTO 2013)

This house was commissioned some 140 years ago by the patriarch of the Lari-ha family in Yazd and several generations of his descendants have lived in it. This building serves as the office for the Iran Cultural Heritage Organization in Yazd since 1984.

A large and a small courtyard together with a collection of *Eivans*, reception halls and rooms, a portico and an entrance vestibule are the main constituent elements of this house. The entrance vestibule is located between the two courtyards and has equal access to both.

Some the service areas such as stables, kitchen or storage spaces have their own separate exterior access.

The house also includes a separate part at its northeastern corner including a small courtyard and a room, with its independent exterior door.

The *Sardābs* and storage areas of the house are located underground, scattered and separated from one another. They do not form a distinct floor, but each of them is connected to its above area via stairways.

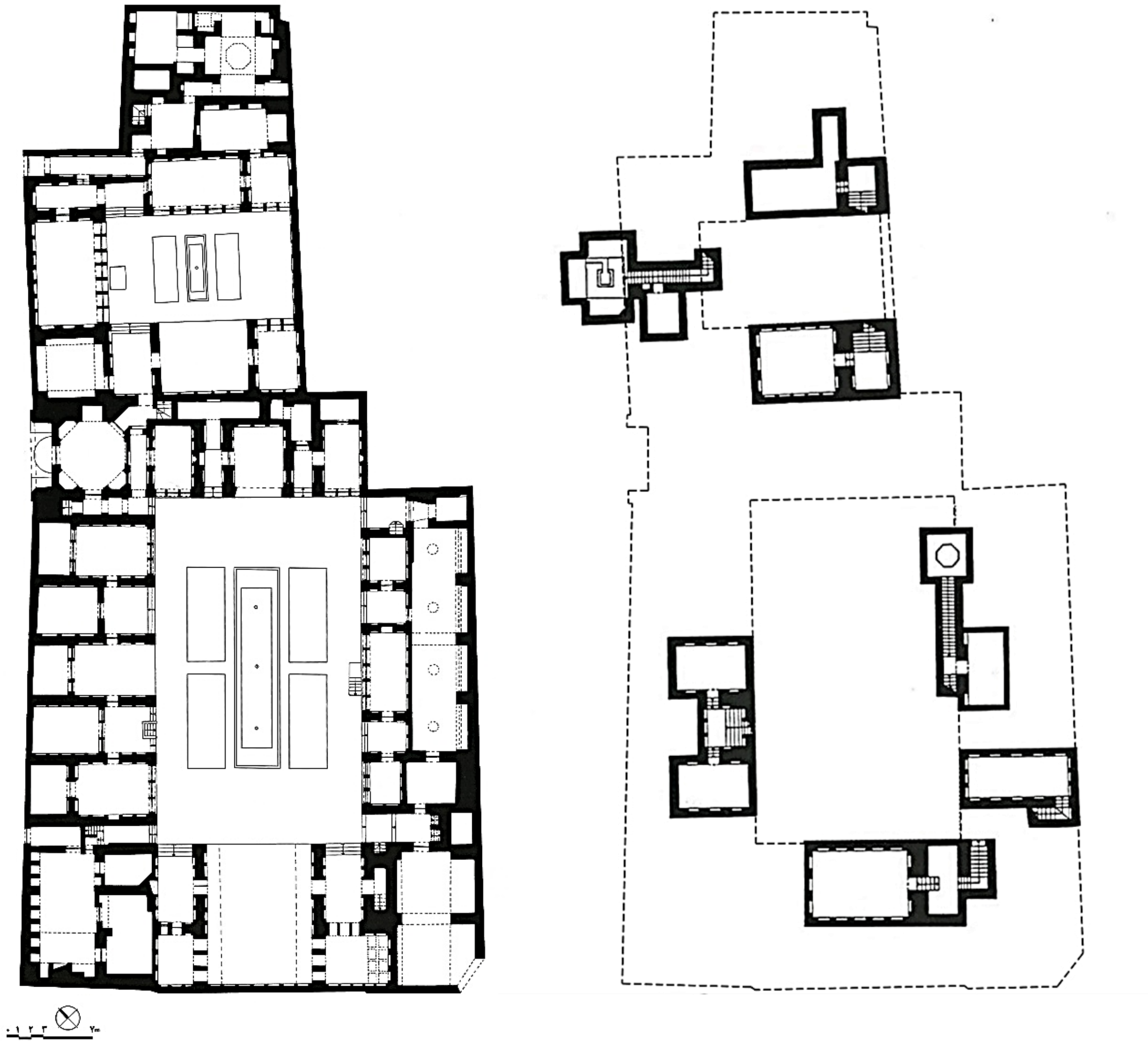


Figure 87, Ground floor plan and basement plan for Lari house, source: (Haji-Qassemi, Harirchi and Qelichkhani 2005, 58)

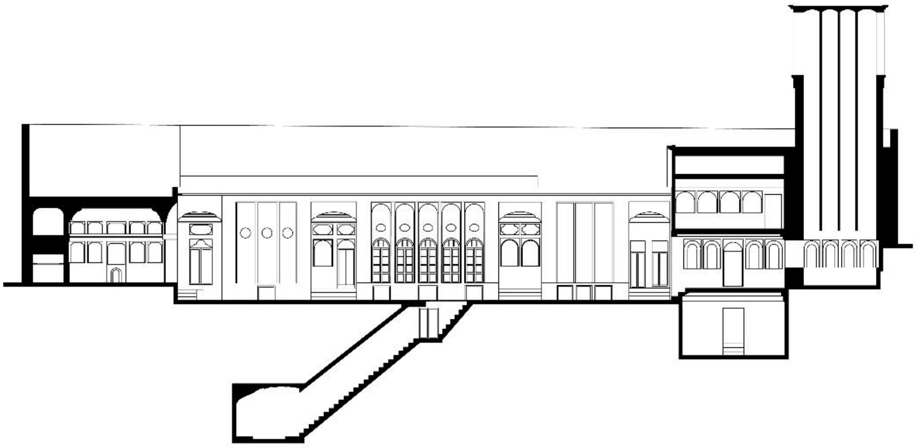


Figure 88, Section through courtyard, Payab and wind catcher for Lari house, source: (Haji-Qassemi, Harirchi and Qelichkhani 2005)

The main courtyard is rectangular, on northeast to southwest axis, with the *Eivans*, reception halls and rooms around it. The service areas are located in the corners, behind the rooms, without direct view to the courtyard.

The most significant and dominant element in this large courtyard is a tall *Eivan* standing at the center of the southwestern side of the courtyard. This large semi-open space has a determining effect on the courtyard's spatial quality, and is taller from the other three sides of the courtyard. The great height and the wide opening of this *Eivan* creates the impression that the courtyard extends into the *Eivan*.

Behind this *Eivan*, there is a tall wind catcher which is visible from within the courtyard and is, unusually, located at the corner of the *Eivan* rather than on its main axis. Other sides of the courtyard consist of small *Eivanchehs* and *She-Dari* and *Panj-Daris*.

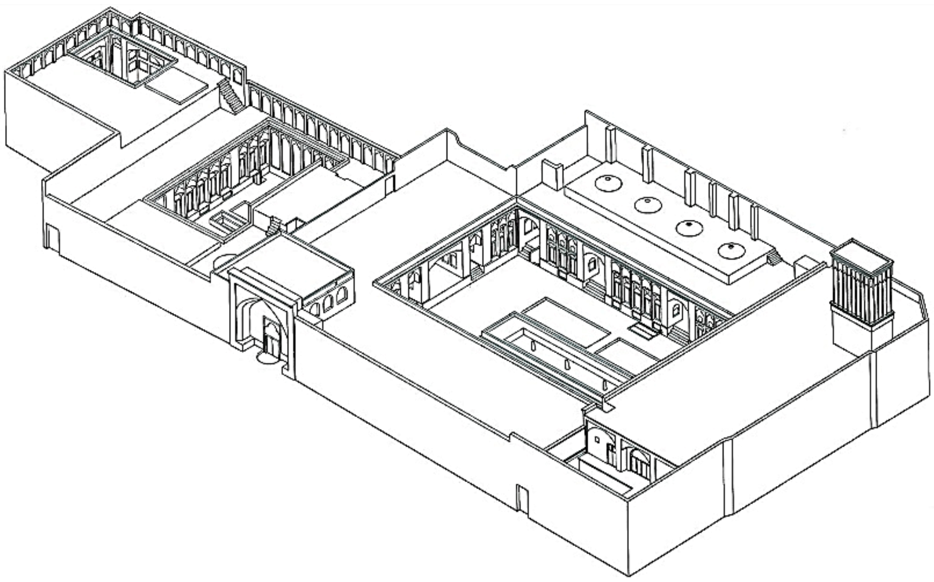


Figure 89, Lari House isometric view, source: (Haji-Qassemi, Harirchi and Qelichkhani 2005, 60)

Figure 90, Lari house main central courtyard, southwestern eivan and windcathcher, source: (YCHHTO 2013)

Figure 91, wooden doors of Panj-dari with glass works and Qajar ornaments of the ceiling in Lari house, source: (YCHHTO 2013)

Oloumi House

This house consists of two central courtyards that were built in different Qajar periods: the first one around 160 years old and the second one 130 years old. The house also owns a large plot of land on its southeastern side which appears to have been a garden previously. This is a rare pattern among the historical houses in Yazd.

The house is located near Mir-Chaqmaq square in Yazd, in Qassab-ha district.

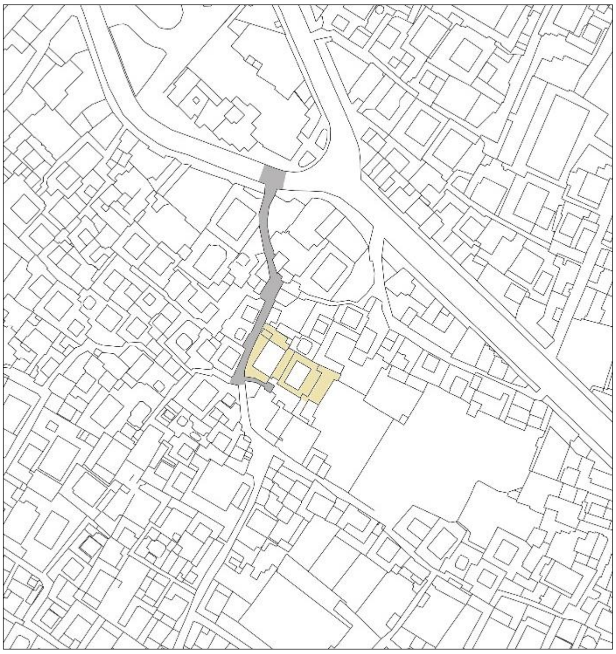


Figure 92, location of Oloumi historical house in Yazd, base map (YCHHTO 2013)

Oloumi-ha house has two courtyards, each with its own independent entrance. The eastern courtyard comprises a large elaborate courtyard with a variety of built areas laid out on its southeastern, southwestern and northwestern sides and a central sunken garden, surrounded by various spaces.

Unlike the western courtyard that has four facades of equal heights, symmetrical two by two, in the eastern courtyard, the southwestern side of the courtyard is taller than the others. Generally regarding the dimensions and forms of the arches and elements, the eastern courtyard creates a different atmosphere from the western courtyard. Thus the inhabitants of this elaborate house experienced different spatial qualities in these two courtyards and their surrounding spaces.

Contributes to the creation of a variety of vistas when one moves from one level to another. The notable point in this house is the remarkable depth of this small sunken courtyard which equals two stories heigh. Therefore when one moves on the upper courtyard, he cannot see the lower courtyards floor, and this makes the sunken garden an independent and private yard in the middle of another courtyard.

Part of the basement rooms are located next to the lower courtyard and benefit from its view and light (Haji-Qassemi, Harirchi and Qelichkhani 2005, 106-110).

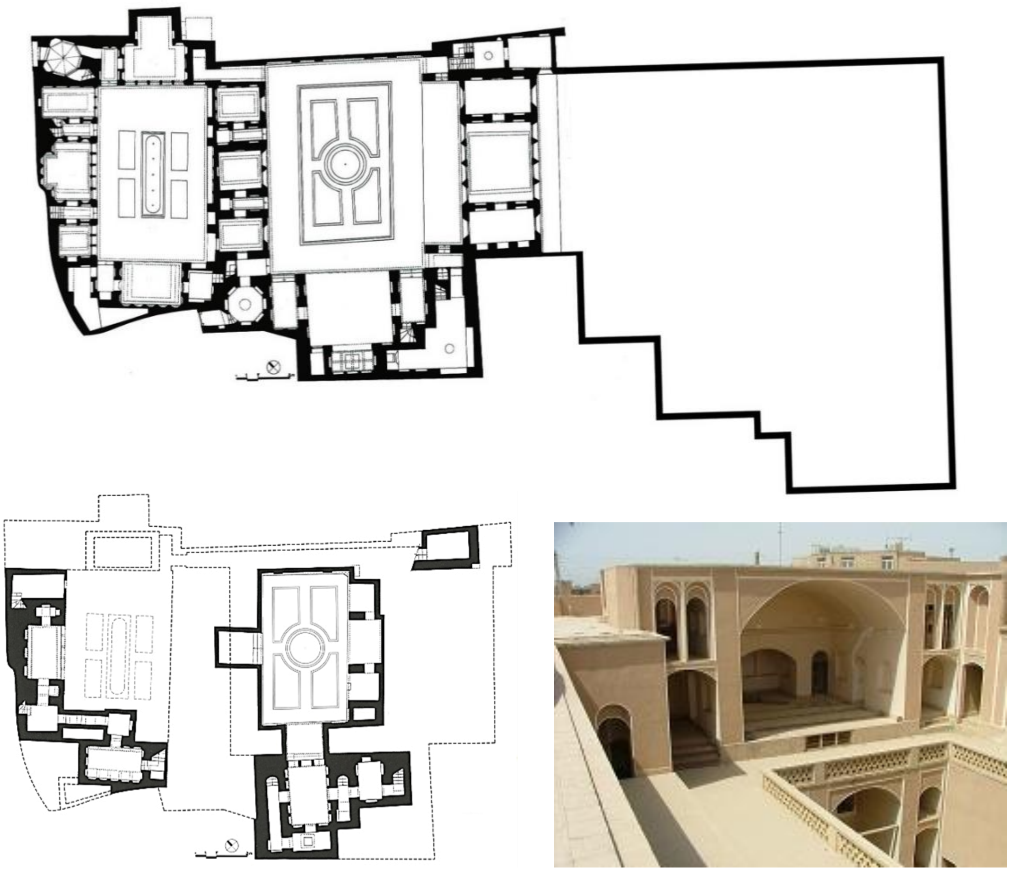


Figure 93, Ground floor and basement plan and photo of the Oloumi house in Yazd, source: (Haji-Qassemi, Harirchi and Qelichkhani 2005, 106-110)

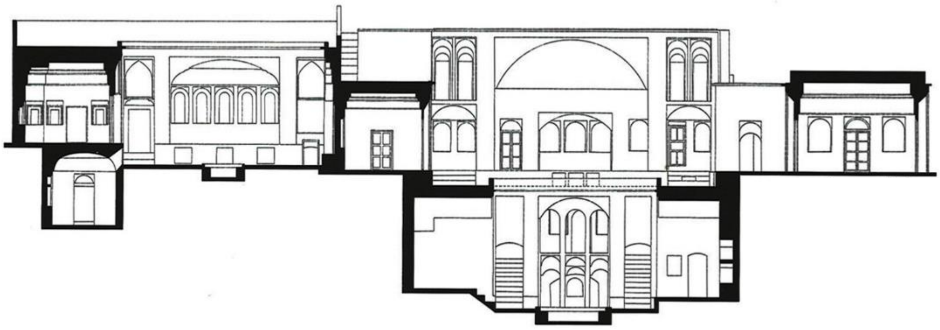


Figure 94, Oloumi House, ground floor plan, basement plan, section and photo of Eivan, Source (Haji-Qassemi, Harirchi and Qelichkhani 2005, 109)

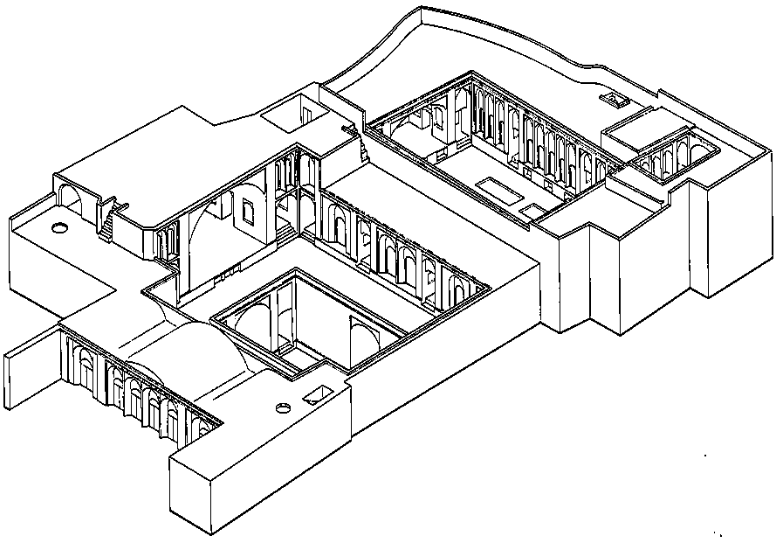


Figure 95, Oloumi House isometric view, source (Haji-Qassemi, Harirchi and Qelichkhani 2005, 105)

Tehrani House

Tehrani-ha (the Tehranis) house is located in a central location in the historical urban fabric of Yazd, near Fahadan

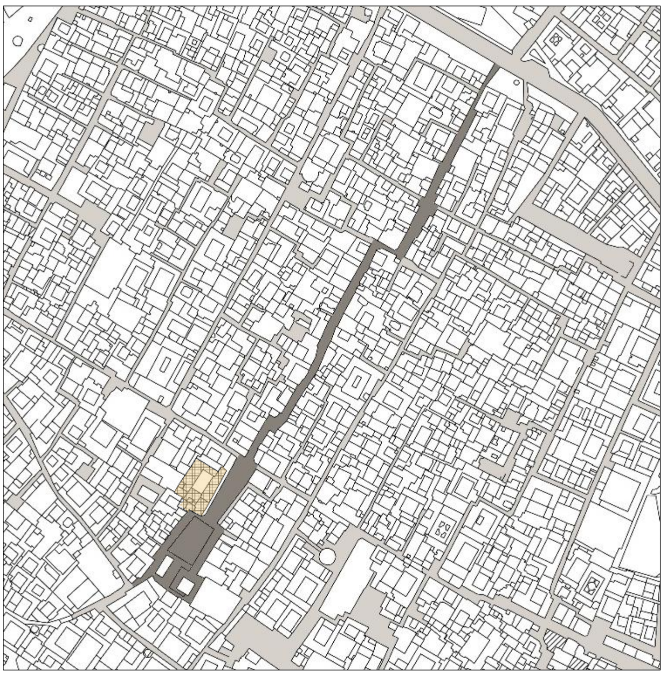


Figure 96, Tehrani house location near Fahadan historical plaza, drawing by author, base map (YCHHTO 2013)

The house dates back to 110-160 years ago and comprises the main part and the service area. The service area is located at the southern end of the house and has a separate entrance. Like the typical pattern of such historical houses in Yazd, the *Eivan*, the reception hall and the large *Seh-Daris* occupy the central axes of the main courtyard and are strongly linked to the courtyard. The smaller rooms are also placed around the courtyard and benefit from its light and view. The spaces at the corners of the courtyard are covered spaces, only lit through their roofs and connected to the courtyard by means of corridors. This shows that the significance of the spaces relates to their linkage to the courtyard.

The rise of the southern side of the courtyard higher than the other three sides that have a two storey height, as well as the presence of the wind catcher on top of this southern side,

A notable point is that the eastern and western sides of the courtyard, despite sharing similarity in facades, are different in horizontal layout.

In the courtyard, the green area and the water pool do not reflect the central symmetry of the facades; the water pool sits in front of the southern *Eivān,* creating a strong assembly together.

Sardābs are located at the basement level, on the eastern, southern and western side. The eastern *sardāb* makes an access by a stairway to an underground water stream. The southern *sardāb* opens at its end into a room connected to the wind catcher.

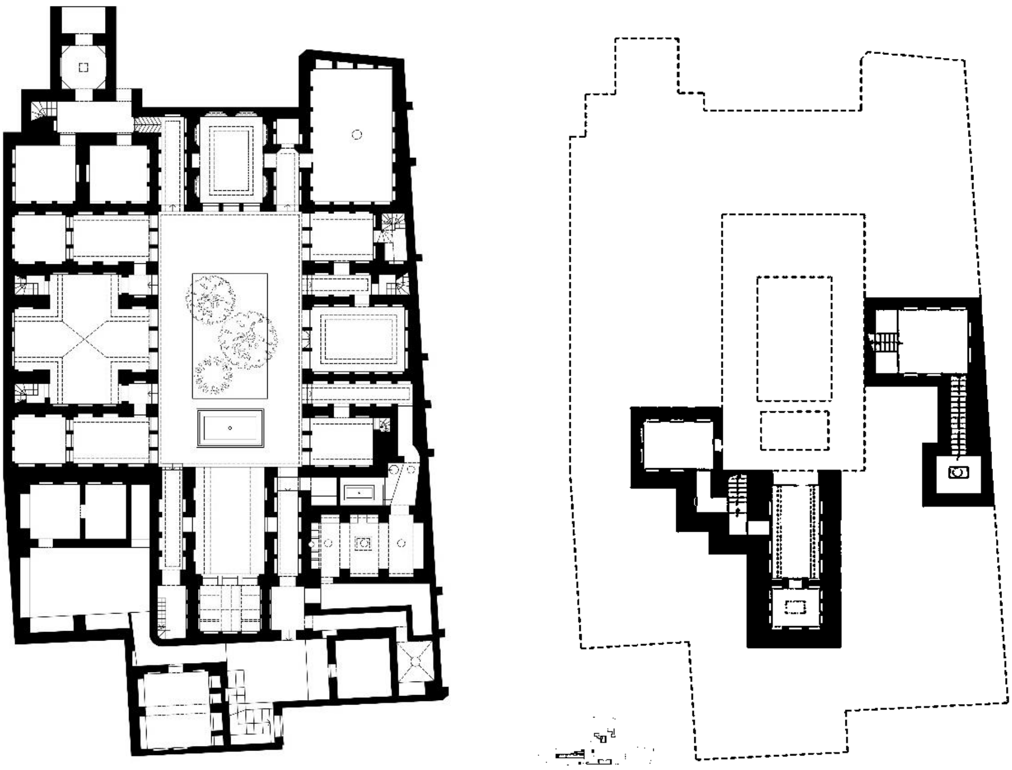


Figure 97, Tehrani house, ground floor and basement plan, source (Haji-Qassemi, Harirchi and Qelichkhani 2005, 195)

Figure 98, Tehrani house, section through central courtyard and wind catcher, source (Haji-Qassemi, Harirchi and Qelichkhani 2005, 191)

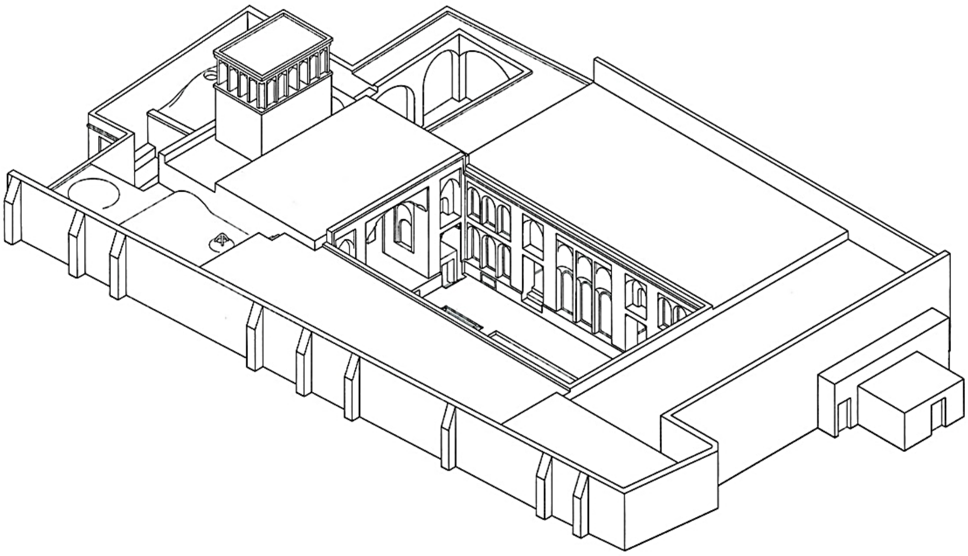


Figure 99, Tehrani House isometric view, source (Haji-Qassemi, Harirchi and Qelichkhani 2005, 196)

At present, this house serves as a boutique hotel (Fahadan Museum-Hotel).

Figure 100, Tehrani house present function as Fahadan Boutique Hotel, photo by author, 2014

ii. Contemporary Case Studies

For a better understanding of the architectural solutions and strategies used in traditional architecture in the hot and arid region of Iran, the architectural solutions and elements are compared with contemporary approaches in today's architecture in the region.

Therefore, in this dissertation, contemporary case studies are also investigated regarding sustainable architectural design. The goal is to either verify or falsify the thesis that the traditional architecture in Yazd is more sustainable, and to learn from the sustainable features of the traditional architecture in Yazd.

For the contemporary case studies, a selection of three different houses presents sufficient data from different housing types in today's Yazd, while as mentioned before, the present national design rules and regulations for housing design in Iran has resulted in design and construction of three major types of housing all over Iran:

- Single family houses with southern courtyards usually in one or two levels with private ownership.
- Multi-level apartments, with 3 or more levels in one block, one or more units on each level with a private parking space and storages on the 0 or -1 level, a common courtyard, and sometimes common services such as reception hall, meeting rooms, swimming pools, and saunas in more luxuries apartments.
- Residential complexes, including several blocks of multilevel housings that share a common open-air area and sometimes urban facilities such as a laundry service, bakery, etc. These residential complexes are usually constructed with large governmental financial support.

These houses follow the same rules regardless of local or climatic conditions of the area.
The following are the sample case studies of these residential buildings in Yazd.

Figure 101, Left and mid.: Project No.2 and Sajjadi house, architect: Mostafa Zadeh, right: Atlassi house: architect: Sadegh Ahmadi

Figure 102, Zanbaq 136 unit residential complex, Honar Sara Memari Yazd consulting Engineers,Client: Yazd Electricity Power Plant housing cooperative, 2009

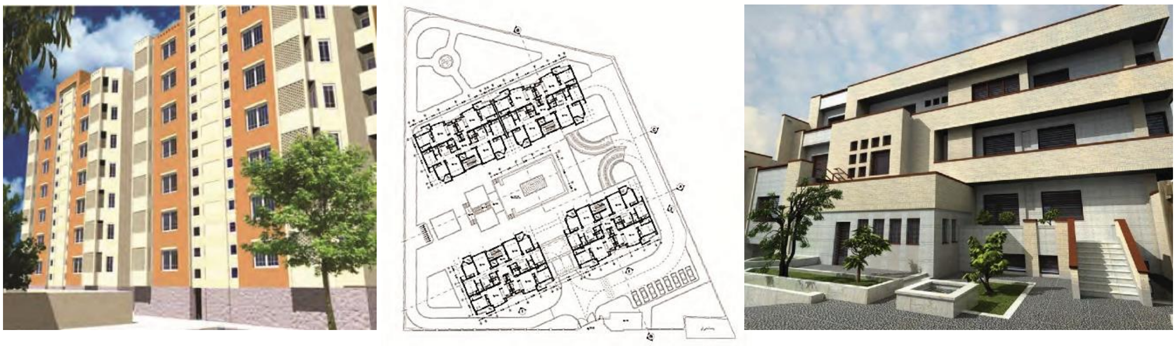


Figure 103, Left and middle, 122 unit Sima Gostar residential complex, Project manager: Owlia, M., Client: Sima Gostarhousing Housing Cooperative, right: Dr. Karger multilevel apartment

The contemporary case studies in Yazd are as follows:

Atlassi Single Family House

Two level house for Atlassi family with a southern courtyard

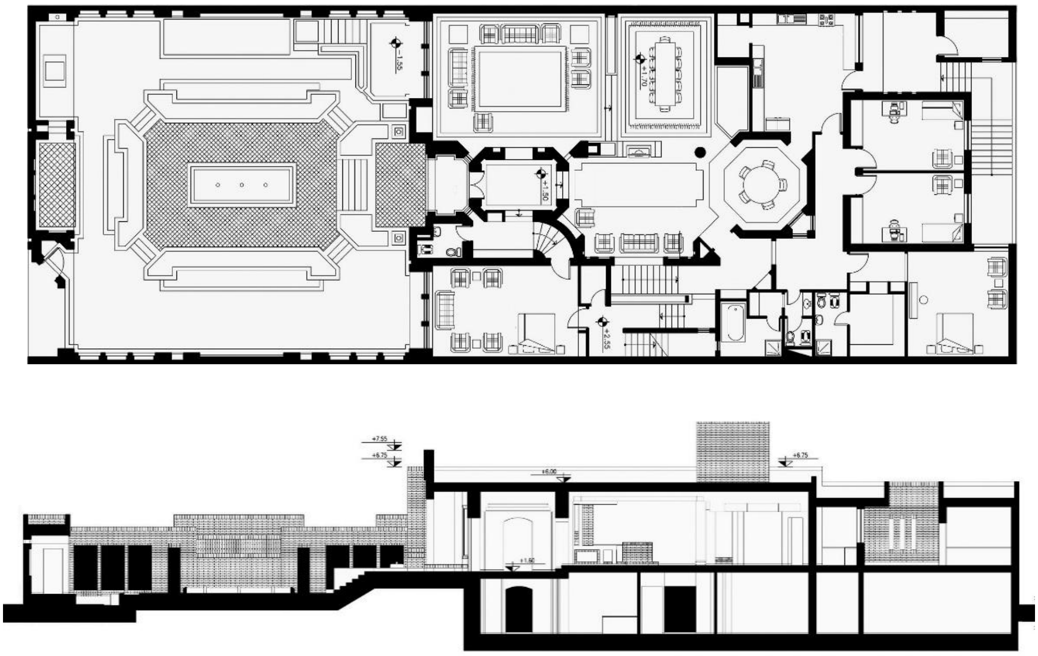


Figure 104, Atlassi house, plan and section, source: (Honar Saraye Memari Consulting Engineers 2013)

Figure 105, Atlassi house, view from courtyard, source (Honar Saraye Memari Consulting Engineers 2013)

This single family house is built with load bearing brick walls in two floors. The ground floor consist of living room and dining room, bathrooms and kitchen, bedrooms, one master bedroom with separate bathroom, and one guest room with toilet. The basement level also includes a smaller house that has a connection from the small backyard to the upper floor, as well as its own access from the parking area.

The courtyard occupies the southern 40% of the land, due to the national design regulations. The facades of the courtyard copy the traditional patterns of the desert houses. This is a typical single family house in the wealthier newly-built district of Yazd, *Safaieyeh*. Although other contemporary villa houses might be smaller or simpler, but the design rules adapted in this house are the common patterns that are used by architects in for evaluation and comparison with other case studies.This dissertation selects the ground floor of this house as a separate unit to compare with other case studies.

Mir Hosseini Multilevel House

With storages and a public meeting room for the inhabitants in the basement, parking spaces on ground floor, and five residential levels, each level containing one separate unit with separate private owners**.**
For the case study, this dissertation selects one of these typical units is investigated.

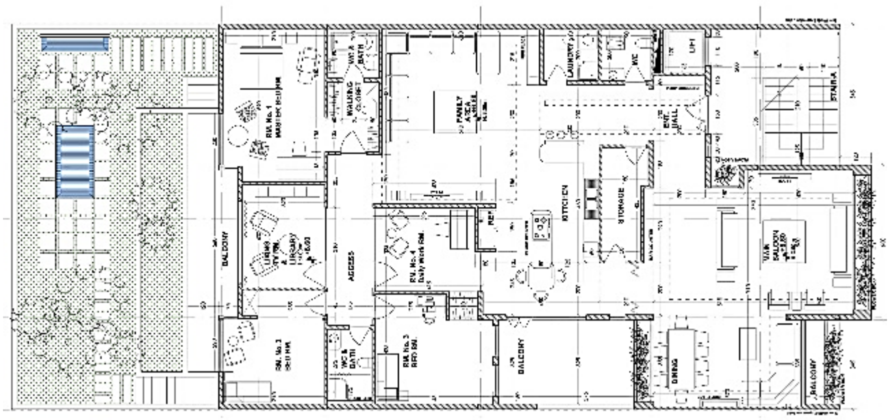


Figure 106, typical floor plan for residential units at different stories of Mir Hosseini multilevel house by architect Dr. M. Mostafa Zadeh

Figure 107, Mir Hosseini multilevel house, typical plan of the residential units and three dimensional view, by architect Dr. M. Mostafa Zadeh

Sima Gostar Residential Complex

Constructed by the Sima Gostar Housing Cooperative, spans four blocks, each containing seven levels above the ground floor, and each floor with 4 separate units.

Construction of such residential complexes have become common during past decades as a respond to the increasing urban population. Most of such complexes are built by governmental cooperatives for the use of their employees or workers.

As the case study for this dissertation, one of the four typical units is selected as a separate house, evaluated and compared to other case study houses.
It is a two bedroom unit with balconies, living room, kitchen and bathroom, with shared lift and staircase. This unit is oriented towards northeast.

Figure 108, Sima Gostar typical floor plan and the selected unit as the case study among the four residential units in each floor, source (Honar Saraye Memari Consulting Engineers 2013)

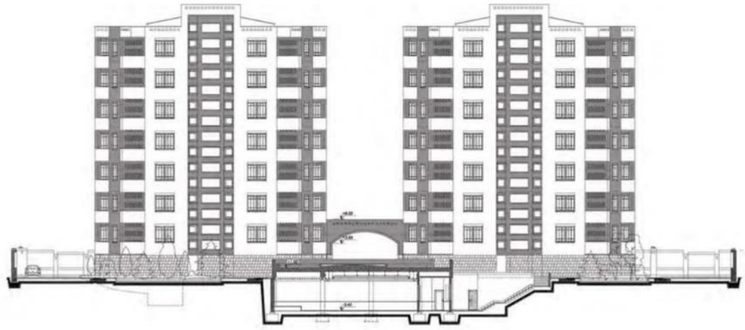



Figure 109, Elevation and 3D view for 122 Unit Sima Gostar Residential Complex, source (Honar Saraye Memari Consulting Engineers 2013)

Chapter 6. Evaluation of Case Studies

As mentioned in Chapter 4 (Sustainability Evaluation Tool), the final evaluation will be made according to the following classification of environmental sustainability features.

Each of six case studies will be evaluated and rated in order to pinpoint the sustainable features of historical and contemporary housing in Iran, as well as their strengths or weaknesses.

SUSTAINABLE DESIGN FEATURES	
1. WATER	W1. Passive Water Supply System
	W2. Alternative Water Sources
2. ENERGY	E1. 'Green' Energy Sources
	E2. Minimizing Energy Needs
	E3. Minimizing Energy Exchange
3. GROUND and LAND-USE	GL1. Land use (footprint)
	GL2. Effective Green Area
	GL3. Avoid Deforestation
4. MATERIAL	MR1. Plentiful Material
	MR2. Low Emitting Materials
5. HEALTH and WELL-BEING	HW1. Safety
	HW2. Comfort
	HW3. Health

Table 11, Brief review of the categories in the evaluation tool for sustainability proposed by the author

In each category, the related features and characteristics of that item will be shortly introduced and discussed in both contemporary as well as traditional houses, and then evaluations and comparisons will be made.

In each part, the instructions made by LEED will also be mentioned and discussed.

6.1. Water (W)

Introduction to Water Supply system for housing in Yazd

A. Contemporary Water Supply in Yazd

The Ministry of Energy[15] supports water for housing consumption in Iran with the assistance of the National Water and Wastewater Engineering Company (NWWEC 2012). The Yazd Province Water and Wastewater Organization is in charge of supplying water for 17 cities in the Yazd province, which includes the city of Yazd (ABFA Yazd 2013). This water is for housing usage, including both potable and non-potable water and irrigation.

The water is supplied through the national pipeline system. It is mainly supplied from two sources: underground water and water dams (Dolat 2012). In Yazd, due to water shortage and aridity in recent decades, this water has been transferred from Isfahan, the neighboring province (see Figure 114).

Mis-consumption

In spite of water shortage in the region, the household water consumption in Iran is high compared to international standards, and this is due to:

- Inefficient equipment
- Misuse by uneducated users
- Not distinguishing source for potable and non-potable uses

The following table is made from a survey from the Isfahan Water Consumption Management Website (Water Consumption Management Portal 2013); it calculates the rate of household daily water consumption by compiling different activities related to water usage.

This calculation is made to estimate the rate of water consumption in a family with 5 members who live in the Atlassi house.

[15] http://www.moe.gov.ir

Residents	5 persons			
Shower	Weekly shower/person? 3 times			
	Duration of each shower? 10-20 min			
WC	Iranian WC? Yes	Daily flush use/person? 3 times	Type of flush: Normal	
	Western WC? Yes	Daily flush use/person? 3 times	Type? Dual flush	
	Turn off the water while hand washing? No	While tooth brushing? Yes	While shaving? Yes	
Kitchen	No. of daily dishwashing by hand? 2	The water runs during dish washing? Yes	Daily machine dishwashing? 1	Vegetables? Wash under water flow
Clothes washing	Wash clothes by hand? No	Washing by wash machine? Yes	Wash-machine: Normal	Weekly no of washing? 3 times x 2
Car washing	No. of cars: 2	Washing: Basket	Once a month	
Leakage in pipes /taps ----				
House cleaning	Weekly WC washing? 2	Weekly bathroom washing? 1	Weekly kitchen floor washing? 3	
Water cooler	----			
Irrigation	Urban water flow	10-30 min	Garden area 26 m	

Table 12, Questionnaire for estimated calculation of daily family water consumption in Atlassi house, source: (Water Consumption Management Portal 2013)

This short calculation reveals that the standard rate of water consumption for such a family in Iran should be **750 liters of water per day**, while the actual daily rate of water consumption in such a house is **1215 liters/day,** which is **1.62** times the standard rate.

Daily water consumption	Standard	750 lit./day
	Atlassi house	1215 lit./day
Daily water consumption in Atlassi house is 1.62 times the standard rate		

Table 13, Comparison of daily water consumption in Atlassi house with 5 family members with Iran's standard rate

LEED

According to LEED, indoor water baseline consumption (per person per day) for a house with one shower, one lavatory, kitchen faucet, one toilet, one washing machine and one dishwasher is 189.7 liters (USGBC 2014, 28), and each 10% more reduction in this rate adds one additional point up to maximum of 6 points.

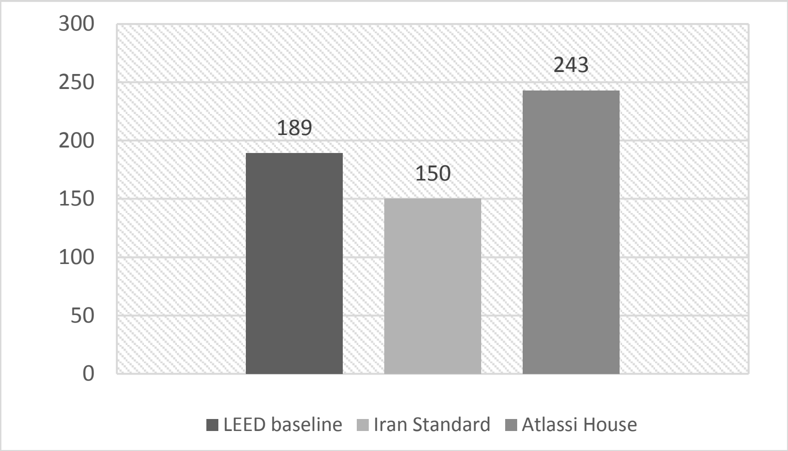


Chart 5, Comparison of rate of indoor water consumption in liters per person per day

SUMMARY

The current pipeline system that provides houses with water in Iran indicates over-consumption. The average water consumption per capita in the housing sector of Iran is higher than standard. One main reason for this is that the water provided for potable usages is used for non-potable usages as well e.g. irrigation…

Besides, education of its users and improvement of equipment and appliances will lead to further sustainability, as indicated by LEED.

At the architectural design stage, the adaption of strategies for reduction of water consumption is beneficiary, e.g. the number of private or shared bathrooms, area and type of vegetation, etc.

B. Traditional Water System in Yazd

Qanāt

"The *Qanāt* is a method for developing and supplying groundwater. It consists of a gently sloping tunnel, cut through alluvial material, which leads water by gravity flow from beneath the water table at its upper end to a ground surface outlet and irrigation canal at its lower end" (Beaumont 1971, 39)

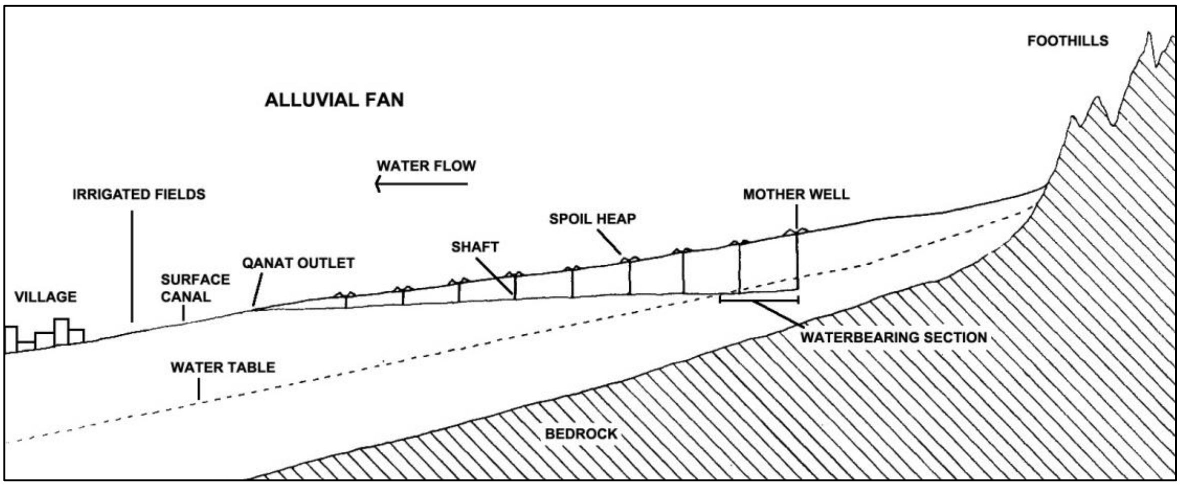


Figure 110, Schematic section of Qanat water canals and wells, source (Beaumont 1971, 39)

For easy access to this water in the historical town, this system of shafts and tunnels connects to public cisterns or private *Pāyābs.*

Cisterns (Āb-anbār)

A cistern is a construction developed in Iran as part of a water management system in areas that acquire their needed water from permanent (springs, Qanāts) or on seasonal (rain) water sources.

A settlement's capacity for storing water guarantees its survival over the hot, dry season when even the permanent water supply would diminish.

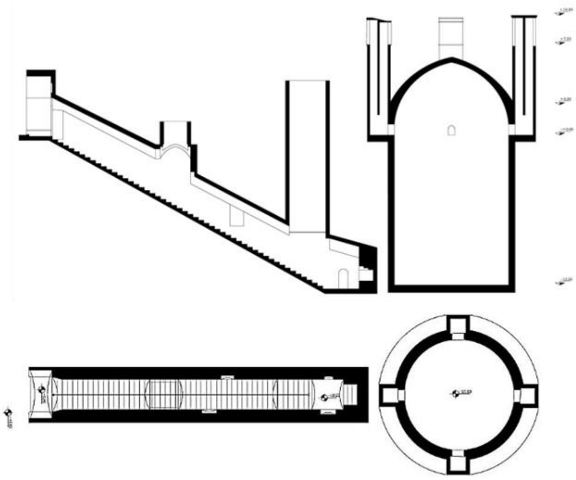


Figure 111, plan and section for Youzdaran cistern, Yazd, source (YCHHTO 2013)

While private houses may have had their own cisterns, filled consecutively from the Qanāts or streams, desert cities such as Yazd or Ṭabas built elaborate structures for public use. These can also be found on caravan routes (Pope 1967, 1391-1410).

In some houses (specifically those belonging to wealthier families), a private entrance to the existing Qanāt canal underneath was built to provide the residents of the house with fresh water through a private Hozkhāneh and Pāyāb (Also named Pādyāv).

The access to the outlet of the Qanat underground water flow in houses is through long deep staircases that end at the Payab. (Ghezelbash and Abolzia 1985)

Pirniā, known as the father of Iranian traditional architecture, describes the origins of these architectural elements in desert houses:

"In Iranian towns and cities around the deserts, where there was lack of sufficient ground floor water flow, Pādyāv from the sacred tombs, changes to the Godālbāqcheh and underground Hozkhāneh, and lets the flow of the Qanāt waters into the houses" (Pirnia and Memarian, Introduction to the Iranian Islamic Architecture 2013, 320).

Private cisterns were filled from Qanāts during the winter months. Surplus flood water could often be stored in open tanks, as well as in the large, public, covered cisterns (Holod 1983, I/1) (Wulff 1977, 258).

Figure 112, Payab and Qanat water flow under Tehrani house, photo from Author

The following are the plans and sections of Lari (left) and Tehrani (right) houses, illustrating their own private access to water through Hozkhaneh and Pāyāb.

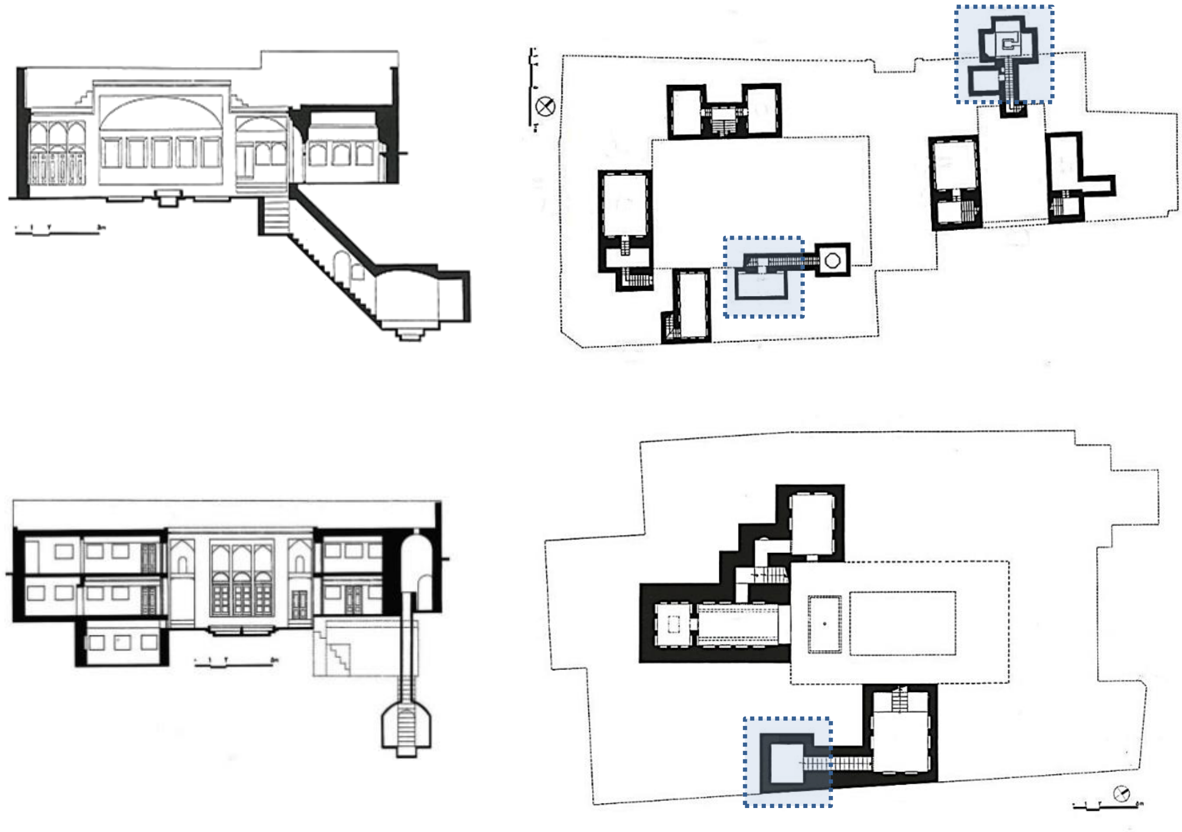


Figure 113, Payab and basement plan and section, up: Lari house, down: Tehrani house, Plans and sections' drawings are in different scales, base drawings from (Haji-Qassemi, Harirchi and Qelichkhani 2005)

Evaluation

After this short introduction to contemporary and historical water systems in Yazd, the following is the evaluation of case studies in two major categories for household sustainability features of water usage:

W1. Passive water supply systems.

W2. Alternative Water Sources

A. Contemporary

As mentioned previously, the national pipeline system in Iran provides water for the housing sector from underground water sources and water dams. Due to water shortage in the desert area of Yazd, in the year 2000, the government of Iran decided to begin transferring water from the Zayandehroud River in Isfahan to Yazd. This is expensive and requires a great amount of energy.

In addition, it interferes with the natural ecosystem of the Zayandehroud River and its terminal basin, while the Zayandehroud River in Isfahan has recently also suffered from drought. It has also received broad objections from farmers in Isfahan due to irrigation problems they faced.

Figure 114, Gavkhuni basin, Isfahan and Yazd city, source: Wikimapia

Figure 115, left and middle: Gavkhuni basin before and after drought, source (Fararu 2013),
Right: Zayandehroud River, Khadju Bridge, Isfahan, Iran, source Wikipedia

SUMMARY
The present system for providing Yazd with water is neither a passive system nor is it sustainable, because:

- It consumes too much energy, due to the water transfer from another province, Isfahan, to Yazd.
- It interferes with the natural ecosystem of the Zayandehroud River and has resulted in the vast drought of the Zayandehroud River and Gavkhouni drainage basin in recent years.

B. Traditional

As explained before, *Qanāt* canals follow the slope from the hillside to the town. Due to the very slight slope of *Qanāt* canals, water flows from the mountains to the city passively.

At the locations where locals access water from *Qanāts* in town, either at a public Cistern or a private *Pāyāb*, there are huge water reservoirs. The lower floor level of the water-reservoir in a cistern compared with the level of *Qanāt* canals results in the passive water flow towards the water.

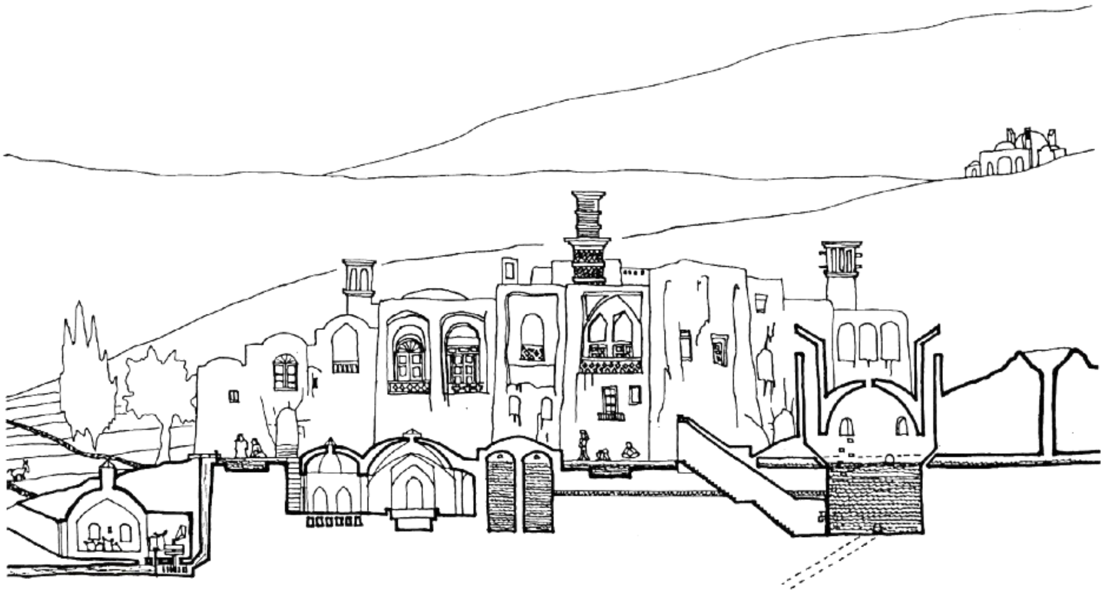


Figure 116, Section through Khoranaq and the role of Qanat to provide water for clean to dirty uses,
The slight slope of the Qanat's underground tunnel and the lower floor level of cistern's water reservoir result in the passively flow of water due to earth gravity and the communicating vessel's hydraulics law
. Image source (Roaf, Fuentes and Thomas 2007, 253)

RESULT
The traditional water system in Yazd was a passive supply system. Due to slight slopes of water tunnels in addition to the lower level of cistern water reservoirs contrasted with water canal levels, water flows by itself through *Qanāts*.

W2. Alternative Water Sources

As Sassi mentions in his book, in developed countries potable water is generally used for all building-related uses regardless of whether such standards of cleanliness are necessary. Using alternative sources of water collected on site reduces the need for the extraction, treatment, and distribution of fresh mains water, reducing pressure on freshwater sources and energy use (Sassi 2006, 264).

In areas with sufficient rain, rainwater may be a good alternative source of water, however, in Yazd, due to the very low rates of rain, it is not a good alternative.

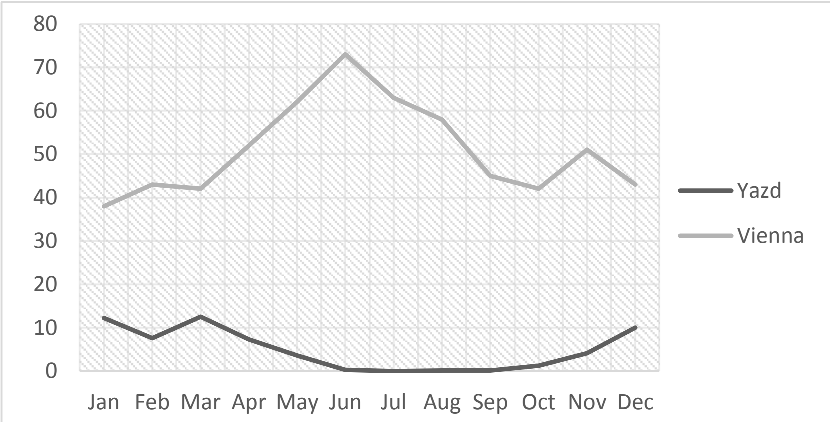


Chart 6, Average monthly precipitation (mm) over the year in Yazd (1953-2010) and Vienna,
Sources: (IRIMO 2011) (WWTO 2014)

Feasibility of Qanāt system as the alternative water source for contemporary city

According to United Nation's standards, potable water must be within a one kilometer distance from users (Dolat 2012).

The following map shows the existing cisterns in the fabric of Yazd. The circles placed around the Lari, Oloumi and Tehrani houses have a 500 and 1000 meter radius around these case studies, to demonstrate the existing easily accessible cisterns for the residents of these houses. Some neighboring cisterns with direct access to case study houses are as follows (Figure 118).

- Kushk-e Now cistern about 215 meters to Lari house and ca. 320 m to Tehrani house.
- Youzdaran cistern ca. 250 meters to Lari house and ca. 130 m to Tehrani house.
- Oloumi house has direct access to the neighboring cisterns Five-Wind Tower cistern (ca. 350 m), Khajeh Khezr cistern (ca. 520 m) and Six-Wind Tower cistern (ca. 560 m).

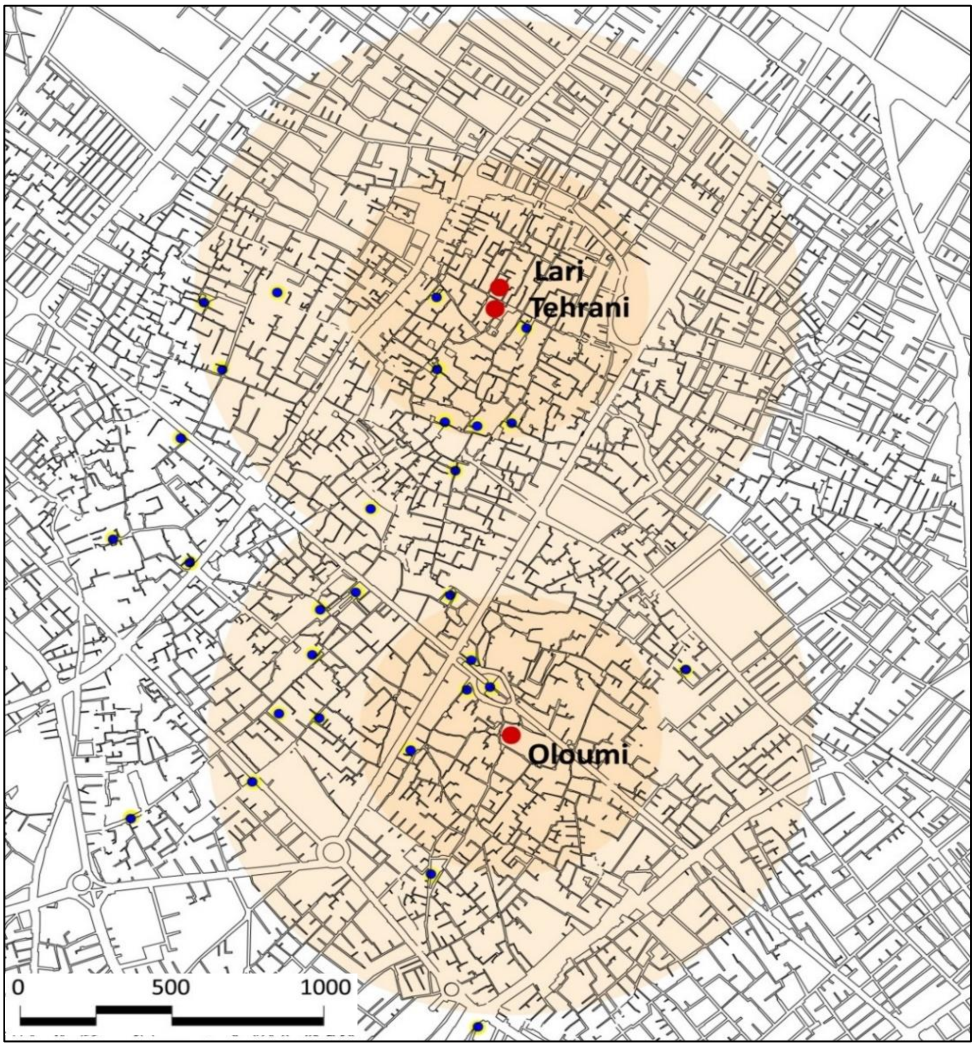


Figure 117, Existing cisterns around Lari, Oloumi and Tehrani houses within 500 and 1000 meters distance, base map: ICHHTO Yazd archive

This shows that there are numerous cisterns within the standard distance surrounding historical houses in Yazd. These serve as an alternative water source that works in parallel with the national pipeline system. According to the Yazd Cultural Heritage Organization report, 509 cisterns are registered in Yazd province (YCHHTO 2013).

107 of them are located in the city of Yazd and only 6 of them are still active.

Cistern	ID Number in YCHHTO list	Date
Bolmiri Sheikhdad	317	NA
Harati	330	Pahlavid
Kiani	360	Qajarid
Barkhordar	386	Pahlavid
Do-dahaneh	390	Late Safavid
Darvazeh Shahi	416	Safavid

Table 14, Active cisterns in the city of Yazd, source: (YCHHTO 2013)

This significant number of existing cisterns in Yazd reveals a high potential for rehabilitation and reuse of this historical system.

The interesting point to note is that the existing routes of *Qanāts* comprise of a network that covers the historical core zone of the city, as well as the contemporary parts. This means that there is a high potential all over the city to revitalize this passive water system in the city, not only beneath the historical urban fabric, but also the new parts of the city.

The quality of this water can be discussed concerning potable water standards. Even if it does not reach the present standards of potable water, this water may be used for non-potable usages, and thus make a notable reduction to the overall rate of household water consumption.

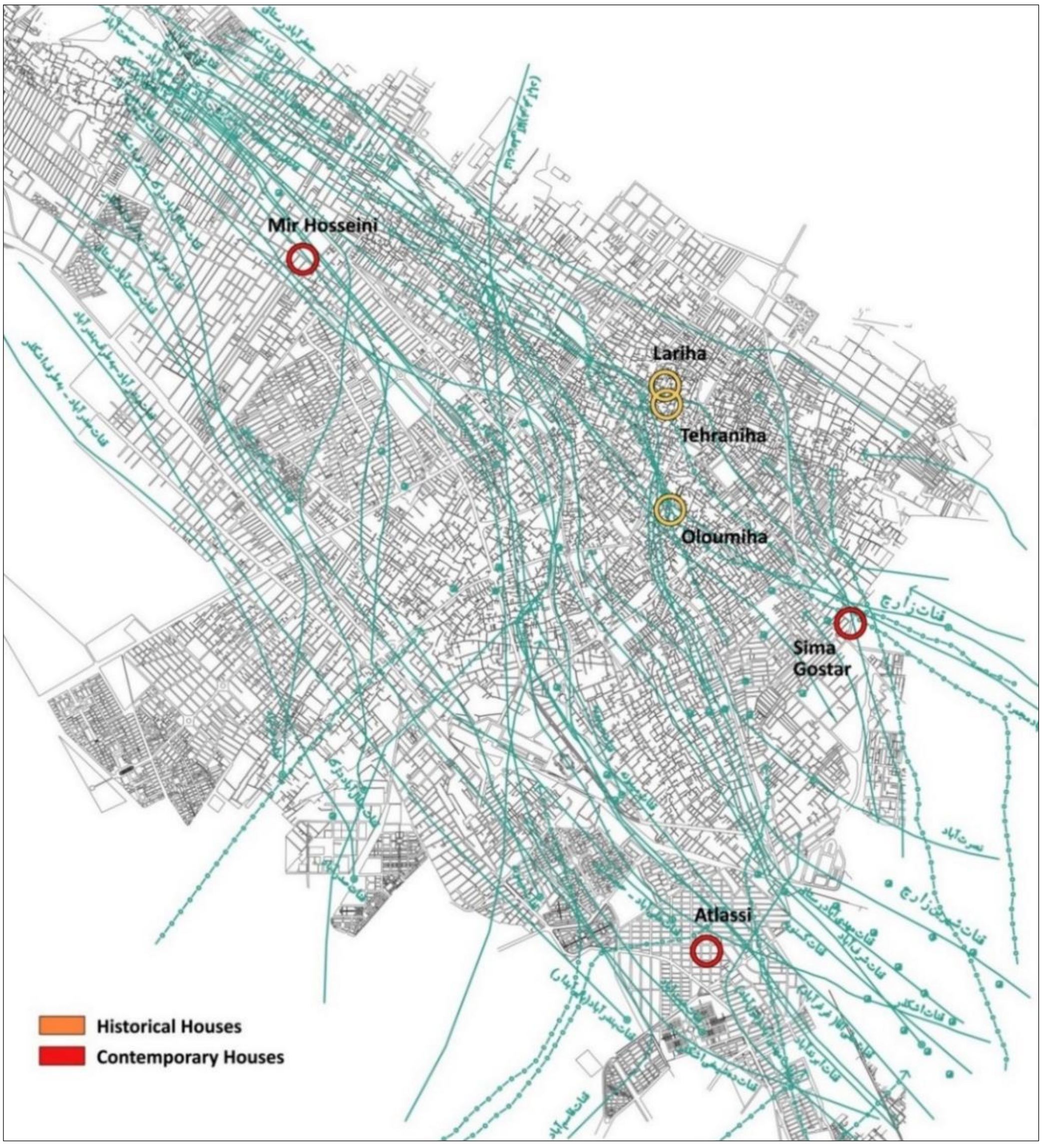


Figure 118, map of the existing (and probable) Qanāt routes and the case study houses locations in Yazd, Graphic by author, base map source: (YCHHTO 2013)

SUMMARY and RESULTS

Providing alternative water sources, especially for non-potable usages, is a strategy that contributes to the reduction of total water consumption.

In arid areas, the *Qanât* system is an ideal alternative to benefit from, to use in parallel with the existing water system. Because of low precipitation, the *Qanât* system, which conducts water passively from a distance (mostly from mountain skirts) to the city, is a good possibility.

Although *Qanât* water may not be an adequate replacement for potable water due to its quality, the water in Yazd specifically, where potable water is provided with high energy and cost as it's transferred from kilometers away, can at least cover the non-potable water demands in the housing sector. This may result in a reduction of the overall water consumption rate.

Meanwhile, the application of small mechanical equipment to improve the quality of water from *Qanâts* as well as to ease access to this water is recommended.

The historical city of Yazd used *Qanâts*, Cisterns, and *Pâyâbs* to supply potable and non-potable water in town. These hydraulic infrastructures still exist after hundreds of years, but many of them were abandoned after the construction of the national pipeline system in the Pahlavi era. They have great potential to be rehabilitated and reused.

Challenges

There are both positive and negative points regarding the idea of rehabilitation of the *Qanāt* system into the modern city:

Opportunities

- Although Yazd has been experiencing extensive physical growth during past decades (Zangeneh Shahraki, et al. 2011), the historical network of *Qanats* extend underneath the city, even beneath new parts. This existing *Qanat* system has good potential, specifically in newly developing parts that need new infrastructure.
- New drilling technologies may be used to make small, low energy equipment for easier maintenance of the system.
- "*Qanat* water, due to underground flow, is less exposed to open-air pollutions such as sand storms, dust etc." (Beaumont 1971, 40)
- This underground water is cool even in summer time because it travels underground
- In case the quality of the *Qanat* water does not meet the health standards for drinking water, this water can be used for non-potable water uses such as irrigation. If this water

system is upgraded with simple solutions of monitoring and purification, it can be used as drinking water too.

- “Maintenance of *Qanats* needs a good co-operation and intricate relationships of shareholders, small landowners and the authorities that is a very important debate in sustainability” (Lightfoot 1996, 6) (Achakzai and Toor 1990, 289)

Threats

- “New technologies such as pump wells in recent decades as well as promotion of different programs for usage of local water supplies, resulted in extensive usage of underground water in the area. Water-table level has gone down and a large number of *Qanāts* have been dewatered.” (Lightfoot 1996), (Beaumont 1971, 40). This means that rehabilitation of *Qanats* depends on management of different ways of using underground water sources in a balanced way.

Weaknesses

- The physical effort that is required to get water from *Payab* is not easily accepted in modern living. Small strategies for safer and easier access to *Qanat* water and Cistern reservoirs is recommended to encourage users.

Further recommendations for designers

- Indicate separate water systems for potable and non-potable water usage in houses. This can result in a significant reduction of total water consumption.
- Use local trees for vegetation in your design.
- Avoid turf grass, which requires a lot of watering in the hot and arid climate of Yazd[16].

[16] See also LEED p 31, WE Credit for outdoor water use, points for reducing turf grass and increasing native plantings, as percentage of total landscape area

6.2. ENERGY (E)

Energy in the building supports a wide range of functions including cooling, heating and lighting. This chapter firstly discusses the climatic conditions of Yazd to determine the strengths (possible energy sources) and weaknesses, and then evaluates the traditional and contemporary case study houses in three previously defined categories for energy evaluation:

- (E1) Green energy sources,
- (E2) Minimizing energy needs,
- (E3) Minimizing energy exchange.

Yazd, Energy Needs, Energy Sources

Climatic Zoning upon Energy Needs

Iran includes four macroclimatic zones ranging between cold mountains climate, mild Caspian climate, Hot and Arid climate and hot and humid climate. Each of these climatic zones have been divided into smaller climatic zones by different researchers and upon different criteria. The following map shows one of these divisions for instance, that divides the country into 12 climatic zones.

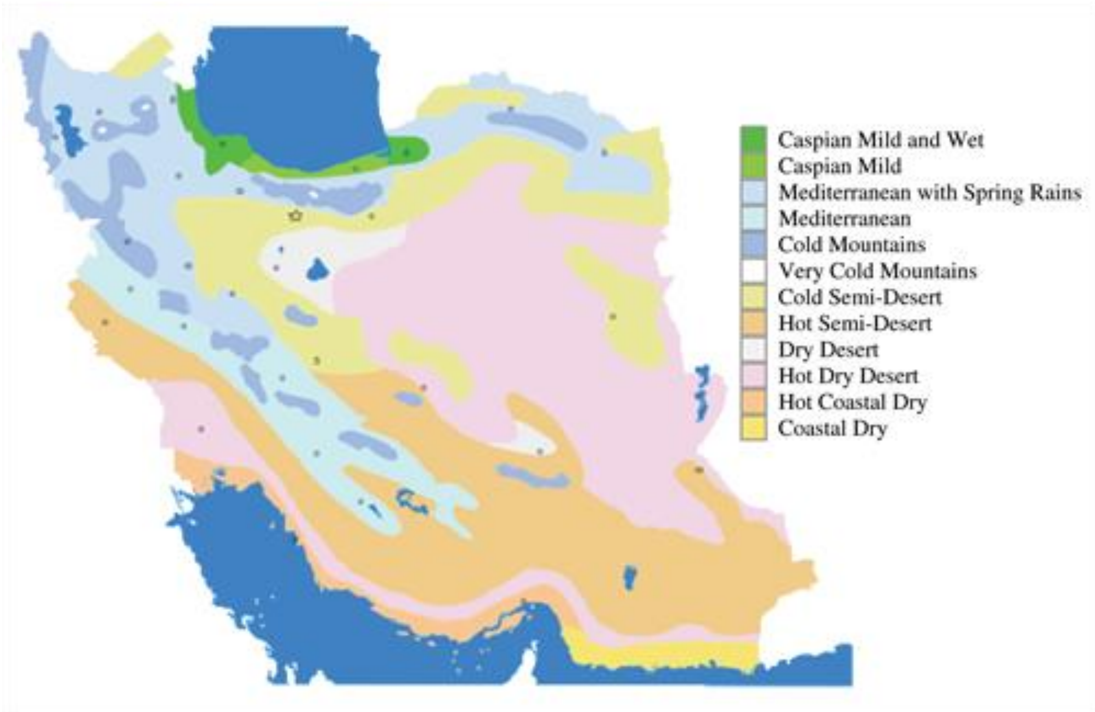


Figure 119, Climatic zones of Iran, Image from (Iran politics 2015)

One of the most recent surveys on climatic zones of Iran that has been made regarding architectural approaches, has been made by Tahbaz and Djalilian in 2008 on the basis of:

- The effect of building envelop
- Human comfort in open air
- The effect of construction materials

This survey divides the country into 8 major climatic zones. Among these zones, Yazd is in category 5, with hot and arid summers, and cold winters (Tahbaz and Djalilian 2008, 10-11).

CLIMATE		CLIMATIC FEATURES
1	Caspian zone	- Rather cold winter - Rather hot summer - High humidity of air and soil
2	High Mountains	- Favorable Summer - Very cold winters with long freezing periods
3	Mountain	- warm summer - Cold winter
4	High Foothills	- Rather hot and arid summer - Cold winter
5	Semi-desert	- Hot and arid summer - Cold winter
6	Desert	- Very hot and arid summer - Cold winter
7	Khuzestan and Jazmourian Plain	- Very hot, semi-arid summer - Mild winter - Rather high humidity of air
8	Southern Coasts and Islands (Persian Gulf and Oman Sea)	- Very hot and humid summer - Mild winter - High humidity of air and soil

Table 15, eight major climatic zones in Iran, source (Tahbaz and Djalilian 2008, 16)

The following building bioclimatic chart of Yazd illustrates the comfort zones conditions in buildings regarding temperature, humidity and vapor pressure.

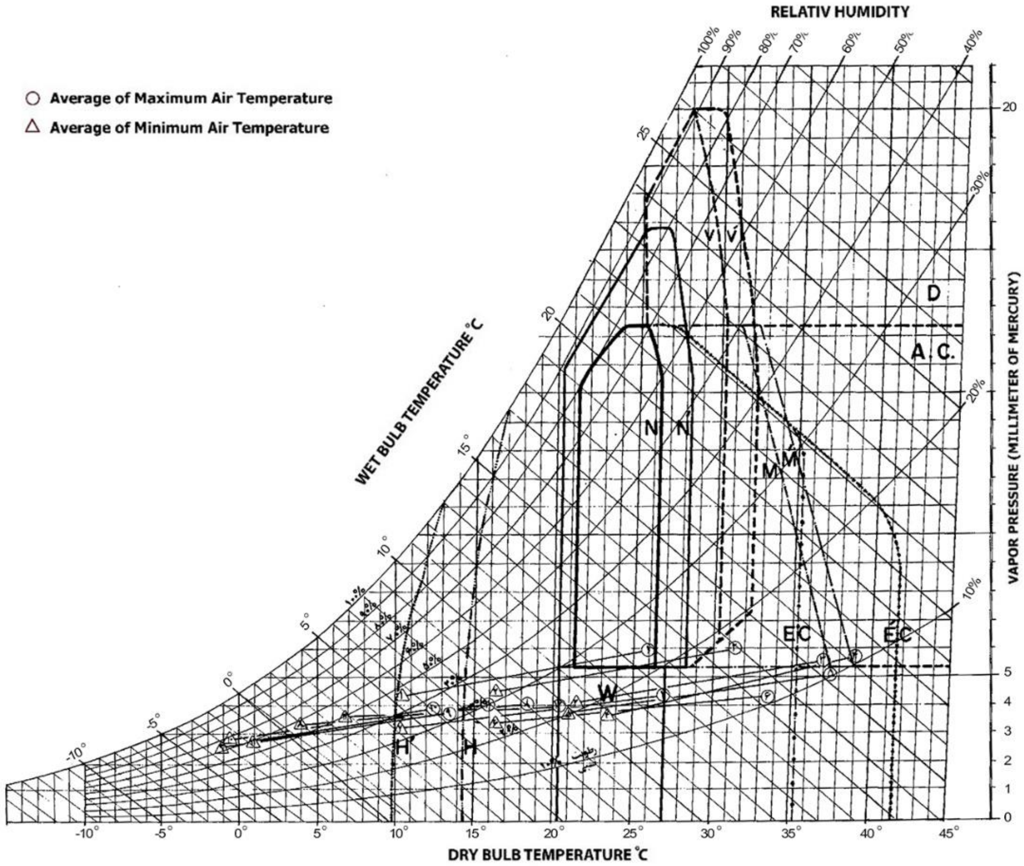


Figure 120, Yazd Building Bioclimatic Chart, (Kasmaei 1984, 401)

The building bioclimatic chart for Yazd illustrates the comfort zone in buildings between 21°C (relative humidity 30% - 80%) to 26.2°C (relative humidity 20% - 70%) during part of April (Zone N).

The application of building materials that are compatible with Yazd's climatic conditions can effectively extend this comfort zone up to 31°C (RH 50%) to 37.5°C (RH 10%) during May and June (Zone M).

The tolerable zone inside buildings which exceeds the comfort zone up to 25°C (RH 90%) to 28.2°C (RH 19% to 60%) during part of May (Zone N') can also increase by up to 32°C (RH 47%) to 39°C (RH 10%) during June and July, in the case that the application of proper building materials are compatible with Yazd's climatic conditions (Zone M').

In normal buildings, a natural air current can be used for cooling the temperatures between 28°C (RH 90%) and 30°C (RH 20- 60%). If natural ventilation strategies in building design are applied, this usage of air current can increase up to 32°C (RH 20%) (Zones V and V').

In normal buildings, electric evaporative coolers, which are the common cooling equipment in the (semi) hot and arid regions of Iran, respond to cooling requirement up to 35°C during the hot months of June and July (Zone EC). In buildings that are efficiently thermally insulated, and their outer layer is white or light-colored, this evaporative cooling equipment can be responsive to up to 41.5°C dry bulb temperatures (E'C).

For cold months, from September to March, the application of specific building materials compatible with Yazd's climatic conditions is recommended (H').

Days with temperatures higher than 25°C and relative humidity lower than 22% need vapor-producing equipment in this arid region.

REVIEW

According to the climatic conditions of Yazd, the comfort zone includes a short time of year during the month of April. During hot months of the year (May-October), specific cooling equipment is required to create comfortable conditions inside houses. In addition to this cooling equipment, if specific climate strategies are adapted in the design and construction of buildings, comfort conditions can be extended to support very hot and arid months with severe climatic conditions.

The same strategies work for cold months of the year. The application of specific materials can improve living conditions during cold times of the year, even when temperatures fall down to 10°C.

Temperature

Temperature statistics (1952-2010) show the average temperature in Yazd to be between 5.9°C to 32°C (IRIMO 2011).

The coldest month recorded is January (min -0.4°C and max 12.3°C) and the warmest month July (min 24.5°C and max 39.5°C) (IRIMO 2011).

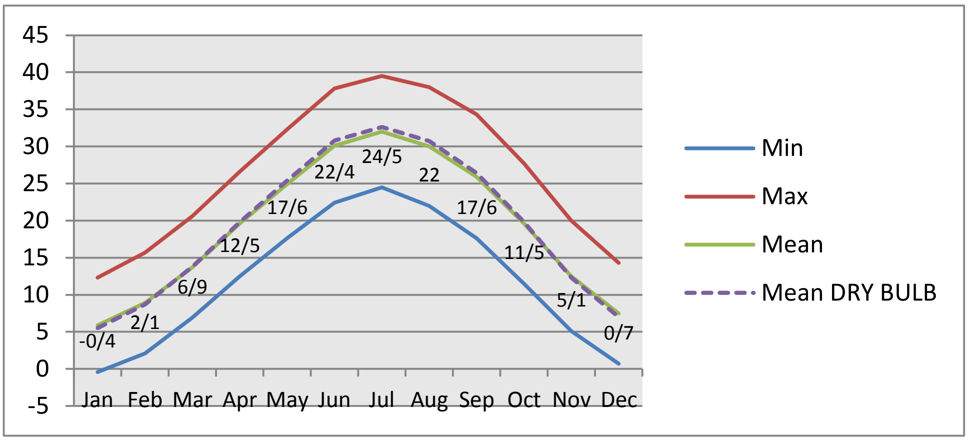


Chart 7, Monthly average of minimum, mean, maximum and dry bulb daily temperature in °C in Yazd (1952- 2010) Source: (IRIMO 2011)

The following chart shows a comparison between two cities of Yazd and Vienna in terms of monthly average minimum and maximum Temperatures in °C.

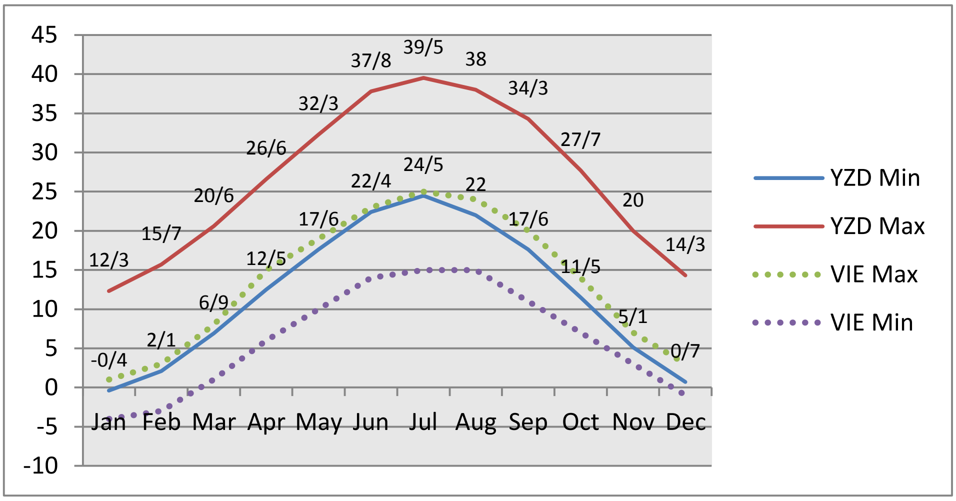


Chart 8, Comparison of monthly average of minimum and maximum daily temperature in °C between Yazd-IRAN and Vienna-AUSTRIA, Source: (IRIMO 2011), (Climate Data 2014)

Compared with a typical European city (Vienna), Yazd experiences higher temperatures throughout the whole year.

Relative Humidity

The following chart shows the monthly average percentage of minimum, mean, and maximum relative humidity (%RH) in Yazd (statistics of 1952 to 2010), as well as the mean percentage of relative humidity in the city of Vienna, Austria in order to better understanding the arid climate in Yazd.

As seen in the chart, even the highest values of the relative humidity in Yazd are dramatically lower than the average relative humidity in Vienna.

The monthly averages of the mean %RH in Yazd are 26% to 54% lower than that of Vienna (lowest difference in January and highest difference in August and September).

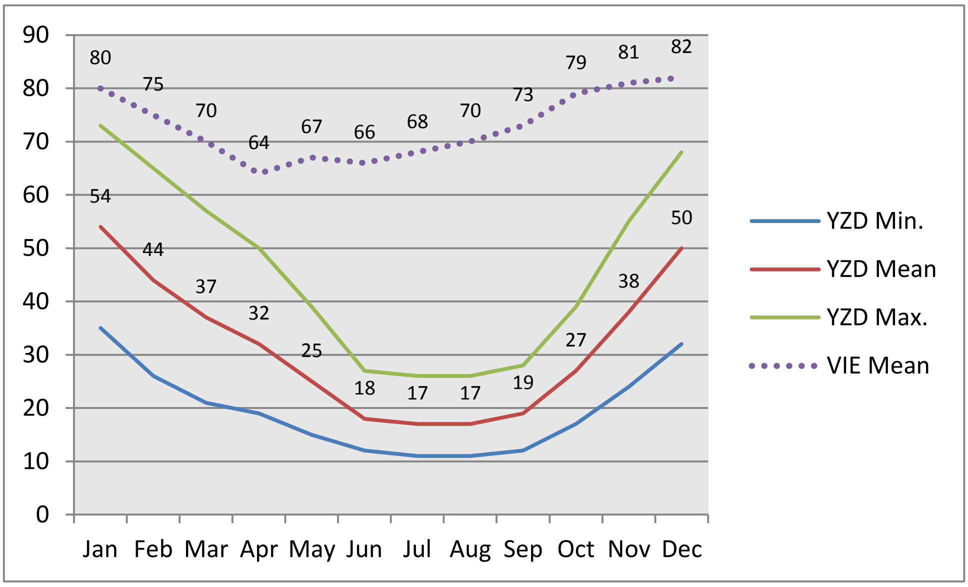


Chart 9, Monthly average of minimum, mean, maximum relative humidity in percent in Yazd (1952- 2010) And average of mean relative humidity in Vienna. Sources: (IRIMO 2011) (WWTO 2014)

This brief comparison shows the high rate of aridity in Yazd compared to a typical European city.

Wind

Wind is an important climatic factor in Yazd. Due to little vegetation and the prominence of barren mountains, winds blow in the region without any natural regulation from geological barriers.

The 2013 report by YCHHTO Documentation Center (YCHHTO 2013) states that the mean annual number of recorded days with windstorms in Yazd and the Ardekan plain is 57.8 days per year. The stormy season is during the spring, with storms containing fine particles of soil and desert sands travelling at a velocity of 90 km/h, sometimes even exceeding 120 km/h. Such sandstorms may occur three to four times during the year (YCHHTO 2013). Chart 10 shows the mean number of observation of wind blow in different months in Yazd.

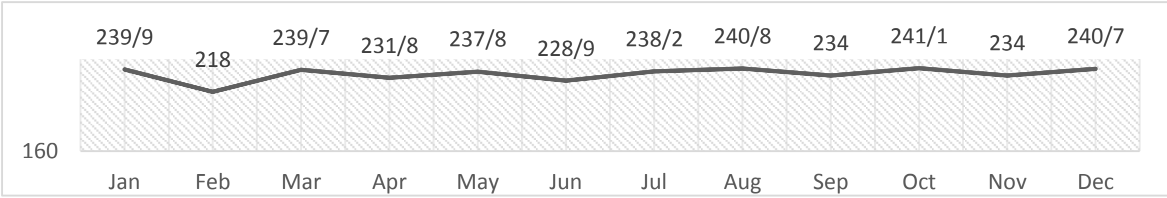


Chart 10, monthly mean recorded number of wind blow in Yazd (IRIMO 2011)

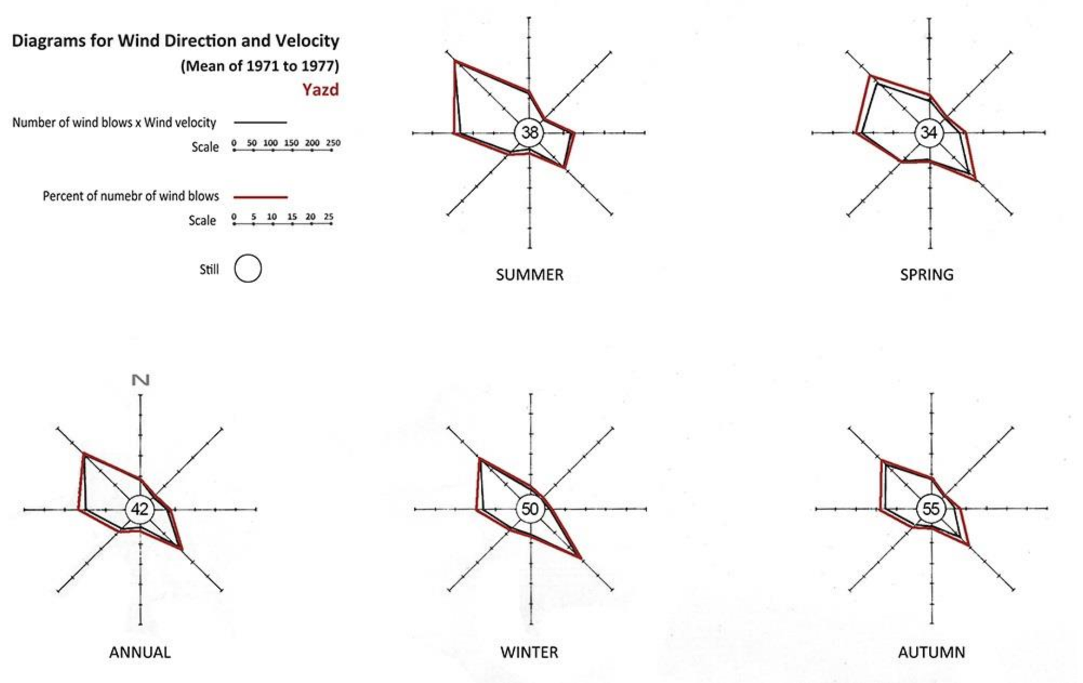


Figure 121, Diagrams for wind direction and velocity in Yazd (mean of 1971-77), source (Kasmaei 1984, 297)

Significant wind exists during all months of the year, and therefore has good potential as a clean energy resource in Yazd.
The probable sand and wind storms that blow in a different direction from favorable wind show the necessity for the adaption of specific strategies regarding wind.

Solar radiation

Metrological statistics of Yazd show the high rate of solar radiation in this area, either in terms of the number of sunny (clear) days or the length of sunshine hours during the day. This shows that solar radiation has a good potential in cold seasons and is a challenging consideration in warm and hot seasons. Hence the important issues are:

- Taking advantage of the natural solar radiation heating during the cold winter time
- Prevention of overheating in summer time

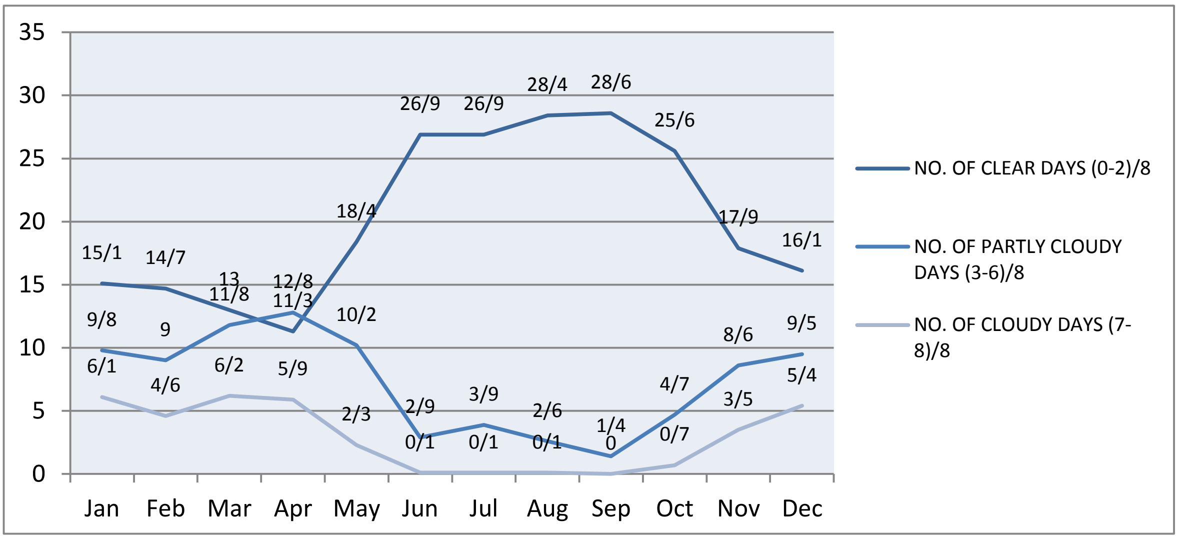


Chart 11, Monthly average number of clear, partly cloudy and cloudy days in Yazd 1952-2005, source: (IRIMO 2011)

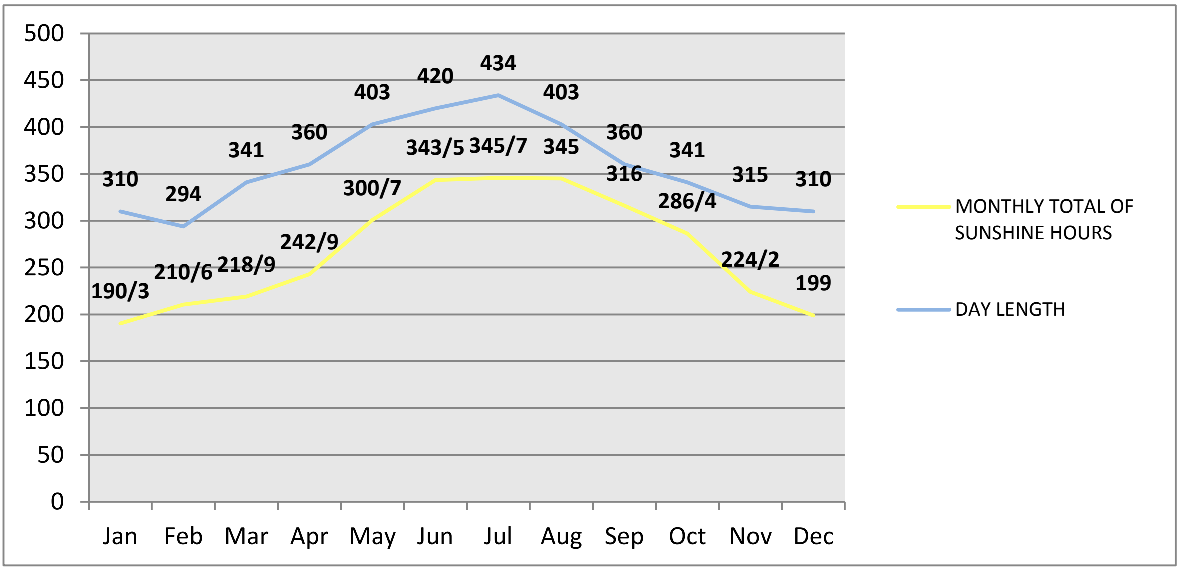


Chart 12, Monthly average of sunny hours in yazd 1971- 2005, source (IRIMO 2011)

Solar radiation in Yazd has a good potential as a clean energy source throughout the year.

SUMMARY

The city of Yazd benefits from high potential of clean energies such as wind and sun.
At the same time, the intense sun and the abundant wind in Yazd require regulation in order to achieve human comfort.
The bioclimatic chart of Yazd reveals that passive strategies such as benefiting from natural wind or sun radiation can extend the comfort zone in buildings in Yazd.

E1. Green Energy Sources

A. Contemporary Energy Sources in Building Sector In Iran

The comparison of the consumption of different energy sources in Iran to world averages shows that Iran is a relatively large consumer of natural gas and oil. The following chart shows the rate of consumption of different energy sources in Iran and the rest of the world in 2011. Iran's consumption of natural gas is 6.1 times the world average consumption, and oil and petroleum use is 1.6 times that of the world average.
The rate of consumption of renewable energy in Iran in 2011 is reported to be zero by the Iran ministry of Energy.

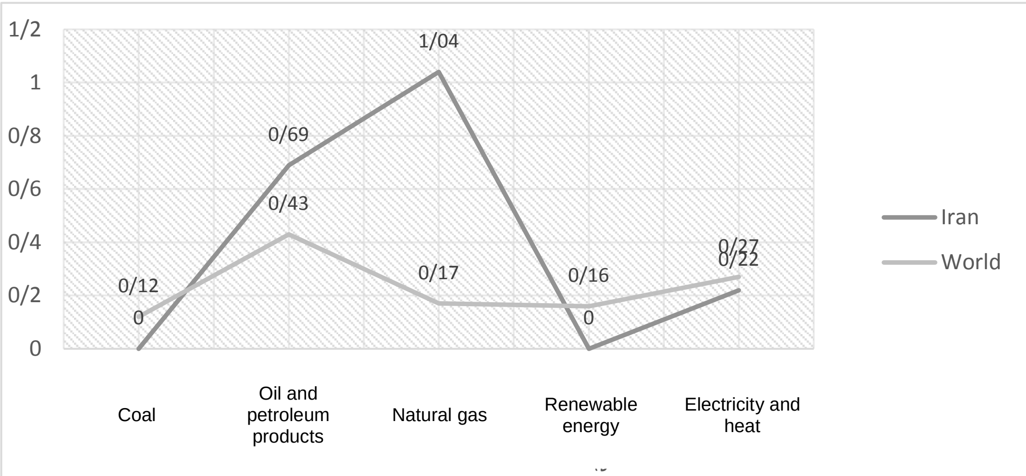


Chart 13, Energy consumption in 2011 (tons per capita), Source (IEEO-SABA 2012, 115)

Table 16 compares statistics of the World Bank on different energy consumptions (percentage per total consumption) in Iran and Austria in 2012. It demonstrates Iran's high dependency on fossil fuel energies.

ENERGY	DESCRIPTION	IRAN	AUSTRIA
Alternative and nuclear energy (% of total energy use)	Clean energy is non-carbohydrate energy that does not produce carbon dioxide when generated. It includes hydropower and nuclear, geothermal, and solar power, among others.	0.7	12.7
Combustible renewables and waste (% of total energy)	Combustible renewables and waste comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste, measured as a percentage of total energy use.	0.2	19.9
Fossil fuel energy consumption (% of total)	Fossil fuel comprises coal, oil, petroleum, and natural gas products.	99.3	66.7

Table 16, energy consumption in Iran and Austria, 2012 statistics of the World Bank, Source (World Bank 2014)

In addition, housing energy consumption in Iran constitutes a notable part of total energy consumption.

Table 17 shows the rate of total and housing sector energy consumption in 2010 in Iran, as well as the percentage of housing to total energy consumption.

Type of Energy		Housing	Total	Housing/Total%
Petroleum products	Liquefied Natural Gas LNG (m^3)	3893219	4476942	87%
	Gasoline (1000lit)	-	22365183	
	Kerosene(1000lit)	4817320	5311516	91%
	Diesel fuel (1000lit)	382547	34711205	
	Mazut (1000lit)	-	15495321	
	Other	1.4	6066	
Natural Gas*(million m^3)		46792.6	88525.9	53%
Electricity (million KWh)		60907.7	184179.4	33%

Table 17, Statistics for rate of consumption of different energies in Iran for housing consumers and the total consumption in 2010 (IEEO-SABA 2012)

* Total consumption by Housing, commercial and public consumers

Housing consumption constitutes a notable part of the total energy consumption in Iran:
Liquefied Natural Gas LNG: 87% of total national consumption
Kerosene: 91% of total national consumption
Natural Gas: 53% of total national consumption
Electricity: 33% of total national consumption (almost equal to the rate of industrial consumption of electricity, 61186 million KWh in 2010)

SUMMARY

- Contemporary housing in Iran constitutes a major percentage of the total rate of national energy consumption.
- The rate of consumption of renewable energy sources in Iran is zero (Iran Energy Balance Sheet Report 2012, Iran Energy Efficiency Organization, ministry of energy)
- Major types of energy resources that are consumed in Iran have notably higher rates than the world average (natural gas 6.12 times and oil 1.6 times the world average consumption), while renewable energy does not have a place as an energy resource in Iran.

B. Traditional sources of energies

As mentioned before, Yazd has high potential with its existing renewable resources of wind and solar energy.

High amounts of solar radiation throughout the year and long hours of sun radiation during the daytime as well as wind current from different directions toward the city present a good opportunity as two clean energy resources.

The severe climatic conditions in this desert area have inspired traditional architects in Yazd to take advantage of the microclimate features in order to utilize clean energy sources and avoid the desert climatic severities.

Micro climate

The climatic conditions of Yazd regarding human comfort standards are generally considered unfavorable due to natural climatic conditions (Ghobadian 1994) such as:

- Low precipitation
- Low humidity of air and far distance from the sea
- Big difference between day and night temperature (high thermal fluctuations between day and night)
- Little vegetation

One solution for making the area more habitable and creating conditions for living within the comfort zone is to take advantage of the microclimate. In traditional houses in Yazd, this microclimate is formed using introverted architecture, which faces the central courtyard in the middle of the house. These central courtyards help to create a favorable microclimate by taking advantage of wind and solar radiation, using elements such as a water pool, vegetation, and wind catchers.

The microclimate operates by bringing these elements together:

- Central courtyard
- Water pool
- Vegetation
- Wind catcher

Other elements such as basements or building materials such as adobe and clay mortar can also improve the operation of this small climatic system (see material chapter).

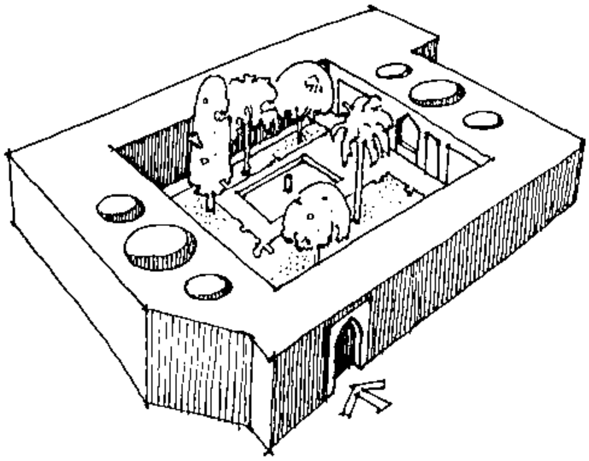


Figure 122, introvert pattern of houses with central courtyards in Iran's traditional desert architecture which create a more favorable microclimate comparing to the regions hot and arid macroclimate

Central courtyards improve microclimatic conditions, setting a higher quality of inhabitants' comfort through the use of:

- Air circulation
- Increasing the humidity of the air (with the aid of trees and vegetation, water pools, and clay walls)
- Decreasing the temperature (through shading by trees and deep walls as well as evaporative cooling, which is strengthened by wind catchers that contribute to better natural air ventilation in the courtyard)

Despite the fact that the term 'Microclimate' is a new word in traditional architecture of Iran and has not been used by researchers of this field, the performance of this climatic system has been widely mentioned and discussed before.

Tavassoli, in his book "*Urban Structure and Architecture in the Hot and Arid Zone of Iran*", described this system and its contributing elements using a small section from a house in Yazd (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002) (Figure 123).

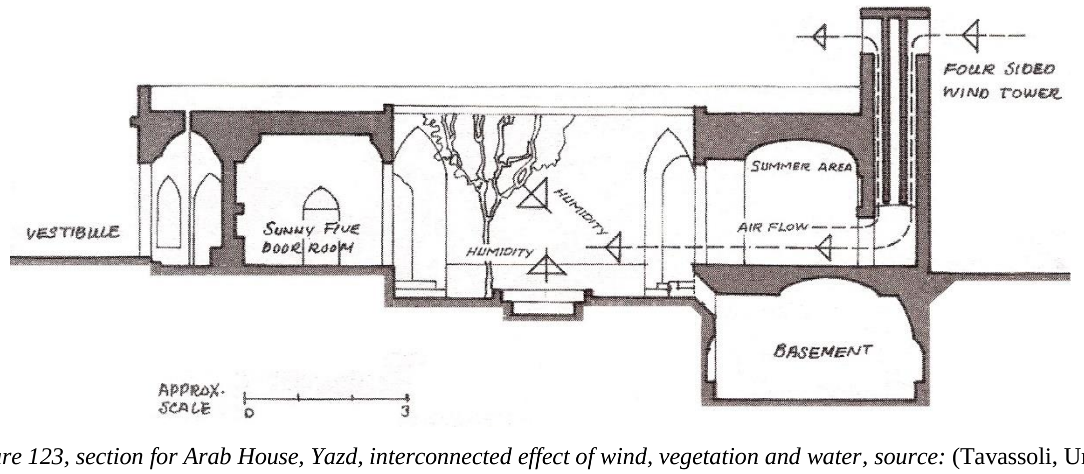


Figure 123, section for Arab House, Yazd, interconnected effect of wind, vegetation and water, source: (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002, 102)

Tavassoli explains that “the depth of a small central courtyard with high walls results in more shade during hot summer times. Besides, during nights when the air temperature falls down, cold and dense air sinks down into lower parts of courtyard, and stays cool until the sun rises to its highest point. As the sun rises and heats the courtyard, the temperature in summer-spaces, which is opposite to sun, is dramatically lower than outside temperatures. That’s why the underground cellar (*Sardāb*) is very cold most of the year.” (Tavassoli, Urban Structure and Architecture in the Hot and Arid Zone of Iran 2002, 102-103).

Case Studies

Following sections show how a system of central courtyard with its related elements such as wind catchers, water pools and trees organize the traditional houses in Yazd.

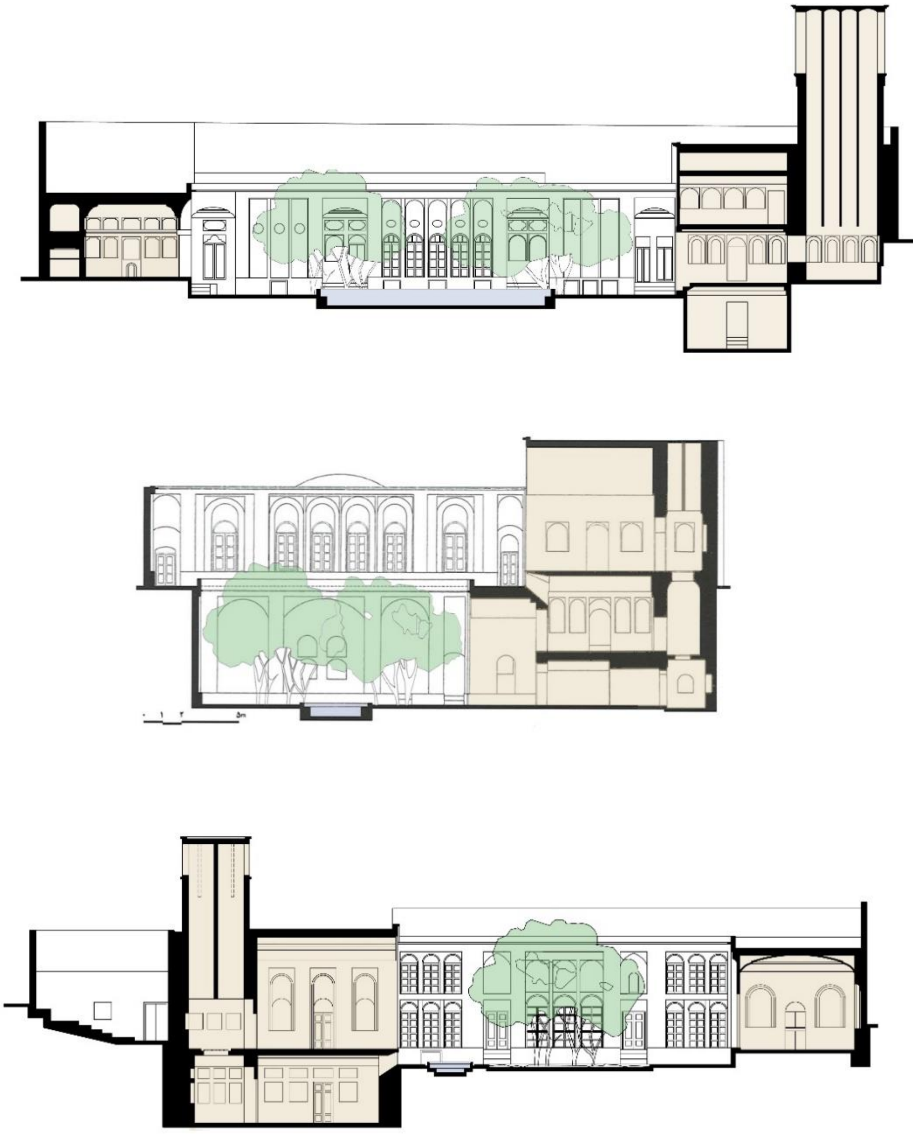


Figure 124, sections for traditional case studies (Lari, Olumi and Tehrani houses) and the contribution of microclimate elements in the house, drawing by author

The following table demonstrates the dimensions (meters) of central courtyards in three historical case studies, including the length, width, and height of central courtyards, as well as the thickness of building materials on each side of courtyards.

This can lead to the right proportions of mass and open space for achieving an effective microclimate system in courtyard houses.

		Lari	Oloumi	Tehrani
Courtyard Dimensions		20.36 x 33.87	10.27 x 16.56	9.42 x 16.76
Height	South	8.60	6.25	7.10
	East, North, West	6.25	6.25	6.5
Mass Depth	North	10	7	6.8
	East	11.5	5.7	7.70
	South	14.5	4.5	11.5
	West	12.5	5.5	10

Table 18, height and mass depth of different sides of the courtyard in traditional case studies

The results of this comparison is demonstrated in figure 125; the average proportions between different dimensions of courtyard (open space) and its surrounding rooms (building material).

Courtyard width = 2a
Courtyard length = 3.2 a ~ 3.5 a

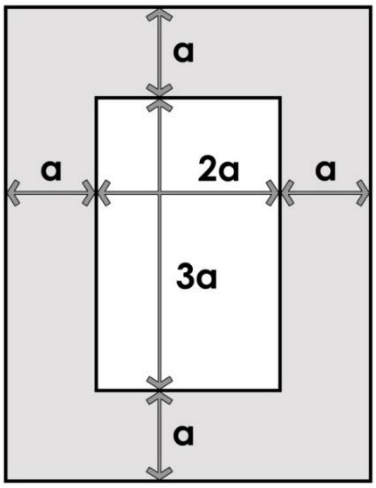


Figure 125, a simple pattern of the proportions of mass and void derived from the historical case studies, drawing by author

The above calculations show that in three historical case studies (Lari, Oloumi and Tehrani house), with an approximate proportion of 2 to 3 in the courtyards, the minimum depth of the mass around the courtyard is around half of the courtyard's width.

What defines the height of courtyard is a base height of about three steps above the courtyard floor plus one story high room, adding to the roof thickness plus the turret's height. It totals about 6.25 to 6.50 on three western, northern and eastern sides of the courtyards.

On the southern side, due to the climatic function of the southern space, including open summer *Eivans* that require a higher roof for better wind capture, as well as the circulation of air inside the space, the height of the southern side is usually higher than the three other sides of the courtyard.

The southern side of the courtyard has a height equal to the other sides in Tehrani house, and up to 2.35 meters higher in bigger courtyard of the Lari house.

This confirms the relation between the size of the courtyard and the Eivan, with higher southern facades.

Another factor which also affects the height of space is construction technology. Due to the construction restrictions, wider courtyards (like the Lari house) have higher southern Eivans. This is because covering larger Eivans requires higher vaulted roofs or (half) domes.

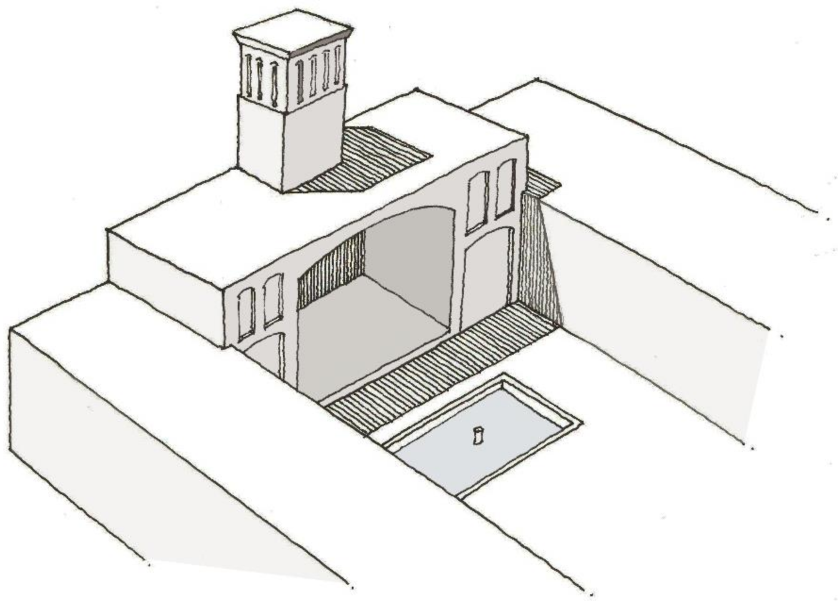


Figure 126, higher roof on Southern side of the central courtyard (Eivan and wind catcher), drawing by author

SUMMARY

The contemporary housing industry in Iran does not use renewable and green energy as sources of energy. It is a major consumer of nonrenewable energy sources, e.g. LNG and Kerosene.

There are neither any specific strategy nor mandatory rule to use renewable energy sources in houses as a source for providing the required energy for heating, cooling and lighting in contemporary Iran.

All three traditional case studies, Lari, Oloumi and Tehrani houses, benefit from wind and solar radiation by the implementation of a microclimate system in their central courtyards, with the aid of wind catchers, water pools, and vegetation, to passively obviate part of the energy demands in houses by using the green energy sources of wind and sun.

The focal element in this microclimate is the central courtyard. Geometrical study on the central courtyards in the traditional case studies show average area of approx. 10x15 m^2 to 20x33 m^2.

This reveals a proportion of around 2:3 (width/length) regarding courtyard plan dimensions and a height of 6.25 to 6.50 on three western, northern and eastern sides.

The southern side of the courtyard can rise up to 2 meters higher than the other sides in larger courtyards in order to improve the operation of this opposing-sun side of the courtyard for shading and better air circulation in the whole microclimate system.

Further characteristics and properties of central courtyards will be discussed in the following parts.

E2. Minimizing Energy Needs

The main focus of this part is the application of passively provided clean energies in houses and its reduction of household dependency on fossil fuel energies. The strategies that assist in more passive solar heat gains during the winter as well as passive ventilation and cooling during the summer will be reviewed.

In arid cities like Yazd, this becomes a challenging issue for designers due to the significant summer heat and winter coldness. Design strategies must take into consideration both conditions, for both cold and warm times.

A wide range of design strategies relate to this issue, such as the orientation of house on the North-South axis, dimensions of house, proportions of courtyards, inward/outward organization, etc.. This part focuses on the influence of the following features for minimizing (fossil fuel) energy needs in houses:

- Optimal shading in summer and winter
- Greatest solar gain in winter
- Best natural ventilation and passive cooling

A. Optimal Shading in summer and winter

Providing residents with sufficient shading is important in desert areas, because the difference between the temperature of shaded areas and the parts exposed to the sun is rather high due to the aridity of the air.

One recorded measurement reports air temperature of the outer passageway and inner courtyard of the Boroujerdiha house in Kashan in a hot and arid region of Iran. The air temperature at 11:30 am on 25th September was recorded to be 36°C in the passageway, 32°C in the central courtyard, and 24°C in the cellar (Ghobadian 1994, 131).

Design strategies for shading

On the city scale, traditional builders adapt strategies such as creating deeper and narrower proportions of passageways or constructing vaulted roofs over passageways *(Sābāt)* to support high walls and simultaneously provide more shade.

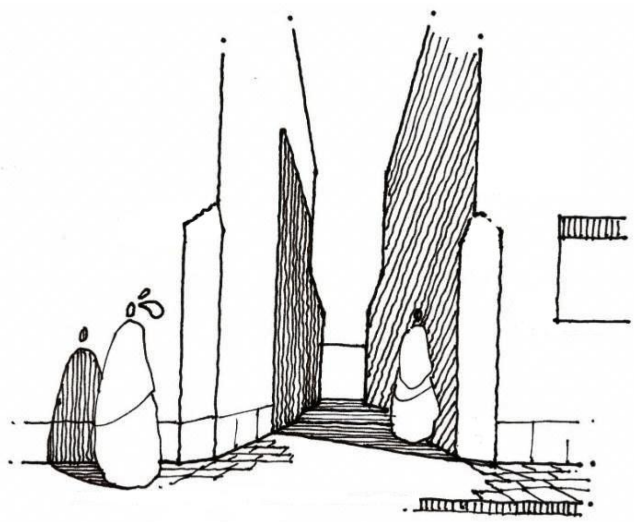


Figure 127, narrow passageways with high walls in Yazd to provide more shading for the passengers, drawing by H. Abbasimehr

On the architectural scale, the contribution of the following two architectural design strategies to the amount of shading in case study houses will be discussed:

- Orientation of central courtyards on the north-south axis
- Proportions of central courtyard

The orientation of the house plays a major role in contributing to the amount of gathered solar energy in the summer and winter.

As mentioned before, in desert areas on warm days, more shading is desired; and on cold days, more solar radiation is beneficial.

The report by Yazd CHHTO mentions that the best orientation of houses in Yazd for achieving natural heating and avoiding the intense midday solar radiation is between 20° to 30° due southwest (YCHHTO 2013).

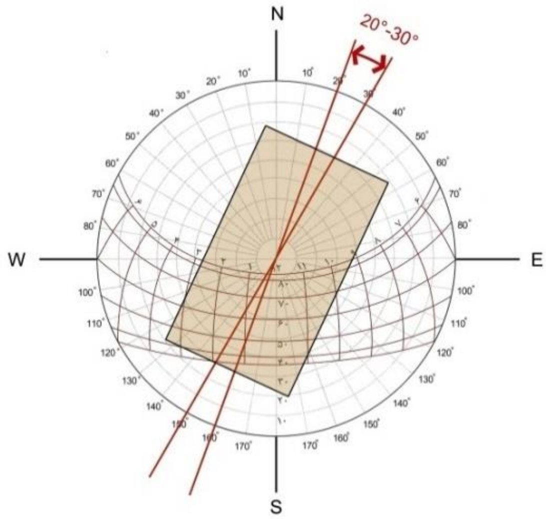


Figure 128, the best direction for the sun radiation in Yazd: 20°-30° NE-SW, drawing by author

In order to develop a better understanding of the role of house orientation in shading, the shaded area of three sample houses with central courtyards are investigated at five different times of the day: 08:00, 10:00, 12:00, 14:00, and 16:00.

In order to measure the shaded area within courtyards, the azimuth and altitude of the sun at these specific times on the 21st of June (summer solstice) and 21st of December (winter solstice) are measured on solar path graph for Yazd.

Figure 130 illustrates the shaded area within three different central courtyard plans with dimensions of 1:1, 2:3 and 3:4.

The average shaded area within each courtyard is calculated separately on June 21st and December 21st.

In order to compare the results for the different cases, the percentage of average shaded area is divided into the related courtyard's area.

$$\text{Average shaded area (at a specific time)} = \frac{\text{Sum of shaded area (at 08:00', 10:00', 12:00', 14:00', 16:00')}}{5}$$

$$\text{Percentage of average shaded area per square meter of the courtyard area} = \frac{\text{Average shaded area}}{\text{Courtyard's area}} \times 100$$

The results are presented and compared in two charts for summer and winter.

The three proportions of courtyards (1:1, 2:3 and 3:4) are chosen in order for the courtyard plan proportions and the amount of average shaded area in the summer and winter to be compared as well, in order to explore the effect of proportions on shading.

Note: The height of the courtyard in all case studies is assumed to be 6 meters, as is common in Yazd courtyard houses.

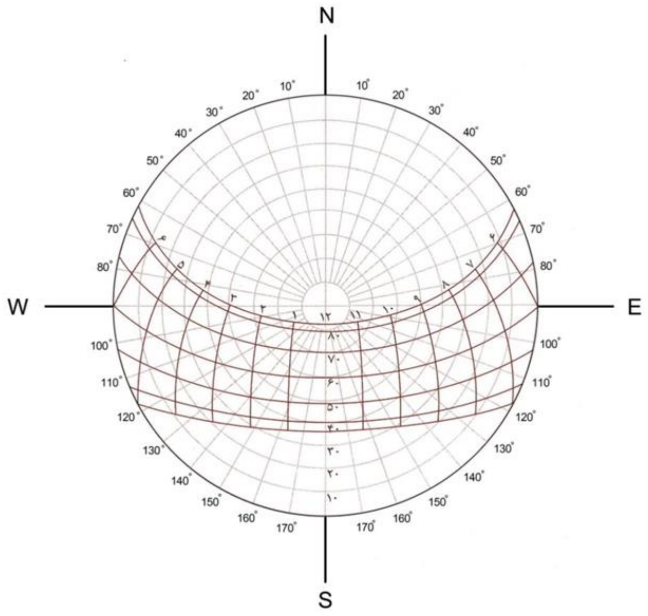
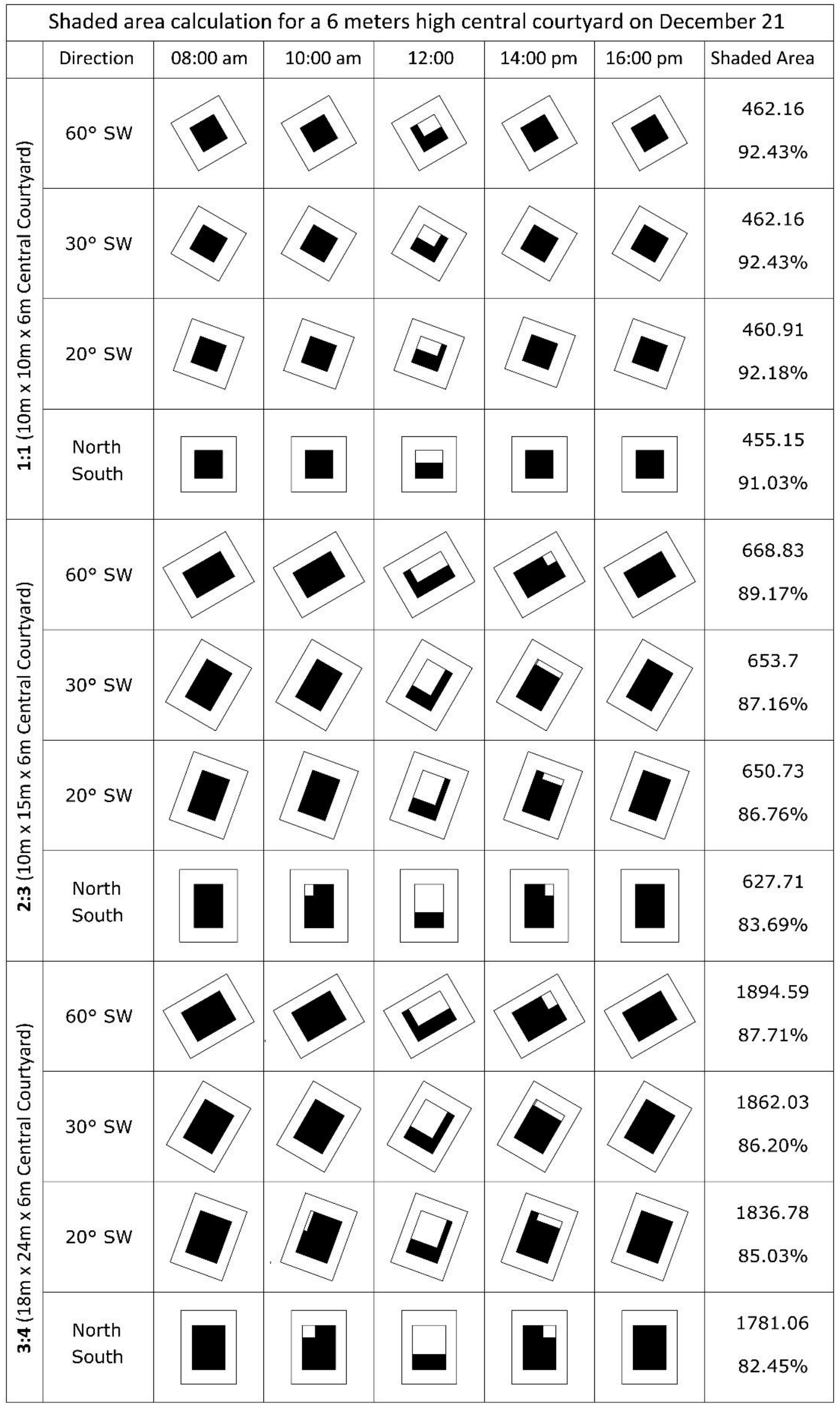
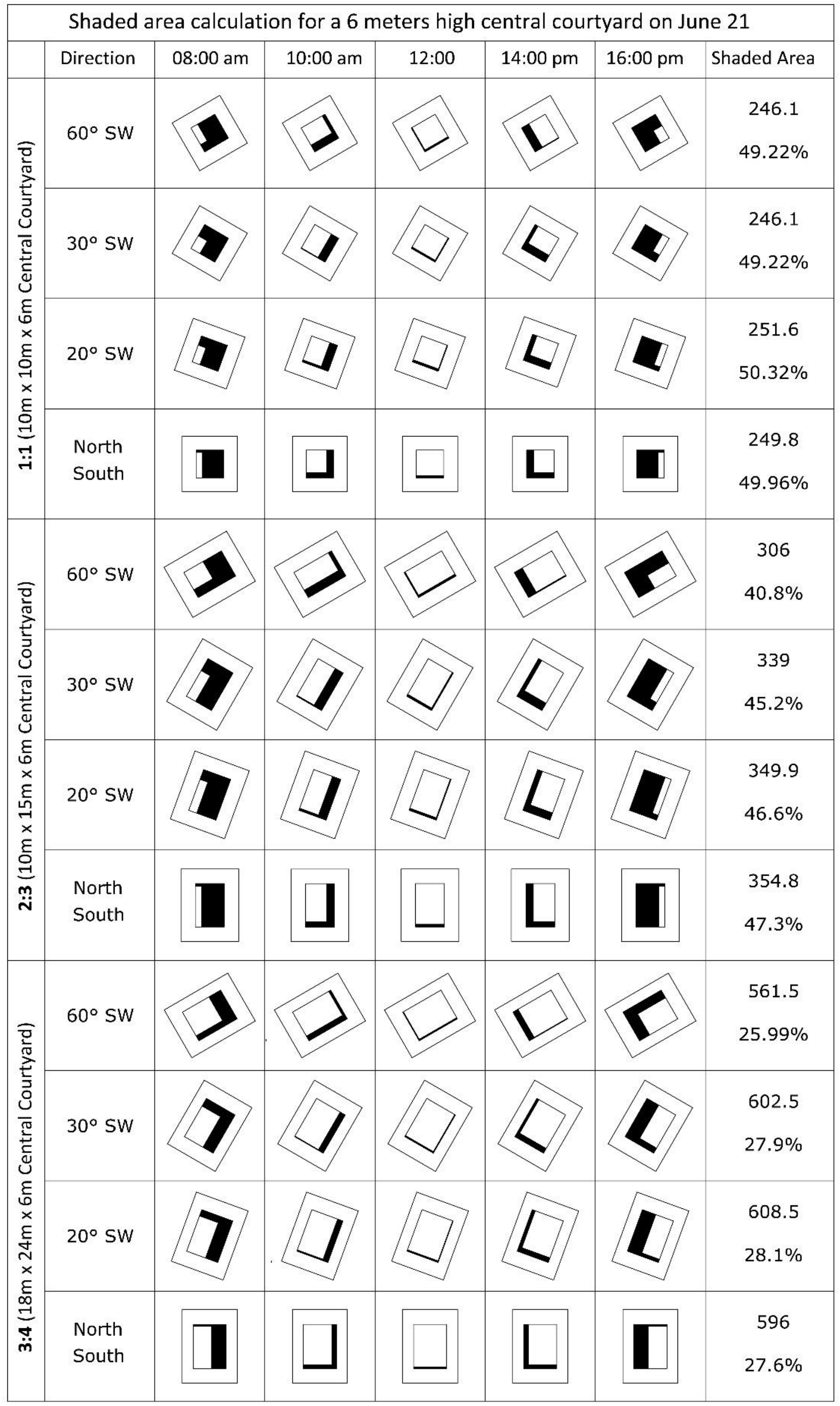


Figure 129, solar path diagram in 31° N, Yazd, source (Kasmaei 1984, 237)

Time	June 21		Dec 21	
	Azimuth	**Altitude**	**Azimuth**	**Altitude**
08:00 am	83	37	126	11
10:00 am	98	62	148	29
12:00	180	82	180	36
14:00 pm	-98	62	-148	29
16:00 pm	-83	37	-126	11

Table 19, Calculation of Sun azimuth and altitude in different times of the day on June 21st and Dec 21st in Yazd





Right: Figure 130, measurement of shaded area in different plan proportions at different times on winter and Summer solstice
For easier comparison, the height of all the courtyards are 6 meters, as it is generally in historical houses in Yazd.

The results are illustrated graphically in the following charts for easier comparison:

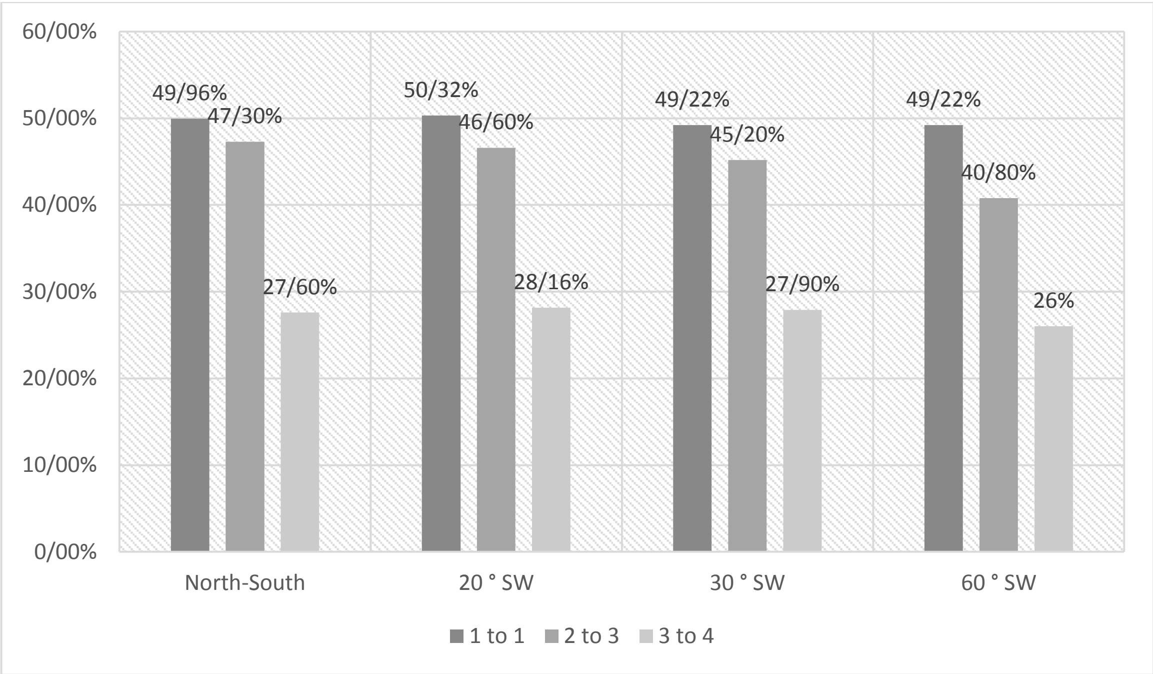


Chart 14, Comparison of percentage of average shaded area of a 1:1 and a 2:3 sample central courtyards on June 21st in Yazd

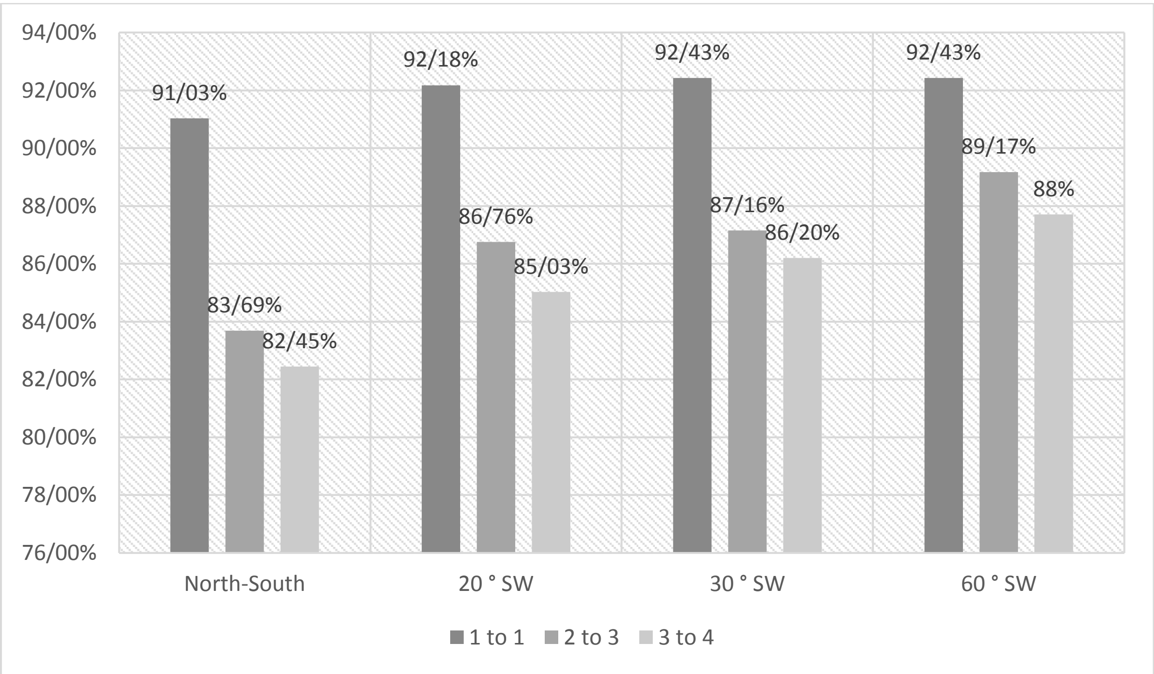


Chart 15, Comparison of percentage of average shaded area of a 1:1 and a 2:3 sample central courtyards on December 21st in Yazd

RESULT 1

Orientation and shading

- Summer Shading

A comparison of the results shows that the orientation of the central courtyard between 0 to 30° due Southwest has the highest percentage of shading (per square meter of the courtyard area) in all studied plan proportions of the courtyard on the Summer solstice. Further rotation of the house due west would result in a reduction of the total shaded area of the courtyard (60° due Southwest).

- Winter Shading

A comparison of the orientation of central courtyard reveals that as the rotation degree of the house due Southwest increases, the average shaded percentage in all plan proportions of courtyard increases as well.
In other words, the lowest shaded percentage on the winter solstice belongs to North-South oriented plans, and the highest shaded percentage belongs to plans oriented 60° due Southwest.

RESULT 2

Courtyard Proportion and Shading Performance

Comparison of the average shaded area percentage (per square meter of the courtyard's area) in the three different proportions of central courtyards reveals that the most balanced shading performance between summer and winter belongs to the 2:3 proportioned courtyard.

In comparison, the 1:1 courtyards yield a high shading percentage in both the summer and winter, which is unfavorable.

The 3:4 courtyards yield the lowest shading percentage in the winter, but it also yields the lowest percentage of shading in summer, which is unfavorable.

Note I. The role of exposed solar radiation throughout the year in proper operation of microclimate in courtyard must be taken into account. The microclimate system needs evaporative cooling by sun radiation to function effectively.

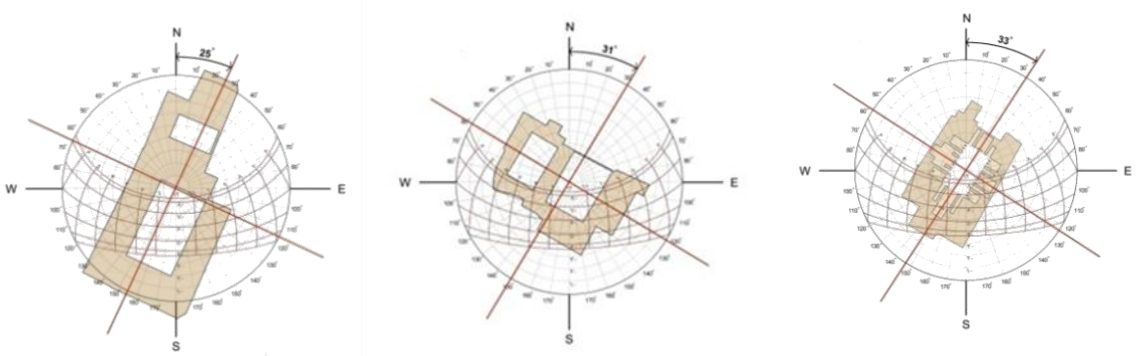
Note II. A longer proportion of central courtyard along the wind blow direction is effective for increasing the airflow current in the courtyard, specifically when the length of the courtyard is oriented towards the favourable Summer breeze, which originates from the Shirkouh mountains in the southwest of Yazd.

Note III. Another source of shading in these central courtyards is vegetation. Local trees and vegetation that need little water for irrigation can produce ample shading and at the same time contribute to better evaporative cooling (through leaves). Trees also protect the house from suspended particles and dust in the air and result in healthier and a higher quality of air in the house.

Case Studies

Orientation

The following figures show the orientation degrees in the six case studies in Yazd.



Lari House
25° NE-SW

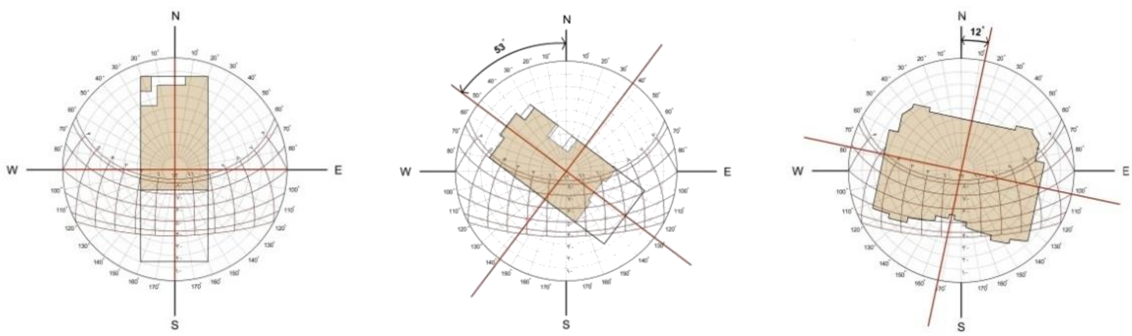
Oloumi House
31° NE-SW

Tehrani House
33° NE-SW

Figure 131, oreintation of traditional case study houses, drawing by author

The three historical houses follow the best orientation for taking advantage of the solar radiation and avoiding overheating (around 30° due southwest).

Contemporary case study houses follow contemporary urban divisions suggested in Yazd's master plan. Despite the mostly homogeneous southwest orientation (Ron) of the traditional urban fabric in Yazd, the contemporary urban fabric's orientation varies dramatically in different parts of the city and neglects climate responsive patterns.



Atlassi House
0° N-S

Mir-Hosseini multi-level
53° NW-SE

Sima Gostar complex
12° NE-SW

Figure 132, oreintation of contemporary case study house, drawing by author

Note: Shading performance of extroverted contemporary housing requires further investigation, and it is out of the scope of this research. However, contemporary housing normally has southern courtyard that are sun-oriented. The light hitting left and right facades is also shaded by the neighboring buildings with single-family houses or multilevel apartments. Therefore, the majority of openings are located on southern façades and are open to direct sun during the day.

SUMMARY

The three traditional case studies benefit from a proper solar design approach in terms of more shading in the summer and less shading in the winter in the central courtyard. This is obtained by an orientation of the main courtyard axis at 20° to 30° due southwest.

Following the Yazd master plan land-divisions, present contemporary housings vary dramatically regarding geographical orientation and do not follow any specific direction for improving shading performance.

The extrovert concept of the houses as well as southern courtyards result in mostly unshaded openings in houses (Southern windows)

Plan Proportions

The following table shows the proportions of the (main) courtyard in traditional case studies in Yazd. All three cases have a proportion of around 2:3 between width and length of the courtyard which results in their best performance for optimal shading in summer and winter time (see Chapter E2.A).

	Lari	**Oloumi**	**Tehrani**
Courtyard dimensions	20.36m x 33.87m	10.27m x 16.56m	9.42m x 16.76m
Proportions	2 : 3.3	2 : 3.3	2 : 3.5

Table 20, plan proportions of courtyards in traditional case studies

RESULT

Courtyards of the three traditional case studies match the best proportions of the courtyard size (width to length= 2:3) for best shading performance in summer and winter.

B. Natural Heating; Greatest Solar Gain in winter

In spite of different patterns of introverted traditional and extroverted contemporary housings, the central courtyards in traditional houses as well as the southern courtyards in contemporary housing result in notable solar gain on south-facing vertical surfaces.

This radiation can be beneficiary as a passive solar energy source during cold months. However, the design strategies must lead to a non-excessive solar gain in warm times too.

Case Studies

Traditional case study houses have nearly identical performance regarding passive solar gain on vertical southern surfaces due to their similar orientation angle (Figure 67).

The Atlassi single-family house has a North-South orientation that can result in summer overheating in the house, while a significant percentage of the southern walls are glass openings. According to LEED, the necessary shading for windows in the summertime must be considered (USGBC 2013, 53).

Mir Hosseini multi-level housing is oriented due southeast, which is not useful for natural heating possibilities regarding the solar path in Yazd.

In the Sima Gostar residential complex, the division of each level into four units (two northern and two southern) prevents northern units from being exposed to direct solar radiation.

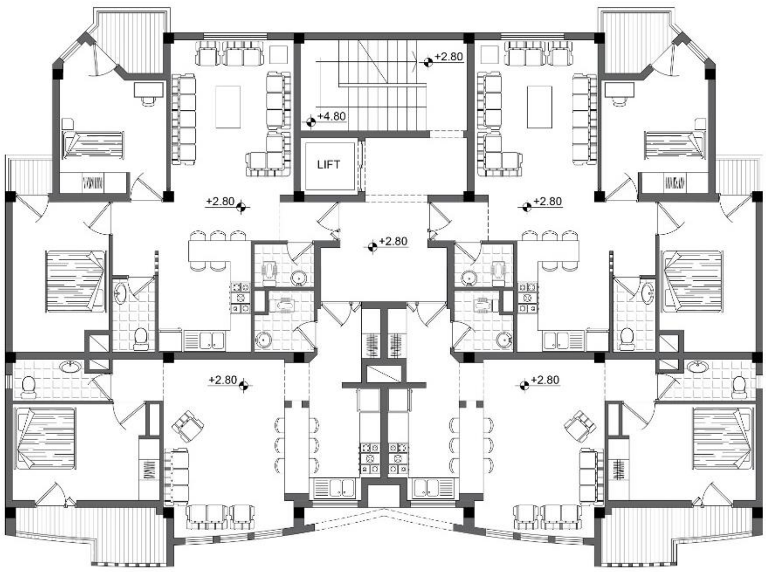


Figure 133, typical floor plan of Sima Gostar 122 unit residential complex in Yazd, source (Honar Saraye Memari Consulting Engineers 2013)

The following is a calculation of the amount of solar radiation on southern vertical surfaces in BTU/h/ft², at 12:00 o'clock on June 21st and December 21st, using a solar protractor at the relevant degree of the case study houses.

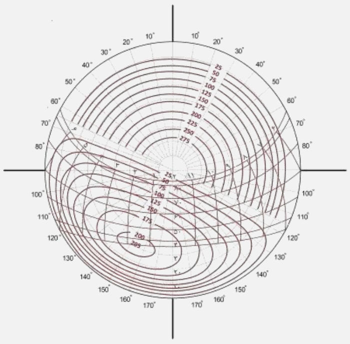
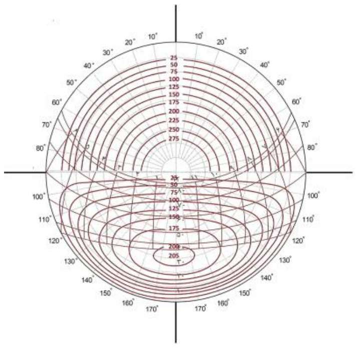
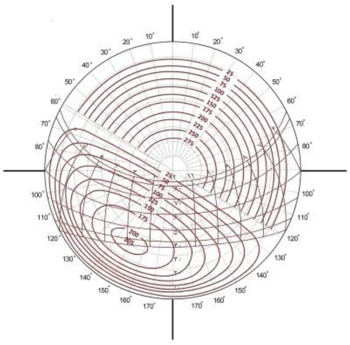
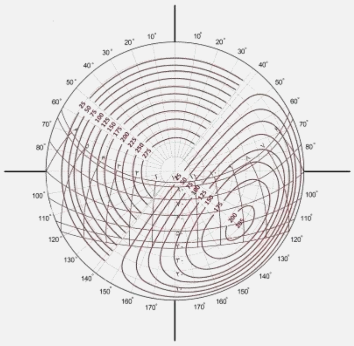
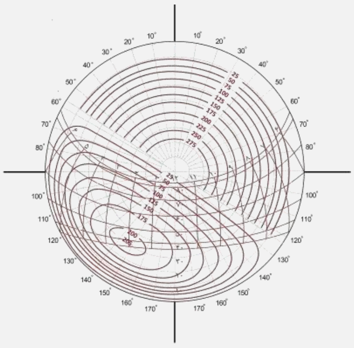
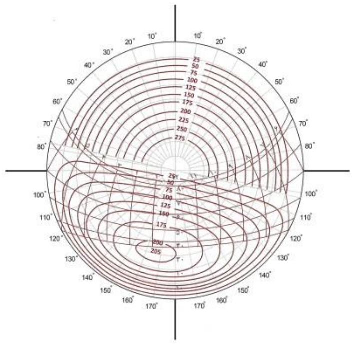
<table>
<tr><th colspan="3">Historical Houses</th><th colspan="3">Contemporary Houses</th></tr>
<tr><td colspan="2">Lariha</td><td rowspan="4"></td><td colspan="2">Atlassi</td><td rowspan="4"></td></tr>
<tr><td colspan="2">25° SW</td><td colspan="2">0° North South</td></tr>
<tr><td>Jun</td><td>36 BTU/h/ft²</td><td>Jun</td><td>42 BTU/h/ft²</td></tr>
<tr><td>Dec</td><td>185 BTU/h/ft²</td><td>Dec</td><td>202 BTU/h/ft²</td></tr>
<tr><td colspan="2">Oloumiha</td><td rowspan="4"></td><td colspan="2">Mir Hosseini</td><td rowspan="4"></td></tr>
<tr><td colspan="2">31° SW</td><td colspan="2">53° SE</td></tr>
<tr><td>Jun</td><td>33 BTU/h/ft²</td><td>Jun</td><td>25 BTU/h/ft²</td></tr>
<tr><td>Dec</td><td>176 BTU/h/ft²</td><td>Dec</td><td>125 BTU/h/ft²</td></tr>
<tr><td colspan="2">Tehraniha</td><td rowspan="4"></td><td colspan="2">Sima Gostar</td><td rowspan="4"></td></tr>
<tr><td colspan="2">33° SW</td><td colspan="2">12° SW</td></tr>
<tr><td>Jun</td><td>32 BTU/h/ft²</td><td>Jun</td><td>38 BTU/h/ft²</td></tr>
<tr><td>Dec</td><td>171 BTU/h/ft²</td><td>Dec</td><td>192 BTU/h/ft²</td></tr>
</table>

Figure 134, Solar Protractor for calculation of sun Radiation on Southern vertical surfaces BTU/h/ft² at 12:00 am in June and December, graphics by author

LEED

LEED in one part of EA credits (for homes) concerning the architectural design pattern contribution in reduction of energy consumption and greenhouse emission mentions the "Building Orientation for Passive Solar" (USGBC 2013, 53), which focuses on designing to maximize opportunities for solar design.

LEED points out that, for areas north of 25 degrees of latitude, the east-west axis of the building is to be within 15 degrees of due east-west.

In areas south of 25 degrees of latitude or where topography significantly impacts insolation, orientation may be adjusted to meet local conditions provided the team provides documentation to demonstrate that its building orientation decision is based on solar and meteorological data for the site.

Comparison

The following chart simplifies the comparison and illustrates that the rate of solar radiation on southern vertical surfaces in Atlassi and Sima-Gostar contemporary housings are the highest among the case studies; but, at the same time, their rate of insolation in the summer is also at a high level.

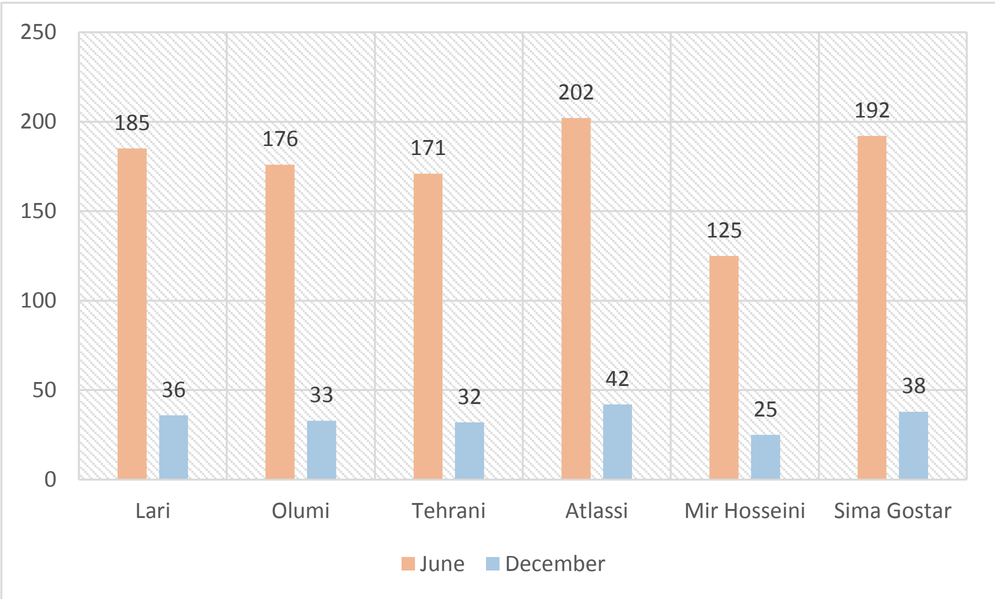


Chart 16, Comparison of the rate of solar radiation on vertical surfaces BTU/h/ft² at 12:00 am in June and December

The three traditional case studies (Lariha, Oloumiha and Tehraniha mansions) have a more balanced performance in terms of the rate of solar radiation on their southern vertical surfaces both during the summer and winter, in comparison to the contemporary housings.

The contemporary Mir Hosseini multilevel house has the lowest rate of solar radiation of all, both in the summer and winter, due to its southwest orientation.

RESULT

Rotation of houses between around 20° and 30° due southwest (traditional case studies rotating 25°, 31° and 33° SW) results in the balanced performance of passive solar energy gain on southern vertical surfaces in the summer and winter.

Rotation below this range (contemporary case studies rotating 0° to 12° SW) results in higher amounts of solar radiation in the winter (10% more than the average of traditional houses), as well as higher solar gain in the summer (21% more than the average of traditional houses).

Rotation due southeast results in much lower solar gain both in the summer and winter (compared to the average for the five other case studies, 11.2 BTU/h/ft reduction for winter amounts and 28.4 BTU/h/ft below the average in summer)

C. Best Natural Ventilation and Passive Cooling

Orientation

As mentioned before (see wind chart), wind is a viable energy source in Yazd all throughout the year.

The prevailing wind source in the hot season is from the northwest and the second wind in this season blows from the west. In the cold season, the prevailing wind blows from the southeast and the second wind from the northwest. Favorable winds blow from the Isfahan direction in the northwest and the Shirkouh mountain in the southwest (YCHHTO 2013).

Figure 135, Winds in Yazd, drawing by author

Ron

Traditional Iranian architecture and urbanism benefits from a strategy for taking advantage of favorable winds and insolation named “Ron” (Pirnia and Memarian, Introduction to the Iranian Islamic Architecture 2013, 155). Ron is defined as the direction and angle of urban texture that matches the best orientation to benefit from winds and solar radiation.

There are three Rons, located in different regions: *Raasteh*, *Kermani* and *Isfahani*. These Rons are resulted from a rectangular shape in different directions inscribed in hexagon (Figure 136).

Yazd's urban texture orientation follows the *Raasteh* Ron in the due northeast-southwest direction. (Pirnia and Memarian, Introduction to the Iranian Islamic Architecture 2013, 155)

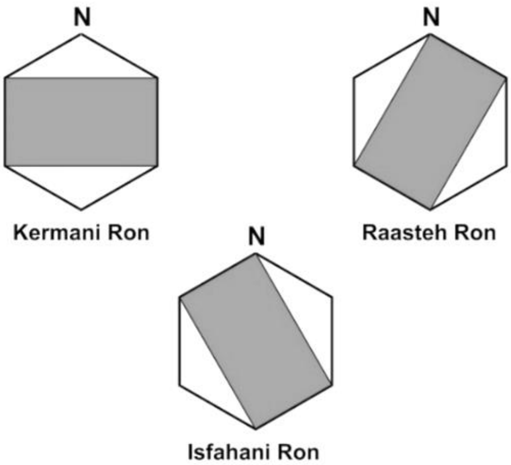


Figure 136, Rons in Iran, image from (Pirnia and Memarian, Introduction to the Iranian Islamic Architecture 2013, 155)

The Yazd ICHHTO report describes this *Ron* more accurately. Regarding the wind direction in Yazd, this report determines that the best housing orientation for both benefiting from the cool summer breeze and avoiding sandstorms is 20°-45° due southwest (YCHHTO 2013).

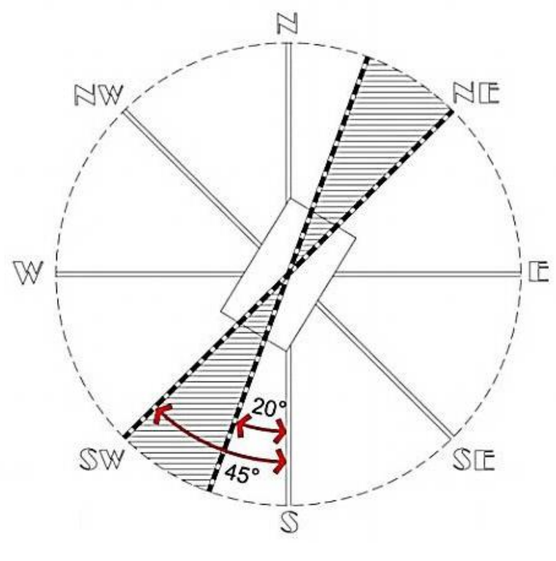


Figure 137, Yazd Ron: best direction for taking advantage of cool summer breeze, drawing by author

The following figures show the direction of the major axes of the six case studies.

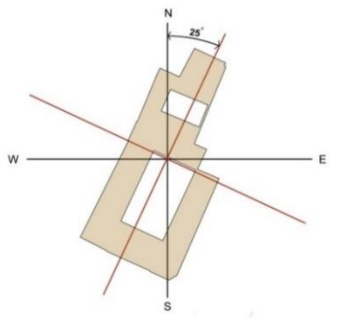
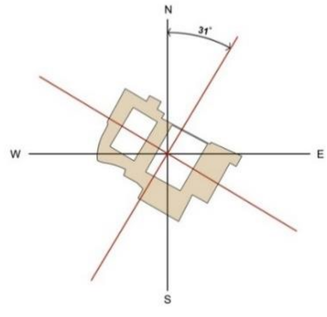
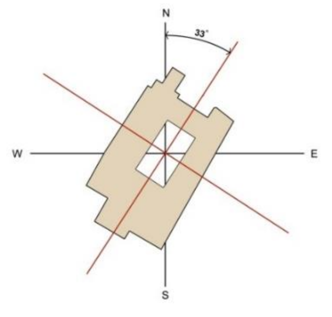
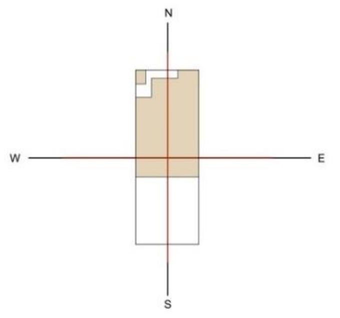
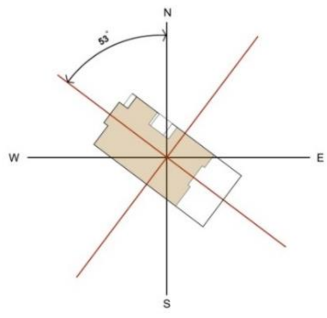
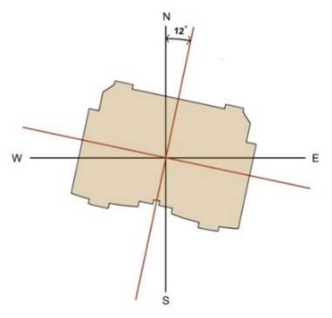
Lari-ha House	Olumi-ha House	Tehrani-ha House
		
25° NE. SW	31° NE. SW	33° NE. SW
Atlassi House	**Mir-Hosseini House**	**122 unit Sima Gostar**
		
0° North. South	53° NW. SE	12° NE. SW

Figure 138, comparison of direction of major axes of the central courtyards in the case study houses

RESULT

A comparison of case studies reveals that all the three traditional housing types are oriented in a good range of directions for benefitting from favorable wind and avoiding the cold winter winds.

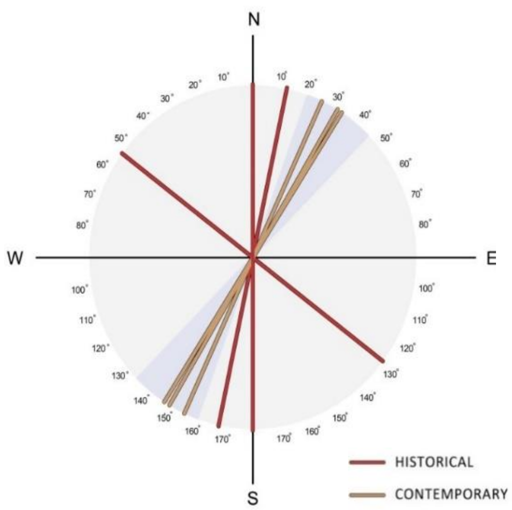


Figure 139, Comparison of orientation of case study houses, drawing by author

Wind Catcher

As mentioned before, wind catcher is an effective element in the performance of microclimates, in combination with the central courtyard (see Chapter E1, B).

Ventilation in closed, introverted, and central courtyards is created using wind catchers (*Bād-gir*) located to the south of the courtyard.

Wind catchers contribute to thermal comfort in central courtyard houses through:

- Natural Ventilation
- Evaporative Cooling

Natural Ventilation

Wind catchers contribute to natural ventilation (Mahmoodi 2009, 42) through:

- Air suction up when the wind does not blow, or blows at a very low velocity; this is called the "chimney effect". The higher surfaces of the wind catcher get warmer because of the sun radiation, and therefore the air flows from the bottom to the top of the tower, and negative pressure around the tower sustains this air flow.

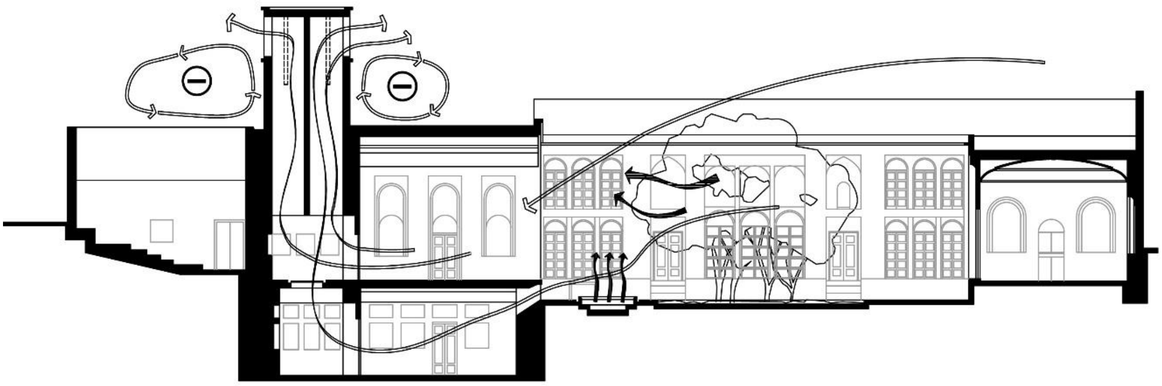


Figure 140, Section of Tehraniaha House 4 sided wind catcher and central courtyard
Airflow when the velocity of wind is very low or zero, drawing by author

- While wind blows at higher velocities, the positive pressure at the sides of the wind tower, facing the wind, as well as the negative pressure that forms on the opposite sides of the wind catcher, pushes the fresh wind down the tower. This fresh air enters the living space. Exhausted air is sucked up from the opposite side.

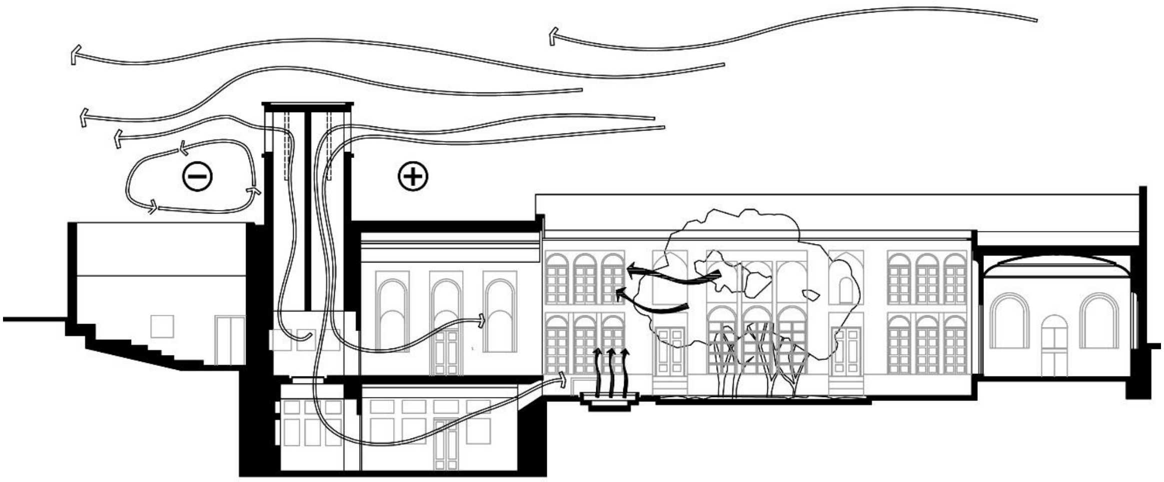


Figure 141, Section of Tehrani House 4 sided wind catcher and central courtyard
Airflow when the wind blows at a high velocity, drawing by author

Evaporative Cooling

Wind catchers can also contribute to cooling of the spaces. Besides natural air ventilation, this circulation system also humidifies the arid air when water pools or vegetation are added to this system. A water pool is located in the courtyard, usually between the garden and the summer space. Sometimes a small pool is also placed under the wind tower or in a small room between the wind tower and the summer space.

This water evaporates faster when the arid air passes over it, and therefore absorbs the air heat to get the required energy for evaporation; this causes a reduction in air temperature. Meanwhile, the water vapor also humidifies the arid air, which results in healthier air.

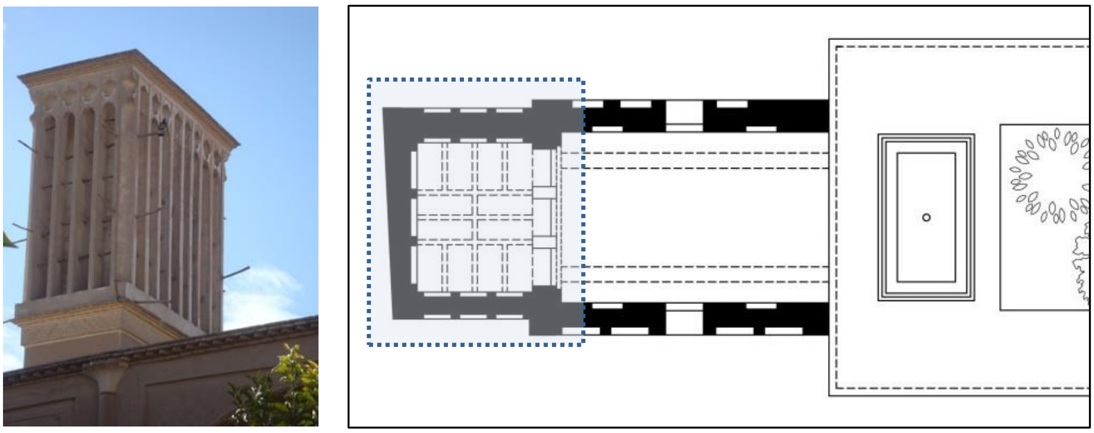


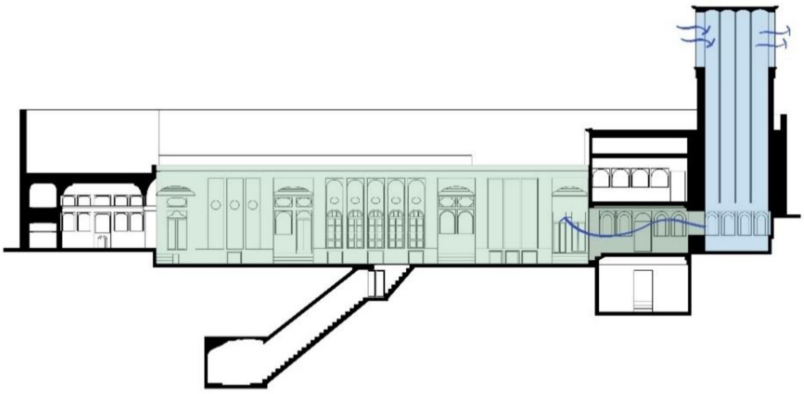
Figure 142, Tehrani House 4 sided wind catcher
Photo and plan of wind catcher and the front Eivan, facing the pool and garden in the courtyard

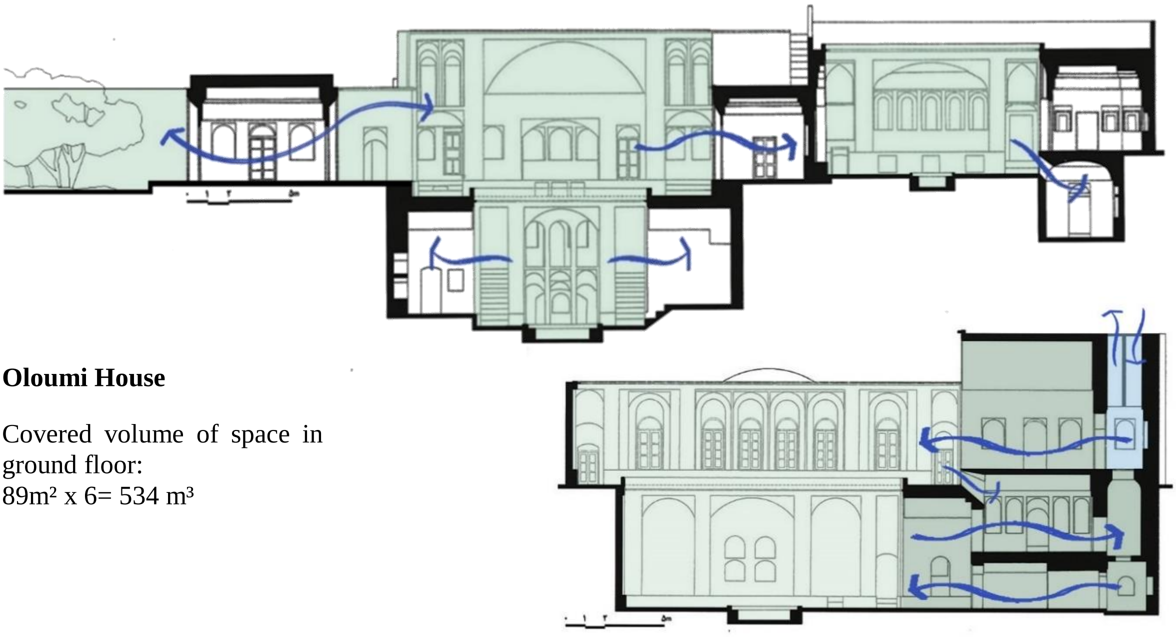
The following figures illustrate the involved architectural elements and spaces in the three traditional sample houses, and makes a simple calculation to show what volume of space is affected by the convection of air in this passive process by microclimate.

Lari House
Dimensions of wind catcher in plan: ~ 2.50 x 4.85

Height from the ground floor level: +15.50m

Covered volume of space in ground floor: 240m² x 6.50= 1560 m³





Oloumi House

Covered volume of space in ground floor:
89m² x 6= 534 m³

Tehrani House
Dimensions of wind catcher in plan: ~ 3.40 x 5.00
Height from the ground floor level:
+10.80m

Covered volume of space in ground floor: 320 m³

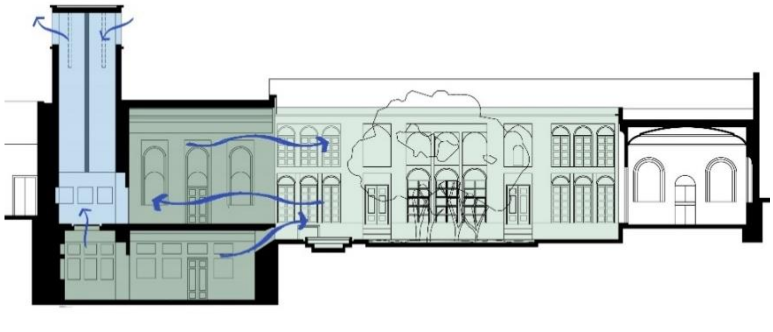


Figure 143, dimensions of the wind catchers and rough calculation of the covered volume of space under the wind catcher in ground floor in three traditional case study houses

SUMMARY

All three traditional case study houses benefit from natural ventilation and passive evaporative cooling, while contemporary houses do not benefit from any specific features for passive ventilation or cooling.

RESULT

The more energy the house earns passively, the lower dependency it will have to fossil fuel energy consumption.

The traditional case study houses adapt strategies to resolve their energy needs by passive systems that use clean energy sources of sun and wind.

These strategies have the potential to be adapted in contemporary houses, to at least cover part of energy requirements, and therefore to minimize the overall rate of energy needs in the house.

Some of these design strategies that contribute in minimizing energy needs in houses in Yazd are as follows:

- To define the best orientation for optimal shading in summer and winter set the main courtyard axis on 20° to 30° due southwest.
- This orientation also results in best solar gain on southern vertical surfaces in winter and an optimal receiving of radiation in summer time.
- The best proportions of central courtyard to respond to optimized shading in hot and cold times, is the plan proportions of approx. 2:3 (width/length).
- Due to the favorable and dominant directions of wind in Yazd, the best orientation for the courtyard to benefit from natural ventilation is 20°-45° due southwest.
- Adaption of wind catchers in the house can result in better performance of the micro climate system, due to more efficient conduction and circulation of a notable volume of air in the courtyard.

In addition to strategies for minimizing energy needs, the reduction of energy exchange also reduces the rate of total energy consumption in buildings. This section discusses strategies in historical and contemporary houses aiming at minimizing energy exchange.

A. Geothermal Heating

Earth's temperature depends on factors such as solar radiation, location, and humidity.

Higher heat capacity of the earth relative to the air results in higher stability of soil temperature. The following figure shows that apart from the soil type and outside air temperature variations, the soil temperature is almost constant, at an underground level of about 6 meters (Hanova and Dowlatabadi 2003).

One investigation in Ottawa, Canada (Williams and Gold 1976) illustrates ground temperature fluctuations, at various depths below the ground.

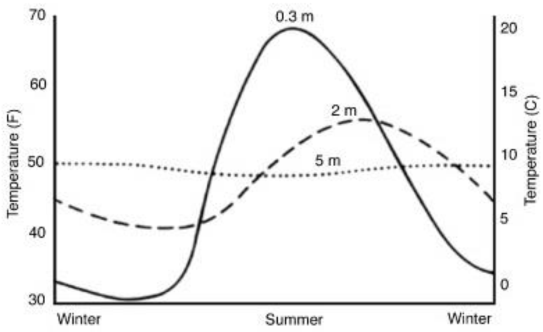


Figure 144, Depth dependence of annual range of ground temperatures in Ottawa, Canada, source (Williams and Gold 1976 , 180)

The difference between summer and winter in the graph is because surface ground temperatures are affected by meteorological factors including incoming solar radiation (insolation), snow cover, air temperature, precipitation and thermal properties of soils. (Hanova and Dowlatabadi 2003).

Besides, in more dry soils the constant temperature happens in upper levels under the ground (Build It Solar 2005)

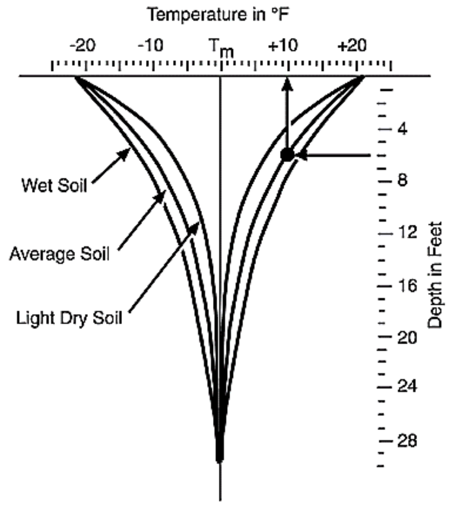


Figure 145, Amplitude of seasonal soil temperature change as a function of depth below ground surface, source (Build It Solar 2005)

These facts confirm that the earth is one of the best probable sources for regulating the thermal fluctuations in open air, specifically in desert areas with large air temperature differences between day and night, or summer and winter.

Building surfaces and walls surrounded by underground soil are subject to less thermal change compared to walls and surfaces exposed to outside air. In other words, when the temperature of the outside air drops down, the walls and spaces neighboring the soil will have less energy exchange.

Comparison of the lowest level of the single family houses below the ground

The following figures show a rough estimate of the percentage of underground area / whole area (UG/W) in the section of the house.

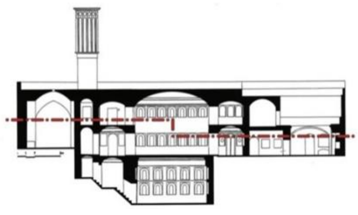
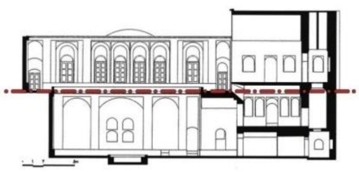
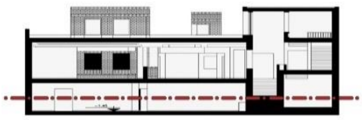
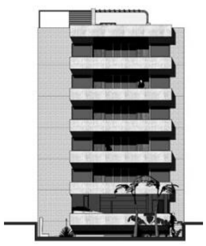
		
Lari House	Oloumi House	Tehrani House
		
Atlassi House	Mir Hosseini multilevel	Sima Gostar Complex

Figure 146, section of the houses below or over the ground level

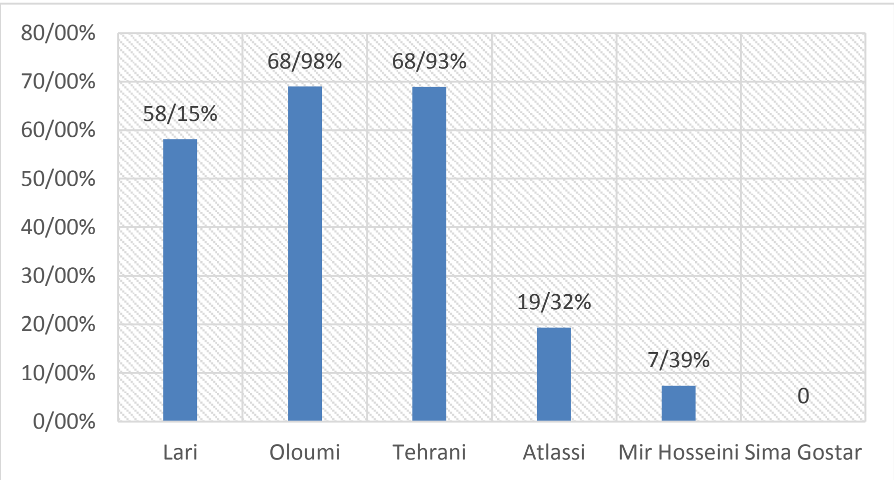


Chart 17, percentage of underground area/whole area in cross section of the case study houses

This comparison illustrates that in traditional houses, a higher percentage of the sample section's area is below the ground level.

In these three traditional case studies, the underground part comprises two of the three levels of each house.

SUMMARY
Historical houses in Yazd have an average ratio of 2/3rd of the house below ground level compared to the rest of the house.

This is more than 5 meters underground, where the thermal fluctuations in dry soil are almost at a constant level (Figure 145)

B. Glazing

The glazing area of the outside walls is important, as there is a larger amount of energy exchange through glass walls than adobe ones. The following table calculates the glazing area of the exterior walls of case study houses.

Area (m²)		Lariha main courtyard	Oloumi one –story courtyard	Tehrani	Atlassi	Mir Hosseini	Sima Gostar
Pure floor*					371.15		
North facing	Façade**	---	---	---	34.77 +15.86	Northwest 36.3	28.30
	Glazing***	---	---	---	7.85	16.37	6.48
	Gl./Fa. %				22.5% 15.5%	45%	22.90%
West facing	Façade**	58	---	58	6.10+75	78.16	---
	Glazing***	46.53	---	18.1	2.25	1.52	---
	Gl./Fa. %	80.2%		31.20%	36.8% 2.77%	1.94%	---
South facing	Façade**	28.90	27.20	16 +5.20	61.70	Southeast 52.65	---
	Glazing***	25.38	4.85	4	13.50	14.67	---
	Gl./Fa. %	87.8%	17.6%	25%	21.80%	27.8%	---
East facing	Façade**	68	51.1	58	---	Northeast 78.15	---
	Glazing***	25.38	8.1	18.1	---	4.72	---
	Gl./Fa. %	37.3%	15.8%	31.20%		6.03%	---
Roof		---	---	---	5.90	---	---
Total glazing area m²		97.29	12.95	40.2	23.6	37.28	6.48

Table 21, measurement of glazing area in different facades of the case study houses

* Pure floor area: (Target floor area) – (walls' footprint area)
** Façade: Target façade area from floor up to the ceiling, including the windows and doors areas, excluding the crossed walls prints
*** Glazing: Pure area of glasses of windows and doors (excluding framings)

The results of glazing area in different case studies are compared in Chart 18. This chart illustrates the percentage of glazing area from the façade area, which faces a different geographic direction in each house.

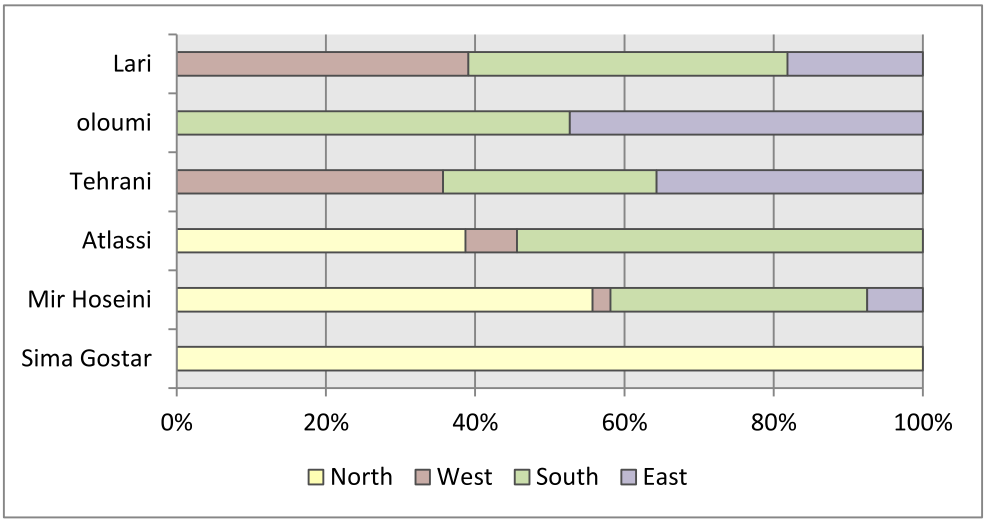


Chart 18, comparison of percentage of glazing/façade area

Traditional Case Studies

Result I, Historical Houses. The three historical case study houses have no glazing areas on the facades towards North. Because this side of the courtyard is actually the *Eivan*, the space towards the courtyard is completely open for summer use.

Result II, Historical Houses. The highest percentage of glazing in the historical houses belongs to the facades facing South and East.

Because of the rotation of these houses due Southwest, the Southern and Eastern glazing is exposed to sun radiation. This strategy matches the four season housing concept: winter spaces are located on Northern and Western sides of the courtyard and require radiation.

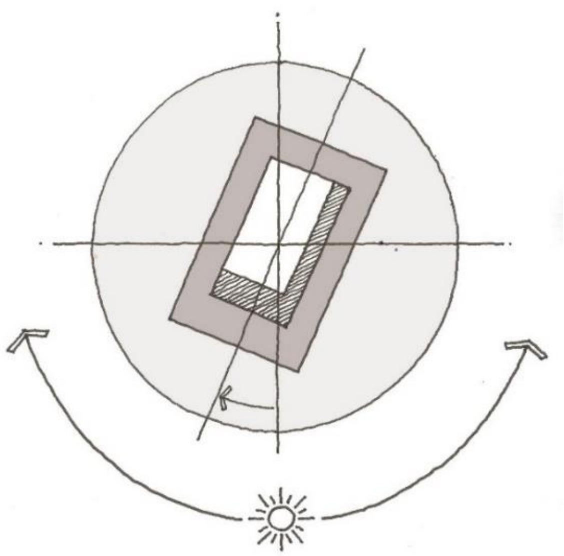


Figure 147, the Northern and Western sides of central courtyards benefit from solar radiation, regarding the traditional houses' rotation due south west, drawing by author

Note I. Strategies such as the usage of windows with adjustable height (*Orossi*) specifically on the Northern side of the courtyard, gives the users the possibility of adjusting the amount of solar radiation exposer, if necessary (Figures 148 and 149).

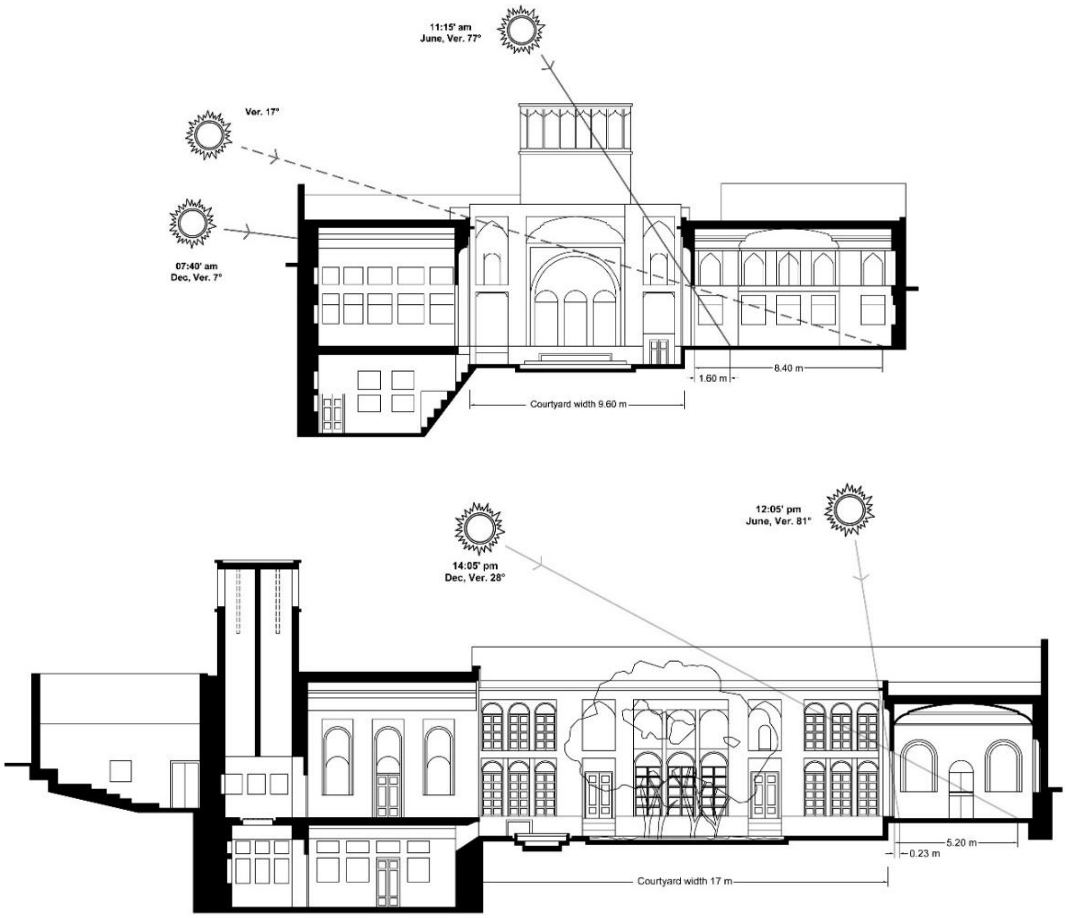


Figure 148, Tehrani house section and the radiation penetration through windows on the highest and lowest position of sun in Yazd, drawing by author

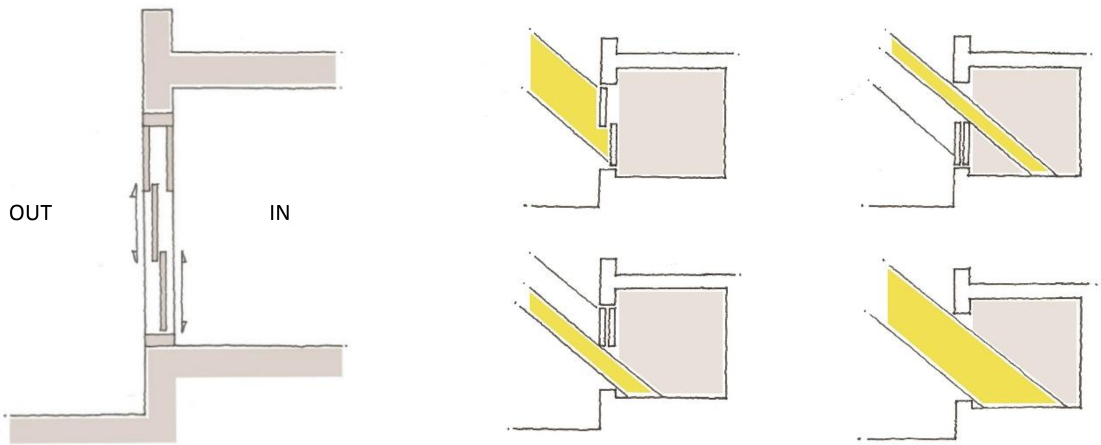


Figure 149, schematic sections for adjustable Orossi windows, drawing by author

Note II. Another characteristic of these height-adjustable windows is the use of colored glasses. The following chart is from an investigation on the effect of tinted glazing on the transmission of daylight and energy in the visible spectrum on the historical samples. (Ghiabaklou and Haghshenas 2009).

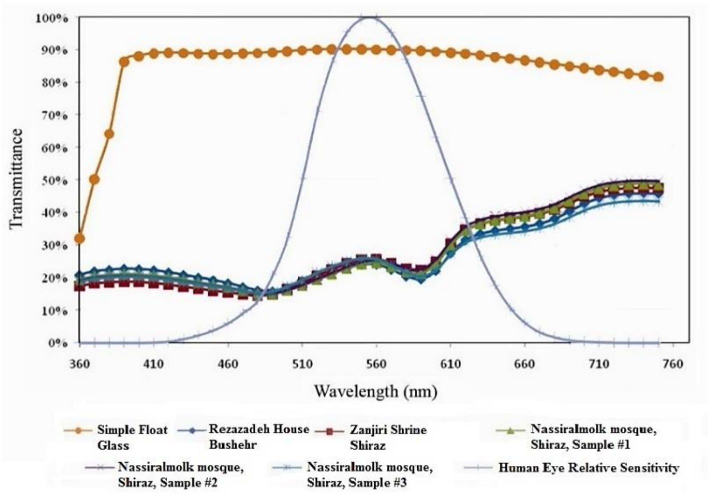


Chart 19, sun's spectrum transmittance in Orosi windows with tinted glass and compared with a normal colorless float glass, source (Ghiabaklou and Haghshenas 2009, 218)

This investigation suggests that these *Orossi* windows with tinted glazing can prevent the transmission of a large amount of the sun's spectrum and operate as solar radiation-control when required.

A calculation of the amount of energy and daylight that passes through the whole window shows that the energy transmittance of the *Orossi* is approximately one third of the transmitted energy through standard float glass.

This tinted glass is what can be used as a strategy in combination with the adjustable-height windows.

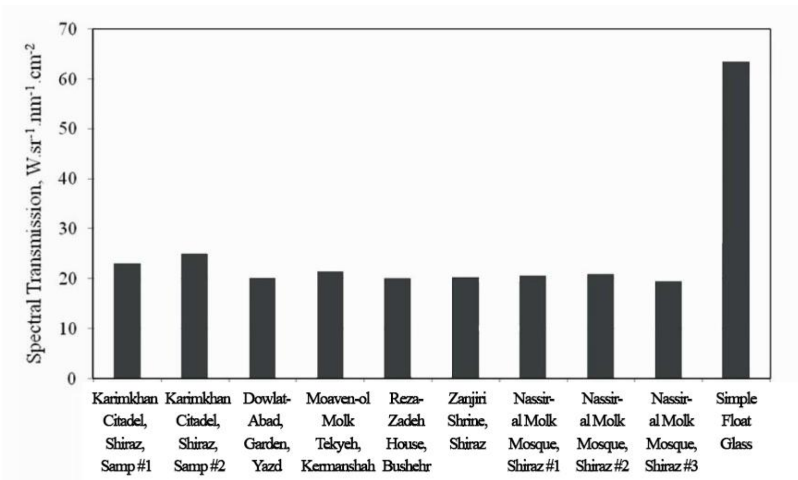


Chart 20, Comparison of energy transmittance of the Orosi to windows with standard float glass, source (Ghiabaklou and Haghshenas 2009, 219)

SUMMARY

Traditional case study houses have a notable percentage of glazing on the northern facades of the courtyard facing south.

These sides include living spaces that were used during winter time, and therefore have a high potential for gaining energy from solar radiation.

Large spaces *(Tâlâr)* use adjustable windows *(Orossi)* with colored glass to adjust the degree of solar energy transmitted into the space.

This also conforms to the LEED standards for designing to maximize opportunities for solar design in buildings over a latitude of 25° north.

It mentions that at least 90% of the south-facing glazing must be completely shaded (by awnings, overhangs, plantings) at solar noon on the summer solstice and unshaded at noon on the winter solstice (USGBC 2013, 53).

The following results on glazing in contemporary case studies are obtained from chart 18:

- In contemporary housings (Atlassi, Mir Hosseini, Sima Gostar), the majority of glazing is towards North and South, due to the contemporary architectural design rules. Contemporary regulations in Iran divide urban areas into North-South blocks for housing. The courtyard occupies the southern 40% of the land. This division provides the house with natural lighting from North and South. Neighbors block the East and West sides; therefore, there are no Eastern or Western windows.

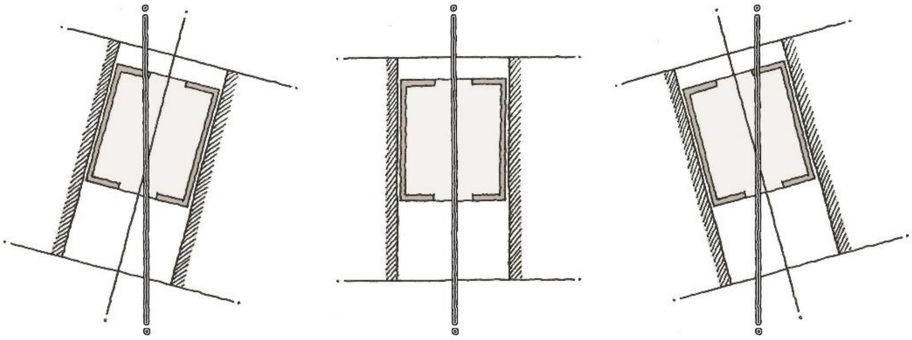


Figure 150, Lighting from South and North common pattern for contemporary low or midrise, with variety of directions matching new urban texture divisions, drawing by author

- In contemporary single-family housing (Atlassi house), the private Southern courtyard creates the potential for more Southern glazing.
- In midrise multi-level housing, in spite of the Southern courtyard, privacy and cultural and religious limitations (*Mahramiyat*) and rules restrict the openings and consequently glazing (compare Atlassi with Mir Hosseini).
- The chart for the Sima Gostar residential complex also exposes the fact that large mass-constructions often have more than two residential units on each floor, and, therefore, the division of each floor into separate units results in single-direction windows in every unit (for example, northern units have only northern windows). The case study in the Sima Gostar complex has all its windows facing north.

Figure 151, Units in one typical floor of Sima Gostar residential complex

LEED Glazing

LEED, in EA Credits for Annual Energy Use (USGBC 2013, 38), states that the percentage of glazing area must be less than 15% of the (conditioned) floor area. Table 22 points out the reference conditioned floor area (ENERGY STAR Qualified Homes 2011, 1).

Bedrooms in Home to be Built	1	2	3	4	5	6	7	8
Conditioned Floor Area m²	93	148	204	260	315	371	426	483

Table 22, Benchmark Home Size, source (ENERGY STAR Qualified Homes 2011, 1)

The gross exterior wall area is shown in table below:

Number of bedrooms	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8 or more**
Area m²	120	154	181	204	223	241	257	+ 14 m² per add. BR

Table 23, Exterior wall area of LEED reference home, by number of bedrooms, source (LEED, 38)

The other part of EA credits (for homes), concerning the architectural design patterns' contribution to the reduction of energy consumption and greenhouse emission, is the "Building Orientation for Passive Solar" (USGBC 2013, 53), which focuses on designing to maximize opportunities for solar design.

The requirements are:

- The south-facing glazing area is at least 50% greater than the sum of the glazing area on the east- and west-facing walls.
- At least 90% of the south-facing glazing is completely shaded (by awnings, overhangs, plantings) at solar noon on the summer solstice and unshaded at noon on the winter solstice.

The following table shows the number of (bed) rooms in each case study. Regarding the definition by Energy Star Qualified Homes 2011, "a bedroom is defined by RESNET as a room or space 70 sq. ft. or greater size, with egress window and closet, used or intended to be used for sleeping. A "den", "library", or "home office" with a closet, egress window, and 70 sq. ft. or greater size or other similar rooms shall count as a bedroom, but living rooms and foyers shall not" (ENERGY STAR Qualified Homes 2011, 4).

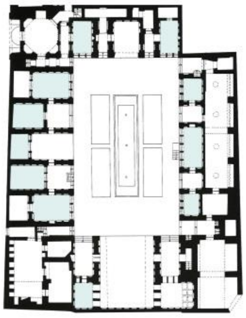
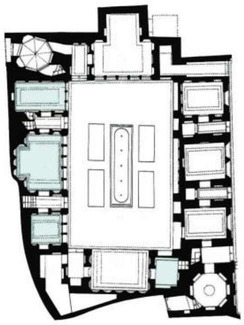
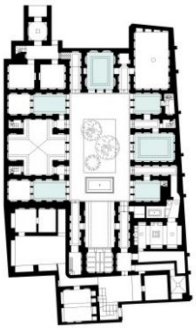
Lari	Olumi	Tehrani
 8 bedrooms	 4 bedrooms	 6 bedrooms
Atlassi	**Mir Hosseini**	**Sima Gostar**
 4 bedrooms	 4 bedrooms	 2 bedrooms

Figure 152, spaces with direct access to fresh outside air, main floor of the case study houses

The following table shows a comparison of the glazing area in the case study houses with LEED definitions.

		Lari	Oloumi	Tehrani	Atlassi	Mir Hosseini	Sima Gostar
Number of bedrooms		11	4	6	4	4	2
Proposed by LEED	CFA[17] (m²)	525	260	371	260	260	148
	Glazing 15%	78.75	39	55.65	39	39	22.2
Total glazing area (TGA) m²		97.29	12.95	40.2	23.6	37.28	6.48
Southern glazing area (SGA) m²		25.38	4.85	4	13.50	14.67	0
SGA/TGA (<50%)		26%	37.5%	9.95%	57.20%	39.35%	0%

Table 24, percentage of total and Southern glazing area and conditioned floor area in main floor of case studies

[17] CFA: Conditioned Floor Area

RESULTS

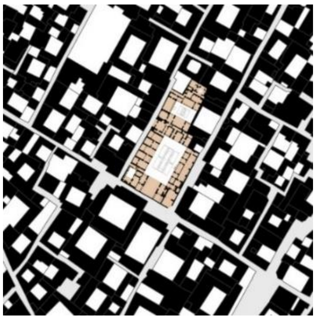
Five case studies follow the LEED standard for glazing which is less than 15% glazing area/ CFA. Lari house exceeds this limit.

In all case studies except Atlassi house, the southern glazing area/ total glazing area SGA/TGA is lower than 50%.

C. Compact Neighborhood

The following figures show the type of footprint (mass, void, passageways, garden) in a neighboring area of 200m x 200m around the case study houses.

Comparisons show that apart from the size of case studies, footprints in the historical fabric have a more compact pattern, with more common walls between the neighbors and narrower passageways.

Lari	**Olumi**	**Tehrani**
		
Void: 11624.6 m² Passageway: 5201.1 m² Mass: 23174.3 m² Mass/whole: 57.93 %	Void: 7763.29 m² Garden: 6961.39 m² Passageway: 5803.93 m² Mass: 19471.39 m² Mass/whole: 48.67 %	Void: 8914.82 m² Passageway: 8291.26 m² Mass: 22793.92 m² Mass/whole: 56.98 %

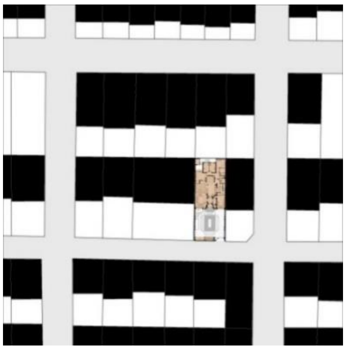
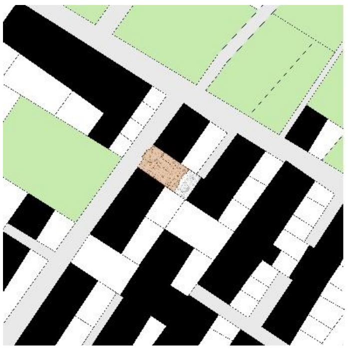
Atlassi	**Mir Hosseini**	**Sima Gostar**
		
Void: 12297.5 m² Passageway: 12538.56 m² Mass: 15163.94 m² Mass/whole: 37.9 %	Void: 18880.79 m² Passageway: 7415.57 m² Mass: 13703.64 m² Mass/whole: 34.25%	Void: 22712.49 m² Passageway: 7909.12 m² Mass: 9378.39 m² Mass/whole: 23.44 %

Figure 153, calculation of footprint of urban compactness in terms of neighboring areas of the case studies in 4 hectare surrounding site

In Mir Hosseini or Sima Gostar surrounding sites, a notable part of the void is barrel land, due to recent urban development and the transformation of agricultural land to housing development.

The following charts compare the results of Figure 153.

Chart 21 shows the footprints of the constructed area, void area and passageway area.

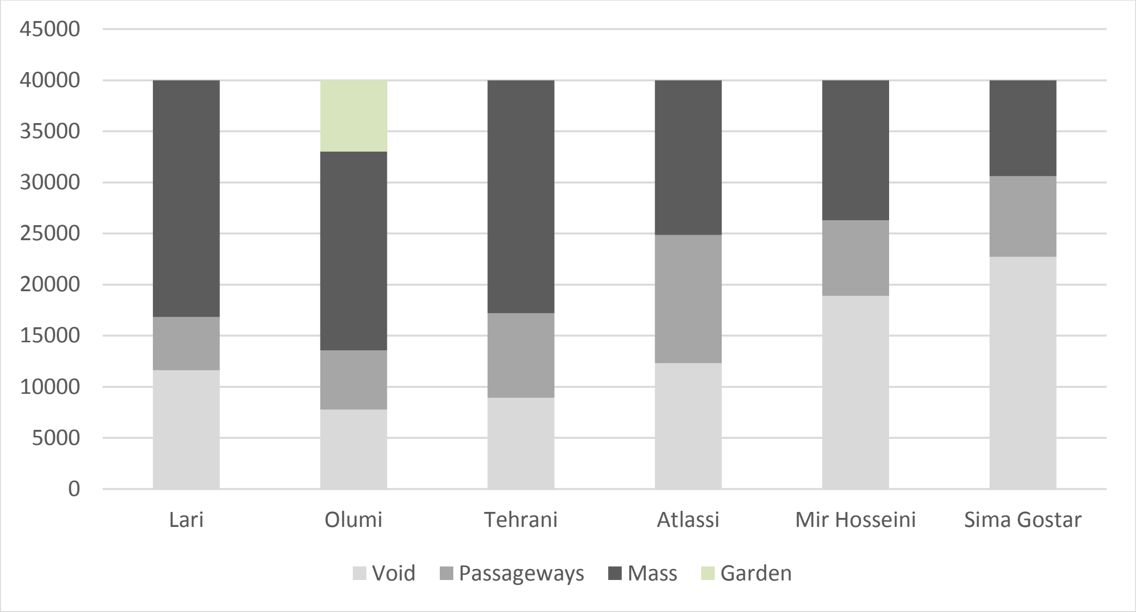


Chart 21, Comparison of constructed footprint, void and passageway area in 20m x 20 m area around case study houses

Chart 22 shows the percentage of constructed area footprint (mass) in the surrounding 40,000 m² area of the site.

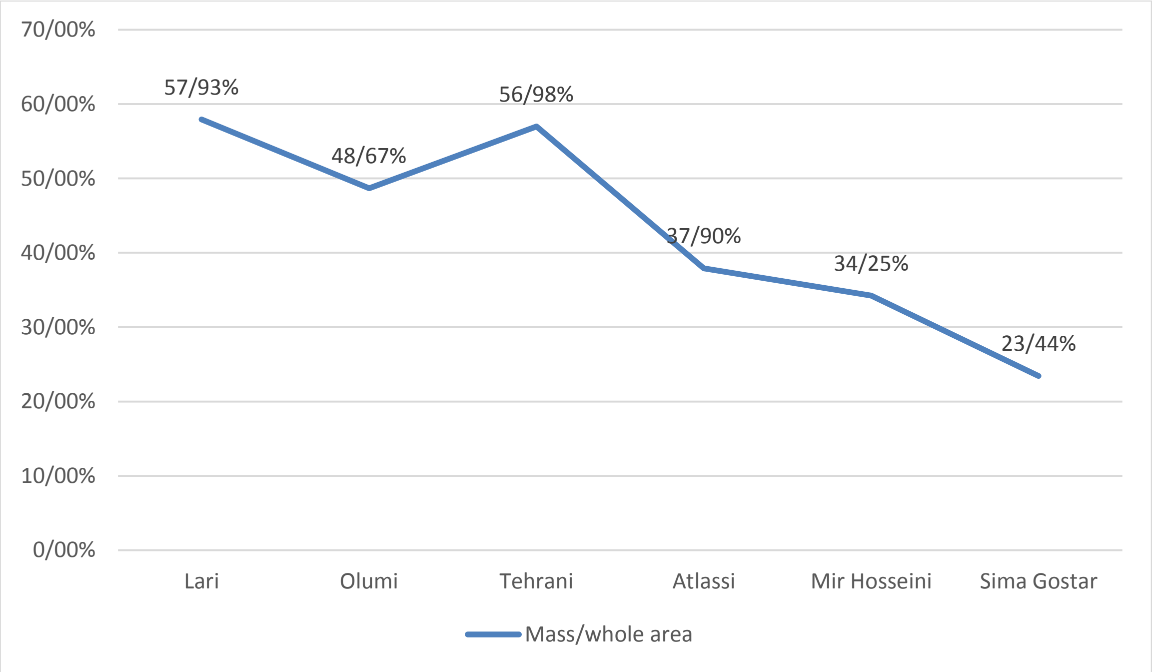


Chart 22, percentage of constructed area footprint (mass) to whole selected area of 20m x 20m

SUMMARY
In historical houses, more than half of the sample area (40 hectares) is constructed area (about 57% in the Lari and Tehrani houses). In Olumi house, this percentage is a bit lower (about 49%) due to the neighboring gardens.

In contemporary housing, the percentage of mass/whole area is lower. In the Atlassi single-family house (where the urban criteria allow an average height of one to two story houses), the percentage is a bit higher than in other types of contemporary housing.

The results show that the higher the houses, the lower the ratio of mass footprint/whole area is.

RESULTS
In terms of the compactness of urban fabric regarding Yazd's climatic conditions, the current urban fabric is much less compact with broader passageways and more open spaces on ground floor.

This sprawled pattern developed in contemporary era, when multilevel mid-rise housings became a common model of housing in Iran: to accumulate the voided spaces of the houses in order to have a larger open space. The masses were brought together, built one on top of the other, and the result would be large, shared, open green area.

Although this may be a response to the rising population of the cities and high demands for the expanding urban population, the final result of these transformations is a new compactness in the city that does not fulfill the climatic requirements.

Density

The following table compares the percentage of footprint and density % in traditional and contemporary case studies.

	Mass footprint %	No of floors	Built floor %	Average
Lari house	57.93 %	1.5	86.89%	81.76%
Oloumi house	48.67 %	1.5	73%	
Tehrani house	56.98 %	1.5	85.47%	
Atlassi single family	37.9 %	2	75.80%	156.27%
Mir Hosseini multilevel	34.25%	6	205.5%	
Sima Gostar complex	23.44 %	8	187.52%	

Table 25, comparison of footprint and density % in traditional and contemporary case studies

The footprint of constructed areas in contemporary housing is much less than in the traditional city, due to wide streets and public open spaces. But as described above, multilevel contemporary housing results in higher population density in some parts of the city.

RESULTS
Contemporary case studies show a higher percentage of built floor area (density) compared to traditional case studies.

D. Thermal Mass

"Thermal mass can be defined as the ability of materials to store significant amounts of thermal energy and delay heat transfer" (Kalogirou, Florides and Tassou 2002).

In most climate zones, the introduction of thermal mass elements into buildings assists in the reduction of energy consumption for heating and cooling, and can significantly reduce the ecological impact of burning fossil fuels for energy production. This also reduces costs, improves comfort, and reduces or eliminates the need for air conditioning (Baggs and Mortensen 2006, 1).

The following table indicates thermal mass for a range of building materials.

Insulation materials only increase R-values. Thermal mass which is a characteristic of the building material, reduces temperature fluctuations and increases time lag. In materials with greater thermal mass, it takes longer to release thermal energy after heat source is removed (Al-Sanea, Zedan and Al-Hussain 2012) (Gregory, et al. 2008).

Material	Density (Kg/m³)	Specific heat (KJ/kg.K)	Volumetric heat capacity thermal mass (kJ/m³.K)
Water	1000	4.186	4186
Concrete	2240	0.920	2060
Autoclaved Aerated Concrete AAC	500	1.100	550
Brick	1700	0.920	1360
Stone (Sandstone)	2000	0.900	1800
FC Sheet (compressed)	1700	0.900	1530
Earth Wall (Adobe)	1550	0.837	1300
Rammed Earth 2	000	0.837	1673
Compressed Earth Blocks	2080	0.837	1740

Table 26, density, specific heat and thermal mass of a range of materials, Source: (Baggs and Mortensen 2006, 1).

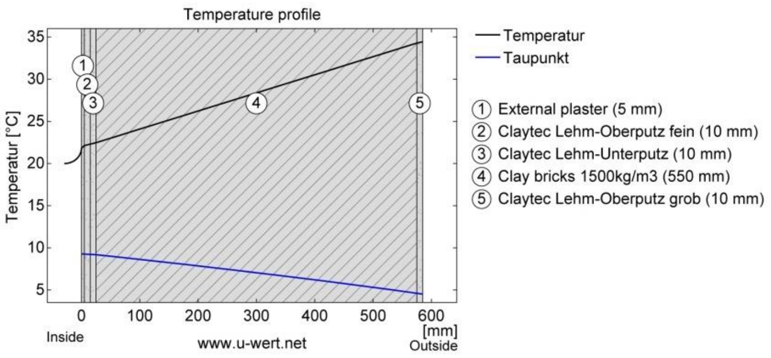
Time lag, as one benefit of thermal mass, is the time span between attaining peak temperatures at outside and inside surfaces of a wall (Geem 1987) (Sanders and Shepherd 2013).

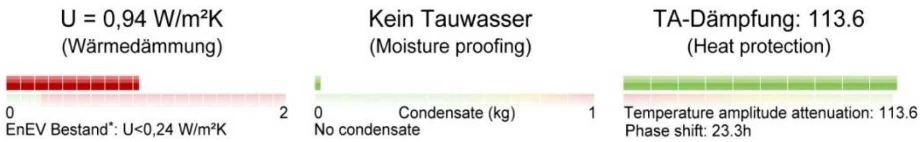
Material thickness (mm)	Time lag (hours)
Double brick (220)	6.2
Concrete (250)	6.9
Autoclaved aerated concrete (200)	7.0
Mud brick/adobe (250)	9.2
Rammed earth (250)	10.3
Compressed earth blocks (250)	10.5
Sandy loam (1000)	30 days

Table 27, Time lag figures for various materials, source (Reardon, McGee and Milne 2013, 184)

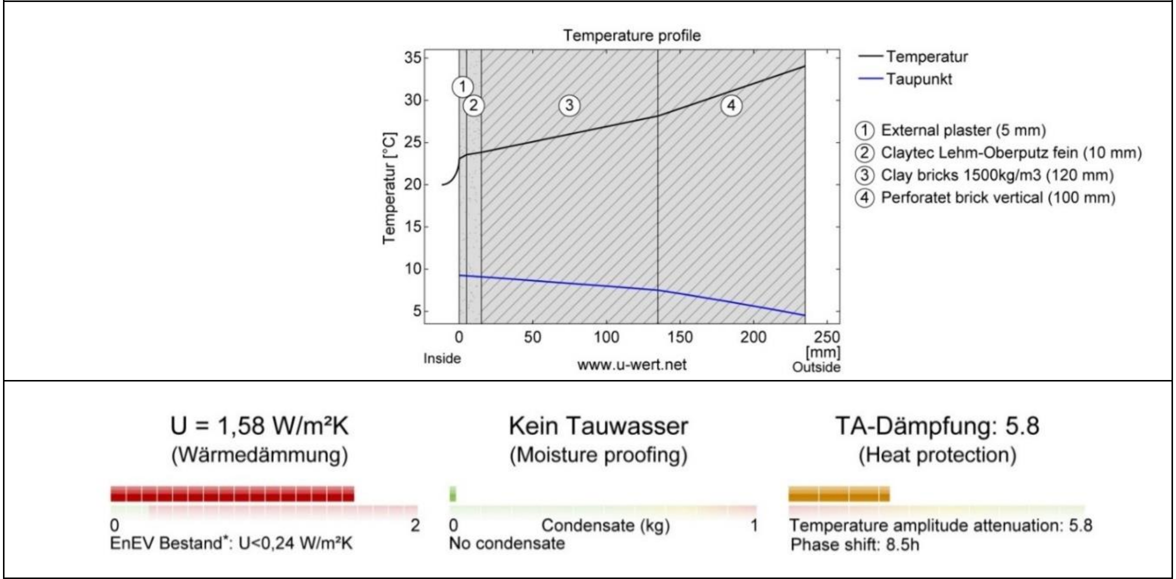
The following figures show calculation of U-Value for three different typical wall details (historical and new) in Yazd with the inside air temperature20°C and humidity 50%, and outside air temperature 35°C, humidity 15%. These calculations are made by an online U-Value calculator (U-Wert 2014).

Historical External Wall , 55 cm thick, Mud brick





External wall 1, (clay brick + brick)



External wall 2 (burnt bricks + stone façade)

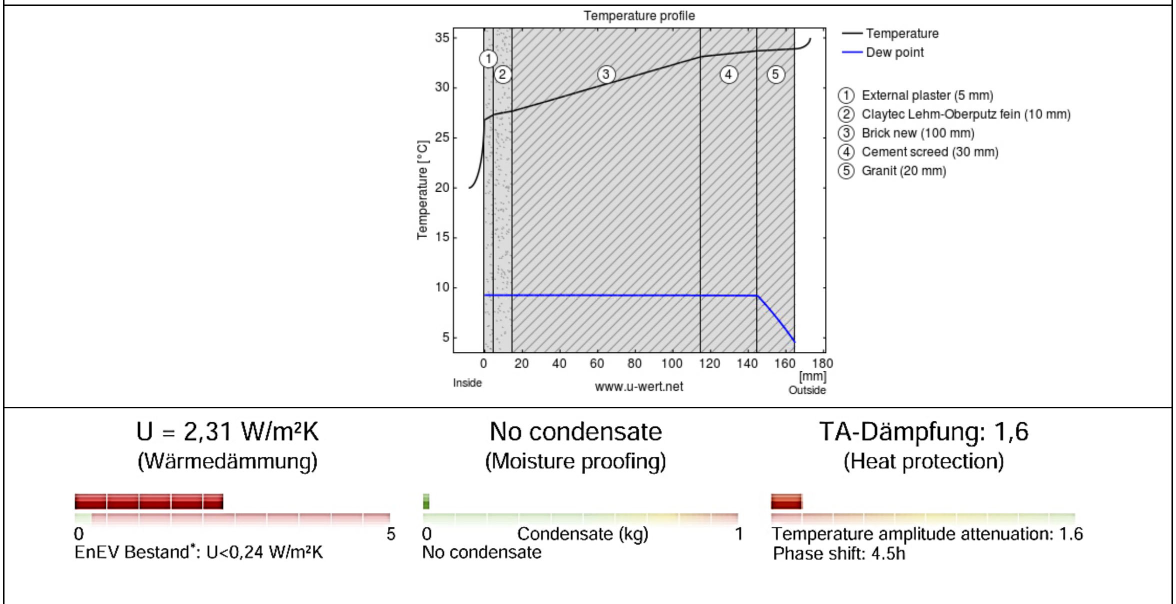


Figure 154, U-Value of the typical external walls in historical and contemporary house in Yazd, Source: u-wert.net, 2014

The above comparison shows that the heat protection in the typical historical mud brick wall is 113.6, while in the two contemporary walls is 5.8 and 1.6.

The phase shift in the contemporary walls 1 and 2 are 8.5 and 4.5 hours, while in the traditional wall the phase shift is 23.3 hours. Therefore, the inside temperature is almost constant in the spaces with traditional wall details (Chart 23).

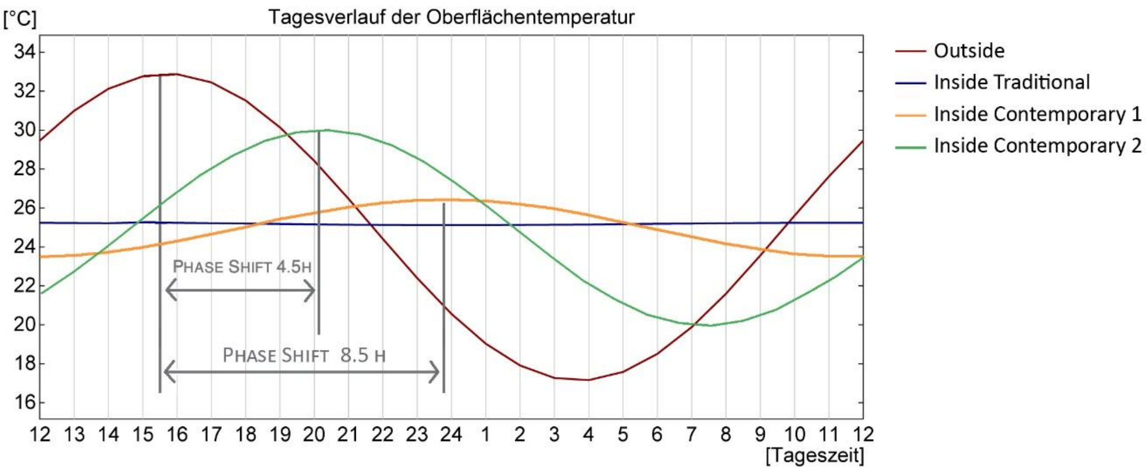


Chart 23, Comparison of temperature changes during the day in two houses in Yazd with historical and contemporary typical wall details source: www.u-wert.net, 2014

SUMMARY

Iranian traditional building materials have higher thermal mass, compared to contemporary construction material, and benefit from longer time lags. This is a very beneficiary characteristic of these adobe walls, located in a desert area with vast temperature fluctuations.

The heat absorbed by the thick mass of adobe walls from solar radiation during warm day time is returned to the central courtyard and spaces during the cold hours of evening.

In reverse, the walls absorb the cold throughout cold desert nights, and return it to the interior space during the day.

6.3. Ground and Land Use (GL)

Land use can be investigated at different scales: from city and district scales to neighborhood and architectural ones. This dissertation's focus is on the architectural scale.[18]

At the neighborhood scale, the contribution of land use to sustainability, in the form of the ratio of the footprint of the mass (building footprint) to void space (passageways), at the neighborhood scale has been discussed in Compact Neighborhood. Therefore, in this part, land use will be studied at the architectural scale to determine the proper land use of a house.

In residential buildings, spaces can vary among the following types:

- Closed spaces, such as living rooms or bedrooms
- Semi open spaces, such as *Eivāns* in traditional houses or terraces in contemporary houses
- Open spaces, such as courtyards

The following analysis makes a quantitative calculation of the rate of open, semi open, and closed areas and compares the percentage of these spaces in traditional case study houses with contemporary ones.

[18] For city or district scale of land use impact on sustainability, please refer to the parallel dissertation on Yazd by Hossein Abbasimehr

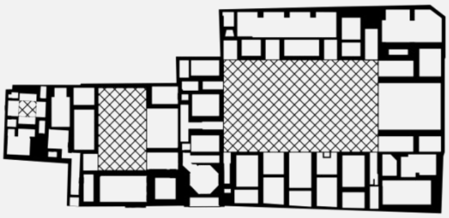
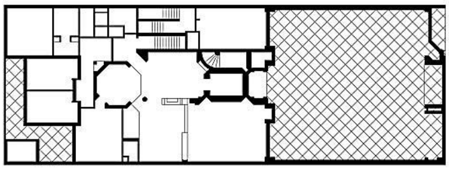
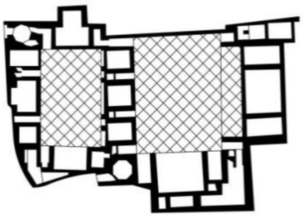
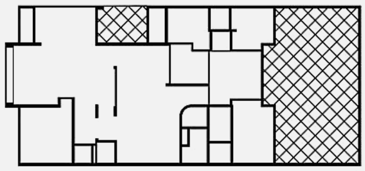
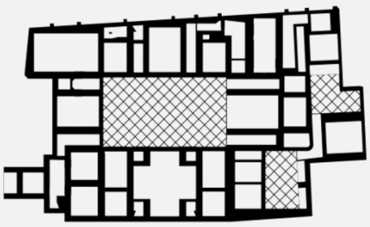
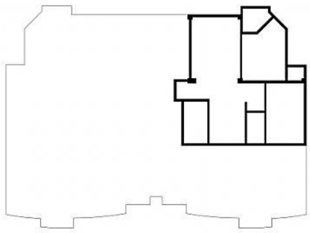
Footprint (Ground floor plan)				
	Historical Houses		**Contemporary**	
Mass and Void Plan	**Lari-ha House**		**Atlassi House**	
				
Overall	3351 m²	100%	859 m²	100%
Roofed	1536.9 m²	45.8%	371.15 m²	43%
Walls	887.72 m²	26.6%	102.6 m²	12 %
Open	926.38 m²	27.6%	385.25 m²	45 %
Mass and Void Plan	**Oloumiha House**		**Mir-Hosseini House**	
				
Overall	1308.3 m²	100%	484.02 m²	100%
Roofed	465.3 m²	35.5%	311.26 m²	64.4%
Walls	330.3 m²	25.5%	33.24 m²	6.8%
Open	512.7 m²	39%	139.52 m²	28.8%
Mass and Void Plan	**Tehrani-ha House**		**122 unit Sima Gostar**	
				
Overall	1131.5 m²	100%	102.8 m²	100%
Roofed	547 m²	48.3%	88.7 m²	86.28%
Walls	363 m²	32.2%	14.1 m²	13.72%
Open	221.5 m²	19.5%		

Table 28, Comparison of footprints in case studies

The following chart shows the percentage of the allocation of ground floor area to the open or closed spaces.

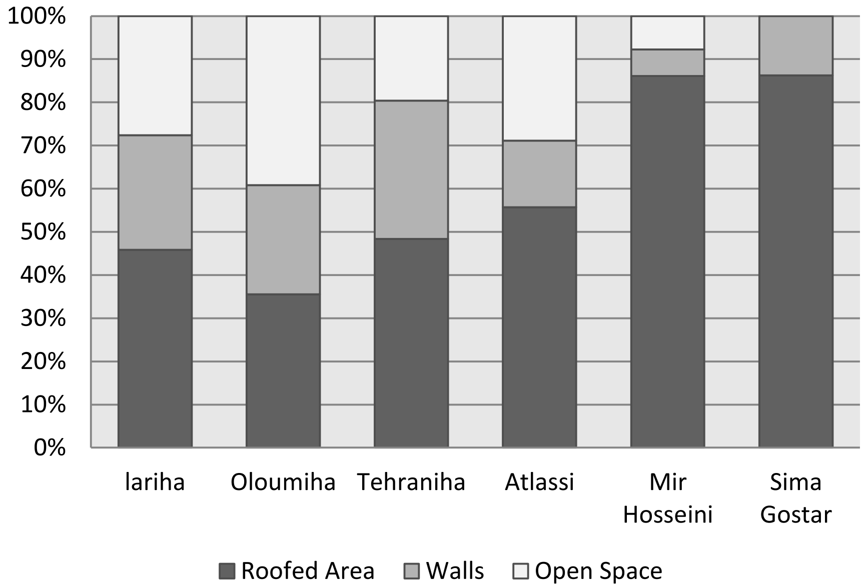


Chart 24, land use % in ground floor plan of historical and contemporary houses in Yazd (footprint)

As observed, in contemporary houses, the majority of the land is constructed as closed spaces, because in present multi-level housing design, private open spaces are removed and replaced with shared common open-spaces outside of the residential units.

In historical houses, the ratio of private open space is much higher.

As the above chart shows, one disadvantage of historical houses is that a notable part of the land in these masonry construction houses is covered by thick adobe walls.

This is partly due to construction limitations at the time of construction of these houses.

However, it must be noted that these thick adobe walls act as thermal masses which regulate thermal fluctuations inside the buildings through longer time lags.

SUMMARY

One disadvantage of traditional houses in terms of land use is that thick walls cover a remarkable area of the land.

Traditional housing allocated a larger area of the land to open spaces in comparison with present-day housing in Iran (20-40%)

Current multi-level housing restricts the private living space to closed spaces and offers shared open spaces outside of the multilevel housing block.

In large residential complexes, open space finds a new definition, which is modeled from the western modern mass residential.

Note I, Even if these types of multilevel housing (such as the Sima Gostar complex, with 122 residential units) provide the inhabitants with a standard area of open space per capita, the quality of space does not support the residents’ required privacy, neither in terms of cultural privacy, nor religious privacy.

Contrastingly, with traditional architecture, this open space is shared between a few families that are relatives or know one another, and therefore will have less privacy issues concerning cultural and religious considerations.

One of the main characteristics of the open spaces and housing courtyards is the green vegetation area that they contain.

The following are some calculations on the quantity of the green area in the case study houses, as well as a quantitative analysis.

This table shows the percentage of green area to whole construction area of all levels in the houses, as well as land area.

	Lari	Oloumi	Tehrani	Atlassi	Mir Hosseini	Sima Gostar
Green/ Construction Area %	4.5%	9.22%	2.96%	5.02 %	-	4.9 %
Green/ Land Area %	4.94%	5.58%	3.55 %	5.96 %	-	10.44 %

Table 29, the percentage of green area to land area and to construction area in case studies

Although the results do not show much difference between the quantity of green spaces in traditional and contemporary housings, the way in which these green areas are located, in combination with all the housing elements (mass or void areas), makes a large difference between traditional and contemporary housing.

This means that not only the size and proportion of the courtyard and green area, but also their arrangement and co-operation, contribute to the environmental performance of the microclimate system.

Traditional case study houses (Lari, Oloumi and Tehrani house) are formed on the basis of the introvert pattern. This means that the central courtyard (including water pool and vegetation) is located in the center, and the mass of the living spaces surround this courtyard. The probable wind-catcher in the south also helps better performance of the microclimate system.

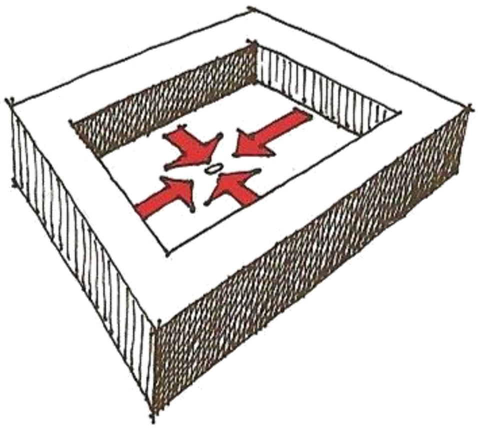
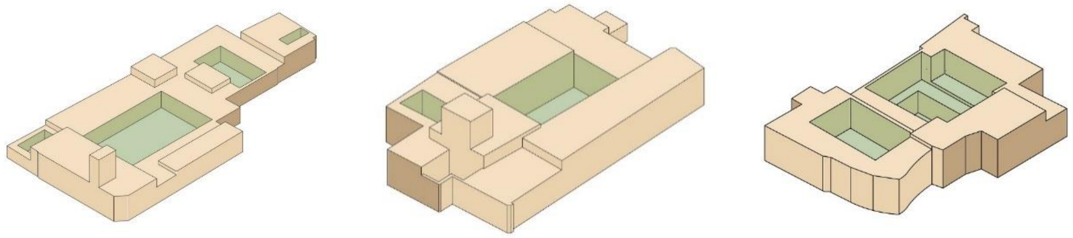


Figure 155, Introvert pattern in Iran's desert traditional architecture by Hossein Abbasimehr



Lari House Tehrani House Oloumi House

Figure 156, Historical case study houses with central courtyards, drawings by author

The following figures show the contemporary housing case studies, the Atlassi single-family house and Mir Hosseini multi-level apartment, which follow the national design regulation to assign 40% of the land (length) to southern courtyards. The Sima Gostar residential complex offers a shared open space surrounding the four residential blocks.

Figure 157, Vegetation in contemporary case studies, drawings by author

The above drawings show the ineffective vegetation in contemporary housing. Although contemporary rules of architectural design in Iran require the allocation of a defined percentage of the house area to green space, this green area does not participate in the formation of a microclimate, as the central courtyards in traditional houses do. The main reason is the location of the residential unit in relation to green space, as well as the distance between them, considering the height of residential housing in contemporary case studies.

SUMMARY

Not only the area, but also other characteristics of the green space in housing, plays a very crucial role in its effectiveness, i.e. location in plan, height and distance of the surrounding area compared with the green area, etc.

In the case studies, although the rate of green area in contemporary and traditional houses does not show much difference, the relationship of the green area and the house shows a significant difference: the green area of traditional houses improves climatic performance, due to its location in combination with other courtyard elements.

GL3. Avoid Deforestation

Due to the vast usage of wood as a building material in western countries, LEED has many instructions for usage of this material. One important discussion on the usage of wood as a building material centers on adaptive strategies to avoid deforestation, which often occurs due to wood consumption.

Although this debate may not be a matter of discussion in desert cities such as Yazd, where timber is not a common construction material, this part of the dissertation will review this topic from another viewpoint, and that is: deforestation in terms of the removal of green spaces and the replacement of them with urban area. This is what has happened in Yazd during the past decades, due to excessive urban sprawl.

In the research made by the cooperation of the University of Tehran, Iran and Autonomous University of Barcelona, Spain, published in 2011, interesting points about land use (urban, agricultural and barren land) were made and changes in Yazd were surveyed and discussed after different turning points such as Iranian land reformations and the Islamic revolution followed by the war. These turning points caused a shift in urban population growth in Iran.

One part of this study (Zangeneh Shahraki, et al. 2011, 526) indicates the following three main transformations in land use in Yazd:

1. Considerable transformation of barren land to impervious (built-up) areas. Within the time period of study, 9613 ha of barren land were transformed into urban land use (commercial, residential, transportation, etc.).

2. The second major change is from barren land to agricultural land. This is also an important deviation from the common pattern of land substitution in many countries by which agricultural land is the main loser in front of the advance of urbanization. In Yazd, however, about 4224 ha of barren land were converted into agricultural land between 1975 and 2009.

3. The third major change has been conversion of agricultural land to urban land, affecting some 2470 ha. This suggests a pattern of frontier settlement by which the original landscape is transformed into agricultural or urban land and, only later, part of the agricultural land is in turn transformed into urban land. Remarkably, however, the net gain in agricultural land, which is used to cultivate saffron, pistachio, wheat, barley, and leafy vegetables (Agricultural Organization of Yazd County, 2008), since 1975 amounts to 887 ha.

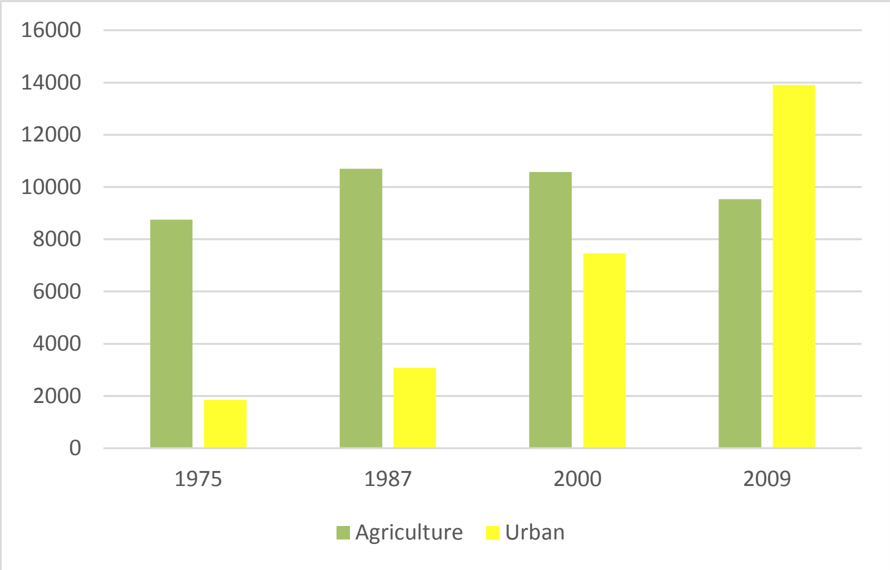


Chart 25, agriculture and urban land cover change in Yazd 1975- 2009,
Source (Zangeneh Shahraki, et al. 2011)

The following aerial maps of Yazd's area graphically show how land use transformed in Yazd in recent decades. As mentioned before, one dramatic change was the growth of built environment (urban land).

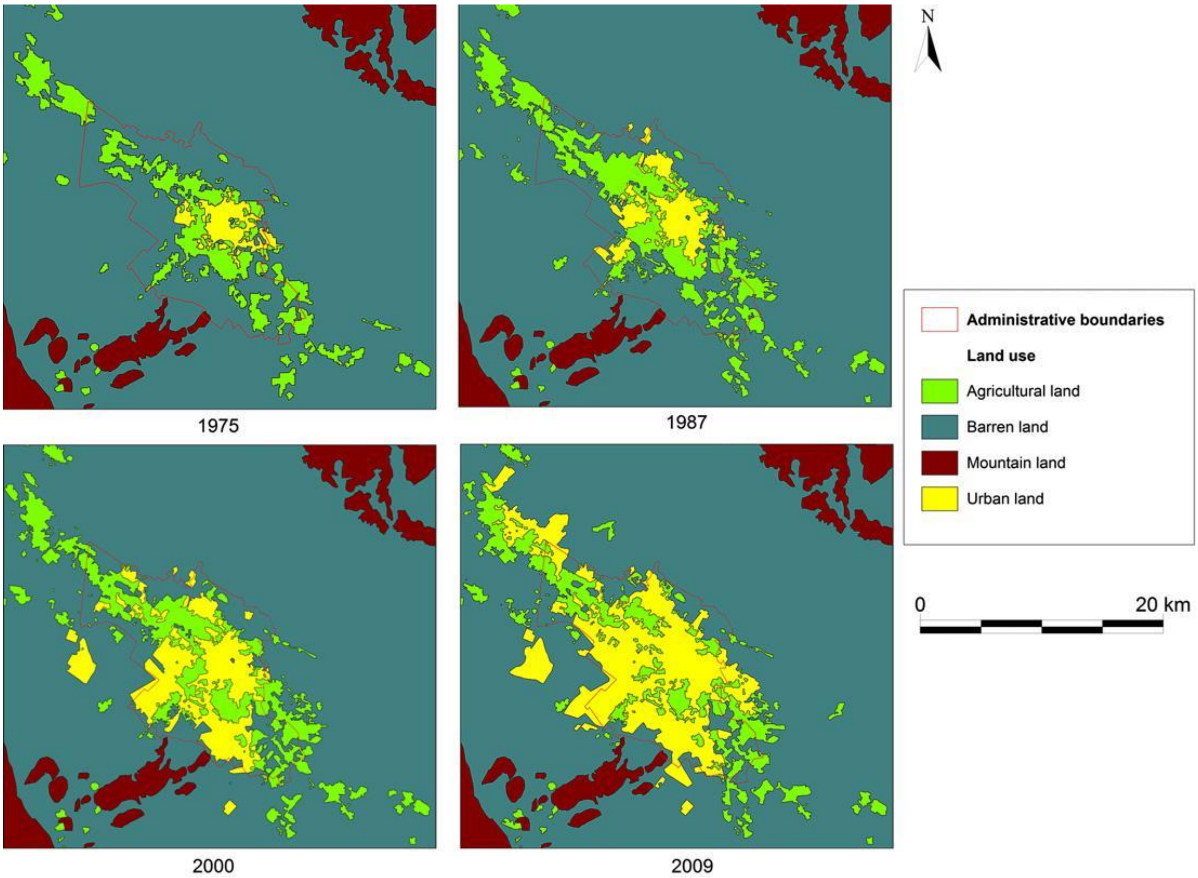


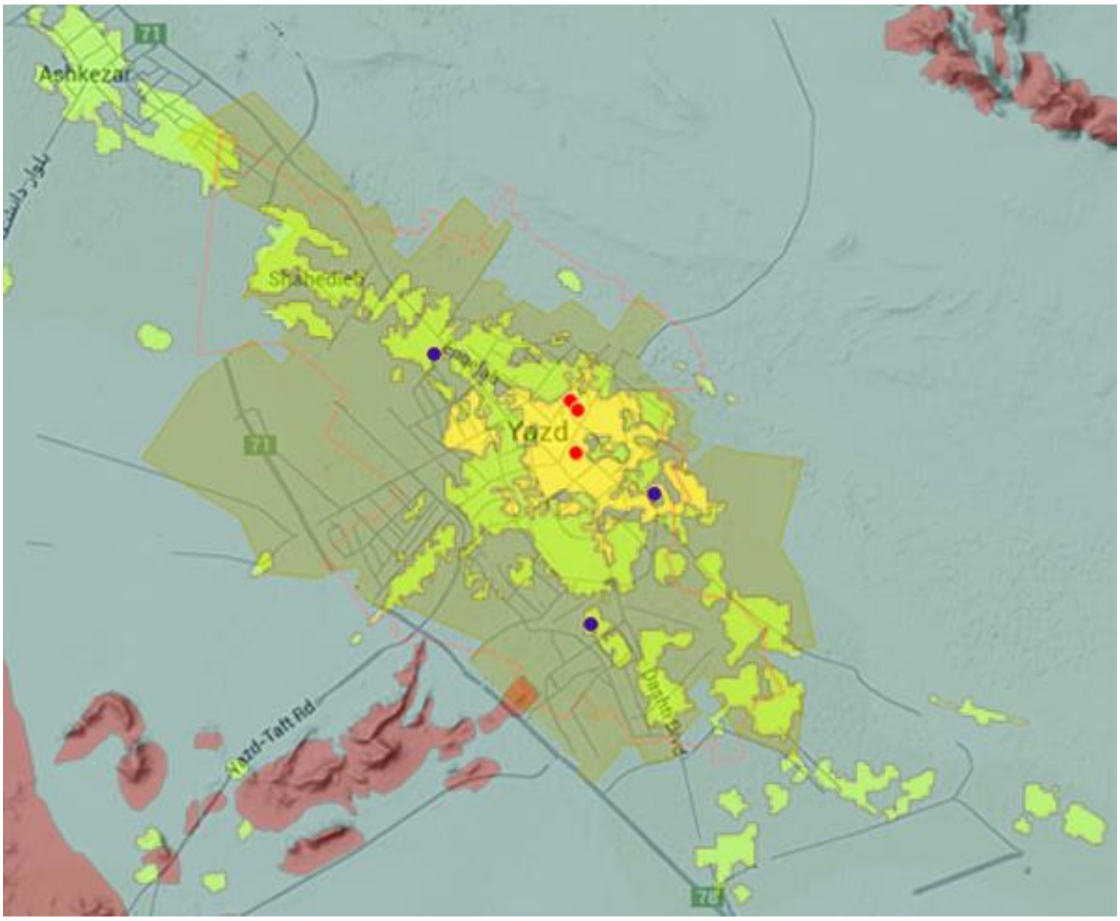
Figure 158, maps of Land-use change in Yazd (1975 – 2009), (Zangeneh Shahraki, et al. 2011)

Although these investigations show a positive growth in the rate (quantity) of agricultural land due to some transformations of barren land into agricultural land (especially economic based products such as saffron and pistachio), it must be considered that the urban land boom has also devoured the green area in the city, which once served to generate abundant oxygen, well-integrated as a lively organism.

This means that the quantitative positive growth of green land use does not always mean improvement of required quality.

The following map was made by the author by overlapping two maps of the city of Yazd in 1975 and the present map of the city area. The three historical case study houses (Lariha, Oloumiha and Tehrani mansions) are specified with red dots, and the three contemporary case studies (Attlasi, Mir Hosseini and Sima Gostar residentials) are shown with blue dots.

Even this 40 year overlap can show the contemporary case studies are built in locations that used to be gardens and farms 40 years ago.



● Historical case studies (Lari, Oloumi and Tehrani mansions)
● Contemporary case studies (Attlasi, Mir Hosseini and Sima Gostar residentials)

Figure 159, overlap of Yazd aerial maps of 1975 and 2015 and the location of the six case studies, map by author, base map (Zangeneh Shahraki, et al. 2011)

The following photos show the present situation of the Safaeieh district, which used to be gardens and green area. There are some remaining old trees in the area; many of them had been removed to construct contemporary housing and streets. Now this district is one of the wealthy districts of the new urban texture in Yazd.

Figure 160, Safaeieh district, present situation, photos by Hossein Abbasimehr, winter 2013

SUMMARY

The city of Yazd has experienced fast growth of its urban area in recent decades. Despite the fact that the rate of vegetation has also increased due to the transformation of barren lands into industrial agriculture, many agricultural lands surrounding the city have also vanished and been replaced by buildings.

Note I, the desired density for the city of Yazd must be considered in order to prevent more urban sprawl in future (see conclusion chapter).

Note II, In addition to gardens and agricultural lands around the urban area, trees and vegetation in the central courtyard could also act as the required green area for refining the dusty desert air in the city.

6.4. Material (M)

Mud brick in Iran's history

Self-sufficiency is mentioned as one of the major characteristics of Iranian architecture throughout history (Pirnia and Memarian, Styles of Iranian Architecture 2008, 31). This means that architects and builders strived to obtain construction materials locally.

Mud brick has been the predominant construction material throughout history in the hot and arid region of Iran. This is due to:
- Abundant clay soil, which is the main component for the production of adobe and brick in the region.
- Ease of production. The blocks of adobe can be made by hand and then dry out under the sun, which shines nearly continuously throughout the year in Yazd (see Charts 11 and 12).
- Production of adobe is a low-tech process that does not need high fossil fuel energies (as it is needed for burning bricks or cement). Burnt bricks have been used in very limited places among the adobe blocks i.e. where additional reinforcement is necessary.
- Due to the high heat capacity of mud brick, thick walls of adobe behave as thermal masses and greatly contribute to minimizing energy consumption and energy exchange through external walls (See Energy chapter).
- Thick adobe walls have relatively long thermal lags and indicate longer thermal lags, which is very useful for the regulation of the air temperature in Yazd, where temperature fluctuations during the day are rather high (see Energy2).

The following info-graphics show a brief review on the history of adobe as a building material in Iran.

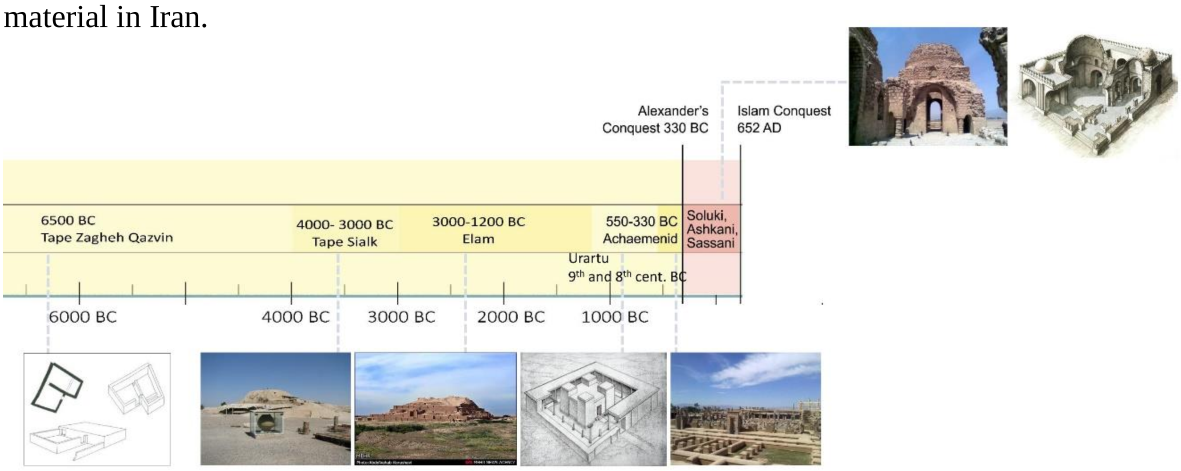


Figure 161, timeline for usage of mud brick as a building material in Iran before Islam[19]

[19] Photo sources: Tepe Zaghe: (Pirnia and Memarian, Styles of Iranian Architecture 2008, 38)
Sialk: Nasser Emami, Panoramio, http://www.behrah.com/photo-show.php?pid=27570456&uid=3258766
Choghazanbil: Abdolvahab Korushavi, Mehr News Agency, http://www.mehrnews.com/news/2312495
Takht-e Jamshid (Persepolis): http://www.starsofiran.blogsky.com/print/post-16/ access 31.07.2015
Arg-e Bam: http://www1.jamejamonline.ir/newstext2.aspx?newsnum=100823431425

Investigations show early application of mud as a building material in Tappeh Zagheh (Malek Shahmirzadi 1993). This mud was obtained from nearby, mixed with vegetation or straw, and sometimes sand was added to make adobe or rammed earth (Pirnia and Memarian, Styles of Iranian Architecture 2008, 43) (see also (Negahban 1997)
The excavated remnants of Tappeh Sialk, dating back to the 40th- 30th centuries BC, also reveal mud brick construction methods. The application of mud brick as the major building material in Choghazanbil (1250) during the Elamite Empire is also observed. Other typical characteristics of this mud brick construction is an outer layer of burnt bricks and vaulted roofs with brick or flat beams (Pirnia and Memarian, Styles of Iranian Architecture 2008, 45) (Hintz 1992).

Although the Achaemenids used stone and wood as the structure of their palaces, they used huge, sometimes double, mud brick walls for insulation, too (Pirnia and Memarian, Styles of Iranian Architecture 2008, 60). It was only after Alexander's conquest that major construction specification of Greek architecture was used in Iran for a short time, before the start of the Islamic period; they built with stone. However, this style of building was not vastly used in Iran, in spite of big stone mines such as the Fakhr Abad mine in Yazd, because it does not meet the climatic conditions' requirements in Iran (ibid).

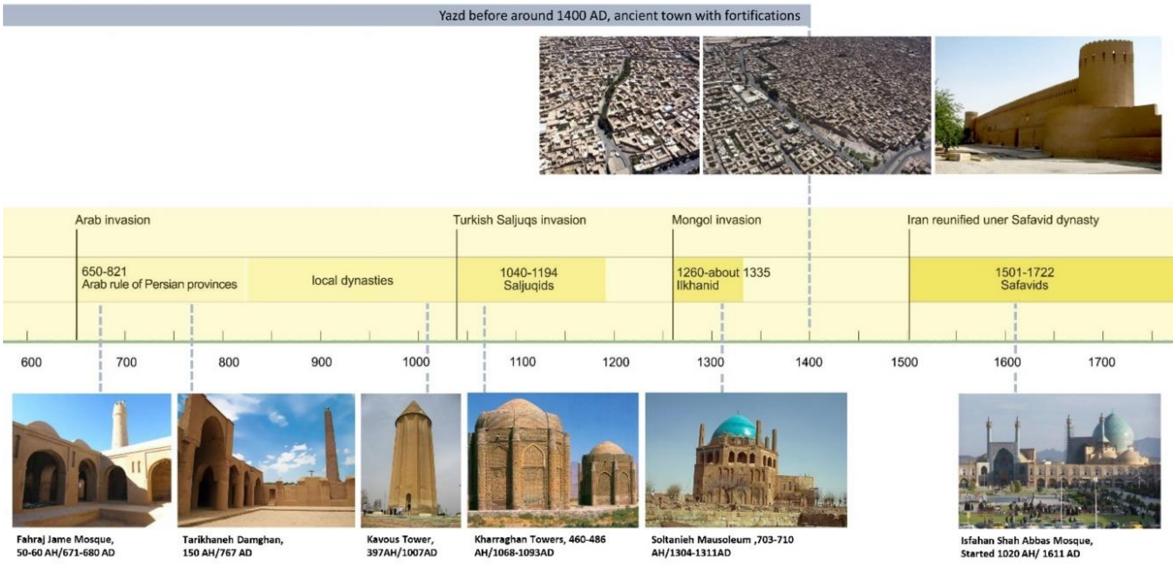


Figure 162, samples of building with mud brick and burnt brick in different parts of hot arid region in Iran after Islam, source: (Yarshater, Iranian history, Islamic period 2012) (Yarshater, Il-khanids 2012)

As Figure 100 illustrates, the application of mud brick and burnt brick as a typical building material continues in different parts of the hot arid region in Iran after Islam, too.

These mud brick constructions comprise of a wide range of building functions and sizes, including single courtyard houses, mosques, urban plazas, and city fortifications (in Yazd)

Local Material in Yazd

In other desert cities in Iran, the major building material throughout history has also been adobe or mud brick. These blocks are traditionally made by hand in wooden molds at an average size of 25x25x5 or 12x20x5 cm, and then dry out under the sun. The mortar for making the walls with adobe is also made of clay.

Ghobadian describes traditional building material in desert area of Iran:

“The major materials utilized in construction of historical houses in the hot and arid region of Iran are brick and adobe. Wood is used for the doors and windows and some columns in *Eivāns* and some beams in flat roofs. Stone is also used for the foundation of the buildings” (Ghobadian 1994, 124).

As Pirnia, the father of Iranian traditional architecture, explains: “Iranian architects believed that building materials must be provided locally. They tried to provide the material for construction from the same location they built the buildings. One example of this attitude is that in desert areas, they needed to dig deep into the ground to reach water for construction; they then changed this hollow into multi-level central courtyards (*Godālbāqcheh*) and built the living spaces around them. The dugout soil was then used as raw building material. These sunken houses also bear a better structure, because the surrounding soil acts as a retaining wall.

In the Shārestān district in Yazd, the ground is covered by a two-meter deep layer of clay which is the proper building material in Yazd. Below lies a very hard layer, which is used as a natural foundation for the buildings. This natural foundation is so strong that in the great entrance of Yazd’s Friday Mosque for example, despite several *Qanāts* passing by beneath the mosque, the building has experienced a subsidence of only 3cm since the 14th century AD" (Pirnia and Memarian, Styles of Iranian Architecture 2008, 31-33).

One reflection of the excessive amounts of clay in Yazd is highly profitable business of brick production. There are several brick kilns in Yazd whose products are exported to other provinces at a fair price. About 60 kilns for burning handmade bricks and 140 pressure and industrial brick kilns are active in Yazd (Mehr News 2013). However, the major historical building material in Yazd has been mud-brick or adobe, not burnt bricks.

Mud plaster (Kāh-gel)

The traditional plaster for covering adobe walls is a clay plaster called *Kāhgel (Kāh-Gel),* which helps better integrate the adobe blocks.

Kāh-Gel (Straw-Clay mortar) is an aerial mortar, which needs air to dry out through the physical process of evaporation. This Iranian building material resembles cob, which is used as a natural building material in Europe.

It is made by combining clay with small pieces of straw, adding water, and kneading them together. (Ramezanianpour, et al. 2003, 25). The small pieces of straw remained from the wheat harvest and are very plentiful, cheap, and easy to produce (Moghtader 1965, 26).

Physical characteristics of Kāh-gel

When the water-clay mixture dries out, it shrinks, and small cracks appear in the mortar. The small pieces of straw reinforce the mixture and prevent these small cracks from spreading in case of tension. The percentage of straw or clay may differ according to the location it is applied to (on the walls or on the roofs).

This plaster is easily made and applied. Simple workers can easily learn to make and apply it easily for new construction or renovations. When it rains, the clay absorbs the water and expands, and therefore does not let the water penetrate and leak through the roofs, this means that it acts almost like a waterproof material.

Its flexibility makes it the best material to apply to vaulted roofs. Also, the high potential of this material for water absorption reduces the environment temperature through evaporative cooling. Therefore, on very hot and arid days, splashing water on these walls will cool down the air.

After this short introduction, building material used in Yazd architecture is investigated in two categories in order to provide strategies that avoid the depletion of resources and pollution of the environment:

- Using construction material that is plentiful in the local region is one of the important assessment criteria for sustainability, because it means less energy investment in its transfer to remote building locations.
- One main strategy for avoiding environmental pollution regarding building material is the application of low emitting materials

M1. Plentiful Material

As Memarian describes in his book *"Iranian Housing Architectural Typology"*, adobe is the major construction material in Yazd (Memarian, Introduction to the Residential Architecture of Iran 1996, 270). Utilization of mud in desert areas and specifically in Yazd has been done due to climatic, functional, and technical considerations (Kasaei 1984).

In addition to high heat capacity and its easy application, the combination of adobe and mud mortar is functionally stronger than brick plus mud mortar, under the scorching sun in desert areas. Adobe plus mud mortar make a united, strong mass after drying (Pirnia and Memarian, Introduction to the Iranian Islamic Architecture 2013, 373-374).

While adobe has been used as the major construction material, brick has been used more rarely in places such as wall skirts, parapet edges, and some parts of wind catchers (Varjavand 1984), (Memarian, Introduction to the Residential Architecture of Iran 1996, 270).

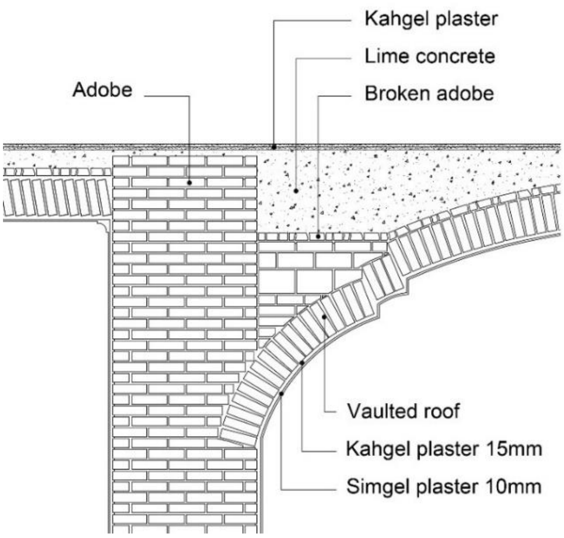


Figure 163, up: Wall to roof joint in Yazd traditional houses, source: (YCHHTO 2013)

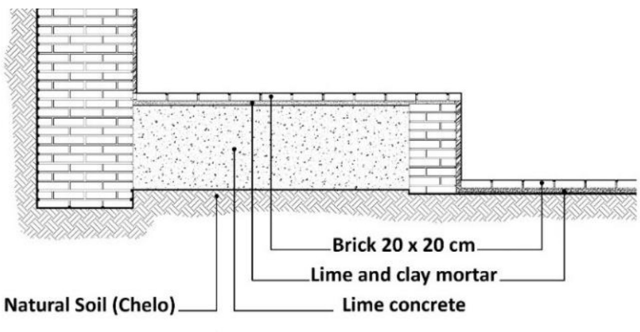


Figure 164, Aghaei house in Yazd, foundation detail, Source: Shamseh consulting engineers, (YCHHTO 2013)

Although Yazd's major traditional construction material was adobe for many centuries, nowadays, because of the National Rules for Construction in Iran, all buildings follow the same detailing for construction. This has resulted in the usage of common building materials all over the country, regardless of climatic conditions.

In recent years, after the emergence of the topic of energy conservation in construction, some revisions have been made in previously uniform construction details. One of the major modifications was the addition of layers of industrial thermal insulation, such as rock wool or polystyrene sheets, between materials due to the local climatic condition.

These industrial thermal insulation panels bring up different issues e.g. high transit costs, resource depletion, and environment pollution (Figure 165)

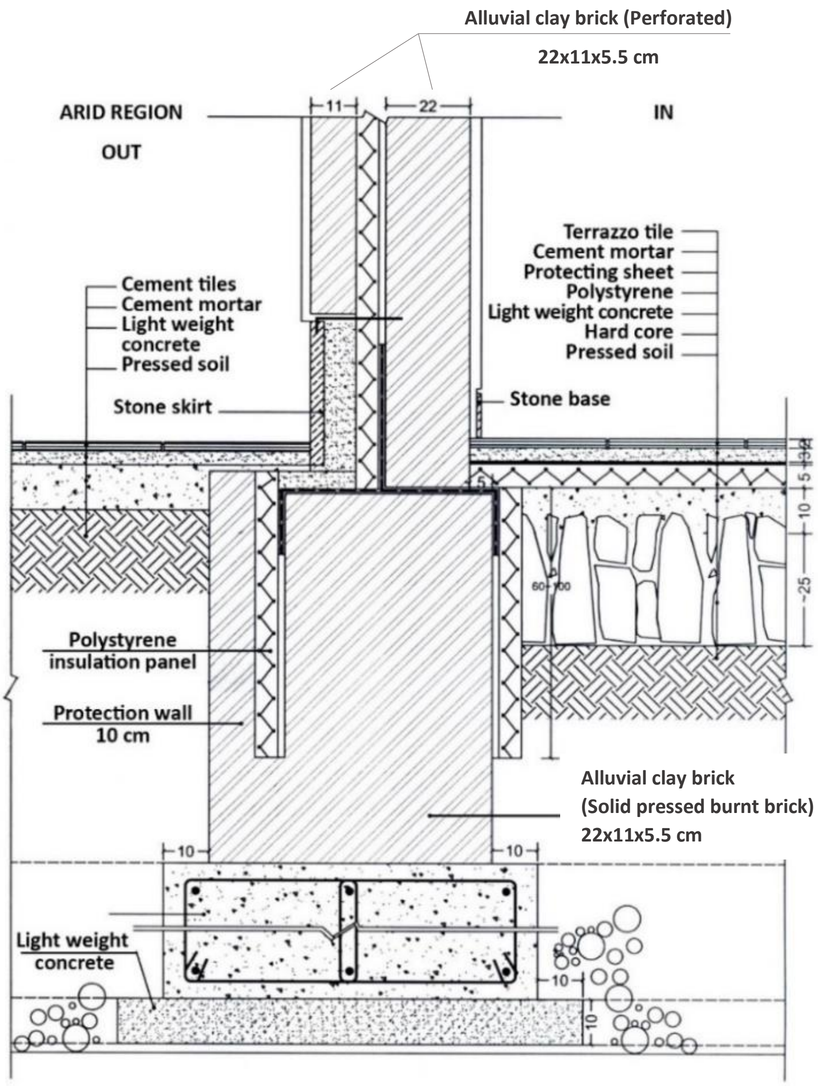


Figure 165, Detail for wall between inside and outside in arid region, Source (Saed Samii 2008, 213)

SUMMARY

Traditional architecture in Yazd used local materials, mostly adobe and mud, which are the most accessible and plentiful material in desert area, and hence the most sustainable due to their low production energy, easy application, and no pollution.

Contemporary building details propose uniform materials all over the country, regardless of availability, ease of implementation, transfer costs, etc.

In recent years, a national trend for using chemical insulation panels, such as polystyrene, has swept the country due to their fast and easy application in buildings as well as insulation characteristics.

Note: the major disadvantage of constructing with adobe and mud brick is its low resistance against natural phenomena such as earthquakes, rain and floods.

Adobe construction are brittle and have heavy weight and low strength, and they develop high levels of seismic forces during earthquakes that they are unable to resist (Blondet and Villa Garcia 2004).

While rain and flood are not issues of hot and arid region in Iran, earthquake instances in Yazd are also reported to be low, compared to other cities in Iran, such as Tehran, but due to importance of this issue, it is discussed in section HW.A and in Recommendation Chapter.

M2. Low Emitting Materials

In our current global setting, building construction and operation results in 50% of all CO_2 emissions worldwide (Roux and Alexander 2009).
One major solution to this problem is to minimize this emission by using low emitting building materials.

Contemporary

Concrete is as widely used construction material for building structural frames, ground works, floors, roofs, and prefabricated elements (Pulselli, et al. 2008)
In Yazd, concrete is one of the major building materials in contemporary construction as well.

Figure 166, a typical house in Yazd with reinforced concrete structure, Daei house, designed by M. Mostafazadeh, photo from Mostafazadeh

Despite the advantages of concrete as a building material, it is estimated that the cement and concrete industry generates up to 7% of global anthropogenic CO_2 emissions, and it is set to increase dramatically in the coming decades as the Earth's population grows (Calkins 2009). Concrete manufacturing is responsible for generating not only carbon dioxide but also other air pollutants such as carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides [$(NO)_x$], hydrogen chloride (HCl), volatile hydrocarbons, and particulate matter (Calkins 2009).

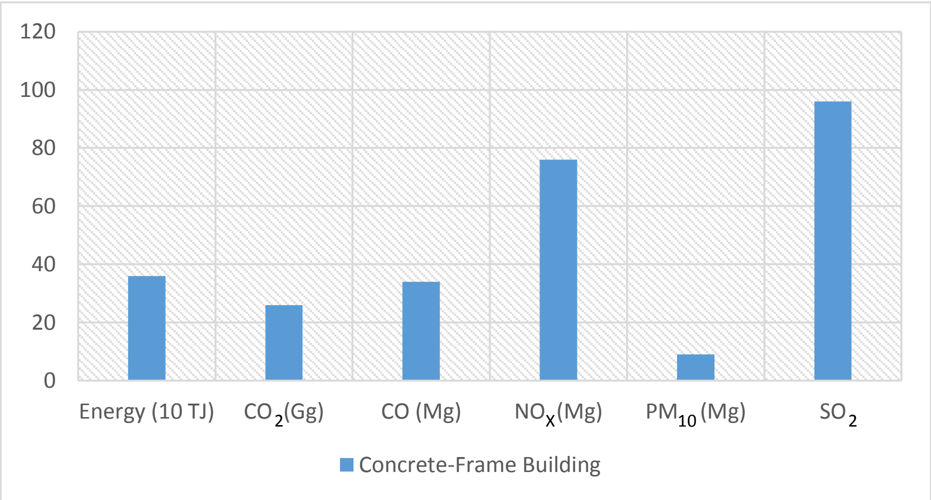


Chart 26, Life cycle assessment for concrete-frame buildings, source: (Acree Guggemos and Horvath 2005)

Another building material vastly used in housing construction is brick. It is mostly used for inner and outer walls. Although it is made of non-toxic materials and has a good potential for being reused (after being burnt at high temperatures), brick still raises environmental concerns all over the world, namely the high-energy usage and greenhouse gas emissions (Joseph and Tretsiakova-McNally 2010).

Materials for earthen construction, such as hydrated lime, clay, cob, adobe (mud bricks), compressed earth blocks, and rammed earth, have been known and used for many years all over the world. Currently, there is a growing interest in these building materials as sustainable alternatives to traditional concrete, brick, and wood (ibid). (Joseph and Tretsiakova-McNally 2010)

Traditional

The usage of unfired bricks, in place of conventional fired ones, can significantly reduce energy consumption and also cut down CO_2 emissions. Unfired clay soil (in the form of sunbaked bricks, mortars, or plaster) is classified as a traditional building material that was very popular in the past, especially in rural areas (Mckinley, et al. 2001, 60).

Unfired clay bricks demonstrated excellent environmental performance; their total energy input was estimated at 657 MJ/ton as opposed to 4,187 MJ/ton for the common fired bricks, while an equivalent output of CO_2 emission was 41 kg CO_2/ton compared to 202 kg CO_2/ton for traditional bricks in mainstream construction (Engel, et al. 2005), (Bastianini, et al. 2005).

SUMMARY

In terms of low emitting materials such as adobe and mud brick, the common building material in traditional architecture in Yazd is considered more sustainable, compared to the current building materials such as concrete and burnt brick.

The present day vastly-used building materials in contemporary housing construction in Yazd, i.e. concrete and burnt brick, have a high emission of greenhouse gas and other air pollutants due to their production process.

Regarding low emitting materials, earthen construction materials, e.g. clay, cob, and adobe, are good examples. Unfired clay bricks demonstrate excellent environmental performance in this regard, too.

6.5. Health and Wellbeing (HW)

HW1. Safety

A. Earthquake

Earthquakes have been one of the most challenging issues in Iran throughout history. As the seismic hazard assessment of Iran made by International Institute of Earthquake Engineering and Seismology (IIEES) in its 2009 Report indicates, "Iran plateau has a very high density of active and recent faults. Although most activity is concentrated along the Zagros fold thrust belt, but less activity is observed in central and eastern Iran" (Tavakoli and Ghafory-Ashtiani 2009).

Iranian Seismic Design Code for Buildings "Standard No. 2800" also indicates that Yazd is located in the place with the medium earthquake hazard (Permanent Committee for Revising the Iranian Code of Practice for Seismic Resistanit Design of Buildings (Standard 2800) 1999). Recent investigations on seismic hazard of the city of Yazd confirm the Peak Ground Accelerations (PGA) equal to 0.25 g for an earthquake with a return period of 475 years offered by Standard No. 2800 (Asadi, Neshat and Barkhordari 2014, 5).

This means that Yazd is not located in a region with a high earthquake risk. However, the operation of traditional adobe construction built to withstand earthquakes has always been one of the most controversial issues for designers, due to the huge number of existing mud brick historical buildings that are still being occupied and used in Yazd as one of the world's largest mud brick cities.

As Mahdi describes the contrast, "on one side are the researchers and scientist who defend the operation of traditional constructions at the time of earthquake, and on the other side are the evidence of failure of many of these constructions in different earthquakes like Bam in 2003, when the huge destruction of ancient earthen citadel resulted in new arguments to discuss how far these earthen architectures can resist earthquake. Many new investigations try to improve design and practice methods instead of blaming traditional systems or local materials for collapse of buildings" (Mahdi 2004).

Contemporary houses in Iran follow the *2800 Seismic Design Code for Buildings* first published in 1988 (Permanent Committee for Revising the Iranian Code of Practice for Seismic Resistanit Design of Buildings (Standard 2800) 1999)[20].

However each building requires its own specific structural design against seismic hazards, this dissertation, in the following part, aims to find the most sustainable building material

[20] See also (IIAEE 1986) and (Tolles, et al. 2000)

that can bind the adobe blocks and act as tensile element in order to strengthen the building against seismic forces.

In the recommendation chapter, some strategies for the architects to adapt at the design stage will be made in order to improve the safety of adobe buildings in case of earthquake.

SUMMARY

Although Yazd is listed a city with medium seismic hazards and an earthquake return period of around 500 years, due to the large number of existing historical mud brick buildings in the city that are still occupied, it is recommended to support mud brick buildings with sufficient strategies for maximizing safety in case of earthquake.

Finding the proper building material as tensile element for binding the adobe buildings in Yazd

As mentioned before, for improvement of the operation of adobe buildings in case of seismic hazards, the massive walls of adobe need a binding material to unify and strengthen the building against seismic lateral forces.

The three possible building material that can be used to bind the adobe bricks are concrete, steel or timber framing.

Following is a short discussion and comparison to find out which is the most suitable material in terms of environmental sustainability to be added to adobe bricks in Yazd.

These building materials are compared regarding:

- Their degree of environmental sustainability
- Locality and abundance of material in the area

1. Degree of environmental sustainability

The degree of environmental sustainability in buildings can be studied in three different phases, from pre to post construction.

The following table is a brief description of each building material, concrete, steel and wood, in these different phases.

TENSILE MATERIAL TO BIND ADOBE CONSTRUCTIN		REINFORCED CONCRETE	STEEL	WOOD
Pre-construction	**Formation and production**	Requires high energy	Requires high energy	Requires lower energy
	Producing pollution	Air Pollution	Air Pollution	No Pollution
	Transfer to Yazd	Medium Distance	Minimum Distance	Maximum Distance
Construction process	**Construction method**	Non-Local Techniques	Non-Local Techniques	Non-Local Techniques
	Height limitation	No Limitation	No Limitation	No Limitation
	Construction pace	Slow	Rapid	Rapid
Post construction	**Earthquake resistant**	Resistant	Resistant	Resistant
	Reusability	Non-Reusable	Reusable	Reusable

Table 30, comparison of environmental sustainability features of concrete, steel and wood, by Abbasimehr, H.; Soltani, A.

As observed, comparisons of these materials show that wood is the most sustainable building material amongst the three. Steel is in the second place, but concrete is the most unsustainable material amongst the three.

2. Locality and abundance of material in the area

The 2012 Minerals Yearbook (Mobbs 2012) indicates the following annual capacities for cement, iron and steel in Iran Mineral Industry (Numbers are in Thousand Metric Tons)

	Total	Yazd and neighboring provinces [i]
Cement	53,200	18,225
Iron Ore [ii] [21]	22,400	22,400
Iron Metal	8,650	4,600
Steel Crude	10,550	7,350

Table 31, Annual production capacity for cement, iron ore, metal and steel crude in Iran (total) and Yazd [Thousand Metric Tons]

[i] Esfahan, Fars, Kerman, Southern Khorasan, Razavi Khorasan, Semnan
[ii] Yazd Chah Gaz and Yazd Mishdovan capacity: NA

As indicated, Yazd province constitutes a notable share of the annual capacity for production of required products for building concrete and steel material.
The following map shows the existing industries in Yazd province and its neighboring provinces that produce cement, iron ore, iron metal and steel crude.

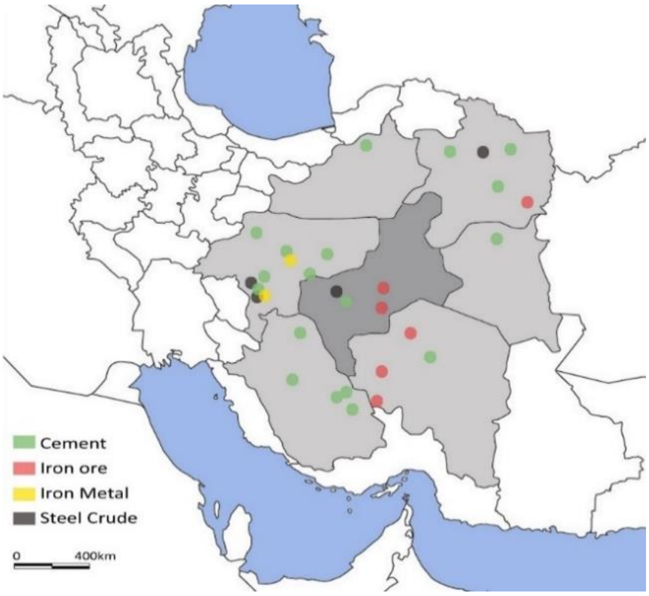


Figure 167, the existing industries for production of cement, iron ore, iron metal and steel crude in Yazd province and its neighboring provinces, Source: drawn by author on basis of 2012 Minerals Yearbook (Mobbs 2012)*, base map: http://www.mapsofworld.com/iran/iran-outline-map.html*

[21] The element iron (Fe) is one of the most abundant on earth, but it does not occur in nature in useful metallic form. Iron ore is the term applied to a natural iron-bearing mineral in which the content of iron is sufficient to be commercially usable. Metallic iron, from which steel is derived, must be extracted from iron ore. By definition, steel is a combination of iron with a small amount of carbon.

The Economic Activity Map of Iran published in the Atlas of the Middle East issued by the U.S. Central Intelligence Agency in January 1993 (Central Intelligence Agency 1993) demonstrates the variety of mineral deposits as well as industries including metal processing and cement industries all over the country and around big cities like Yazd

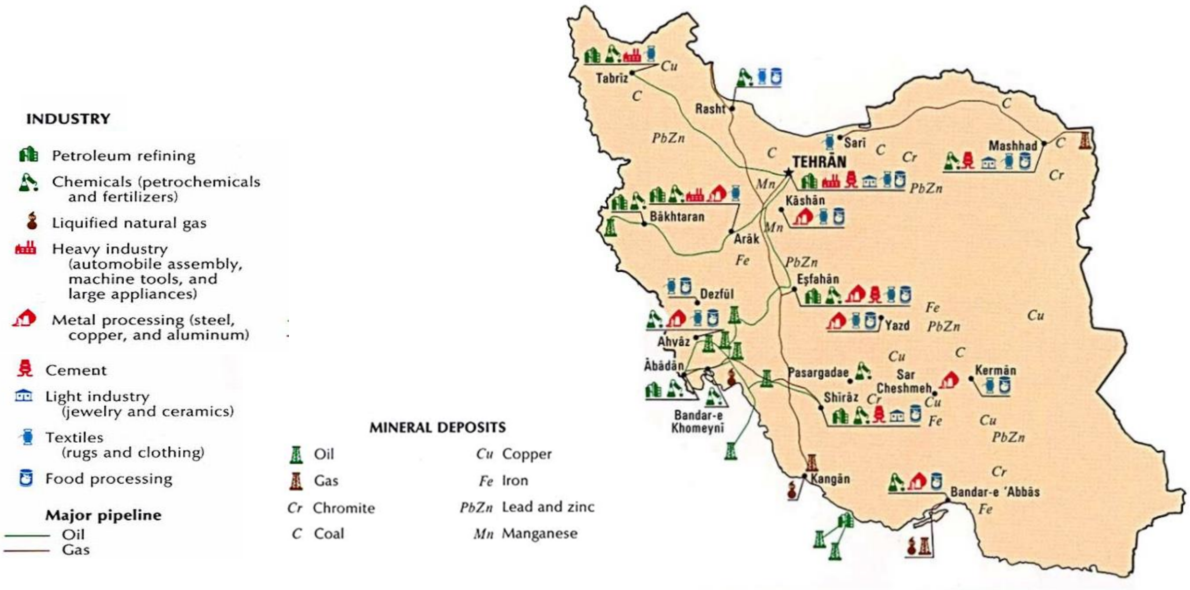


Figure 168, the Economic Activity Map of Iran, Source (Central Intelligence Agency 1993)

All these documents confirm the good infrastructure for production of the required amounts of steel or concrete as a building material in the country, while national authorities such as Iran Concrete Institute ICI and Esfahan's Mobarakeh Steel Company MSC state that Iran is a large exporter of cement and steel as well (ICI 1999) (MSC 1981). These building materials can therefore be transferred to the construction site easily.

Wood's case is different. Wood in Iran is not as abundant as in Europe specifically in desert area such as Yazd province that suffers from lack of wood resources and far distance from the limited wood resources in the north of the country.

FAO (Food and Agriculture Organization of the United Nations) in its 2011 Report states that the sparse forests of oak *Quercus* spp. in central Iran stretching from north to south along the Zagros Mountains are subject to over-exploitation and degradation due to intensive human activities and overgrazing (FAO 2011).

United Nations Environment Program UNEP survey states that (Lambrechts, et al. 2009), the forests in central Iran cover less than 10% of the surfaces.

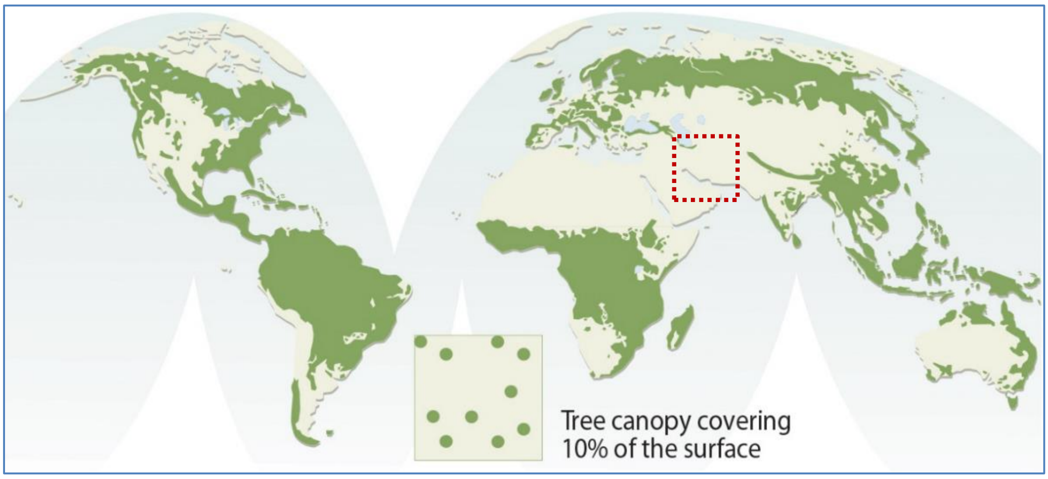


Figure 169: Forest cover and definition map, Source: (UNEP 2003)

Due to lack of required sources of wood in central Iran, one solution for providing the required wood for construction in Yazd area is to use other wood sources in the country. Following is a brief study on the forests of Iran, and an estimation of their capacity for production of wood.

Iran's Resources of Wood

Iran forests cover an area of about 12 million ha, over 90% of which are hardwoods (FAO 2011). Iran natural forest resources include five types regarding their canopy (FRW 2016):

- Closed Forest (canopy greater than 70% in northern forests and greater than 50% in others): 12.4 % of the total forest area
- Semi closed Forests (canopy between 40-70% in northern forests and between 25-50% in others): 24.2 % of the total forest area
- Open Forests (canopy between 10-40% in northern forests and between 5-25% in others): 56.6 % of the total forest area
- Mangrove: 0.2 % of the total forest area
- Planted Forests: 6.6% of the total forest area

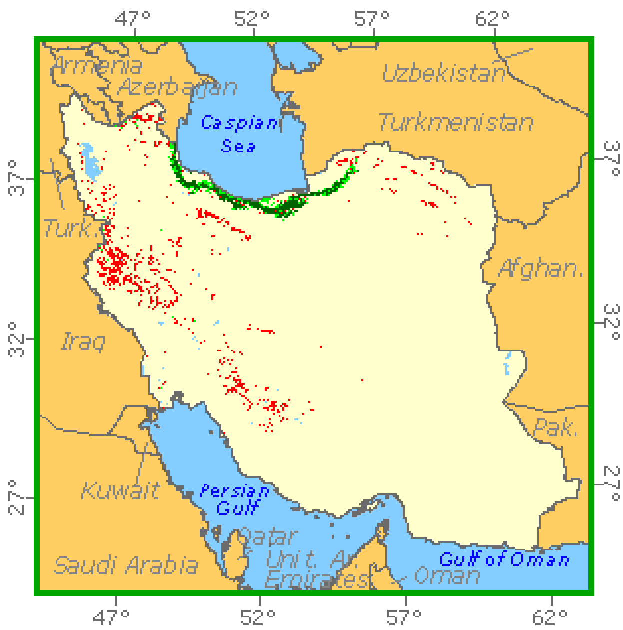


Figure 170, distributions of wooded lands in Iran, FAO (Global Forest Resources Assessment 2000)

Five different regional forest types may be distinguished in Iran as follows:

1. The Caspian broadleaved deciduous temperate forests or the Hyrcanian forests

Located on the south coast of the Caspian Sea and the northern slopes of the Alborz mountain range from sea level to 2800 m altitude with an area of about 1900000 ha. Approximately 60 percent of these forests are used for commercial purposes and the rest of them are more or less degraded. These are the most valuable forests in Iran.

2. Arasbaran sub-higrophic forest

These forests, located in north-western Iran, look like the Hyrcanian forest but some of species such as *Fagus orientalis* and *Quercus castaneifolia* do not grow in the Arasbaran region.

3. Irano-Toranian evergreen and broadleaved forests

These cover an area of about 3500000 ha in the central plateau and mountainous part of the country. The region is arid to semi-arid and the annual precipitation varies between 100 and 400 mm.

4. Zagrosian broadleaved deciduous forests

The main constituent of these forests is oak, *Quercus* spp. They stretch from north to south along the Zagros mountains, extending as far as Shiraz. They are subject to over-exploitation and degradation due to intensive human activities and overgrazing.

5. The Khalijo-Ommanian forests

This region comprises the entire southern part of Iran between the southern watersheds of the Zagros, the coast of the Persian Gulf and the sea of Oman. The climate is subtropical with hot summers. The average annual rainfall is less than 200 mm.

Figure 171, five different regional forest types in Iran, images from (FRW 2016)

FAO statistics demonstrate the volume of growing stock in forest and other wooded land in 2005 as 527 million cubic meters over bark, 416 million cubic meters of which was announced commercial growing stock.

Growing stock in forest and other wooded lands of Iran			
FRA 2005 categories	**Volume (million cubic meters over bark)**		
	1990	**2000**	**2005**
Growing stock	516	517	527
Commercial growing stock	405	407	416

Table 32, Total and commercial growing stock in forest and other wooded lands of Iran, source (FAO 2011)

Iran forests contain certain types of trees predominate in various geographical regions due to differences in temperature, moisture supply, soil conditions and elevation.

Following are the types of species and composition of growing stock in Iran forests in 1990 and 2000 issued by FAO (FAO 2011), many of which are proper for timber construction usages.

Rank	Common Name	Scientific Name	Growing stock in Iran forests (million cubic meters)	
			1990	2000
1st	Hornbeam	Carpinus betulus	126	125
2nd	Oriental beech	Fagus orientalis	132	123
3rd	Alder	Alnus sp.	31	36
4th	Oak	Quercus castaneafolia	34	36
5th	Maple	Acer sp.	30	27
6th	Persian ironwood	Parrotia persica	16	21
7th	Lime	Tillia sp.	11	11
8th	Date plum	Diospyrus lotus	6	10
9th	Ash	Fraxinus sp.	1	1
Remaining			17	16
Total			**405**	**407**

Table 33, Types of trees and their growing stock (million cubic meters) in Iran forests in 1990 and 2000, source (FAO 2011)

Afforestation

Tree planting has a long history in Iran since ancient times. Afforestation has roots in Iran's traditional and national customs and in religious beliefs of Iranians.

Modern afforestation started in southern coasts of Iran by the First World War (1914-1918). Until 1999, the total area of afforested lands in Iran was 781200 ha. At present, the annual afforestation rate is about 6541.7 ha in the north and 14016.2 ha in other regions (Ajorlo 2003).

Deforestation

Despite the good potential of forests in Iran and increasing attempts for afforestation and reforestation in Iran, FAO indicates that some of these forests have been destroyed or severely degraded (FAO 2011).

FAO investigations in 2001 declares the average percentage of 19% for forest area in Asian countries.

The first estimation of forest area in Iran was made in 1942 by Karim Saeei that showed an area of 19.5 million ha (11.8% of the Iran's area) (DOE 2015).

In year 2000, FAO stated that forests cover about 12.4 million ha of Iran's area (7.5% of the country) (FAO 2011).

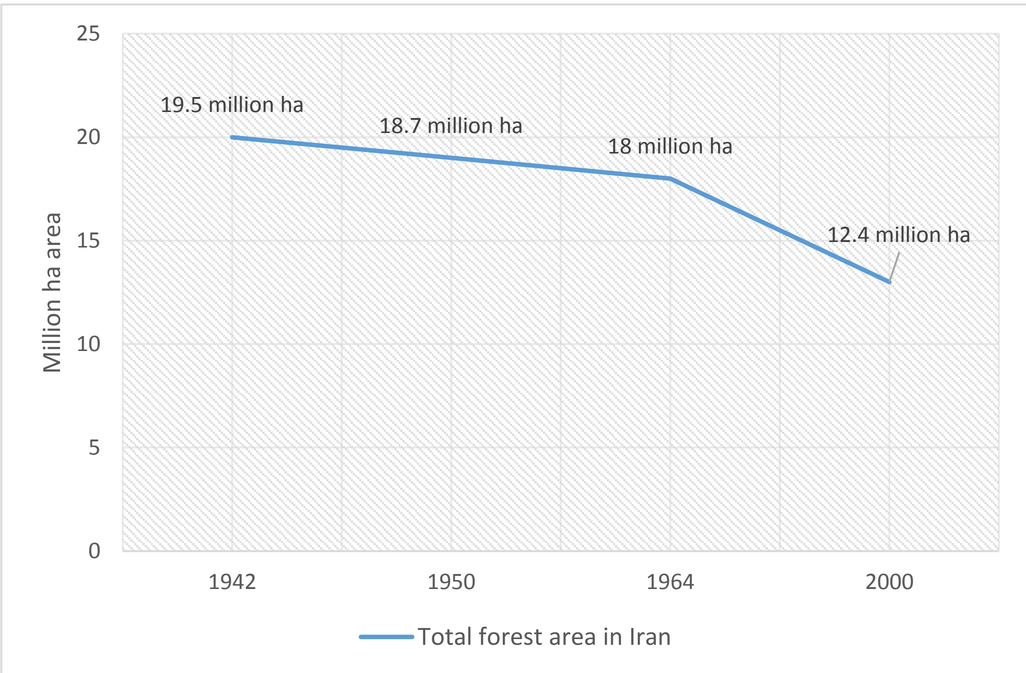


Chart 27, Total forest area in Iran from 1942 to 2000 and its descending rate, chart data source (DOE 2015, 6)

This has been due to harvesting forest wood by companies for business in the past, which is now prohibited, but still done illegally by some companies and individuals.

In addition, utilization of wood as an affordable energy source in remote rural areas with lack of proper infrastructure, development of roads that result in accessibility of forests, as well as promotion of tourism industries have been increasing the rate of forest destruction in Iran in recent years.

Overgrazing as well as inefficient agricultural methods are additional reasons of deforestation of Iranian forests.

Climate change has also affected the quality of forest areas (DOE 2015).

The present average for forest per capita in Iran is 0.17 ha, that compared with the global average of 0.62 ha, signifies the need for forests development and conservation (FRW 2016).

Indicating that the poor quality of many of these weak forests result from deforestation phenomenon in Iran (FAO 2011), FAO also emphasizes the plans for planting forests in Iran:
“In the last 25 years, programs were established to plant irrigated and non-irrigated areas to meet local needs for timber and environmental protection. By the year 1999, the total planted area reached 2221100 ha. The main purposes are to supply wood for forest industry and to minimize impacts on the natural forests of the country” (Mirsadeghi, et al. 1999).

Outlook

The serious problems for the forests in the country has drawn public awareness and attracted the non-governmental organizations' attention in recent years. Iran's government has also aimed at making strategies for approach towards a sustainable development in Iran forests in its fourth (2005-2009) and fifth (2011-2015) Five Year Development Plans (DOE 2015) including practices for:

- Management of watershed, livestock and local residents of the northern forests
- Rehabilitation and restoration of degraded forests
- Preserving the previous forest plantations
- Construction and maintenance of forest roads
- Providing the seedlings for plantation of proper species of trees
- Promoting public participation for protection of natural resources
- Education of users, administrators and operators
- Codification of regulations and technical standards for natural resources and forests (FRW 2016).

For northern forests that are the most valuable natural resources, programs for rehabilitation of forests have been established in recent decade such as:

- Codification and implementation of forestry management plans. 1.4 million ha out of 1.85 million ha of these forests have forestry management plans since 1959. Presently these plans are implemented in 1.07 million ha of these forest by governmental, private or cooperative sectors. Instead, these responsible sides get the permission to harvest and use the wood under the supervision of Iran Natural Resources Organization. Besides, the rate of forest exploitation has decreased from 1.7 million cubic meters in 1996 to 800 thousand cubic meters in 2007.

- In 1985 4,370,000 livestock units existed in northern forests. 1,207,531 of them have left northern forests and 3,782 local families in these forests are organized. Livestock grazing hurts seedlings and causes soil crush that prevents seed germination and trees growth.

- Besides afforestation, establishment of roads, protection and development plans, removal of old and degraded trees can effectively increase the quality of forests. While tree germination and generation in northern forests of Iran exceeds an annual rate of 4 million cubic meters, harvesting 800,000 cubic meters per year guarantees proper growth and higher quality of seedlings and young trees. The total volume of the northern forests trees are estimated 391 million cubic meters, 50% of which are trees with a diameter larger than 60 centimeters.

- Production of forest seedlings, reforestation and restoration of degraded forest areas and preservation of forest parks started in 1952 by the Iran government. By 2007, 453,977 ha of northern forests were rehabilitated through such plans. Most of these rehabilitation plans focus on upgrading the quality of forest areas, but do not extend the forest area. (Javanshir, et al. 2002) (Marvi Mohajer 2005, 387).

Adaption of such strategies and implementation of them results in achieving independent production of wood in the country, preserving the natural resources as well as sustainable development of forests.

SUMMARY

Wood is the most environmentally sustainable building material to be used as the binding material in adobe buildings in Yazd.

But Iran's forests in their present situation cannot supply the required wood for construction in Yazd.

Meanwhile the present programs for revitalization of these deforested lands can provide the required wood for construction in near future.

Therefore at present time, wood cannot be the first choice as the strengthening material in adobe buildings in Yazd, but is the best material in long term (after improvement of Iran forests).

For the short term, according to table 30, steel can be used as the binding material in the second rank after wood, revealing more benefits in terms of environmental sustainability compared with concrete.

A composition of steel-timber is also a proper alternative.

HW2. COMFORT

A. Identity and independence: accessible and lifetime homes

One of the important features promoting comfort in houses is its ability to serve all ages and types of inhabitants, from toddlers to elderly people and handicapped people.

This feature is studied in the six case study houses, in terms of the number of stairs one has to climb up or down while going from the entrance door to the living room in each house. These stairs do not currently have any alternatives such as inclines or elevators.

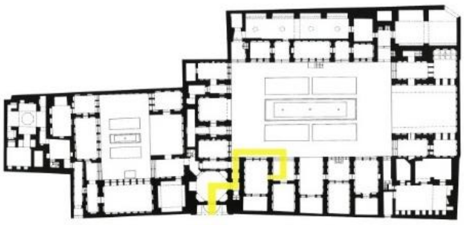
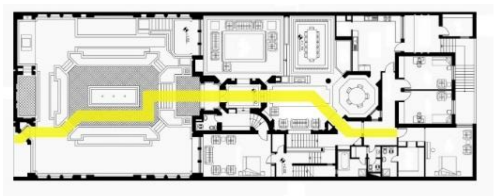
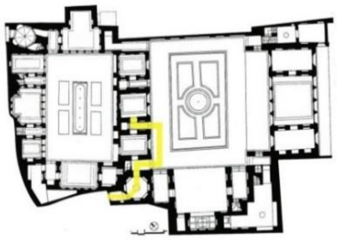
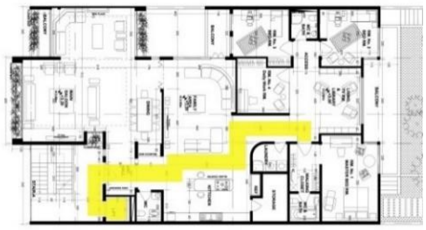
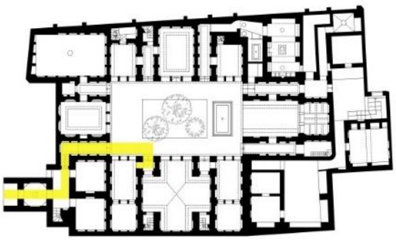
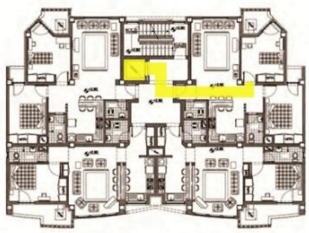
Lari: 6 stairs	Atlassi: 15 stairs
	
Olumi: 8 stairs	Mir-Hosseini: lift 19 stairs
	
Tehrani: Ramp + 5 stairs	Sima Gostar: lift or 18 stairs
	

Table 34, comparison of level difference for access from main entrance to a bedroom

SUMMARY

Table 34 shows that the residents of three historical houses, as well as the Tehrani single-family house, suffer from floor level differences and staircases in the house, which increases the risk for vulnerable inhabitants, such as babies, old people, and people with disabilities.

This level difference in historical houses is due to sunken house pattern.
In multilevel case study housing, there is no choice for access other than a lift or staircase.

B. Sound Insulation

One important issue in contribution to comfort in a house is sound insulation. LEED does not take this matter into consideration in its Health and Well-being category.

Although many of the acoustic-based regulations for housing target the mechanical equipment and insulation materials and detailing, good design practice can participate in the reduction of noise penetration from outside the dwelling into the inside, and also between inner spaces and rooms, and therefore results in the minimization of construction costs.

The following are some building plan layout tips for the reduction of noise penetration:

- It is good design practice to locate noise-sensitive rooms away from noisy areas where possible, both within each unit and also between adjoining units.
- Noisy areas such as living rooms, kitchens, laundries and bathrooms should be grouped together possibly sharing common walls.
- Locating wet areas above one another can result in significant cost savings in relation to sound insulation requirements, particularly where pipes penetrate the separating slab.
- Quiet areas such as studies and bedrooms should be grouped away from noisy areas and they again should be grouped together. (ABCB 2004)

Contemporary case studies

Contemporary multilevel housing reveals more acoustic problems compared to traditional houses:

1. Different acoustic types of spaces with common floors or ceilings on different floors, such as the common floor of the first floor with parking or sport and recreational spaces of the building.

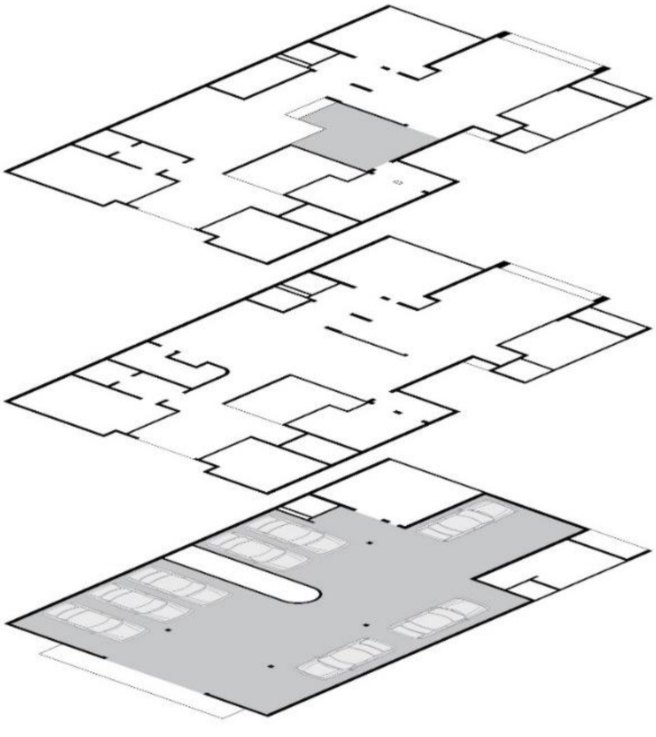


Figure 172, Mir Hosseini case study, ground, 1st and 2nd floor, drawing by author

Figure 171 shows the first floor in Mir Hosseini multilevel apartment as the case study in this dissertation, and the two surrounding floors; ground floor (parking space) and second floor.

As illustrated, the living area on first floor is located under the kitchen of the second floor. This means that the designer did not pay attention to the acoustics (nor the probable water penetration problems).

Also, the lower floor serves as a parking place that generates a lot of sound pollution, especially for the residents of the first floor. Normally, the design rules in Iran do not ask for any acoustic insulation measures for the ceilings of the parking area in multilevel housings.

2. Different acoustic types of spaces with common walls in different units of one level, like the adjoining living room and toilets from one or separate neighboring units that surround the bedrooms.

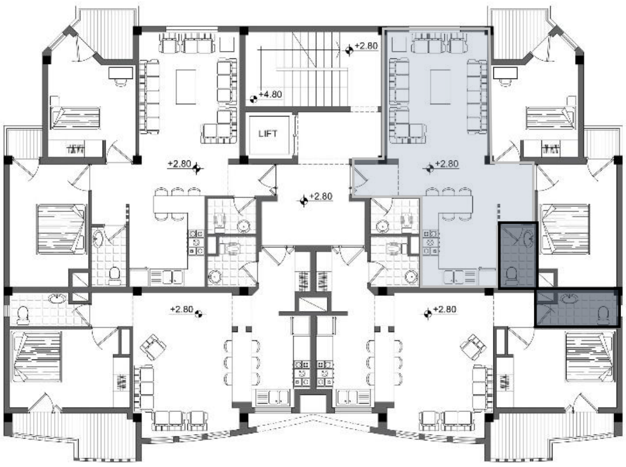


Figure 173, Sima Gostar case study unit and noisy spaces from neighboring units in the same floor

SUMMARY

Contemporary housing case studies suffer from the penetration of noise from noisy areas to quiet areas. This is due to inappropriate design, which does not separate the noisy areas from the quiet ones, and may result in the need for more sound insulation materials and equipment.

One advantage of architectural design in traditional houses in Yazd is the good zoning of spaces. Figure 173 shows three different groups of spaces in the Tehrani house plan: living/bed rooms[22], noisy areas and connecting halls.

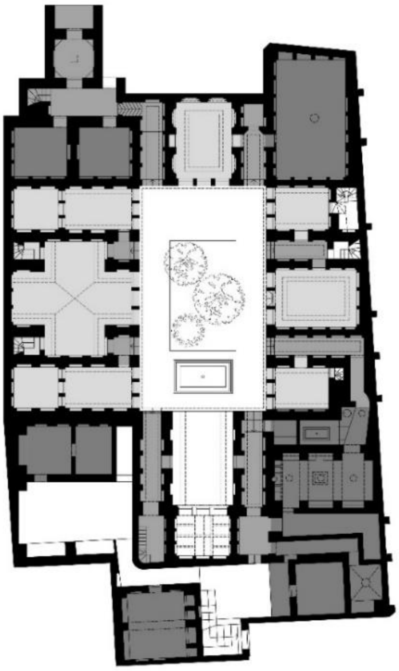


Figure 174, Tehrani house, ground floor plan, drawing by author, base map from (Haji-Qassemi, Harirchi and Qelichkhani 2005)

This figure reveals the following points that are the characteristics of the planning of architectural spaces in traditional Iranian houses with central courtyards in Yazd:

- The living spaces (public, semi public or private rooms) are laid on the main axes of the central courtyard.
- These spaces are connected to each other or to the courtyard, with narrow halls. These connecting corridors provide rooms with less penetration of open air and noise, and they offer greater privacy.
- The blind corners of the house are allocated to service spaces such as a toilet, bathroom, and kitchen, washing place or even places to keep animals, such as horses.
- The thick walls of the house also prevent noise penetration between spaces.
- Trees in the courtyard can also prevent penetration of exterior noise or visual access.

RESULT

The layout of historical case studies share many helpful design strategies, in terms of acoustic comfort, which is quantified by defining specific zoning for daily living activities in the house.

[22] Traditionally, bedrooms in Iranian culture is not a separate room. The same room that is used during the day for living activities turns into the room for sleeping during the night. Warm floor allows the residents to sleep on mattresses on the floor without using beds. So by folding the sleeping mattresses, more space will be available during day.

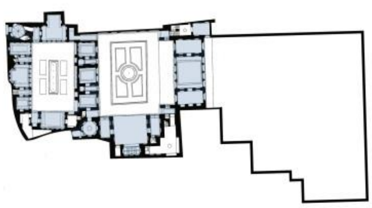
HW3. Health

A. Access to Fresh Air

One of the most important elements in buildings that participates in healthier living is the indoor air quality. There are various ways to reduce indoor air pollution and improve its quality. Increasing ventilation and air exchange with the outside will help prevent the accumulation or reduce the amount of air pollutants indoors. (Kobayashi, et al. 2007)

The direct access of spaces to outdoor fresh air is therefore an advantage, since this can result in easier natural ventilation through simple design strategies and minimize dependency of the house on mechanical equipment for ventilation.

Table 36 demonstrates the ratio of the area of the rooms with direct access to fresh air to the net area of the rooms in the ground floor in each case study. Due to the high ratio of the rooms' area covered with walls in historical houses, the net area of the rooms is calculated by subtracting the wall footprint area from the overall room area.

Lari House		**Atlassi House**	
			
Land: 3351 m² Rooms: 1578.16 m² Courtyard: 885.12 m² Walls: 887.72 m²	Direct ventilation/rooms: 1070/1578= 0.68	Land: 859 m² Rooms; 371.15 m² Courtyard : 385.25 m² Walls:102.6 m²	Direct ventilation/rooms: 176.12/371.15= 0.47
	68% direct fresh air		**47% direct fresh air**
Olumi House		**Mir-Hosseini House**	
			
Land: 1308.3 m² Rooms: 465.3 m² Courtyard: 512.7 m² Walls:330.3 m²	Direct ventilation/rooms: 391/465.3=0.84	Land: 484.02 m² Rooms:328.83 m² Courtyard: 125.60 m² Walls: 29.6 m²	Direct ventilation/rooms: 102.58/302.23= 0.34
	84% direct fresh air		**34% direct fresh air**

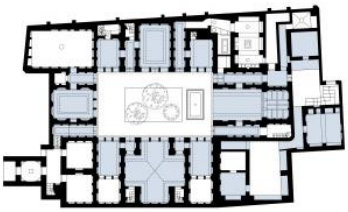
<table>
<tr><th colspan="2">Tehrani House</th><th colspan="2">122 unit Sima Gostar</th></tr>
<tr><td colspan="2"></td><td colspan="2"></td></tr>
<tr><td rowspan="2">Land: 1131.5 m²
Rooms: 547 m²
Courtyard: 221.5 m²
Walls: 363 m²</td><td>Direct ventilation/rooms: 351/547=0.61</td><td rowspan="2">Land:102.8
Rooms:88.7
Courtyard: ---
Walls: 14.1</td><td>Direct ventilation/rooms 51.8/ 88.7= 0.58</td></tr>
<tr><td>64% direct fresh air</td><td>58% direct fresh air</td></tr>
</table>

Table 35, ratio of area of the rooms with direct access to fresh air

Charts 26 and 27 show the comparison between the results of the ratio and percentage of areas with direct access to fresh air in the sample houses.

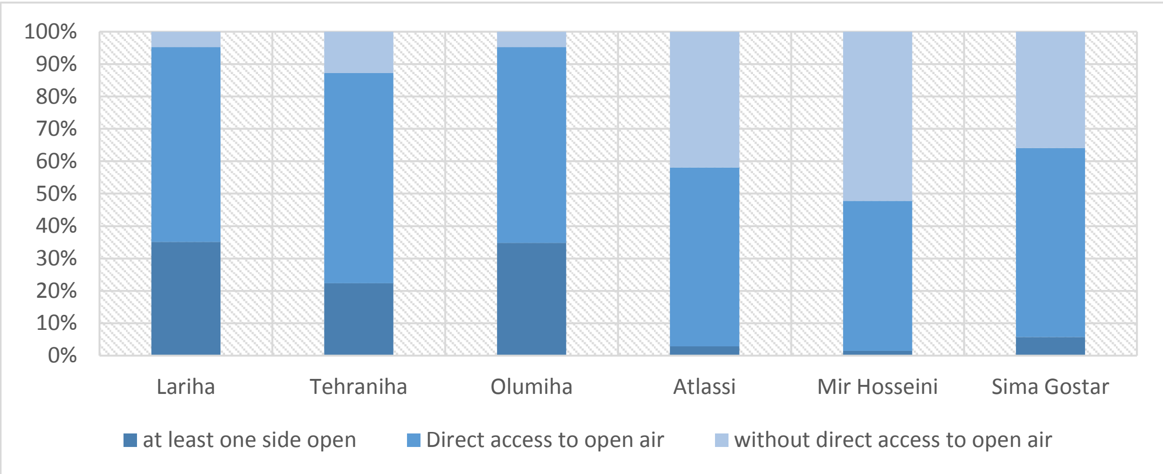


Chart 28, Comparison between percentage of area of open spaces, spaces with direct access to open air and spaces without direct access to open air in historical and contemporary case study houses

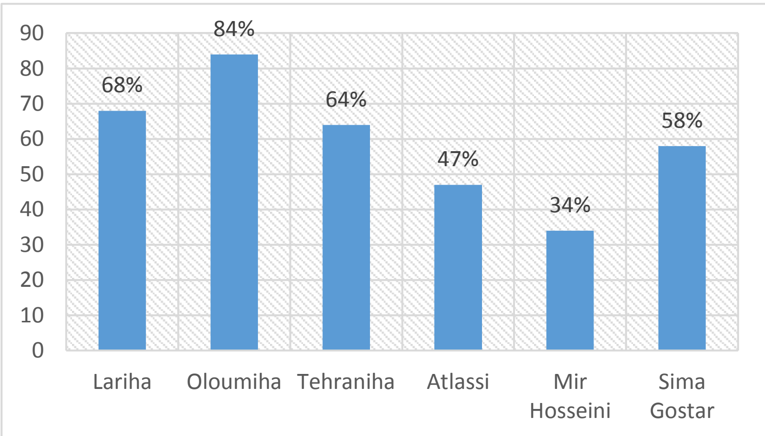


Chart 29, Comparison between percentage of room area with direct access to open air /overall area of roofed spaces in historical and contemporary case study houses (%)

RESULT

These comparisons show that historical case study houses have larger area of spaces with direct access to fresh air (average result of 72% for area of rooms with direct access to fresh air out of the net built area in traditional houses compared with 46% in contemporary houses) (Chart 29).

An average 45% area of the rooms in contemporary houses do not have any direct or secondary access to fresh air, while this rate in traditional houses is less than 7% (Chart 28).

The main reason for this is the organizational pattern in traditional houses: a central courtyard in the center, which provides the surrounding spaces with fresh air.

While southern courtyards in contemporary single family houses or adjoining of several units in each floor of the multi-level contemporary residential restrict direct access to fresh air for rooms.

B. Purifying air with plants

Access to open air (discussed in previous part) in desert areas where the air contains dust or even sand during sand storms can present disadvantages, unless this air is purified.

Plants are natural air purifiers. They absorb the suspended dust in the air and provide air with higher quality.

While houseplants are not a total solution to improving indoor air quality, they should not be overlooked as an aid in creating interior spaces conducive to the health of those who occupy them (Kobayashi, et al. 2007) (see also (Watkins 2001) (Relf 1996).

Plants can increase the humidity of the air and have a relaxing effect on people, and removing dust aids by reducing potentially allergy-inducing particles (Kobayashi, et al. 2007). Vaporizing the arid air in desert regions like Yazd can be very beneficial.

In addition, plants also participate in the absorption of organic gases and chemicals in the air. They support cultures of microbes around their roots that degrade complex organic gases found in the air (Sassi 2006, 122) (Kobayashi, et al. 2007).

The type of the plant is very important regarding its contribution to the purification of air. Wolverton, in his book *Eco-Friendly House Plants*, tests and rates 50 plants in terms of total chemical absorption, transpiration rate, ease of growth, and maintenance and resistance to insect infection (Wolverton 1997).

Another investigation on plants to clean indoor air (Kobayashi, et al. 2007) shows that not all of the tested plants have proven equally effective ability to clean indoor air and neither all harmful pollutants can be removed by houseplants.

FAO in its page for Iran planted forests describes the species of trees planted in different climates of Iran: "The species planted in the desert zone are generally limited to indigenous or well-established species such as *Haloxylon* spp., *Tamarix* spp. and *Zygophyllum* spp" (Jafari and Hossinzadeh 1997). Of course most of these plants are planted to avoid desert expansion.

Traditional housing in Yazd with the central courtyard's pattern is a proper potential for purification of the indoor air with plants. As discussed in chapter 5.3, part GL2 (Effective Green Area), the central courtyard, as well as the arrangement of the spaces around it up to a certain height (normally due to the desert local trees' height, two to three levels, like in historical houses), provide the residents of houses with purified, fresh air.

For upper levels that do not benefit effectively from the vegetation in the central courtyard, application of additional small green spaces can help.

SUMMARY

Plants can provide the residents with healthier air, specifically in arid regions where the air needs to be humidified.

In traditional houses planting in the courtyard can support the surrounding spaces more efficiently. This becomes harder for in multilevel housing, where all the green area is accumulated in the ground floor.

Another important item is to use the right species of plants which can purify the air, and do not need much water in the arid region.

CHAPTER 7. RECOMMENDATIONS

WATER

Features

In Iran the water provided by the national pipeline system is used for all (potable/non-potable) usages in houses, and this results in higher rates of water consumption comparing with the international standards.

On the other hand the water from *Qanāt* system may not reach the required quality for drinking, and needs to be improved.

Investigations show that the city of Yazd benefits from a very extensive system of existing *Qanāts* underneath the ground, a major part of which has been abandoned during past decades.

This is a passive water system that can provide the city with notable amount of water in case of revitalization and continuous maintenance.

At present, the Cultural Heritage Organization of Yazd in cooperation with Yazd Agriculture Organization[23] have rehabilitated several Qanāts in Yazd province during the past years. Some of the oldest of them have been inscribed on World Heritage List of UNESCO according to their significant contribution to the life in deserts. A large amount of the provided water is used for agricultural purposes. Some of these Qanats possess a notable Debi of water and a very high quality of water at their sources.

The contemporary expansion of the city also conforms to the layout of this passive water system, and therefore this water system can be used in both historical as well as the contemporary parts (see Figure 118).

Proposed Strategies

Being inspired from the passive water system in the historical city of Yazd, this research proposes rehabilitation of *Qanāt* system to provide the inhabitants with alternative water systems, specifically for non-potable water consumption such as irrigation or daily wash usages. Following are the proposed strategies:

- A limited amount of energy and work can revitalize the existing *Qanāts* and cisterns system in Yazd, which can contribute in major reduction of overall water usage in the country.
- The water from *Qanāts* can be used for non-potable usages.
- Water obtained from *Qanāts* can be an alternative water source during years of drought.

[23] http://www.yazd.agri-jahad.ir/

- The quality of water from *Qanāts* can also be improved by usage of small modern technologies for water purification, and then be used as potable water.
- The access to *Qanāts*, which is traditionally through deep stairways, can be upgraded by additional simple pipeline system for transferring the water to the ground level.

Besides, the following strategies can be beneficiary:

- Education of users and improvement of equipment and appliances will lead to further sustainability, as indicated by LEED.
- At the architectural design stage, the adaption of strategies for reduction of water consumption is beneficiary, e.g. the number of private or shared bathrooms, area and type of vegetation, etc.
- Separation of grey water from drinking water is proposed as well.

ENERGY

The bioclimatic chart for Yazd indicates that specific design strategies and application of low tech solutions can effectively cover a notable amount of energy needs in Yazd and therefore participate in moderation of the climatic situations at housing and city scale.

Features

Metrological data in Yazd indicate that this city benefits from a good potential of renewable clean energy sources i.e. wind and sun radiation.

At the same time, the intense sun and the abundant wind in Yazd require to be moderated in order to achieve human comfort conditions.

Contemporary housing in Iran is a huge consumer of non-renewable energy sources, while traditional houses benefit from design patterns that contribute in sustainable usage of renewable energies.

Yazd bioclimatic chart demonstrates that adaption of simple strategies such as application of specific building materials that are compatible with Yazd's climatic conditions, adaption of natural ventilation strategies, efficient thermal insulation with outer layer white or light-colored can extend the human comfort zone in houses up to a notable range.

Strategies

Review of case studies reveal patterns and design strategies which are compatible with climatic and environmental characteristics of Yazd.

These strategies conduct designers to make decisions at the design stage that lead to housings which use green energy sources and have minimum energy needs and energy exchange.

In such houses, dependency upon fossil fuel sources or specific mechanical equipment and tools for reduction of energy consumption will therefore decrease.

Following, some major guidelines for design strategies inspired from traditional architecture in Yazd, found in the evaluation chapter will be shortly introduced and recommended. These strategies conduct to a more sustainable contribution in energy consumption in houses.

Micro Climate

Due to severe environmental conditions of desert area, application of micro climate systems are recommended.

Regarding the environmental strengths and problems in each city, this microclimate has its own architectural features and elements such as central courtyard with specific plan proportions and geographic orientation, number of floor levels; type, size, number and location of wind catchers, its connection to basement, water pools and vegetation for evaporative cooling etc.

This set of central courtyards and their associated elements such as wind catchers, water pools and gardens etc. contribute in creation of a microclimate at housing scale, in the middle of the severe desert climate of the region. They then develop the comfort zone conditions at the neighborhood scale, and at a larger scale in the city.

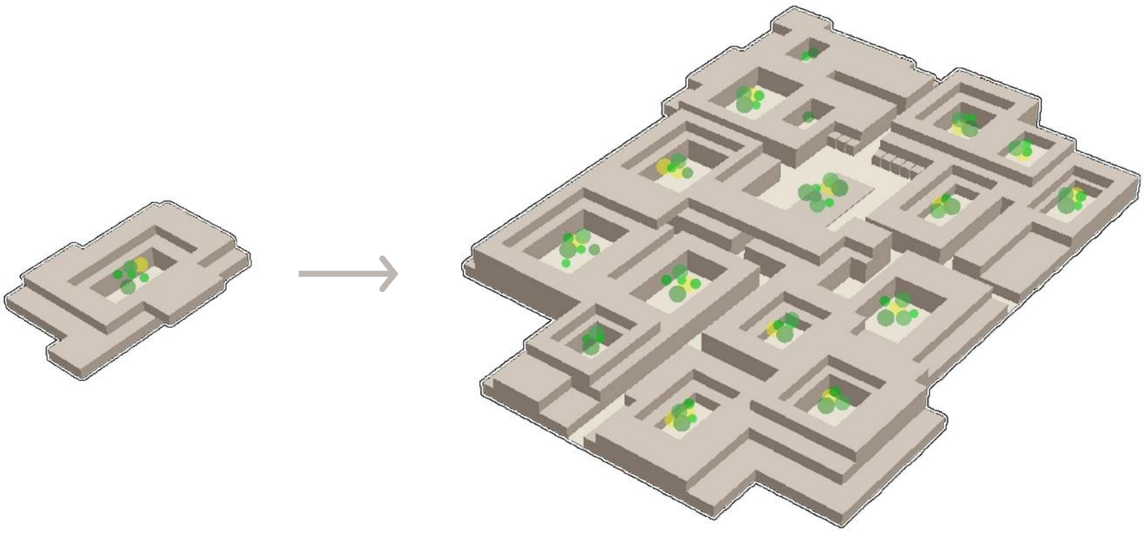


Figure 175, development of microclimate through the city, drawing by author

Central Courtyard

As mentioned previously, central courtyards are the major elements of microclimate systems in desert houses. Following, are recommendations for architects in early stages of designing, to adapt an efficient system of microclimate in central courtyards in Yazd:

- Use central courtyard as the basic organizing element of the design and the major element for building up a microclimate.

Define a rectangle void as the courtyard and arrange the neighboring independent units around it.

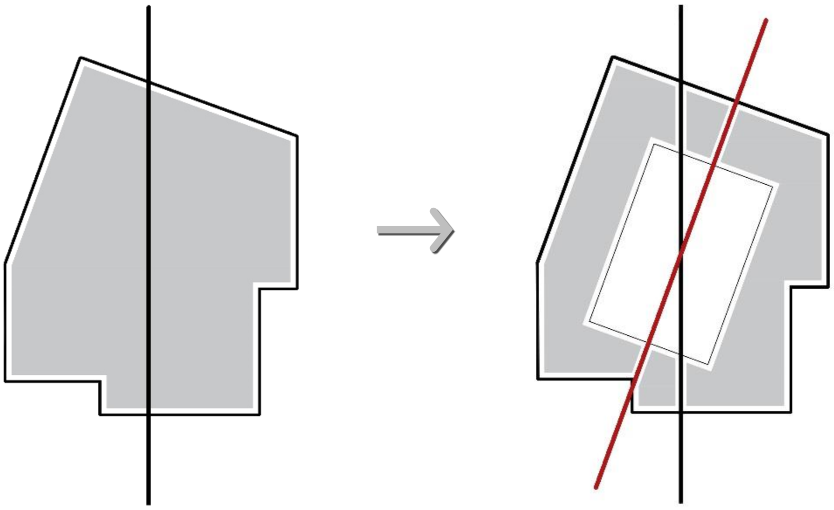


Figure 176, central courtyard as the basic organizing element of the house design

- For best performance of the central courtyard as a microclimate unit, this dissertation has studied the following features in courtyards:

1. Optimum shading in summer and winter
2. Best solar gain on vertical surfaces in winter
3. Best natural ventilation

Considering the degree of orientation of the house for its best energy performance, the following results are achieved:

1. References for Iranian traditional architecture, like *Pirniā*; known as the father of Iranian traditional architecture, define Yazd *Ron* for best climatic performance as due southwest.
2. Traditional case studies propose 25° to 33° due Southwest.
3. Yazd CHHTO guidelines for gaining natural heating and avoiding the intense solar radiation of around noon in summer proposes 20° to 30° due Southwest.
4. Author's sample calculations for best shading performance for more shade in summer and less shade in winter time reveal rotation of central courtyard within 30° due Southwest.
5. Solar protractor shows a balanced heat gain (passive solar gain) on southern vertical surfaces for traditional case studies (25° to 33° due SW), while high amounts of solar energy is gained by contemporary houses on North-South direction or 12° due SW which is a negative point for these latter orientations.
6. By LEED, best design strategy on building orientation to maximize opportunities for passive Solar gain is within 15 degrees due west for areas north of 25 degrees latitude

7. Yazd CHHTO guidelines propose the best orientation to benefit from Yazd favorable wind that blow from Shirkouh mountains, to be 20° to 45° due southwest.

Taking into account all the items mentioned above, the best orientation of the central courtyards in response to balances shading, passive heating and natural cooling is between 20° to 30° due southwest.

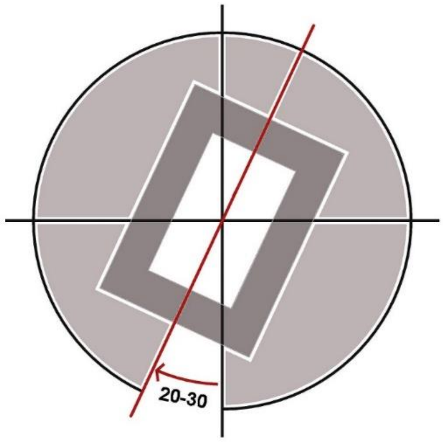


Figure 177, recommended orientation for best energy performance, drawing by author

- The best plan proportion of the courtyard for good shading performance in both summer and winter time is width to length proportion of around 2:3 to 2:3.5.

- Geometrical study of the central courtyards in the traditional case studies in Yazd demonstrate average area of approximately 10x15 m² to 20x33 m² for these central courtyards.

- Design sunken houses to avoid vast fluctuations of temperature changes, between day/night in desert area. Construction of houses beneath the ground level reduces heat exchange due to geothermal heating.

In arid area, the temperature of dry soil is constant at a depth of -5.00 meters below ground.

With this sunken into earth pattern, the house benefits from geothermal heating, and therefore has less thermal exchange.

Historical houses in Yazd propose an average ratio of two third of the house height below ground level, including at least one living level plus basements.

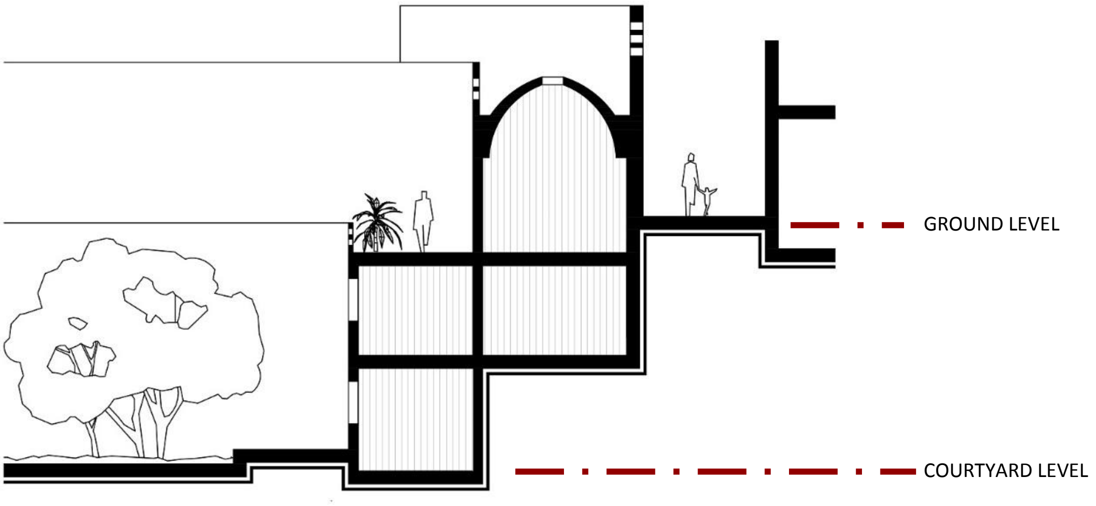


Figure 178, schematic section, the lower floor of the central courtyard compared to the passageway floor level in sunken houses creates a house surrounded by the earth, where the temperature is constant at a level of -5.00 meters in desert area, drawing by author

- Common outer walls shared with neighboring houses also prevent energy exchange. Adjoining neighbors which share back-to-back walls assist decrease in thermal exchange.

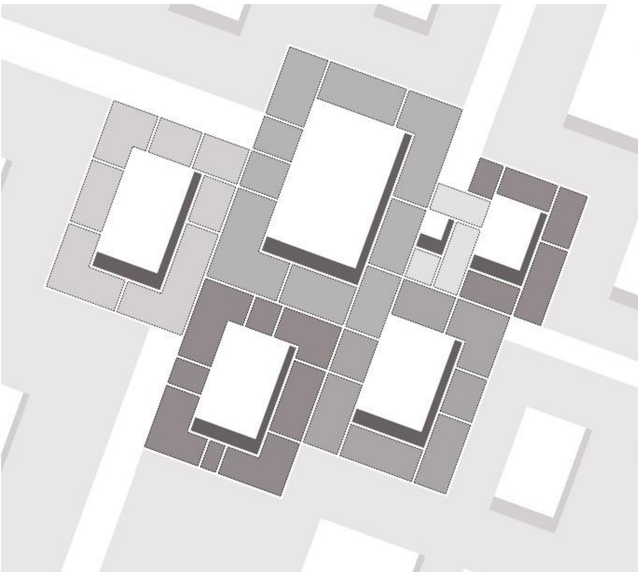


Figure 179, common walls, shared between neighboring units in one courtyard house, or between neighboring courtyard houses reduce the heat exchange by reduction of the outer envelope disposal to air, drawing by author

Glazing

- The spaces facing South and East have the highest percentage of glazing area in order to benefit from sun in winter time.

These sides played the role of the winter space in traditional four season houses. In multilevel contemporary houses with shared central courtyard, these sides are allocated to separate living units. Therefore strategies for possibility of adjustment of radiation transmit into these facing sun spaces must be adapted to avoid over heating in these housing units.

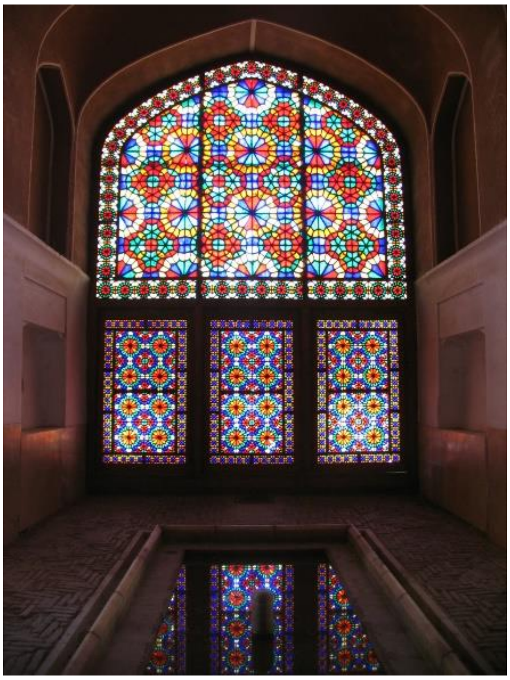


Figure 180, Orossi windows, Dowlatabad Garden, Yazd, photo by author, 2008

Use *Orossi* windows, with adjustable heights and colored glasses, especially on facades facing south, and on upper floors, where the spaces are at more radiation and climatic risk. These adjustable windows with colored glass can adjust the degree of solar energy transmitted into the space.

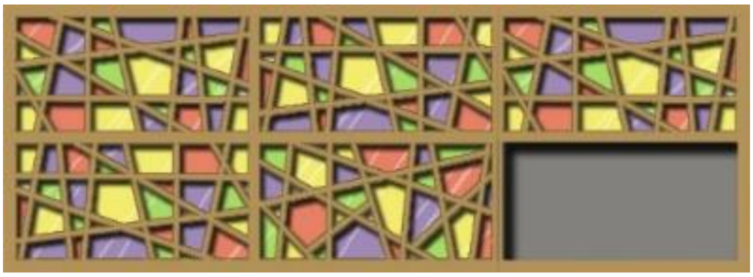


Figure 181, proposed windows with colored glasses and adjustable heights, drawing by author

LEED standards for designing to maximize opportunities for solar design in buildings over a latitude of 25° north also mentions that at least 90% of the south-facing glazing must be completely shaded (by awnings, overhangs, plantings) at solar noon on the summer solstice and unshaded at noon on the winter solstice.

Adaption of simple tools such as traditional reed mats or textile curtains on the facades of the central courtyards are recommended. The following figure shows

Figure 182, Folding/sliding timber shading, drawing by author

- Meanwhile, due to notable energy exchange through glazing area, it is recommended that the percentage of glazing area must be less than 15% of the (conditioned) floor area, and the ratio of southern glazing area (SGA) out of total glazing area (TGA) must be less than 50%.

Green Area

- Use local vegetation for better operation of the microclimate system. Trees provide more shading and also contribute in better evaporative cooling and therefore more efficient microclimate (see chapter GL2, Effective Green Area).

- For a more effective green area, the quantity of the green area must be taken into account, as well as the spatial contribution of green space in a two way interaction with the built spaces of the house:

- The average ratio of green area/land area is around 5%.

- Due to favorable wind direction in Yazd, it is recommended to set the garden in the middle of the courtyard.

- Use water pools in the courtyard to increase evaporative cooling performance of the microclimate system, and to decrease aridity of the air.

In traditional courtyard, big shallow water pools are located along the courtyard in the middle in bigger courtyards, or in front of the southern side of the courtyard (*Eivan* and wind catcher).

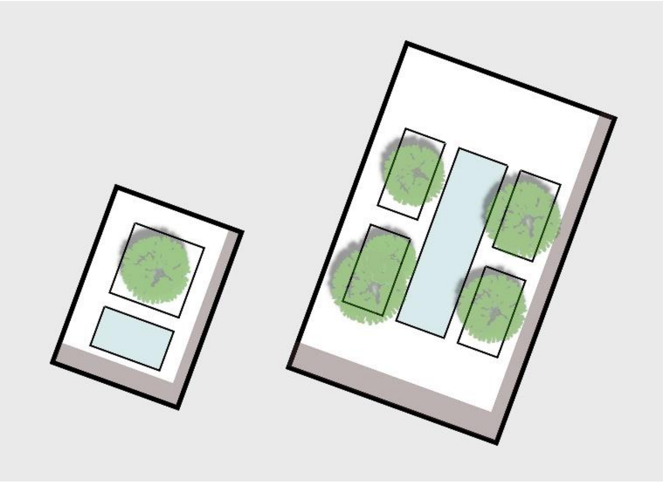


Figure 183, schematic plan for location of water pools in the courtyard, in the middle or southern side of courtyard, drawing by author

- Due to the average height of trees in Yazd, the trees in the garden normally cover two levels of housing in contribution to effective microclimate.

Therefore in the recommended three story houses, the two lower levels can benefit from water pool and vegetation in courtyard that cool the space through evaporative cooling and shading, but for upper levels, additional vegetation is recommended.

Figure 184, for floors upper than the second, additional vegetation improves the micro-climate efficiency, drawing by author

This allocation of green spaces on upper floor also creates small semi-private open spaces for each housing unit.

- Traditional patterns propose open space in houses 20-40% of the built area. This ratio is ignored in contemporary housing, where the rules ask for 40% of the land as the courtyard, regardless of the number of levels and units in the building.

- Traditional courtyard houses were the resident for multi families, mostly different generations of a family (grandparents, parents, children and grandchildren) or families with close relations.

But modern patterns of living in Iran is based on leave of children after their marriage, and each single family unit requires its independent living area.

While this study recommends the central courtyard pattern for houses to achieve an efficient microclimatic system in the house, the change in the modern family needs affects the arrangement of spaces around the central courtyard: winter and summer spaces on different sides of courtyard in traditional houses is replaced by several independent units. This pattern creates a new courtyard organization that still has its own climatic function and responds to social necessities of the modern families as well.

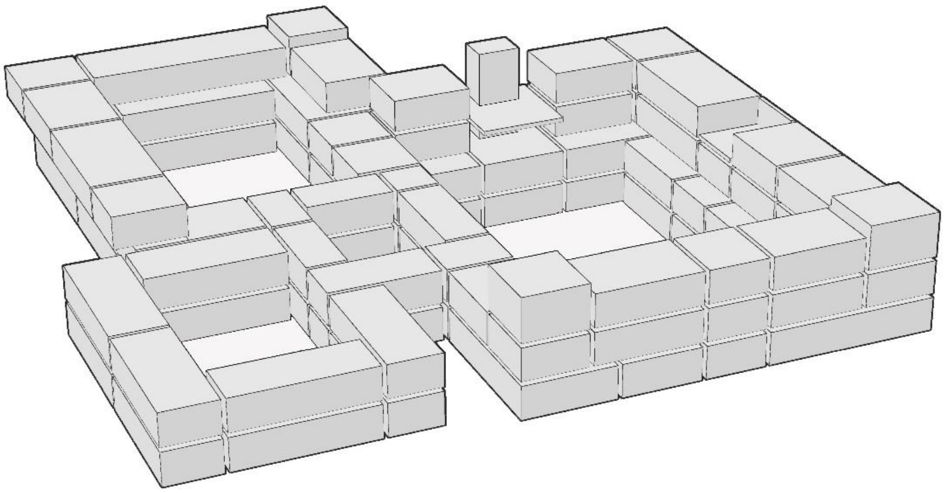


Figure 185, new courtyard houses, separate residential units around courtyard, drawing by author

- This new multifamily courtyard with separate residential units can then expand in dimensions to prepare more space for more residential units that benefit from microclimate system.

Multilevel central courtyards can fulfill the required number of houses for the desired density in Yazd.

- The recommended number of levels for housing is three floors (plus basement in southern sides of the central courtyard):

The average footprint of three traditional case studies is 54.52% (See chapter 7.3, GL1). With the proposed height of 3 floors for the new town, the outcome density will be:

<u>54.52% x 3= 163.56%</u>

This covers the need of present density of the city, which is an average of 156.27%.

- The height of the courtyard façade in traditional case studies is 6.50 meters (southern façade is around 2 meters higher). This height covers a two-level housing regarding contemporary standards.

This height provides the courtyard with an amount of unshaded area in the winter, which is vital for better thermal performance of the central courtyard through insolation.

If the courtyard's height changes but the plan dimensions remains the same, then a large area (or even the whole area) of the courtyard would be covered with shading, which is a disadvantage due to possibility of freezing in winter and malfunction of microclimate in summer time.

In this case, there are actually two ways to keep the percentage of unshaded courtyard area constant, when the height rises:

1. Build the additional level further backward.
2. Increase the plan dimensions of the courtyard as the height increases.

The following graphics show a simple calculation to see what plan enlargement is necessary if these 6.5m high walls of the courtyard rise to 10.5m (according to the present architectural design rules that define the height for a 3 level housing (M2 criteria) to be 10.5 meters high).

The first row of Figure 180 shows the dimensions and the size of unshaded area of the central courtyards on Dec 21st at 12:00 o'clock. The second row of Figure 180 shows the increased plan dimensions of the central courtyard in three case study houses in case the height of the courtyard rises to 10.5 meters, in order to keep a constant percentage of unshaded area in the courtyard on Dec 21st at 12:00 o'clock (Table 36).

	Central Courtyard	Lari	Oloumi	Tehrani
Present height	Present dimensions (m)	20.36 x 33.87 x 6.25	10.27 x 16.56 x 6.25	9.42 x 16.76 x 6.5
	Unshaded area on Dec. 21 at 12:00’	434.44 m²	52.72 m²	39.46 m²
	Unshaded / courtyard area %	63%	31%	25%
10.5 meters high (one additional level)	Extended dimensions	33.89 x 56.38 x 10.5	17.05 x 27.49 x 10.5	14.48 x 25.76 x 10.5
	Unshaded area on Dec. 21 at 12:00’	1202.77 m²	145.11 m²	93.25 m²
	Unshaded / courtyard area %	63%	31%	25%

Table 36, Comparison of the area and percentage of shaded area in central courtyards of the traditional houses with their present wall height and an additional level on top

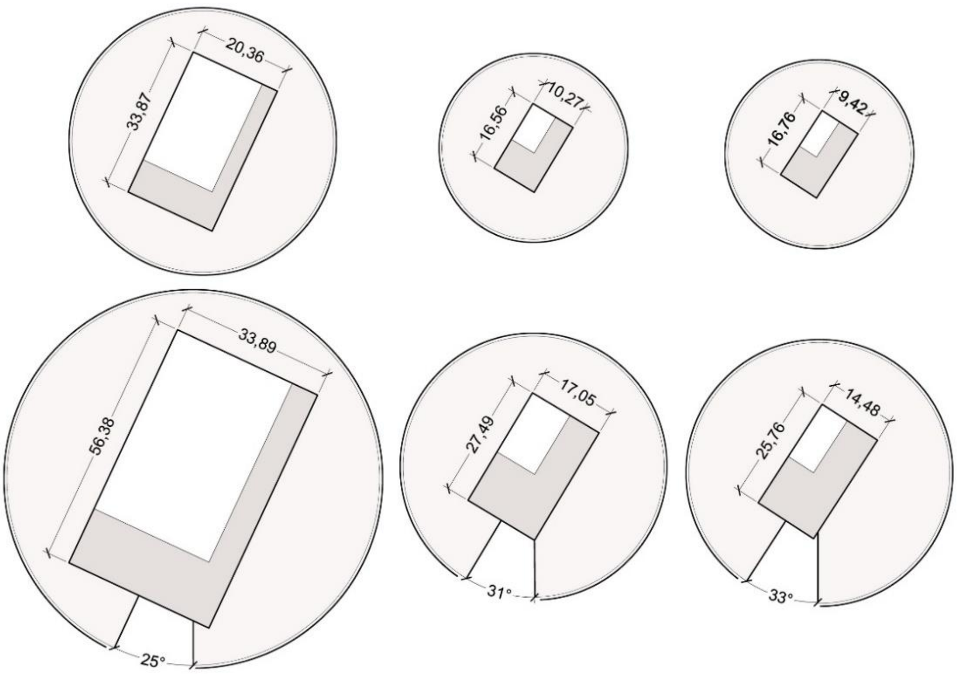


Figure 186, left to right: Lari, Oloumi, and Tehrani house courtyard
Up: present dimensions, down, dimensions after rising one level up, drawing by author

The results illustrate that if the three case study houses add a level on top which is not set backward, the courtyard plan dimensions must extend in order to get the same percentage of unshaded area on Dec. 21st noon:

- Lari house (courtyard Width x Length (m)): 20.36 x 33.87 → **x 1.66** → 33.89 x 56.38
- Oloumi house (courtyard Width x Length (m)): 10.27 x 16.56 → **x 1.66** → 17.05 x 27.5
- Tehrani house (courtyard Width x Length (m)): 9.42 x 16.76 → **x 1.53** → 14.48 x 25.76

This small calculation reveals that for keeping the shading performance of the courtyard at a constant rate as its height increases from 6.5 to 10.5 meters (one additional floor higher), the plan dimensions (width and length of the courtyard) must increase around 1.6 times too.

Therefore in case of an additional level on top, one of the following strategies are recommended:

- Set the third level backward in order to avoid affecting the shading performance of new courtyard. This strategy creates open-air spaces for residents of the third level, as well as for vegetation on top, which improves microclimate's performance.

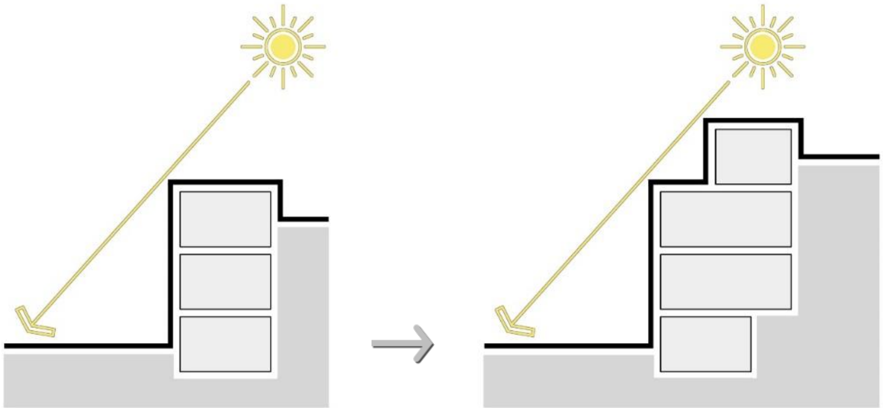


Figure 187, Set back upper levels to keep the shading performance constant.

(OR)

- For the additional level with a height of 3 meters (maximum total skyline of 10.5 meters high for three story housing (M2 buildings criteria in Iranian Cities Master Plans), extend the courtyard to 1.6 times the existing plan size of courtyard.

This extension of width and length of the courtyard results in at least the same rate of shading performance in winter, so that the courtyard benefits from receiving equal solar percentage of radiation.

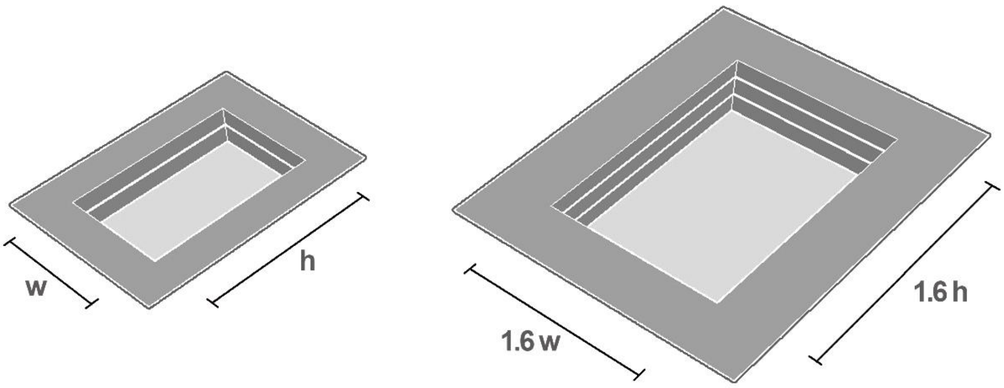


Figure 188, one additional floor, needs extension of the courtyard width and height 1.6 times more, to avoid deep over-shaded courtyard

- Adaption of wind catchers in the house can result in better performance of the micro climate system, due to more efficient conduction and circulation of a notable volume of air in the courtyard.

However the definition of wind catcher in traditional housing is a bit different. In traditional houses the wind catcher contributes in creation of cool spaces in the south, to be used by the family in summer time. This private summer-space does not exist in modern multifamily housing. Nevertheless, contribution of wind catcher in better air ventilation will remain the same in contemporary houses

- Adaption of an *Eivān* in the southern side of the courtyard that is supported by wind catcher in the back, for better natural air ventilation is recommended.

This *Eivān* can rise up a few meters higher than the other sides of the courtyard's height for more efficient air ventilation (Figure 191).

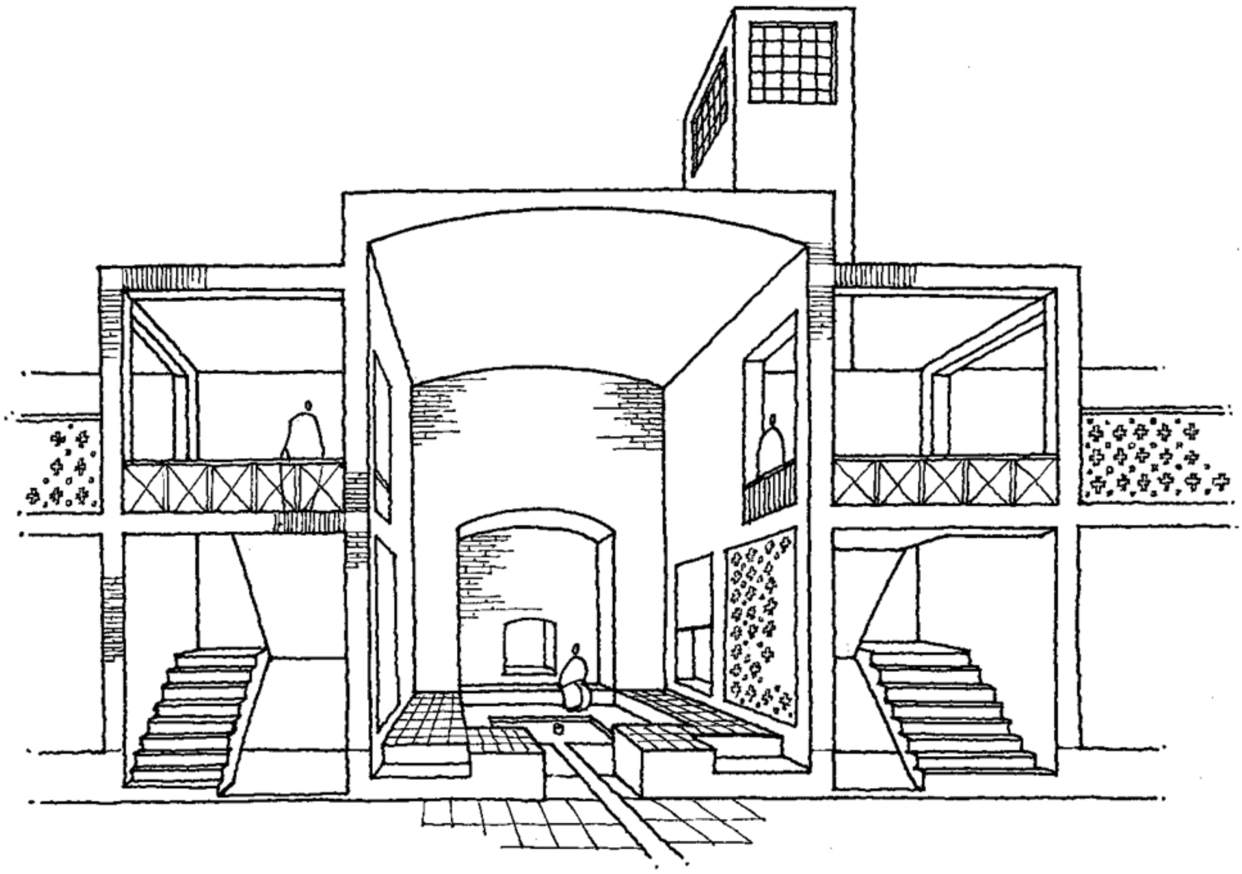


Figure 189, Eivan and Wind catcher, as elements for more efficient natural air ventilation in the courtyard, have new dimensions and new definitions in new multifamily houses, design by author, drawing by Hossein Abbasimehr

- In a house with rotation due southwest in Yazd, the Southeast and Southwest spaces (opposing-sun), function similarly regarding solar radiation, and Northeast and Northwest spaces (sun-facing) operate the same, as winter spaces.

Division of spaces around the courtyard between different units must therefore be made in a way that each unit can benefit from adequate sun and shade.

Since these central courtyards are semi-private, in special cases, one unit may have the opportunity to get shade from one courtyard, and solar radiation from neighboring courtyard (Figure 185 unit 1).

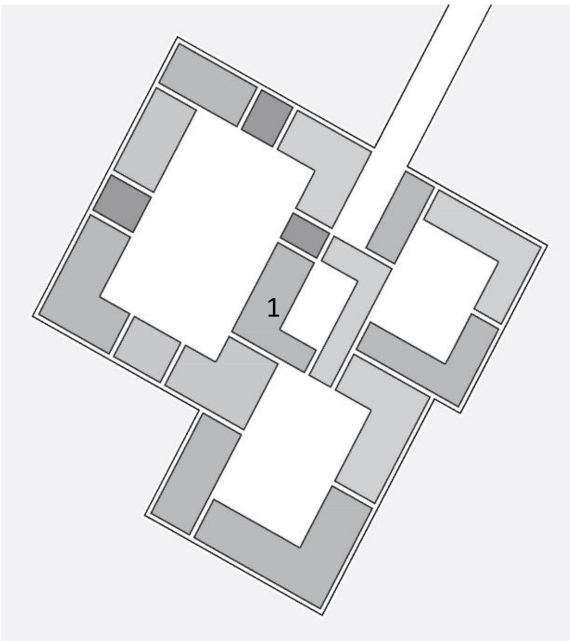


Figure 190, multifamily units, in an interwoven context, each unit is provided with sun and shade, drawing by author

Due to wide range of daily temperature change in Yazd (14.7° C annual average of maximum and minimum daily temperature difference compared with average of 7.3° C in Vienna), it is recommended to use building material with long thermal lag to absorb the daily heat and release it to the space during nights, and in reverse, give back the nights' absorbed coldness into the courtyard little by little during the day (at least for the first hours after sunrise).

As mentioned before, adobe has been the major building material in Yazd traditional houses. This building material shows lots of environmental sustainability advantages, for instance:

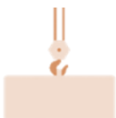
✓ 

X 

X 

X 

✓ 

X 

- Adobe is local material in Yazd. Its components (clay, straw and little water) are accessible from the nearby area, without need for big excavations or mining operations, and are therefore cheap. However the clay soil's quality must be tested in advance, and the right proportions of the components to build the mixture must be taken into consideration too.

- Simple local non-expert workers can easily be trained to prepare, produce and apply it by hand.

- Another advantage of this material is that unlike concrete or steel, adobe does not require high fossil fuel energy to be manufactured and therefore does not pollute the environment. Natural solar energy (plentiful in Yazd) is sufficient for production of it.

- The other advantage of this material is that thick walls of adobe, with their rather long thermal phase shifts, can be one of the best solutions in moderation of wide range of temperature fluctuations between hot day hours and cold night hours in Yazd.

The following charts show the heat performance of a 30 cm thick adobe wall on an exemplary hot summer day in Yazd. Traditional walls' thickness may extend over 50 centimeters thick. However the exact thickness of proposed walls for masonry adobe construction must be calculated in each case. Meanwhile it must be considered that such adobe masonry buildings also have weaknesses like high risk at the time of earthquake that must be improved by additional strategies.

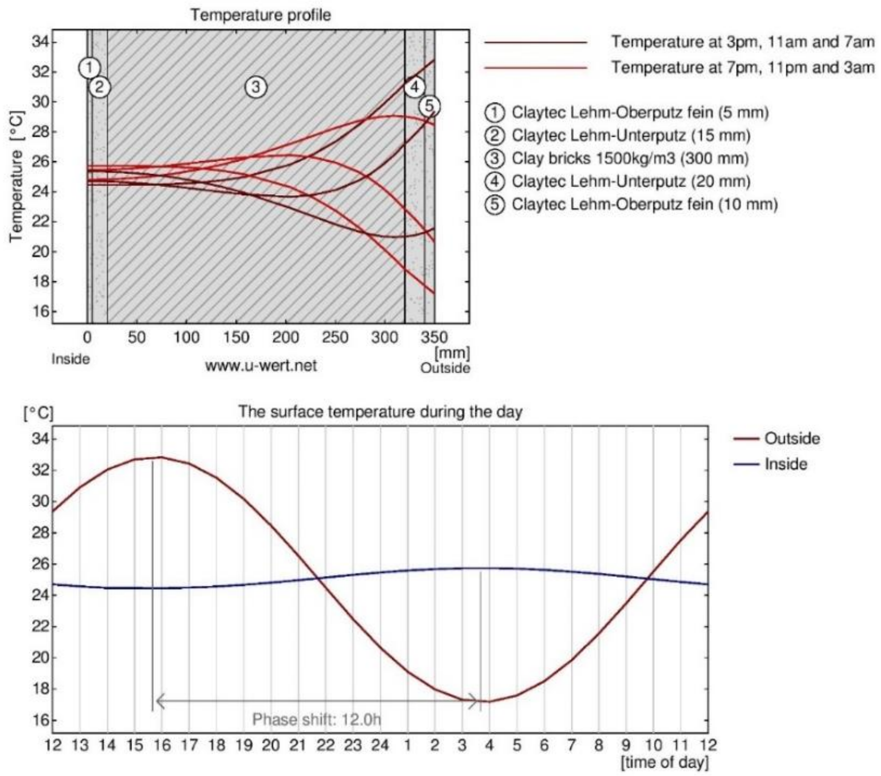


Figure 191, Heat protection simulation of the 30 cm adobe wall on an exemplary hot summer day, Source: u-wert.net, 2014

- Considering the mentioned items, this dissertation proposes adobe as the major building material for housing construction in Yazd. For specific parts addition of burnt brick can strengthen the load bearing walls or outer walls that are exposed to humidity.

- The best plaster to integrate the adobe walls is mud mortar, reinforced by straw pieces (also see Health and Wellbeing recommendations regarding plaster).

- Earthen construction materials, e.g. clay, cob, and adobe, are good examples regarding low emission. Unfired clay bricks demonstrate excellent environmental performance in this regard, too.

- Due to proposal of sunken house pattern, the houses will need stairs for access from outside into the house. The designers must provide the house with necessary elements to ease the access for disabled, elderly or children, such as ramps etc. so that they can independently use the houses.

- For improvement of comfort standards in houses, the following design strategies are recommended for reduction of noise penetration in the house:
  - It is good design practice to locate noise-sensitive rooms away from noisy areas where possible, both within each unit and also between adjoining units.
  - Noisy areas such as living rooms, kitchens, laundries and bathrooms should be grouped together possibly sharing common walls.
  - Locating wet areas above one another can result in significant cost savings in relation to sound insulation requirements, particularly where pipes penetrate the separating slab.
  - Quiet areas such as studies and bedrooms should be grouped away from noisy areas and they again should be grouped together (ABCB 2004).

- The layout of historical case studies share many helpful design strategies, regarding acoustic comfort, which is quantified by defining specific zoning for daily living activities in the house:
  - Rooms are connected to each other or to the courtyard, with narrow halls. These connecting corridors provide rooms with less penetration of open air and noise, and they offer greater privacy.
  - The blind corners of the house are allocated to service spaces such as a toilet, bathroom, and kitchen, washing place.
  - The thick walls of the house also prevent noise penetration between spaces.
  - Trees in the courtyard can also prevent penetration of exterior noise or vision.

- Access to fresh air participates both in healthier atmosphere for houses, as well as higher safety in case of hazards such as earthquake or fire.

Traditional case study houses reveal an average result of 72% for area of rooms with direct access to fresh air out of the net built area (compared with 46% in contemporary houses).

Average 45% of rooms' area in contemporary houses do not have any direct or secondary access to fresh air, while this rate in traditional houses is less than 7%.

- Consider areas for plants specifically in upper floors that are at a distance from the courtyard vegetation area. Plants can provide the residents with healthier air, specifically in arid regions where the air needs to be humidified.
Use the right species of plants which can purify the air, and do not need much water in the arid region.

Earthquake

As mentioned before, the desired building height in response to required density for the city of Yazd is three stories above basement (M2 criteria). Although Yazd owns enough land to expand over its present borders, but to avoid sprawl of this city that has been expanding very rapidly in recent years, making a compact city with multi-story houses (M2) is recommended.

This dissertation recommends masonry adobe construction, majorly due to its environmental sustainability advantages such as locality as well as appropriate thermal performance.

While most traditional adobe houses in Yazd include one to two levels above one level of basement with adobe masonry structure, and besides, Yazd is a city with low earthquake risk compared to other cities in Iran (like Tehran), but for construction of multilevel houses, strategies for improving performance of adobe buildings to resist in case of earthquake are recommended.

Following are some design strategies to reduce the risk of adobe buildings at the time of earthquake. These strategies are recommended for application at the architectural design stage. Of course the structural dimensions of the building must be calculated accurately in each case.

- The major strategy for resistance against earthquake is to add tensile elements to the adobe blocks. This is possible by binding the adobe building by a second material such as wood, steel or concrete beams.

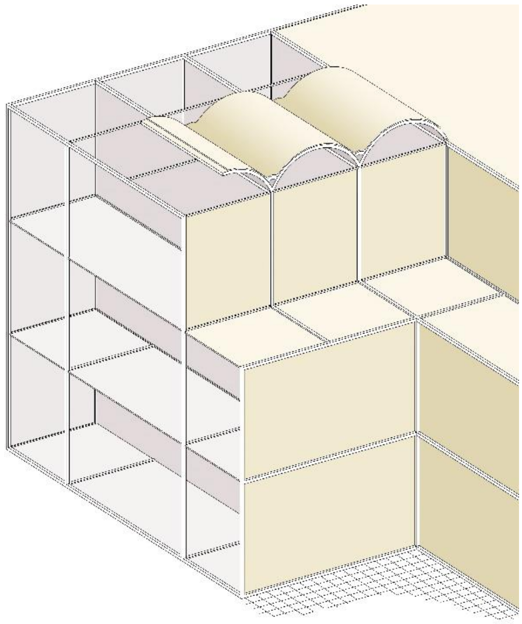


Figure 192, recommendation of application of light steel frame in buildings for post and beam system, drawing by author

According to the analysis of Chapter HW1.A, this dissertation presently recommends application of a light steel frame in adobe buildings. This is due to abundant production of steel in Iran at present, and the better sustainable characteristics of steel in comparison with concrete.

Regarding the degree of environmental sustainability, wood is the best environment-friendly material among the three. But lack of required sources of wood eliminates this choice for present time. However due the planting programs in Iran for rehabilitation of forest areasand the high capacity of northern forests of Iran, wood is recommended as the future option to be used as a tensile element for strengthening of adobe constructions.

A composition of steel-timber is also a proper alternative.

In the following, further strategies to be adapted at the design stage for better performance of adobe buildings in case of earthquake are pointed out from other reference:

- As Mienke discusses (Mienke 2001, 9), the more compact a plan, the better the stability it will show. This means a square plan is better than a rectangular one. L shaped plans are less stable.
Therefore for better resistance of building during earthquake, separate the elements of L shaped parts of building and try to break long rectangles in plan, into square plans.

If a rectangular plan is desired, buttresses or tensile elements connecting the beams are required.

- Spaces with direct access to outer space (central courtyard) demonstrate safer operation in case of earthquakes (Kameli, et al. 2013).

- Spaces with vaulted roofs or domes reveal better performance against earthquakes compared with the flat roofs, provided that they are designed and constructed appropriately (Mahdi 2004).

Some weak points in these traditional structures are:

- Supporting walls
- Thick domes or vaulted roofs
- The connection of these roofs with walls

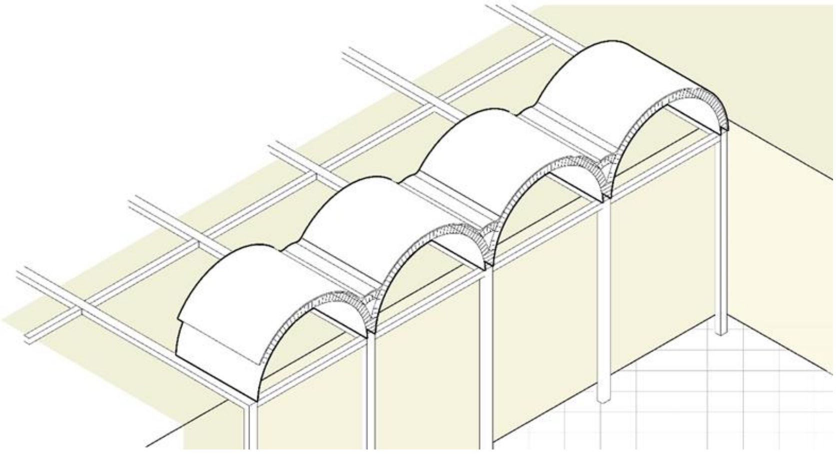


Figure 193, interconnect the walls and roof very well and so rigid that no deformation occurs in the earthquake, drawing by author

- For adobe buildings, use horizontal and vertical buttresses. Interconnect the walls and roof very well and so rigid that no deformation occurs in the earthquake (Mienke 2001, 24)

- If the ring beams act as support for the roof structure in the case of adobe walls, the upper layer of adobe may break under seismic movement, therefore it is recommended that a top layer of burnt bricks be built for better stress distribution (Mienke 2001, 37).

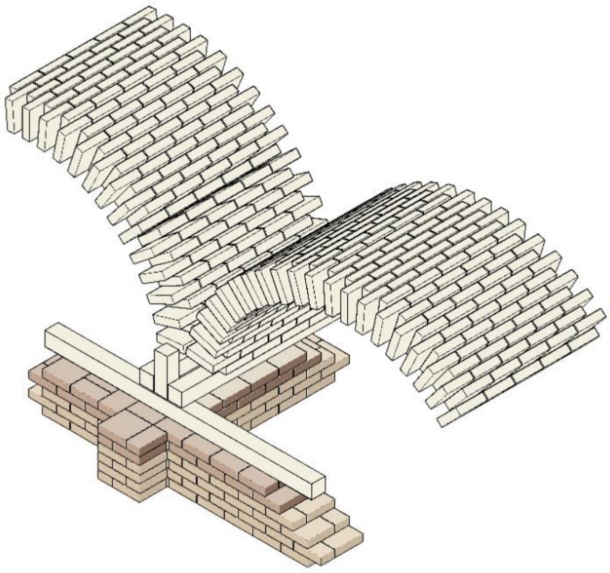


Figure 194, mud brick walls with the last row(s) of burnt bricks beneath the light tensile beams of steel or wood, and vaulted roofs, drawing by author

- Adobe walls have to be plastered by mortars made of earth or lime, or by earth stabilized with cement, lime or bitumen. If an earth mortar is used for plastering, it is recommended that the surface be made waterproof by applying a paint of lime or lime-casein (Mienke 2001, 49)

SUMMARY AND CONCLUSION

As mentioned in the Evaluation Chapter, there are several environmentally sustainable solutions in the Iranian traditional architecture that can define strategies for architects to adapt in their design stage.

This dissertation does not claim to produce a comprehensive guideline for housing design in hot and arid region, but aims to elicit the solutions inspired from the traditional architecture that are appropriate for adaption in contemporary housing design.

These strategies were discussed in the Recommendation Chapter. The following table gives a brief review of these recommendation (Table 37).

1. WATER (W)	W1. PASSIVE WATER SUPPLY SYSTEM
	- ***Qanāt*** system is an efficient water supply system that provides notable amounts of water passively. The city of Yazd owns an extensive existing system of historical *Qanāt*s. This research proposes **rehabilitation** of Yazd's *Qanāt* system that can operate **parallel** with the contemporary water system and reduce the consumption of water that is provided through national pipeline system.
	W2. ALTERNATIVE WATER SYSTEM
	The existing *Qanāt* system in Yazd covers **the whole city** with an efficient **infrastructure** of cisterns, *Pāyābs*, water reservoirs and water canals. If this extensive structure is rehabilitated, it can provide the inhabitants of the present city as an alternative water system, specifically for **non-potable** water consumption such as irrigation or daily wash usages. - The access to *Qanāts*, which is traditionally through deep stairways, can be upgraded by **additional simple pipeline system** for transferring the water to the ground level.

2. ENERGY (E)	E1. GREEN ENERGY SOURCES
	Meteorological studies on Yazd show that this city benefits from abundant clean energies such as wind and sun throughout the year. Implementation of a **microclimate system** in the houses can passively obviate a notable part of the energy demands by using the green energy sources of wind and sun. - The focal element in this microclimate is the **central courtyard** that operates in an integrate system including wind catchers, water pools, and vegetation Geometrical studies on the central courtyards in the traditional case studies show average area of approx. **10x15 to 20x33 m²** in **two storey** high central courtyards (see GL1). - This reveals a proportion of around **2:3 (width/length)** regarding courtyard plan dimensions and a height of 6.25 to 6.50 on three western, northern and eastern sides . The southern side of the courtyard can rise **up to 2 meters higher** than the other sides in larger courtyards in order to improve the operation of this opposing-sun side of the courtyard for shading and better air circulation in the whole microclimate system.

2. ENERGY (E)	E2. MINIMIZING ENERGY NEEDS	
	- Investigations and evaluation of the traditional and contemporary case studies regarding optimal shading in summer and winter, greatest solar gain in winter, and best natural ventilation and passive cooling reveal design strategies that contribute in minimizing energy needs in houses in Yazd as follows: - To define the best orientation for optimal shading in summer and winter, set the main courtyard axis on **20° to 30° due southwest**. This orientation also results in best solar gain on southern vertical surfaces in winter and an optimal receiving of radiation in summer time. - The best proportions of central courtyard to respond to optimized shading in hot and cold times, is the plan proportions of approx. 2:**3 (width/length).** Due to the favorable and dominant directions of wind in Yazd, the best orientation for the courtyard to benefit from **natural ventilation** is **20°-45° due southwest**. - **Wind catchers** can result in better performance of the micro climate system, due to more efficient conduction and circulation of a notable volume of air.	
	E3. MINIMIZING ENERGY EXCHANGE	
	GEOTHERMAL HEATING	Historical (two-three floors high) houses' patterns in Yazd recommend an average ratio of 2/3 of the house height below ground level. This is **more than 5 meters below the ground**, where the thermal fluctuations in dry soil are almost at a constant level.
	GLAZING	- Case studies in Yazd define the **glazing area** on the facades to be less than **15% of the conditioned floor area** (CFA) and the southern glazing area/ total glazing area SGA/TGA is lower than 50%. This also conforms to the LEED standards for designing to maximize opportunities for solar design in buildings over a latitude of 25° north. LEED also adds that the **south-facing glazing area** is at least **50% greater** than the sum of the

2. ENERGY (E)	GLAZING	glazing area on the east- and west-facing walls, and **at least 90%** of the south-facing glazing is completely shaded (by awnings, overhangs, plantings) at solar noon on the summer solstice and unshaded at noon on the winter solstice. - Using traditional windows with **adjustable height** (*Orossi*) specifically on the south-facing side of the courtyard gives the users the possibility of adjusting the amount of solar radiation exposer, if necessary. - These ***Orossi* windows with tinted glazing** can prevent the transmission of a large amount of the sun's spectrum and operate as solar radiation-control when required. The energy transmittance of the *Orossi* is approximately **one third** of the energy transmitted through standard float glass.
	COMPACT NEIGHBORHOOD	- Traditional city offers the ratio of the **footprint** for built area round **55%.** - The **density** offered by the historical city of Yazd is around 82% while that of the contemporary city of Yazd is around 152%. In order to achieve the required density for the contemporary city with the percentage of 55% for the built area, the GL Chapter suggest an average of **three floors** for houses.
	THERMAL MASS	**Thick adobe walls (30-55 cm thick)** as the major traditional construction element in Yazd have higher thermal mass compared to contemporary construction material, and benefit from **longer time lags**. This is a very beneficiary characteristic of these adobe walls in a desert area with vast temperature fluctuations during the day that participate in absorbing the heat during day time and return of this heat to the central courtyard and living spaces during the cold hours of evening. In reverse, the walls absorb the cold throughout cold desert nights, and return it to the interior space during the day (see Material Chapter).

3. GROUND & LANDUSE (GL)	GL1. FOOTPRINT
	- The recommended housing pattern is a **multifamily with shared courtyard** and **separate residential units** around it, with **20-40%** of the built area as **open space** and the recommended built footprint of around 55%. - As mentioned in part E1, central courtyards with two floors are approx. 10x15 to 20x33 m² in plan. Each additional level on top (the third or fourth floor) must **step backwards** to **prevent over-shading** in the courtyard. Otherwise for each additional level (the third or fourth floor) the dimensions of the courtyard in plan must extend to **1.6 times larger**. - The main **wind catcher** and **shared *Eivān*** are placed on the **south**, and function as shared spaces for the neighboring residential units. **Corners** include the **service area**.
	GL2. EFFECTIVE GREEN AREA
	Due to the average height of the trees in Yazd, the gardens in the central courtyard support the efficiency of the microclimatic systems up to **two levels**. For upper floors, **additional vegetation** is necessary (Figures 195).
	GL3. AVOID DEFORESTATION
	M2 Criteria for housing (**three floors above basement or 10.5m high skyline**) with around 55% built footprint fulfills the required number of houses for the desired density in Yazd. This criteria preserves the city from **unnecessary urban sprawl** that damages the surrounding agricultural lands.

4. MATERIAL (M)	- MR1. PLENTIFUL MATERIALS
	- **Adobe and mud brick** as the traditional local building material in Yazd are the most accessible and plentiful material in desert area, and hence the most sustainable due to their low production energy, easy application, and no pollution. - For specific parts in building addition of **burnt brick** can strengthen the load bearing walls or outer walls that are exposed to humidity. - The best plaster to integrate the adobe walls is mud mortar, reinforced by straw pieces. Due to safety issues, additional binding material is proposed in HW1 Chapter.

4. MATERIAL (M)	MR2. LOW EMITTING MATERIALS
	- **Earthen construction materials**, e.g. clay, cob, and adobe, are good low emitting materials. - **Unfired clay bricks** demonstrate excellent environmental performance in this regard, too.

5. HEALTH AND WELLBEING (HW)	HW1. SAFETY	
	EARTHQUAKE	- **Bind** the adobe building by a tensile material. - Regarding the degree of environmental sustainability, **wood** is the best environment-friendly material compared with steel or concrete. But the present lack of required sources of wood eliminates this choice at least for present time. However due the planting programs in Iran for rehabilitation of forest areas, wood is recommended as the future option to be used as a tensile element for strengthening of adobe constructions. - This dissertation presently recommends application of a light **steel** frame in adobe and brick buildings due to remarkable existing industrial infrastructure for production of steel and considerable iron mines, and the better sustainable characteristics of steel in comparison with concrete. - A composition of **steel-timber** can also be a proper alternative. - V**aulted roofs or domes** reveal good operation in efficient natural ventilation and shading of the roof. If they are designed and constructed appropriately, they also perform better against earthquakes compared with flat roofs. - Interconnect the walls and roof by **horizontal and vertical buttresses** very well and so rigid that no deformation occurs in the earthquake. - Build a **top layer of burnt bricks** on adobe walls for better stress distribution where the ring beams act as support for the roof structure.

5. HEALTH AND WELLBEING (HW)	HW2. COMFORT	
	INDEPENDENCE	Provide the houses with necessary elements like ramps to **ease the access** for disabled, elderly or children so that they can **independently use** the houses.
	SOUND INSULATION	Historical case studies define **specific zoning** for daily living activities in the house that results in acoustic comfort: - The **connecting corridors** between rooms and courtyard provide rooms with less penetration of open air and noise, and they also offer greater privacy. - The **blind corners** of the house are allocated to **service spaces** such as a toilet, bathroom, and kitchen, washing place etc. - **Thick walls** also prevent noise penetration between spaces and **courtyard trees** can also prevent penetration of exterior noise or vision. For reduction of noise penetration in the house, also follow these design strategies: - Locate **noise-sensitive rooms** away from noisy areas where possible, both within each unit and also between adjoining units. - **Noisy areas** such as living rooms, kitchens, laundries and bathrooms should be **grouped together** possibly **sharing common walls**. - Locating **wet areas above one another** can result in significant cost savings in relation to sound insulation requirements, particularly where pipes penetrate the separating slab. - **Quiet areas** such as studies and bedrooms should be grouped away from noisy areas and they again should be grouped together.

5. HEALTH AND WELLBEING (HW)	HW3. HEALTH	
	ACCESS TO FRESH AIR	Traditional case study houses reveal an average of **72%** for area of rooms in the net built area with **direct access to fresh air** (such areas with direct access to exterior space are also safer in case of **earthquake**).
	PURIFY AIR WITH PLANTS	Plants can provide the residents with healthier air, specifically in arid regions where the air needs to be humidified. - Use **the right species** of plants which can purify the air and do not need much water in the arid region. - Consider areas for plants specifically in upper floors that are at a distance from the courtyard vegetation area (see Figures 197 and 198).

Table 37, Brief review of the environmentally sustainable recommendations inspired from the Iranian traditional architecture in this dissertation

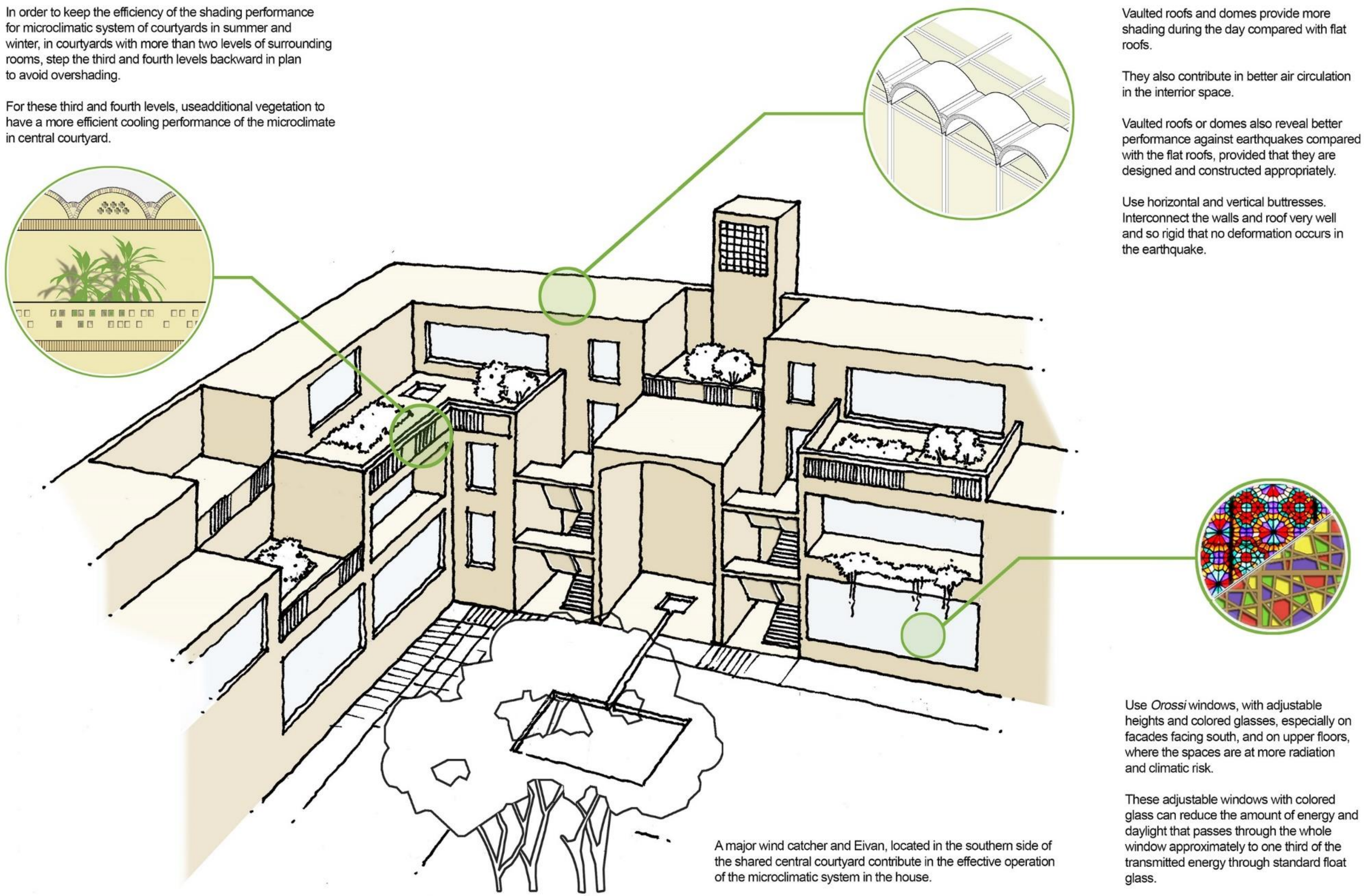


Figure 195, Sample view from inside the recommended multifamily multilevel central courtyard, with the main wind catcher and share Eivan in the south. Upper floors have stepped backward to avoid over shading in the courtyard. This prepares spaces for additional vegetation on top floors as well as private open spaces for the residents, drawing by Hossein Abbasimehr and Afsaneh Soltani

The major wind catcher(s) is placed on the southern side of the central courtyard and is an important element in the appropriate function of the microclimatic system in the central courtyard.

In addition to that, smaller wind catchers that are shared between neighboring residential units can contribute in more efficient natural circulation of the fresh air coming from the central courtyard, passing through rooms.

In case the dimensions of the central courtyard does not allow the upper floors to step backward above the second floor, it is recommended that for each additional level, the dimensions of the courtyard in plan is extended to 1.6 times larger, in order to keep the appropriate amount of shading in summer and winter.

In such houses, specific small places for additional vegetation on upper floors are prepared.

Figure 196, Sample view from an exemplary façade of the multilevel central courtyard and the places for additional vegetation on upper floors, where the upper floors do not have the possibility to step backward due to design or land limitations, drawing by author

GLOSSARY

- ***Andarouni,*** (Inner spaces) A complete unit in the house for the private use of family members even sometimes with a separate access to outside.

- ***Birouni,*** (Exterior spaces) for non-family-member guests.

- ***Bād-gir,*** Wind catcher, a traditional Persian architectural element to create natural ventilation in buildings that come in various designs: unidirectional, bi-directional, and multi-directional.

- ***Eivān,*** A rectangular hall or space, usually vaulted, walled on three sides, with one end entirely open.

- ***Godāl-Bāqche****,* Multilevel central courtyard.

- ***Hashti***, vestibule, an entrance space after the door of the traditional houses, usually octagon in plan, that provides indirect access to the central courtyard for more privacy

- ***Hoz-Khāneh,*** Room with small water pool, usually under the wind catcher to evaporate and cool the circulated air.

- ***Mahramiyat,*** religious privacy in Islam, to prevent the private spaces of a house from view or access of strangers or non-family members.

- ***Orossi,*** A sash window or hung sash window is made of one or more movable panels, or "sashes" that form a frame to hold panes of glass, which are often separated from other panes (or "lights") by glazing bars. Orossi in desert cities of Iran are made with very elegant fine geometric patterns of wood frames filled with colorful glasses in between.

- ***Pāyāb/ Pāadyāv,*** A small space that climbs down the stairs average one to two floors underneath the central courtyard level to provide access to the Qanāt water.

- ***Qanāt,*** The traditional water system in Iran desert cities consisting of vertical shafts and horizontal water tunnel (with a slight slope) to transfer water from mountain sides to the city.

- ***Ron,*** The dominant orientation of urban fabric in a city.

- ***Sābāt,*** Vaulted roofs or rooms that cover parts of passageways in desert cities, to support the passengers with shade**.**

- ***Sardāb,*** Cellar or basement in traditional Iranian desert houses which is cooler in summer time

- ***She-dari, Panj-dari;*** she=3 and panj=5, a set of three or five glass-wooden doors that are separated with masonry columns in between, that open the rooms around the courtyard to the open space and make a pleasant symmetric façade in the courtyard

- ***Tālār,*** major space in courtyard houses, usually two floors high, located on the center of the northern side of the central courtyard, which usually contains the most elegant decorations in the house such as roof paintings, mirror works, with colorful glass and wood *Orossi*, used traditionally as the guest room.

LIST OF FIGURES

LIST OF TABLES

List of Charts

BIBLIOGRAPHY

ABCB. 2004. *Sound insulation in Buildings.* Canberra. file:///D:/Back%20Up/Drive%20D/Yazd%20PhD%20Afi/Acoustics/2004_sound_insulation-buildings.pdf.

ABFA Yazd. 2013. *Yazd Province Water & Wastewater Website.* Accessed 12 17, 2013. http://en.abfayazd.com/node/1 posted on Thu, 09/26/2013 - 02:10 accessed online on 17.12.2013 .

Achakzai, G.N., and A.S. Toor. 1990. "Conservation and management of karez water in Balochistan. In: Proceedings of a ." *National Seminar on Water Resources Development and its Management in Arid Areas.* Quetta: Pakistan Water Resources Research Centre.

Aftab News. 2013. *Maybod Tourism Attractions.* 07 01. Accessed 11 11, 2014. http://aftabnews.ir/fa/news/199453.

Ahari, Z, and M Habibi. 2001. *Isfahan School in Urbanism.* Tehran: Art University of Tehran Publications.

Ahmadi et al., Mohammad Taghi. 2009. *Iran National Building Codes, Booklet 19: Energy Conservation.* Tehran: Iran Ministry of Housing and Urban Development.

Ahmadi, Mohammad Taghi, Hamid Reza Hafezi, Mohammad Taghi Hariri, Faramarz Sadr, Behrouz Kari, Gholamreza Golmohammadi, Rima Fayyaz, Jamshid Riazi, and Morteza Kasmaei. 2002. *Iran National Building Regulations, Booklet 19, Energy Conservation.* Tehran: Nashre Tose'eh Iran.

Ahmadkhani Maleki, B. 2011. "Traditional sustainable solutions in Iranian desert architecture to solve the energy problem." *International Journal of Technical and physical problems of engineering". Vol. 3* P85.

Al-Sanea, S. A., M. F. Zedan, and S. N. Al-Hussain. 2012. "Effect of thermal mass on performance of insulated building walls and the concept of energy savings potential." *Applied Energy* 89: 430-442.

Annie R. Pearce, Yong Hahn Ahn and HanmiGlobal. 2012. *Sustainable buildings and infrastructure, paths to the future.* New York: Routledge.

Ardalan Associates, LLC. 2015. *Ardalan Consultants in Architecture.* Accessed 05 09, 2016. http://ardalanassociates.com/projects/iran-center-for-management-studies-tehran-iran/.

Ardalan, Nader. 1996. "Architecture viii. Pahlavi, after World War II." In *Encyclopaedia Iranica, online edition*, Vol. II, Fasc. 4, pp. 351-355. New York. Accessed 11 20, 2014. http://www.iranicaonline.org/articles/architecture-viii.

Ardalan, Nader. 1970. "The Structure of Traditional Architecture and Urban Design in Iran, Preliminary Studies,." In *The Interaction of Tradition and Technology*, by Laleh ed. Bakhtiar and Leila Farhad, 34. Isfahan: Ministry of Housing and Development of the Imperial Government of Iran.

Ardalan, Nader, and Laleh Bakhtiar. 1973. *The Sense of unity, The Sufi Tradition in Persian architecture.* California: The Center of the Middle Eastern Studies.

2016. *Arel.* Accessed 5 25, 2016. http://www.arel.ir.

Asadi, A., Sh. Neshat, and M.K. Barkhordari. 2014. "Seismic Hazard Assessment and Determination of Maximum Design Base Acceleration of Yazd." *Journal of Rehabilitation in Civil Engineering* 1-9.

Ayatollahi, H. 2002. *The Book of Iran: The History of Iranian Art.* Tehran: The ministry of culture and Islamic guidance publications.

Badi'ee, R. 1988. *Iran's Extensive Geography, Vol I.* Tehran: Eqbal Institute.

Badripour, Hossein. 2004. *Islamic Republic of Iran Forage Resource Profiles.* Online report, Tehran: FAO.

Baggs, David, and Neal Mortensen. 2006. *Thermal Mass in Building Design.* Melburne: Australian Institute of Architects. Accessed 09 15, 2014. http://www.yourbuilding.org/library/DES04.pdf.

Bakhtiar, Laleh, and Leila Farhad. 1972. "The Interaction of Tradition and Technology." Ungers in round-table discussion on tradition, Tehran.

Bani Masoud, Amir. 2009. *Iranian Contemporary Architecture.* Tehran: Honare Memari.

Bastianini, F., M. Corradi, A. Borri, and A. di Tomasso. 2005. "Retrofit and monitoring of a historical building using Smart CFRP with embedded fibre optic Brillouin sensors." *Construction building master* 19: 525-535.

Baycan, T et al. 2008. *Urban planning.* Cheltenham: Edward Elgar Publishing.

Beaumont, P. 1971. "QANAT SYSTEMS IN IRAN." *International Association of Scientific Hydrology. Bulletin, 16:1* (International Association of Scientific Hydrology Bulletin) 39-50. Accessed 01 31, 2014. http://www.tandfonline.com/doi/pdf/10.1080/02626667109493031.

Beheshti, Mohammad. 2015. "Museum Poetry." *Symposium of Museum and Sustainable Architecture.* 05 30. Accessed 2015. https://soundcloud.com/behnamabout/f9fzdf7giksf.

BHRC. 2013. *Iran Ministry of Road and Urban Development.* Accessed 07 27, 2013. http://www.bhrc.ac.ir.

Brian Edwards, P. Hyett. 2001. *Rough Guide to Sustainability.* London: RIBA Publications.

Brundtland, Gro Harlem. 1987. *Report of the World Commission on Environment and Development: Our Common Future.* Oslo: Oxford University Press.

2005. *Build It Solar.* Accessed 04 14, 2014. http://www.builditsolar.com/Projects/Cooling/EarthTemperatures.htm.

Calkins, M. 2009. *Materials for Sustainable Sites: A Complete Guide to the Evaluation, Selection, and Use of Sustainable Construction Materials* . Hoboken, NJ, USA: John Wiley & Sons.

Cantacuzino, Sherban, and Kenneth Browner. 1976. "Making of the City." *Architectural Review vol. 159, no. 951.*

Central Intelligence Agency. 1993. *Atlas of the Middle East.* Washington DC: US Government Editting Office. Accessed 05 04, 2015. http://www.lib.utexas.edu/maps/atlas_middle_east/atlas_middle_east.html.

Chaharbaghi, K. & Willis, R. 1999. "Study and practice of sustainable development." *Engineering management journal, Vol. 9, No. 1* Pp 41-48.

Climate Data. 2014. "Climate Vienna - Austria." *Climatedata EU, Temperature - Precipitation - Sunshine.* Accessed 09 02, 2014. http://www.climatedata.eu/climate.php?loc=auxx0025&lang=en.

DAZ Architects, Planners and Engineers. 1986. "Shushtar New Town." *The Aga Khan Award for Architecture.* Tehran, Iran: Aga Khan Foundation. http://www.akdn.org/architecture/pdf/0117_Ira.pdf.

DAZ. 1986. "Technical Report for Aga Khan Award." *Aga Khan Award for Architecture.* Accessed 07 08, 2013. http://www.akdn.org/architecture/project.asp?id=117 . accessed July 08, 2013.

DBT. 2010. *Embassy of Germany in Tehran.* Accessed 04 27, 2016. http://www.teheran.diplo.de/Vertretung/teheran/fa/05__wirtschaft/Forschung__und__Technologie/YoungCities-S.html.

DETR. 2000. *Sustainable Development: What It Is and What You Can Do.* UK: DETR Green Ministers Report.

Diba, Darab, and Mozayyan Dehbashi. 2004. "Trends in Modern Iranian Architecture." In *Iran: Architecture for Changing Societies*, by Philip Jodidio (ed), 31-38. Torino: Umberto Allemandi & C.

Diba, K. 2014. *Kamran Diba Facebook.* 10 12. Accessed 6 3, 2016. https://www.facebook.com/search/top/?q=kamran%20diba%20architecture%20%20art.

Dolat. 2012. *Iran Government's Official Website.* 10 15. Accessed 10 09, 2014. http://www.dolat.ir/NSite/FullStory/News/?Serv=106&Id=221115.

Ehlers, E, M E Bonine, T Krafft, and G Stober. 1994. *The Middle Eastern City and Islamic urbanism. An Annotated Bibliography of Western Literature.* Bonn: Bonner Geographische Abhandlungen 91.

Ehlers, E., and W. Floor. 1993. "Urban Change in Iran, 1920-1941." *Iranian studies, Vol. 26, No. 3/4.*

Elke Pahl-Weber, Holger Ohlenburg, Sebastian Seelig, Nadine Kuhla von Bergmann, Rudolf Schäfer. 2013. *Urban Challenges and Urban Design Approaches for Resource-Efficient and Climate-Sensitive Urban Design in the MENA Region.* Berlin: Universitätsverlag der TU Berlin.

Emami, Farshid. 2011. *Civic Visions, National Politics, and International Designs: Three Proposals for a New Urban Center in Tehran (1966-76).* MA Thesis, Cambridge, Massachusetts: MIT.

Emmanuel, R. 2015. "Sustainable buildings. Abingdon: Routhledge. Volume 3."

ENERGY STAR Qualified Homes . 2011. *HERS Index Target Procedure For National Program Requirements.* USA, 03 25. Accessed 08 2014, 22.

http://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/V3HERS_IndexTargetProcedure.pdf.

Engel, J.M., L. Zhao, Z. Fan, J. Chen, and C. Liu. 2005. "Smart brick." *Masonry Construction, World Masonry* 18: 39-41.

FAO. 2011. *Food and Agriculture Organization of the United Nations.* 12 14. http://www.fao.org/forestry/country/18314/en/irn/.

—. 2011. "Iran National Forest Formation." *Food and griculture Organisation of the United Nations.* 12 14. Accessed 08 10, 2015. http://www.fao.org/forestry/country/18314/en/irn/.

Fararu. 2013. *Fararu.* 05 19. http://fararu.com/fa/news/190836/%D8%AA%D8%B5%D8%A7%D9%88%DB%8C%D8%B1-%D8%AA%D8%A7%D9%84%D8%A7%D8%A8%E2%80%8C-%DA%AF%D8%A7%D9%88%D8%AE%D9%88%D9%86%DB%8C-%D8%AF%D8%B1-%D8%AD%D8%AC%D9%84%D9%87-%D8%AE%D8%B4%DA%A9%D8%B3%D8%A7%D9%84%DB%8C.

Farhad, Leila, and Laleh Bakhtiar. 1972. *The Interaction between Tradition and Technology: Proceedings of the First International Congress of Architects, Isfahan.* Tehran: Hamdami Foundation.

Fathy, H, W Shearer, and A Sultan. 1986. *Natural Energy and Vernacular Architecture, Principles and Examples with Reference to Hot Arid Climates.* Chicago: University of Chicago Press.

Geem, M. G. Van. 1987. "Measuring Thermal Performance of Wall Assemblies Under Dynamic Temperature Conditions." *Journal of Testing and Evaluation* 15: 178-187.

Ghiabaklou, Z., and M. Haghshenas. 2009. "Investigation of Tinted Glazing's Effect in Transmission of Daylight and Energy in the Visible Spectrum ." *Journal of Color Science and Technology* 213-220.

Ghobadian, Vahid. 1994. "Climatic Analysis of the Traditional Iranian Buildings." 123-131. Tehran: Tehran University Press.

Graham Farmer, Simon Guy. 2005. "Hybrid Environments, the spaces of sustainable design." In *Sustainable Architectures, Cultures and Natures in North America*, by Steven A. Moore Simon Guy, 21-22. New York: Taylor & Francis.

Gregory, K., B. Moghtaderi, H. Sugo, and A. Page. 2008. "'Effect of thermal mass on the thermal performance of various Australian residential constructions systems." *Energy Build.* 40: 459-465.

Guy, S, and S. Moore. 2005. *Sustainable Architectures.* New York: Spon press.

Habitat Bill of Rights. 1976. *Habitat Bill of Rights presented by Iran to the first "Habitat: United Nations Conference on Human Settlements," in Vancouver, Canada, 31 May – 11 June 1976.* Tehran: Hamdami Foundation.

HABITAT. 1976. "The Vancouver Declaration On Human Settlements." Accessed 08 05, 2015. http://habitat.igc.org/vancouver/van-decl.htm.

Haji-Qassemi, Kambiz, Zand Harirchi, and Behnam Qelichkhani. 2005. *GANJNAMEH Cyclopaedia of Iranian Islamic Architecture, vol.14, Yazd Houses.* Tehran: Shahid Beheshti University, Faculty of Architecture and Urban Planning, Documentation and Research Center.

Hanova, J, and H. Dowlatabadi. 2003. "Strategic GHG reduction through the use of ground source heat pump technology." *Environmental Research Letters.* http://iopscience.iop.org/1748-9326/2/4/044001/fulltext/.

Hawken, P, A Lovins, and H Lovins. 1999. *Natural Capitalism.* New York: Earthscan.

Hintz, Walther. 1992. *The Lost World of Elam.* Translated by Firouz Firouznia. Tehran: Elmi Farhangi Publications.

Holod, R. 1983, I/1 . "AB-ANBĀR i. History,." In *Encyclopaedia Iranica*, 39-41. New York: http://www.iranicaonline.org/articles/ab-anbar-i-history.

Honar Saraye Memari Consulting Engineers. 2013. 06 21. Accessed 06 23, 2013. http://www.architecthome.ir/index.php/projeha/9-project/31-16.

Hosseini, Parvaneh. 2010. "New Quality- Pilot Project in Hashtgerd New Town." *BHRC Building and Housing Research Center.* http://site.bhrc.ac.ir/portal/tabid/56/articleType/ArticleView/articleId/100/--New-Quality--Pilot-Project----.aspx.

2015. *IBPSA.* Accessed 1 20, 2015. http://www.ibpsa.org/proceedings/BS2013/p_2377.pdf.

ICI. 1999. *Iran Concrete Institute.* Tehran. http://www.ici.ir/.

IEEO-SABA, Iran Energy Efficiency Organization. 2012. *Iran Energy Balance Sheet report.* Tehran: Iran ministry of energy,. Accessed 09 04, 2014. http://www.saba.org.ir/fa/energyinfo/tashilat/taraz.

IIAEE. 1986. "Guidelines for Earthquake Resistant Non-Engineered Construction." Tokyo.

Iran National Building Regulations. 2010. Accessed 07 31, 2013. http://www.inbr.ir/SPage/USPage.aspx?ID=193 accessed online on July 31, 2013.

2015. *Iran politics.* Accessed 6 16, 2015. http://iranpoliticsclub.net/maps/maps14/.

2016. *Iran Review.* Accessed 5 28, 2016. http://www.iranreview.org/content/Documents/Enjoyable-Moments-in-Tehran-with-a-Cup-of-History.htm.

IRCEO. 2011. *Iran Construction Engineering Organisation.* Accessed 07 27, 2013. http://irceo.net/Default.aspx.

IRIMO. 2011. "Iran Meteorological Organization Data Processing Center." *Charmahal and Bakhtiari Meteorological Administration.* Accessed 09 02, 2014. http://www.chaharmahalmet.ir/stat/archive/iran/yaz/YAZD/25.asp.

IRNA. 2015. "Drought in Zagros forests." Tehran, 05 23. http://www3.irna.ir/fa/News/81618986/.

ISU. n.d. *Imam Sadiq University.* Accessed 05 09, 2016. http://gzn.isu.ac.ir/details.aspx?p=news&id=73 .

Jafari, M., and A. Hossinzadeh. 1997. *Present status of afforestation in I.R. of Iran.* . Technical Publication No. 176., Iran: Research Institute of Forests and Rangeland, Iran.

Jenks M., and Dempsey N. 2005. *Future forms and design for sustainable cities.* Oxford:: Elsevier.

Jenks, M & Buigess, R. 2000. *Compact cities: Sustainable Urban Forms for Developing Countries.* London: Spon press.

Joseph, P, and S Tretsiakova-McNally. 2010. "Sustainable Non-Metallic Building Materials." *Sustainability* 2: 400-427.

Kalogirou, S. A., G. Florides, and S. Tassou. 2002. "Energy analysis of buildings employing thermal mass in Cyprus." *Renewable Energy* 27: 353-368.

Kameli, M, M Soltani, M Ostad Jafari, and M, Mohseni, E Heidary. 2013. " Analyzing with SWOT method on traditional desert houses spatial structure against earthquake disaster (Arabs set buildings as case study)." *Life Science Journal* 557-563. Accessed 06 23, 2015. http://www.lifesciencesite.com/lsj/life1006s/086_17790life1006s_557_563.pdf.

Kasaei, Reza. 1984. "A Look at the Mudbrick Buildings." In *Iran Architecture*, by Asieh Javadi, 892-901. Tehran: Mojarrad Publications.

Kasmaei, Morteza. 1984. *Climate and Architecture.* Tehran: Iran House Building Company .

Kasmaiee, Morteza. 1992. *Climatic Classification of Iran for Housing and Residential Environments.* Tehran: Building and Housing Research Center, Iran Ministry of Housing and Urban Development.

Kasmaiee, Morteza. 1991. *Map of Climatic Zones of Iran.* Tehran. Accessed 10 24, 2014. http://climaticdesign.net/wp-content/uploads/2011/01/Res_Map_2000.jpg.

Kateb, A. 1965. *New History of Yazd.* Tehran: Farhange Iran Zamin.

Khademzadeh, Hassan, Majid Oloumi, and Elaheh Alvandian. 2008. *Mozaffarid Architecture in Yazd.* Tehran: Hampa and YCHTO.

Kheirabadi, M. 2000. *Iranian Cities: Formation and Development.* Syracuse: Syracuse University Press.

Kobayashi, Kent D., Andrew J. Kaufman, John Griffis, and James McConnell. 2007. *Using Houseplants To Clean Indoor Air.* Hawaii: Cooperative Extension Service.

Lambrechts, C., M. L. Wilkie, I. Rucevska, UNEP, FAO, and UNFF. 2009. *Vital Forest Graphics.* Nairobi, Kenya: United Nations.

Lightfoot, Dale R. 1996. "Syrian qanat Romani: history, ecology, abandonment." *Journal of Arid Environments* 33 (3): 321–336.

Mahdi, T. 2004. "Performance of Traditional Arches and Domes in Recent Iranian Earthquakes ." *13th World Conference on Earthquake Engineering.* Vancouver, B.C., Canada .

Mahmoodi, Mahnaz. 2009. *Wind Catcher, the Symbol for Iran's Architecture.* Tehran: Yazda Publications.

Malek Shahmirzadi, Sadegh. 1993. "Tappeh Zagheh; a Brief Analysis of the Houses." *Journal of Archaeology and History, Year 6, No. 1,2* 2-12.

Manzoor, S. 1989. *Tradition and Development: An Approach to Vernacular Architectural Patterns in Iran.* . Gothenburg: Chalmers University of Technology.

Marzban, Parviz. 2007. *A Summary of the History of Art.* Tehran: Katibeh Scientific and Cultural Publications.

Mckinley, J.D., H.R. Thomas, K.P. Williams, and J.M. Reid. 2001, 60. "Chemical analysis of contaminated soil strengthened by the addition of lime." *Engineering Geology* 181-192.

Mehr News, Agency. 2013. http://www.mehrnews.com/detail/News/1643626. Mehr News Agency (News ref. 1643626).

Memarian, Gholamhossein. 1996. *Introduction to the Residential Architecture of Iran.* Tehran: Iran University of science and Technology.

—. 2007. *Theoretical Principles of Iranian Architecture.* Tehran: Soroush Danesh.

Mienke, Gernot. 2001. *Construction manual for earthquake-resistant houses built of earth.* Eschborn, Germany: GATE - BASIN (Building Advisory Service and Information Network) at GTZ GmbH.

Mir Moghtada, Mahta, Elke Pahl Weber, and Sebastian Seelig. 2009. "Designing a Sustainable Neighborhood in Hashtgerd New Town, 35 ha Pilot Project." Edited by Persian Translation by Mahta Mirmoghtadaei. *Construction Engineering and Housing Sciences* 15 (07): 73-90.

Mirrazavi, Firouzeh. 2009. "Iranian Architecture." *Iran Review.* 01 11. Accessed 08 19, 2014. http://www.iranreview.org/content/Documents/Iranian_Architecture.htm.

Mirsadeghi, M. A., B. Biglarbeigi, J. A. Zamani, and M. E. & Majid Saifollahian Rastaghi. 1999. *Forest data of Iran, FRA 2000 country report.* Teheran: Forest and Range Organization. http://www.fao.org/forestry/country/18316/en/irn/.

Mobbs, Philip M. 2012. *2012 Minerals Yearbook, IRAN [ADVANCE RELEASE].* U.S. Department of the Interior U.S. Geological Survey,. Accessed 07 28, 2015. http://www.parstimes.com/library/mineral_industry_2012.pdf.

Moghtader, Mohammadreza. 1965. "Kahgel and Urban Landscape." *Art and Human (Honar va Mardom)* 25-30.

MRUD. 2010. "Ministry of Roads and Urban Development." *History.* Accessed 08 17, 2013. http://mrud.ir/Portal/Home/Default.aspx?CategoryID=8d0a09aa-6081-49c1-b815-0ef5639888e6.

MSC. 1981. *Esfahan's Mobarakeh Steel Company.* Esfahan. http://www.msc.ir.

Naqsh, Consulting Engineers. 2012. *Memarnet.* 12 31. Accessed 05 09, 2016. http://www.memarnet.com/fa/node/680.

Nasrollahi, Farshad. 2009. *Climate and Energy Responsive Housing in Continental Climates, the Suitability of Passive Houses for Iran's Dry and Cold Climate.* Berlin: TU Berlin.

2011. *Nature.* Accessed 6 24, 2014. http://www.nature.com/scitable/knowledge/library/factors-affecting-global-climate-17079163.

Negahban, Ezzatollah. 1997. "A Review of 50 Years of Archaeology in Iran." *Miraz Farhangi* 354-373.

NWWEC. 2012. *National Water & Wastewater Engineering Company of Iran.* 12 19. Accessed 12 17, 2013. http://www.nww.ir/ShowPage.aspx?page_=form&order=show&lang=2&sub=0&PageId=1141&codeV=1&tempname=EngInternal.

Office for Codification and Development of National Building Codes. 2005. *National Building Codes, Booklet 2, Administrative Systems.* Tehran: Nashre Tose'eh Iran. Accessed 07 31, 2013.

Olgay, Victor. 1963. *Design with Climate.* Princeton: Princeton University Press.

Pahl-Weber, Elke, Annette Wolpert, and Phillip Wehage. 2013. "New Town Development in Tehran, Karaj (Iran)." *Future Megacities.* 09 17. Accessed 04 27, 2016. http://future-megacities.org/fileadmin/documents/forschungsergebnisse/aktuell/KAR-AB8.pdf .

Parinoush, Zohreh. 2008. "Museum of Ancient Iran." *Tebyan.* Accessed 05 15, 2016. http://www.tebyan.net/newindex.aspx?pid=84983.

Pearce, A et al. 2012. *Sustainable Buildings and Infrastructure.* Abingdon: Routledge.

Pedret, Annie. 2013. *Team 10: an Archival History.* London, New York: Routledge.

Permanent Committee for Revising the Iranian Code of Practice for Seismic Resistanit Design of Buildings (Standard 2800). 1999. *Iranian Code of Practice for Seismic Resistant Design of Buildings, Standard No. 2800, 3rd Revision, , Tehran, Iran.* 2nd Edition. Tehran, Iran: Iran Building and Housing Research Center, the Ministry of Housing and Urban Development.

Pirnia, Mohammad Karim, and Gholamhossein Memarian. 2013. *Introduction to the Iranian Islamic Architecture.* Tehran: Soroush-e Danesh.

—. 2008. *Styles of Iranian Architecture.* Edited by Ali Mohammad Ranjbar Kermani. Tehran: Soroush-e Danesh.

Pope, Arthur Upham. 1967. "City Plans in A Survey of Persian Art From Pre-Historic Times to the Present." 1391-1410. Tokyo: Meiji Shobo .

Pulselli, R.M., E. Simoncini, R. Ridolfi, and S. Bastianoni. 2008. "Specific emergy of cement and concrete: An energy-based appraisal of building materials and their transport." (Ecological Indicators) 647-656.

Rahimieh, Farangis, and Mostafa Robubi. 1974. *Architecture in Hot and Semi-Arid Climate in Dezful and Shushtar.* Tehran: Tehran University, Faculty of Fine Arts Students Association.

Ramezanianpour, Ali Akbar, Hassan Tabesh, Ahmad Khorasanchian, Hormoz Famili, Alireza Khalou, Fatemeh Jafarpour, and Mohammad Hossein Majedi Ardekani. 2003. *Iran National Building Codes, Booklet 5: Building Materials.* Tehran: Ministry of Housing and Urban Development.

Reardon, Chris, Caitlin McGee, and Geoff Milne. 2013. "Passive Design, Thermal Mass." In *Your Home*, by Department of Industry, Innovation and Science Commonwealth of Australia, 178-187. Australia. https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0ahUKEwi6gbLyzYnNAhWGd5oKHbIVB08QFggcMAA&url=http%3A%2F%2Fwww.yourhome.gov.au%2Fsites%2Fprod.yourhome.gov.au%2Ffiles%2Fpdf%2FYOURHOME-2-PassiveDesign-9-ThermalMass-(4Dec13).

Relf, D. 1996. *Plants actually clean the air!* . Virginia: Virginia Cooperative Extension, Virginia Polytechnic Institute and State University. .

RHUD. 2013. *Roads, Housing and Urban Development Research Center.* 01 10. Accessed 07 31, 2013. http://www.bhrc.ac.ir/portal/Default.aspx?tabid=485 accessed online on July 31, 2013.

Roaf, S, M Fuentes, and S Thomas. 2007. *Ecohouse: A Design Guide.* Oxford: Elsevier.

Roux, P, and A Alexander. 2009. "Sustainable Building materials." In *Sustainable Neighbourhood Design Manual: A Non-Technical Guide*, by The Sustainability Institute, edited by Lisa Thompson-Smeddle. South African National Department of Housing and Cordaid (the Netherlands).

Sabetghadam, M. 2006. *Energy and Sustainable Development in Iran.* Helio International, 7. Accessed 6 3, 2016. https://sustainabledevelopment.un.org/content/documents/854Iran-EN.pdf.

Saed Samii, Asghar. 2008. *Guideline for building construction, second edition,.* Second edition. Tehran: Honar Farda Institute.

Safa, Zabihollah. 1977. *Summary of Iran's Political, Social and Cultural History.* Tehran: Amir Kabir Publications.

Samizay, R. 2012. "Spatial Heritage of Sustainable Urbanism in Yazd, Iran." In *Heritage and Sustainability in the Islamic Built Environment*, by B Kazimee. Boston: WIT Press.

SANA, Ministry of Energy. 1995. *Renewable Energy Organization of Iran.* Accessed 09 09, 2013. http://www.suna.org.ir/en/proj.

Sanders, John, and Graham Shepherd. 2013. *R-Value and Thermal Mass of Brick Masonry.* Clemson University, May.

Santamournis, M. 2006. *Environmental Design of Urban Buildings, an Integrated Approach.* London: Earthscan.

Sassi, Paola. 2006. *Strategies for Sustainable Architecture.* New York: Taylor & Francis.

Schäfer, Rudolf. 2011. *YOUNG CITIES - Developing Energy-Efficient Urban Fabric in the Tehran-Karaj Region.* 31 01. https://www.wanacu.tu-berlin.de/menue/activities/associated_activities/young_cities_hashtgerd_iran/.

SCI, Statistical Center of Iran. 2012. *Amar Organisation.* Accessed 09 17, 2013. http://www.amar.org.ir/Default.aspx?tabid=96&agentType=ViewType&PropertyTypeID=4.

Seelig, S, P Wehage, and E Pahl-Weber. 2011. "Energie und Identität-Stadtgestaltung für eine Energiegerechte New Town in Iran." *Stadtbauwelt, 189* 64-69.

Seelig, Sebastian. 2011. "A master plan for low carbon and resilient housing: The 35 ha area in Hashtgerd New Town, Iran." *elsevier* 545–556. www.elsevier.com/locate/cities.

SHHS, ICHHTO. 2009. "World Heritage List, Shushtar Historical Hydraulic System." *World Heritage Convention, UNESCO.* Accessed 05 11, 2014. http://whc.unesco.org/en/list/1315/.

Simon Guy, Steven A. moore et al. 2005. *Sustainable architectures.* New York: Spon Press.

Soltani, Afsaneh, and Hossein Abbasimehr. 2013. "Shustar New Town, Report for Building and Context Course." TU Vienna, 6 9.

Standard 2800, Permanent comittee for revising. 2007. *The Iranian Code of Practice for Seismic Resistant Design of Buildings.* 3rd edition. Tehran: BHRC Publication. http://www.apadanabana.com/uploads/news7_En_iranian%20cod%20of%20practice%20for%20seismic%20resistant%20design%20of%20buildins.pdf.

Tahbaz, Mansoureh, and Shahrbanoo Djalilian. 2008. *Architectural Design Principals Compatible with Climatic Conditions of Iran, with Focus on Mosque Design.* Tehran: Shahid Beheshti University Publication Center.

Tavakoli, B, and M Ghafory-Ashtiani. 2009. "Seismic Hazard Assessment og iran." International Institute of Earthquake Engineering and Seismology (IIEES), Tehran, 2. Accessed 06 23, 2015. http://www.iiees.ac.ir/fa/wp-content/uploads/2009/06/Seismic_Hazard_Assessment_of_Iran.pdf.

Tavassoli, Mahmoud. 2002. *Urban Structure and Architecture in the Hot and Arid Zone of Iran.* 4th Edition (1981). Tehran: Payam, Pevand-e Now.

Tavassoli, Mahmoud, and Naser Bonyadi. 1992. *Urban Space Design 1.* Tehran: Urban Planning and Architecture Research Center of Iran.

Tolles, E, E Kimbro, F Webster, and W Ginell. 2000. *Seismic stabilization of historic adobe structures.* Los Angeles: The Getty Conservation Institute .

Tzonis, Alexander, and Liane Lefaivre. 2012. *Architecture of Regionalism.* London: Routledge.

UNEP. 2003. "Vital Forest Graphics, Forest Cover and Definition." *United Nations Environment Programme, Environment for Development.* Accessed 2015. Forest cover and definition map, (UNEP n.d.)United Nations Envirohttp://www.unep.org/vitalforest/graphics.asp.

UNESCO. 2007. "Tentative Lists, Historic city of Yazd." *UNESCO.* 08 09. Accessed 10 23, 2013. http://whc.unesco.org/en/tentativelists/5191/ accessed online 23.10.2013.

USGBC. 2014. *Checklist: LEED v4 for Homes Design and Construction.* Washington DC: The U.S. Green Building Council. http://www.usgbc.org/resources/leed-v4-homes-design-and-construction-checklist.

—. 2013. *LEED v4 for Homes and Midrise.* Washington DC: the U.S. Green Building Council. http://www.usgbc.org/resources/leed-v4-homes-and-midrise-ballot-version.

2014. *U-Wert.* Accessed 09 15, 2014. http://www.u-wert.net/berechnung/u-wert-rechner/?&d0=0.5&mid0=2615&d1=1&mid1=4037&d2=10&mid2=42&d3=10&mid3=46&bt=0&T_i=20&RH_i=50&T_e=35&RH_e=15&outside=0.

Varjavand, Parviz. 1984. "Mudbrick and Plaster's Role in Conservation of Adobe Buildings." In *Iran Architecture,* by Asieh Javadi, 880-887. Tehran: Mojarrad Publication.

2013. "Water Consumption Management Portal." *Isfahan Water and Wastewater Company.* Accessed 2013. http://abnama.nww.ir/Home/WaterConsumption.

Watkins, T. 2001. *House plants help indoor air quality.* Florida: Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, Univ. of Florida. .

WCED, World Commission on the Environment and Development. 1987. *Our Common Future.* Oxford: Oxford University Press.

Westbrook, Nigel. 2014. "The Regionalist Debate in the Context of the 1970s." *The Society of Architectural Historians, Australia and New Zealand.* Auckland, New Zealand; Gold Coast, Queensland: SAHANZ and Unitec ePress. 385-396.

Wilber, D. N. 1996. "Architecture vii. Pahlavi, before World War II." In *Encyclopaedia Iranica, online edition*. New York. Accessed 11 20, 2014. http://www.iranicaonline.org/articles/architecture-vii.

Williams, G P, and L W Gold. 1976 . "Ground Temperatures ." *Canadian Building Digest* 180.

Wolverton, B.C. 1997. *Eco-Friendly House Plants.* London: Phoenix Illustrated.

World Bank. 2014. "Indicators, Fossil Fuel Energy Consumption." *The World Bank.* Accessed 09 06, 2015. http://data.worldbank.org/indicator/EG.USE.COMM.FO.ZS/countries.

Wulff, H. 1977. *The Traditional Crafts of Persia,,* . Cambridge, Mass.

WWTO, World Wide Travel Organisation. 2014. "Vienna, Austria." *World Weather and Climate Information.* Accessed 09 02, 2014. https://weather-and-climate.com/average-monthly-Rainfall-Temperature-Sunshine,Vienna,Austria.

Yarshater, Ehsan. 2012. "Il-khanids." *Encyclopaedia Iranica.* 03 27. Accessed 08 01, 2015. http://www.iranicaonline.org/articles/il-khanids-index.

—. 2012. "Iranian history, Islamic period." *Encyclopaedia Iranica.* 03 29. Accessed 08 01, 2015. http://www.iranicaonline.org/articles/iran-ii2-islamic-period-page-1.

YCHHTO. 2013. "Yazd Cultural Heritage, Handicrafts and Tourism Organization." *Documentation Center Archive.* Yazd, 8 12.

Zangeneh Shahraki, Saeed, David Sauri, Pere Serra, Sirio Modugno, Faranak Seifolddini, and Ahmad Pourahmad. 2011. "Urban sprawl pattern and land-use change detection in Yazd, Iran." *Elsevier* (Habitat International 35) 521-528.