Adapting vernacular strategies for the design of an energy efficient residential building in a hot and arid climate: City of Yazd, Iran

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Adapting vernacular strategies for the design of an energy efficient residential building in a hot and arid climate:
City of Yazd, Iran

by

Farzad Hashemi

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Architecture

Program of Study Committee:
Ulrike Passe, Major Professor
Kristen Cetin
Andrea Wheeler

The student author, whose presentation of the scholarship herein was approved by the program of study committee, is solely responsible for the content of this thesis. The Graduate College will ensure this thesis is globally accessible and will not permit alterations after a degree is conferred.

Iowa State University
Ames, Iowa

2018

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<td>NZEB</td>
<td>Net Zero Energy Building</td>
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<tr>
<td>TMY</td>
<td>Typical Meteorological Year</td>
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<td>KSA</td>
<td>Kingdom of Saudi Arabia</td>
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<td>MBRSC</td>
<td>Mohammed bin Rashid Space Center</td>
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<td>AAC</td>
<td>Autoclaved Aerated Concrete</td>
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<td>EPW</td>
<td>EnergyPlus Weather</td>
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<td>sDA</td>
<td>Spatial Daylight Autonomy</td>
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<td>DOE</td>
<td>Department of Energy</td>
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ABSTRACT

Today, buildings consume a significant amount of primary energy, and consequently they are a major source for greenhouse gas emissions resulting in global warming. During the last decades, the concept of sustainable architecture with the major aim of diminishing negative environmental impact of the building has brought significant demands and changes to the profession of architecture. In this way, decreasing the dependency of buildings on fossil fuels and their high rate of energy consumption in underdeveloped countries like Iran is receiving more attention by architects and governments. Iran is a country with a powerful history in using vernacular solutions to maintain an acceptable indoor environment, such as harnessing natural ventilation, using local and high thermal mass materials, optimizing building orientation. Despite this successful history, temporary Iranian architecture suffers from high consumption and inefficient building construction.

The research presented in this thesis is initially concerned with investigating the traditional and vernacular features of Iranian architecture found in a hot–dry region. These features were considered in two shapes; energy efficiency features and social-cultural features. Moreover, the concept of Net Zero Energy Building with the significant aim of constructing sustainable has been assessed. As the result, by presenting a comprehensive study for features of Iranian vernacular architecture and Net ZEB concept, they have been combined to locate a high energy-efficient building in the city of Yazd with a hot and arid climate at the central area of Iran. Lessons derived from vernacular architecture caused considerable improvement in energy consumption of the proposed building, especially in heating, cooling, and lighting demands.
CHAPTER 1. INTRODUCTION

1.1 Sustainable Architecture

Today, the global warming due to increase of the greenhouse gases concentration in the atmosphere and significant reduction of natural resources are big threats for the world. Therefore, there is a substantial need to reconsider resource use, and to enlarge tactics to mitigate the changing climate. One of the current means of solving this problem introduced by architecture and construction industry is the construction of environmentally-friendly and sustainable buildings. Sustainable architecture seeks to mitigate the negative environmental impact of buildings by enhancing efficiency and moderation in the use of materials, energy, and development space (Fergus and Roaf, 2007). In fact, sustainable architecture is mostly referred to ameliorating adverse interaction between nature and human developments. In 1987, the World Commission on Environment and Development report *Our Common Future* (also known as the *Brundtland Report*) provided an early (and still much-used) authoritative definition of what constitutes sustainable development. According to the *Brundtland*, (1987) report:

“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. The concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities”.

After nearly three decades, sustainable architecture and design as a global concern succeed to catch the attention of architect and designers from around the world. Paolo, Sassi (2006) in his book, *Strategies for Sustainable Architecture*, asserted that sustainable buildings should metaphorically ‘tread lightly on the Earth’ by limiting the ecological impacts derived from their construction, their life in use and at the end of their life. Environmental footprints of sustainable buildings must be minimized. Sustainable architecture, then, is a revised conceptualization of architecture in response to a myriad of contemporary concerns about the effects of human activity. The label ‘sustainable’ is used to differentiate this conceptualization from others that do not respond so clearly to these concerns. Not long ago a major part of the image of good architecture was a building that was *suitable* for its environmental context – one that would adequately protect the inhabitants from the climate. More recently it is ‘the environment’ that has been seen as needing protection (Bennetts et al, 2003).

1.1.1 **What Are NZEBs?**

There are different definitions by experts for what are NZEBs and some of globally accepted boundaries and metrics are presented in followings. W. Gillijamse (1995) provided one of the first definition. He asserted that a zero energy house as a house in which no fossil fuels are consumed, and the annual electricity consumption equals annual electricity production. Unlike the autarkic situation, the electricity grid acts as a virtual buffer with annually balanced delivers and returns. Torcellini et al, (2006) expressed that a net zero energy building (ZEB) is a residential or commercial building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies. Laustsen (2008) believed that Zero Net Energy Buildings are
buildings that over a year are neutral, meaning that they deliver as much energy to the supply grids as they use from the grids. Seen in these terms they do not need any fossil fuel for heating, cooling, lighting or other energy uses although they sometimes draw energy from the grid.

### 1.2 Vernacular Architecture

Climate was approached as a starting point for vernacular building design, which led to take not only building forms and practices into account by architects but also generated cultural virtues. Over centuries, a trial-and-error evolution was able to produce “vernacular” design solutions that are climatically appropriate, culturally relevant and aesthetically pleasing (Emmanuel, 2012). In fact, our ancestors were able to control climatic environment in buildings they designed when there were no mechanical system invented.

Vernacular architecture is an architectural style that is based on interrelations between ecological, economic, material, political and social factors (Asquith and Vellinga, 2006) and it provides a good solution to the climatic constraints. History shows that vernacular techniques and materials have been shaped by the local culture, weather and geographical location. The selection of these techniques and materials for such a building is usually dependent on the desired benefits, as well as the local availability of construction materials and skilled labor (Alrashed et al, 2017).

#### 1.2.1 Vernacular Architecture in Iran

One of the countries with powerful history in vernacular architecture and sustainable inventories is Iran. Iran’s vernacular architecture was successfully able to illustrate the art of adaptation to context by developing different architectures in different regions of the country. Despite their different appearances, these architectures follow the same logic in
spirit: adaptation to context (Sahebzadeh et al, 2017). Iran has four main climate regions from hot and arid to humid and rainy region and Iranian vernacular architecture achieved acceptable climate comfort conditions in interior spaces within different exterior climates by using intelligent spatial strategies and adapting to the natural and social conditions of the specific locations (Soleymanpour et al, 2015).

1.3 Research Question

Although Iran has a strong historical background in creating the efficient and climate responsive buildings, today this country suffers significantly from the high amount of energy consumption in buildings sector. This thesis explores the following research question, what are the features of vernacular and traditional architecture that made their products able to sustain efficiently through centuries? It has been proven by different studies and research projects that vernacular architecture, were both environmentally and socially compatible to their contexts. What are the keys of this successful performance? Thus, the major question, which this thesis aims to answer, is to what extent vernacular architecture of a region can benefit contemporary architecture design in order to improve their energy efficiency?

1.4 Goals

The major goal of this thesis is to seek vernacular features from traditional architecture in Iran, which can be employed to improve the energy efficiency of contemporary buildings, particularly in the residential sector in a hot and arid climate. The design of an energy efficient residential building in the city of Yazd, Iran addresses on energy management and socio-cultural attributes.
1.5 Research Methodology

The research methodology for thesis relies on two phases. Literature reviews, and simulation research design. As the first step, a comprehensive literature review support the framing of a concise research question. The fundamental principles of two keywords i.e. sustainable and vernacular features of Iranian architecture are considered in the first phase. A thorough review over the mechanism of the mentioned keywords will provide a useful framework for achieving the goal of this thesis. In the first phase of the review, well-known features of Iranian vernacular architecture in hot and arid climate are investigated carefully with the emphasis on their social, economy, and environmental aspects. In the next step of this phase, real case studies empowered by sustainable and energy efficiency approaches from a same climate are considered in order to figure out their pros and cons.

In the next phase, modeling and simulation or “copies” of reality research method is employed to represent the model of intended building. The dictionary defines simulation as “the representation of the behavior or characteristics of one system through the use of another system, especially a computer program designed for the purpose” (Groat and Wang, 2013). Applied to simulation research, it is possible to predict the performance of a building without the expense of actually building it. In this purpose, simulation research method has a major role to predict the energy self-sufficiency of the proposed building.

The simulation part contains these following steps:

- First, climatic features of the city of Yazd have been assessed in order to find the best passive solutions for heating, cooling, and lightings.

- Second, a detailed 2D/3D model of the proposed building has been developed according to findings from literatures based on vernacular and
ZEB features. In the design stages, socio-cultural and passive strategies have been employed as a guideline.

- Third, daylight simulation has been conducted to reach the most suitable passive lighting strategies in order to reduce electrical lighting loads.

- Fourth, natural ventilation strategies have been analyzed in design process to minimize the active cooling demand by the building.

- Finally, after proposing the most suitable passive strategies and preparing all required inputs, energy simulation were run in order to investigate the energy-use performance of the building. In this stage, Typical Meteorological Year (TMY) data of the city were incorporated into energy simulation software to predict the performance of the proposed building under real conditions.

At the end, the results for energy-use performance are presented for the design of an energy efficient residential building in a hot and arid climate based on the evaluation of the theoretical studies, literature reviews, case studies, and climatic analysis.
CHAPTER 2. LITERATURE REVIEW

2.1 Sustainable and Vernacular Architecture strategies

Due to the importance of terms of sustainability and vernacular, many pieces of research were done in those fields from considering the ancient building techniques to modern passive and active solutions to decrease the dependency of buildings on fossil fuels imports. On the one hand, existing traditional strategies used by Iranian architects in purpose of creating the environmentally responsible buildings at different climatic regions has been discussed by (Eiraji and Akbari, 2011) and (Shahamipour and Farzanmanesh, 2013). They showed how Iranian ancient design was based on the region and its local climate conditions. Maleki (2011) studied characteristic of Iranian architecture and their high compatibility with climatic factors and the great role of local construction material in this kind of architecture. In this regard, (Cho and Mohammadzadeh, 2013) tested traditional courtyards in the city of Kashan, Iran, to analyze the indoor thermal comfort conditions and effectiveness of the natural ventilation systems along with other native design strategies in term of thermal comfort. As another well-known traditional feature, downdraught (wind-catcher) cooling is considered as an energy efficient and cost-effective alternative to conventional air-conditioning for new and existing buildings by (Ford et al, 2010) in their design sourcebook. It is claimed that passive downdraught evaporative cooling can meet 25-85% of the cooling load on non-domestic building (equivalent to 15 – 60kWh/m2pa). The typology of the wind-catchers is also studied through the physical analyzing, patterns and common concepts as incorporated in them by (Zarandi, 2009). In this study, fluids dynamics science, Fluent software and numerical analysis are used as an analytical approach.
On the other hand, passive strategies to improve the building’s energy-use have been considered by many resources. The effects of thermal mass and phase change material on building cooling/heating loads and peak loads are discussed by Sadineni et al., (2011). They concluded that as an energy saving method, application of thermal mass is more effective in places where the outside ambient air temperature differences between the days and nights are high. Okba (2005) has developed a checklist for envelope design techniques to provide architects with the principles and design strategies for envelope design as a passive cooling technique. Alaidroos and Krarti (2016) has evaluated three passive cooling techniques including natural ventilation, downdraft evaporative cooling, and earth tube cooling to evaluate their effectiveness in reducing cooling thermal loads and air conditioning energy-use for residential buildings in Kingdom of Saudi Arabia (KSA). Kharrufa and Adil (2012) considered various numbers of traditional techniques under the name of passive methods, which provide cooling loads at the hot-arid climates. Dabaieh et al, (2015) used a designed algorithmic hybrid matrix to simulate 37 roof design probabilities alternating roof shape, roof material and construction. The result of this study claims that using a vault roof with high albedo coating shows a fall of 53% in discomfort hours and saves 826 kW h during the summer season compared to the base case of the conventional non-insulated flat roof in typical Cairo residential buildings.

In the next step of this chapter, the literature review has been conducted on the features of Iranian vernacular architecture in hot and arid area, as the context for this thesis.
2.2 Features of Iranian Vernacular Architecture

This section describes the major features of Iranian vernacular architecture in hot and arid climate.

2.2.1 Sidewalks

Narrow and mainly curved sidewalks surrounded by tall adobe walls on both sides help to protect the people against summer sunlight and accelerating breezes (Figure 2.1). With an overall east–west direction, sidewalks and Sabats used to maximize shading for cooling pedestrians (Tavassoli, 2002). These roofed and narrow passages (Figure 2.2) with surrounding high walls provide an effective solution for dealing with the harsh climate by reducing solar radiation reached by building facades (Moradi, 2005).

Figure 2.1 Sidewalks in historic core of Yazd, Iran (Source: www.pinterest.com)
2.2.2 Openings – Air Flow to Remove Heat and Exchange Stale Air

Naturally Ventilated building are a feature of vernacular architecture, with carefully positioned opening windows and louvered vents to incorporate shading and provide sufficient air flow through the buildings. Vernacular buildings were designed and built to respect their local climate and use it to maximize internal comfort. The use of passive ventilation is gaining widespread acceptance as an environmentally responsible way in which to ventilate buildings (Emmitt and Grose, 2010). In vernacular architecture of hot climate, the numbers of windows that open to the sidewalks are minimized to avoid having the unfavorable climate penetrate into the indoor area (Figure 2.3). To prevent dust and excessive sunlight from getting into the buildings, windows and openings are usually placed in the ceiling or high up the walls. These openings are equipped with decorative wooden frames and colored glasses (Figure 2.4) that provide privacy, block the direct sunlight radiation and furthermore do not disturb the ventilation and airflow between the rooms (Meamarian, 1999).
2.2.3 Materials

One of the most important design parameters affecting indoor thermal comfort especially in hot region is the building envelope design and the materials used, as the envelope separates and mitigates the outdoor and indoor environment. The prominent materials used in this region, mud, adobe, and brick are made with clay. The major reason of using clay is its high thermal capacity resulting in minimizing temperature fluctuations inside the building between day and night (Figure 2.5 and 2.6). Clay used in this kind of material is mainly excavated from the ground in the building construction process in order to dig the underground spaces (Pirnia, 2005). These kinds of materials in addition to their insulating
properties function as heat reservoirs: during the hot day, the heat flow from exterior to interior is retarded and during cooler hours, a given part of the heat imprisoned in the walls is released towards internal spaces. The consequence is a minimization of temperature change inside the building (Alp, 1991).

![Image of adobe construction](source: www.pinterest.com)

Figure 2.5 Use of adobe in construction, Yazd, Iran (Source: www.pinterest.com)

![Image of adobe tile](source: Sahebzadeh et al, 2017)

Figure 2.6 Adobe tile made by clay (Source: Sahebzadeh et al, 2017)

### 2.2.4 Courtyards

The use of courtyards (Figures 2.7 and 2.8) in residential buildings in Iran is many centuries old. The courtyard provided security and privacy for the inhabitants, and daylight
for the surrounding rooms and basements. Having a pool in the middle and planting deciduous trees in the yard, a pleasant space has been created for the residents to spend a portion of their time during summer months. In addition to the above features, courtyards provided other benefits in the hot-arid climates. With their tall walls, the rooms (built around the courtyard) provided wind sheltering effects for one another, thus reducing the infiltration of hot and often dusty winds to the rooms. With their trees, flowers, shrubs and a pool of water, the courtyards created a micro-environment, a few degrees lower in air temperature and slightly higher in relative humidity. Furthermore, the tall trees in the courtyards shaded the walls and the ground from the intense direct solar radiation of summer. All these features reduced the heat gains of the building (Safarzadeh and Bahadori, 2003).

Figure 2.7 Ameriha House, Kashan, Iran (Source: https://friendlyiran.com/blog/iranian-traditional-house/)
2.2.5 Summer Area and Winter Area

Houses in hot region of Iran are divided into two parts, a summer area and a winter area. In the summer, the summer area of the building is in the shadows most of the time. Across the yard from the summer area is the winter area, which provides access to the warmth of the sunlight during the winter. Houses with yards in the middle and two other areas that connect the summer area and the winter area are called four-season houses. However, the summer area best demonstrates the importance of the art of architecture in protecting people from adverse climatic conditions (Keshtkaran, 2011).

2.2.6 Roofs (Vaults and Domes)

In hot and arid region of Iran, roofs were mainly arched or domed roofs. These shapes have been emerged due the lack of rainfall and structural timber (Figure 2.9). Therefore, available materials such as adobe and brick are utilized in order to cover the houses’ spaces and create an acceptable indoor environment in the only way possible, which is constructing domes and vaults (Pirnia, 2005).

Some advantages of vault and domes roofs used by Iranian architects are listed as below (Sahebzadeh et al, 2017):
• Lower roof temperature on the part, which is always shaded.
• Providing “Stack effect” due to the extra space below the domes and vaults.
• Due to their thickness caused by the nature of their materials, vaults and domes act as thermal hampers (see section 2.2.3).

![Figure 2.9 Historic core of Yazd, Iran (Source: yazd.today)](image)

2.2.7 Wind Catcher

Another important feature of the traditional Iranian houses is the wind tower, called Baudgeer in Persian. These towers catch the passing winds and direct them down to the ground and basement living spaces (Figure 2.10). These wind towers serve to cool the spaces on summer mornings and evenings when the air temperature above the building is lower than air in interior rooms. In addition, they provide an effective ventilation to refresh the air and remove unwanted smells from cooking especially in the basements (Nisrine, 2007). One side of the tower rises from the roof while the other side leads down to the basement or lowest spaces. The upper part on the roof is the wind catcher, which is divided into several vertical air passages that terminate in openings at the top. Local designs exhibit variations in the
height, the air-passages division, location and number of openings, the placement of the tower in relation to the building, and finally the material (Alp, 1991).

Climatic features of cities is mainly affecting appearance and the design of Baudgeers. (Figure 2.11). Uni-channel (one-sided) Baudgeers are normally employed in the areas where favorite wind exists just in one certain direction while three- or four- sided Baudgeers are used in the areas where the wind is blowing in multi directions (Bahadori, 2016).

Figure 2.10 A common Baudgeer (Source: M. N. Bahadori, 2016)
(Figures 2.12 and 2.13) show a Baudgeer in the city of Bam cooling the interior by means of an underground tunnel crossing the courtyard, which is always wet due to the watering of the greenery and the penetration of the water into the passage. The air passing through this wet underground tunnel becomes cooler, due to evaporative cooling process and then enters the building (Bahadori, 2016).
Figure 2.12 A Baudgeer in City of Bam, Iran (Source: Bahadori, 2016)

Figure 2.13 Cross section of a Baudgeer in City of Bam (Source: Bahadori, 2016)
CHAPTER 3. CASE STUDIES

3.1 Net ZEB Case Studies

This chapter contains two sections. First, three recent NZEB project have been chosen from hot and arid regions with almost similar socio-cultural background to our context. These projects are considered to figure out their main properties and mechanism and then extract their possible advantages to use in our proposed design. At the end of this section, significant properties of NZEB case studies are collected in Table 3.1.

In the second section of this chapter, an Iranian house, Boroojerdi-ha House, as a successful sample from Iranian vernacular architecture is investigated in order to understanding the performance of vernacular features used in the house. Boroojerdi-ha House is located in city of Kashan with the same climate conditions as city of Yazd.

3.1.1 Mohammed bin Rashid Space Project, Dubai

The Autonomous House designed and constructed by Mohammed bin Rashid Space Center (MBRSC) engineers (Figure 3.1). Following description for the project are quoted from the developer of the project, MBRSC:

“Using the smart technologies, the house ensures quality of life, top-notch comfort and healthy living conditions. This energy plus building operates cooling and lighting systems and home electronics using renewable energy sources, efficiently transforming solar power captured by solar panels into electricity. The house employs super smart sensors and an air conditioning system based on chilled water. It also maintains clean air, stable temperature and humidity levels all day long throughout the year (MBRSC Passive Housing).
“The design chooses to use a prefabricated European timber platform frame technology, which is not local and consequently sustainable but made the building possible to realize in less than 100 days. Three different cooling systems have been installed for research purposes: supply air cooling or dehumidifying, recirculated air cooling and floor cooling (avoided in UAE, as current technology is unable to deal with condensation phenomena), with the possibility to couple them to get the best results in terms of efficiency and comfort” (MBRSC Passive Housing, 2018).

3.1.2 Baytana Villa - Qatar

The Baytana villa is probably the first energy-efficient house experiment in the region. The significance of this project lies in the fact that the project consists of two identical villas in terms of size, spatial arrangements, and comfort requirements (Figure 3.2). Chahem et al (2016) conducted a thorough review for this project and compare these two adjacent projects:
“They differ in the design specifications. One of them was design based on passive house strategies with solar panels (on the right side) whereas the other was designed in a similar way to its conventional villas in Qatar to act as a control case (on left side). This allows a comparison between the two houses in terms of energy consumption, CO₂ emissions, cost effectiveness, comfort levels, and occupant’s satisfaction.

![Image of Baytana Villa, Qatar](image)

Figure 3.2 Baytana Villa, Qatar (Source: A. Chahem et. al., 2016)

The energy efficient villa was designed according to the Passive House Institute standards in order to achieve at least 50% reduction in annual operational energy consumption, water usage, and CO₂ emissions when compared to its conventional twin house. The project aims to achieve this reduction with no more than 20% additional capital cost of the capital cost of the conventional house” (Chahem et al, 2016).
3.1.3 SQU Oman Eco-House Project

Chahem et al (2016) considered also Oman Eco-House Project as below:

“The house is one of the first research-based attempts to design, built and operated an energy-efficient house in Oman based on collaboration between academic, governmental and industrial local bodies. The house was designed to fulfil the living pattern of the modern Omani family while respecting social norms. The house uses references from the vernacular architecture to emphasis the depth of the Omani architecture and its historical and traditional roots. A carefully designed shading system was developed and supported by a double-shell system where a perforated second structure is introduced outside the main building in order to provide protection from direct solar radiation. This created a shaded cavity between the two shells where air current cools the in-between air and reduces heat gain in the main building. Optimized oriented courtyards, differences in air temperature and pressure, and carefully designed window openings were combined to maximize nature ventilation in the Omani winter. Landscaping was also utilized to moderate the microclimate of the site, provide shading in the needed directions, and control air currents. With these strategies, the project aims to achieve comfort by natural ventilation alone for four months” (Chahem et al, 2016).
Table 3.1 Major properties of the case studies

<table>
<thead>
<tr>
<th>Net ZEB Case Studies</th>
<th>General Information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mohammed bin Rashid space project, Dubai</strong></td>
<td><strong>Baytana - Qatar</strong></td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td><strong>Number of apartments/units</strong></td>
</tr>
<tr>
<td>AR - 21183 Dubai, Al Khawaneej (Dubai)</td>
<td>1</td>
</tr>
<tr>
<td>Baytana project, Barwa City, Qatar</td>
<td>1</td>
</tr>
<tr>
<td>Sultan Qaboos University, Muscat 123, Sultanate of Oman</td>
<td>2-story</td>
</tr>
</tbody>
</table>

Figure 3.3 SQU Ecohouse, Oman (Source: http://www.ecohouse.om/)
Table 3.1 (continued)

<table>
<thead>
<tr>
<th><strong>Basement floor / floor slab</strong></th>
<th><strong>Flooring</strong>, screed (60 mm), XPS-insulation (20 mm), perlite added screed (155 mm), XPS-insulation (225 mm)</th>
<th>150 mm slab</th>
<th>150 mm slab</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Roof</strong></td>
<td>Flat roof, Sealing sheet (thermoplastic elastomere), XPS-insulation (200 mm), OSB (15 mm), mineral fibre insulation between rafters (280 mm), plasterboard (25 mm)</td>
<td>100 mm slab</td>
<td>Is fully shaded and incorporates a 100mm thermal insulation</td>
</tr>
<tr>
<td><strong>Frame</strong></td>
<td>Bayerwald, BW80 PVC window, thermal bridge-free installation</td>
<td><strong>U</strong>-value = 0.89 W/(m²K)</td>
<td></td>
</tr>
<tr>
<td><strong>Glazing</strong></td>
<td>Triple thermal protection glazing</td>
<td><strong>U</strong>-value = 0.5 W/(m²K)</td>
<td></td>
</tr>
<tr>
<td><strong>Entrance door</strong></td>
<td>Schüco - ADS 90.SI</td>
<td><strong>U</strong>-value = 0.95 W/(m²K)</td>
<td>Triple glazed door</td>
</tr>
<tr>
<td><strong>Mechanical systems</strong></td>
<td>PAUL Wärmerückgewinnung</td>
<td>Natural ventilation for four months, mechanical</td>
<td></td>
</tr>
</tbody>
</table>
At the end of this section, all data driven case studies are listed in Table 3.1. In a short, data from Table 3.1 and section 3.1 show that all three houses:

- Are empowered by passive cooling and heating strategies like, optimized orientation, shading strategies, natural ventilation.
- Use references from the vernacular architecture to emphasis the depth of the historical and traditional roots of the context. Material used in two projects, SQU Eco-house and Baytana villa are local.
- Use renewable sources of energy, solar energy in particular.

3.2 Traditional Houses of Iran

Iranian architecture, which emerged first in the plateau of Iran and then scattered over other territories was highly influenced by Iranian climate and culture. Same as all other architecture with roots in native architecture, climate was playing a major role in this kind of architecture and many precious examples of this vernacular architecture still exist in Iran from 14th century. Boroujerdi-ha House, Tabatabaee-ha House, Ameri-ha House, and Abbasian House are famous samples of this architecture style. In this regard, following section investigates Boroujerdi House, which is one of the most famous houses of Kashan and is still under use from 1875.
3.2.1 **Boroojerdi-ha House, Kashan:**

Kashan is a city in Isfahan Province, Iran. The city is known as one of Iran’s main tourist attractions and as a gateway between Tehran (current capital of Iran) and Isfahan (capital of Iran in the 16th century) located at 33°59'N, 51°26'E and 955m above the sea level. The vicinity of Yazd and Kashan to Dasht-e-Kavir (a large desert lying in the middle of Iranian Plateau) results in a hot and dry climate for both. The hot and dry weather in summer and cold and dry in winter combined with a very low level of rainfall is the main characteristic of the climate in Kashan and Yazd. The same climate and culture (Yazd and Kashan are also known as high religious cities in Iran) brought them the development of the same style of architecture. In this way, Boroojerdi-ha House (Figure 3.4, 3.5, and 3.6) has been chosen to study as a four-seasons house and a symbol of desert architecture in Iran.

![Figure 3.4 Boroojerdi-ha House, taken by Roham Sheikholeslami](image-url)
The major features, which made the house most compatible with its context, in both cultural and environmental aspects, and are unfortunately fading through Iranian contemporary architecture, are listed as below:

- In order to optimize the sun light during cooling and heating seasons, parts of the house are located wisely according to the sun light direction.
• The house was mainly constructed by using local material like bricks and adobe, known as the most sustainable construction method.

• Three 40-meter-tall wind catchers with functions of wind-driven and stack effect were used properly to work with and without wind.

• Functions in the house are predicted with attention to the privacy of occupants (Figure 3.7).

• The courtyard as the heart of the building and the pool were greatly helpful to moderate adjacent places in the summer. It also provided a comfort place for sitting, eating and communicating.

![Figure 3.7 Privacy level of spaces in Boroojerdi-ha House, Source: Author](image)

The house features described above made the building unique and still operable after more than a century. Lessons from both cultural features (like respecting privacy and security of the inhabitants) and environmental features (orientations, courtyards, wind tower, construction materials) are wise choices, which can be used in our design. Containing advantages of the house features in our design process made us able to walk in the path toward the goal of this thesis i.e. design an energy efficient residential building.
CHAPTER 4. THE RESEARCH REGION-YAZD

4.1 Iran’s Geography and Climate

Iran has an area of 1,648,195 km² (636,372 square miles). It lies between latitudes 32° N and 53° E (US Central Intelligence Agency). Iran has four climatic regions (Figure 4.1). The most parts of the Iranian plateau have a dry and hot climate. North and west side of the country consists a cold and snowy climate. Northern shores of the Persian Gulf and the Sea of Oman comprises the hot and humid climate and humid and rainy climate embraces the southern shores of the Caspian Sea (Ghobadian, 1998).

Figure 4.1 Climate zones of Iran (Source: Nejad Ebrahimi et al, 2013)
Two deserts, Dasht-e-Kavir and Kavir-e-Lout, occupy 15% of Iran area are located in the center of Iran. In this area, summer is very hot and arid with the highest recorded temperature of 70.7 °C in Lout desert and winter is very cold and harsh with lowest temperature of -7 °C in the city of Yazd. The regions have no rain for at least six months of the year and most months of the year the sky is clear without cloud. Relative humidity is low too. Briefly, high temperature in the days of hot seasons, so much difference between day and night temperature, extreme radiation of sun light and relative dryness of atmosphere are considered as climatic specifications of salty desert areas. Shortage of water resources, few herbal cover, and desert (dusty) winds, which spread sands in the area, are main elements responsible for the harsh situation. The habitable states of these regions are scattered with different distances from each other and are normally condensed (Nazem, 2015).

4.2 Yazd’s Geography and Climate

4.2.1 Yazd Geographical Features

Yazd Province is located in central Iran, one of the most ancient province of Iran. Yazd is between geographical latitude of 29° to 33° North and longitude of 52° to 56° East of the meridian origin. The area of Yazd Province is approximately 72,000 square kilometers, or more than four percent of the total area of the country (Kasmae, 1984). The province’s population was 1,140,000 at the 2016 national census (Iran data Portal).

The city of Yazd (31° North, 54° East) is situated in the center of Iran (Figure 4.2) has hot and dry climate conditions. At the 2016 census, the city’s population was 657,000 (Iran data Portal) and it is currently 15th largest city and the driest major city in Iran. The area of the city is 110 square kilometers and to have a better imagination of the city area and population, it can be compared to the city of Boston, the capital city of Massachusetts State,
U.S. The city’s climate conditions is almost same to the city of Phoenix, the capital city of Arizona State, U.S.

Yazd resides in a valley between Shirkuh Mountain (the highest mountain in the region with a height of 4075 m) and Kharaneq, located at 203 m above the sea level, and is the biggest city located in the central plateau (Sahebzadeh et al, 2017).

![Map of Iran with the location of Yazd](image)

Figure 4.2 *Iran map with the location of Yazd in the country (Source: Shahraki et al. 2011)*

### 4.2.2 Yazd’s Climatic Features

About 55 millimeters of precipitation falls annually for only 23 days in Yazd and is the hottest city at the north of the Persian Gulf coast (Climate Data, 2018). Summer temperatures very frequently above 40 °C. Even at night, the temperatures in summer are rather uncomfortable. In the winter, the days remain mild and sunny, but in the morning the thin air and low cloudiness cause cold temperatures that can sometimes fall well below 0 °C (Wikipedia, 2018). In the following, the climatic features of Yazd are obtained from (Climate Consultant 6.0, 2018) software. Typical Meteorological Year (TMY) weather data in
EnergyPlus Weather (EPW) file format was used for Yazd and downloaded from EnergyPlus (2018) website.

Figure 4.3 shows a summary of weather data for the city of Yazd in a typical year. Global Horizontal and Direct Normal Illumination were not recorded in TMY data for the city of Yazd.

Figure 4.3 Weather data summary for Yazd (Source: Climate Consultant software tool)
It is important to note that Adaptive Comfort Model in ASHRAE Standard 55-2010 was used as the source for comfort prediction. In naturally ventilated spaces where occupants can open and close windows, their thermal response will depend in part on the outdoor climate, and may have a wider comfort range than in buildings with centralized HVAC systems. This model assumes occupants adapt their clothing to thermal conditions, and are sedentary (1.0 to 1.3 met). “met” is a unit to describe the energy generated inside the body due to metabolic activity, defined as 58.2 w/m² (18.4 Btu/h.ft²), which is equal to the energy produced per unit surface area of an average person seated at rest (ASHRAE standard 55-2004). The surface area of an average person is 1.8 m² (19 ft²). Comfort low temperature and comfort high temperature in this climate are 18.4 °C and 30.3 °C respectively (Figure 4.4).
Figure 4.5 Temperature range for Yazd (Source: Climate Consultant software)

Figure 4.5 shows that annual mean temperature for Yazd is approximately 19°C (67°F) while comfort zone according to Adaptive Comfort Model in ASHRAE Standard 55-2010 is different due to months and has a range from 18.4°C to 30.3°C (65°F to 86°F). The highest recorded temperature for a typical year in Yazd was 42°C (108°F) in August and the lowest temperature was -7°C (19°F) in January.

Figure 4.6 shows monthly diurnal average for Yazd, from June to August the Global Horizontal radiation is at the peak of about 1000 Wh/sq.m, when the dry and wet bulb temperature are also at the maximum amount. Furthermore, the highest received amounts for Global Horizontal is 1000 Wh/sq.m on June, 600 Wh/sq.m for Direct Normal on September, and 600 Wh/sq.m for Diffuse radiation on April.
Figure 4.6 Monthly diurnal average for Yazd (Source: Climate Consultant software)
Figure 4.7 Sky cover range for Yazd (Source: Climate Consultant software)

Figure 4.8 Wind velocity for Yazd, Source: Web based Climate Consultant software tool.
Sky cover and wind velocity for a typical year of Yazd are illustrated in Figures 4.7 and 4.8 respectively. The annual mean amount of sky cover is between 40 to 50%. The annual mean of wind velocity is a little bit more than 5 m/s. The highest recorded wind velocity is 16 m/s on May while no wind has been recorded during at least 8 months.

Wind Wheel in Figure 4.9 shows for each wind direction, the Wind Velocity and frequency of occurrence along with concurrent average Dry Bulb Temperature and Relative Humidity. The prevailing wind direction are West and North-West.

Figure 4.9 Wind Wheel for Yazd, Source: Web based Climate Consultant software tool.
The precipitation diagram (Figure 4.10) of typical meteorological year data for Yazd shows how many days per months, certain precipitation amounts are reached. From June to the end of October no precipitation has been recorded for the city. Other climatic features for the city are inserted in Appendix A.

After discussing the major factors of weather conditions in Yazd, the Psychometric Chart for Adaptive Comfort Model has been provided by Climate Consultant software (Figure 4.11).
Figure 4.11 Psychrometric chart and design strategies for Yazd, Source: Climate Consultant software)

Three different attributes i.e. dry-bulb temperature, humidity ratio and relative humidity of the climate are displayed concurrently on Psychrometric chart and it can show if humans will be comfortable in spaces with these characteristics or not. In a more important manner, it can guide to design buildings envelopes efficiently that can modify or filter the external climate conditions and create comfortable indoor environments (Murray, 2007). Psychrometric chart with the major design strategy for Yazd is shown in Figure 4.11.

Assuming only the Design Strategies that were selected on the Psychrometric Chart, 15.5% of the hours will be Comfortable.
This list of Residential Design guidelines applies specifically to this particular climate, starting with the most important first is provided below from Climate Consultant 6.0 (2018):

- Good natural ventilation can reduce or eliminate air conditioning in warm weather, if windows are well shaded and oriented to prevailing breezes.
- Long narrow building floorplan can help maximize cross ventilation in hot climates.
- To facilitate cross ventilation, locate door and window openings on opposite sides of building with larger openings facing up-wind if possible.
- On hot days ceiling fans or indoor air motion can make it seem cooler by 2.8 °C or more, thus less air conditioning is needed.
- Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required.
- To produce stack ventilation, even when wind speeds are low, maximize vertical height between air inlet and outlet (open stairwells, two story spaces, roof monitors)
- Traditional passive homes in hot dry climates used high mass construction with small recessed shaded openings, operable for night ventilation to cool the mass.
- Flat roofs work well in hot dry climates.
- An Evaporative Cooler can provide enough cooling capacity (if water is available and humidity is low) thus reducing or even eliminating air conditioning.
- Window overhangs (designed for this latitude) or operable sunshades (awnings that extend in summer) can reduce or eliminate air conditioning
- Earth sheltering, occupied basements, or earth tubes reduce heat loads in very hot dry climates because the earth stays near average annual temperature.
• Locate garages or storage areas on the side of the building facing the coldest wind to help insulate.

• Organize floorplan so winter sun penetrates into daytime use spaces with specific functions that coincide with solar orientation.

• Use light colored building materials and cool roofs (with high emissivity) to minimize conducted heat gain.

• Humidify hot dry air before it enters the building from enclosed outdoor spaces with spray-like fountains, misters, wet pavement, or cooling towers.

• Sunny wind-protected outdoor spaces can extend living areas in cool weather (seasonal sun rooms, enclosed patios, courtyards, or verandahs).

• Keep the building small (right-sized) because excessive floor area wastes heating and cooling energy.

• High Efficiency furnace (at least Energy Star) should prove cost effective.

• Use open plan interiors to promote natural cross ventilation, or use louvered doors, or instead use jump ducts if privacy is required.

In more details (Soleymanpour et al, 2015) provides some design recommendations by using Givoni’s charts for Yazd climate that are shown in Figure 4.12. These recommendations are developed by extracting meteorological data effective on climate comfort such as temperature and relative humidity from the synoptic station of Iran’s cities.
Table 4.1 Analyzing bioclimatic chart of Yazd (Source: Soleymanpour et al, 2015)

<table>
<thead>
<tr>
<th>Month</th>
<th>Time</th>
<th>Zone</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dec, Jan, Feb</td>
<td>Day</td>
<td>Cold, H’</td>
<td>Materials with high thermal capacity, Using solar heat</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>Under heated</td>
<td>Require heat sources and mechanical equipment, minimum heat exchange</td>
</tr>
<tr>
<td>Nov, March</td>
<td>Day</td>
<td>H’, H</td>
<td>Materials with high thermal capacity, Using solar heat, minimum heat exchange</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>Cold, H’</td>
<td>Materials with high thermal capacity, sometimes requiring heat sources</td>
</tr>
<tr>
<td>Apr, Oct</td>
<td>Day</td>
<td>N, W</td>
<td>Need to Increase humidity</td>
</tr>
<tr>
<td></td>
<td>Night</td>
<td>H’, H</td>
<td>Materials with high thermal capacity, minimum heat exchange with the outside</td>
</tr>
<tr>
<td>May</td>
<td>Day</td>
<td>N, V</td>
<td>Need to natural ventilation</td>
</tr>
<tr>
<td>Table 4.1 (continued)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------</td>
<td>--------</td>
<td>--------</td>
<td>--------------------------------------------</td>
</tr>
<tr>
<td>Night</td>
<td>W, H</td>
<td></td>
<td>Materials with high thermal capacity, Need to Increase humidity</td>
</tr>
<tr>
<td><strong>Sep</strong></td>
<td>Day</td>
<td>EC</td>
<td>Need to natural ventilation and Increasing humidity</td>
</tr>
<tr>
<td>Night</td>
<td>W, H</td>
<td></td>
<td>Materials with high thermal capacity, Need to Increase humidity</td>
</tr>
<tr>
<td><strong>June, July, Aug</strong></td>
<td>Day</td>
<td>EC</td>
<td>Need to natural ventilation and Increasing humidity</td>
</tr>
<tr>
<td>Night</td>
<td>W</td>
<td></td>
<td>Need to Increase humidity</td>
</tr>
</tbody>
</table>

Table 4.1 shows the principles of climate design for Yazd city from Givoni’s psychrometric chart.
CHAPTER 5: URBAN DESIGN

5.1 Urban Studies

Cities are dynamic systems and are constantly evolving and changing so architectural projects must inevitably respond to cities changes in order to be known as successful projects. Moreover, policies and urban regulations in cities are regularly reviewed and updated to match the new residents’ demands. Any urban development project, first of all requires identifying needs, opportunities, objectives, and strategies which will be obtained after thorough studies in urban scale. In this section, the city of Yazd was considered to find opportunities, which lead us to choose the site for our project. At the end of this section, a SWOT analysis was prepared for the chosen site.

5.1.1 City Development

Figure 5.1 Yazd development directions (Source for background image: Google 2018)
City of Yazd, also spelled Yezd was founded on the 5th century CE was described as the “noble city of Yazd” by Marco Polo. The city expanded linearly from North-West to South-East during last 30 years (Figure 5.1). The North and North-East side of the city is surrounded by unlivable desert hills. Thus, the major development and expansion direction of the city was shaped in North-West to South-East. The extreme climatic conditions, which is mainly due to the direct impact of solar radiation and unpleasant wind, cause to create a dense urban design. The major characteristic of urban design in Yazd cause to plant buildings close to each other to optimize the shading effects of the buildings. Open spaces are limited to courtyards and inner spaces, which normally contain trees and vegetation to benefit from their cooling effects.

Figure 5.2 Historical core of Yazd (Source: Google 2018)
Figure 5.2 shows the style of architecture in parts of the city. Old or historic area, which is located at the center of the city, is constructed according to vernacular strategies. The Historic part survived and flourished despite the harsh desert environment due to Qanat system of collecting water from the nearby mountains. The nominated property is characterized by its earthen buildings and distinctive architectural features such as wind-catchers, domes, vaults and minarets. It is also characterized by its physical system of spatial organization made up of courtyards, alleyways, streets and public squares as well as roofed and open alleys (World Heritage Center). From 100 years ago, especially after Pahlavi dynasty (started on 1925), Mixed area appeared to have a modern vision in construction with respect to the city’s ancient history.

Figure 5.3 Historical division of the city, Yazd (Source for background image: Google 2018)
Buildings with moderate high elevation emerged in this period. There is no specific style for new construction especially in recent 30 years at developing area. The sample of architecture from each area are also depicted in Figure 5.3.

5.2 Site Analysis

5.2.1 Site Location

The building’s site has been chosen from developing area. Regarding to the development direction of the city toward this area and consequently more vacant sites for planting a big scale residential complex this site was chosen in South-East of the city (Figure 5.4). The site is located close to two main boulevards, Modarres and Emam Hossein.

Figure 5.4 the site location in urban scale (Source for background image: Google 2018)
Figure 5.5 shows the dispersion of green spaces in the city, with the focus on the site neighborhood. It can be seen the city suffers from lack of sufficient green spaces. Lack of adequate water resources is the strong reason for not having the desired leisure spaces for the region and whole the city itself.

Figure 5.5 *Green analysis for the city with the focus on site neighborhood.*
The road network of the city in two categories, main and secondary access, are shown in Figure 5.6. The intended site is fed by two major boulevards of the city, Modarres and Emam Hossein boulevards, which are connecting South-East part of the city to the center and North-West part.

### 5.2.2 SWOT Analysis

SWOT analysis provides a summary of strengths, weakness, opportunity, and threats associated with the potential expansion of the site (Table 5.1). Strengths and weaknesses refer to the existing conditions of the site, which are either helpful or harmful to achieving the goals of the project. Strengths are favorable conditions that need to be built upon, whereas weaknesses are unfavorable conditions that need to be considered in the design and planning of the future stage. Opportunities and threats refer to potential future conditions of
the site. Opportunities are potential improvements and favorable conditions that the project will seek to achieve. Threats are the potential barriers that may impede the realization of project goals. Opportunities need to be prioritized and optimized whereas threats need to be countered or minimized.

Table 5.1 SWOT analysis of the site

<table>
<thead>
<tr>
<th><strong>Strength</strong></th>
<th><strong>Opportunity</strong></th>
<th><strong>Weakness</strong></th>
<th><strong>Threat</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Close to main roads (accessibility)</td>
<td>The neighborhood is under fast development</td>
<td>Lack of enough public transportation and pedestrian ways around the site</td>
<td>Increasing the traffic volume around the site</td>
</tr>
<tr>
<td>Largely enough spaces for planting a residential complex</td>
<td>Good connection with different classes, lower income in specific</td>
<td>It is not well oriented</td>
<td>Bringing low and high classes level into the neighborhood</td>
</tr>
<tr>
<td>Existing residential building around</td>
<td>Enough vacant spaces around the site for future expansion</td>
<td>Lack of enough bike routes around the site</td>
<td>Limited width of roadways threatens the provision of new bike routes</td>
</tr>
<tr>
<td>Far from the city center and old area (lower vehicle traffic)</td>
<td>Creating a new green node to connect surrounding existing green areas</td>
<td>Not well-designed buildings without any specific style of architecture</td>
<td></td>
</tr>
<tr>
<td>Close access to public functions like gas stations, hospital restaurants, and offices</td>
<td></td>
<td>Not enough green spaces and poor public facilities</td>
<td></td>
</tr>
</tbody>
</table>
5.2.3 Site Dimension

The site chosen for this study (Figure 40) has a rectangular shape with average length of 2435 feet and the average width of 1280 feet. The longer side of the site is lied on North-East to South-West direction.

Figure 5.7 Site orientation and dimension (Source for background image: Google 2018)

5.2.4 Social and Economic Status of the Neighborhood

The social status of the site neighborhood was obtained from municipality website of Yazd. The area in terms of economic, educational and employment can be introduces as follows:

- This region has the highest population growth rates in the city area
- Neighborhood residents are mainly from low and middle income levels
• Lower literacy rate compare to other urban areas

• The middle relative percentage of employed men & women

• lower employed in the administrative sector and higher employed in the industry sector

• Average family member of 4.5

The photographic study (Figure 5.8) of the site shows prominent style of architecture in the neighborhood. Buildings are normally low-rise with the maximum height of five stories. Prominent material are brick and decorative stones.

Figure 5.8 Photographic study of the site
CHAPTER 6. ARCHITECTURAL DESIGN

6.1 Site Shadow Analysis

In the first step of architectural design, shadow analysis has been conducted for the site (Figures 6.1, 6.2, 6.3, and 6.4). South-West boundary of the site is impacted by surrounding buildings shadow in winter. Therefore, proper distance from this side for planting the building in order to benefit winter sun and its heating effects needs to be taken into account.

Figure 6.1 July to September shadow analysis for the site (Created by Diva for Rhino)

Figure 6.2 April to June shadow analysis for the site (Created by Diva for Rhino)

Figure 6.3 October to December shadow analysis for the site (Created by Diva for Rhino)

Figure 6.4 January to March shadow analysis for the site (Created by Diva for Rhino)
6.2 Site Wind Analysis

In the next step, wind analysis has been added to our study (Figure 6.5). The prominent wind with highest velocity is coming from West and North West. Wind velocity exceeds 9 m/s sometimes.

![Wind analysis for the site](image)

Figure 6.5 Wind analysis for the site (Created by Diva for Rhino)

In the follow section, some general design strategies aimed at reducing energy-use of the building, cooling demand in particular, will be described. Strategies used for design of the building mainly have a passive essence and are essential in order to create a highly efficient building.
6.3 Topology and Shape

The form and shape of a building is one of the significant factors, which highly affect the building energy-use during day and night. In fact, the amount of heat, which a building will be received during day and night, is highly based on its typology and shape. In hot and dry climates, the major goal for choosing a shape for buildings is trying to minimize sun exposure and maximize opportunities to create shade. In this regard, some common shapes have been analyzed to see their shadow creating performance in a hot day (July 10) from 9 AM to 5 PM on our site.

![Shadow test on most common shapes](image)

**Figure 6.6 Shadow test on most common shapes (Created by Diva for Rhino)**

In this step a building with a same area of 200 square meters but in different shape was tested to see how much shadow will be casted around the building (Figure 6.6). Shape number 3 in comparison to other shapes provide more shaded surfaces, especially on the inner side on a hot day.

6.4 Orientation

The amount of solar radiation received by a building depends on its orientation. With good orientation, the need for supporting heating and cooling is reduced, resulting in lower
energy consumption. Good orientation of a house in a hot, dry climate will protect the building from the hot sunshine on summer days. (Nabavi et al, 2012) considered thirty selected traditional Iranian houses in Yazd and showed they are all located in North- South direction but because of the topography of Yazd, two sub-directions are realized. Twenty houses are in North- East to South- West and ten are orientated in North- West to South-East. Therefore, in the next step our volume chosen from previous session entered into the site in order to find the best orientation. Figure 6.7 shows North-South and North-West to South-East of the chosen shape. Facades, which receive South (heating) and North (lighting) sunlight, are shown in red and blue color respectively. It is conceivable that by $45^\circ$ rotating the building it will possible to benefit more sunlight on more façade areas.

Figure 6.7 Finding the best orientation for the volume (Created by Diva for Rhino)
On the next step, to maximize the benefit of sunlight during winter days on south facades, the shape has been stretched in North-West to South-East Direction (Figure 6.8). Having more facade area with red and blue color will provide the opportunity of decreasing heating and cooling demands in their adjacent spaces.

![Figure 6.8 Geometry creation process on plan (Created by Diva for Rhino)](image)

At the final step, the chosen shape with proper rotation is elevated to create more residential units and achieve the aim of having at least 8 units in the building. Tall walls around the inner spaces (courtyard) will cast more shadows on its adjacent spaces as well.

![Figure 6.9 Geometry creation process on elevation (Created by Diva for Rhino)](image)
6.5 Architectural Approaches in Design Process

After choosing the proper shape and orientation for the building, architectural plan are drawn by attention to some of general characteristic of Iranian residential houses. These characteristic have socio-cultural roots and their origins back to 6000 years of Iranian architecture history. Iranian houses have been deigned in a modular, proportional, and functional manner and they were respectful to humanistic scales and inhabitants’ privacy. Two socio-cultural aspects of Iranian houses are taken into account for designing houses plan.

6.5.1 Modular System

A modular system of 1.2 m by 1.2 m has been chosen for building plans. 1.2 m is the minimum and the most efficient width for corridor, stairs, stairs landing, and Iranian toilets. Therefore, the modular system allowed to offset all spaces by multiplying them by 1.2 (Figures 6.10, 6.11, and 6.12). Moreover, living rooms and bedrooms designed by this modular system provided residents with suitable dimension to use their two most common Persian carpets i.e. 2 * 3 m and 3* 4 m in part of having enough spaces for closet and drawers. Persian carpets are a major factor of Iranian life and known as a precious symbol of Iranian culture.

6.5.2 Privacy, Security and Peace

The relation between building occupants and guests were important during the history of Iranian architecture. Privacy as a major factor of Iranian culture and religion played a crucial role in their houses. Privacy in Iranian architecture has been emerged in the shape of having the private, semi-private and public spaces.
In this way, attention to privacy was one of our major strategy, so spaces according to their function in serving owner or guests have been separated. Each unit is designed in a duplex way to locate private spaces like bedrooms or family living room on the upper floor and spaces like kitchen and living room that guests can take on the lower floor (Figure 6.13).
6.6 Passive Strategies in Design Process

There are adverse methods used by traditional architecture to improve energy efficiency in buildings, with the aim of decreasing heating and cooling loads of the building and consequently building energy-use. Some of these efficient methods and strategies employed by Iranian vernacular architecture in a hot and arid climate are already explained in section 2.2. In what the follows, traditional and passive strategies, which have been used in the design process of the proposed building, are described.

6.6.1 Courtyards and Ponds

One of the main and popular factor in residential buildings in Iran is courtyards. The courtyard provided security and privacy for the inhabitants, and daylight for the surrounding rooms. Having a pool in the middle and planting deciduous trees in the yard, a pleasant space has been created for the residents to spend a portion of their time during summer months. In fact, this system is a microclimate with few degrees lower air temperature and higher relative humidity in comparison to inner spaces. In order to have a most efficient performance of courtyards, their aspect ratio to enclosed spaces are critical.

Figure 6.13 Spaces arrangement regarding to privacy
2016) the different area assigned to courtyards and enclosed spaces for six selected Iranian houses are investigated. All the six houses have averages of 20 to 25% for area of courtyard to total house area. In the proposed building, the aspect ratio of courtyard is 25%. A close-up of the courtyard and its function at the complex has been shown in Figure 6.14.

![Diagram of courtyard and its functions](image)

**Figure 6.14 Courtyard as a microclimate modifier**

### 6.6.2 Shading Strategies

In hot climate, walls and particularly windows exposed to summer sun should be shaded by overhangs and shading devices. A study of the weather condition and the sun angles at various locations between 30° and 50° latitude indicates that a standard 76, 40 cm overhang (horizontal projection of 76 cm located 40 cm above the top of the window) will provide good sun control on south windows for the range of latitudes of Yazd (Lavafpour and Surat, 2011). So, a horizontal shading device was positioned in the south façade of the building in order to block sun gain in summer and maximize sun gain in winter (Figure 6.15). Windows on this side are designed widely with small height to perform well in winter when sun angle is low. Vertical shading devices are predicted for west and east side to block
undesirable sunlight (Figure 6.16). Windows on north head to ceiling in order to catch more sunlight in winter. Moreover, double pane high performance glazing (Low-E) are predicted on west, north, and east. For opening on the south clear pane can maximize passive solar gain.

![Shading strategy for windows on South](image)

**Figure 6.15** *Shading strategy for windows on South*

![Shading strategy for windows on west and east](image)

**Figure 6.16** *Shading strategy for windows on west and east*

### 6.6.3 Natural Ventilation

Pressure differences between inside and outside of the building will cause the flow of air. Temperature-induced pressure difference and wind-induced pressure differences are two common ventilation strategy cause air movement in the buildings. The pressure difference is a result of the temperature difference between the column of warm inside the building and the ambient temperature outside of the building as well as of the height of the column of the warm air (Passe and Battaglia, 2015). In order to utilize stack effect ventilation there two different strategies. The first one assumes homogenous temperature within the building and requires the interior temperature to be higher than outside temperature. The second strategy keeps the occupied zones within the buildings below the outside temperature, for example through nighttime ventilation, and relies solely on the buoyancy effect. Passe and Battaglia
(2015) in their book asserted that for a three story-building with a height of approximately ten meters, like our case, the difference between indoor and outdoor temperature should be about 23 °C or 10 pa. This temperature difference rarely occur in summer and thus most stack ventilation strategies need to be combined with wind pressure in order to operate at the required air exchange rate.

Wind-driven airflow over a building induces positive (inward acting) pressure on windward surfaces and negative (outward-acting) pressures on leeward surfaces; thus the building creates a pressure difference across the section that drives cross-ventilation. It occurs when inlet and outlet are positioned on opposite external walls of the building or space, with a clear flow path designed between them. Wind-induced cross–ventilation can also be combined with a local stack component. The depth of a ventilation path has to be limited to about five times the height of the room. A narrow plan building has been chosen which is very well adapted for natural ventilation (Figure 6.17 and 6.18). The maximum and minimum width of plans are 6.2 and 5 meters respectively which are both lower than 5 times ceiling height.

![Cross ventilation strategy used in the building.](image)

*Figure 6.17 Cross ventilation strategy used in the building.*
6.6.4 Material Color

One of the distinctive features chosen by the architect for a building is the exterior colors of the building’s envelope. When a color absorbs light, it turns the light into thermal energy (heat). An experimental study done by (Giovani, 1988) shows the external and internal surface temperatures of a horizontal roof with white and grey colors. The experiment was carried out in Haifa, Israel, which has hot-dry climate in summer. A dark roof can be 50°C hotter than the ambient air temperature while a white roof will be only about 10°C hotter.
In traditional houses of hot and dry climate windows’ glass were designed in different colors and ornaments in order to provide sufficient sun light and block the intense sunshine (Lavafpour and Surat, 2011).

### 6.6.5 Constructional Materials

One of the most important design considerations when conceptualizing an energy efficient building is its envelope. It is proven that keeping heat in or out of a building is one of the most cost-effective ways to save energy. Using materials with the poor heat conductivity and high thermal mass will reduce the heat flow through the building in hot-dry climates resulting in reducing energy cost inside the buildings. Thick and heavy walls made of construction materials with the poor thermal conduction provide thermal flywheel effect resulting of cool environment in summer and warm environment in winter (Lavafpour and Surat, 2011). Table 6.1 shows a range of thermal conductivities of some materials and it is
conceivable that concrete and bricks from the table are good choices for the proposed building as they are local materials as well. Wood is not chose because it is not local for Yazd.

Table 6.1 *Thermal Conductivity of materials, Source: (Guide. A, 2006)*

<table>
<thead>
<tr>
<th>Material</th>
<th>Thermal conductivity (W/Mk)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>214</td>
</tr>
<tr>
<td>Steel (carbon 1%)</td>
<td>43</td>
</tr>
<tr>
<td>Concrete, dense</td>
<td>1.3</td>
</tr>
<tr>
<td>Bricks</td>
<td>0.73</td>
</tr>
<tr>
<td>Water (20 °C)</td>
<td>0.60</td>
</tr>
<tr>
<td>Sand (Dry)</td>
<td>0.30</td>
</tr>
<tr>
<td>Wood (oak)</td>
<td>0.17</td>
</tr>
<tr>
<td>Glass fiber quilt</td>
<td>0.035</td>
</tr>
<tr>
<td>Air</td>
<td>0.024</td>
</tr>
</tbody>
</table>

6.7 **Proposed Architectural Drawings**

By considering all of the above mentioned techniques and strategies, in the following, schemes, drawings and renders of the proposed building are represented.
Figure 6.20 Proposed Ground Floor plan
Figure 6.21 Proposed Second floor plan
Figure 6.22 Proposed South-West elevation
Figure 6.23 Proposed South-East elevation
Figure 6.24 Proposed North-East elevation
Figure 6.25 Proposed North-West elevation
Figure 6.26 Proposed Courtyard North-East elevation
Figure 6.27 Proposed Courtyard South-West elevation
Figure 6.28 Proposed Passive Strategies, Section A-A
Figure 6.29 Proposed Passive Strategies, Section B-B
6.8 Proposed Master Plan

At the end of this section, a proposed master is illustrated in Figure 69. All the buildings are served with private parking, green and pedestrian buffers, public gathering, and semi-arid area for their inhabitants (courtyards).

Figure 6.30 Proposed Master Plan
CHAPTER 7. SIMULATION

7.1 Daylight Analysis

In order to simulate daylight performance of the proposed buildings and units DIVA for Rhino plugin was employed. DIVA for Rhino is a daylighting analysis tool using Radiance and DAYSIM as simulation engines for climate-based daylighting calculations. The plug-in was developed at Graduate School of Design at Harvard University, and it is now developed by Solemma LLC (2018). It performs hourly calculations based on input information, including location, weather data, material properties, and sky conditions. The metric which is used for the simulation is Spatial Daylight Autonomy (sDA), reporting a percentage of floor area that exceeds a specified amount of illuminance level which in this study is considered to be 300 lux, for more than 50% of occupied hours. Occupied hours have been defined from 8am to 6pm in this simulation.

In order to control the sunlight absorption of the building and to decrease energy loss through openings, Window to Wall ratio is predicted low in the building. WWRatio for South-West façade is 0.16, for North-West façade is 0.09, for North-East façade is 0.18, and for South-East façade is 0.07. This low WWRatio causes lower amount of daylight received by the spaces. Thus, one strategy has been used in the building is light shelf to intensify sunlight on the south face in particular. Light shelf is one of the passive systems for daylight controlling and is a horizontal plate made of light-colored and reflective materials that reflects daylight. It is placed above human eye level in the upper half of the window. It decreases the light severity near the window and increases the light penetration depth; distributes daylight more properly in space and also decreases glare by reflecting daylight to the ceiling and reflecting it into the space (Moazzeni and Ghiabaklou, 2016).
At the first step of daylight analysis, it has been proposed to test the impact of light shelf on day light autonomy for one unit. The positive impact of light shelf is proved by 2% improvement of total Daylight Area for the floor (Figure 69, 70, 71, and 72). In this way for other units, a light shelf by 2 feet width has been added on the south windows and then results were achieved. In what the follows results are shown for each separated units. The logo on the right below side of the figures show the location of the unit.

Figure 7.1 Daylight autonomy simulation without light shelf on the ground floor of unit located at South-West corner
Figure 7.2 Daylight autonomy simulation without light shelf on the first floor of unit located at South-West corner

Figure 7.3 Daylight autonomy simulation with light shelf on the ground floor of unit located at South-West corner
Figure 7.4 Daylight autonomy simulation with light shelf on the first floor of unit located at South-West corner

Figure 7.5 Daylight autonomy simulation on the Ground floor of unit located at South corner
Figure 7.6 Daylight autonomy simulation on the First floor of unit located at South corner

Figure 7.7 Daylight autonomy simulation on the Ground floor of unit located at South-East corner
Figure 7.8 *Daylight autonomy simulation on the First floor of unit located at South-East corner*

Figure 7.9 *Daylight autonomy simulation on the Ground floor of unit located at North corner*
Natural light is more pleasant in the building instead of artificial light resources. The building that benefits as much more as possible daylight will save more energy and electricity needed for lighting. Lower daylight autonomy of 71% (the worst case) and higher daylight autonomy of 85% (the best case) show highly enough amount of day light reach to each units and its sub spaces.
7.2 Natural Ventilation Simulation

In this stage, the performance of our two natural ventilation strategies i.e. cross ventilation and proposed chimney have been analyzed. In this way, MIT CoolVent (2018), the natural ventilation simulation tool has been employed. A similar sample of one unit from our building is created in CoolVent. The simulation for both strategies are done for 24 hours of a three-month period, the warmest months in Yazd, from June to August.

7.2.1 Chimney Type

Inputs for creation the model by chimney type and its results are shown in following figures.

![Figure 7.11 Main inputs for chimney type (Created using CoolVent)](image-url)
Figure 7.12 Chimney type and building dimension (Created using CoolVent)

Figure 7.13 CoolVent thermal comfort results for chimney type (Created using CoolVent)
The percent comfort of total number of occupied hours in chimney type for each zone (floor) according to Adaptive Comfort Model of 2010 ASHRAE Standard 55 are shown in Figure 7.13. The average of 32% comfort is predicted for all zones (floors). The sample of hourly results for thermal comfort are also shown in Appendix B.

### 7.2.2 Cross Ventilation Type

![Main input for cross ventilation type](Created using CoolVent)

Figure 7.14 Main input for cross ventilation type (Created using CoolVent)
Figure 7.15 Cross ventilation type and building dimension (Created using CoolVent)

Figure 7.16 CoolVent thermal comfort results for cross ventilation type (Created using CoolVent)
The percent comfort of total number of occupied hours in cross ventilation type for each zone (floor) according to Adaptive Comfort Model of 2010 ASHRAE Standard 55 are shown in Figure 88. The average of 22% comfort is predicted for all zones (floors). The sample of hourly results for thermal comfort are also shown in Appendix B.

7.3 Thermal Simulation

At this step, the heating, cooling, and lighting loads of the building are calculated by using eQUEST energy simulation software. eQUEST is built on DOE-2 simulation engine. First, the 3-D model of the building according to all drawings and strategies has been made in the software (Figure 89.)

Figure 7.17 Rendering of the proposed building in eQUEST
Then, the model was simulated by using inputs from Table 7.1. All the inputs are resulted from studies through the thesis and Standard for the Design of High-Performance Green Building.

Table 7.1 *Building's inputs in eQUEST energy simulation tool.*

<table>
<thead>
<tr>
<th>Building Area</th>
<th>16800 ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Building Envelope Construction</strong></td>
<td></td>
</tr>
<tr>
<td>Roof Surfaces</td>
<td>6 in. Concrete with 3 in. Polystyrene (R-12)</td>
</tr>
<tr>
<td>Above Grade Walls</td>
<td>6 in. HW Concrete with 3 in. Polystyrene (R-12)</td>
</tr>
<tr>
<td>Ground Floor</td>
<td>Earth Contact, 6 in. Concrete</td>
</tr>
<tr>
<td>Interior Finish</td>
<td>Carpet with fiber pad</td>
</tr>
<tr>
<td>Infiltration (Shell Tightness)</td>
<td>0.038 CFM/ft² (exterior wall area) and 0.001 CFM/ft² (floor area)</td>
</tr>
<tr>
<td>Windows types</td>
<td>North, East, and West: Double Low-E Clear ¼ in South: Single Clear 1/4in</td>
</tr>
<tr>
<td><strong>Loads and Profiles</strong></td>
<td></td>
</tr>
<tr>
<td>Interior Lighting</td>
<td>0.60 W/SqFt</td>
</tr>
<tr>
<td>Miscellaneous Loads and Profiles</td>
<td>0.30 W/SqFt</td>
</tr>
<tr>
<td><strong>HVAC system type</strong></td>
<td></td>
</tr>
<tr>
<td>Cooling Source</td>
<td>Evaporative Coolers</td>
</tr>
<tr>
<td>Heating Source</td>
<td>Furnace</td>
</tr>
<tr>
<td><strong>Seasonal Thermostat Setpoints</strong></td>
<td></td>
</tr>
<tr>
<td>Cool</td>
<td>Occupied: 77 °F  Unoccupied: 82 °F</td>
</tr>
<tr>
<td>Heat</td>
<td>Occupied: 71 °F  Unoccupied: 65 °F</td>
</tr>
</tbody>
</table>
Figure 7.18 Yearly result of the building energy consumption from eQUEST
CHAPTER 8. RESULTS AND DISCUSSION

The model provided input into eQUEST to simulate the energy-use performance of the building. Simulations were performed assuming typical meteorological year (TMY) conditions using the TMY data set for the city of Yazd, which has been converted to DOE-2 (bin) format to be used by eQUEST. Building’s envelope construction used for the simulation are mainly assumed with the aim of providing the convinient insulating material resistance (R-value).

The preliminary results for energy-use performance of the proposed building indicate a great amount of saving for annual cooling, heating, and lighting energy consumption compared to the total amount of annual energy consumption. The building’s annual energy consumption is 147580 kWh while energy consumption for heating, cooling, and lighting are approximately 4% (5420 kWh), 3% (3800 kWh), and 23% (34270 kWh) of the total amount respectively. In short, energy-use for all other sectors are mentioned in Table 8.1.

Table 8.1 Energy consumption by all the sectors at the proposed building.

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>Heating (kWh x000)</th>
<th>Cooling (kWh x000)</th>
<th>Lighting (kWh x000)</th>
<th>Misc. Equip. (kWh x000)</th>
<th>Vent. Fans (kWh x000)</th>
<th>Total (kWh x000)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly</td>
<td>5.42</td>
<td>3.8</td>
<td>34.27</td>
<td>85.68</td>
<td>18.41</td>
<td>147.58</td>
</tr>
</tbody>
</table>

Moreover, the building is energy self-sufficient for heating and cooling during six months of a year. An active HVAC system for cooling is needed just for three warmest months from June to August. Active HVAC system for heating operation is needed for three coolest months, December to January. In the current model, the biggest part of energy consumption is due to miscellaneous equipment, which is not utilized by an exact operation
schedule-use. It is important to note that in order to achieve the more accurate results for total energy consumption of the building a more investigated schedule-use for miscellaneous and other energy use sectors will be necessary.

CHAPTER 9. CONCLUSION

It is possible to conserve great amounts of energy in a building only by optimization and employing passive strategies in architectural design. The proposed residential building with eight housing units was designed with consideration of socio-cultural factors and traditional passive strategies found in the city of Yazd, Iran. From the study of climate, a hot and arid climate with hot summers and moderately cold winters was recognized. With the aim of minimizing the energy-use of the building, climatic responsive design and environmentally friendly approaches were required. The concept of passive design was employed in order to decrease the heating, cooling and lighting demands of the building and meet the inhabitant’s comfort based on Adaptive Comfort Model in ASHRAE Standard 55-2010 for the city and occupants. Strategies used in this thesis, such as optimizing natural ventilation by chimney and cross ventilation, daylights with using a narrow plan design, orientation, shape, and suitable material chosen are mainly inherited from traditional and vernacular architecture. As a result, the proposed building shows great promise for lowering energy-use by three major sectors i.e. heating, cooling, and lighting.

Although the preliminary results from this thesis can be improved by adding exact and refined schedule-use for energy consumption sectors, strategies of energy conservation and energy efficiency can be applied to all residential buildings in hot and arid climate of Iran and worldwide.
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APPENDIX A: CLIMATIC DATA OF YAZD, IRAN

**GROUND TEMPERATURE (MONTHLY AVERAGE)**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Yazd, IRN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude/Longitude:</td>
<td>31° 46' North, 54° 26' East. Time Zone from Greenwich: 3h</td>
</tr>
<tr>
<td>Data Source:</td>
<td>ITN</td>
</tr>
</tbody>
</table>

**LEGEND**

- DEPTH (meters): 1.5
- 0.5
- 2.0
- 3.0
- 4.0
- (Surface in bold)

**TEMPERATURE RANGE:**

- -13 to 47°C
-_FL_Iso

Figure A-1 *Ground temperature (monthly average) for Yazd (Source: Climate Consultant software)*

**RADIATION RANGE**

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>Yazd, IRN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude/Longitude:</td>
<td>31° 46' North, 54° 26' East. Time Zone from Greenwich: 3h</td>
</tr>
<tr>
<td>Data Source:</td>
<td>ITN</td>
</tr>
</tbody>
</table>

**LEGEND**

- HOURLY AVERAGES DAYLIT HOURS ONLY
  - RECORDED HIGH: ●
  - AVERAGE HIGH: ●
  - AVERAGE LOW: ●
  - RECORDED LOW: ●
  - DIRECT NORMAL:
  - GLOBAL HORIZONTAL:
  - TOTAL SURFACE:
  - THEORETICAL:

**Tilted Surface Radiation Input:**

- 0.0: Tilt degree from Horizontal (Vertical = 90°)
- 0.0: Bearing degrees from South (South = 0°, East = 90°)
- 10.0: % Ground Reflectance (20% = grass)
- 50%

**Plot:**

- Hourly Avg. Daily Total

Figure 0-2 *Radiation range for Yazd (Source: Climate Consultant software)*
Figure A-3 Sun shading chart for Yazd (Source: Climate Consultant software)

Figure A-4 3-D chart of dry bulb temperature for Yazd (Source: Climate Consultant software)
APPENDIX B: HOURLY RESULT FOR NATURAL VENTILATION STRATEGIES

Figure B-1  Simulation results for a random day of June 14 at 7.30 AM with chimney strategy

Figure B-2  Simulation results for a random day of June 14 at 12.30 PM with chimney strategy
Figure B-3 Simulation results for a random day of June 29 at 7.30 PM with cross ventilation strategy

Figure B-4 Simulation results for a random day of June 29 at 12.30 PM with cross ventilation Strategy