THERMAL PERFORMANCE OF ARCHITECTURAL FEATURES IN TRADITIONAL PERSIAN DWELLINGS

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To...

My parents for their unconditional love

&

Shahraam for his endless support

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ABSTRACT

Since non-renewable sources of energy are being greatly depleted, energy consumption in residential buildings should be more frequently considered. The climatic design of traditional Persian dwellings sheds light on the potential of traditional architecture for natural solutions to provide residents with thermal comfort with no dependency on technology and non-renewable energy sources. Although traditional architectural features cannot be included in contemporary architecture because of the changes in lifestyle and technology, there are many principles that can be applied in modern dwellings.

In this study, principles of thermally efficient architectural features in traditional Persian architecture are investigated by focusing on a hot and arid climate. After general explanation and analysis of various thermally efficient methods and techniques in this kind of climate, the thermal performance of wind catchers and central courtyards as the most efficient means is carefully examined through numeric calculation and experiential analysis in two case studies. The focus of the study is on the traditional dwellings in the city of Yazd, a historical city in the heart of Iran's central desert. After the evaluation of the efficiency of these traditional features, their potential to be adapted to contemporary architecture is analyzed. Consequently, some applicable changes and alterations are included as proposed ideas through computational modelling and graphic analysis of their plans and photographs.

At the end, calculations and analysis of thermal performance of wind catcher and central courtyard in traditional Persian dwellings shows them as capable features to adapt to contemporary buildings with modification in their details and orientation. A sketch plan of a contemporary single-family dwelling is designed based on traditional thermal efficient principles to show applicable changes of these traditional features for modern living style.

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CHAPTER I

INTRODUCTION

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INTRODUCTION

1.1 RATIONALE OF THE STUDY

1.1.1 Energy Conservation

Nowadays, people are increasingly cognizant of the negative environmental impact of using fossil energy sources, such as petroleum, in their day-to-day lives. Individuals and companies alike have taken additional steps to employ renewable energy sources, including solar, wind, and, geothermal sources. According to the Iranian Fuel Conservation Company (IFCO), 70% of energy in Iran's residential distribution is used for heat, 23% for hot water and 7% for cooking (Ghobadian 2). These statistics shed light on the necessity of finding thermally efficient solutions in design and construction of buildings, especially residential ones.

Reviewing traditional living spaces in Iran indicates that it was due to the clever architecture of the buildings that residents were able to tolerate difficult climatic environments, such as the hot and arid climate in central Iran. Thus, thermal comfort without complete dependency on technology in Persian traditional buildings shows that relying on natural resources and taking advantage of traditional local architecture not only reduce energy consumption in temperature control, but also provide sustainable means of lowering other costs, such as construction and maintenance.

Although contemporary changes in lifestyle prevent architects from employing traditional architectural features and methods as they were used in the past, there is still much to be learned from traditional architecture, its features and its materials. Traditional architecture can thus be adapted to contemporary lifestyle requirements and applied in contemporary buildings to create thermal comfort for residents with less energy and cost.

The subject of thermal efficiency and climatic design inspired by traditional architecture has been addressed in the work of well-known architects such as Nader Khalili (1936-2008), an Iranian architect who founded the California Institute of Art and Architecture. He proposed building shelters for the world’s homeless and then improved his theory to produce sustainable homes based on the concept of traditional Iranian building. His proposal for building on moon was presented to NASA in 1984.

Another architect, Hassan Fathi (1900-1989), is an Egyptian architect who utilized ancient design methods and materials. He integrated his knowledge of the rural Egyptian economic situation with a wide knowledge of ancient architectural and town design techniques. He trained local inhabitants to make their own materials and build their own buildings (http://archnet.org).

Vahid Ghobadian has also done significant research on the traditional architecture of Iran, focusing on climatic design principles in his book *Climatic Analysis of Traditional Iranian Buildings* (2005). The common denominator in such buildings is the attempt to achieve affordability and sustainability by reducing the amount of energy consumption (Figure 1.1).

The main attempt of these research studies is to reduce personal and environmental costs, including construction costs and living expenses for residents, to achieve more affordable and sustainable architecture. According to the research on adapting traditional principles to contemporary lifestyles, the potential for applying thermal efficient methods in order to reduce energy consumption in residential buildings should be studied.

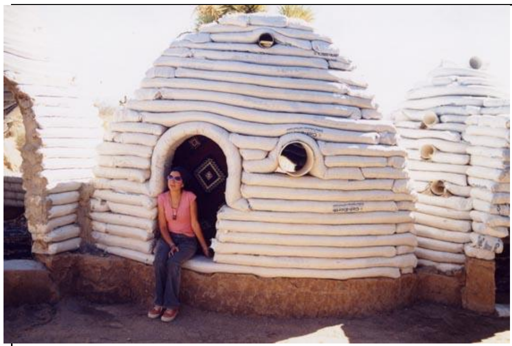
	**Eco Dome "Moon Cocoon"** This building is located in the Californian desert, on the site of the Calearth Institute, where architect Nadr Khalili has become the champion of sustainable development.
	**Mit Rehan**, A neo-traditional house in Cairo, Egypt, by architect Hassan Fathy was completed in 1981.

Figure 1.1: Traditional Based Climatic Design by Pioneer architects, Nader Khalili and Hassan Fat'hi. (Sources: http://calearth.org, http://arch.ced.berkeley.edu)

1.1.2 Disappearance of Traditional Local Architecture

Under the Qajar dynasty in Iran (nineteenth to mid-twentieth centuries), the commencement of innovations in the transportation industry, along with traveling to European countries and other parts of the world, became commonplace among the upper social class. Upon returning from their journeys outside Iran, these travelers brought photographs of Western buildings and tried to build their houses to resemble them. Consequently, European-style buildings became the symbol of prosperity for Iranian people.

This imitation took place only in the formal aspects of the architecture, and architects mostly started copying forms without understanding the philosophy behind them. Thus, importing new materials became necessary, as Iranian traditional materials, primarily mud brick and clay, were not suitable for constructing those new forms. However, imported materials were not adaptively suited to Iran's climate, which differs from Europe's. As a result, the imported architecture failed to provide the residents with suitable thermal comfort in buildings because it ignored local materials and architectural styles. To resolve the new buildings' climatic issues, constructors applied technology to bring desirable situations into the residential space (Ghobadian 11).

Technology dependency for creating thermal comfort in buildings not only increased construction costs, but it also affected the environment due to pollution and recycling problems with materials and other construction elements – such as electronic heating and cooling systems. Consequently, sustainability disappeared in Iranian architecture, and contemporary architecture lost its local identity.

Looking back to the climatic principles of traditional Persian architecture and their feasibility for adaptation to contemporary lifestyles helps architects to build sustainable residential buildings. In this research work, the main concern is to study local methods and strategies for applying natural energies to heat and cool residential dwellings in the central desert of Iran with its hot, arid climate.

Lack of rain and humidity, temperature fluctuation between day and night, and severe winds containing dust and sand are of major climatic problems in this region. To provide residents with thermal comfort in the hot and arid summers, various strategies have been applied in traditional dwellings, for example, windcatchers, central courtyards and seasonal divisions (Figure 1.2).

Figure 1.2: Examples of thermally efficient features such as wind catcher and central courtyard and strategies such as inner-directed arrangement in traditional Persian Dwellings.

1.2 RESEARCH QUESTION

The primary research question of this study is:

Which architectural features and construction methods of traditional dwellings can be adapted to improve the thermal efficiency of contemporary residential buildings in central Iran?

The study of this main question will lead to these sub-questions:

- Which traditional architectural features have better thermal performance?
- Why are traditional methods no longer included in architecture?
- What adaptations can be applied in contemporary buildings?

1.3 GOALS AND OBJECTIVES

The goal of this study is to find solutions that can improve the thermal efficiency of contemporary Iranian residential buildings by investigating tried-and-true traditional methods of architecture. The chief objective is to study the potential of traditional thermally efficient methods and combine them with the advantages of contemporary technology to improve climatic situations in residential spaces.

In order to achieve suitable climatic conditions in houses with less energy consumption, performance of thermally efficient architectural features in houses, their structure, function, effects on other spaces in the building, and advantages and disadvantages will be investigated. In addition, changes in lifestyle and the results of them on living spaces will be studied to find necessary changes and adaptations to traditional methods to increase their effect and make them applicable in contemporary living spaces.

Since contemporary architecture – for the most part – fails to supply residents with thermal comfort under the tough climatic conditions of the hot and arid areas of Iran, climatic design principles which were applied in traditional architecture will be investigated in this research so that they can be developed and used to bring thermal comfort with less dependency on technology and non-renewable sources of energy.

1.4 METHODOLOGY

This research study includes three main parts. First, thermally efficient architectural features in Persian traditional architecture are analyzed according to three categories: materials, techniques and architectural elements. This part concentrates on the architecture of the hot and arid area in Yazd, a city located some 120 km south-east of Isfahan (Figure 1.3). Each category is explained and reviewed. The focus here is to evaluate the efficiency of each feature and its adaptability to contemporary lifestyles and technology. Archival documentation is the main database in this step. Data from books, research studies, articles and papers has been collected and analyzed.

The next part of the study focuses on the most feasible features in terms of thermal efficiency and the ability to develop and apply them in new architecture. In this part, the function of the selected features is investigated in two case studies and in two phases. First, by numerical analysis, the efficiency of these features is studied and, next, the typology, structure and orientation of them in the building are explained. For the numerical analysis, as a result of visiting the case studies, some experiential information has been included. The thermal conditions have been recorded and analyzed. For the next section, photographs, plans and other graphic documentation are included.

Finally, the last part of this research work is a diagnostic review in which the architectural elements studied, available solutions and possible developments of these features will be scrutinized through computational modeling and diagrammatical analysis. These ideas will be presented as a proposal to be applied for improving traditional thermally efficient methods in contemporary architecture.

Figure 1.3: Location of the city of Yazd, Iran

1.5 SCOPE

This research work focuses on thermally efficient strategies in the traditional architecture of central Iran to take advantage of natural sources of energy in building construction. Climatic issues, such as wind and light, play important roles in the conditions of interior living spaces. By focusing on the function of wind catchers and central courtyards, which are among the most thermally efficient elements in the traditional architecture of Iran, in the city of Yazd, the possibilities of taking advantage of the wind as a natural source of energy and the effects of a central courtyard as a green space in a hot and arid climate are evaluated.

One way to achieve sustainable and affordable buildings is to reduce dependency on energy consuming features in architecture (Tahbaz 4). This research work studies how contemporary buildings can rely more on natural energy sources to maintain climatically comfortable living spaces. The thermal performance of wind catchers and central courtyards in traditional buildings are analyzed, and possible changes are assessed to improve their performance in contemporary architecture.

To strengthen the application of naturally based thermally efficient features in contemporary architecture, this study outlines the principles of climatic design, focusing on a hot and arid climate. It also outlines what could be done to develop traditional thermally efficient methods through the use of wind catchers and central courtyards.

1.6 INTENDED AUDIENCE

Climatic design with respect to local architecture in the hot and arid areas of Iran helps architects achieve sustainability in contemporary architecture. Traditional local architecture includes the most efficient methods for dealing with climatic conditions that have been developed over time. However, changes in technology, lifestyle and, as a result, the demands of users prevent architects from returning to traditional architectural methods. Thus, designers and architectural researchers should study traditional architecture to create new climatic designs based on the valuable potential of traditional local architectural design.

To expand affordable housing, climatic design should be considered in building codes for designers, constructors and house developers. To provide residents, especially middle-class home owners, with a comfortable living situation, this architectural research attempts to provide practical strategies for applying the compatible thermally efficient strategies of traditional Persian architecture to contemporary buildings. Hence, this research can help Building Engineering Organization legislators of building codes to encourage architects to consider more carefully environmental and climatic issues in the design of residential dwellings in Iran.

1.7 OUTLINE

Chapter 1: Introduction.

In this Chapter, the significance of the subject matter is explained. A brief definition of the topic is included as well. The main points and structure of the study are outlined and the methodology is specified.

Chapter 2: Literature review.

An analysis of various thermally efficient features and techniques in the traditional architecture of Iran is given in this chapter. This analysis includes structure, function, orientation and effects on designing areas related to the features. The thermally efficient features in traditional Persian architecture are explained in three categories: materials, architectural elements and construction techniques.

Chapter 3: Case studies.

In this chapter, first, a brief history and typology of wind catchers as one of the most thermally efficient features in traditional Persian architecture is given. After explaining the general function, typology and orientation of them, their performance and effect on other parts of the building in design and lifestyle are analyzed through a case study.

In this case study, the function of a traditional wind catcher in Lariha's house in the city of Yazd in the hot and arid area of central Iran is studied. By using climatic information and calculations, the efficiency of the specific type of wind catcher in Lariha's house is evaluated in diagrams. This evaluation is done to find the potential for adaptation to contemporary architecture.

The second part of this chapter is dedicated to the thermal performance of central courtyards. This part includes, first, the general function and typology of courtyards in traditional

Persian houses. Then, the performance of the central courtyard in Rasoulian's house (which is now the School of Architecture at Yazd University) is investigated and analyzed.

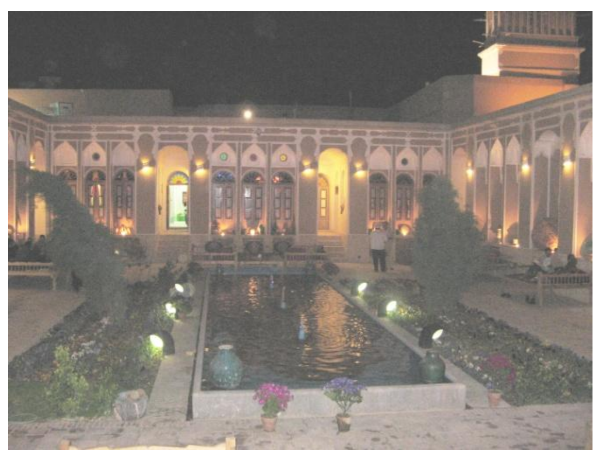
Chapter 4: Discussion and conclusion

Following the study of the traditional windcatchers and central courtyard in the climatic conditions of the city of Yazd, this chapter will propose ideas and techniques to eliminate some problems of using traditional windcatchers in contemporary buildings. These ideas are presented as conceptual models which can be developed, examined, and applied to contemporary buildings in order to increase the use of sustainable architectural features.

Finally, this report concludes with an assessment of the possibilities for adaptation of traditional thermally efficient features to achieve sustainable climatic design. In the last part of this chapter, the potential for future research in the field for affordable housing is noted.

CHAPTER II

LITERATURE REVIEW



CHAPTER II

LITERATURE REVIEW

2.1 INTRODUCTION

One of the most important features of traditional Persian architecture is its adaptability to climatic conditions. With no modern technology, it was only through clever manipulation of architecture that created comfortable living spaces in intolerable climatic circumstances. Today, it is necessary to concentrate on the architecture of traditional buildings to learn from already experienced climatic solutions which have been the most sustainable and affordable ones that can be used to confront climatic issues in contemporary architecture.

In this chapter, the concentration is on analyzing the methods and materials used in the traditional architecture of the central part of Iran with its hot and arid climate. First, various thermal efficient methods, elements, and materials will be presented with an analysis of their structure, function, required materials, and construction methods.

From the analysis of the climatic features of traditional architecture, the most thermally efficient and applicable ones will be selected to concentrate on in the following chapters in order to evaluate their efficiency and potential applications to contemporary buildings.

To investigate the architecture of residential buildings in the above-mentioned circumstances, *Persian Residential Architecture* by Gholamhossein Memarian (2006) is the first resource. It includes a typological analysis of houses in the central part of Iran, including their special spaces and characteristics. In addition, *Architecture of Iran: A Study of traditional* *materials* by Hossein Zomarshidi (1998) will be drawn on for the characteristics of traditional materials, their application, and required methods. Furthermore, *Climatic Analysis of Traditional Iranian Buildings* by Vahid Ghobadian (2005) is useful for investigating specific climatic elements in the traditional architecture of Iran, how the buildings were built, and how they worked to overcome climatic problems.

2.2 CLIMATIC CONDITIONS

The central plateau of Iran is a blistering and arid area with barren lands "including 15% of the entire country" (Gobadian 124). Characteristics of this particular climate include hot and dry summers along with cold and arid winters, low amounts of rainfall, low humidity, low vegetation density, thermal fluctuation between day and night time, and heavy, gritty sandstorms.

Under these tough climatic conditions, making a suitable shelter for living is complicated and gives rise to a number of concerns. Overcoming natural conditions such as winds, stark sun light, and water shortages, as well as the rare availability of wood, is the major concern for architecture in these areas. However, experienced traditional architects have found reasonable and pleasing solutions both on the urban scale and in residual architecture. These solutions comprise techniques, materials and architectural features.

2.3 ARCHITECTURAL CHARACTERISTICS OF HOUSES IN THE CENTRAL PART OF IRAN

Before proceeding with an analysis of the climatic features of traditional houses in the hot, arid part of Iran, it is necessary to describe the residential buildings in this area and their typology.

Houses, in traditional Persian architecture, were built based on distinct patterns and principles, which were the same for almost all houses, whatever their size and cost. These principles were rooted in cultural, climatic and structural conditions. The first and most basic characteristic of these houses was their inner-directed arrangement. This configuration was, firstly, a cultural issue, because in traditional Persian culture, the private and social lives of families were completely separated. As a result, gatherings and hosting had an important role in families' lives; but they did not want guests and other visitors to intrude into their private lives (Memarian 132). Secondly, due to undesirable climatic conditions, all open spaces were located in the central part of the building to create a manmade natural open space for family use only (Figure 2.1).

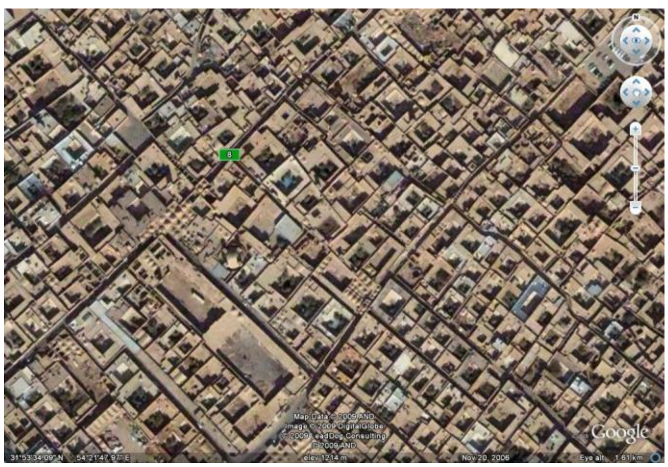


Figure 2.1: Arrangement of houses in central part of Iran, Yazd (Source: Google Earth)

Another important element in the traditional Persian lifestyle was multi-generational living. In this regard, the sons used to move into a separate room in their parents' house after marriage. Thus, grandparents with their children and grandchildren lived together in one house with private rooms and shared areas such as the kitchen, bathrooms, dining rooms and other gathering spaces (Memarian 141).

According to these general aspects of lifestyle, and depending upon the financial circumstances of the residents, there were certain common spaces in all traditional houses. First, a large traditional house with dimensions of 48 by 48 meters included an entrance and private and semi-private spaces (Memarian 240). The semi-private part included a large living and dining room for guests, which was called the five-door room, or *Panj-dari*[1], because its size was based on traditional Persian modules, and a courtyard (Memarian 242). Apart from it, the private space included a private courtyard, Around this private courtyard, were a small living room, which was called three-door room or *Seh-dari*[2], for private guests and women, a large family room, which was called *Taalaar*, for summer time, and another one called Tehrani for winter time. As well, there were bathrooms, kitchens, prayer rooms, and small areas for servants, storage and other service areas. These service areas, especially the kitchen, were located in a place between the private and the semi-private parts in order to serve all the residents. Finally, most of the houses in central part of Iran had basements for living space because of the climatic circumstances (Memarian 245-255) (Figure 2.2).

[1] Panjdari: traditional Persian dwellings are modular. In these houses doors are used as module and 5-door rooms are large living rooms called Panjdari.

[2] Sedari: Smaller size living room or 3-door room.

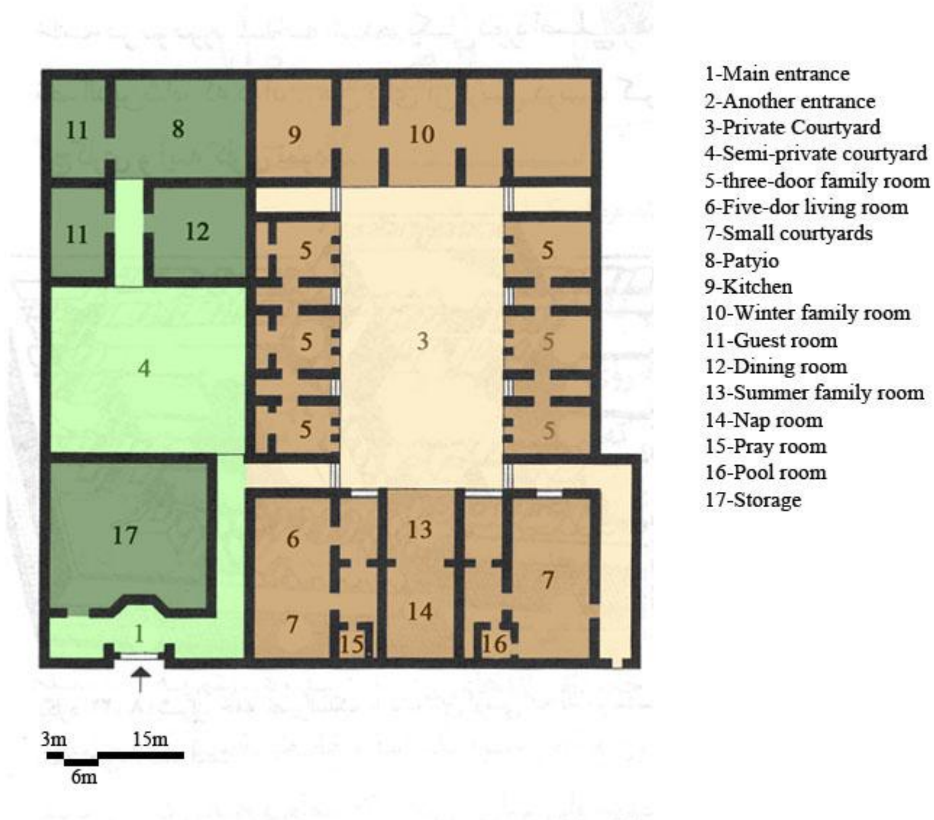


Figure 2.2: Spaces of a large traditional Persian house (Source: After Persian Residential Architecture 246, Memarian, 2006)

In addition to the large houses for large and wealthy families, another type with a smaller module of 32 by 32 meters provided smaller families with affordable and comfortable living spaces (Memarian 262). These houses contained practically the same spaces, although they were smaller in size and number but had the same arrangement and configuration. As a case in point, the three-door living rooms in large houses were changed into five-door living rooms for smaller ones. Moreover, there is a difference in the entrance, which separate entrances for the private and semi-private parts in small types of houses in order to reduce the area of corridors (Memarian 264-268)(Figure 2.3).

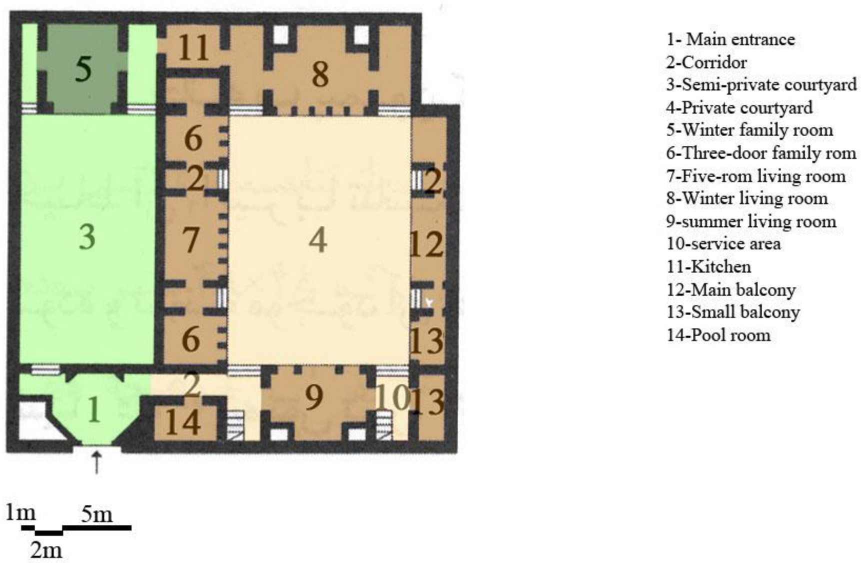


Figure 2.3: Spaces of a small traditional Persian house (Source: After Persian Residential Architecture 266, Memarian, 2006)

In traditional houses, in addition to the proper orientation of the house and special configuration of the mentioned areas, all major spaces had to be supplied with specific architectural elements or techniques to provide their residents with desirable climatic conditions. The following are some of these features and their impact on the thermal performance of the building under harsh climatic conditions.

2.4 THERMALLY EFFICIENT TECHNIQUES IN RESIDENTIAL BUILDINGS

All buildings in the hot and arid area of Iran are completely enclosed and covered (Ghobadian 125), which means, there are no openings except their entrance. This covered envelope helps residents to be protected against severe winds containing sand and dust. As well, there is no reason to have visual connection with exterior spaces since the latter have nothing to attract the residents; there are no green areas or visually pleasant sights. On the other hand, houses have a central courtyard and green areas inside the property, and all the living spaces are shaped around the courtyard.

Moreover, all the houses are built on a level below that of the street and have high and thick walls (Memarian 145). The reason for constructing on the lower level is to take advantage of the thermal capacity of the soil under the high thermal fluctuations in extreme temperature conditions. Furthermore, the walls are higher than regular ones to increase the interior volume and to collect hot air at a level higher than the living area. Also, with openings under ceilings or domes, this hot air can easily be conducted out (Figure 2.4). The roofs of these buildings are mostly dome-shaped or vaults for three major reasons: first, to accommodate the wind flows over the city and not to create whirlwinds in between buildings. In addition, this technique reduces the erosion of the materials and increases the lifetime of the structure. Second, as mentioned above, the technique helps to circulate the interior air. Finally, in summer, the sun’s rays are approximately vertical on flat surfaces but on domes and vaults, they shine at an angle and, because of their shape, some part of the roof is always in the shadow. As a result, heat absorption is decreased.

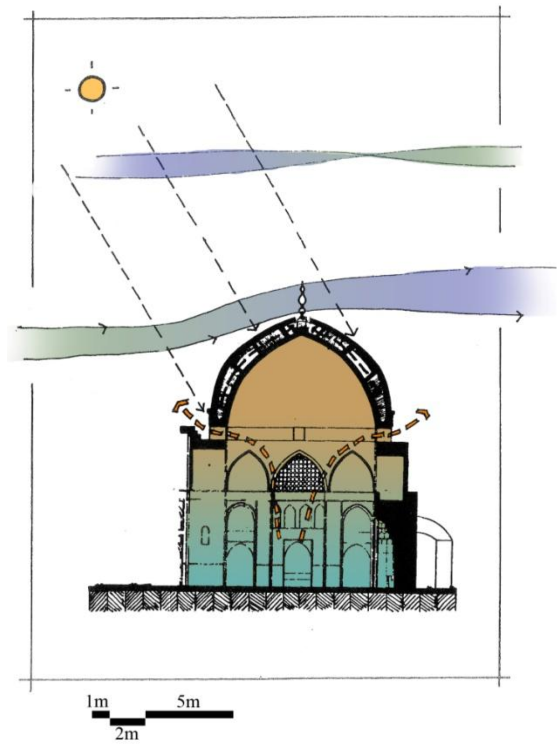


Figure 2.4: Function of a dome shaped roof (Source: After Climatic Analysis of Iranian Traditional Buildings 38, Ghobadian, 2005)

Another formal characteristic of traditional houses is separating winter and summer living areas (Memarian 153). Since all the spaces are located around a courtyard, the northern spaces, which catch winter sunshine inside the rooms, are used as winter living rooms and for day-time activities. This winter part includes 3-door rooms (family room), 5-door rooms (living room), fireplace rooms and upper level bedrooms (Memarian 155). Conversely, the southern parts, which are shaded in summer, feature other climatic facilities (to be explained) that bring thermal comfort to the residents. The summer part includes a large basement and a high living room for guests and the Tanabi, which is a small bedroom for day-time relaxation, between the large living room and the wind catcher room (Memarian 157) (Figure 2.5).

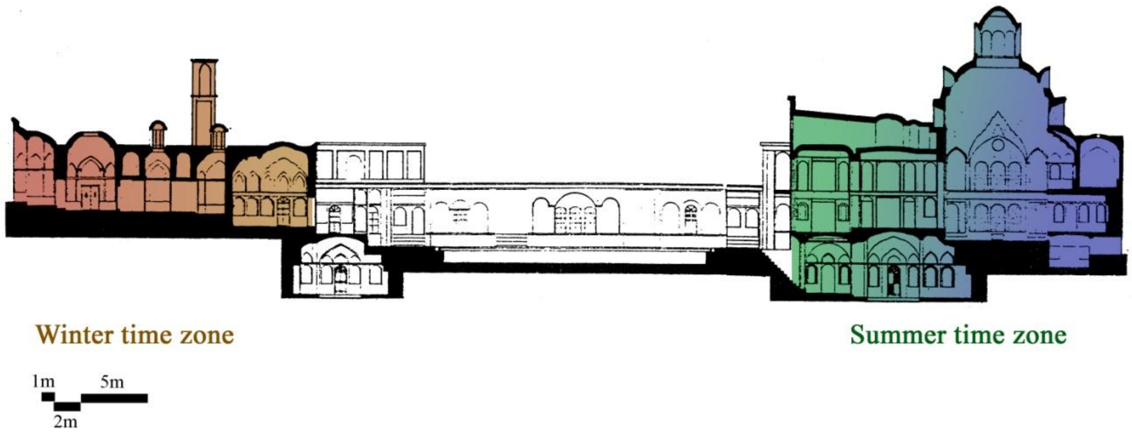


Figure 2.5: Seasonal separation of living spaces in a house (Source: After Architecture of Iran 210, Pirnia, 2008)

The other spaces of a house, including the service areas, such as the Hashti (the entrance space which separates access to the private and semi-private spaces of the house), the kitchen, bathrooms, storage room and other spaces are located in the eastern and western parts of a house.

2.5 BUILDING MATERIALS IN TRADITIONAL HOUSES IN A HOT AND ARID CLIMATE

Due to the climatic circumstances in a hot and arid climate with shortages of water, wood and stone, which are available mostly in mountainous areas or regions near rivers, the most common material in the traditional architecture of Iran in this kind of climate is mud brick or adobe. This material is suitable because of its accessibility, affordability, and durability under tough climatic conditions and its adaptability to climatic issues.

Building with adobe and mud brick dates back in Iran to 6200-5800 B.C.E. (Zomarshidi 23). Usage of this material has a climatic, technical and functional basis. No other material could resist the extreme sunshine and heat of the desert. Moreover, it is practical and does not need sophisticated construction techniques, although it is applicable to required construction techniques such as covering the building. And finally, the combination of this material with clay plaster makes for a congenial and resilient outcome (Zomarshidi 31).

The soil from grading for foundations is used to make mud brick. At first, builders formed bricks from clay and dried them under the sun's heat. Later, they used wooden moulds to shape the clay. Mud bricks contain 20%-30% gravel and 70%-80% clay plus water and some straw to increase their resilience (Ghobadian 142). The thermal capacity of such bricks and also of the improved version of them, that is baked bricks or industrially produced bricks, is advantageous for confronting high temperature fluctuations and also the differences between indoor and outdoor temperatures.

Moreover, mud bricks are used not only in the structure of buildings but also for pavements and other spaces, such as porches. As an example, by comparing a newly built building with mosaic tiles and metal banisters in this climate with a traditional one with brick pavement and wooden banisters, one can clearly see the major differences concerning climatic comfort in spaces with the same function (Ghobadian 145).

In addition to mud bricks for the main structure of the buildings, various other materials have been used for specific functions. As a case in point, wood is the most suitable material for covering openings such as doors and the frame of windows and also for banisters (Memarian 165). The thermal capacity of wood is suitable for the climate, and it can be easily shaped, recycled, and fitted to many places.

2.6 THERMALLY EFFICIENT ARCHITECTURAL FEATURES

Besides materials and techniques that have been used in traditional buildings in the hot and arid areas of Iran, there are some specific architectural elements which provide the interiors of these buildings with desirable conditions even when the outside weather is hardly bearable.

2.6.1 Basement

The most important space of a house on a torrid summer day in this climate is its basement. The basement is located below the main floor and can be accessed by the stairs from the courtyard. In some basements, the different spaces are connected via corridors while in others they are separate and have access only from the courtyard (Memarian 166) (Figure 2.6).

Figure 2.6: Sample of cool basement in hot summers (Source: After Persian Residential Architecture 164, Memarian, 2006)

For the most part, basements have natural lighting through sky lights or openings on the plinths of walls (Memarian 168). These openings provide natural light and ventilation into the space. Moreover, most of these basements have access to natural underground water resources; and as a result, they are not only a place of thermal comfort in the summer, but also act as a cooling and purifying system for the courtyards and other spaces in the house (Ghobadian 135).

2.6.2 Khishkhan

In addition to basement there is another cooling element which has been in use for thousands of years in Iran and is called *Khishkhan* (Ghobadian 144). "Other countries took it, developed it and invented electrical coolers based on its structure" (qtd. in Pirnia 146). Khishkhan is a kind of small hut covered by a mat. By wetting the mat in summer, cool air can come in along with wind.

In hot and arid climate, on top of the building there is a pore and a dome. Several small holes are drilled in this pore. Thus, natural light and air can come into the building (Ghobadian 145-146) (Figure2.7). Usually, a Khishkhan is built on top of the *Howzkhaneh*, the place in basement with a small cool water pool, to intensify the effect of its cooling system. It can create a liveable space by bringing in fresh air and natural light into it. In some places, this comfortable living space served as a meeting room or evening gathering place on hot summer evenings (Memarian 148).

Figure 2.7: View of Khishkhans from the roof top, Yazd, Iran

2.6.3 Shade and Tabeshband

To avoid scorching summer sun light, there are several techniques to lessen the heat and create shade in interior spaces. One of them is to build a 6cm to 15cm-thick border around the windows and openings. Vertical shades made from brick or gypsum in 60cm to 70cm widths and located between two openings can prevent sunlight from penetrating into a room (Memarian 133) (Figure 2.8).

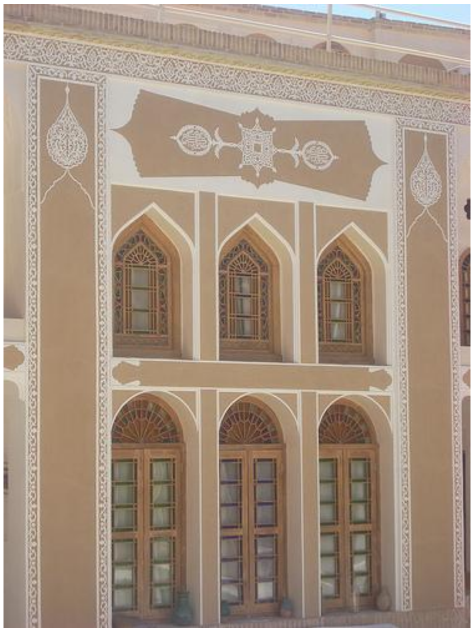


Figure 2.8: Tabeshband around windows (Source: Mahoor.org/images)

In addition to this element, another feature to reduce the sun's heat in summer was to use colourful glass to cover windows and openings (Memarian 134). This way, people took advantage of the natural light but with less heat inside the room. Moreover, to cover windows, they did not use large panes of glass. Instead, small wooden frames for windows were designed to reduce the amount of glass used in order to lessen the heat transmission through the window (Memarian 136) (Figure 2.9).

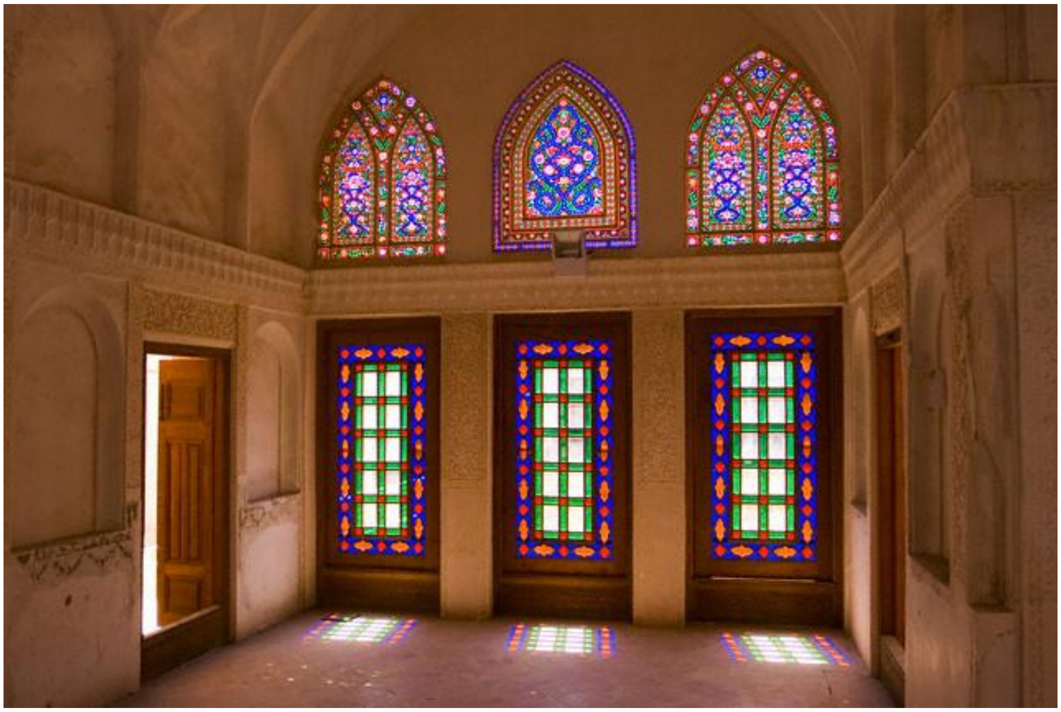


Figure 2.9: Filtering sunlight by covering openings with colourful glass (Source: http://twip.org/photo)

2.6.4 Wind Catchers

According to the direction of the desired wind in each region, there are various forms of wind catchers to lead the desired wind into the building and, simultaneously, to prevent undesirable wind from entering the building (Figure 2.10). Most of them are built in a cubic shape, but in some regions there are octagonal wind catchers (Pirnia 283).

Figure 2.10: Wind catcher of Dowlat Abad, Yazd (Source: http://www.gardenvisit.com/assets/madge)

The number of openings a wind catcher has depends on the direction of the desired wind. In sweltering parts of Iran, because of the north-eastern summer wind, wind catchers are built facing north east, and their openings are only on this side. However, a few double-sided wind catchers are also built in this climate. One side acts as the wind catcher and the other as a circulator (Pirnia 279-281) (Figure 2.11). Their efficiency is based on their scale. Bigger wind catchers are more efficient than smaller ones, but the shape and the height are related to the climate (Ghobadian 131).

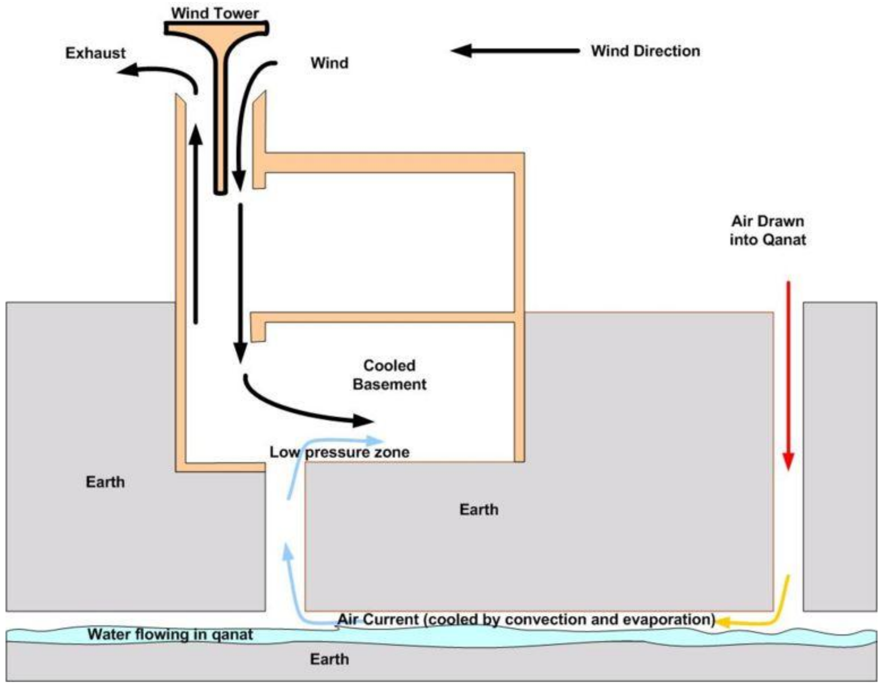


Figure 2.11: Function of a wind catcher (Source: After Climatic Analysis of Iranian Traditional Buildings 132, Ghobadian, 2005)

There are two desired winds in the heart of the torrid region of Iran. One is from west to east, and the other is in the north-south direction. Hence, wind catchers are built in a rectangular shape so that the long side faces north and the shorter side faces north-west. This element is located on the top of the roof. It is completely closed up to a definite height; and over this height, openings are made. These openings are designed with partitions in order to conduct the wind directly into the building. In wind catchers that have different parts for vacuuming the interior air, the openings should be exactly in front of each other (Pirnia 283-286).

In some cities, the shape of wind catchers is different because there are desired winds in only one direction or there are horrible typhoons. Therefore, the wind catchers have only one opening and the back side is curved to increase protection against undesired winds (Ghobadian 133) (Figure 2.12).

Figure 2.12: Different shapes of wind catcher; Square with one opening (Source: yazd.com/images)

2.6.5 Central Courtyard

As mentioned earlier, to protect interior spaces against the wind, open spaces are located at the heart of the building, and openings face onto this courtyard. Having a small pool, some trees, or vegetation in the yard minimizes the aridity and purifies the air.

Central courtyards are located on the level lower rather than on the street level. This location has several advantages: first, it facilitates bringing natural water from aqueducts or gutters into the garden and the reservoir in the basement. Secondly, the removed soil can be used to make mud bricks for construction; thirdly, the thermal capacity of soil minimizes the difference between indoor and outdoor temperatures; and finally, it increases the building's resistance to earthquakes (Ghobadian 137) (Figure 2.13).

Figure 2.13: Central courtyard of Lariha's House, Yazd

Central courtyards have two variations in traditional houses; the first contains the regular yards on the ground-floor level with a rectangular plan and includes small pools along the length of the courtyard; and parallel to it, there are two to four well-designed gardens (Memarian 168). However, the second variation, called "Gowdal Baghcheh," is a type of yard built on the level of the basement. Gowdal Baghchehs are built one level below the ground, and the spaces around them function as basement spaces. Due to their location at a lower level and the trees planted there, Gowdal Bachghehs provide a cool and humid place on hot summer evenings. They also have access to natural underground water sources (Memarian 169-170).

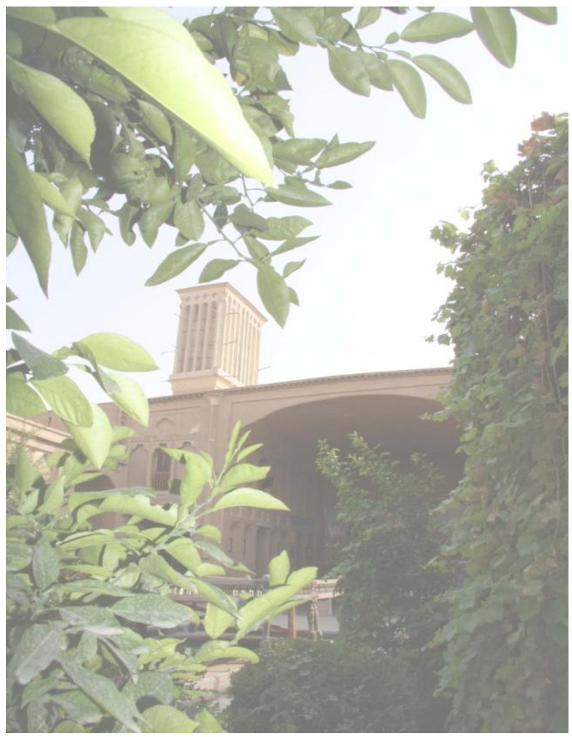
In the past, the number of central courtyards depended on the financial status of the residents and varied from one to six (Ghobadian 139). However, additional courtyards had other functions as well as providing climatic advantages. For example, in wealthy families' houses, there was a courtyard for horses right beside the entrance where visitors could hitch their horses and then enter the building. Another courtyard was for growing oranges and tangerines and for enjoying their evergreen leaves in a private open space during all four seasons (Memarian 173).

2.7 CONCLUSION

Overall, although traditional buildings in Persian architecture seem simple in their avoidance of advanced technology and other modern facilities, there are various techniques, elements, and spaces that have made these buildings, especially residential ones, places that need to be re-discovered. Regarding thermal efficiency issues, some of the traditional and local treatments to overcome thermal problems in houses have been discussed thus far in this study. However, these are only a few of the clever solutions that experienced architects created a hundred years ago to make a desirable place to live in the heart of the desert. In the following chapter, wind catchers and courtyards will be seen as the most thermally efficient elements and will be analyzed in detail. Their structure and function will be explained to evaluate their efficiency and their applicability to contemporary buildings and for future generations.

CHAPTER III

Chapter III: Case Studies



CHAPTER III

WIND CATCHER AND CENTRAL COURTYARD: MASTERPIECES OF TRADITIONAL PERSIAN ARCHITECTURE

3.1 INTRODUCTION

For centuries, wind catchers have been used as natural ventilators in Middle Eastern buildings, where the climate is hot and arid or hot and humid (Bahadorinejad 2). The main function of this architectural element is to conduct natural air from outside the building, cool it down, and circulate it inside the living spaces.

Based on the architectural typology, wind direction, and climatic situations, there are various types of wind catchers in Iranian cities such as Yazd, Ardekan and Boushehr (Figure 3.1). These structures differ in shape, height, and number of openings (Bahadorinejad 3).

In addition to the wind catchers, in the past central courtyards were the core of traditional Persian houses in this climate and had formal, aesthetic and climatic characteristics. All living and service zones in a house were organized around this feature. Thus, the number of spaces and the area of each space were dependent on the area and number of courtyards in a house.

In this chapter, a typology of wind catchers will be presented first, and their structure and functions will be analyzed by focusing on the wind catchers in the city of Yazd, a historical city located in the heart of Iran's Central Desert. Then, the thermal efficiency of this feature will be analyzed in Lariha's House in Yazd as a case study. This analysis will evaluate the efficiency of a wind catcher and analyze the potential of its adaptability to contemporary architecture in hot and arid climates.

The second part of this chapter is dedicated to the analysis of the central courtyard as another thermally efficient feature that has the potential to be applied in new architecture. Its function will be demonstrated; and then, it will be reviewed in Rasoulian's House, located in historical city of Yazd, as a case study.

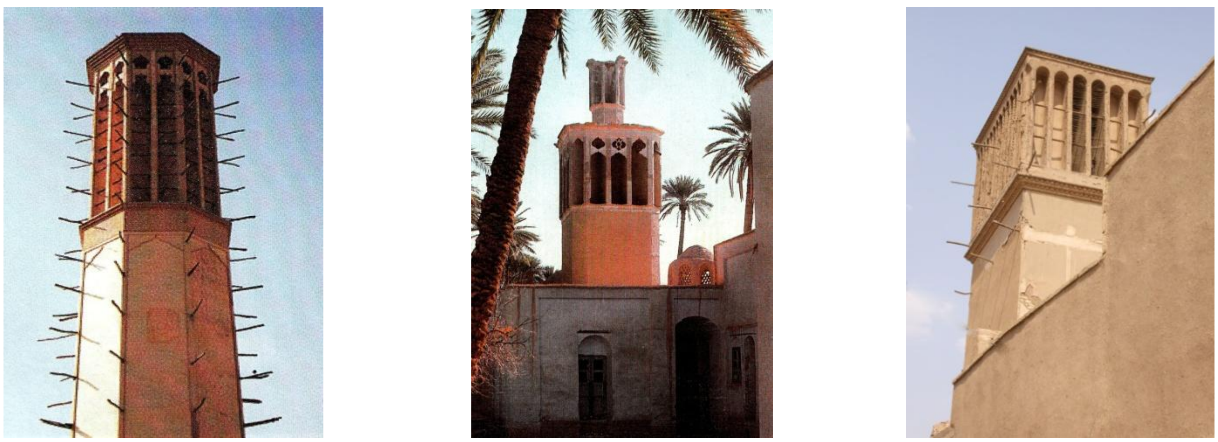


Figure 3. 1: Different types of wind catchers in Iran including octagonal and cubic forms (Source: Windcatchers 29 and 31, Bahadorinejad 2008)

3.2 GENERAL FUNCTION OF WIND CATCHER

As normal seasonal winds are main features of central Iran, wind catchers in these regions have been built in the direction of the desired winds. Their tops are open on two, six, or eight sides. Beneath these openings, the structure is closed, and the channel continues into the basement or the underground water storage area (Bahadorinejad 13).

During the day, the hot air-flow's temperature decreases upon contact with the wind catcher's sides, which have cooled over night. This cool air flows into the building and finally exits from other openings, such as windows and doors.

This circulation is reversed during the night; that is, at night, in the absence of wind, wind catcher cools the building through a chimney effect[1]. It soaks up the hot air inside the building and conducts it outside through its openings on top. Since the mass of the wind catcher’s structure is limited and the thermal capacity of the material, which is clay, is low, the efficiency of wind catchers for natural ventilation is low in the absence of wind (Bahadorinejad 32) (Figure 3.2).

Wind flow between the wind catcher’s and building’s openings causes a pressure difference that makes the air circulate into the building. In most buildings, the wind catcher has been designed in such a way that this pressure difference causes the air to enter the wind catcher and to depart from windows or openings below it. However, the orientation of the wind catcher could mean that windows could conduct the natural air into the building, and that the pressure difference would circulate it to the wind catcher via the chimney effect This design is appropriate for buildings that are located in large gardens. The evaporation in the garden purifies and cools the air; thus, this fresh air can come from the windows into the building and go out through the wind catcher (Bahadorinejad 15).

[1] The tendency of heated air or gas to rise in a duct or other vertical passage, as in a chimney, small enclosure, or building, due to its lower density compared to the surrounding air or gas (Source: http://www.daviddarling.info)

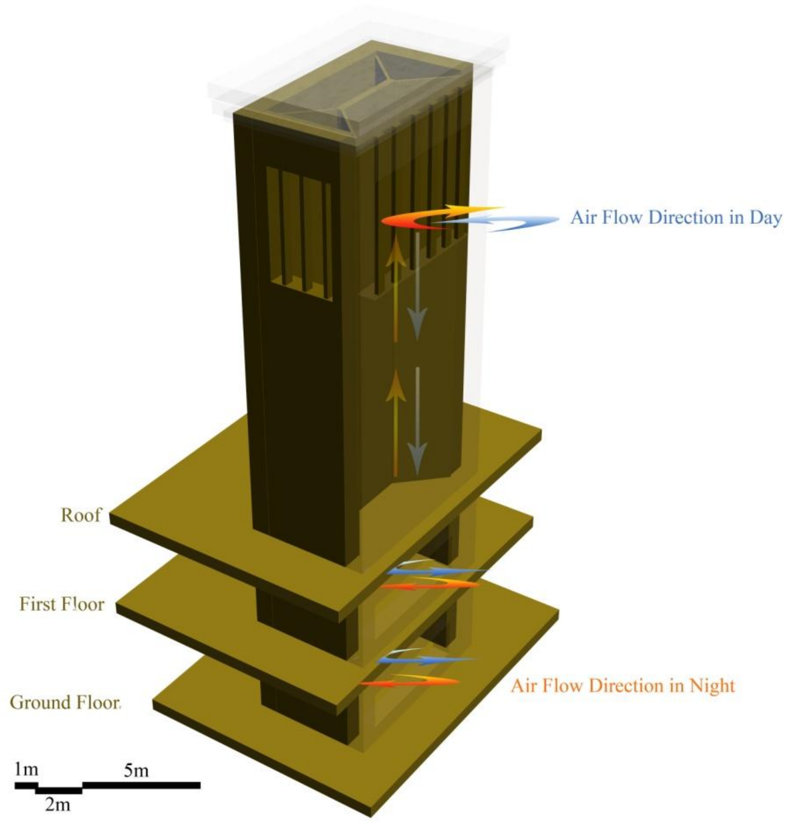


Figure 3.2: Air flow direction in wind catcher during day and night (Source: After Climatic Analysis of Iranian Traditional Buildings14, Ghobadian, 1998)

Although wind catchers have been used for centuries in Iran and some other countries, they have certain deficiencies, especially in the hot seasons:

- Openings or entry holes may allow sand, dust, insects and even small birds to enter the building.

- In wind catchers with more than one opening, some of the air that enters from one opening may exit from another opening at the roof level, which reduces their efficiency.

- The amount of energy that can be saved for cooling the building is low since the mass of the structure and thermal capacity of its material are low. Moreover, the contact area for the hot air is limited. Thus, cool air production is not sufficient on hot days.

- Although in a hot and arid climate evaporation could play a very important role in reducing temperature and freshening the air, even in buildings with a water pool in the basement, the potential of evaporation for cooling has not been used efficiently.

- Wind catchers are not thermally efficient in regions where the speed of the wind is insufficient.

These deficiencies could be removed by developing wind catchers with higher efficiency for contemporary buildings.

3.3 TYPOLOGY OF WIND CATCHERS IN THE CITY OF YAZD

The orientation of the wind catcher, the height of the tower and its proportion to the rest of the building are important factors in determining its efficiency. Moreover, the orientation and direction of the openings are required for accurate calculation and design.

Wind catchers include four main parts: tower or channel; opening or entry hole; partition; and shelter (Pirnia 279) (Figure 3.3).

The tower is mainly built in cubic or prism shapes with square, rectangular, hexagonal or octagonal cross sections. To enhance the sustainability of the wind catcher, wooden meshes are built into its structure. The ends of the timbers are used for external maintenance.

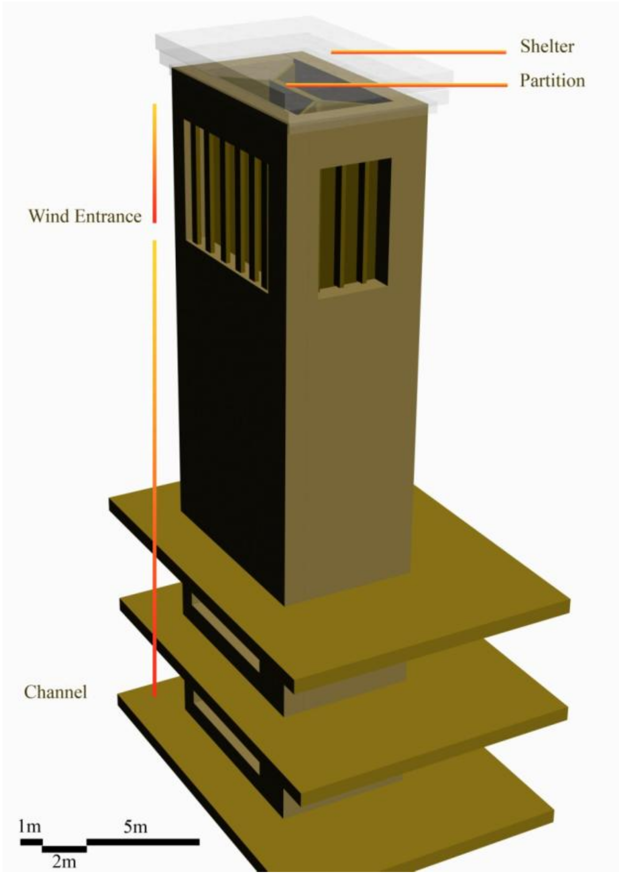


Figure 3.3: Structure of a wind catcher

Because the direction of the desired wind in the city of Yazd is from the north-west (Isfahani desired wind), ninety percent of wind catchers in this city are built in this direction. The typology of wind catchers in this city is based on their shape and function (Bahadorinejad 256).

3.3.1 Number of Entries

Depending upon the number of openings, the wind catcher can be one of four types: one side open, two-sides, four-sides, or diagonal. In the city of Yazd, because of the type and direction of the desired winds, there are three types:

- Two-openings, comprising 5% of all the wind catchers in this city.

- Four-openings, the most common type in Yazd with 93% of the wind catchers.

- Six- and eight-openings, which are more efficient because they can absorb winds from all directions. This type is built mostly for water storage. One of them is found in Dowlatabal, a residential building in the city of Yazd (Bahadorinejad 257).

3.3.2 Shape of the Plan

The shape of the plan has the most important role from the urban point of view. Yazd is famous for the variety of the shapes of its wind catchers, such as square, rectangular, octagonal and circular. Moreover, differences in plan are not only in the general shape of the plan but also in the shape of the interior and the form of the partitions inside the tower. These partitions, made of clay and mud brick, divide the volume of the channel into smaller parts. There are two types of partitions:

- Major partitions that start from the main floor and continue to the top. These dividers have a mostly functional role and are located in the opening holes.

- Minor partitions that have mostly a decorative role and can be seen on the external façades of windcatchers. Based on the geometric form of the plan and the arrangement of partitions, windcatchers are divided into three different types:

3.3.2.1 Square

In the square-shaped plan, there are three designs for the main partitions: diagonal, H-shaped and cross-shaped (Bahadorinejad 258) (Figure 3.4).

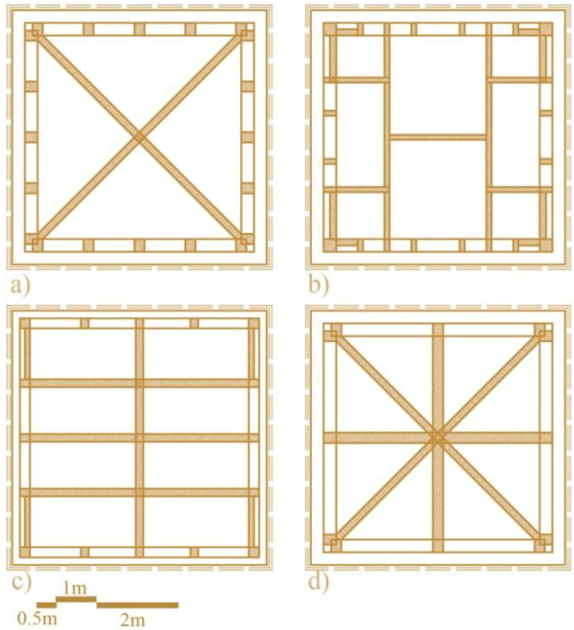


Figure 3.4: Four types of wind catchers with Square Plan (Source: After Windcatchers 258, Bahadorinejad, 2008)

3.3.2.2 Hexagonal and Octagonal

The main partitions in this type are diagonal. As a result, there are no varieties in the shape of this type. This type of wind catcher is built mostly in water storage buildings, and the highest octagonal wind catcher in the city of Yazd is in the Dowlatabad house (Bahadorinejad 259) (Figure 3.5).

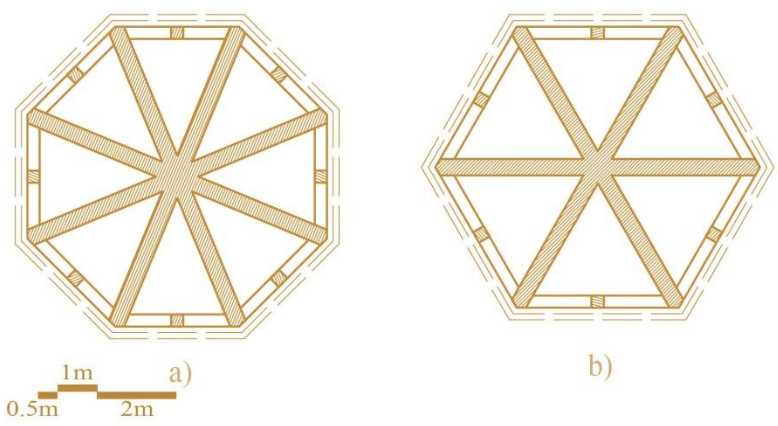


Figure 3.5: Wind catcher with Hexagonal and Octagonal Plan (Source: After Windcatchers 259, Bahadorinejad, 2008)

3.3.2.3 Rectangular

The most common shape of wind catcher is rectangular. The arrangement of the main partitions in rectangular windcatchers has a greater variety in plans (Bahadorinejad 260) (Figures 3.6-3.8).

A: X-Shaped Partitions

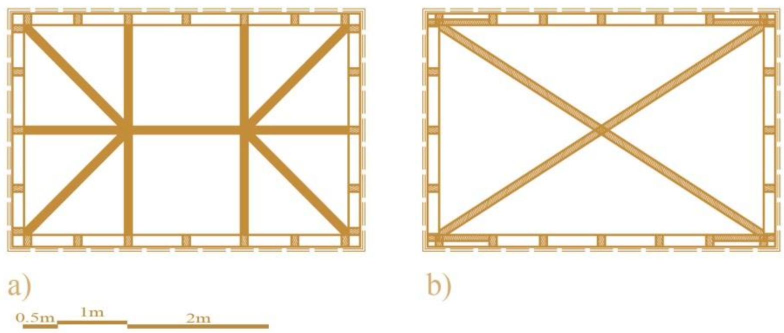


Figure 3.6: Wind catchers with Rectangular Plan (Source: After Windcatchers 260, Bahadorinejad, 2008)

B: Cruciate-Shaped Partitions

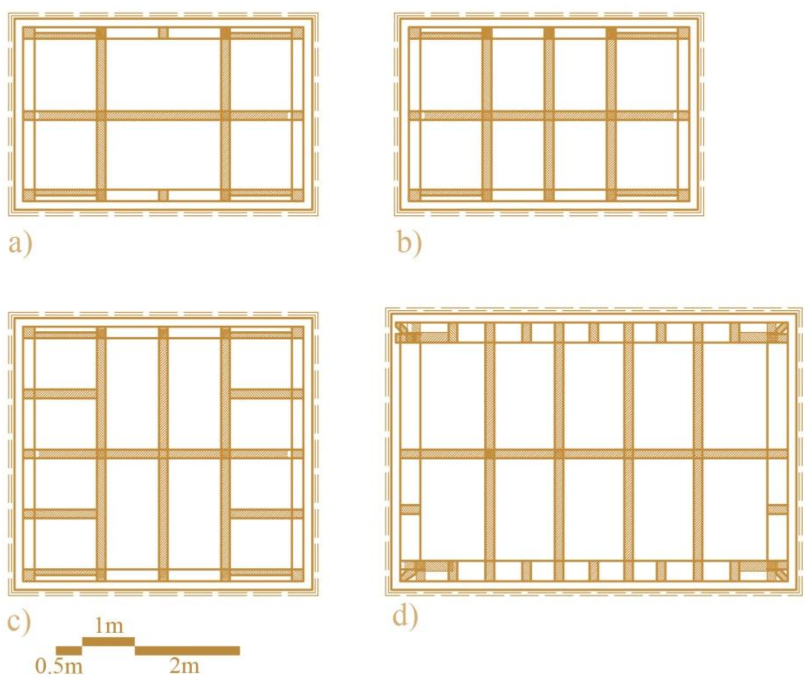


Figure 3.7: Wind catcher with Cruciate-shaped Plan (Source: After Windcatchers 260, Bahadorinejad, 2008)

C: H-Shaped Partitions

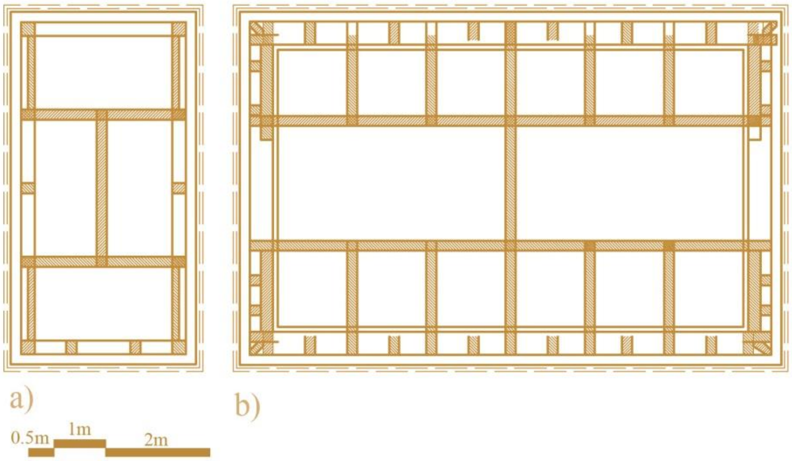


Figure 3.8: Wind catcher with H-shaped Plan (Source: After Windcatchers 261, Bahadorinejad, 2008)

3.3.3 Shape of the façade

The design of the envelope of wind catchers has an important effect on the identity of the city and urban sightlines. About 90% of the wind catchers in the city of Yazd are rectangular in shape. There are two different façades for wind catchers of this type. The main façade, which is the longitudinal façade, faces north-west. In analyzing the façades of rectangular wind catchers, factors which affect the external view of it include: height, form of the shelter, form of the opening, decoration of the façade and material (Dehghani 5).

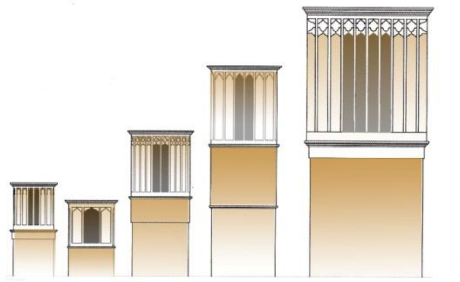


Figure 3.9: Windcatchers with square entry in facade

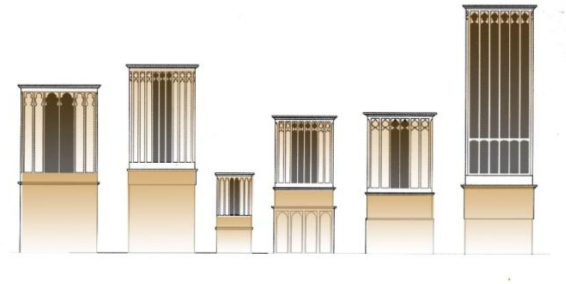


Figure 3.10: Windcatchers with rectangular entry in façade

3.3.3.1 Form of the Entries

The entry is located on top of the wind catcher and includes partitions and air conducting canals. Even though wind catchers may have the same plans; they can vary in the height, shape and proportions of the openings. The general forms of the openings are square, vertically rectangular or horizontally rectangular (Figure 3.9 and 3.10). Partitions in the openings are at the ends of some main partitions, while others are just in the openings to prevent birds from entering the wind catcher as well as for aesthetic reasons. The spaces between the partitions are in some instances open, and in others the two ends are closed for horizontal air circulation in the tower. The shadows created by these opened and closed valves make for a unique landscape in Yazd (Dehghani 6) (Figure 3.11).

Figure 3.11: Skyscape of the Yazd

3.3.3.2 Height

In the city of Yazd, wind catchers are built higher than in other cities where the wind catcher is part of the local architecture in a hot and arid region. The varied heights of wind catchers in Yazd have made a pleasant skyline for this city. The average height of Yazd's wind catchers from the roof of the building is approximately 5 meters (Bahadorinejad 261).

3.3.4 Orientation of wind catchers in the plan of a building

The design and location of wind catchers in the buildings of the city of Yazd differ from each other. For this reason, wind catchers, as the apexes of the skyline of each house, have specific shapes and effects on building. This variety also affects the skyline of the city. All wind catchers are located in summer-time living spaces, which are in southern part of the building. There are three different types of wind catchers in terms of their location in the building and their relation to other spaces in the house in the summer-time zone:

- Locating the wind catcher behind the rectangular living room (Talar) and on its axis. In this type, the axis of the wind catcher, living room and courtyard runs along each; and in houses with high ceilings (5 meters high) the wind catcher cools the sitting room on top of the Talar, or living room.
- Locating the wind catcher in the northern corner of the Talar, or living room. In this type, the Talar is set across the axis of the courtyard, and the wind catcher's axis is not along that of the Talar.
- Locating the wind catcher in the corner of courtyard. In this type, the wind catcher has no direct connection to the Talar (living room) and is connected to it only through the water pool space in the basement (Tahbaz 39).

Case Study 1: Thermal Performance of the Wind Catcher in Lariha's House

Location: Iran, City of Yazd, Historical Site

Area of the house: 1700m^2.

Year of construction: 1837

Number of wind catchers: One

Number of central courtyards: Three

Figure 3.12: View of the Lariha's House Wind catcher, Yazd, Iran (Source: flickr.com)

Lariha's house was built in the Fahadan district, Youzdaran Street, during the Last Qajar period, around 170 years ago, by Gholamhossein Molazeynal. The building currently belongs to the Iran Cultural Heritage, Handcrafts and Tourism Organization (Mollazadeh 338).

This house includes three central courtyards and a combination of Eivan and Talar rooms, entrance and vestibule. The entrance and vestibule are located between the two courtyards and have access to both. Some service zones of the building have separate access to the street (Figure 3.13).

The main living spaces, including Porch, Talars and main rooms, are designed around the large courtyard. Service areas are for the most part located in corners or behind the living spaces and rooms. The South-West section of the main courtyard is longer than the other parts and includes a large porch. There are several rooms on two stories beside this porch that have openings onto it. The wind catcher is located behind this porch. This zone is designated for summer since it is protected from the direct radiation of the sun (Mollazadeh 339).The opposite side includes a small porch and is surrounded by small closed areas. The other sides around the courtyard differ from these two and comprise Panjdari[2] and Sedari[3], an anteroom and a small porch.

The second courtyard is surrounded by almost the same spaces as the first, but they are different in area, design and decoration because of the diversity of their users. This courtyard was dedicated to semi-private use, including reception of guests. To illustrate the difference, the living room in the north-west side of the main courtyard is a seven-door room instead of the five-door room in the smaller courtyard.

The third courtyard, is located one level above the other courtyards. The surrounding areas have fewer connections with the other parts of the house since this part was mostly the service yard near the kitchen. Underneath this courtyard, there is a cruciform space which has a

[2]Panjdari: traditional Persian dwellings are modular. In these houses doors are used as module and 5-door rooms are large living rooms called Panjdari.

[3]Sedari: Smaller size living room or 3-door room.

skylight located in the middle of the courtyard. There are several small separate basements underneath this building.

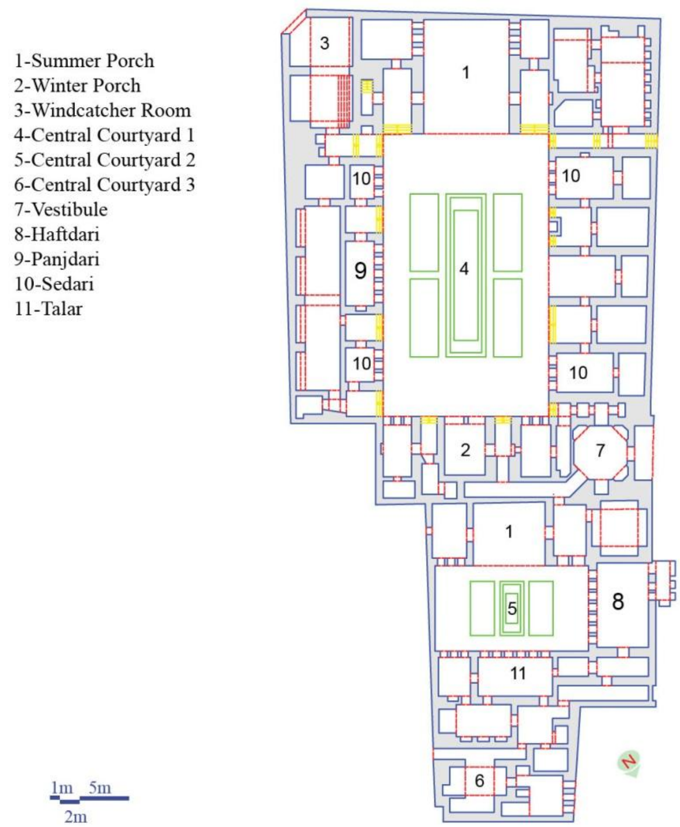


Figure 3.13: Plan of Lariha's House, Yazd (Source: After the Historical Houses 693, Mollazadeh, 2007)

3.4 NUMERICAL ANALYSIS OF THE TRADITIONAL WIND CATCHER’S FUNCTION IN LARIHA’S HOUSE

For analyzing the function of the wind catcher in Lariha’s house, its structure is explained in figure 3.14. This wind catcher comprises three parts: the wind entrance, the wind catcher’s major channel, and a gate to circulate the wind into the building.

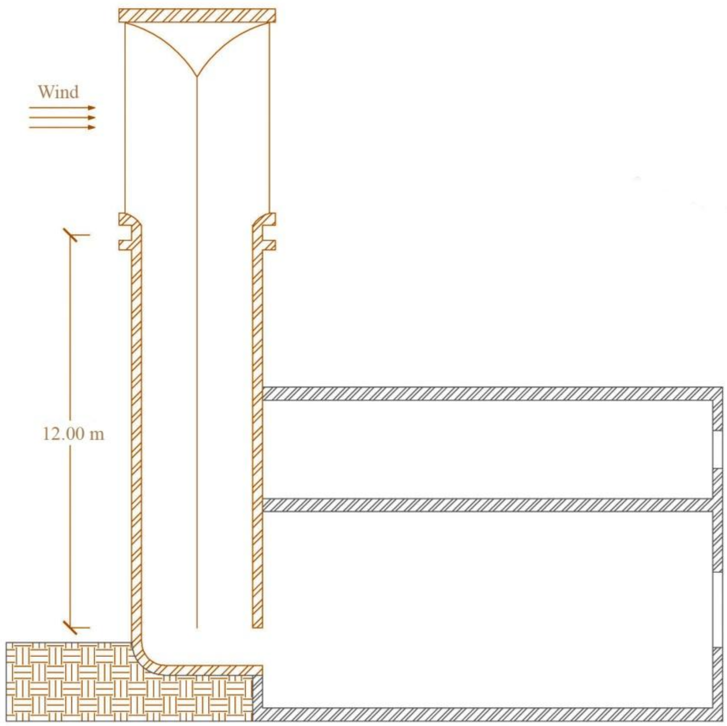


Figure 3.14: Structure of the Wind Catcher in Lariha's House

3.4.1 Environmental Factors in Determining Air Temperature and Air Flow in Traditional Wind Catcher

Wind pressure is different on the sides facing the wind in a building and the sides behind or parallel to the wind's direction. In general, wind pressure can be determined from Equation 3-1.

$$p_w = C_p \frac{1}{2}\rho {V_0}^2 \tag{3-1}$$

In this equation, V_0 is wind speed, ρ is density, and, C_p is the wind pressure coefficient. Table 3.1 indicates C_p for a wind catcher and its related building.

Wind direction and speed are shown in the Figure 3.15.

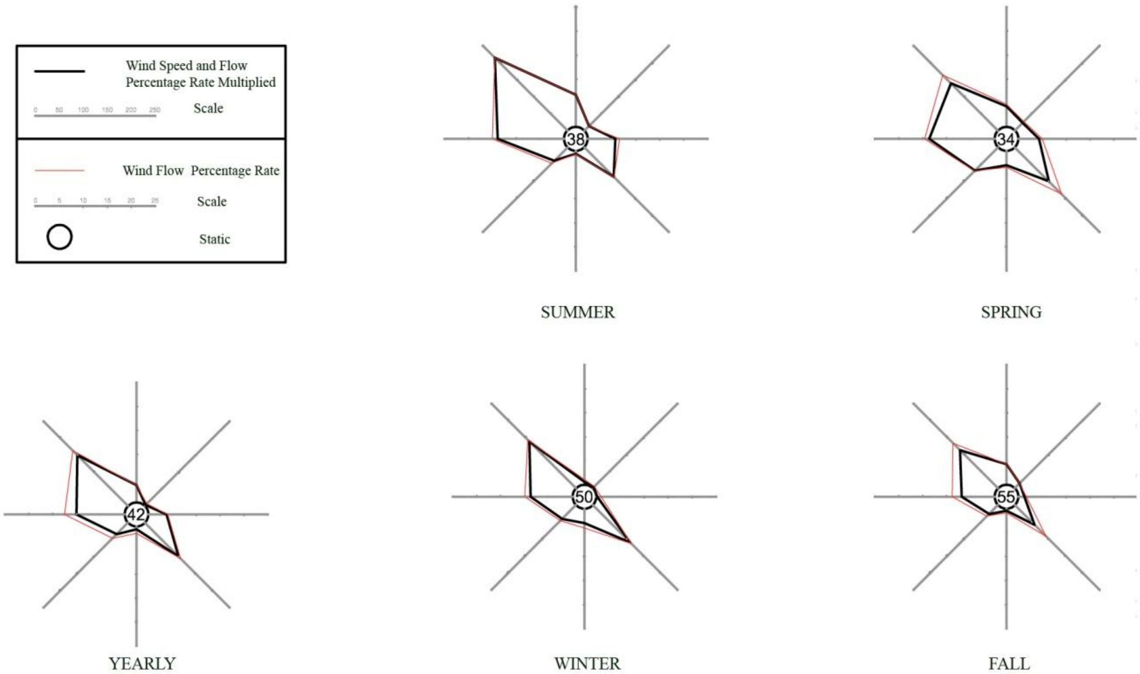


Figure 3.15: Wind direction and speed in different seasons in the city of Yazd (Source: Climate and Architecture 191, Kasmai, 2003)

As indicated above, in summer, when the performance of the wind catcher is necessary, the wind's direction is from south-east to north-west in Yazd. Based on the orientation of the building and its wind catcher, the entry wind speed varies from 45 to 90 degrees. Table 3.2 shows the maximum wind speed in different months. Based on these data, the wind pressure can be calculated for different wind angles:

side	Wind Direction Angle, α												
	0	15	30	45	60	75	90	105	120	135	150	165	180
1	0.86	0.91	0.70	0.41	0.03	-.49	-.74	-.68	-.65	-.61	-.52	-.42	-.39

Table 3.1 Wind pressure coefficients for wind catcher's openings (Source: Windcatcher 279, Bahadorinejad, 2008)

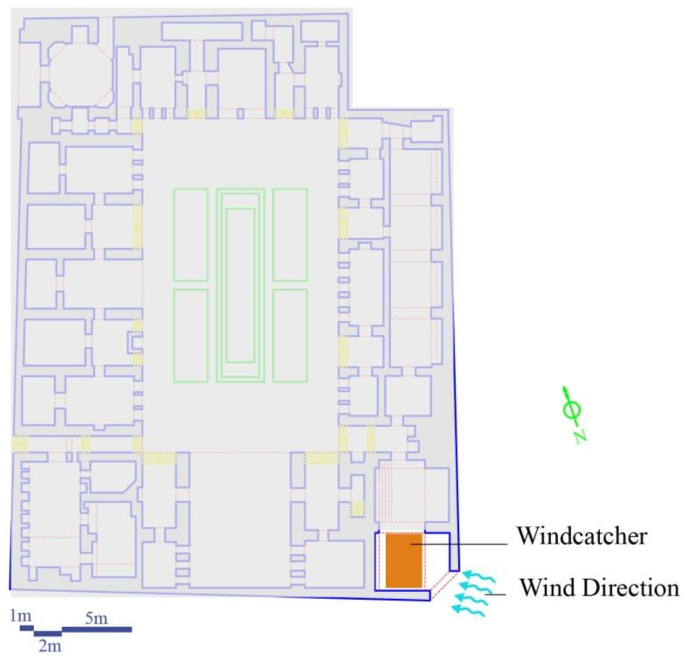


Figure 3.16: Direction of the wind entering the Lariha House wind catcher

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wind Speed(m/hr)	5.9	5.9	9.1	9.7	10	8.8	9.6	8.7	8.0	6.7	5.2	5.7

Table 3.2: Maximum wind speed in different months in the city of Yazd (Source: Climate and Architecture 187, Kasmai, 2003)

July- $\alpha = 45$: $p_w = 0.41 \times \frac{1}{2} \times 1.3 \times 9.6^2 = 24.56$

July- $\alpha = 60$: $p_w = 0.03 \times \frac{1}{2} \times 1.3 \times 9.6^2 = 1.79$

July- $\alpha = 75$: $p_w = -0.49 \times \frac{1}{2} \times 1.3 \times 9.6^2 = -29.35$

July- $\alpha = 90$: $p_w = -0.74 \times \frac{1}{2} \times 1.3 \times 9.6^2 = -44.32$

3.4.1.1 Ambient Temperature

The common method to determine ambient temperature is based on the maximum monthly average temperature ($T_{x,}$) and the minimum monthly average temperature (T_n) of the region. Table 3.3 represents $T_{x,}$ T_n and $\overline{K}_T$ for the city of Yazd in each month to calculate the daily outside air temperature:

$$T = \bar{T} + \frac{1}{2} A_t \cos \omega \ (t - 15) \qquad (3\text{-}2)$$

In this equation $\omega = \frac{2\pi}{24}$ and t is time (12 at solar noon). $\bar{T}$, and A_t are determined from equations below:

$$\bar{T} = \frac{1}{2} (T_x + T_n) \qquad (3\text{-}3)$$

$$A_t = T_x - T_n \qquad (3\text{-}4)$$

M	January			February			March			April			May			June		
	$\overline{K}_T$	T_n	T_x	$\overline{K}_T$	T_n	T_x	$\overline{K}_T$	T_n	T_x	$\overline{K}_T$	T_n	T_x	$\overline{K}_T$	T_n	T_x	$\overline{K}_T$	T_n	T_x
	0.60	0.8	14.5	0.62	2.8	16	0.59	8.6	32.1	0.61	13.7	28.2	0.68	17.7	32.9	0.74	21.4	36.1
M	July			August			September			October			November			December		
	0.73	23.2	38.8	0.77	20.9	38.2	0.76	13.7	33	0.74	9.8	26.1	0.65	4.1	22.9	0.64	1.0	18.3

Table 3.3: Climatic information for the City of Yazd (Source: Climate and Architecture 190, Kasmai, 1998)

Since July is the hottest month of the year in this city, the efficiency of the wind catcher is calculated based on the information for this month:

$$\bar{T} = \frac{1}{2} (38.8 + 23.2) = 31$$

$$A_t = 38.8 - 23.2 = 15.6$$

In addition, the hourly air temperature can be calculated by putting these data into equation 3-1 and data from cosine graph:

t=06:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-\pi}{4}$ =25.54

t=07:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-2\pi}{3}$ =27.88

t=08:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-7\pi}{12}$ =28.66

t=09:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-\pi}{2}$ =31.00

t=10:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-5\pi}{12}$ =33.34

t=11:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-\pi}{3}$ =34.12

t=12:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-\pi}{4}$ =36.46

t=13:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-\pi}{6}$ =38.02

t=14:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-\pi}{12}$ =38.41

t=15:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos 0$ =38.80

t=16:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{\pi}{12}$ =38.41

t=17:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{\pi}{6}$ =38.02

t=18:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{\pi}{4}$ =36.46

t=19:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{\pi}{3}$ =34.12

t=20:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{5\pi}{12}$ =33.34

t=21:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{\pi}{2}$ =31.00

t=22:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{7\pi}{12}$ =28.66

t=23:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{2\pi}{3}$ =27.88

t=24:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{\pi}{4}$ =25.54

t=01:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-7\pi}{3}$ =23.98

t=02:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-13\pi}{12}$ =23.59

t=03:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos -\pi$ =23.20

t=04:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-11\pi}{12}$ =23.98

t=05:00 $T = 31 + \frac{1}{2}\ 15.6\ \cos\frac{-5\pi}{6}$ =24.74

3.4.1.2 Solar Energy Radiated to the Surfaces

The amount of the energy produced by the sun's radiation depends on the angle of incidence of the sun's path to the radiated surface. That is, in a specific location at a particular time, the solar energy radiated to surfaces with different angles is absolutely different. Victor Olgyay has defined a calculation method based on a protractor-shape graph and the sun's trajectory graph. The protractor graph includes a circle that is divided to two parts. The arcs in the upper part indicate the solar energy radiated to horizontal surfaces; and in the lower part, the arcs show the solar energy radiated to walls and vertical surfaces. By applying this graph to the sun position chart for the desired location, the solar energy can be determined for all vertical and horizontal surfaces (Aghai 35).

In this case, the sun's trajectory graph for Yazd at latitude 31° can be applied to determine the solar energy radiated to the vertical surfaces of the wind catcher. Furthermore, the protractor graph should be adjusted with the 31° angle because of the orientation of building and its wind catcher along the geographic directions. The calculation is done for July, which is the hottest month in this location. Figure 3.17 indicates the sun's trajectory graph for latitude 31° using Olgyay's protractor graph.

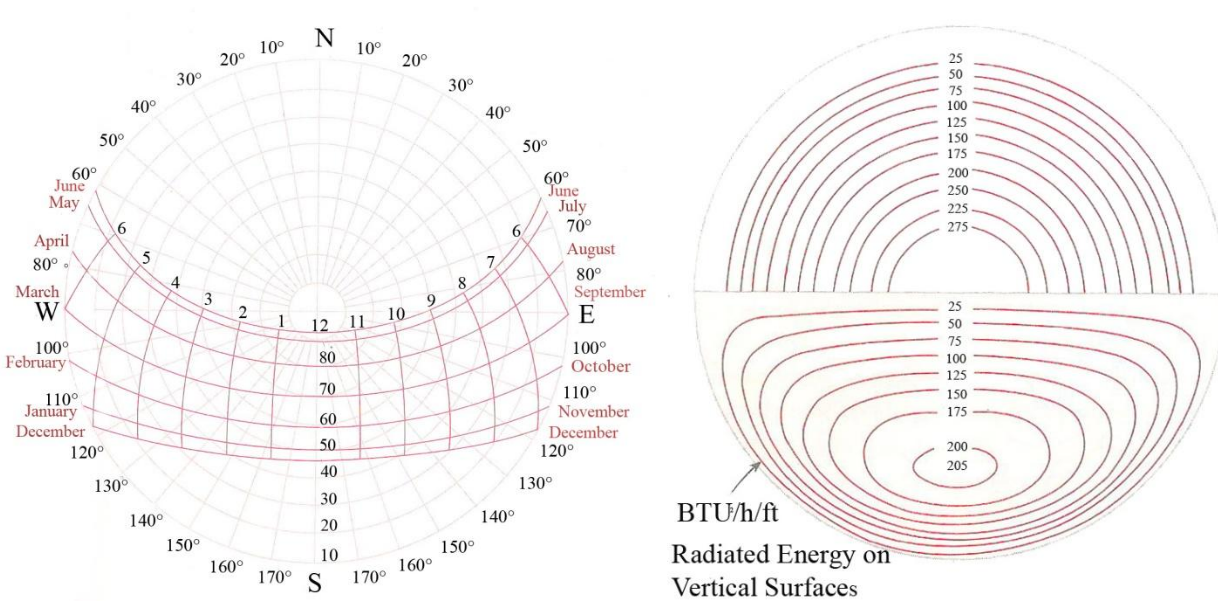


Figure 3.17: Sun's Trajectory for the city of Yazd – Olgyay's Graph for determining Solar Energy (Source: Sun, Wind, Light, Climatic Design 37, Aghai, 2007)

The results from adjusting the above graphs showing the solar energy radiated to vertical surfaces of the wind catcher are illustrated in Figure 3.18.

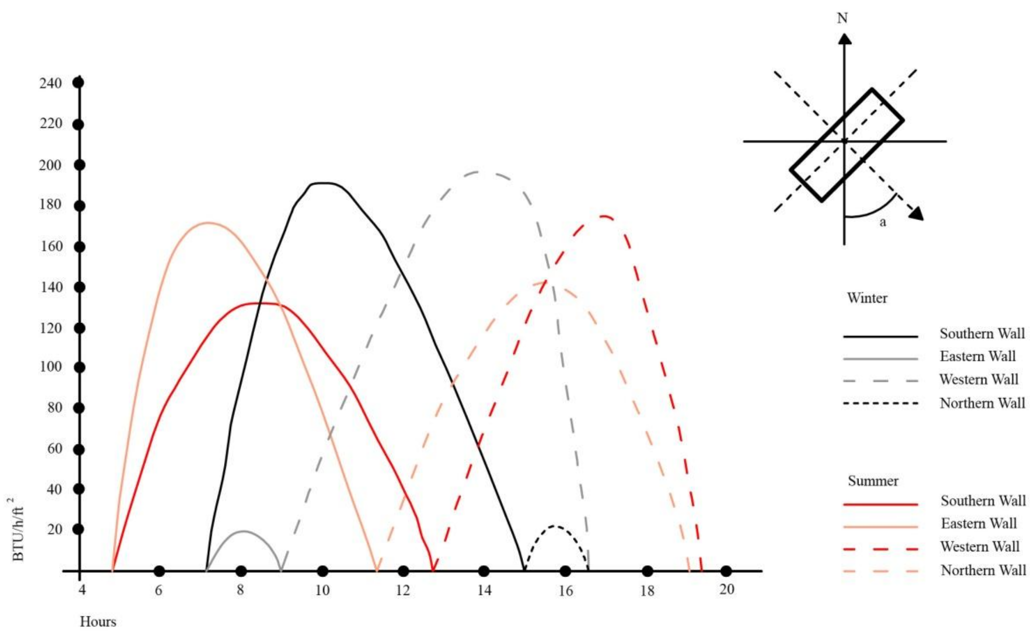


Figure 3.18: Solar energy radiated to vertical surfaces of the wind catcher in Lariha's House (Source: After Climate and Architecture 202, Kasmai, 2003)

3.4.1.3 Effects of Solar Energy on Internal Thermal Conditions

In addition to the amount of the solar energy radiated to the surfaces of the building, other factors have an impact on the temperature of the internal and external surfaces and, as a result, also have an impact on the temperature of the interior spaces (for example the colour of the material), the thermal capacity of the material and the thermal absorption coefficient.

The colour of the material has a significant impact on the radiation of thermal energy and eventually on the surface's temperature. Table 3.4 indicates the solar thermal absorption coefficient for different colours. According to this table, the thermal absorption percentage varies from 10% for light colours to 95% for extremely dark colours. Since the wind catcher in Lariha's House is made of mud brick, the 75 coefficient expresses its walls' thermal absorption percentage. This coefficient means that the wind catcher's walls absorb a high amount of the solar energy; and, as a result, the temperature of the external surfaces rises intensely in solar radiation peak times. However, the temperature of the interior surfaces of these walls is affected by other factors, such as thickness of the walls and the material's properties, especially its thermal capacity.

Colour Type	**Thermal Absorption Percentage (%)**
White	10-15
White-Oily	20-30
White-Reflective	40-50
Concrete	60-70
Brick	70-75
Black-Reflective	80-85
Light-Matte	90-95

Table 3.4: Solar thermal absorption coefficient for different colours (Source: Climate and Architecture 33, Kasmai, 2003)

For determining the temperature of wind catchers' interior surfaces, other important factors are the thermal resistance and thermal capacity of the materials. The reason for this is the transmission of heat from exterior surfaces into interiors. As an illustration, the wall consists of various layers. Heat is transmitted from the exterior layer to the interior one; and in this transmission, a part of the energy is saved in the layer and other parts are transmitted to the next one. Thus, each layer receives relatively less energy than the previous one; and the last layer, which is the interior one, has a lower temperature than the exterior surface.

After the air temperature reaches its apex, it decreases and the exterior surface temperature decreases as well. Thus, the direction of heat transmission is changed. First, the heat that has been saved in the material is transmitted in both directions, inward and outward; but after a while, the transmission changes to the outward direction and the gained heat is lost.

The temperature fluctuation between the exterior and interior surfaces depends on the heat resistance of the material; that is, the temperature fluctuation is reduced when the heat resistance of the material increases. On the other hand, the delay time for reaching extreme temperatures on the interior surface, in comparison to the exterior surface, depends on the thermal capacity of the material. The thermal capacity of the material depends in turn on the specific heat and density of the material, while the thermal capacity of the wall depends on the thickness and density of the materials.

Table 3.5 shows the conductivity coefficient and delay time for varying thicknesses of a wall made of brick.

Material	Thickness (cm)	Conductivity Coefficient (BTU/h/ft^2)	Delay Time(hr)
Brick	10	0.60	2.3
	20	0.41	5.5
	30	0.31	8.5
	40	0.25	12.0

Table 3.5: Conductivity coefficient and delay time for different thicknesses of a wall made of brick (Source: Climate and Architecture 35, Kasmai, 2003)

In the present case, since the walls of the wind catcher of Lariha's House have a thickness of 40 cm, the 12-hour delay time causes a significant difference between the layers inside and outside of the wind catcher. To determine the temperature of interior surface of the wind catcher's walls, Olgyay defines a graph that points out the effects of the material's properties on the temperature of the interior spaces (Figure 3.19).

According to graph in Figure 3.19, the inside air temperature fluctuation in a building built from brick is not considerable because of the high delay time for heat conductivity of this material. On the other hand, the differences between interior and exterior temperatures are significant, especially in higher temperatures. As a case in point, when the ambient air in July reaches around 30°C, the inside air temperature reaches 27°C or less.

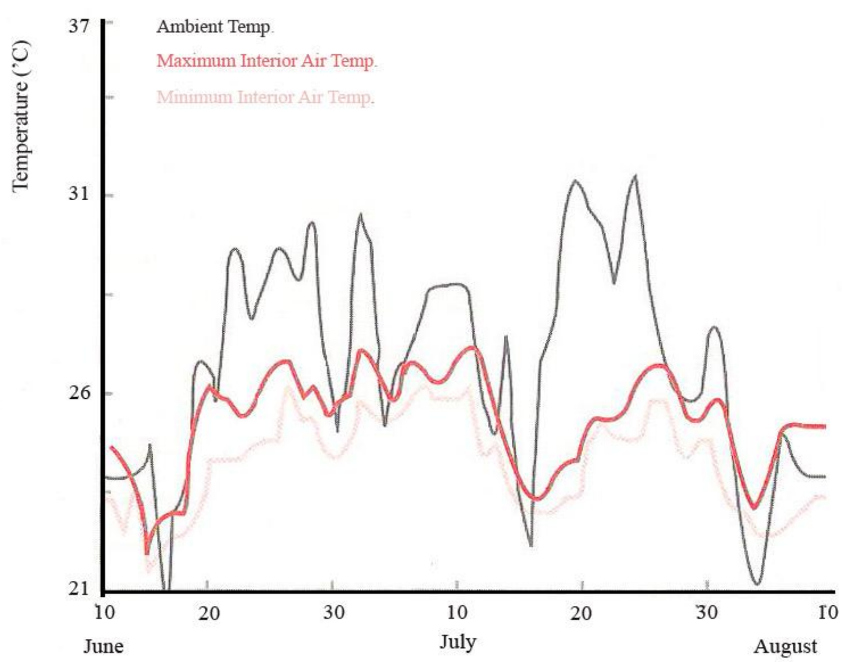


Figure 3.19: Olgayay's graph for the effects of a material's properties on interior space temperature (Source: Climate and Architecture 37, Kasmai, 2003)

According to the results of equation 3-1 for determining the ambient temperature in the city of Yazd in July, the temperature varies from 23°C to 39°C. Regarding the conductivity delay time and the conductivity coefficient of a 40cm thick wall brick, in addition to the temperature differences between the interior and exterior air temperatures of a brick building, it can be predicted that the wind catcher's output air temperature differs within approximately 5 to 7°C. Nevertheless, the wind's speed and pressure decrease in the wind catcher's channel. Figure 3.20 is an estimation of the wind catcher's output air temperature according to the calculations and climatic information above.

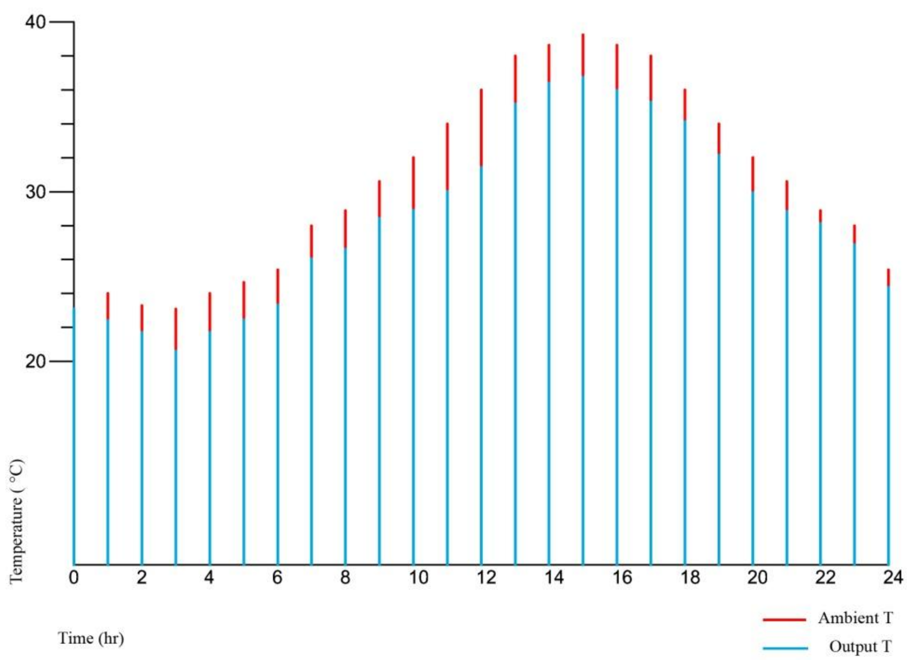


Figure 3.20: Prediction of the Lariha House wind catcher's output air temperature

3.5 EXPERIENTIAL ANALYSIS OF THE TRADITIONAL WIND CATCHER'S FUNCTION

The temperature of the entry air of the Lariha House wind catcher and the entry air of the wind catcher's room were recorded on July 29, 2009 from 8:00 a.m. to 6:00 p.m. when the ambient temperature varied from 26.5°C to 39.2°C and the maximum wind speed was 9.8 km/hr. Figure 3.21 represents the input and output air temperatures of the wind catcher.

As indicated in this graph, the experienced temperature is less than that expected from the calculations and analysis of material's properties. However, this reduction in the temperature could have a significant impact in the thermal comfort of the living space when combined with the effect of the wind's speed in the room and the effects of other climatic strategies. These strategies include the effect of the shadows in the room by locating the summer living space in southern part of the site, the circulation of the air from the wind catcher to the central courtyard, and the effects of the building material.

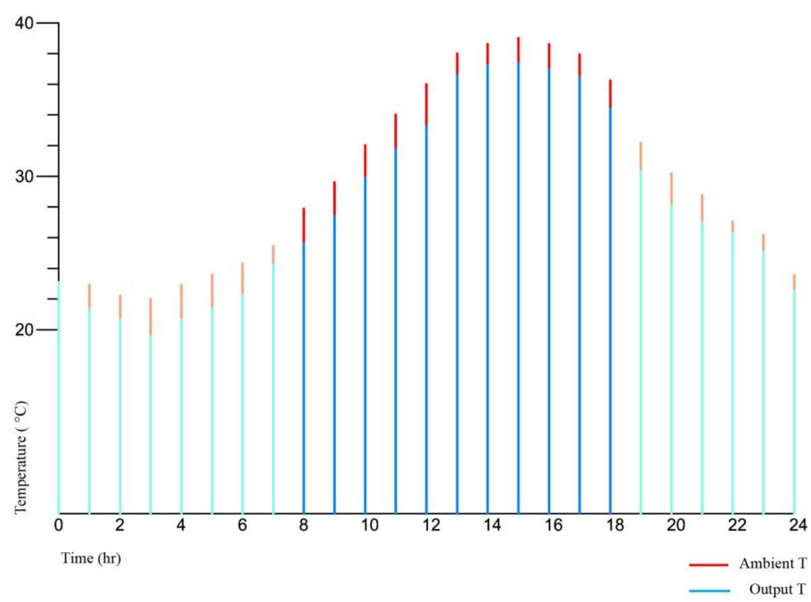


Figure 3.21: Recorded output air temperature in Lariha's House

3.6 RESULTS OF THE NUMERICAL ANALYSIS OF THE WIND CATCHER'S FUNCTION

According to the graphs from the estimation of the output air temperature of the wind catcher in Lariha's house and the hourly records of the input and output air temperature, the wind catcher, as one of the most effective thermally efficient features, affects the indoor thermal conditions significantly. Comparing the ambient temperature to the windcatcher's output temperature shows that this feature can reduce temperature from 4% to 15% in the hottest conditions. According to energy saving tips in IESO (Independent Electricity System Operator) reducing 1°C in temperature can decrease energy consumption up to 5% (www.ieso.ca). Thus, in Lariha's house, cooling energy consumption can be reduced up to 20%. Therefore, considering the cost of construction and the area usage for this element in a contemporary lifestyle, the efficiency of wind catchers should be developed.

3.7 LARIHA HOUSE WIND CATCHER'S DESIGN

In this part, the wind catcher in Lariha's house will be analyzed from its architectural aspects, including its typology, orientation, and its access to other living and service areas of the house.

3.7.1 Typology of the wind catcher in Lariha's house

The analysis of this wind catcher's typology is divided into four parts: number of entries, plan, cross section and its façade.

3.7.1.1 Number of entries

To take advantage of the desired south-east to north-west wind in Yazd, this wind catcher has two entries on opposite longer sides to absorb the wind from one side and to evacuate interior air from the other. The openings are on the longer sides in order to capture the most effective winds into the building. The other two sides of this wind catcher have only decorative openings and both are closed (Figure 3.22).

Figure 3.22: Wind catcher of Lariha's House from the Street

3.7.1.2 Plan

In Lariha's house, the wind catcher is a rectangular one. In this rectangular structure, the proportion of length and width is two to one. The cross section of the wind catcher is of type (b) in Figure 3.7, and the partitions in the channel are functional and continuous throughout it. As previously mentioned, these partitions increase the contact surface with the air as well as the total thermal capacity and, as a result, decrease the temperature as much as possible (Figure 3.23).

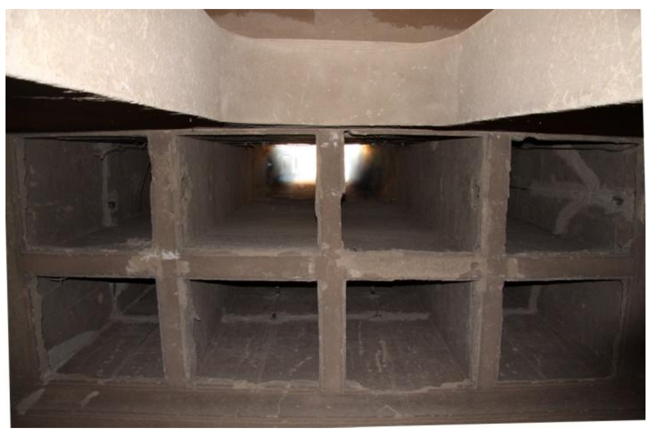


Figure 3.23: View from the Opening of the Lariha House wind catcher

3.7.1.3 Façade

The façade of the wind catcher plays an important aesthetic role, both in the building's general form and the skyline of the city. In this house, the entry of the wind catcher is square shaped. It has nine vertical dividers, which make eight openings. Four of these openings are functional and others are just formal to increase the wind flow potential through this side. The combination of light and shade in these openings makes for a unique view of it under various conditions (Figure 3.24).

The height of the wind catcher is in harmony with its neighbours'. This height is the median height for both efficiency and building cost. However, higher wind catchers receive cooler and less polluted air. Of course, construction cost and material pose significant impacts on this dimension. Since building with masonry materials affects the weight of the structure, some limitations have to be considered in its structure. Furthermore, the proportion of the channel height and the building is important for the landscape and general skyline of the city.

The decorations on the top of the openings have no function. The cover of this wind catcher's opening part is a combination of gypsum and brick. The arrangement of the layers of brick and decorative shapes made of gypsum in the design of the façade is a kind of identification for the building and creates a landmark in the city. Moreover, the dimensions of the wind catcher echo the dimensions of the related porch and, thus, the ambience of the whole building.

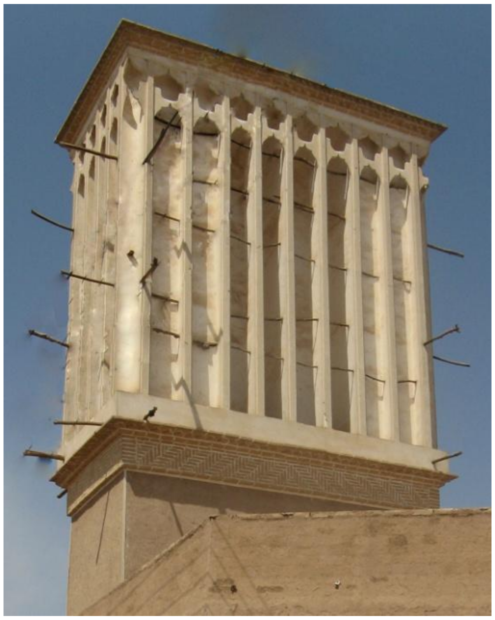


Figure 3.24: Facade of the Lariha's House wind catcher

3.7.2 Location of the Wind Catcher in Lariha's House

Like all other wind catchers, this architectural feature is located in the summer-time zone of the building. However, in contrast with the most common houses, in this house, the channel is not located on the symmetry axis of the Talar but is located beside it on top of a separate room called the wind-catcher room. The wind catcher is built in the directions of the building's main walls. That is, the wind catcher's sides are rotated from the main geographic directions by 45°. This angle has been designed to correspond to the city's desired wind direction. It helps the wind catcher to absorb the wind at the most effective angle, which is 45° to 90° (Figure 3.25).

The wind catcher room, located under the wind catcher channel, is connected to the large porch called the Ivaan. This large semi-open space located on the main axis of the building and courtyard used to be the main living space during hot summer evenings because of its particular thermal condition in comparison with the other zones of the house. The reason is that the cool air from the wind catcher enters this porch and the purified air from the courtyard passes through this area to be evacuated through the wind catcher.

Figure 3.25: Orientation of the wind catcher in Lariha's House and the direction of its entry wind

Although there are underground rooms that are cooler in summer because they are underground and are connected to the underground water sources, the Talar is more pleasant since it has a view of courtyard and the benefits of natural air and light on summer evenings. Family members used to gather in the Talar after watering the trees and plants in the courtyard. This watering not only purifies the air, but also reduces the temperature significantly by lowering the mud brick-ground floor’s temperature.

Figure 3.26: The wind catcher room and its connected space in Lariha's House

Figure 3.27: View of the Lariha House courtyard from the Summer Porch

The traditional Persian way of life was completely different from the contemporary lifestyle. In the past, multi-family and multi-generational living arrangements were commonplace. Thus, large numbers of people shared the semi-private areas and service zones of the house to take advantage of the larger living space. For this reason, they could separate their living spaces seasonally. Moreover, land and building costs were lower than they are today because of the smaller population.

In contemporary single-family houses, it is impossible to allocate a wind catcher's room to the summer and leave it unused during other seasons. Moreover, shrinkage in the size is necessary for this specific area owing to the number of users and the dimensions of the other parts of a house.

3.8 CONCLUSION

Analysis of the wind catcher in Lariha's house indicates that the wind catcher as a natural solution for achieving thermal comfort in a hot and arid area was efficient. However, applying this method in contemporary architecture requires certain developments and modifications in terms of its structure, function and orientation.

With today's improvements in building technology, a wind catcher can make use of materials with more thermal capacity and less weight. Thus, the structure of the channel could be redesigned to reduce its mass and to achieve greater sustainability.

Changes should also be applied to the orientation of this feature because of the changes in lifestyle. Returning to the traditional methods in the same way they were used in the past might well be a failure in contemporary architecture. In other words, design and lifestyle need to be directly correlated. Changes in building technology affect the architecture and design of living spaces, and these changes result in alterations in people's culture and lifestyle. Conversely, revolutions in lifestyle initiate new spatial requirements and the demands of these requirements initiate new architecture.

In the following chapter, some of the changes which are needed to adapt this traditional architectural feature will be analyzed. Then, some possible solutions will be given in order to strengthen the potential for applying traditional natural methods in contemporary architecture.

3.9 CENTRAL COURTYARDS

The importance of providing green areas inside living spaces in the hot and arid climate of Yazd made courtyards the most important part of the house both functionally and formally. Central courtyards in the houses of Yazd are the core of the building. All of the interior spaces are shaped around them, and most of the living spaces have direct access to these yards.

The central courtyard also has a significant impact on the thermal conditions of the building. Thus, the second case study will be dedicated to an analysis of this thermally efficient architectural feature in traditional houses in a hot and arid climate. Before the analysis, the general function, typology and orientation of this element will be described.

3.9.1 General Function of the Central Courtyard

The central courtyards of Yazd are the best representation of its people's inward-directed lifestyle. In this city, courtyards have a definitely different atmosphere compared to the outside spaces. Residents made the tough environment more pleasant and tolerable by growing plants and vegetation in addition to constructing small pools and fountains inside their courtyards. The combination of vivid colours, including green, blue and khaki, also increases the visual quality of the yard. Furthermore, the courtyard has an important role in organizing the other spaces in the house. Thus, it has been used as the circulating and connecting space for all the other living and service zones.

This traditional feature in hot and arid areas has been a thermally efficient element as well. Its location on a level lower than the street level is the first reason for its having a better thermal condition than the other spaces. Moreover, the floor's finishing, which is mud brick with an appropriate thermal capacity and heat conductivity coefficient, is another feature that intensifies its thermal efficiency. Additionally, the role of the small pool is considerable in providing residents with purified, moisturized and cool air.

Another important aspect of the central courtyard in this climate is its vegetation. This green area not only has the advantage of decreasing the temperature and moisturizing the air, which is quite critical in hot climate, but it also serves as a sustainability feature by growing food. Most of the courtyards in Yazd are full of edible green plants, such as figs, pomegranates, grapes, and pears, in addition to other decorative plants and flowers (Figure 3.28).

Figure 3.28: Central courtyard of Lariha's House, showing its food producing function

3.9.2 Typology of Central Courtyards in Traditional Persian Houses

The number and dimensions of the courtyards depended on the size of the houses and the number of families who lived in them. However, the most common type was houses with one and two courtyards. In houses with two courtyards, one was allocated to private use and the other to guests.

The most common shape for courtyards is the rectangle; however, some hexagonal and octagonal courtyards can be found in this city. The proportions of the rectangle depend on the area and number of spaces surrounding it. Courtyards and their related features have been built in two major forms based on their location in the building (Pirnia 148).

The first type includes flat courtyards located on the ground floor level (Figure 3.29). In this type, the pool is designed on the symmetry axis of the courtyard, and two to four small growing areas are designed along the length of the pool. The shape and design of the pools and the small gardens vary with each house, depending on the architect or the residents' wishes (Memarian 120).

The second type of courtyard is the one located on the basement level (Figure 3.30). In this case, the ground floor spaces are located around a platform called the Mahtabi; and the courtyard, called the Gowdal baghcheh, is located one level down. Thus, the courtyard's surrounding spaces can function as basement spaces, and they can have natural lighting and ventilation. Moreover, the Gowdal baghcheh also has access to the natural water resources for watering the plants. Since this type of courtyard has the advantage of having more shade, thermal conditions are more pleasant there (Memarian 121).

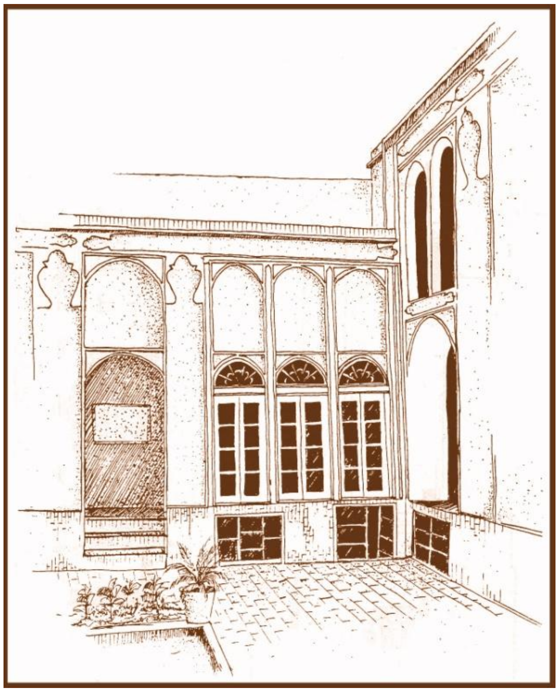


Figure 3.29: Sample of a Flat Central Courtyard **Figure 3.30: Sample of a Gowdal Baghcheh Central Courtyard**
(Source: Persian Residential Architecture 121, Memarian 2006)

Case Study 2: Thermal Performance of the Central Courtyard in Rasoulian’s House

Location: Iran, City of Yazd, Historical Site

Area of the house: 1500m^2.

Year of construction: 1900

Number of wind catchers: One

Number of central courtyards: Three

This building is located in the Gowdal Mossala district and is part of the Yazd historical site. Its construction dates back to the Qajar period, and it was designed by Mohammad Hassan Rahim. Rasoulian’s house was built for Abdolrasoul. Currently, the School of Architecture of the University of Yazd is located in this building (Mollazadeh 366).

Figure 3.31: View of Rasoulian's House main central courtyard from the roof

Rasoulian’s House, with its almost square plan surrounds two courtyards, a large one and a small one. The two wind catchers are located on top of each courtyard’s summer porch (Figure 3.32). In addition to these two courtyards, there is another smaller yard beside the kitchen for service. The entry of the house includes the vestibule and corridors that have access to various parts of the house.

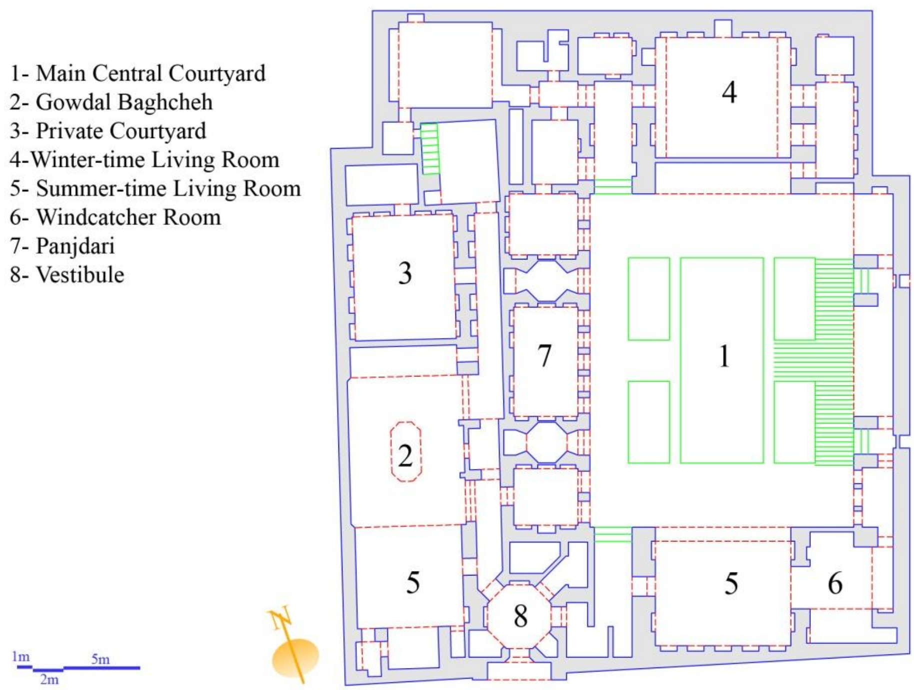


Figure 3.32: Plan of Rasoulian's House, Yazd (Source: After Architecture of Iran 321, Memarian, 2008)

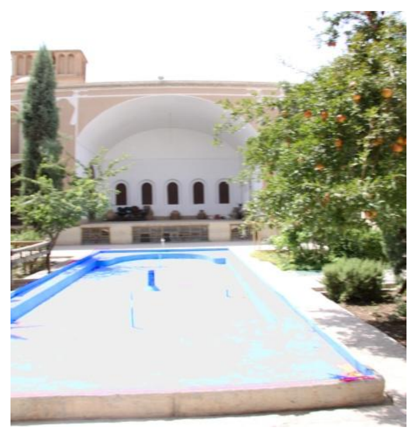
The main courtyard is surrounded by one-story rooms. However, the south-west side is higher than the others and a large porch is located there.

In this section, the courtyards and their thermal efficiency will be analyzed.

The largest courtyard of Rasoulian’s house is located in its eastern part and has access from the main entrance through a short corridor. It includes a large pool and four small gardens. The smaller one, located in the eastern part, also has access from the main entrance through a short corridor. This courtyard was used for guests as a semi-private zone of the house. These two courtyards have parallel axes. Almost everything is the same for this courtyard as the main one but on a smaller scale. The smallest one however, has neither aesthetic nor thermally efficient roles. This courtyard was not a functional yard, as were the other two. It was just a transitional space for the kitchen and its related areas for the servants (Memarian 317).

3.10 TYPOLOGIES OF CENTRAL COURTYARDS IN RASOULIAN'S HOUSE

The main courtyard is categorized in the first group of central courtyards, that is, the flat type on the same level as the street. The main winter-time and summer-time zones are located on its northern and southern sides and the other living and service zones are in its eastern and western parts (Figures 3.33 and 3.34).



Figures 3.33 and 3.34: Views of the winter porch and the summer porch from the central courtyard of Rasoulian's House

The smaller courtyard, by contrast is a Gowdal baghche. It is one story lower than the building. Therefore, it can take more advantage of the shade and has a lower temperature. The surrounding spaces on this level are more tolerable due to its better climatic conditioning. As shown in Figure 3.35, spaces around this courtyard receive less direct sunlight in the summer and benefit from the high thermal capacity of the soil.

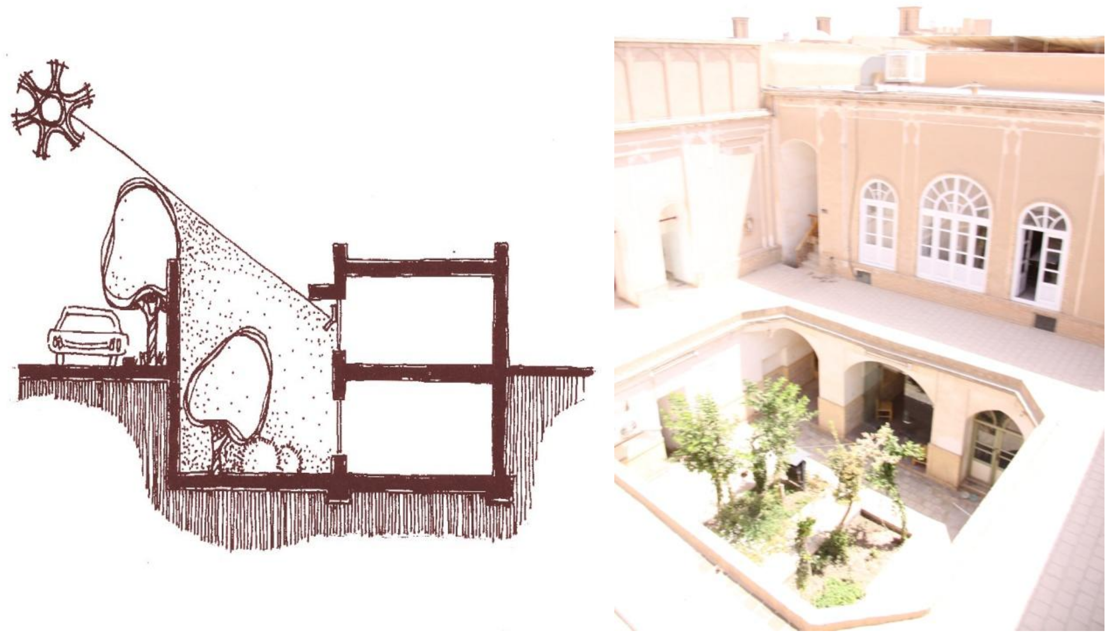


Figure 3.35: Effects of the location of the courtyard below the ground (Source: Architectural Design Principles Compatible with Climatic Conditions of Iran 119, Tahbaz, 2008)

3.11 THERMAL EFFICIENCY OF THE COURTYARDS IN RASOULIAN'S HOUSE

In contrast to the wind catcher, the central courtyard is not a seasonal thermally efficient element. It has advantages in both summer and winter regarding the thermal conditions in the living spaces. Moreover, the advantages of this feature are not limited to its thermal efficiency. The impact of the natural light and solar radiation on humans' physical and mental health and the visual and physical effects of having green areas and water in the living space are other advantages of the central courtyard that make it the most important feature in hot and arid areas.

To exploit natural sunlight in winter, the length of the courtyard from the building to the southern wall should not be less than twice the height of the wall. In the northern parts this dimension should not be less than the height of the wall (Figure 3.36) (Tahbaz 122)

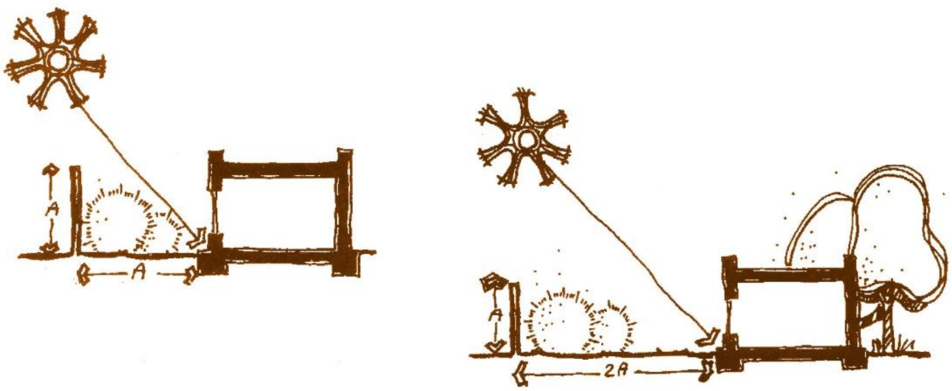


Figure 3.36: The appropriate proportions of wall and courtyard for sunlight (Source: Architectural Design Principles Compatible with Climatic Conditions of Iran 119, Tahbaz, 2008)

In Rasoulian's house, the height of the walls extends up to five meters. Thus, the northern part of the building, where the winter-time zone is located, benefits from the solar energy and radiation in the cold seasons. Since the southern part of the building is allocated to the hot seasons, in has no openings in its southern end; and as a result, there is no direct sunlight in this part of the building (Figure 3.37).

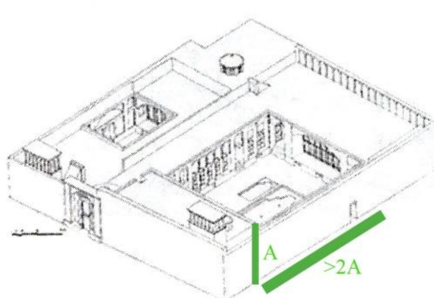


Figure 3.37: Proportions of courtyard and southern wall In Rasoulian's House (Architecture of Iran 322, Memarian, 2008)

In summer, the courtyard affects the thermal conditions of the building in various ways. First, because of the lack of humidity in this climate, water and vegetation in the courtyard significantly decrease the temperature. Moreover, the texture of the vegetation and water absorbs the sun radiation more than the floor material and, thus, reflects less heat back into the environment. Figure 3.38 indicates the heat reflection percentage for brick, water and vegetation surfaces. Furthermore, planting trees with more and bigger leaves increases the shade and helps reduce the temperature. However, these trees should be deciduous so that they lose their leaves in winter when there is no need to their shade.

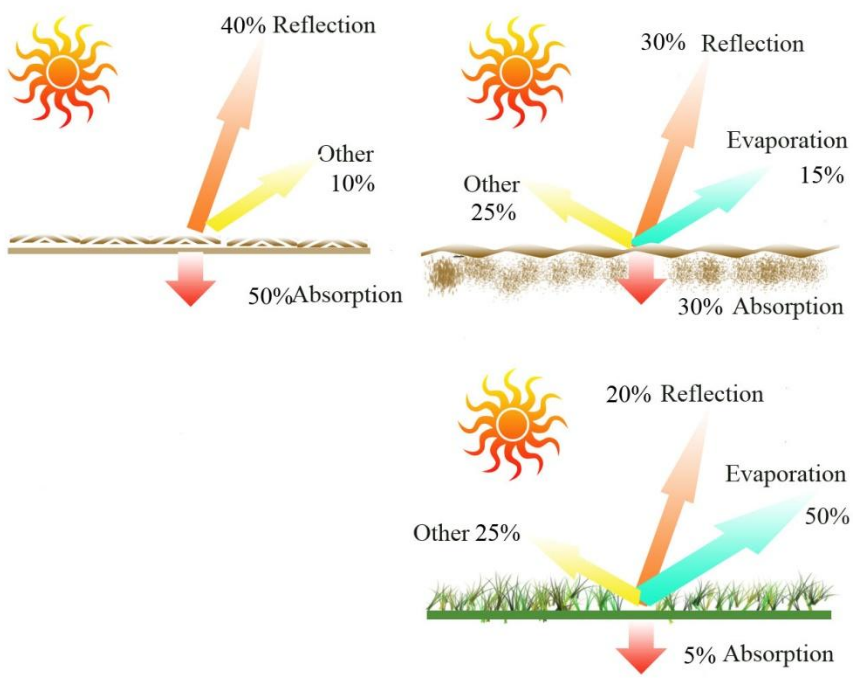


Figure 3.38: Comparison of Heat Reflection for Different Materials (Source: After Architectural Design Principles Compatible with Climatic Conditions of Iran 45, Tahbaz, 2008)

Vegetation has cooling effects with the combination of evaporation and shading. However, under hot and arid climatic conditions, evaporation is more effective. According to the researches, 15% to 35% of the total cooling energy saved by plants is the effect of their shade

(Aghai, 122). Moreover, in all climatic conditions, the combination of shade and evaporation in green spaces increases from 17% to 57% in saved cooling energy as a result of a 25% increase in vegetation cover (Aghai 123). Figure 3.39 shows the effect of the amount of vegetation on temperature reduction.

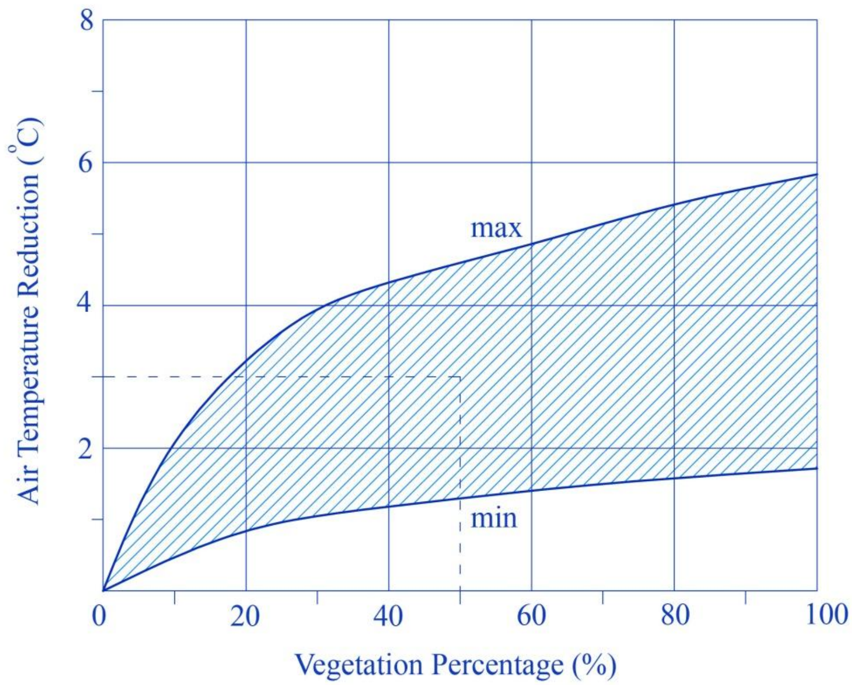


Figure 3.39: Temperature reduction from vegetation in central courtyards (Source: After Aghai 123, Sun, Wind and Light, 2007)

Using this information, the reduction in air temperature in Rasoulian's house as a result of vegetation in the main central courtyard is calculated below:

$S = 20 \times 16 = 320\ \mathrm{m}^2$

$S_1 = 2.5 \times 5 \times 4 = 50\ \mathrm{m}^2$

$\frac{S_1}{S} = \frac{50}{320} = 0.15$

In these equations, S is the total area of the main central courtyard and S_1 is the area of the four small gardens under vegetation in this courtyard. As indicated in the calculations, the percentage of vegetation in this courtyard is 15%. Thus, according to Figure 3.39, the distribution of vegetation in reducing the air temperature in Rasoulian's house at the maximum rate is 3° C.

In addition to vegetation in central courtyards, water pools or fountains in a hot and arid climate are effective in temperature reduction. The function of the pool is to moisturize and purify the air in this kind of climate. In conditions with moderate air temperature, humidity, and wind speed, the cooling energy produced from $21m^2$ of water surface is 200 W ($682 \, {}^{Btu}/_{hr}$) which indicates that heat transfer between the air and a shallow water surface is not considerable (Santamouris and Asimakapolous 111). Thus, increasing the water surface to increase the contact between water and air should improve its efficiency. However, in the central courtyard of Rasoulian's house the pool's thermal performance is better because the area of the pool is $65m^2$, humidity is low, especially in summer, and the temperature is extremely high. Comparing these conditions to the amount mentioned shows the considerable efficiency of the pool in this house. Furthermore, another impact of the water pool in the central courtyard is that the temperature of the moisturized air is also reduced. Thus, a pressure difference occurs in the interior air and causes an air flow in the building.

To evaluate the effects of the central courtyard on thermal comfort in Rasoulian's house, one may refer to the bio-climatic chart for the city of Yazd (Figure 3.41), which shows the conditions in which evaporation, shade, and natural ventilation can create thermal comfort in this building.

According to this chart, in the hot season, from June to September, the confluences of the maximum average temperature and the relative humanity are in EC and EC' areas (circles 3 to 6 in the chart). Referring to the chart's information, in both the EC and EC' areas, it is necessary to have a water cooling system to achieve thermal comfort.

From the above calculations, the central courtyard in Rasoulian's house can reduce the temperature up to 3° C through the effects of vegetation. Moreover, the shade reduces the temperature, and evaporation from both vegetation and the water pool increases the relative humidity. Thus, the conditions in the bio-climatic chart can reach the M' zone, which is the tolerable climatic range by only applying appropriate materials in the building.

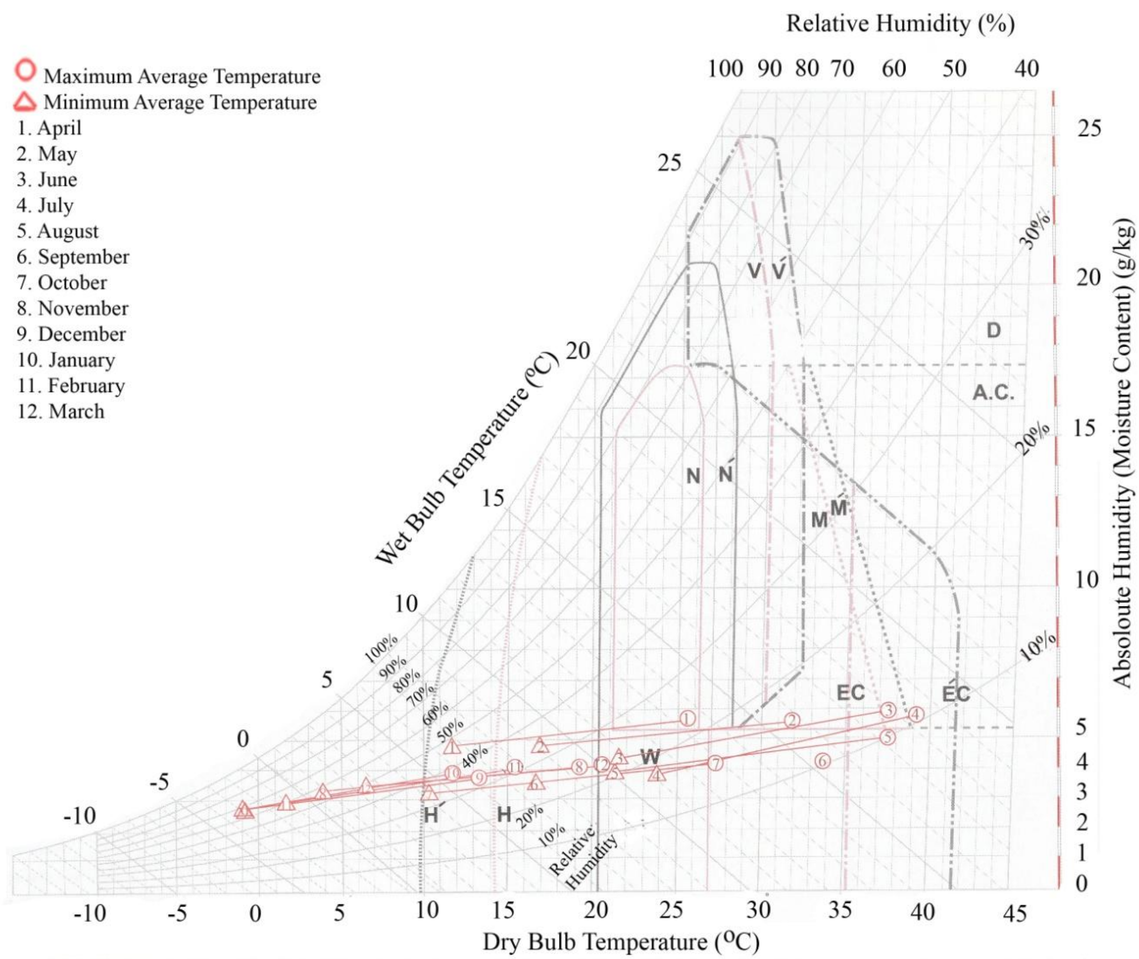


Figure 3.40: Bio-Climatic chart for the city of Yazd (Source: Climate and Architecture 295, Kasmai, 2003)

The necessity of the presence of natural elements such as water, plants and sunlight in living spaces is obvious. Moreover, the thermal efficiency of the traditional courtyard in the building, in addition to its psychological effects on the residents, makes it appropriate for being adapted to contemporary architecture. This adaptation should take place in various aspects. The physical aspects include the changes in the value and cost of land and new potentials due to improvements in building technology. On the other hand, changes in culture and lifestyle include single family living instead of traditional multi-family living and the way people spend their time in the house. All these changes should be considered in reapplying courtyards in contemporary houses.

3.12 SUMMERY

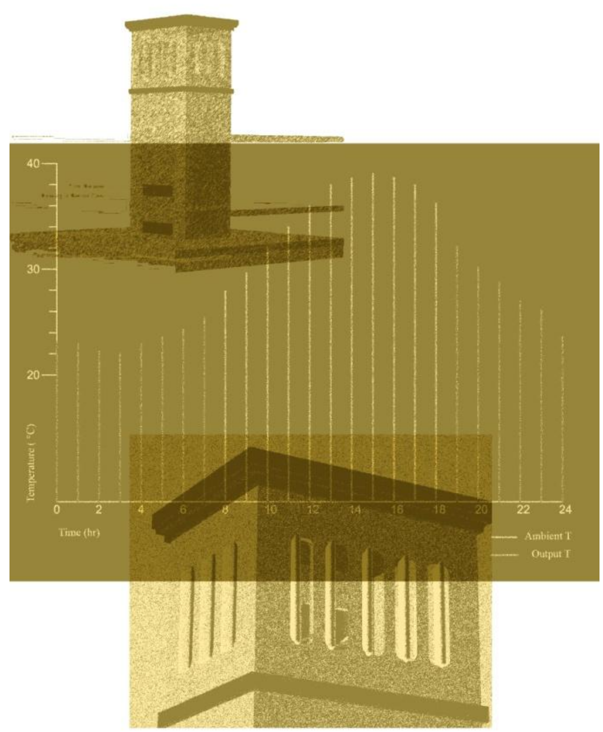
This review of the thermal efficiency of two major traditional features of Persian Architecture, wind catchers and central courtyards, sheds light on the proposal to reconsider traditional sustainable methods in architecture. However, this reconsideration should not mean repeating or copying the past. By evaluating these features, we should study their fundamental elements and their advantages and disadvantages. This evaluation can determine the potential for reapplying these features and their methods and techniques in today’s architecture.

The potential for adapting the wind catcher and the central courtyard as sustainable energy saving features in architecture has been analyzed in this chapter. This analysis includes the way they were applied in the context of a traditional lifestyle as well as how they were built and used. According to the numerical and architectural analyses, these two features could be applied in contemporary houses if they were adapted to new lifestyles and technology.

In the following chapter, some ideas will be given regarding the way to adapt wind catchers and central courtyards in new buildings in order to reduce energy consumption.

CHAPTER IV

DISCUSSION AND CONCLUSION



CHAPTER IV

DISCUSSION AND CONCLUSION

Due to the depletion of non-renewable energy sources, providing buildings' residents with thermal comfort should mean that architects ought to be relying more on natural and renewable sources of energy. In other words, to increase sustainability in buildings, designers should more often consider natural solutions for thermal comfort in residential spaces. In this regard, traditional architecture is one of the best sources of inspiration.

In the previous chapters, natural, thermally efficient solutions in the traditional architecture of Central Iran, with its hot and arid climate, have been analyzed. The study has focused on two architectural features: wind catchers and central courtyards. Although these elements were in the past the best answer to harsh climatic conditions, they are not necessarily as efficient and applicable today. That is to say, some modifications and adaptations are needed in order to reapply these traditional methods to reduce energy consumption in residential buildings.

Moreover, in changes to the traditional methods certain other factors should be considered in addition to energy efficiency; they include environmental issues, building costs and sustainability. Otherwise, the adapted features would fail in comparison to technologically advanced thermal equipment. As a case in point, the cost of constructing a redesigned wind catcher should not exceed the energy cost for the effective life of the building.

In this chapter, based on the studies in the previous chapters, some applicable adaptations of the mentioned features of traditional Persian architecture will be conceptually presented. These proposals could be applied in contemporary architecture in the place of their origin, the City of Yazd.

4.1 APPLICABLE ADAPTATIONS IN THE STRUCTURE OF WIND CATCHERS

Due to the climatic characteristics of the City of Yazd, humidity is one of the most important requirements for living spaces. Moistening the air through the channel of the wind catcher can both intensify humidity and reduce air temperature. Traditionally, architects tried to find a solution for this problem. The method they used was to build a small pool in the basement and put the wind catcher on top if; thus, the evaporation could moisten and reduce the temperature to some degree (Figure 4.1). This was the best solution given the technology and materials of that time. However, today, this method would not be sufficiently efficient because of the value and cost of the space and land that would have to be allocated for building it.

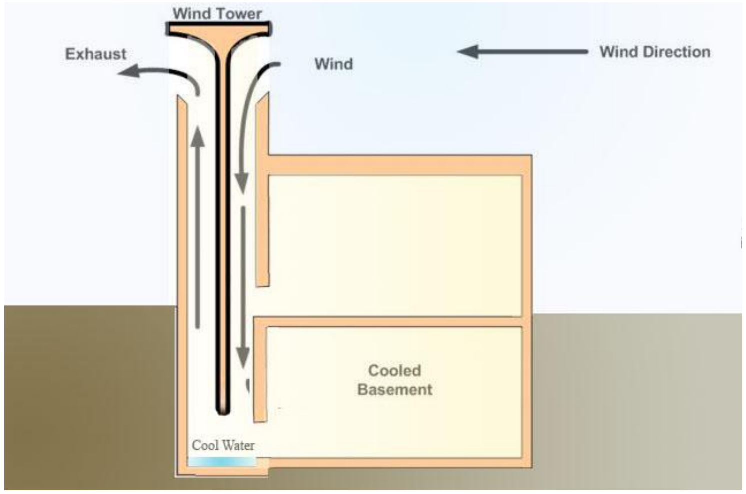


Figure 4.1: Wind catcher with cool pool in basement for increasing humidity (After Climatic Analysis of Iranian Traditional Buildings 132, Ghobadian, 2005)

Although some mechanical engineers have done research and proposed ideas for this problem, more adaptations and alteration still need to be developed for it to become an energy efficient feature. As a case in point, one idea suggested by M.N. Bahadorinejad and A.R Dehghani in *Windcatcher: A Masterpiece of Iranian Engineering* (2009), is to install special water pipes in the channel of the wind catcher. These pipes humidify the vertical surfaces of the wind catcher from the top. A small pool has been designed to sit under the channel and collect the water pouring from the surfaces; the water is then sent to pumps (Figure 4.2).

In spite of the fact that this suggestion has several advantages and increases significantly the humidity of the wind catcher’s output air, energy consumption for pumping water is a considerable problem. Not only is the cost of the energy for the residents important, but the public cost for the environment should also be taken into account. In this regard, this research study draws on ideas for enhancing the efficiency of wind catchers by eliminating the use of non-renewable types of energy.

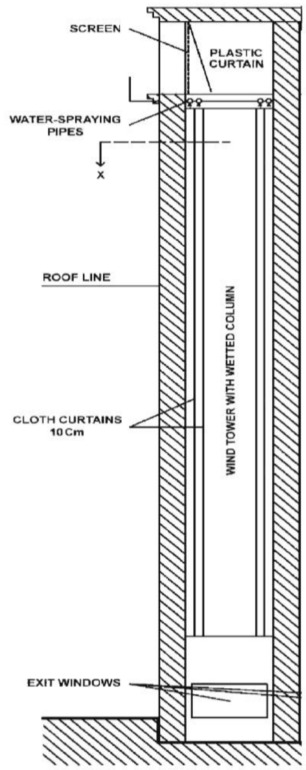


Figure 4.2 Proposed design of wind catcher by M.N. Bahadorinejad (Source: Windcatcher, a Masterpiece of Iranian Engineering 21, Bahadorinejad 2008)

4.1.1 Wind Catchers with Hydrophilic Fibers

The problem for traditional wind catchers with a pool underneath is that the air's contact with the cool water is low. Increasing air contact with cool and moisturized surfaces can dramatically reduce the temperature throughout the channel. In this regard, using materials with high water absorption on the vertical surfaces can be a solution. A layer of a hydrophilic material should be installed on the vertical surfaces; it must be rooted in the cool water pool at the bottom of the channel. The effective height of this fibre sheets should be calculated (Figure 4.3).

With this method, residents just need to check the pool's water supply periodically, for evaporation occurs much more because of the increase in the surface for evaporation. Moreover, the fibre sheets can act as a filter by taking in the dust and sand in the channel. Thus, from time to time, these sheets need to be changes for clean ones.

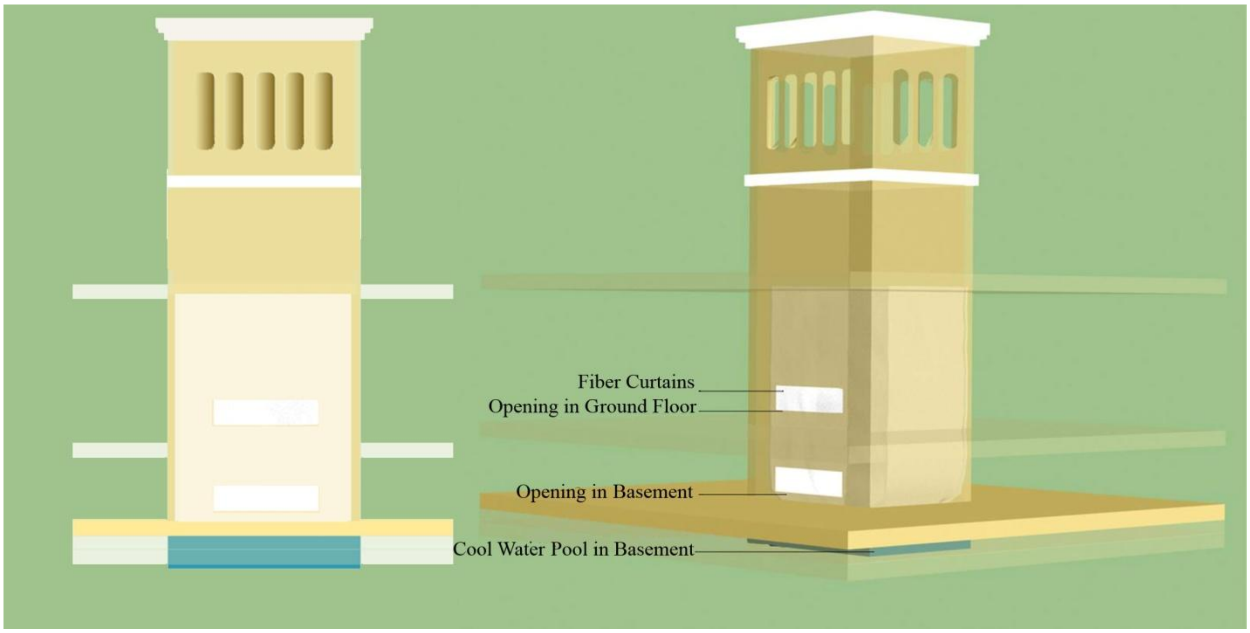


Figure 4.3: Proposed wind catcher model with hydrophilic fibres

Furthermore, the height of absorption would not cover the wind catchers' walls completely. To intensify the efficiency of the cool water pool, another strategy is to install metal sheets under the fibre sheets from the pool up to the channels' entry (Figure 4.4). Since the thermal conductivity of metals is quite high, the sheets can conduct coolness from the bottom to the top. Thus, the more air contact with a cool surface increases, the more the temperature decreases. As well, this metal sheet acts as an insulator under the fibres. Hence, the moisture will not affect the channel's structure.

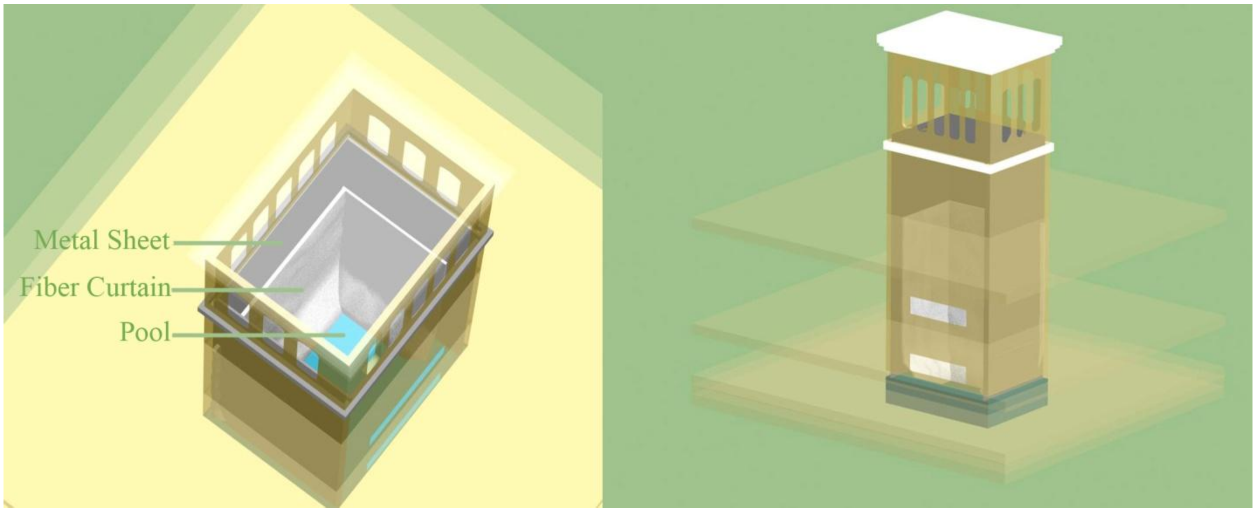


Figure 4.4: Proposed wind catcher with hydrophilic fibres and metal sheet

4.1.2 Wind Catchers with Controlling Lids in the Openings

The intrusion of dust, insects and birds is another problem of traditional wind catchers because of their large open entries. The open entries of wind catchers are not only places to conduct sand and birds into the living space, but they are also heat-wasting outlets. In winter, when there is no need to cool the living space, the wind-catcher channel's air should be isolated from the interior spaces.

In contemporary buildings, if proper lids are designed for the channel's openings on both the bottom and the top, residents can control the air entering the building according to the season. The entries can be open in summer; but in winter, both can be closed or, if air circulation is necessary, the opening in the living space can be opened. In the latter case, if the lids are insulated properly, the cold outside winter air cannot affect the interior temperature (Figure 4.5).

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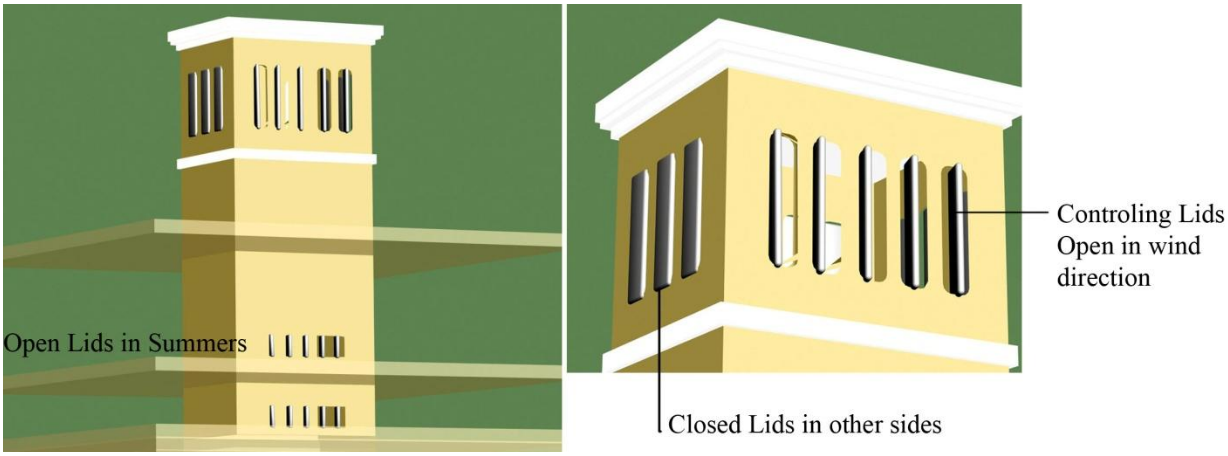

Figure 4.5: Proposed controlling valves for wind catcher's entries

Additionally, in wind catchers with openings on more than one side, in cities with pleasant winds from several directions, these lids can be used to control the input and output directions. When only the opening in the wind's direction is open and the others are closed, the waste cool air would be eliminated. The reason is that the negative pressure in front of the other openings would not take the inside air outside through the chimney effect.

4.2 APPLICABLE ADAPTATIONS IN THE ORIENTATION OF WIND CATCHERS AND CENTRAL COURTYARDS

As mentioned above, due to changes in lifestyle, wind catchers and central courtyards cannot be applied in contemporary houses in the same way as they have been used in the past. Today, through the growth of the population and people's need for living space, the demand for land has noticeably increased. This rise affects the value and cost of land. Thus, dividing a house seasonally is no longer applicable. Houses need to be designed in such a way that the same space can provide residents with thermal comfort in all seasons.

Wind catchers used to be built in the southern part of the house where the summer-time zone was located. The wind catcher-room and the large open porch connected to it were all located in this part, and in winter they were rarely used (Figure 5.6).

Today, however, with limited building areas, one living room has to be the main family gathering place all year round. Therefore, the wind catcher should be located on top of this living room (Figure 5.7). By adding the abovementioned valves over entries and isolating the channel's air in winter, the negative effects should be eliminated.

Another change in the lifestyle involves the division of the living spaces for private and semi-private functions. This issue had an impact on the number and size of the central courtyards. Although in contemporary houses the division is still needed, the way in which it is accommodated has to be changed due the limitation of land.

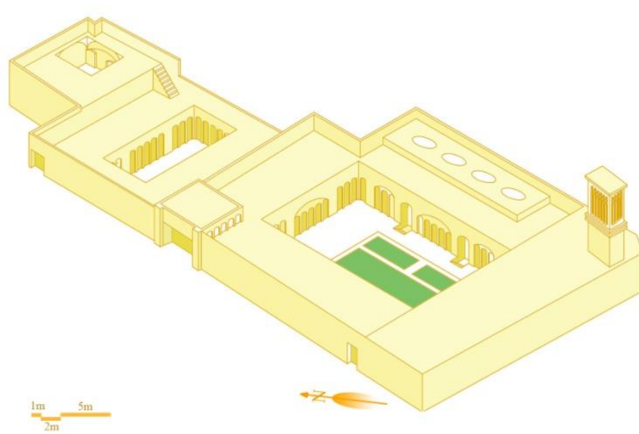

Figure 4.6: Orientation of wind catcher in a traditional Persian house

Figure 5.7 is a suggestion for the orientation of the wind catcher and central courtyard in a contemporary house. In contemporary Iranian houses, living spaces are divided into two different zones for day-time and night-time activities. The private and semi-private zones are defined in this way. In the modern lifestyle, the bedrooms function less during the day compared to other areas. Moreover, the most problematic time with respect to climatic conditions in the hot and arid area is day-time in the summer. In the city of Yazd, according to the climatic information given above, the sun radiates on southern surfaces in summer. Thus, by allocating the southern part to the bedrooms and the northern part to the living room, dining room and other living spaces, advantage would be taken of the shade in the zones where people spend most of their time during the summer.

Moreover, by designing a small patio in the middle of the house, we can simulate the central courtyard so as to benefit from this pleasant area in small houses. The benefits include natural light and ventilation, a green area and a small pool. Furthermore, if the patio is located in the centre of the house, it can act as a divider between the private and semi-private zones, as did the traditional courtyards. The wind catcher should be oriented on this central patio and on top of the pool. The reason for rotating the patio 45°, in addition to aesthetic concerns, is for the elevation to catch the best wind direction, which is from south-east to north-west.

To reduce direct heat from the sun in the summer, small gardens in front of the building can cast shade onto the southern wall. The plants growing in these gardens should be selected from the types which have big leaves in the summer but lose them in the cold seasons. Regarding the temperature fluctuations between day and night in this hot and arid climate, because of the high thermal capacity of brick construction, the bedrooms ought to be thermally comfortable, especially on winter nights.

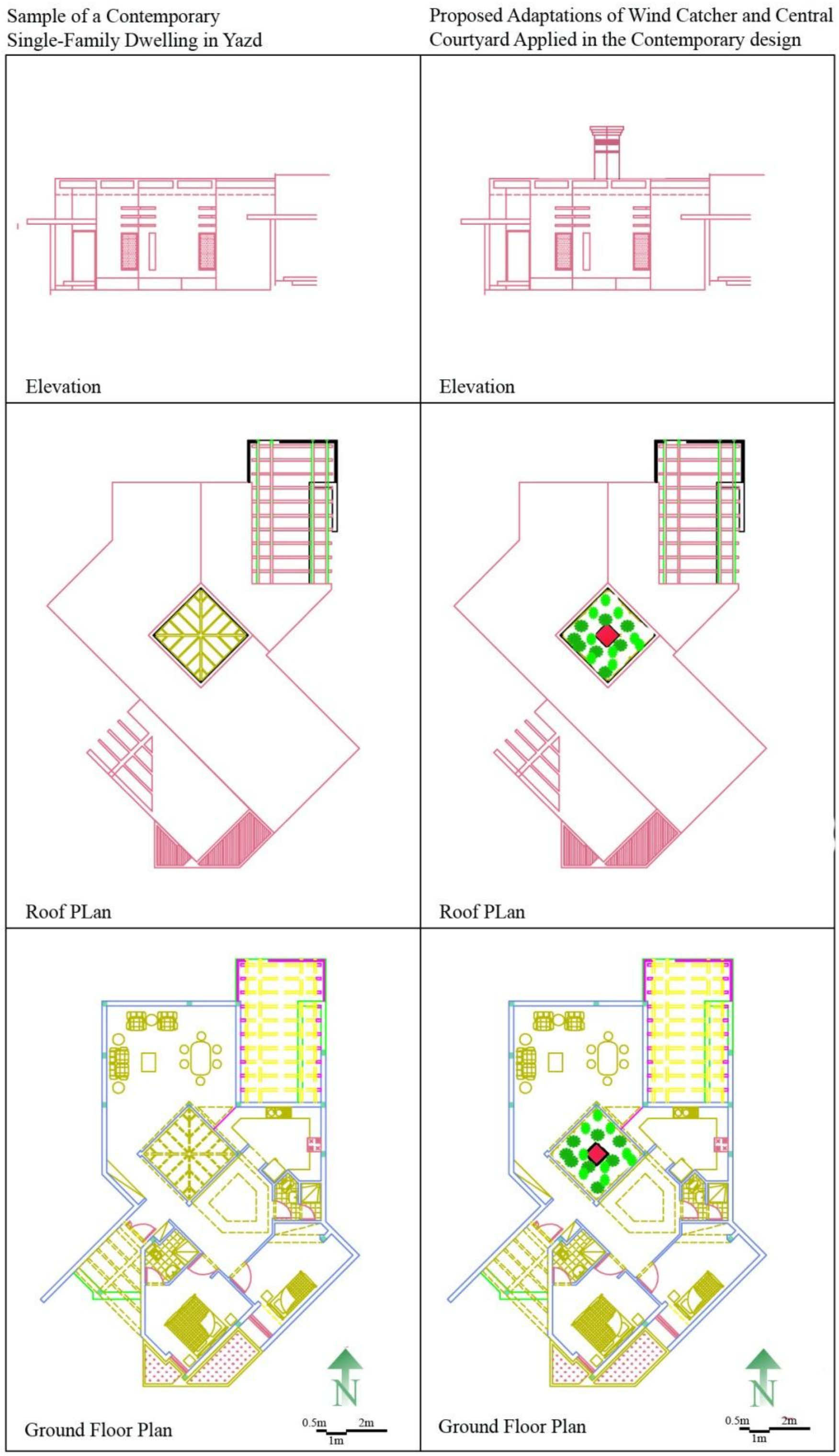

Figure 4.7: Proposed design for orientation of wind catcher and central courtyard in a contemporary house in Yazd

4.3 FUTURE RESEARCH DIRECTIONS

Future research on the thermal efficiency of architectural features in the traditional architecture of Iran should focus on the techniques for adapting these features to contemporary architecture. This adaptation should take place in the field of materials and spatial changes. Through developments in technology, more environmentally friendly and sustainable materials should be applied in these adaptations. By producing materials with more heat insulation and thermal capacity and a lower heat conductivity coefficient, we can reduce the energy consumption for heating and cooling the living spaces.

Finally, several ideas, techniques and materials should be examined practically. The most important factor for evaluation is the amount of savings in non-renewable energy consumption for thermal comfort in contemporary buildings. However, cultural issues and the psychological effects of the adaptations should also be considered in making spatial changes.

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