

Climatic guidelines for designing open spaces in residential complexes of Yazd (With emphasis on desired orientation and proportions and its radiation effects analysis)

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Abstract

Human's ignorance to nature and consequently his living environment's distance from natural endowments and potentials have caused many problems. Human's living spaces are less desirable, and have destroyed his comfort in many cases, as man-made things. In this regard, public open spaces in residential areas can be mentioned because they are usually considered among the most vulnerable spaces due to having the least thermal comfort and spatial quality. This is because they are able to provide comfort only if they interact with nature and use natural energy sources such as sun, wind, plants etc. In this regard, this study focused on providing comfort specifically thermal comfort in residential public open spaces by using natural endowments and energies especially the sun and shadow provided by solar radiation.

Although this research is qualitative (due to data collection and mapping and analysis of traditional residential houses in Yazd), it is also quantitative one since it proves the theory of relationship between courtyard and thermal comfort proportions. In this regard, the proportions of length, width and height of a number of Yazd traditional houses courtyard was checked and real shade mask of these walls was drawn. Aforementioned cases analyzed and studied in order to achieve to a logical relation between solar radiation, courtyard proportions and formation of shadows. At the end, climate guidelines have presented based on studies of Yazd climate conditions, emphasizing on two factors of orientation and proportions to achieve desired open space.

Keywords: Climate, Open spaces, Shade and sun mask, Thermal comfort.

1. Introduction

With technology rapid advancement and urbanization process acceleration, human's living spaces have lost its vital connection with nature. Ignoring of nature and natural potentials in the present era has caused many problems for human beings such as environmental pollution, adverse psychological consequences resulting from separation from nature, destruction of fossil energy resources, and finally depriving human from health and comfort. Therefore, exposing to these crises once again has led humankind to seek modern solutions to harmonize with nature and natural forces.

Therefore, many ideas have formed based on using natural forces and less dependence on non-renewable energies.

A building can be modify by spending money and using mechanical devices even in the worst possible design, but the specific nature of open spaces in residential complexes denies the possibility of modifying the situation and using mechanical cooling and heating equipments.

The present study attempts to investigate the possibility of making thermal comfort in open spaces of some traditional houses in Yazd by drawing the sun and shade mask. Designing residential complexes is not complete by disregarding the (public) open spaces. Considerable time of people's lives is spent in open environments rather than the closed environment inside the building. Everyone recognizes that architecture is a combination of open and closed spaces and it is companion of open and semi-open environments with indoor areas of the building that gives meaning to architecture. Therefore, the open spaces in designing are as importance interior architecture [1]. In addition, open spaces climate control impacts people of outside and inside of buildings directly and indirectly. Direct impact is on welfare of people in open spaces that could desirably affect their presence and experience of

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space and consequently affect life and joy of the complex by appropriate designing of public open spaces. Indirect effect is on environmental regulation of the interior spaces by modifying residential complexes at microclimate and mesoclimate.

2. Literature Review

Postgraduate Thesis entitled "Comfort in Open Spaces and Pathways" [2], and the book entitled "Sun and the Orientation of the Building" [3], could be mentioned as the first scientific records in this field. Nowadays, climate and climate design have been considered again in Iran due to fossil fuel resources reduction, urban pollution, and irreparable damage of fossil fuels to the environment. Following researches could be noted in this field: "Determining the Thermal Comfort Zone in Dry Climate(Case Study: Yazd)" [4], "Optimization of Open Spaces Orientation in Saghez Based on Climate Conditions" [5], "Home Home Outside and Inside Comfort According to "Penwarden" and "Mahani" Criteria, a case study in Ahwaz" [6], " Radiation and Comfort (Analysis of Radiation Effects on Architecture of Traditional House in Yazd)" [7]; In particular, there are a few researches about Yazd traditional houses regarding to optimal proportions and orientation of open spaces. Present study tries to find out optimal solutions in aforementioned area.

3. Methodology

In order to get proportions' dimensions of Yazd traditional houses open spaces, after general introduction of Yazd city and types of yards, the city climate information was collected at first place; This information was estimated by using of Penwarden criteria emphasizing on thermal information and radiation in second place, then needed shade and sun times were specified. In order to review and case study of open space, shade and sun mask for each one of Yazd traditional houses drawn separately. At this stage, the relationship between courtyard

proportions (length, width and height) and shadow formation level in open space in Yazd considered. After analyzing of different types of open space (deep and wide), strategies and guidelines suggested for optimal proportions and dimensions regarding to aforementioned factors consideration and their results have presented.

4. General Introduction of Yazd City and Types of Yards in Houses of Yazd

4.1. Yazd

According to historical books, Yazd has a long history. For Zoroastrian, it was a holy city and a shrine for Persians of India and revered like the Mecca for Muslims. Yazd in Persian language has common root with word of God and it means pure, holy and worthy of praise and creator of goodness.

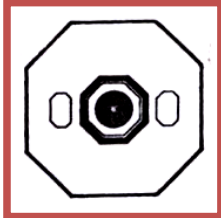
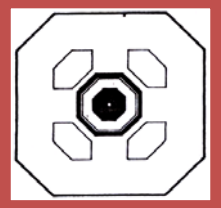
Yazd is located in the East of Isfahan and south of Lut desert in latitude of 31 degrees and 25' in the center of Iran. The absolute minimum mean temperature is 16 °C and the maximum absolute is 45 °C. The number of sunny days is 300 days thus it has a desert climate.

4.2. Types of yards

Yard is the heart of a traditional house and is the most private open space and this characteristic places yard in a higher order than other open spaces. The houses only have the view of yard in a compressed and back - to - back format. Tall walls determine the exterior limit of the house from outside.

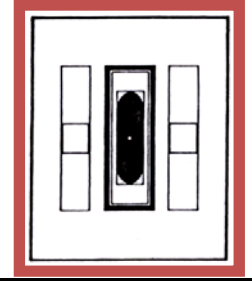
Types of typical yards in traditional houses have formed according to the material and spiritual needs and in compliance with hierarchy of private and public spheres. They have known as Narenjestan, Exterior and Interior [Table 1] and the yard dimension is proportional to the number and type of rooms around it.

Table 1 Types of yards in traditional houses in Iran

4-2-1-	Narenjestan Yard	A very small yard with an area that can be covered in order to avoid citrus trees to get frostbitten in winter [^]. In the book of "Iranian Architectural encyclopedia", Narenjestan describes as a place that can be covered and orange and other trees can be planted in its garden. Narenjestan's yard is a small yard in the interior set and in addition to providing light for the surrounding spaces; it provides the possibility of keeping the plants that are sensitive to freezing nights of winter in desert areas [9].	
4-2-2-	Exterior yard	A small square or rectangular yard that is open to guests and ones who are not relative of the house.	

4-2-3- Interior Yard

It is a big yard and its proportion accords with the location of rooms around the house, and sometimes it is very close to the garden size. This yard generally has a rectangular shape and is specifically for the family life, and in hierarchy of private and public spheres, it is the most private yard and others should not enter it.



The unique features of such yards such as sitting lower than street level, tall external walls and the solar orientation of the house mean accordance of yard diameters on north-south axis or alignment of one side of yard toward Qibla. In addition, they create a construction that provides the highest shade level during the hottest hours of summer and the deepest penetration of warming sunlight to the depth of the rooms in winter. By this solar orientation, the yard's four axes become specific areas and each front of the yard allocated to specific season.

5. Analysis of Yazd Climate Information

Since 64.66% of the country's land area of 1,046,446 square kilometers is in arid and ultra-arid climate [10], determining the range of thermal comfort in this climate was a priority. Therefore, Yazd, located at longitude of 054°24'E and altitude of 1230 meters above sea level, with dry and cold climate and no humid month was considered an ideal example of arid climate [4].

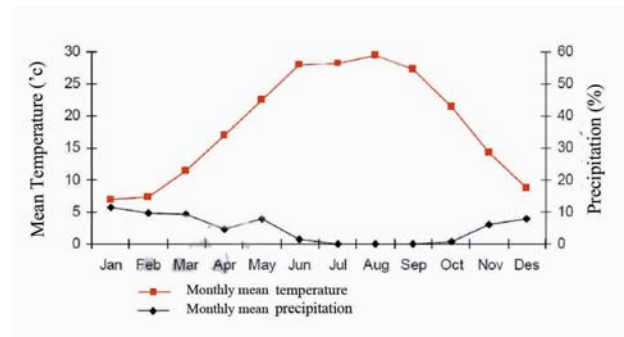


Fig. 1 Climagram of Yazd station from 1997 to 2006 [4]

5.1. Detection of heat and cool and comfort times

Comfort availability process is a complex and dynamic process that many factors play role in it. Penwarden has studied Comfort relationship with two groups of factors: a)

atmospheric such as wind, temperature, and radiation, and b) Manmade such as human dominant behavior in outdoors [11].

According to Penwarden criteria [12] (Fig. 2) and based on temperature reports from meteorological station of Yazd, comfort times, times of need to solar or wind energy, and heat and cool times in open spaces is detected. Temperature of 16 to 22°C creates a sense of definite comfort. Temperature of 4 to 16°C and 21 to 25°C, respectively, give a sense of comfort at sunny and windy conditions. At temperatures higher than 25 °C, the weather is hot and even the wind does not help to relieve the hot weather. It is cold at -4 °C with the sun and no wind, and at lower than 3 °C at nights with no wind [13].

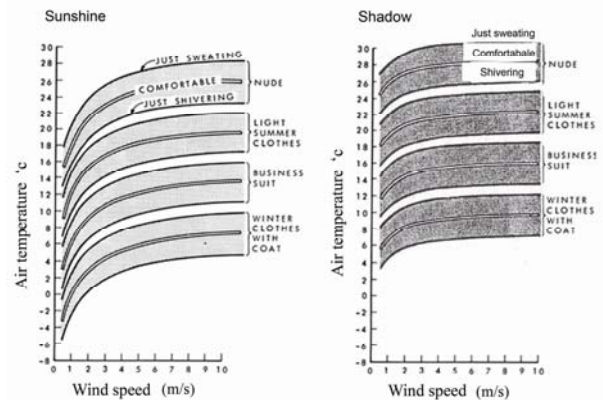


Fig. 2 Penwarden comfort criterion in shade and sunshine [12]

By calculating monthly and annual mean relative humidity and mean dry temperature of Yazd station during a 10-years statistical period (1997-2006) (Table 2), it is obvious that Yazd lower and upper limits of thermal comfort (Fig. 3) in summer is 21.2 c' and 28 c' respectively and lower and upper limits of thermal comfort in winter is 20.4 c' and 24.8 c' respectively [14].

Table 2 The mean monthly and annual dry temperature and relative humidity of Yazd station (1997 to 2006) [15]

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Dry temperature	6.49	9.98	14.62	20.84	26.28	31.18	33.44	33.54	27.66	21.39	12.89	8.1	20.34
Relative humidity (%)	52.8	36.3	30.4	25.6	18.9	13.6	14.5	13.3	14.6	21.8	37.5	50.6	26.9

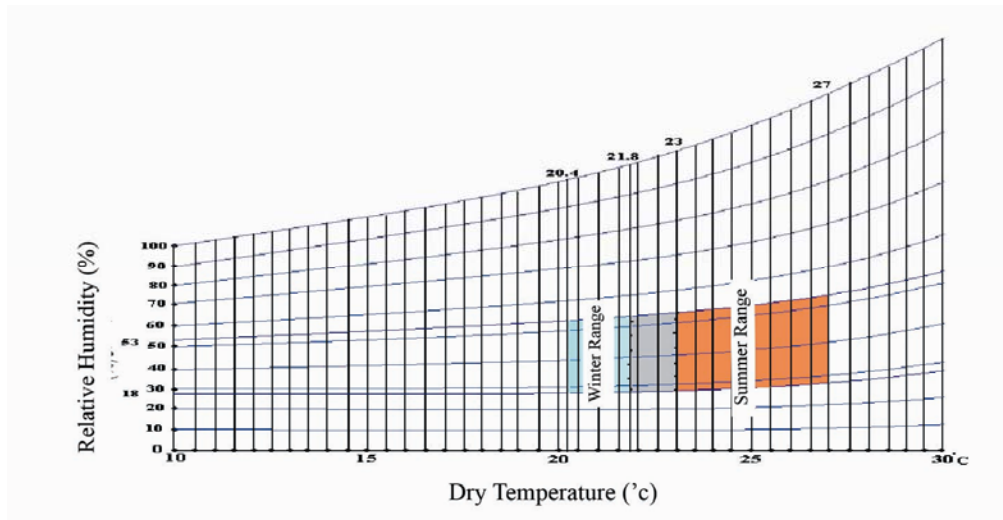


Fig. 3 Table of bio-climate thermal comfort in summer and winter for the city of Yazd [4]

By checking the temperature every three hours and according to Penwarden diagram [12] (Fig. 2), times, heat, cold and comfort in open spaces is presented. The information in the mentioned figure (Fig. 4) can be elaborated as follows. Heat is probable from early April to early May and from late October to late November from around 9 AM till sunset and from late June up to mid-August all day long. Cold is more likely from late night till

dawn especially between 3 and 4 AM, from late December till late February. At times in December, January and February around noon and sometimes in the morning and evening of March, May and November, it is possible to feel comfortable. In other times of the year, it is possible to feel thermal comfort in case of proper utilization of radiation, shade and wind [15].

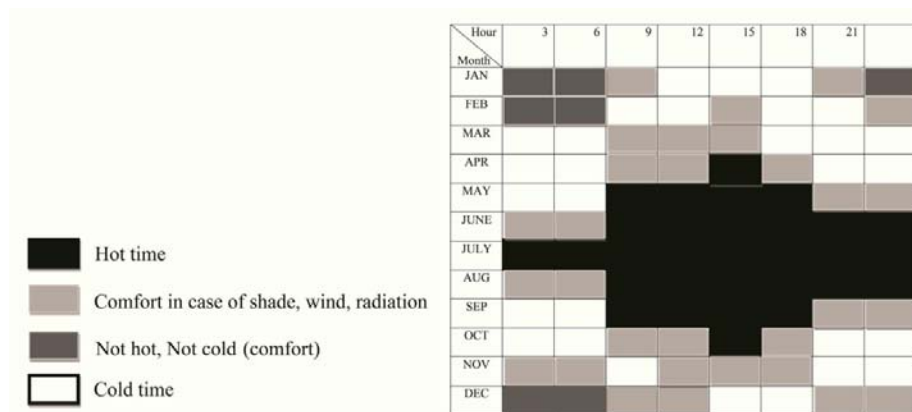


Fig. 4 Hot, cold and comfort time of the year in open spaces of Yazd [15]

5. 2. Determining the times that sun and shade are required

Needed sun and shade times in open spaces recognized according to Penwaden criteria (Fig. 2) and air temperature in Yazd meteorological station (Fig. 5) (As can be seen on the vertical axis of this table as dry temperature, needed sunlight, etc.). Thermal comfort is obtained in temperatures lower than 4.4 ° C in case of sunshine. The sunrise in open spaces is permitted from 4.4°C up to 12°C. In a temperature between 12 to 22°C, the sunrise in open spaces has no problem. In a temperature above 22°C, the sunshine is irritating [13]. Using temperature data for every three hours in Yazd and according to Penwarden criteria (Fig. 2),

needed sun and shade times in open spaces presented in the table. The information of mentioned table include: from early April till early June and from early September to early November from 9 AM till sunset and from early June to early September all day long, the sunshine disturbs people's comfort. In short times in the mornings in December, January and February, solar radiation is the only requirement to have comfort in open spaces. From late December until late January, from around 6 AM until sunset and sometimes during morning and evenings for short times in November, December, February and March, it is possible to tolerate sun. In other times of the year, solar radiation is fine if the wind is blowing (Fig. 5).

As can be observed in data from Yazd meteorological station regarding sunny times and cloud coverage in the sky,

in 3 cold months of December, January and February in which according to shade and sun requirement, sunshine is rather essential and fine in open spaces, the weather is sunny in 50% of the times. In hot times from mid-June till early

October, the weather is sunny in 90% of the times. Since Yazd is located in a desert hot and dry climate as can be interpreted from meteorological data, its sky is sunny most of the time.

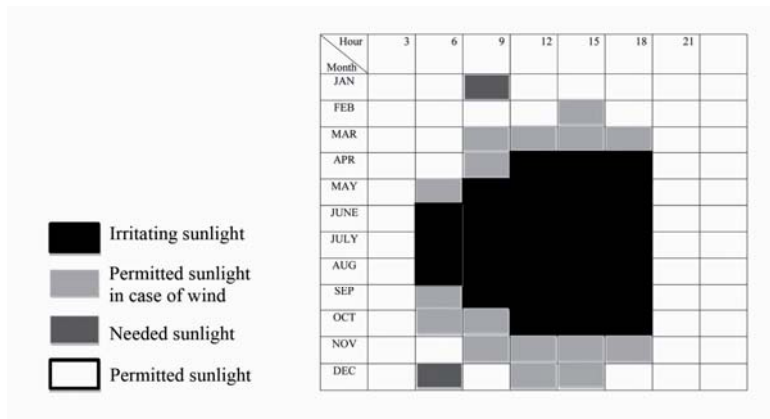


Fig. 5 The times that shade and sun are required in open spaces of Yazd [16]

6. Factors Affecting Thermal Comfort in Open Spaces

6.1 Human and thermal comfort

Dealing with unwanted heat and cold environment is one of primary concerns of human beings. Body organs particularly brain cells have a desirable efficiency when they operate at a constant temperature. Therefore, in order to gain physical and mental comfort, body temperature should remain constant despite changes in the surrounding temperature. If surrounding temperature is controlled and kept constant by proper designing, activity of body organs to regulate and stabilize the heat would be reduced and efficiency of physical and mental abilities will increase [16]. Hence, thermal comfort is defined as the sum of situations that human mind is satisfied with its surrounding (thermal) environment [17]. Thermal comfort easily generalized into physical, physiological, psychological, cognitive, communicative, behavioral, and optional comfort [18].

6.2. Factors affecting thermal comfort in public open spaces

According to the definition, thermal comfort is a range of temperature and humidity in which mechanisms of body temperature regulation has its least activity [19]. Creating thermal comfort in open spaces is not possible unless gaining a thorough understanding of the factors affecting the thermal condition of these spaces because these factors change their surrounding climatic factors by intensifying or weakening the climatic factors at micro-scale. Therefore, first we need to know the influential factors. As emphasized earlier in this paper, solar radiation has gotten more attention among natural factors affecting thermal comfort. Solar radiation is one of the most important exothermic and cryogenics natural energies that affect

environment temperature by amplification or modulation. On the other hand, man-made ones are also important such as orientation, size of buildings in open space, density, height, geometry [16].

7. Analyzing the Influence of Man-Made Structures on Thermal Comfort

In this section, aiming to utilize these potentials and controlling the undesirable situation, the man-made structures of the residential complex (orientation, dimensions, proportions and some other things related to open spaces) will be analyzed. As mentioned, man-made structures in small and moderate scales affect the climate conditions, and create an artificial climate that is different from the meteorological data of the region. However, how can this man-made climate be created in accordance with human thermal comfort by maximum use of the potential resources of the environment? In this regard, the effects of man-made structures on climatic phenomena such as weather temperature and radiation in residential complexes are investigated in this section. To investigate the effect of man-made structures on thermal conditions of open spaces, plan of several housing complexes in Yazd will be examined as subjects with certain assumptions.

As we know, sunlight is always necessary to create a natural lighting but since this light is converted to heat, it must be controlled based on climatic conditions. In open spaces such as streets, yards etc. what causes the increase in temperature due to solar radiation is the little heat that is directly taken from the sun and mostly from the indirect heat which is received from objects on the earth [20]. According to studies, the cooling effects of the plants in lowering the temperature in cities is felt when the area of green spaces encompass 10% to 20% of the city area [21]. This can be found in the historical texture of Yazd city. Therefore, small dispersed green spaces are more effective in modifying the surrounding air in comparison with large, compacted green spaces [21].

Regarding to relationship between solar radiation, shade and temperature, in order to reach to a favorable state, the solar radiation intensity on various surfaces, sun and shade levels in open spaces and external walls of buildings should be control. Therefore, the ideal condition to utilize solar radiation is considered as follows: use of minimum radiation and heat (maximum shade) during the warm months and maximum utilization of radiation and heat (sun) during cold times of the year. Detection of sun and shade conditions in various levels (including open spaces and building) performed with respect to the shade mask concept. Therefore, at first place concept of shade mask investigated from the perspective of the people residing in the complex.

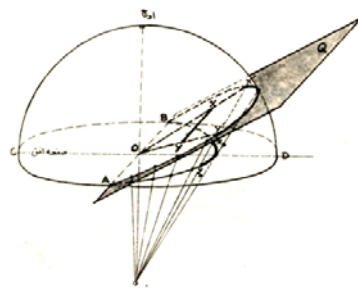


Fig. 6 Stereograph of a direct horizontal line shade mask [22]

7.2. The sun and shade mask in yard

According to shade mask concept, a yard is considered to be in a shade when the sun in the sky cannot be observed from inside the yard; otherwise, the yard is located in a sunny area. In yards etc, proportion (proportion of wall heights H , to width W) and orientation issues considered as important factors in determining shade and sun level in open spaces that can be an important factor in thermal comfort of open spaces. In this regard, relationship of yard proportions such as length, width, height, and the size of shade can be found by investigating real shade mask of several yards of Yazd houses.

8. Investigation of Shade and Sun Mask in Several Houses of Yazd

The purpose of investigating shade and sun mask in several houses of Yazd is to reach guidelines and rules for thermal comfort in open spaces of residential complexes such as issuing climatic rules for the best orientation and the best yard proportions. In this regard, real shade and sun mask was investigated for 10 old houses in Yazd which provided the best thermal comfort without any mechanical or electronic utilities. This could be a great help for designers to provide the thermal comfort in open spaces of residential complexes

7.1. Shade – sun mask

The shade mask concept determined in accordance with people living in the complex. For instance, consider an observer standing in a wide area, environmental conditions are such that he can see the sky hemisphere from one horizon to the other. Now, if a dark object is placed in front of the observer's sight so that he cannot see a part of the sky and the sun is hidden from his sight (behind the mask) while passing that point, the person is placed in the shade. By drawing the hidden part figure on a horizontal surface using solar direction chart, the shade mask of the object is attained. This opaque object can be a tree or any vertical surface or cloud, horizontal shade and other types of horizontal surfaces [۲۲]. The following figures clarify the concept of shade sun mask (Fig. 6 and Fig. 7).

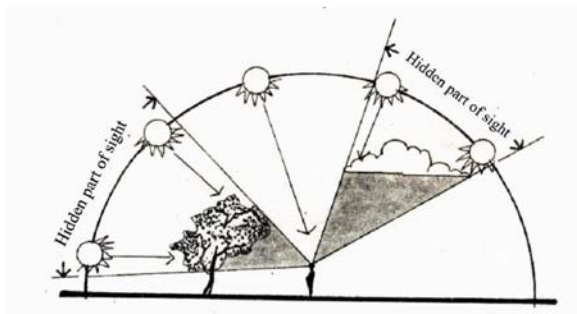


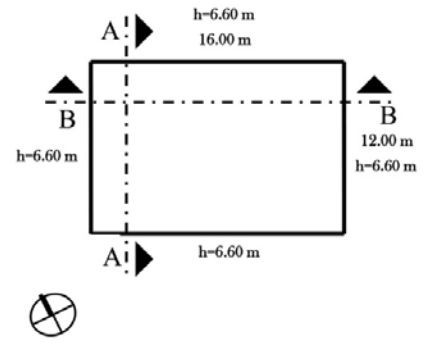
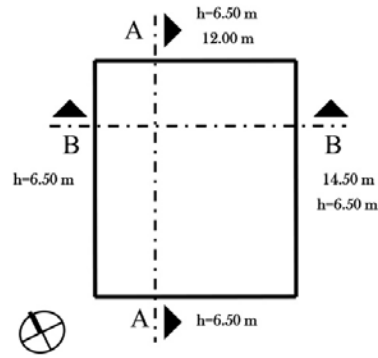
Fig. 7 Opaque objects such as tree, cloud etc that hide a part of sky hemisphere [22]

nowadays. The studied houses are located almost in one district. Their names are as follows: Arab Mohit's house, Ebrahim Pour's house, Fazeli's house, the Laris' house, Malek Zadeh's house, Koochak Arabha's house, Nazeri's house, Shahid Sadooghi's house, Shafi Pour's house, an old house in Yazd. The investigation of dimensions and proportion of yards and their real shade and sun mask is presented in the following table:

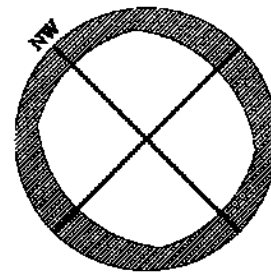
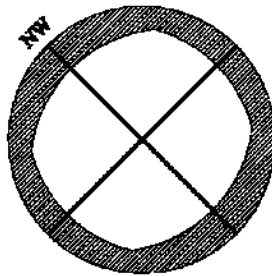
Table 3 The summary of investigation on Yazd houses data

	Laris' house	Arab Mohit's house
Plan		
Proportions and yard's wall sizes		
Real shade mask		
Proportion of length, width and height of yard	$H/W=0.38$ $L/W=1.70$	$H/W=0.41$ $L/W=1.40$
	Shahid Sadooghi's house	Malek Zadeh's house
Plan		

Proportions and yard's wall sizes



Real shade mask



Proportion of length, width and height of yard

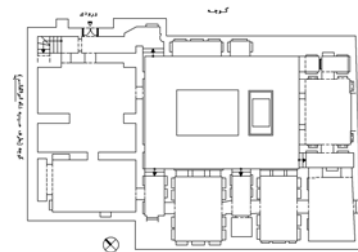
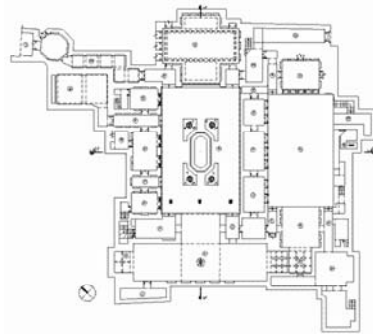
$H/W=0.54$
 $L/W=1.20$

$H/W=0.54$
 $L/W=1.20$

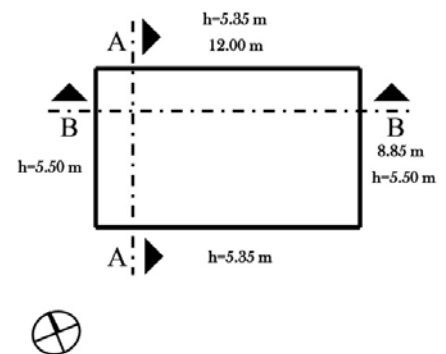
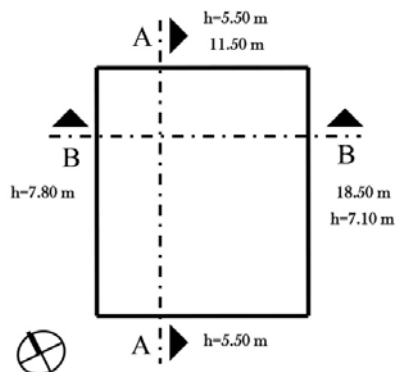
Shafi Pour's house

Ebrahim Pour's house

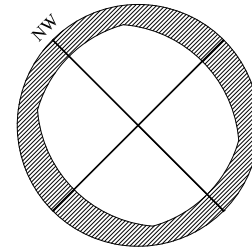
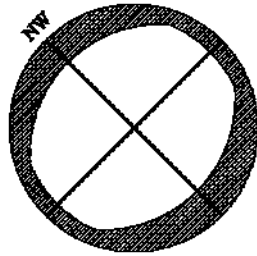
Plan



Proportions and yard's wall sizes



Real shade mask



Proportion of length,
width and height of yard

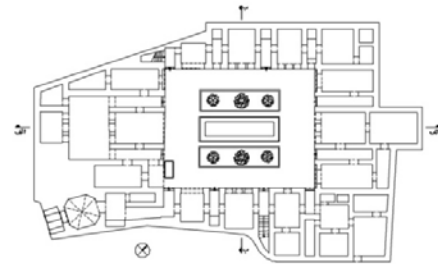
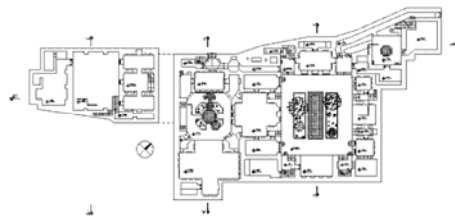
$H/W=0.65$
 $L/W=1.60$

$H/W=0.44$
 $L/W=1.35$

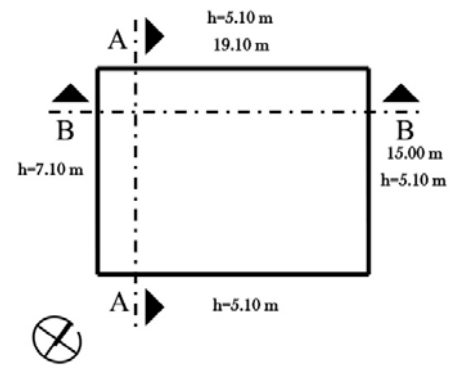
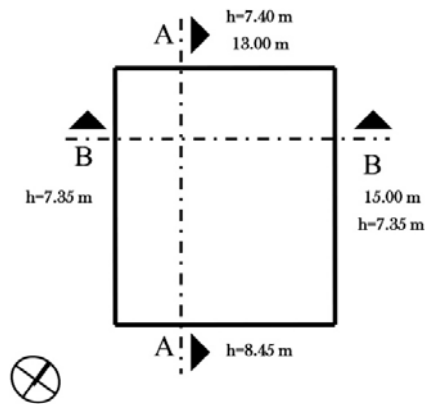
Koochak Arabha's house

Fazeli's house

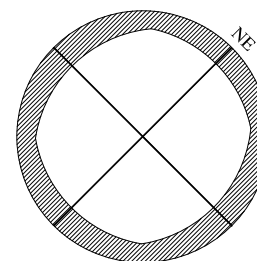
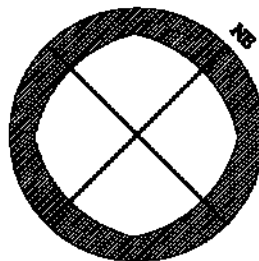
Plan



Proportions and yard's
wall sizes



Real shade mask

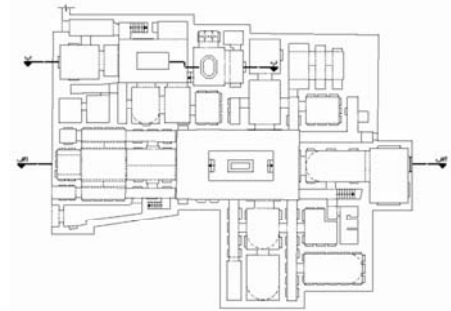
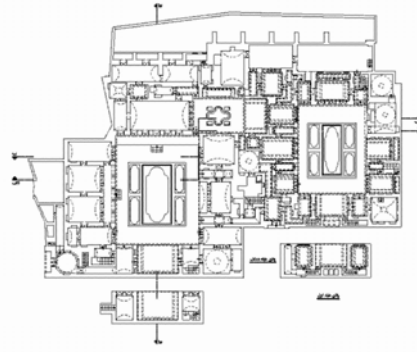


Proportion of length,
width and height of yard

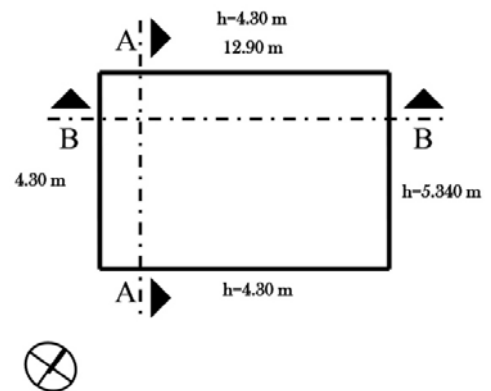
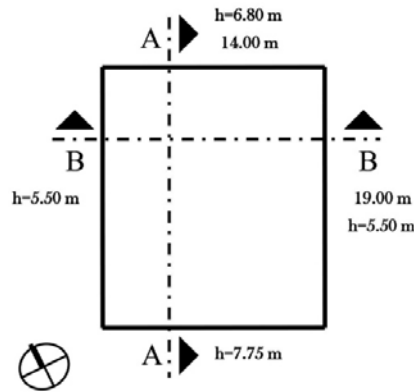
$H/W=0.56$
 $L/W=1.20$

$H/W=0.33$
 $L/W=1.30$

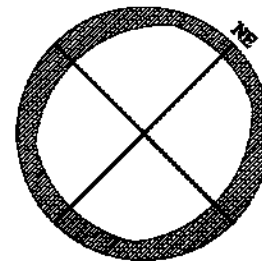
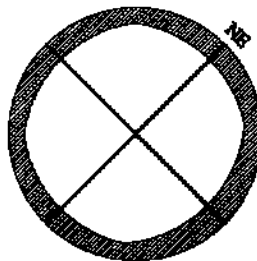
Plan



Proportions and yard's wall sizes



Real shade mask



Proportion of length, width and height of yard

$H/W=0.4$
 $L/W=1.35$

$H/W=0.58$
 $L/W=1.75$

9. Conclusion and Issuing Sectional Orders

Overall, the yards or open spaces can be labeled as two headings: the wide open spaces and the deep open spaces. In wide open spaces, the proportion of height to width of the yard is $H/w < 1$. This means the proportion of yard height to width is less than 1. Yet, in deep open spaces, the proportion of height to width of yard is $H/W > 1$. This means the proportion of yard height to width is more than one. In wide open spaces, there is so much sunlight in the space; therefore, wide open spaces with any kind of orientation provide better conditions in cold times. However, deep open spaces provide more shade during the year and their orientation in creating ideal shade and sun situation is prominent [23].

In general, according to the dimensions of the studied yards, all the yards can be labeled as wide open spaces: $H:W < 1$. By comparing shade masks, it can be concluded as: $0.33 < H:W < 0.6$, also by comparing yard dimensions, it can be concluded that it is $(1.2 < H:W < 1.7)$ which is almost equal to golden ratio. Regarding the effect of orientation on solar radiation, it can be said that northeast-southwest yards are solar absorber in the morning during hot seasons and in the afternoon during cold seasons. Definitely, the former is more related to Yazd houses, which is why orientation in most houses in Yazd is northeast-southwest.

The open spaces contain favorable shade and sun during the year if they are sunny during cold times hence open spaces should be wide during cold times. However, open spaces should provide shade during hot times. Consequently, open spaces should be deep during hot

times. Regarding level of solar radiation, it could be concluded that during either cold times or hot times, the walls in deep open spaces and the floor in wide open spaces have the most share of receiving the solar heat. Regarding Yazd in which most yards are wide open spaces, the floor has the highest energy absorption and is the most effective in increasing the surroundings heat in both cold and hot times [24] (Fig. 8).

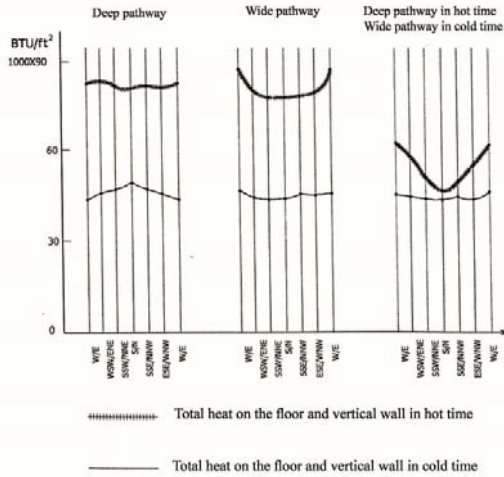


Fig. 8 Solar energy received in deep and wide pathways [2]

Maybe it is assumed that these yards have been designed wide, but by considering the heat absorption by

open space walls during hot times and the importance of open space floors in receiving heat during cold times, the best conditions is to make wide open spaces and the shade be provided by various shades and small leaf trees during hot times. Based on shade and sun mask in Yazd's traditional houses, designing deep open spaces deteriorates situation and while it provides shade during summer, it does not provide a favorable situation for winters.

The existence of a fixed shade and deep propositions does not help to sun - shade and thermal comfort conditions. Therefore, arrangements to use natural mobile vertical shades such as trees and plants on the surface and roof top sounds more logical for arranging the proportion of width to height (Fig. 9).

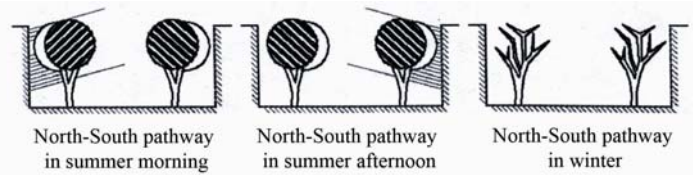


Fig. 9 Mobile shade to fix H : W proportion [23]

Using trailing plants as a cover and temporary roof can improve the space quality in addition to providing comfort (Fig. 11 and Fig. 12).

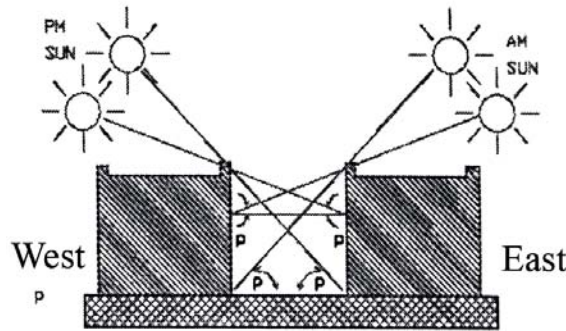


Fig. 10 The impact of H : W dimensions on shade and sun in open spaces [21]

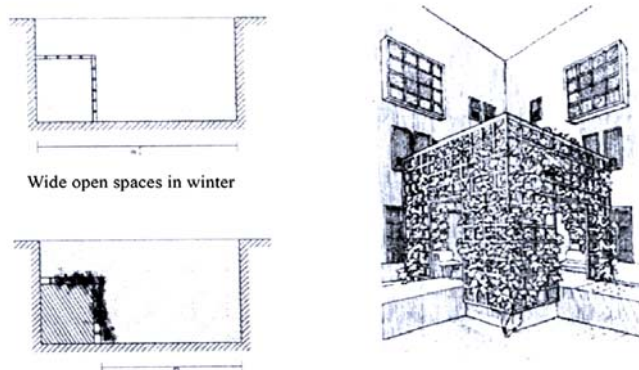


Fig. 11 The arrangement of open space dimensions in winter and summer using trailing plants [21]

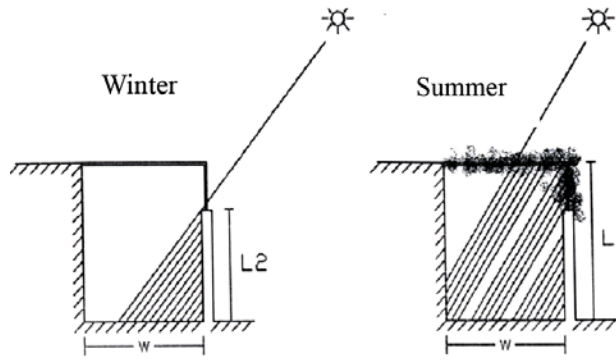


Fig. 12 Using trailing plants as a temporary horizontal shade ($L1 < L2$) [23]

Creating a transparent layer like a porch or portico in open spaces can also be effective in reducing the solar radiation and providing the required shade for people (Fig .13). Since in traditional houses in Yazd, this possibility is

considered for the adjustment of width to height proportion and we see the design of a half-open porch of 3 m deep for each floor so that provides the favorable shadow and sunlight at hot and cold times.



Fig. 13 Porch as a fix shade toward south front [25]

The most important point regarding all the traditional houses of Yazd is that these open spaces are sunny with any type of orientation, dimension and proportion, in direct sun radiation during summer afternoons regardless of the ideal situation and the only solution is to use horizontal shades in open spaces and yards. In the past,

trees used instead of pergolas to function as horizontal shades and provide maximum shade. Results of open spaces orientation can be summarized in table 4, regarding to ideal situation and previous studies on shade, sun and intensity of solar radiation in yards.

Table 4 Orientation and proportions in streets and open spaces

Orientation	Hot seasons	Cold seasons
Radiation and Temperature		
Consider north – south orientation up to 30 degrees deviation for open spaces on condition that: Open spaces be deep in hot seasons open spaces be wide in cold seasons		

The ideal design of open spaces provided by considering right proportions and orientations, sun and shade masks of the walls and with the help of ideal green

spaces so that it would be useful in creating thermal comfort and health of people in open spaces.

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