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Original Research Article

An Investigation of the Relation between the Structural Components of the Vernacular Houses in Hot and Arid Areas in Iran (Case Study: Qajar Houses in Yazd)*

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Abstract

Problem statement: Environmental issues and energy crisis are among the problems of contemporary man for which the local architecture in hot and arid areas in Iran has offered some wise solutions. This kind of architecture could obtain great success in thermal balancing with the help of suitable materials and knowledge of the local architects. That is why recognizing the patterns of this architecture can be useful for designing modern houses. This research studies the structural components of Yazd Qajar houses in the hot and arid areas of Iran. The statistical population of this study contains ten traditional houses in Qajar era because most of these buildings have been built in this period.

Research objective: The main objective of this research is recognizing the structural components of the vernacular houses in hot and arid areas in Iran. The main questions are about the ways the structural components of this area could reach to a climatic accordance.

Research method: The correlation method has been used for finding the relations between different spaces and geometric patterns. Data analysis and achieving to the conclusions have been done by comparison and induction. After doing field studies and collecting data, the measured dimensions of the structural components have been presented in different tables. The design standards used by traditional architects and also the structural patterns have been surveyed. The proportions and spatial relations between various areas have been investigated. According to the aim, this is a quantitative-qualitative research.

Conclusion: The correct proportions of the structural components in hot and arid areas in Iran have been reported. This study pointed out that this kind of architecture (in its entirety and details) is in harmony with climatic conditions. Obtained results indicated that these traditional houses could provide the comfort of the residents. The results of this research show the success of traditional architects in reducing consumption of energy. The findings of this study may contribute to the knowledge of architects in new residential design and reduce energy expenses.

Keywords: *Vernacular Architecture, Hot and Arid Area, Yazd Houses, Structural Components, Climatic Accordance.*

* This article is extracted from Yasaman Yzadi's Ph.D. dissertation entitled "A Survey on the Relationship between Central Courtyard and Summer Hall, Ivan and in their Intact on the Sustainability of Residential Architecture in Hot and Arid areas of Iran (Case Study: Yazd Vernacular Houses in Qajar era)" which is done under supervision of Dr. Seyed Majid Mofidi Shemirani and advisement of Dr. Iraj Etesam at Islamic Azad University, Science and Research Branch, in 2019.

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Introduction and problem statement

Nowadays, the energy crisis and environmental issues have affected many human activities. They also caused some difficult problems for architects to reduce energy consumption. Architecture may be perilous for the environment and nature but on the other hand, a reasonable design can benefit from the climate factors. The ancient Persian architecture, especially in hot and arid areas, has been successful in coordinating with the environment and confronting from hard climatic situations. The traditional architecture with their precious experiences could present some valuable patterns and wise solutions in sustainable architecture. Building typology in different areas shows that the architecture of these areas is influenced by some climatic and even cultural factors.

There are various kinds of architecture in Iran which are in harmony with four climatic areas and the house architecture, as the first human residence, follows their rules. The hot and arid architecture succeeded in thermal balancing with the help of its elements, materials and also the knowledge of the builders. The main purpose of this article is cognition the ways of accordance between the hot and arid climatic situations and the physical elements such as three-door room (Sedari), five-door room, (Panjdari), winter room (Zemestantan Neshin) and summer room (Tabestan Neshin). Recognizing the functions of these spaces has been also considered as the main purpose. After gathering necessary information about Yazd Qajar houses, the physical elements containing the building establishment system, courtyard and water application were surveyed. By measuring the dimensions of different spaces, general geometric structure of the building, visual components and their links were analyzed. For achieving the main purpose of this research, it is necessary to answer a couple of questions:

- What are the relations between the structural components of Yazd endemic houses in the Qajar era?
- By which ways the architecture of Yazd endemic houses interact with the hot and arid climate situation?

Research method

The correlation method was used for finding the relations between different spaces and geometric patterns. Data analysis and achieving to the conclusions have been done by comparison and induction. After doing field studies and collecting data, the measured dimensions of the structural components have been presented in different tables. The design standards used by traditional architects and also the structural patterns have been surveyed. The proportions and spatial relations between various areas have been investigated. The proportions and spatial relations of various areas were investigated. The statistical population of this study includes ten traditional houses in the Qajar era because most of these kinds of buildings have been built in this period.

Research background

The most relative studies are as follows. Soflaee (2004) has examined the courtyards of different houses in the four hot and arid climatic parts in Iran and compared them with each other. The correct climatic proportions of the courtyards and the summer halls have been also reported.

Ahadi (2013) has studied the climatic architecture of the courtyards in the residential buildings of the cold areas in Iran. The physical structures as well as climatic standards have been verified in the selected cases of the cold areas.

Sohrabi (2015) has studied some climatic functions of Ivans[1] in traditional buildings of the hot and arid areas in Iran. The two local Ivans on the adjacent residential spaces have been also surveyed.

Nikghadam (2013) has examined the climatic patterns of the courtyards in the residents of hot and humid areas. The endemic residential arrangements in different parts of the hot and humid areas have been also verified.

Ahmadi (2012) has examined the courtyards which are in harmony with the dessert architecture and the principles of the sustainable architecture. A comparative study among some cases has been also carried out.

The background of the studies shows that some reviews about the typology and the structures of the houses in hot and arid areas have been done. On the other hand, the components of these houses have been also surveyed; but the relations between the basic spaces of these houses have not been surveyed. This article studied the role of the courtyards, as one of the components of residential architecture in hot and arid areas. Some typological studies with the structural approach have been also carried out. In these studies, the main focus has been on the details such as windcatchers (Badgeer)[2], shading forms and geometry of the openings (Bazsho).

Theoretical foundations

In desert areas and its margins, different spaces of the houses are very restricted and enclosed. This spatial organization is important from a belief and psychological point of view and also allows the houses to have less visual and physical connection to the exterior dry environment. For harmonizing with nature, the architecture of this area has put forward the internal migration. According to this principle, all spaces of the house have been divided into summertime and wintertime parts. The summer spaces[3] include underground, hall (Talar), Hozkhaneh4, stable, payab[5] and Tanbi[6]. The winter rooms include some spaces such as Tehrani, three-door room (Sedari), five-door room (Panjdari), upstairs room (Balakhaneh), Korsikhaneh. The summer part is located in the eastern front and the winter part is in the opposite front. To benefit from the eastern light, some arcades and small Ivans have been built in eastern front. To benefit from the eastern light, some arcades and Ivans have been sorted in the eastern front (Memarian, 2008, 266).

Yazd traditional houses, with the whole design in common, are usually extensive patriarchal ones belonging to the Qajar period. Introversion is the main characteristic of these houses; the outer walls were left flat and shapeless while more credit was given to the inner walls. Another feature of these houses is their alignment with the hard nature of the area. To cope with a hot and arid climate, the traditional architects made deep and shady yards in the middle of the buildings and connected open spaces with the closed ones. Making semi-open spaces as the most important locations in the house was another way to coordinate with the hot climate. Native architects used other ways to deal with the tough climate; they made high windcatchers, sunscreens (Aftab shekan), thick walls and arcs, pools and gardens. For creating a suitable place to live in a desert, the local architects made Daarbands, flower beds and pools in the yards and benefited from roofs and basements.

- **Main spaces of the house**

Over time the main spaces of the houses in Yazd reached a high-grade of evolution and expansion. The most important components which have been surveyed in this research are the halls, courtyards, pools, Ivans, summer space, winter space[7] and three-door and five-door rooms. Yazd houses, even the simplest ones, have welcoming entrances. The entrance and the clay wall have the same altitude. The surfaces of the entrances have been usually covered with some decorative motifs. The Hashtis[8] are in different forms and usually located in one of the corners of the plan. The dimensions of Hashtis are different. Their coatings are varied too; Karbandi[9] has been used in some houses like Rasoulian, Mortaz, Hadj Arab Kermani, while Tarkin vault[10] has been used in Lariha house. According to their desired functions, different components have been established in each side of Hashtis. These components are platforms, hallways to the yard, stairs to the roof (Rahbaam) and stairs to the well cellars (Chah khaneh) (ibid., 285).

In Dehkhoda dictionary, Hayat (yard) means enclosure and enclosed place. It also means a

house (Dehkhoda, 1994, 146). Another definition for Hayat is a roofless room as the basic center of the house (Ferrer-Forés, 2010, 840). A courtyard in Yazd houses is a perfect sign of extraversion. It is also an important element for organizing different spaces in various seasons. Its motional and communicative role is another characteristic of the yard whose dimensions may vary according to the total area and the required spaces. The yards regarding their areas and design, are divided into inner (Andarooni) and outer spaces (Birooni). Hall (Soffah) as a semi-open space is a common and important place in all Yazd traditional houses. This architectural element has a history of several thousand years. Windcachter (Badgeer) is usually located behind the hall but in some houses like Lariha, Rasoolian, Haj Arab Kermani, it may be built completely separated from the hall and located in a room with basin (Hozkhaneh). The function of the hall (Talar) in overall space and producing a major axis in arranging other spaces is also significant (Memarian, 2008, 276).

Except in very cold days of the year, the hall is the most important space in the house. It is located on the southern front of the house to protect residents from direct summer sunshine (Figs. 1 & 2). The shape of the hall may be square or rectangular. One or two squares called Goushvareh (ring), may be connected to it and change its form to a cross. Some Oresis[11] with five, seven or nine doors are in the front part of the hall, opposite to the yard (Pirnia, 2003, 164). The ceilings of the halls are high for better ventilation. Dome-shaped ceilings and the shadow on them prevent heat increase. The holes in the ceiling called Herno[12] provide better light and ventilation for the hall. For controlling the heat of the inner spaces, the architects made thick walls and used the material with high thermal capacity (Bayat, 2017, 194). The rooms are arranged in different fronts of the yard with special order. They are related to each other by a corridor. The winter room (Tehrani) is located on the main axis of the house, along with Talar. Some Tehrani rooms are cross-shaped; this type can be seen in Nematolahhi and Hadj Arab Kermani houses. The rooms in the margin of the yard get light through the doors, windows and Goljaams. These elements, in their original forms, are located in some horizontal or vertical Tabeshbands[13] enclosed in a frame. The rooms which do not overlook the yard get light through the ceiling. Five-door room (Panjdari) is used for family gatherings in the early days of spring and autumn; it is a winter room. Tanbi which is located between the hall and the Windcatcher is a summer room used for relaxing and sleeping. The autumn and winter rooms are in the western and northern fronts of the house while the summer rooms are settled in the lightless front. The kitchen is usually located close to the winter rooms (Memarian, 2008, 286).

- **Climatic studies and the structure of Yazd houses**

Yazd is the third largest province situated in the middle of the central plateau of Iran and some

Fig. 1. Fatehha House, Summer Hall in northwest and south of the haj abdol-vahab Yard. Source: Hadji Ghasemi, 2004, 131.

Fig. 2. Lariha House, Summer Hall and Windcatcher in Northwest Front of the main Yard. Source: Hadji Ghasemi, 2004, 17.

vast parts of it are situated on different desserts (Shayestehfar & Behzadi, 2011, 91). Yazd city is located in a wide valley in south east of Iran between Shirkooh and Kharanekh mountain ranges. Extensive parts of Yazd province is in hot and arid climate. Being far from big aquifers, lack of rainfall and abundant evaporation are some reasons for dryness of this province. Because of low humidity and being away from the sea, there is a big temperature difference during the day. On the other hand, severe desert winds spread sand and soil on biological areas and do not provide a favorable environment for living (Soflaee, 2004, 116). Climate is one of the most affecting factors in forming houses in the cities of warm and dry areas. Because of the intense sunlight and special climatic conditions, the cities have a compact structure to prevent the radiation of sunlight. The walls and ceilings are considered thick to protect the interior parts from outside heat. The urban structure is designed in a way that the arteries are open toward the desired wind and block the unfavorable wind and the sand storms (Tavassoli, 1974, 62).

One of the most widely accepted methods of climate divisions has been selected as the Köppen climate divisions system. One of the main reasons for the popularity of this method is its simplicity. Climate divisions of Köppen based on rainfall and the average monthly and annual temperature created on this basis are as follows:

- Tropical humid climate: A
- Arid and semi-arid climate: B
- Temperate and humid climate: C
- Cold climate: D
- Very cold polar climate: E

Due to the large size of the hot and dry area, the inter-climatic divisions on the Köppen climatic zoning map was chosen for selecting samples. The arid region (B) in Iran is found in two forms. The boundary between different climates in group B is not only determined by the amount of rainfall but the amount of transpiration. This area can be found in (BW) and (BS) forms; (BS) is semi-desert and foothills area. Based on Köppen classification, some sections of mountainous areas inside Iran are also parts of BS area. BW includes inner desert areas. The height of this area is less than BS area. Other small letters used in climate B are as follows:

h: The average annual temperature is more than 18 degrees Celsius;

k: The average annual temperature is less than 18 degrees Celsius;

k': The temperature in the warmest month of the year is less than 18 degrees Celsius;

s: Summer dryness, rain in the most humid month of summer, at least three times rainfall in the driest month in the summer.

w: Areas with dry winters, rainfall in the most humid month of summer, at least ten times rainfall in the driest month in the winter (Soflaee, 2004, 115).

The arid and dry regions in Iran can be divided into four (BShs, BSks, BWhs, BWks) inter-climatic zones (ibid., 116). According to Köppen classification, studies about climatic zones in Iran show that Yazd is located in BWhs zone (Mofidi Shemirani, 2007, 20) (Fig.3).

In the following, more details are shown about the the samples' plan and area in table 1 & 2.

Fig. 3. Inter-climatic zones in dry and arid climatic areas based on Köppen classification. Source: Mofidi Shemirani, 2007, 20.

• **Central yard and surrounding spaces**

Central yard plays an important role in confronting sunlight and also controlling the high temperature caused by the wind. The warm air of the central courtyard rises at night and the cool air above the yard gradually replaces it. Cool air is stored in the thin layers of the yard body and it is transmitted to the rooms and the surrounding spaces. In the morning, the central courtyard gets warmer slowly and the cold stays in the yard until the sun radiation comes directly into the yard (Fig. 4). The warm wind that during the day passes through the house does not enter the yard and only creates blinds inside the house (Dunhamm, 1960, 130).

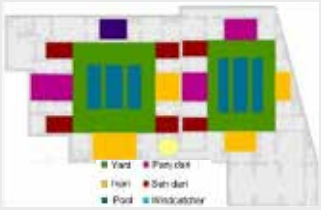
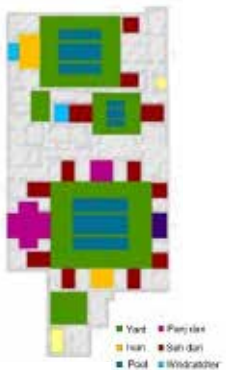
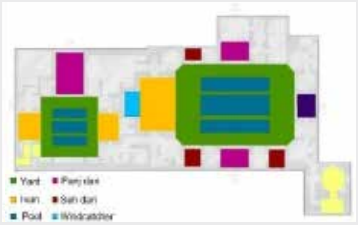
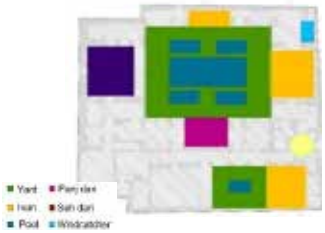
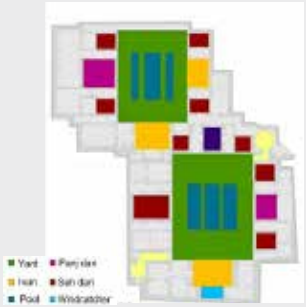
The results about the dimensions and proportions of ten houses and their relations with other spaces are as follows: The average length of the yard is 20.55 meter. The average width of the yards is 14. 66 meter. This average in all houses is within ±5 meter different. The average length to width ratio is 1.38 meter that is within ±0.5 meter different. The average area of the yards is 307.7 square meters. Table 3, 4 & 5 compares the proportions and dimensions of the surrounding spaces of the yards. The similarities and differences are also examined.

Symmetry is one of the important principles in designing houses in Yazd, to maintain the symmetry in the northern front; some spaces like five-door and three-door rooms have been arranged in front of the summer hall. For getting more sunshine, the depth of these rooms is considered less than their length. The most important space is in the front and on the south side of the hall; the rooms and the corridors are mirrored around it. The average area of the spaces on the southern front is 48.5 square meters. This average on the northern front is 42. 5 square meters. The north and south spaces have the same length on the front yard but the average area is more because of the greater depth of space on the southern front and also due to the presence of hall on this side. To provide the best ventilation, the length of the main space in southern side of the hall is more than other spaces (Bemanian, Gholami Rostam & Rahmatpanah, 2011, 20).

On the eastern and the western sides around the courtyard, five-door or three-door rooms are in the middle of the front with two smaller spaces around them. In order to maintain the symmetry of the fronts, there is always a main space on the eastern front opposite the similar space on the western front. The space in the middle of the yard on the eastern front is bigger than the same one on the western front which provides more comfort for the residents of the eastern front. The average area of space on the north side is 39.2 square meters and on the north side is 52.9 square meters. The east and west sides have the same length but because of the greater depth of the west side spaces, the rooms are larger on this side. More depth in the west front rooms reduces sunlight in this front. The depth of the hall (average 6.31 m) is longer than other spaces. To get better sunlight, all the south front spaces have more depth; the west front rooms have also deeper to protect residents from the sunshine.

Fig. 4. Fatehha House, Pools and Gardens Arrangement in the Yards. Source: Hadji Ghasemi, 2004, 129.

Table 1. Physical Examination of the Plan and Area of Different Spaces. Source: Authors.

Building Name	Physical Plan Review	Length of openings on four sides	Examination of the Area of Different Spaces
Fatehha House		North: 7.8 m to yard ratio: 53% south: 7.8 m to ratio to yard: 53% East: 7 m To yard ratio: 40% West: 10 m To yard ratio: 57%	Central Yard Area: 295 m² Summer Area: 64.5 m² (to yard ratio 19%) Five-door Area: 39 m² (to yard ratio13.2%) Three-door Area: 81 m² (to yard ratio 27%) Pool Area: 69.5 m² (to yard ratio 24%) Entrance Area: 9.5 m² (to yard ratio 6.5%) Winter Space Area: 19.5 m² Winter Space Length: 4.7 m² Winter Space width: 4 m²
Arabs House		North: 8.8 m to yard ratio: 53% South: 4.8 m ratio to yard: 30% East: 10 m to yard ratio: 41% West: 12 m to yard ratio: 50%	Central Yard Area: 413 m² Summer Area: 22 m² (to yard ratio 5%) Five-door Area: 41 m² (to yard ratio 10%) Three-door Area: 104 m² (to yard ratio 25%) Pool Area: 120 m² (to yard ratio 29%) Entrance Area: 14.3 m² (to yard ratio 4.5%) Winter Space Area: 58.8 m² Second Yard Area: 55.8 m² Winter Area: 18.5 m² Winter Space Length: 5 m² Winter Space width: 3.7 m²
Mortaz House		North: 8.4 m to yard ratio: 68% South: 10.4 m ratio to yard: 86% East: 8.8 m to yard ratio: 43% West: 8.8 m to yard ratio: 43%	Central Yard Area: 365 m² Summer Area: 73.42 m² (to yard ratio 20%) Five-door Area: 56 m² (to yard ratio 15%) Three-door Area: 18.42 m² (to yard ratio 5%) Pool Area: 129 m² (to yard ratio 35%) Entrance Area: 33 m² Second Yard Area: 132 m² Winter Space Area: 17 m² (to yard ratio 4.7%) Winter Space Length: 4.3 m² Winter Space width: 3.6 m²
Rasoulian House		North: 7.8 m to yard ratio: 52% South: 7.84 m ratio to yard: 52% East: 6.7 m to yard ratio: 33% West: 12.4 m to Yard Ratio: 62%	Central Yard Area: 300 m² Summer Area: 53 m² (to yard ratio 18%) Five-door Area: 33.34 m² (to yard ratio 11%) Pool Area: 113 m² (to yard ratio 37%) Entrance Area: 11.57 m² Second Yard Area: 60.10 m² Windcatcher Area: 6.8 m² Winter Space Area: 60.37 m² (to yard ratio 20%)
Farhangi House		North: 7.7 m to yard ratio: 50% South: 7.5 m ratio to yard:48% East: 9 m to yard ratio: 43% West: 9.8 m to Yard Ratio: 48%	Central Yard Area: 320 m2 Summer Area: 38 m2 (to yard ratio 12%) Five-door Area: 19.14 m2 (to yard ratio 6%) Three-door Area: 87 m2 (to yard ratio 27%) Pool Area: 75 m2 (to yard ratio 24%) Entrance Area: 33 m2 Second Yard Area: 238 m2 Winter Space Area: 16 m2 (to yard ratio 5%) Windcatcher Area: 9.6 m2

Rest of Table 1.

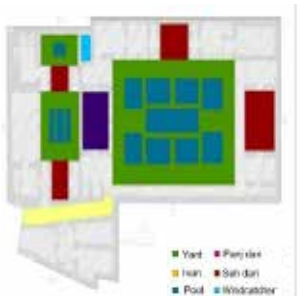
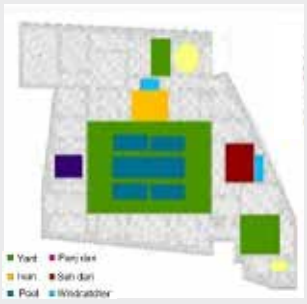
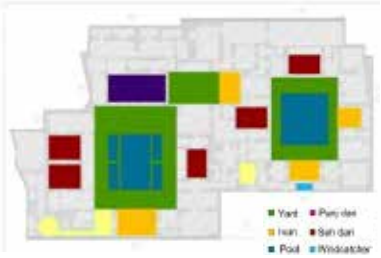
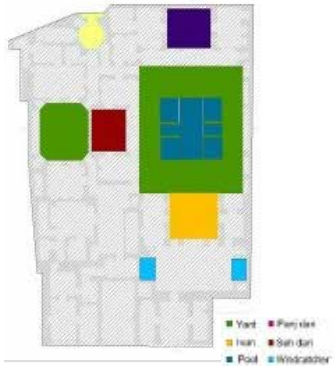
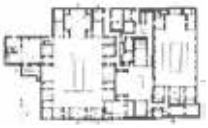
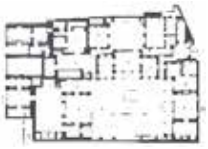
Arab Kermani		North: 12 m to yard ratio: 70% South:11m ratio to yard: 65% East: 14.4 m to yard ratio: 55% west: - to yard ratio: -	Central Yard Area: 426 m² Three-door Area: 90 m² (to yard ratio 21%) Pool Area: 160 m² (to yard ratio 37%) Entrance Area: 7 m² Winter Space Area: 74 m² Windcatcher Area: 7 m² (to yard ratio 10%) Winter Space Length: 17 m² Winter Space width: 7.5 m²
Sigari House		North: 5.6 m to yard ratio: 40% South: 3.6 m to yard ratio: 24% East: 10 m to yard ratio: 42% west: 12.8 m to yard ratio: 54%	Central Yard Area: 342 m² Summer Space Area: 70 m² (to yard ratio 21%) Three-door Area: 25.68 m² (to yard ratio 7.5%) Pool Area: 118 m² (to yard ratio 34%) Entrance Area: 24 m² Second Yard Area: 69 m² Winter Space Area: 20 m² (to yard ratio 5.7%) Winter Space Length: 5 m² Winter Space width: 4 m²
Golshan House		North: 6 m to yard ratio: 40% South: 6 m ratio to yard: 46% East: 8 m to yard ratio: 41% West: 12 m to yard ratio: 60%	Central Yard Area: 294 m² Summer Area: 35.36 m² (to yard ratio 12%) Five-door Area: 53.64 m² (to yard ratio 18%) Three-door Area: 71.64 m² (to yard ratio 25%) Pool Area: 93 m² (to yard ratio 31%) Entrance Area: 54.34 m² Second Yard Area: 56.64 m² Winter Space Area: 53.6 m² (to yard ratio 19%) Winter Space Length: 4.3 m² Winter Space width: 3.6 m²
Lariha House		North: 8.8 m to yard ratio: 51% in South: 8.9 m ratio to yard: 51% East: 12 m to yard ratio: 40% West: 9.1 m to yard ratio: 31%	Central Yard Area: 510 m² Summer Space Area: 100 m² (to yard ratio 19%) Five-door Area: 26 m² (to yard ratio 6%) Pool Area: 118 m² (to yard ratio 23%) Entrance Area: 34.84 m² Second Yard Area: 144 m² Windcatcher Area: 7.7 m² Winter Space Area: 27.5 m² (to yard ratio 5.3%) Winter Space Length: 5.8 m² Winter Space width: 5 m²
Koroghloo House		North: 9 m to yard ratio: 65% in South: 6.4 m ratio to yard: 47% East: - to yard ratio: - West: 10.4 m to yard ratio: 61%	Central Yard Area: 235 m² Summer Space Area: 40 m² (to yard ratio 18%) Three-door Area: 57.5 m² (to yard ratio 25%) Pool Area: 65.8 m² (to yard ratio 28%) Entrance Area: 13 m² Second Yard Area: 48 m² Windcatcher Area: 11.5 m² Winter Space Area: 31.5 m² (to yard ratio 13%) Winter Space Length: 6.5 m² Winter Space width: 6 m²

Table 2. Investigation of Plan and Area of Different Spaces in Yazd Houses. Source: Authors.

Building Name	Physical plan review	Entrance Area	Pool Area	Gardens Area	Hall Area	Hall Dimensions		Yard Area	L to W ratio	Yard Dimensions	
						Width	Length			Width	Length
Fatehha		9.5	14.5	51	40.5	5.2	7.8	259	1.6	15	17.5
		-	21	52.2	21.8	3.9	5.6	210	1.45	12	17.5
Arabha		5.2	53.2	66.5	68	9.7	5	4.8	1.41	17	24
		14.3	21	63	33.5	5	6.7	266	1.35	14	19
Mortaz		18.7	53.2	66.5	73.5	7	10.5	371	1.48	15.8	23.5
		-	16.75	26.6	24.7	4.5	5.5	131	95	11.7	11.2
Rasoulian		11.5	60	48	56	7	8	300	1.3	15	20
Sigari		18.8	49	70	24	2.9	8	340	1.62	14.5	23.5
Golshan		11.1	57.7	31.5	35	5	7	292	1.3	15	19.5
		12.8	35	30	22	4	5.5	186	1.29	12	15.5
Lariha		24.8	32	48	103.5	11.5	9	510	1.76	17	30
Kermani		-	33	128	48	6	8	420	1.54	16.5	25.5
Farhangi		33	75	46	38	5	7.5	320	1.4	15	21
Koroghloo		13	65.8	45	40	5	8	235	1.38	13	18

The depth of the main rooms (average 3.4 m) on the east front is shorter than other fronts. The length of the main spaces on the east is longer than the west and they are more prone to radiation. By reducing the length of the spaces, the radiation has been minimized. After the east front, the highest length to depth ratio exists on the north front; this shows that the local architects tried to absorb the maximum radiation by increasing length of the winter room.

• The proportions and templates of the summer hall and the surrounding spaces

Table 6 has been drawn after calculating the dimensions and proportions of the samples and examining their relations with each other. According to the calculations, the average length of the halls is 7 meters and their depth is 6.1 meters; in all cases, it is nearly the same with the difference of ±2 meter. The length of the halls is longer than their depth to increase outdoor communication and better air ventilation. The average area of the halls is 40.7 square meters; in all cases, it is nearly the same with the difference of ±15 square meters. 15% of the halls have Badgeers. About 15% of the halls are located in the south. The proportions and templates of the summer halls and its surrounding spaces have been calculated and compared with each other. The dimensions of

Table 3. Comparison of Area and Dimensions of Central Courtyard. Source: Authors.

Yard ratios	Courtyard area	Length to yard ratio	Average yard width	Average yard length
Dimensions	307.7 m^2	1.38	14.66 m	20.55 m

Table 4. Comparison of Area and Dimensions of Summer Space to Central Courtyard. Source: Authors.

Proportions of Spaces around the Yard	Average length to depth ratio	The length of the main front space	Depth of main space front	Average area of spaces
North	1.27	5.75 m	4.5 m	43.5 m^2
South	1.08	6.8 m	6.3 m	48.5 m^2
East	1.61	5.5 m	3.4 m	39.2 m^2
West	1.61	5.35 m	4.6 m	52.9 m^2

Table 5. Comparison of Area and Dimensions of openings to Central Courtyard. Source: Authors.

Openings to Yard Ratios	Average Yard Length on each Front	Average Openings Length	Ratio of Openings to Yard Length
North	14.66 m	8.1%	53.9%
South	14.66 m	8.07%	51%
East	20.55 m	10.95%	48%
West	20.55 m	10.2%	50%

Table 6. Hall Ratios. Source: Authors.

Hall Ratios	Area of Windcatcher	Windcatcher position	Average Hall Area	Average length to depth of hall	Average depth of hall	Average length of hall
Dimensions	7.14 m^2	66% South of the Hall	40.7 m^2	1.34 m	6.1 m	7 m

the windscreens and their relations with the halls were also investigated. As table 7 shows, on the east, the average area of the hall adjacent rooms is 11 square meters. This average on the west is 11.1 square meters. In all cases, it is nearly the same with the difference of ±5 square meters. To keep the symmetry in both fronts, the area of the rooms on both sides of the hall is the same. The area of the hall adjacent rooms in the east and west is almost the same to maintain the principle of symmetry. The ratio of the hall area to its adjacent spaces is 30%. The average area of the windcatchers is 7.14 square meters. The average ratio of the area of the windcatchers to the hall is 15%; in all cases, it is nearly the same with the difference of ±0.07.

Case studies and proportions calculations in table 8 show that the ratio of the summer space to the yard area is 14%; in all cases, it is nearly the same with the difference of ±5. The average ratio of the hall to the yard is 49% so nearly half length of the yard has been covered by the summer hall. The average length-to-depth ratio of the halls is 1.34; in all cases, it is nearly the same with the difference of ±0.2. The average length-to-depth ratio of the yards is 1.38; in all cases, it is nearly the same with the difference of ±0.5. There is an interesting point to mention; the average length to depth ratio in the halls and the yards is almost the same so it can be concluded that the halls and the central yards proportions are similar. The dimensions and proportions of the pools and the gardens have been calculated and their average sizes have been obtained in table 9. Their proportions in relation to the yard and the hall have been also studied. The average garden area is 50.34 square meters; in all cases, it is nearly the same with the difference of ±15 square meters. The average pool area is 37.2 square meters. Average ratio of garden area to hall is 0.86 and the average ratio of pools area to hall is 1.10. The average ratio of pool area to yard is 12% and the average ratio of garden area to yard is 18.41. In all houses, the average distance of the halls to the pool and the ratio to the gardens is 4 meters.

Entrances dimensions and their relation with the central yard and also with the summer spaces were investigated in table 10. Most of the main entrances are hexagonal and do not have square and corridor forms. In 92% of the cases, the access to the central yard is via the corridors. The average

Table 7. Relation of the Hall with other Spaces. Source: Authors.

Spaces around the Hall	Proportions of the Hall to East and West Area	Proportions of Room Area in the west to the Hall	Proportions of Room Area in the east to the Hall	Room Area in the West of the Hall	Room Area in the East of the Hall
Dimensions and ratios	30%	0.28	0.27	11.1 m^2	11 m^2

Table 8. Hall-to-Yard Relation Ratios. Source: Authors.

Hall and Yard	Average Length to Yard Width	Average Length by width of the Hall	Area Ratio of the Hall to Yard	Hall Length to the Yard
Dimensions and ratios	1.38%	1.34%	14%	49%

Table 9. Yard's space-to-Yard Relation Ratios. Source: Authors.

Details Ratio	Distance to Hall	Garden Area to the Hall	Pool Area to the Hall	Pool Area to the Yard	Garden Area to the Yard	Pool Area	Garden Area
Dimensions and ratios	4 m	0.86	1.10	12%	18.41%	37.2 m^2	50.34 m^2

yard-to-entrance distance is 10.2 meters. In 66% of the halls, the entrance is on the south side while in 34% of them, the entrance is on the north side. The average distance from the vestibule (Hashti) on the southern side to the hall is 10.38 meters; in all cases, it is nearly the same with the difference of ±4 meters. The length of the inlet opening depends on its front and the length of the wall. It also depends on whether the entrance is main or secondary. The average inlet opening length is 2.6 meters. In table 11, the proportion of dimensions and area of spaces in ten Yazd houses have been shown. The numbers have been compared and their mean has been calculated. Starred houses represent the numbers that are far from the mean.

Investigating and analyzing houses

After calculating the ratio of the summer space area

Table 10. Entrance-to-Yard Relation Ratios. Source: Authors.

Entrance Ratio	Form	Entrance Length	Distance to Hall	Distance to Yard	Average Area	Location	Connection to the Yard
Dimensions and ratios	Octagon	2.6 m	10.38 m	10.2 m	14 m²	46% Southern	92% Corridor

Table 11. Investigation and comparison the area and dimensions of different spaces. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Yard	413	342	300	365	510	294	295	426	235	320	350
Summer Hall	-	-	18%	20%	19%	12%*	19%	-	18%	12%*	19%
Pool	29%	34%	35%	35%	32%	31%	24%*	35%	28%	24%*	31%
Three-door Room	25%	21%	-	5%*	23%	25%	27%	20%	25%	27%	24%
Five-door Room	10%	-	11%	15%	6%*	18%	13%	-	-	6%*	13%
Summer Hall	-	-	52%	86%*	51%	47%	52%	-	47%	48%	50%
Hall in Eastern Front	22%	28%	33%	-	-	-	-	-	-	-	-
Hall in Western Front	-	-	-	-	15%	-	-	-	-	-	-
Winter Space Openings	53%	40%	52%	68%	51%	40%	53%	70%	65%	50%	55%
Summer Space Opening	30%	24%	-	-	-	-	-	65%	-	-	-
East Side Openings	41%	42%	-	43%	40%	41%	40%	55%	-	43%	43%
West Side Openings	41%	54%	62%	43%	31%	60%	57%	-	61%	48%	50%

to the main yard, its number (as percentage) has been expressed in table 12. In the summer front, due to the strong sunshine in the warm season, semi-open spaces like summer halls are very important and useful. The exact number for the average ratio of summer space area to the yard is 19%; in all cases, it is nearly the same with the difference of ±1%. This difference in Farhangi and Golshan houses is 2%. It seems that the area of the halls has been slightly reduced due to the constriction of the outside wall of the building. There is no summer space in Sigariha and Arab houses. On the summer front of the Sigariha house, some rooms have been built behind a porch to protect from the sun. Using this clever method, the rooms are in accordance with the climate of the area even on the summer front without a hall. Table 13 shows the ratio of the pool area to the yard. The average ratio of the pool area to the main yard is 31%; in all cases, it is nearly the same with the difference of ±4%.

Table 14 shows the ratio of the area of the three-door and five-door rooms to the main courtyard. The ratio of the area of the three-door rooms to the main courtyard is 24% ±3%. Only in Mortaz house,

Table 12. Comparison of area and dimensions of summer residence. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Yard	413 m2	342 m2	300 m2	365 m2	510 m2	294 m2	295 m2	426 m2	235 m2	320 m2	350 m2
Summer Space	-	-	18%	20%	19%	12%*	19%	-	18%	12%*	19%

Table 13. Comparison of area and dimensions of the main yard pool. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Yard	413 m^2	342 m^2	300 m^2	365 m^2	510 m^2	294 m^2	295 m^2	426 m^2	235 m^2	320 m^2	350 m^2
Pool	29%	34%	35%	35%	32%	31%	24%*	35%	28%	24%*	31%

Table 14. Survey the area and dimensions of the three-door and five-door rooms. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Yard	413 m^2	342 m^2	300 m^2	365 m^2	510 m^2	294 m^2	295 m^2	426 m^2	235 m^2	320 m^2	350 m^2
Three-door Room	25%	21%	-	5%*	23%	25%	27%	20%	25%	27%	24%
Five-door Room	10%	-	11%	15%	6%*	18%	13%	-	-	6%*	13%

this figure is 5%, due to its large hall and numerous five-door rooms. The ratio of the area of the five-door rooms to the main courtyard is 13% ±3%. Except in Lariha and Farhangi houses, this figure is 6%, due to their numerous three-door rooms.

Table 15 shows the ratio of the length of the halls on different fronts to the yard. The ratio of the summer space to the yard length on the same front is 50% ±3%. The statistics show that the semi-open spaces, like the halls, are bigger than other spaces in the summer front because they are more useful in the hot season. The largest summer space is located in Mortaz house which occupies 85% of its front. This summer front is occupied by a hall without any room around it. Only in three houses (Sigari, Rasoulian and Arab), the halls are located in on the east side. There are halls on both summer spaces and also eastern front in Rasoulian house. In Sigari house, there is a hall (Ravagh[14]) which is located on the east side. Only in Lariha house, in addition to the summer space, there is an Ivan on the west side.

Table 16 shows the ratio of the length of the openings (Bazsho) to the yard length on the same front. The openings in the central courtyard are of great importance. Natural ventilation through the windows and the holes is an important component of the passive ventilation system (Soflaee, 2004, 140). Most doors are on the winter side of the house. According to the architectural principles of the region, the winter rooms face the sun to take advantage of the mild winter sunlight. The average of the ratio on the winter side is 55% ±10%. In Arab Kermani house, this number reaches to 70% because there are more openings on the winter side. Due to the intense sunshine in hot season, semi-open spaces like halls are widely used so there is no room or opening on the winter side. In Kermani

Table 15. Comparison of the area and dimensions of the halls. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Summer Hall	-	-	52%	86%*	51%	47%	52%	-	47%	48%	50%
Hall on the Eastern Front	22%	28%	33%	-	-	-	-	-	-	-	-
Hall on the Western Front	-	-	-	-	15%	-	-	-	-	-	-

Table 16. Comparison of the ratio of the openings to yard length. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Winter Openings	53%	40%	52%	68%	51%	40%	53%	70%*	65%	50%	55%
Summer Openings	30%	24%	-	-	-	-	-	65%	-	-	-
East Side Openings	41%	42%	-	43%	40%	41%	40%	55%*	-	43%	43%
West Side Openings	41%	54%	62%	43%	31%	60%	57%	-	61%	48%	50%

and Sigari houses, there is a Ravagh instead of a hall on this front and the rooms behind it are protected from excessive radiation. The ratio of the length of the east side opening to the length of the yard on the same front is 43% ±3%; except in Arab Kermani house which this number reaches to 55%. On the west side of the house, ratio of the openings length to the yard length on the same front is 50% ±10%.

Table 17 shows the dimensions and area of the winter rooms. In this table, Rasoulian, Golshan, Arab Kermani and Koroghli houses (with different dimensions and sizes) have been also examined. The winter room is very large houses and occupies half the length of the courtyard. On this front of these four houses, there is only a winter room which is bigger than others. In other houses, there are some other spaces such as three-door rooms and five-door rooms around the winter space. In all cases (except those four houses) accurate results of the ratio and size of the winter room have been obtained. The winter room to main yard ratio is 5.2% ±1%; the length to the width ratio of this room is 1.23% ±0.1%. The winter room to the yard ratio on the same front is 30% ±3%.

Patterns structure in house spaces

After examining case samples, physical-environmental criteria related to proportions have been analyzed. The results of environmental analysis (as coherent as possible) have been presented to be used to design central courtyards and summer halls in contemporary architecture. The means of the dimensions of different elements in these houses were calculated and compared with each other. The ratios of the length to width of the yard, summer halls and adjacent spaces have been obtained. Their proportions in relation to each other have been calculated and their means have been also calculated. The proper proportions of the central yards and summer halls are presented in table 18. In this table, some patterns for the correct dimensions of the central courtyard have been presented. This table also shows the area of the central yards, gardens and pools, winter spaces and the length of the openings on each front.

In table 19 the correct proportions of 12 summer halls with their physical and environmental criteria have been presented. The correct dimensions of the summer halls include the area of the hall, windcatcher, western and eastern spaces of the hall, gardens and the pool.

Conclusion

The physical and environmental data of ten Qajar vernacular houses in Yazd has been studied in this research. After gathering the necessary data, these houses have been studied in terms of shape, size and proportion of spaces in relation to climate and stability conditions. Dimensions of different spaces

Table 17. Comparison of the area and dimensions of the winter room. Source: Authors.

Houses Names / Dimensions and ratios	Arab	Sigari	Rasoulian	Mortaz	Lariha	Golshan	Fatehha	Kermani	Koroghli	Farhangi	Average
Yard	413 m^2	342 m^2	300 m^2	365 m^2	510 m^2	294 m^2	295 m^2	426 m^2	235 m^2	320 m^2	350 m^2
Winter Space	4.5%	5.7%	20%	4.7%	5.3%	19%	6.5%	10%	13%	5%	5.2%
L to W of Room	1.3%	1.2%	1%	1.2%	1.2%	2.1%	1.1%	1.3%	6%	1.2%	1.2%
The Length of the Room to the Yard	30%	27%	53%	33%	29%	65%	32%	44%	44%	30%	30%

have been calculated and modeled with AutoCAD software and then the dimensions were compared and their mean has been calculated. Exceptions have been also reported and the reasons and factors of sudden numbers changes have been studied.

In the study of the winter room, the ratio of its area to the main yard has been calculated. The length to width ratio of this room and its length ratio to the yard on the same front has been also calculated. By examining the ratio of the floor lengths of the openings on different fronts, it can be seen that most of the openings are in the winter side of the house. According to the climate architecture of this region, the winter rooms face the sun to benefit from mild sunlight in winter; the resulting numbers confirm this claim. On the summer front of the houses, the semi-open spaces such as the halls are very useful. There is no other room on this front.

The design criteria in the structure of the Qajar central yard and summer halls in a warm and dry climate can be summarized as follows: the comparison of the tables shows that despite minor differences in environmental conditions, the central yards and the summer halls have close proportions and similar physical patterns. This indicates the influence of climatic factors on their designs. The daylight and fresh air of the central yards comes into the rooms through the summer halls. The central yard has three functions to benefit from the temperature changes in summer days. The yard lets the cool air get into its surrounding rooms, especially the hall which has the most ventilation and the most benefit from airflow. Walls, roofs, columns, ceilings and furniture get cool during the night that remain for a long time so central yards and summer halls can be used as suitable places to sleep in summer nights. At noon when the sun gets directly into the central yard and summer hall, the cool air moves up and heat transfer makes residents feel comfortable. Then the yard and around the house get warmer; there is more heat transmission during the afternoon and the cool air of the house is dispersed until sunset. Therefore, the role of central yard and summer hall as a micro-climate agent is creating coolness and ventilation for living spaces. They also play an effective role in arrangement of the buildings (especially the residential houses). The comparison of the dimensions shows that there are some accurate relations between the

Table 18. Correct proportions of central courtyard and other spaces (W = Width of the Yard, W = a / L = Length of the Yard, L = 1.38a). Source: Authors.

Patterns	Areas
AC = 1.38 a^2	AC = Yard Area
Ln = 0.53a	Ln = Opening Length to the North
Ls = 0.51a	Ls = Opening Length to the South
Le = 0.48a 1.38	Le = Opening Length to the East
Lw = 0.53a 1.38	Lw = Opening Length to the West
Aw = AC (0.052)	Aw = winter space Area
Lwi = 0.41 a	Lwi = Length of winter space
Ag = 0.18. a^2 .1.38	Ag = Garden Area
Ap = 0.12a ^2 .1.38	Ap = Pool Area
Py = 1.38	Ap = Length to width of the yard
As = 0.24 AC	As = five-door Room Area
Af = 0.13 AC	Af = Three-door Room Area

Table 19. Correct proportions of summer hall (Wt = Hall Width, Wt = b / Lt = Hall Length, Lt = 1.31b). Source: Authors.

Patterns	Areas
At = 1.31 b^2	At = Hall Area
Ai = 0.2. b^2. 1.31	Ai = Wind catcher Area
Ae = 0.3. b^2. 1.31	Ae = Area of East Hall Spaces
Aw = 0.3. b^2. 1.31	Aw = Area of West Hall
Ag = 1.4. b^2. 1.31	Ag = Garden Area
Ap = 1.03. b^2. 1.31	Ap = Pool Area
Pt = 1.31	Pt = Length to width of the Hall
P = Py/ Pt = 1.05	P = Length to width of the yard to Length to width of the Hall

different components of the hall and the yard; so there is a significant relation between them in the warm and dry climate houses. The correct proportions of the yard and hall are shown in table 18 and 19. The calculations and findings of the research illustrate how flexible the architecture is with the climate in the Yazd traditional homes. The Structure of these houses illustrates the local architects' understanding of the best environmental conditions for the comfort of the residents. The Structure of traditional houses (in its entirety and in minor elements) is in harmony with Yazd climatic conditions. Dimension comparison shows that there are precise proportions between the different components of vernacular houses. There is also a significant relationship between the central yard and other spaces. The exact numbers and ratios indicate that the various components and spaces of these houses are built in accordance with the principles of climate architecture. Therefore, these points should be taken into account in designing new houses in order to reduce energy consumption.

Endnote

1. "Ivan" is a rectangular hall or space, usually vaulted, walled on three sides, with one end entirely open.
2. "Badgir" (windtower or wind catcher) is an element to create natural ventilation in buildings. It is in various designs such as unidirectional, bidirectional, and multidirectional.
3. "Summer space" is located on the south side of the courtyard to avoid direct sunlight in summer. Its main axis is usually a semi-open space with a hall.
4. "Hozkhaneh" is a summer space with a small basin in it. It has usually an octagonal shape.
5. "Payab" was part of the house which is made for easy access by residents to the aqueduct. It was built as a corridor or a staircase to the basement where the aqueduct (ghanat) was flowing.
6. "Tanbi" also called the long room is a large room in the middle of the building which other spaces are around it.
7. "Winter space" is referred to all spaces built on the north side of the yard that take advantage of the winter sun shining through the rooms.
8. "Hashti" is the space behind the doorway. Hashti is designed in many different shapes, including octagonal, hexagonal, square and rectangular.
9. "Karbandi" is used to light the space through the roof. The light directly enters the space and illuminates only part of it. Karbandi is a cover consisting of arches which intersect each other under geometrical rules and form and make the cover. It sometimes used as the main roof.
10. Tarkin vault: Geometrically, the space covered by this vault is a rectangular or polygon square. There are some cracks on the interior of this vault.
11. "Oresi" is a grille that rises on the heel and stays in a compartment. Its role is like windows and wooden porches.
12. "Herno" is at the top of the vault for lightening. For example, in most bazars, there are often open holes call herno for lighting and ventilation.
13. "Tabeshband" or "Aftabshekan" was made with plaster and straw and contains the blades of 2 to 4 cm wide and sometimes up to 3 m high. It controlled the sun's entry into space.
14. "Ravagh" is a space consisting of a roof and a column that is blocked at least on one side and protects residents from exposure to sunlight and radiation.

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