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Morphological Analysis of the Central Courtyard of Indigenous Residential Buildings in Hot-Arid Regions; Case Study: Yazd City*

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ABSTRACT

The courtyard, as one of the most important elements of indigenous architecture, has taken various forms in different climates by observing the principles of environmental compatibility. These features and differences can be considered criteria for climatic analysis of the central courtyard inindigenous houses in different climatesof anarea. The criteria are determined according to the common physical features of the samples, the influence of environmental conditions, and spatial organization. Therefore, the present study aims tophysically study the central courtyard and identify the influential hot-arid climate factors to provide a new perspective to achieve a conventional design for the inhabitants of this climate. The present study is fundamental-applied descriptive-analytical research. Focusing on the climatic and environmental role of the courtyard and its walls, twenty historical houses in Yazd city, which is located in the hot-arid climate zone (BWhs) of Iran, are selected as samples. The collected data are analyzed and presented indiagrams and tables using SPSS software. The results indicate that orientation and physical-climatic components are of great importance and can be used as effective factors in designing houses. Moreover, the best relationship between the length and width of a courtyard was obtained with three linear equations for designingcourtyards based on geometric proportions. Considering the results of the design, the significant effects of sustainable architecture can be perceived.

Keywords: Central Courtyard, Indigenous Houses, Hot-Arid Climate, Yazd.

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1. INTRODUCTION

Human thermal comfort is influenced by environmental-climatic factors, air temperature, humidity, radiation, and wind speed. Indigenous desert houses with central open spaces work admirably to be compatible with the unbearable climate of the desert. Climatic conditions play a key role in forming spaces such as the central courtyard. In hot-arid regions, tree-coveredcourtyards with ponds and areas of low-water plants are one of the most effective factors for creating humidity. The rooms opening only to the courtyards are protected against wind and sandstorms (Kasmaei 2012). Conscious solar orientation plays a key rolein the emergence of this microclimate. Indigenous architects have found how to determine the building orientation in different climates based on their experiences of weather characteristics, sunlight, wind direction, and other factors (Pirnia 2004, 180). The courtyard acts as an element connecting living spaces to other parts of the house, meaning that it connects various spaces in residential units (Soflaei 2016, 1152). The formation of the courtyard in Iranian houses can be studied in two aspects of its function anduses. In introverted houses, the spatial organization is based on the courtyard. The design of the house starts from the courtyard and the enclosed and closed spaces are placed around it. In the spatial organization of these houses, the courtyard spatially contributes to the communication between the residents and nature, on the one hand, and the communication between the residents and society, on the other hand (Haeri 2009, 107). Iranian architecture can be considered the product of the compatibility of lifestyles with environmental conditions, which is of fundamental importance in sustainable architecture. The central courtyard is one of the most widely-used vernacularbuilding patterns in Iran and had a special place in past architecture (Vakilinejad 2016). The central open space in the houses has been an effective factor in the material and spiritual lives of human society. Considering the hot-arid climate of the central plateau of Iran, the courtyardwas considered the main element of open space and hada special place in architecture, and it can be described in typology, arrangement of functions, geometric form, proportions, shading, leveling, and materials. This element is greatly influencedby the features of the platform and local executive capability, urban encroachment and occupation, maximum productivity of full and empty space. (Soflaei and Shochouhian 2011). The landscape of the central courtyard not only creates an ecological space for the introverted building to respire but also connects the surrounding spaces and minimizes internal movements (Soflaei 2006). Considering the abovementioned, the present study aims to studyhow the central courtyard in the hot-arid climate, especially in Yazd city, is landscaped. So, it seeks to answer the following questions: what are the architectural features of the central courtyard landscape inthe hot-aridclimate? What are the central courtyard landscape patterns in relation to the climate and physical proportions in the hot-arid climate? What are the geometry, proportions, and elements of the central courtyardsinYazd,and which of the components of the central courtyard can be used in modern residential architecture?

The present study investigated the central courtyard landscape and its role focusing on case studies and using library and field studies. Moreover, it attempts to make optimal use of architectural experiences regarding local landscaping.

2. THEORETICAL FOUNDATIONS

This section addresses the existing theories and foundations regarding the history and functions of the courtyard in the architecture appliedin the hot-arid regions in Iran.

2.1. History of the Courtyard

The existence of the central courtyard in houses in hot-arid regions of Iran manifests introversion. Introversion is one of the characteristics showing the importance of the inside versus the importance of appearance (Tahbaz and Jalilian 2012). In the traditional houses in the hot-humid climate during the Qajar period, the spaces are arranged together according to a specific system. Living spaces are connected to other parts of the house through the courtyard, and the courtyard acts as an element connecting the different spaces of the residential units (Soflaei 2004). In these areas, various solutions, including the use of light colors on exterior walls, the use of various sunshades, and the improvement of the thermal properties of materials, were applied to control solar radiant energy. It is very important to consider the proper proportions of the courtyard, in such a way that it can perform best in terms of meeting the need for shade (Taban, Pourjafar, and Bemanian 2013). The courtyard can be differently located in the house. In the hot-arid climate, the city fabric was dense and compact, and most of the houses were built in the form of a central courtyard house (introverted houses). In these houses, the building facesor backs to the sun (The sun-facing side is the main front of the house in most cases and most decorations are usually used on this front). The courtyard plays a key role in the cohesion of Iranian housesin three social-cultural, climatic-environmental, and physical-construction dimensions (Ghazizadeh 2011).

2.2. The Function of the Central Courtyard

The size and type of the house and the design of the spaces in the house were determined based on the socio-economic status of the family. Also, local decorations and materials were used depending on the economic status of the family (Soflaei and Shochohian 2007).The traditional courtyard houses

in Iran can be considered a successful strategy for sustainable design since they were designed with careful attention to climatic conditions andsocio-cultural contexts. Although all of these traditional principles can't be applied in the design of contemporary buildings due to population growth and changes in culture and social lifestyle, some of them are still used in the present architectural design in this city or urban areas with similar environmental and cultural characteristics (Zinilian and Okhovat 2015). In Iranian architecture, a house without a courtyard, trees, and greenery has no meaning (Pirnia 1992, 203). The followings are the reasons necessitating the use of the central courtyard: 1. The courtyard unifies several elements; 2. The courtyard plays a key role in the organization of different spaces; and 3. The courtyard is a safe and quiet area providing the comfort of the family. Although the central courtyard pattern was formed due to the great influence of the environmental conditions induced by the hot-arid climate of the plateau (Qobadian 2012), it, dueto its other advantages,is seen in other regions with different climate characteristics, generally with a change in its size, proportions, the organization of the walls, even in its greenery (Soflaei 2004). In traditional houses examined in this research, the open space is the courtyard, whose general use has been identified as a context for the presence of people and its users (Mona'am 2011).

3. METHOD

In the present study, first, the studies on the hot-arid climate of Iran were reviewed. According to the principle of compatibility with the environment, there are different physical patterns and types of the courtyard in different climates, which can be used as criteria for climate analysis of the courtyard in indigenous houses in different climates of a region. The criteria are determined according to the common physical features of the samples, the influence of environmental conditions, and spatial organization. The present study is descriptive-analytical research whose main part was carried out using the field study. In the present study, the case studies are compared and analyzed in orientation, courtyard form, courtyard proportions, and spatial organization. For this purpose, the obtained data were analyzed in two sections, physical proportions, and spatial organization. In the "physical proportions"section, the criteria such as the rotation of the courtyard, proportions of facades and all components of the courtyard, elongation, the open space area/enclosed space area ratio, etc. were examined and in the "spatial organization" section, the criteria such as the location of the entrance, type of access to spaces, separation of spaces into three residential, service, and circulation spaces, and the area of each of these spaces/ the area of the entire complex ratio were investigated. Considering the research purpose, the samples were selected from the residential buildingsconstructed in the Qajar and Safavid periods, in which the architecture did not need mechanical facilities for cooling and heating living spaces and providing human comfort. Twenty-two houses, with historical and cultural values, were selected as case studies to be examined and analyzed to achieve practical results for contemporary architecture. Some of these houses were among the cultural heritage works and have a national registration number. The analysis criteria were selected considering the hot-arid climate of Yazd city, the common elements in the case studies, and their changes in two groups of physical-climatic proportions and spatial organization. The obtained data were analyzed geometrically based on the measurements by the researcher. Moreover, the correlations between the length, width, and height of the courtyard were analyzed using the one-way analysis of variance (ANOVA) in SPSS software to provide a model representing the ratios between these three variablesin the form of a linear equation.

4. ANALYSIS OF FINDINGS

In the analysis section, the case studies are analyzed separately based on the criteria of physical proportions and spatial organization as follows:

4.1. Study of Physical Proportions

Physical proportions includecourtyard form (CF), courtyard orientation (CO), courtyard proportion (CDP), courtyard shape (SC), courtyard proportion (FDP), façade proportion (FAP), and openings' area/ facade area ratio (OA:FA). The followings were used to obtain the proportions of the courtyard:
1. Courtyard orientation and rotation angle (Table 1), 2. Dimensions and proportions of the pond and garden (Table 4), 3. Shape and geometric proportions of the courtyard (Table 2), 4. Dimensions and proportions of the walls of the courtyard (Table 5), 5. The dimensions and proportions of the open spaces in the courtyard (Table 3), and 6. The dimensions and proportions of the transparent surfaces in the courtyard (Table 6).

4.1.1. The Orientation and Rotation Angle of the Central Courtyard

In the design of indigenous houses, summer and winter spaces were placed on opposite sides and with different lighting qualities. The houses in Yazd are no exception to this rule and most of them are located in the Qibla direction, resulting in the provision of summer and winter spaces. The summer space is located on the southern side of the house. In the summer, it is in the shade and enjoys natural ventilation through the windcatcher. The winter space is located in the northern part of the building and in the winter, it enjoys solar thermal energy. Table 1 presents the orientation and rotation angle of the courtyard in the houses studied.

Table 1. The Orientation and Rotation Angle of the Central Courtyard in the Houses Studied

House	Orientation	Rotation Angle	House	Orientation	Rotation Angle
Haji Babaei House	Northeast	43°	Akhavan Tabrizi House	Northwest-Southeast	35°
Mortaz House	Northwest	31°	Bahadori House	Northwest-Southeast	40°
Seda Sima House	Northwest	45°	Papeli House	Southwest	32°
Arab Complex	Northeast	45°	Borujerdi-ha House	Northeast	57°
Lariha House	Southeast	46°	Golshan House	Northeast	62°
Imamzadehei House	East	0°	Madanipour House	Southwest	44°
Dr.Vaziri's House	Northeast	4°	Ahramian House	Northeast	24°
Yazdi-ha House	Northwest	53°	Ardeshir House	Southeast	31°
Nemat Elahi House	Southeast	3°	Janfada House	Northeast	60°
Rasoulian House	Northeast-Southwest	34°	Mirza Lak House	Southwest	33°
Kermani House	Northeast-Southwest	30°	Taraqi House	Northwest	43°

4.1.2. The Shape and Geometric Proportions of the Central Courtyard

A perfect geometry guarantees the stability of the building. Proportion makes all the components harmoniously connected within the whole complex and finally, a pleasant design is formed (Hejazi 2008). In the past, a rule similar to the conventional model used in classical architecture, which was called module, was used to establish required proportions. Observing these rules would create order and harmony in architecture (Bemanian, Okhovat, and Baqaei 2011). In the past, Iranian architects used the Persian golden rectangle to design courtyards. The Persian golden rectangle is obtained by inscribing a rectangle in a hexagon. The width/length ratio of this rectangle is 1.73 and for half of this rectangle, the ratio is 1.15 (Zakeri 2015). So, in the present study, the studied houses were investigated in the geometric proportions of the courtyard and the results are presented in Table 2.

Table 2. The Shape and Geometric Proportions of the Central Courtyard in the Houses Studied

Houses	Atotal	Acy	Acs	AN	AS	AE	AW	AN Acs	AS Acs	AE Acs	AW Acs
Average	1782.97	434.45	2298.6	386.5	334.27	389.8	431.2	0.24	0.22	0.24	0.3

4.1.3. Geometric Characteristicsof the Central Courtyard and the Ratios between its Dimensions

The shape and dimensions of indigenouscourtyards are considered according to their length, width, and height and the ratios between them, i.e. height/ length, height/width, and length/width ratios. The optimal ratio and the appropriate dimensions of the central courtyard were determined for the courtyards that were identified to function energy-efficiently in contemporary buildings. Table 3 shows the different areas assigned to some selected courtyards. The enclosed space is considered similarly in all cases and the area of each part is calculated based on the built dimensions. The last four columns of Table 3 show the ratios between the northern, southern, eastern, and western parts of the enclosed space and the total area of the enclosed space.

Table 3. Geometric Characteristics of the Courtyard and the Ratiosbetween Its Dimensions (in Meters)

Houses	Lcy	Wcy	Hcy	Acy	Hcy Lcy	Hcy Wcy	Lcy Wcy	Acy Atotal	SHcy
Average	20.32	17.95	7.70	443.45	0.36	0.45	1.14	0.35	-

4.1.4. Imensions and Proportions of the Areas Covered by Plants and Water in the Courtyards

Water is used in different forms in the indigenous central courtyards. For example, one can refer to the pond or fountain. The pond, which often had a shallow depth, was built to increase the area covered by water to absorb the sun's rays, increase evaporation, and provide more humidity to reduce the dryness of the air, as well as create convection currents to provide

passive cooling and natural ventilation for each house. Green surfaces, including low-water trees and indigenous plants, which were chosen because of their compatibility with the hot climate, play an important role in providing shade and preventing intense sunlight in different seasons (Soflaei 2006, 111). Plants contribute to naturally cooling indoor spaces by providing shade in the summer to reduce sunlight through the courtyard and the facade of the courtyard. So, the dimensions of the areas covered by soil and water as natural objects in the central courtyard of indigenous houses were investigated. Moreover, the ratios of the areas covered by water (fountain), soil, and plants (garden) to the total area of the courtyard in the houses studied were investigated (Table 4).

Table 4. The Dimensions and Proportion of the Areas Covered by Plants and Water in the Courtyards of the Houses Studied (in Meters)

Houses	N_{wt}	SH_{wt}	Awt	$\frac{A_{wt}}{A_{cy}}$	Nsl	SH_{sl}	A_{sl}	$\frac{A_{sl}}{A_{cy}}$
Average	3	Rectangle	46.22	17%	2	Square-Rectangle	20.59	8%

4.1.5. Dimensions and Proportions of Courtyard Walls (Facades)

The facade of the central courtyard in indigenous houses in hot-arid areas prevents heat penetration from the outdoor environment to the interior. Therefore, the dimensions, proportions, and especially the height of the northern, southern, western, and easternfacades of a courtyard are different. The higher facadesare located on the north and south sides. This prevents the direct absorption of solar radiation by the higher facades.The shorter facades are located on the west and east sides and receive sunlight and heat directly in summer, but not in winter. Table 5 summarizes the results of the analysiscarried out in this sub-section.

Table 5. Dimensions and proportions of Courtyard Walls (Facades) (in Meters)

Houses	N_{wt}	SH_{wt}	Awt	$\frac{A_{wt}}{A_{cy}}$	Nsl	SH_{sl}	A_{sl}	$\frac{A_{sl}}{A_{cy}}$
Average	1.3	Rectangle	55.36	12%	2.3	Square-Rectangle	89.92	17%

4.1.6. Dimensions of Transparent Surfaces of the Courtyard (Openings) and the Ratio of their Area/Total Area of the Facade

In the central regions of Iran, the openings occupy a small area of the facade and are more concentrated on certain fronts of the building. The total area and size of openings have been affected by two factors, i.e. culture and climate. In the past, the use of natural light was one of the principles observed in the construction of buildings, and building orientation, dimensions, proportions, and the composition of full and vacant spaces in building complexes were selected according to sun path and the amount of sunlight, leading to the illuminating of the interior spaces with natural light to be considered one of the main needs in the selection of the main design ideas (Seyfian and Mahmoudi 2007). Table 6 presents the analysis of the proportions of transparent surfaces.

Table 6. Dimensions of Transparent Surfaces of the Courtyard (Openings) and the Ratio of their Area to the Total Area of the Facade (in Meters)

Houses	ANel	ASel	AEel	AWel	HNel	HSel	HEel	Anel Atotal	Asel/ ATotal	AEel/ ATotal	Awel/ ATotal
Average	2309	531.50	301.8	424.3	7.44	8.58	6.67	0.26	0.38	0.22	0.29

The data listed in the above tables, which are the result of the physical proportions of all the components of the courtyard, are summarized in Table 7.

Table 7. The Results of the Analysis of Indigenous Houses in Yazd City in the Criteria of Physical Proportions

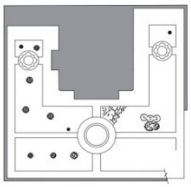
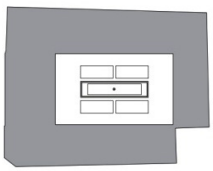
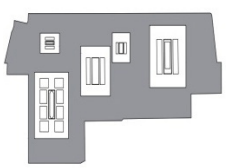
Complex Name Abbreviation of Critereria	Sigari	Emamzadehei	Haji Babaei	Bahadori	Rasoulian	Kermani	Madani	Papeli	Lariha	Janfada
(CF)	CF5	CF5	CF5	CF5	CF5	CF4	CF5	CF5	CF5	CF1
CO	NE-CW	NE-SW	NE-SW	NE-SW	NE-SW	NW-SE	NE-SW	NE-SW	NESE	NESE
CDP	65	68	86	11	13	10	76	14	60	48

Complex Name Abbreviation of Critereria		Sigari	Emamzadehei	Haji Babaei	Bahadori	Rasoulian	Kermani	Madani	Papeli	Lariha	Janfada
SC		Re	Re	Re	Re	Re	Re	Re	Re	Re	Re
An-C		53	40	43	32	30	41	24	57	28	9
CA:BA		-	6	24	30	41	34	37	43	46	43
FDP	NH:D	12	21	24	20	33	19	18	26	21	59
	SH:D	20	23	16	14	34	15	23	23	16	33
	Eh:D	14	19	20	17	19	20	12	15	14	34
	WH:D	02	15	14	13	25	21	11	28	11	19
Average		12.25	19.5	18.5	16	27.75	18.75	16	23	15.5	36.25
FAP	NFA:TFA	01	64	24	81	01	03	01	48	15	57
	SFA:TFA	03	09	58	18	63	22	05	23	03	05
	EFA:TFA	02	46	18	51	53	04	15	25	02	14
	WFA:TFA	12	12	45	13	10	17	13	30	86	3
Average		4.5	32.75	36.25	40.75	31.75	11.5	8.5	31.5	26.5	19.75
OA:FA	OA:NFA	9	05	08	02	18	45	22	26	6	12
	OA:SFA	5	03	12	12	41	58	04	20	27	20
	OA:EFA	7	11	25	11	25	31	23	13	36	14
	OA:WFA	02	12	15	16	15	15	25	29	18	02
Average		5.75	7.75	15	10.25	24.75	37.25	7	22	21.75	12

4.2. Study of Spatial Organization

His section analyzes the houses in spatial organization. To this end, the following criteria are investigated: the location of the entrance and the hierarchy of entry (CEH), the type of access to spaces, the separation of spaces into three residential, service, and circulationspaces, the area of each of these spaces/ the area of the entire complex ratio, the location of the building mass in relation to the courtyard (BL), the courtyardarea/the building area (CA:BA), and the compatibility of functionsneighboring the courtyard(FCP). The criteria were divided into sub-criteria so that they can be assessed. Table 8 shows the detailed results of analysis for several case studies including Arab House, Lariha House, Tabrizi House, and Nemat Elahi House, and the results of analysis of other case studies are summarized in Table 9.

Table 8. The Results of the Analysis of Tabrizi House, Lariha House, Arab House, and Nemat Elahi House in the Spatial Organization

Complex name / Abbreviation	Akhavan Tabrizi House	Lariha House	Arab House	Nemat Elahi House
Ground floor				

Abbreviation \ Complex name	Akhavan Tabrizi House	Lariha House	Arab House	Nemat Elahi House
CEL	NESE	NESE	NESE	SWSE
CEH	DEIDE	DEIDE	DEIDE	DEIDE
RFA:TA	21	24	35	56
SFA:TA	12	18	26	26
CFA:TA	20	12	21	30
OFA:TA	53	28	32	59

5. FINDINGS

According to Table 8, the criteria that can be included are as follows:

a) Indigenous courtyard houses in Yazd have relatively the same orientation.

b) Most of the enclosed spaces are in the northern and southern parts of the courtyard (about 67% of the enclosed space area), which is about twice the area in the eastern and western parts (about 33%).

c) A high level of thermal comfort is achieved by rectangular courtyards with a length/width ratio between 1.3 and 1.4.

The length/height and width/heightratios are also presented in this section. According to the elevation differences around the courtyard, more accurate results are obtained.

d) In the courtyards of these houses, the average ratio of the area covered by soil/total courtyard area is lower than the average ratio of the area covered by water/total courtyard area).

e) Despite the greater area of the eastern and western facades, in all cases, their height is shorter than the height of the northern and southern facades.

f) The ratio of the area of openings to thecorresponding height is a function of the courtyard size, meaning that a house with a greater area has a greater open space.

Table 9. Summary of the Results of the Analysis of Indigenous Houses in Yazd in the Proportions of the Courtyards

Criterion	Parameter	Value	Criterion	Parameter	Value
Criterion 1 Table 4-11	Orientation Rotation	NE–SW 36.6	Criterion 4 Table 4-14	Awt=Acy Asl=Acy	18.8 24.4
Criterion 2 Table 4-12	AN=Acs AS=Acs AE=Acs AW=Acs	0.22 0.22 0.23 0.21	Criterion 5 Table 4-15	ANel=Atotal ASel=Atotal AEel=Atotal AWel=Atotal	0.26 0.36 0.22 0.29
Criterion 4 Table 4-13	Hcy=Lcy Hcy=Wcy Lcy=Wcy Acy=Atotal	0.36 0.45 1.14 0.35	Criterion 6 Table 4-16	AONel=ANel AOSel=ASel AOEel=AEel AOWel=AWel	0.11 0.09 0.15 0.11

Table 10. Results and Average Criteria of Physical Proportions of Indigenous Houses in Yazd

Abbreviation	CDP	An-C	CA: BA	OA:FA	FDP	FAP
Average	45.5	36.05	29.3	5.75	20.36	22.18

As seen in Table (9) show, the entrances of the buildingsare located in their northeast-southwest part. Also, in most cases, the hierarchy of entry is as follows: entrance, vestibule, corridor, and finally the courtyard. Table (10) presents a summary of the results of the analysis of twenty-two indigenous houses as follows:

a) The average courtyard dimensions proportions is

20.36.
b) The average mass area/courtyard area ratio is 29.3.
c) The average opening area/ facade area ratio is 5.75.
d) The average rotation angle is 36.05.
Table 11 shows the average results of the analysis of 22 indigenous houses investigated in the present research in the spatial organization. The detailed results of the analysis of four houses, including Tabrizi House, Lariha House, Arab House, and Nemat Elahi House, are briefly listed in Table 8 and the final results of other cases are presented in Table 9.

Table 11. Average Results of the Analysis of the Indigenous Houses Studied in the Spatial Organization

Abbreviation	RFA:TA	SFA:TA	CFA:TA	OFA:TA	CEH	CEL
Average	31.1	17.1	18.5	33.1	Entrance- Vestibule- Corridor- Courtyard	NESE=77

According to Table 11, there are relatively constant ratios between the areas of the circulation, service, and residential parts and the total house area as follows:
a) The courtyard area/ the total area ratio is 33.1.
b) The service part area/the total area is 17.1.
c) The circulation area/ the total area is 18.5.
d) The residential part area/ the total level is 31.3.
The building orientation is mostly north-south, which can be said to be dependent on climatic conditions. The largest area and openings are on the southern front and the least on the western front. The location of the entrance is a function of the length of the courtyard and the type of urban passway. In the design of the houses, the spaces are arranged in such a way that the courtyard and residential spaces are first seen when entering the house, followed by the service and circulation spaces. In most cases, the halls are located in the north and south parts of the building, confirming the need for the lighting of important residential spaceson the north and south fronts. The entrances of the building are in such a way that the outside is connected to the inside through a circulation space (vestibule) and in most cases, it is built in the northern part, which can be subject to the courtyard form. Attention to the environmental conditions of the regioncan be an appropriate answer to the climatic conditions and conformity to the principles of indigenous architecture can be considered one of the sustainable architecture principles. Other findings of the present study are presented as diagrams in Figures 1 and 2.
According to the data obtained from the above table, a model is presented for the design of the courtyard as a climate moderator in the hot-arid climate zone(BWhs) based on the orientation, dimensions, and proportions of traditional Iranian courtyard houses using six environmental physical criteria. The northeast-southwest orientation with a slight rotation from the north can be considered a suitable orientation for courtyards. However, local geography, environmental conditions, and location should not be neglected in this issue.

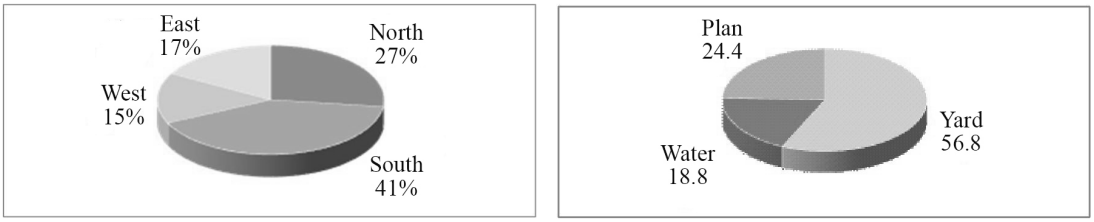


Fig. 1. Correlation between Length, Width, and Height of Courtyards; Length and Height, Width and Height, Width and Length

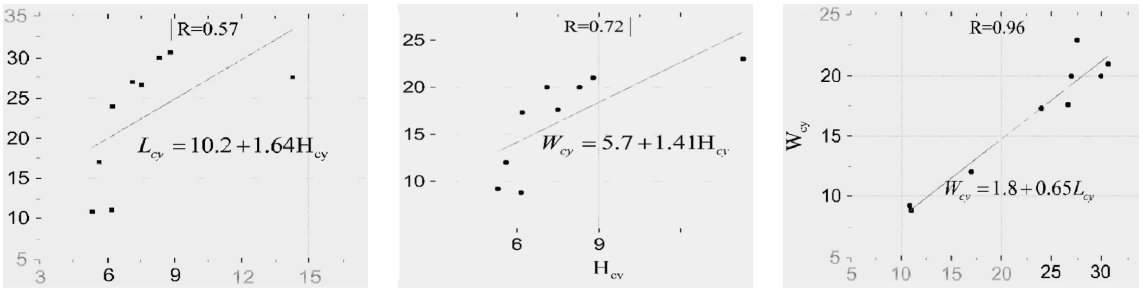


Fig. 2. The Model Designed for the Courtyards of Indigenous Houses in the Hot-Arid Climate Zone (BWhs Zone)

6. PRESENTATION OF THE MODEL DESIGNED FOR THE CENTRAL COURTYARD IN A HOT-ARID CLIMATE (YAZD)

The total areas of facades in the northern, southern, eastern, and western parts of the courtyard can be considered almost the same, but the heights of the surrounding walls should be designed differently. The present study provides a modelbased on the ratios between length, width, and height according to the results of the analysis of six criteria. This model shows the best matching line with dispersion. Figure 1 shows the result and R. A linear equation I presented for the design of the courtyards based on the geometric ratio. The best correlation between the length and width of the courtyard is obtained by the following equation:

Wcy=¼ l: 8Þ * 0. 65Lcy Eq. (1)

7. DISCUSSION AND CONCLUSION

The present study aims to investigate the morphology of the central courtyardsin indigenous houses in Yazd which have a common history and are in the same hot-arid climate. Although there are numerous studies on this topic, they have addressed this topic theoretically and generally and none of them have identified a specific pattern. In the present study, twenty-two indigenous houses in Yazd city were investigated in physical proportions defined as corrections for weather conditions. The final result provides a design model for courtyards as micro-climate moderators in the BWhs region based on the orientation, dimensions, and proportions of indigenous Iranian courtyard houses in this region (Fig. 2).

The average results indicate that the major part of the southern front of the courtyard must be considered for the enclosed space (41%). However, the total areas of the northern and southern parts are the same as those of the eastern and western parts (Fig. 2-a). According to the average results reported for criterion 4, about 61.2% of the courtyard can be allocated to natural elements, 18.8% to water, and 24.4% to soil and plants. As the results of previous observations and studies have shown, these ratios can provide suitable thermal comfort in a courtyard and its surrounding areas (Fig. 2-b). Also, the total area of the facades in the northern, southern, eastern, and western parts of the courtyard can be considered almost the same, but their height should be different. According to the results, for configuration, the height of the facades in the northern and southern parts should be taller than that of the facades in the eastern and westernparts. Considering local constraints and priorities, the best courtyard orientation can be north-south. Based on the ratio of the total area of the openings to the corresponding height, 32-35% of the façade area can be considered for openings. Also, according to the geometric proportions and the linear equation obtained in the previous section, Eq.1 can be used to design the courtyard. According to the results of the analysis of the case studies in spatial organization, it can be acknowledged that about one-third of the total area of the house is the courtyard, one-third of it is the residential space, and the rest includes service and circulation spaces.

REFERENCES

- Archives of Yazd Province's Cultural Heritage, Tourism,and Handicrafts Organization. http://www.portal.yazdcity.ir
- Bemanian, Mohammadreza, Haniyeh Okhovat, and Parham Baqaei. 2011. *Application of geometry and proportion in architecture*. Tehran: Hale Publications.
- Haeri, Mohammadreza. 2009. *House, culture, nature (Study of the architecture of historical and contemporary houses to develop a process and standards for house design)*. Tehran: Urban Planning and Architecture Research Center of Iran. https://semega.mmfi.ir
- Hejazi, Mehrdad. 2008. Sacred geometry in nature and Persian architecture. *Journal of History of Science* 6(2): 15-36. https://jihs.ut.ac.ir
- Kasmaei, Morteza. 2012. *Climate and architecture*. Tehran: Iran Housing Investment Company. http://www.khanehsazi ir
- Mona'am, Alireza. 2011. Environmental comfort in urban open spaces, assessment of thermal comfort in selected parks in Tehran. Doctoral Thesis, Iran University of Science and Technology, Tehran.
- Moultrie, Carolyn. 2010. Architectural Design Principles and Processes for Sustainability. Glasgow, Scotland: University of Strathclyde Glasgow. 50–58. Effect of courtyard proportions on solar heat gain and energy requirement in the temperate climate of Rome. *Building and Environment* 41(3): 245-253. https://www. sciencedirect. com/science/article/abs/pii/S0360132305000491
- Pirnia, Mohammadkarim. 1992. *The style of Iranian architecture*. Third edition. Danesh Publication. https://b2n.ir/136409
- Pirnia, Mohammadkarim. 2004. *Islamic Architecture of Iran*. Tehran: Iran University of Science and Technology. https://b2n.ir/136409
- Qazizadeh, Seyyed Neda. 2011. The role of residential open space design in creating a sense of attachment to the place, Case study: selected residential complexes, Tehran. Doctoral thesis. University of Tehran, Tehran.
- Qobadian, Vahid. 2012. Climatic architecture and sustainable architecture in Iran. *Designer* (5): 127. www.designer-magazine.Com
- Seyfiyan, Mohammad Kazem, and Mohammad Reza Mahmoudi. 2016. Privacy in Traditional Architecture of Iran. *Hoviat Shahr* 1(1): 14-3. https://hoviatshahr.srbiau.ac.ir
- Soflaei, Farzaneh. 2004. Study of the concepts and experiences of sustainable architecture. *Abadi* (42): 62-67.
- Soflaei, Farzaneh. 2006. The environmental role of the central courtyard in the architecture of sustainable residential areas in hot-arid regions of Iran. Doctoral thesis. The discipline of architecture.
- Soflaei, Farzaneh, and Mehdi Shochouhian. 2007. Environmental effect of courtyard in sustainable architecture of Iran (Hot-arid regions, mesoclimate BWks)(Case study: courtyard houses in Isfahan & Kerman). *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century*, Crete island, Greece. https://www. researchgate. net/publication/237692758_Environmental_effect_of_courtyard_in_sustainable_architecture_of_Iran_Hot-arid_regions_mesoclimate_BWks_Case_study_courtyard_houses_in_Isfahan_Kerman
- Sofalai, Farzaneh. 2015. The environmental effect of courtyards in sustainable architecture in Iran (hot and dry regions), case study: courtyard houses in Yazd, Kashan and Semnan. In *Proceedings of the International Arab Regional Solar Energy Conference, Bahrain*, 111-125. https://elmnet.ir
- Soflaei, Farzaneh, Mehdi Shokouhian, and Wenyi Zhu. 2016. Socio-environmental sustainability in traditional courtyard houses of Iran and China. *Renewable and Sustainable Energy Reviews* 69: 1147-1169. https://www.sciencedirect. com/science/article/abs/pii/S1364032116306402
- Taban, Mohsen, Mohammadreza Pourjafar, Mohammadreza Bemanian, and Shahin Heidary. 2014. Determining Optimal Courtyard Pattern in Dezful Traditional Houses By Relying on Shadow Analysis. *Bagh-e Nazar* 10(27): 39-48. http://www.bagh-sj.com/article_3966.html
- Tahbaz, Mansoureh, and Shahrbanoo Jalilian. 2011. *The role of architectural design in reducing energy consumption in buildings (architecture compatible with the climate and problems caused by paying no attention to it)*. Center for Applied Scientific Education, Rah Shahr International Group. http://www.rahshahr.com
- Tahbaz, Mansoureh, and Shahrbanoo Jalilian. 2013. The effect of architectural design on the play of natural light in traditional Iranian houses.
- Vakilinejad, Roza. 2016. The hybrid effect of the physical characteristics of the building skin and ventilation patterns on the energy consumption in residential buildings, (Case study: Shiraz). Doctoral thesis, Islamic Azad University (Science and Research Branch).
- Zakeri, Seyyed Mohammad Hossein, Arezoo Ghahramani, Dorsa Shahnazi, and Esmaeil Bazyar Hamze Khani. 2015. Module and Iranian golden rectangle theory in historical houses of Qajar era in Shiraz City. *Researches in*

Islamic Architecture 4(1): 16-30. http://jria.iust.ac.ir

- Zeinalian, Nafiseh, and Haniyeh Okhovat. 2015. The structure of courtyards in Qajar houses in hot-arid climate and hot-humid climate with a focus on the "central courtyard" type, Case study: Houses in Yazd and Dezful. University of Tehran. 44.

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