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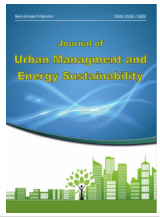

ORIGINAL RESEARCH PAPER

Classifying and Selecting Suitable Courtyard Houses for Sustainability Research

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ABSTRACT

The increasing energy consumption and the phenomenon of global warming underscore the importance of adopting building strategies that are in harmony with climatic conditions. Courtyard houses, recognized for their alignment with hot and dry climates through attention to weather conditions, serve as a successful model. However, changes in lifestyle patterns and urban development have gradually marginalized these traditional houses. Given this, examining the compatibility of courtyard houses with specific climatic conditions has become crucial, necessitating the development of suitable models for empirical evaluations. This study aimed at classifying and selecting suitable courtyard houses as models based on criteria effective for coping with hot and dry conditions. It involved an examination of 39 traditional courtyard houses in Yazd, drawn from the Ganjnameh book from Shahid Beheshti University. These houses were categorized into two main types based on indicators such as the number of facades with rooms, shape, orientation, and courtyard proportions, which influence thermal efficiency. The first group included 15 houses with rooms on all four facades, northeast-southwest orientation, and a taller southwest facade; the second group consisted of 7 houses with similar characteristics but with the southwest facade being equal in height to the other facades. Further analysis of courtyard proportions led to the identification of the Mortaz and Fateh-ha houses as suitable models for the first and second types, respectively. These findings highlight the significant role of revisiting and revitalizing traditional architecture in addressing contemporary environmental challenges and providing sustainable solutions for urban design and architecture.

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INTRODUCTION

Driven by growing concerns about climate change and resource depletion, the need for environmental sustainability and energy efficiency in buildings has become more urgent. Within this paradigm, the integration of passive heating and cooling strategies in architectural design is identified as a pivotal component in the reduction of energy consumption whilst ensuring thermal comfort. Notably, the traditional courtyard building design is distinguished by its inherent capacity to facilitate climatic comfort, foster social cohesion, and enhance aesthetic value. Throughout history, the design of courtyards has played a crucial role in architecture worldwide, meeting a wide range of needs from biological comfort to social gathering spaces across different cultures and climates. The rich architectural heritage of courtyard buildings, traceable back to the Neolithic period, exemplifies a sophisticated comprehension of passive cooling and heating methodologies, progressively honed over millennia (Edwards, 2006).

Despite the well-recognized value of courtyard designs within both historical and contemporary architectural contexts, a pronounced gap persists in the exhaustive analysis of their thermal performance and adaptability to contemporary exigencies. Predominant studies have tended to rely on a simplified, homogeneous model of courtyard buildings, concentrating primarily on the prototypical square courtyard configuration, thereby neglecting the rich diversity inherent in traditional manifestations (Akhlaghinezhad & Bagheri Sabzevar, 2023; Hajali Zadeh, 2023). Such a reductionist approach potentially overlooks critical design variations that are essential for optimizing thermal efficiency and advancing environmental sustainability across distinct contexts.

This gap underscores the necessity for an in-depth exploration of courtyard house typologies, with a specific focus on the historic city of Yazd, celebrated for its unique architectural heritage and adaptive strategies in arid climates. Employing a methodological framework that combines typological analysis and the Friedman test, this inquiry endeavors to categorize courtyard houses according to principal architectural characteristics, including orientation, dimensions, and spatial configurations. This effort aims to enrich the architectural vocabulary by identifying specific courtyard typologies. Additionally, it seeks to establish a solid empirical foundation for integrating traditional design principles into modern sustainable architectural practices.

This study enriches architectural discussions by introducing a detailed classification of courtyard houses and provides clear, practical advice for architects and urban planners., thereby addressing the research query: What constitutes the typology of courtyard houses in Yazd, and which exemplars embody each typology?

Future research on courtyard houses should explore their adaptation to various climates, integration of sustainable technologies, and impact on occupants' well-being. It should also investigate the use of sustainable materials, their role in urban planning, and economic benefits, alongside examining their historical significance and adaptability to modern living needs. This research will deepen our understanding of courtyard houses as sustainable and culturally relevant habitats.

Thermal performance of courtyard

The central courtyard is used as a passive method in traditional houses, especially in hot and arid areas, which is studied by considering two climatic factors: solar radiation, and wind flow. The first climatic factor focuses on the number of surfaces of the courtyard and building facades exposed to solar radiation. In summer, the goal is to increase shading to reduce heat and thus, to reduce temperature. However, in winter, the goal is to increase the levels exposed to the sun's rays to increase heat and temperature. The rate of increase and decrease of this shading depends directly on the proportions and orientation of the courtyard (Sabzevar et al., 2014). Regarding the

second climatic factor, the flow of wind outside can affect the microclimate inside the courtyard, depending on the courtyard's orientation and proportions (Tablada et al., 2005). Therefore, the courtyard's form, orientation, and proportions can affect the courtyard's thermal efficiency and, of course, the surrounding rooms. In the following, some of the related studies are mentioned.

One study investigated the effect of changing courtyards' shape on cooling loads using P/H and W/L relations. These relations show the effect of courtyard's rectangular dimensions and orientation on creating shadows in four different places (Muhaisen, 2006). In the city of Baghdad, a hot dry climate, Al-Hafith et al. (2017) examined the effects of central courtyard features on the amount of shading. The study concluded that the geometry of central courtyard and its orientation significantly affect the amount of shading. According to this study, the W/H ratio of central courtyard is the most important influencing factor in this regard. In another study, Xu et al. (2018) evaluated the effect of central courtyard design on its performance in climates with cold winters and hot summers and considered China a case study. The results of this research indicate that the proper combination of the general layout of the courtyard and its proportions can significantly affect the amount and manner of ventilation in the summer season and prevent adverse wind in winter. Hassan (2012a) studied the possibility of a ventilated courtyard for passive cooling in a small building in the hot desert region of the new city of Aswan, Egypt. The results illustrate that the courtyard's orientation and geometry are the most critical factors that affect the thermal efficiency of the courtyard building type. Zamani et al. (2018) investigated that the courtyard details in the houses can reduce energy use and provide better climate conditions for the buildings. This study evaluated the most crucial courtyard designs (such as opening, geometry, and direction) by assessing energy efficiency, interior temperature, and natural ventilation in diverse regions. Martinelli and Matzarakis (2017) investigated a numerical study of the thermal comfort of courtyards in Italian climatic zones and considered the effects of the H/W ratio. The results indicated thermal comfort for both summer and winter seasons.

Prototype and Typology

A building typology classifies building parameters including building sizes, construction materials, and construction styles (Loga and Diefenbach, 2011). Lang et al. (2018) illustrated that defining a comprehensive building classification scheme requires an understanding of building typology. Within a specific field of study or discipline, typology explores the types or common elements. In architecture, it can be used to organize and classify buildings based on their form or function, for instance.

Schramm (2008) discussed the classification of courtyard houses in terms of shape, such as L-shaped, U-shaped, fully enclosed on all four sides, multi-courtyard houses, striped courtyard houses and multi-story courtyard houses and presented examples of each category in different cities and countries.

Anna-Maria (2009) classified the residential buildings of a Greek city, Sernikaki, into twelve subcategories and four main categories based on the geographic location, historical roots, and climatic conditions. The study examined building orientation, space, shape, whole condition, and each building type's respective envelope, as well as construction technology, building materials, and site planning. Dascalaki et al. (2011) studied the evolution of the design standards based on the number of heating days, building type, and year of construction of Greek residential structures. According to Filogamo et al. (2014) collected survey data on year of construction, number of floors, climate separation, climate partitioning, and other related factors. Based on the construction year and building shape, the sample buildings were divided into seven categories and 12 subcategories according to the method of typology class, which considered five steps.

MATERIALS AND METHODS

Since the present research categorizes and compares the formal and geometrical characteristics of Yazd's traditional courtyard houses regarding climatic factors, it is an applied type of research. The study's primary data including plans were extracted from the fourteenth volume of GanjNameh published by Shahid Beheshti University Press. Houses in the city of Yazd were explored in this study, which have been registered in the Organization of Cultural Heritage, Handicrafts, and Tourism in Iran (Haji Ghasemi, 1996).

The research process was conducted in two steps. In the first step, to order the typology of courtyard houses, they were classified based on the way the rooms are located around the courtyard, the orientation of the courtyard, and the equality of the height of the southwest facade with others. In the second step, to select a suitable sample for each type of courtyard housing, the proportions of each courtyard were scrutinized. The following geometric variables of a courtyard house were employed for the second step.

- (H/W): it is called aspect ratio and includes the relationship between the courtyard height and width (Rodríguez-Algeciras et al., 2018; Yousef, 2021).
- (P/H): it is the courtyard perimeter to height ratio. (Muhaisen & Gadi, 2006; Sabzevar et al., 2014; Yousef, 2021).
- (WI): it is known as well index with the ratio (H(W+L))/ (2WL) (Aizlewood, 1995)
- (AR): it is the courtyard area to the square height of courtyard walls (A/(H^2)) (DeKay, 2010; Yousef, 2021)

To select a suitable sample(s) from all samples, the proportions of the courtyards were examined because of their essential role in the thermal efficiency of the houses. For this purpose, the suitable sample(s) can be the house that has the closest proportions to the average house proportions. Therefore, at first, the absolute distance from the mean for each ratio was calculated. Afterwards, due to the difference in ratios, they were normalized. Finally, the average of all ratios for each sample was calculated. Of these figures, the lowest one was considered the suitable sample(s) for a courtyard house in Yazd.

The Friedman test is applied to determine the prioritization and ranking of courtyard houses in terms of proportions. It is particularly useful when the same individuals are measured under different conditions or at different times (Pereira et al., 2015). Figure 1 illustrates the research methodology workflow, which is divided into 3 phases: a) The Selection of samples, b) Classification, c) Sample selection of each classification

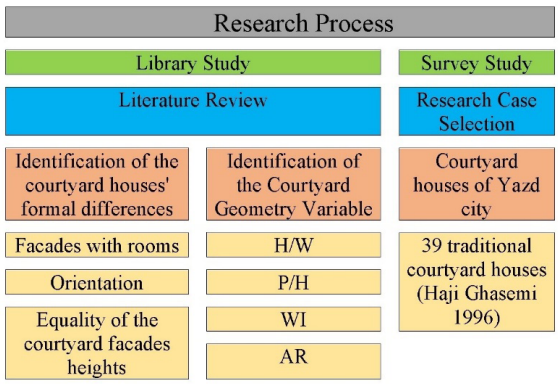


Figure 1: Research methodology workflow.

Although other parameters such as color and building materials affect the thermal efficiency, since such variables were the same in all houses of Yazd, they were not considered in this research.

Table 1 depicts some characteristics of 39 courtyard houses studied in this research. In addition, the locations of these houses in the context of the city of Yazd have also been portrayed in Fig. 2. In this research, analyses were conducted to establish a typology of courtyard houses, categorizing them based on their similarities and differences according to the following parameters:

1- Courtyard facades with rooms

2- Courtyard orientation

3- Relative height of the southwest facade to others

Table 1: The studied courtyard houses

Houses number	Name of house	The height equality of the southwest facade to others	Orientation	Courtyard facades with rooms
1	Akhavan Sigari	yes	NE-SW	NE,NW,SE,SW
2	Ardakanian (East courtyard)	yes	NE-SW	NE,NW,SW
3	Ardakanian (West courtyrad)	yes	NE-SW	NE,NW,SW
4	Tehrani-ha	yes	NE-SW	NE,NW,SE,SW
5	Rasolian (East courtyrad)	yes	NE-SW	NE,NW,SW
6	Rasolian (West courtyrad)	no	NE-SW	NE,SW
7	Roohanian (West courtyrad)	yes	NE-SW	NE,NW,SE,SW
8	Rismanian	yes	NE-SW	NE,NW,SE,SW
9	Semsar	no	NE-SW	NE,NW,SW
10	Shfi pour	no	NE-SW	NE,NW,SE,SW
11	Arab (Bibi righayeh)	no	NE-SW	NE,NW,SE,SW
12	Arab (Alireza)	yes	NE-SW	NE,NW,SE,SW
13	Arab Kermani (West courtyrad)	no	NE-SW	NE,SE,SW
14	Arab Kermani (East courtyrad)	no	NW-SE	NE,NW,SE,SW
15	Arab_ha (West courtyrad)	yes	NE-SW	NE,SW
16	Arab_ha (Mid courtyrad)	no	NE-SW	NE,SW,SE
17	Arab_ha (East courtyrad)	yes	NE-SW	NE,NW,SE,SW
18	Olomi_ha (West courtyrad)	no	NE-SW	NE,NW,SW
19	Olomi_ha (East courtyrad)	yes	NE-SW	SE,SW,NW
20	Fateh_ha (East courtyrad)	no	NE-SW	NE,NW,SE,SW
21	Fateh_ha (West courtyrad)	yes	NE-SW	NE,NW,SE,SW
22	Farhangi (South courtyrad)	yes	NE-SW	NW,SE,SW
23	Farhangi (North courtyrad)	yes	NE-SW	NE,NW,SE,SW
24	Keraoghli (Big courtyard)	yes	NE-SW	NE,NW,SW
25	Keraoghli (Small courtyard)	no	NE-SW	NE,SW
26	Gerami (West courtyrad)	no	NE-SW	NE,NW,SE,SW
27	Gerami (East courtyrad)	no	NE-SW	NW,SE
28	Golshan (big courtyard)	yes	NE-SW	NE,NW,SE,SW
29	Golshan (small courtyard)	no	NW-SE	NE,NW,SE,SW
30	Golshan (mid courtyard)	yes	NE-SW	NE,NW,SE,SW
31	Lari_ha (West courtyrad)	yes	NE-SW	NE,NW,SE,SW
32	Lari_ha (East courtyrad)	yes	NW-SE	NE,NW,SW
33	Mortaz (West courtyrad)	no	NW-SE	NE,NW,SW
34	Mortaz (East courtyrad)	yes	NE-SW	NE,NW,SE,SW
35	Mester Vay	no	NE-SW	NE,NW,SE,SW
36	Mashrote	yes	NE-SW	NE,NW,SE,SW
37	Meshkian	yes	NE-SW	NE,NW,SE,SW
38	Malek (big courtyard)	yes	NE-SW	NE,NW,SE,SW
39	Malek (small courtyard)	no	NE-SW	NE,SE,SW

DISCUSSION AND FINDINGS

Analysis of climatic conditions of Yazd

Yazd, situated in the heart of Iran with coordinates at 31.8°N latitude and 54.3°E longitude, endures warm, arid summers and chilly winters. The yearly average temperature stands at 19.1°C, with the highest average in June reaching about 31.8°C and the lowest in December approximately 4.9°C. The temperature varies significantly, from a low of -6°C at nighttime to highs of +43°C in daytime.

Results of classification of courtyard houses

Classification based on the number of courtyard facades with rooms

The types of courtyard houses were classified based on the number of facades from the courtyard that have rooms (Tab. 2). The first type, which has the largest share, includes 24 houses with rooms on all four sides. The second type displays 6 houses with rooms on the northeast, northwest, and southwest facades. The third type embraces 3 houses with rooms on the northeast, southwest, and southeast facades. Only 2 houses can be categorized in the fourth type with rooms on the northeast, southwest, and southeast facades. The fifth type comprises 3 houses that have rooms only on the northeast and southwest facades. Ultimately, the sixth type poses just 1 house that has rooms on the southeast and northwest facades.

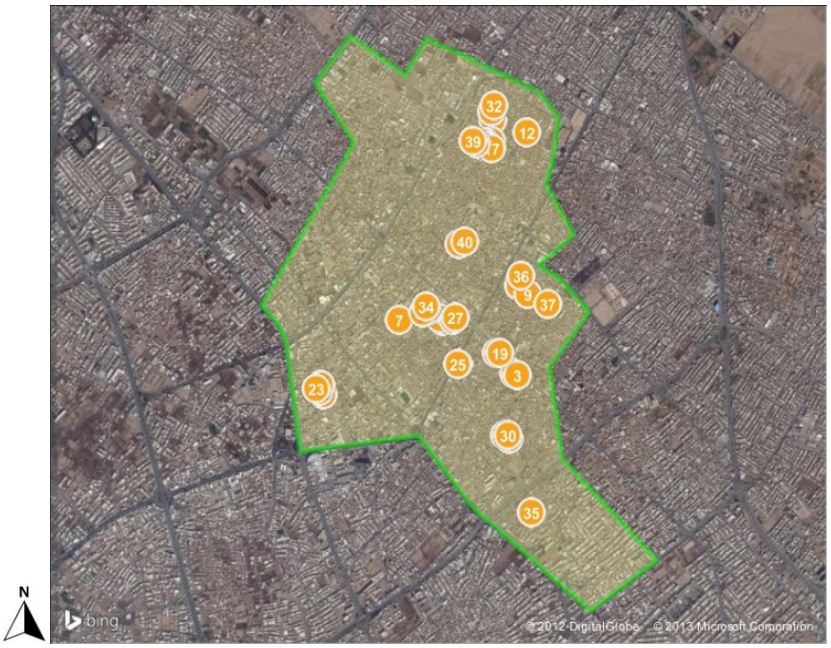


Figure 2: Distribution of the studied houses in the old city of Yazd

Table 2: Classification by the number of courtyard facades with room

Typology of courtyard houses N						
Number	Type 1: 24	Type 2: 6	Type 3: 3	Type 4: 2	Type 5: 3	Type 6: 1

According to Table 2, the first type with 24 samples is the most common among the courtyard houses. As a result, the study focused on houses with four-room facades.

Classification based on the orientation of the courtyard

Table 3 shows the classification of courtyard houses used in this research based on the orientation of the courtyards. The first type of courtyard house has a northeast-southwest orientation, and the second type has a northwest-southeast orientation.

Table 3: Classification by the courtyard orientation

Orientation		
Number	Type 1: 35	Type 2: 4

According to Table 3, the first type with 35 samples has the largest number and the most common condition among the courtyard houses in Yazd city. So, this research focused on houses with a northeast-southwest orientation.

Classification by the height comparison of the southwest facade to others

The courtyard houses in this research were categorized based on the height of the southwest facade, with the other facades shown in Table 4. The first type includes courtyard houses, whose height on the southwest facade is higher than the other facades, and the second type comprises courtyard houses, whose height on the southwest facade is equal to the other facades.

According to Table 4, the first type with 21 samples and the second type with 18 samples comprise the main types used in Yazd. Since both of them are common with almost equal proportions, the research process concentrated on both types.

The typology of courtyard houses

The courtyard houses taken from the GanjNameh book were examined in order to find the typology of courtyard houses in Yazd. They were divided into two general types (Tab. 3).

The first type is courtyard houses with four facades with rooms around the central courtyard, rectangular in terms of shape, with a northeast-southwest extension, and a higher southwest facade in comparison to the others.

The second type is courtyard houses with four facades with rooms around the central courtyard, rectangular in terms of shape, northeast-southwest extension, and four facades with equal height.

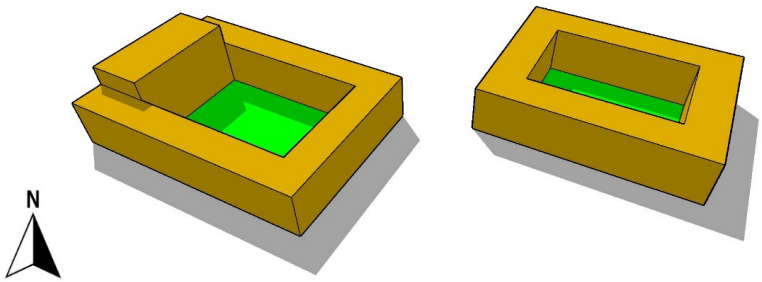
Results of courtyard houses proportions

The first and second types, which include 15 and 7 courtyard houses, respectively, have similar formal characteristics, presented in Tables 5 and 6 with their sizes and ratios based on H/W, P/H, WI, AR.

The goal of this research was to obtain a suitable sample(s) of courtyard houses. Therefore, the absolute distance from the mean was calculated for each house in each ratio. Then they were normalized in the range between 0 and 1. The results have been presented in Fig. 4&5 for the first and second type, respectively.

Table 4: Classification by the height comparison of the southwest facade to others

height comparison of the southwest facade to others		
Number	Type 1: 21	Type 2: 18



a: Type 1 b: Type 2

Figure 3: Two general types of courtyard houses in Yazd

Table 5: Names, dimensions and proportions of courtyard house in the first typology

Houses number	Length	Width	Northeast height	The height of the southwest facade	Southeast and northwest height	H/W	P/H	WI	AR
1	23.05	14.65	6.9	6.6	5.55	0.45	13.59	0.31	10.96
4	16.9	9.4	6.45	7.05	6.45	0.75	8.16	0.53	3.82
7	16.25	12.15	5.5	6.3	5.5	0.52	10.33	0.40	6.53
8	21.6	14.65	5.45	7.65	5.45	0.52	13.30	0.31	10.65
12	18.9	12.25	5.45	7.65	5.45	0.62	11.43	0.37	7.79
17	24.15	17.1	5.8	7.5	5.8	0.44	14.22	0.29	12.28
21	17.45	14.7	6.2	9	6.2	0.61	10.37	0.39	6.67
22	20.55	15.6	5.5	7.5	5.5	0.48	13.15	0.31	10.60
28	19.25	15	5.35	7.15	5.35	0.48	12.80	0.32	10.09
30	15.6	12.2	5.45	7.15	5.45	0.59	10.20	0.40	6.41
31	28	16.8	6.05	8.6	6.05	0.51	14.81	0.29	12.85
34	23.6	16	7	8.3	7	0.52	11.31	0.37	7.71
36	14.2	10.45	5.25	6.4	5.25	0.61	9.39	0.44	5.38
37	18.95	14.85	5.45	7.5	5.45	0.51	12.40	0.33	9.47
38	14.9	13	5.85	7.05	5.85	0.54	9.54	0.42	5.66

Table 6: Names, dimensions and proportions of courtyard house in the second typologym

Houses number	Length	width	northeast height	The height of the southwest facade	Southeast and northwest height	H/W	P/H	WI	AR
10	17.9	12.1	6.3	6.3	6.3	0.52	9.52	0.44	5.46
11	12.15	7.15	4.9	4.9	4.9	0.69	7.88	0.54	3.62
14	7.8	8.95	6.95	5.15	5.15	0.58	6.50	0.62	2.63
20	17.55	12	7.2	7.2	7.2	0.60	8.21	0.51	4.06
26	13.8	9.55	6.95	6.95	6.95	0.73	6.72	0.62	2.73
29	6.25	9.25	5.1	5.1	5.1	0.55	6.08	0.68	2.22
35	22.95	12.4	6.7	6.7	6.7	0.54	10.55	0.42	6.34

As presented in Table 7, the houses of Mortaz (east courtyard) and Fateh_ha (east courtyard) have the lowest rank among the courtyard houses, indicating the lowest effect on the common and general proportions of the courtyard houses. In addition, the Friedman test showed a p_value of less than 0.05, indicating a significant difference between the proportions of courtyards.

These results show that the courtyard houses of Mortaz (east courtyard) and Fateh_ha (east courtyard) can be the appropriate samples for the first and second typologies of courtyard houses in Yazd, respectively.

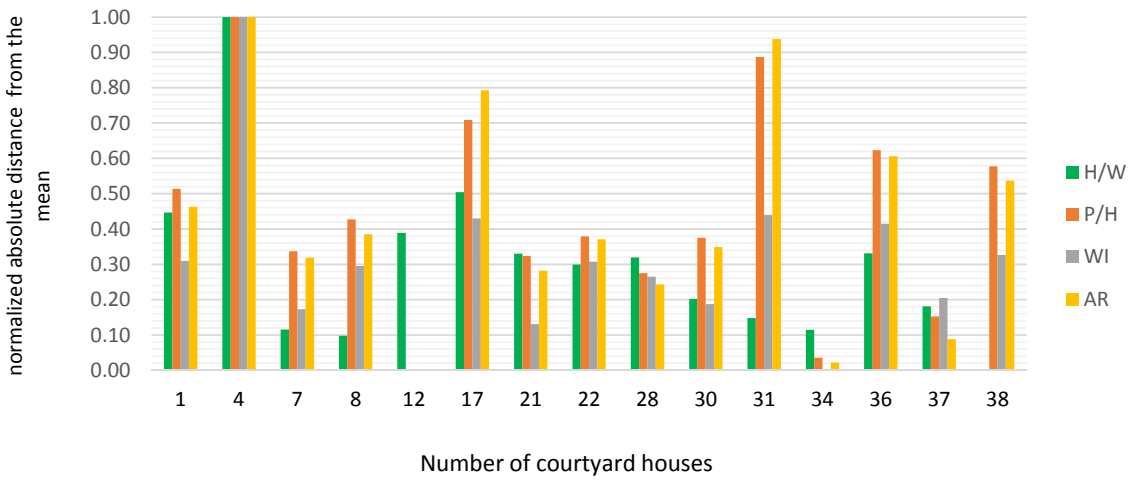


Figure 4: The normalized absolute distance from the mean of ratios for each courtyard house and the average in the first typology

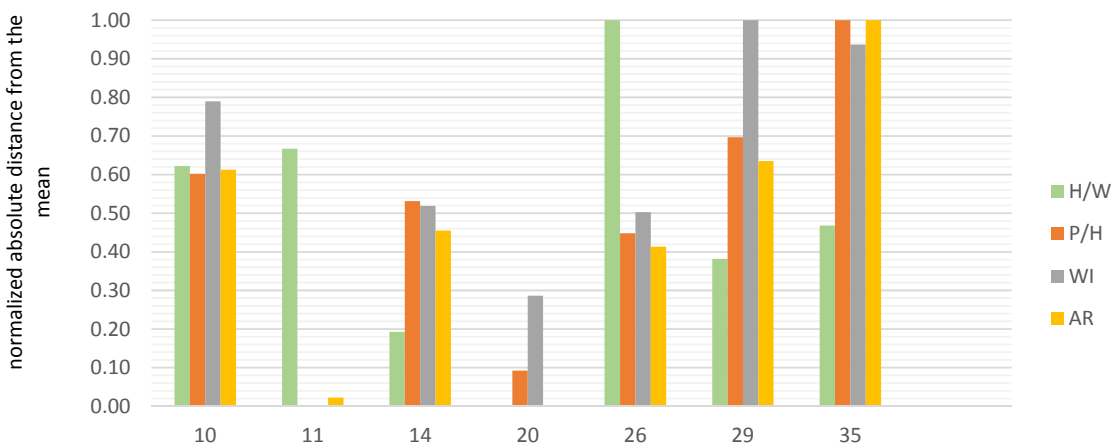


Figure 5: The normalized absolute distance from the mean of ratios for each courtyard house and the average in the second typology

Table 7: Friedman test for the first and second typologies

The first typology

Courtyard houses number	Mean Rank
1	10.75
4	15.00
7	5.00
8	7.00
12	3.75
17	13.25
21	5.75
22	8.25
28	6.00
30	6.50
31	11.75
34	2.25
36	11.75
37	4.50
38	8.50

Test Statistics

N	4
df	14
Asymp. Sig. .(p-value)	.000

The second typology

Courtyard houses number	Mean Rank
10	5.00
11	2.50
14	3.50
20	1.50
26	4.00
29	5.50
35	6.00

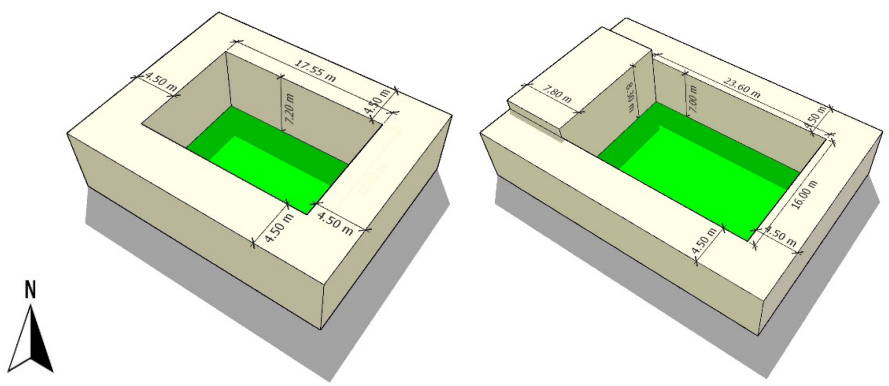
Test Statistics

N	4
df	6
Asymp. Sig. .(p-value)	.033

Table 8 and Fig. 6 display the specifications and forms of suitable houses.

Table 8: Specifications of suitable samples

Typology	Suitable sample	Length	width	southwest facade height	other facades height	southwest room depth	other rooms depth
Type 1	Mortaz house (East courtyrad)	23.6	16	8.3	7	7.8	4.5
Type 2	Fateh_ha house (East courtyrad)	17.55	12	7.2	7.2	4.5	4.5



a: The Mortaz House for the first type b: The Fateh-ha House for the second type

Figure 6: Form and dimensions of suitable houses for each type

RESULT AND CONCLUSION

The analysis of courtyard houses in Yazd reveals deep insights into traditional architectural techniques for climate adaptation, especially through the study of classifications and proportions. This research aligns with existing literature, like Hassan (2012b) examination of the thermal performance of Egyptian courtyard houses, highlighting the crucial roles of orientation and proportion. The study also considers facade heights and orientations for a comprehensive approach to thermal comfort, slightly differing from Akhlaghinezhad et al. (2024) study, which utilizes simulation to calculate the shadow-sunlit index. Despite recognizing a common structure with rooms around the central courtyard, oriented from northeast to southwest, their study selected the Arab house as an ideal archetype. This research differs from Sabzevar et al. (2017) suggestion of an east-west orientation for cortyard building, attributing lifestyle and methodological differences as reasons for varying conclusions. However, observations are in line with Sharami's (2023) acknowledgment of Yazdi houses' southwest-facing orientation.

The study underscores the lasting value of traditional architectural knowledge in modern sustainable design, especially in regions with similar climates. The detailed analysis of typologies and proportions provides architects and urban planners a foundational framework for incorporating passive cooling and privacy strategies into contemporary designs. Although focusing on Yazd and specific houses, the research suggests further exploration of courtyard houses in different climates and integrating modern sustainable technologies with traditional forms. This could reaffirm the significance of traditional architectural principles in contemporary and future design and planning. The research highlights the perpetual importance of Yazd's courtyard houses as a source of inspiration for sustainable architecture, showing the delicate balance between environmental adaptation, privacy, and community life—essential elements for sustainable urban development. The precise understanding from the classification based on orientation, facade heights, and proportions, along with introducing the Mortaz and Fateh-ha houses as suitable sample in terms of efficient design courtyard, accentuates crucial design elements for improving thermal comfort and energy efficiency.

Considering the study's limitations, including its geographical focus on Yazd and the selection of particular houses, future research is encouraged to investigate courtyard houses in other climates and examine the integration of modern sustainable technologies with traditional designs. Such efforts could further validate the application of traditional principles in contemporary architecture and urban planning.

Recent studies have focused on understanding the performance of passive methods in traditional courtyard buildings as a sustainable architecture approach. In most of these studies, the need to have a model or sample is an important step. Likewise, in this study 39 courtyard houses were selected in the Ganjnameh book published by Shahid Beheshti University Press to find the model of traditional courtyard houses in Yazd. They were built between 1200 and 1300 AH and are located in different areas of the old city of Yazd. Studies were conducted on these houses, and general information and physical dimensions were recorded. The houses were classified based on the form, including the number of facades with rooms around the courtyard, and the orientation of the courtyard, comparing the height of the southwest facade to other facades.

The classification of houses in Yazd showed that most houses have facades with room, rectangular shapes with northeast-southwest extension. In two types, the southwest facade was higher than the others in 15 samples while it was equal to the other facades in 7 samples.

Subsequently, the houses were analyzed in terms of the proportions of the courtyard, as these are important for solar radiation and airflow, which in turn affect energy consumption

and thermal comfort in the rooms around the courtyard. The analyses were based on the H/W, P/H, WI and AR ratios to find the common and general proportions according to the Friedman test. Finally, the Mortaz house with a higher southwest facade compared to the others, and Fateh_ha house, with all facades at the equal height, were identified as suitable samples.

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