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A comparison of the traditional use of court houses in two cities

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Abstract

For many years central court houses have been used in parts of Iran with different climates. Though initially there appear to be many similarities, some aspects of these houses vary from one climatic zone to another. Several studies have also suggested that users of these houses moved within them as they sought for better thermal situations. This article sets out how differing sizes, forms and dimensional ratios of central courts in two climate zones of Iran (Yazd, hot and dry, and Bushehr, hot and humid) can support this behaviour. In both places these central court forms can provide good situations for human comfort on various sides and levels of the court. Consequently, residents could move within the house with the seasons to get their desired level of thermal comfort but these traditional patterns of movement differ for each climate zone.

Keywords: Central court houses; Iranian architecture; Behaviour; Yazd; Bushehr

1. Introduction

The old architecture of Iran with a history that goes back 8000 years is famous for its central court houses, which were designed to be used in the different climates of the country (Memarian and Brown, 2006). Cooling and warming of these houses were completely based on natural energy sources like the wind and sun, the latter being "the principle source of comfort and discomfort" (Ragette, 2003:84). Iranian builders could control the effects of weather conditions mostly using architectural means. Several studies support a widespread belief among people that residents used to move within their houses seeking for better thermal situations (Foruzanmehr, 2012, 2014; Foruzanmehr and Vellinga, 2011; Roaf et al., 2005, 2009 ed.; Roaf, 1988; Nicol et al., 2012; Heidari et al., 2000; Bonine, 1980; Madanipour, 1998; Memarian and Brown (2006)), thus linking the form of the traditional court house with behaviour. Because these central courts are used in the different climates of Iran the question arises as to how these similar forms of house can respond to these, either through design or behaviour. It seems that though there are similarities, there are also big differences in the arrangement of these central courts because as Memarian and Brown (2006:23) state "variation in climate led to variation in architectural response" both in Iran and the Arabic countries of the Middle East. This article sets out to determine how ancient Iranian architects and builders have chosen the dimensions and proportions of central courts to offer human comfort in

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the different climatic situations and what movement patterns around the houses are required.

2. Background

Many studies have addressed the issue of Iranian central court houses. As Memarian and Brown (2006) state, building materials with high thermal mass, the presence of a basement and semi-open spaces, use of wind-catchers, and changes in the sectional profile of the courtyard are all methods used to maintain comfort in Iranian and Arabic central court houses. This paper looks at the latter, this being a topic that has not yet been fully investigated, especially as some of the features, like wind catchers are only found in hot dry climates, not hot wet ones like Bushehr, although courts are found in both.

The presence of summer and winter rooms in Iranian central court houses and moving from one space to another to find the best thermal comfort on different days of a year and different times of the day have been studied by others (Foruzanmehr, 2012, 2014; Foruzanmehr and Vellinga, 2011 Roaf et al., 2005, 2009 ed.; Roaf, 1988; Nicol et al., 2012; Heidari et al., 2000; Bonine, 1980; Madanipour, 1998; Memarian and Brown, 2006). However, there is no study of how architectural decisions about the size of the courts can support this trend. In addition, most available studies are focussed on Yazd with its hot and arid climate, even though there is agreement the form is found in other climate types (Memarian and Brown (2006) and Ragette (2003)). This study aims to fill the knowledge gap about the role of the central court house in a hot humid climate through comparing its performance with a court house in the more familiar hot dry climate. For this reason, Yazd and Bushehr are selected to represent respectively ancient cities with these different climates.

3. Methodology

Ten case study houses from the two different climatic zones of Yazd and Bushehr were selected. All houses are located in the ancient zones of both cites and are examples of old central court houses. All Bushehr cases are based on measured drawings as part of Persian Gulf University of Bushehr student projects (Khajehzadeh and Yavari, 2012) and data for all Yazd houses are taken from Haji-Qassemi (2005). For Bushehr, all chosen houses are the two storey on all four sides type, which is a popular form, and for Yazd, the chosen houses are a mixture of small and big houses of one storey on all four sides, again a popular type.

The ground floor plan and a vertical section generated from the measurements of each house have been used to create a table of characteristics. Length, width, height and area of open space have been taken from the drawings and according to these data other physical characteristics of the houses such as ground floor area/total building foot print, area of central court/building foot print, width/length of central court, width/height of central court and length/height of central court are calculated as percentages for each. Finally, two tables of averages of all these ratios for the Bushehr and Yazd houses are created for a comparison and conclusions have been extracted.

4. A brief look at Iranian central court houses

4.1. Yazd

A typical central court house in Yazd is surrounded by built area on all four sides and rooms on 2, 3 or 4 sides of the central court (Foruzanmehr, 2014) (Figs. 1–3). All parts of these houses including foundations, walls and roofs are

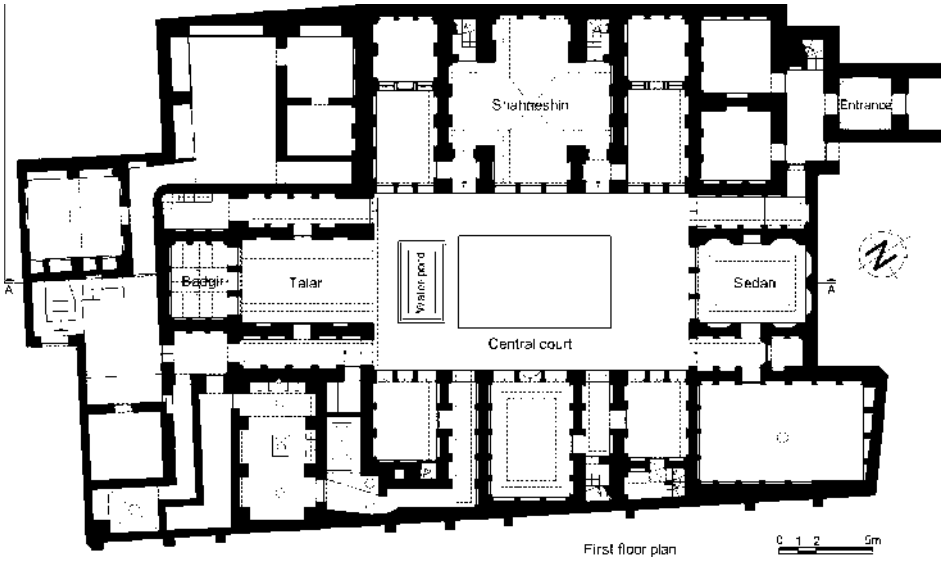


Figure 1. First floor plan, Tehraniha house, Yazd (*after:* Haji-Qassemi (2005)).

Figure 2. Longitudinal section, Tehraniha house, Yazd (*after:* Haji-Qassemi (2005)).

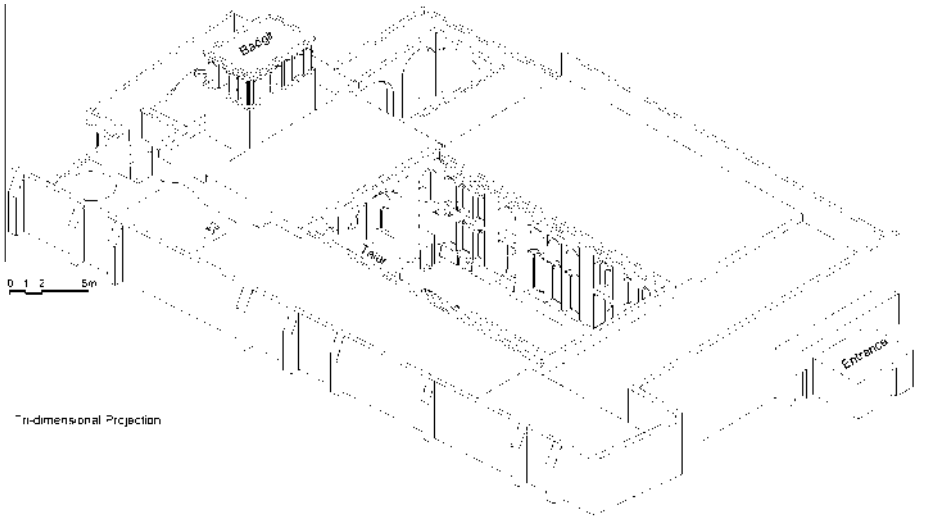


Figure 3. Three-dimensional projection, Tehraniha house, Yazd (*after:* Haji-Qassemi (2005)).

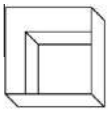
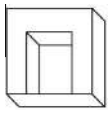
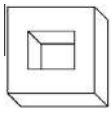
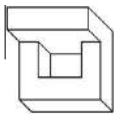
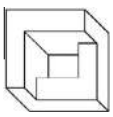
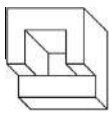
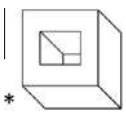
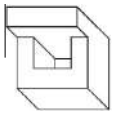
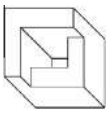
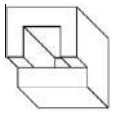
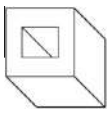
of mud plastered adobe (Bonine, 1980). Traditionally the adobe was made from the clay produced by excavation of the land on which the house was to be built in. The adobe walls are very thick, usually 70 cm but sometimes reaching 100 cm, and are covered with mud plaster. Roofs have two layers with a curved form inside which changes to a flattened form outside. The only opening of the house to the public area is the entrance door and all windows open to the central court (Bonine, 1980). The form of the central court is usually a rectangle with its long axis rotated 30 degrees clockwise from the north. In most of Yazd's central court houses the smaller southern side of the court is in the Qeble direction (Memarian and Brown (2006) and Kheirabadi (1991)) (Qeble is the direction towards Mecca, a holy place in Saudi Arabia for all Muslims, who anywhere in the world must keep facing Qeble when making their daily prayers).

These houses are usually built with one storey above the ground and one underground although the underground level is normally only on the southern side of the court (Bonine, 1980). Rooms have different uses on different sides of the central court. In most large houses, the northern side has one big room, called the "panjdari" (five doors) or "haftdari" (seven doors) (Memarian, 1998). This is the most beautiful room of the house, mostly used for guests, and contains many decorative artefacts. The western is the longest side and has several small sized rooms usually called "sedari" (Memarian, 1998). These rooms were used by the family members during the winter. In most houses, the eastern side has no rooms although in some cases porches are formed here which are good for summer morning use (Foruzanmehr, 2014). The two storey southern side has an upper level which is a little higher than the other three sides of the house (Kheirabadi (1991)). This side contains a very big, high space called the "Talar" or "Shahneshin" which is used by both family members and guests during summer (Kheirabadi (1991)). This side of the house is usually supported by a "Badgir" (wind catcher) (Kheirabadi (1991)) to the back and a "Kolahfarangi" in the corner (a heightened space with a domed roof with several openings), which are both used for ventilation and cooling. The underground level contains several rooms used mostly at noon in summer. In many cases the "Badgir" is also continued to the underground level.

The central court houses were usually home to more than one family. Because of the Islamic regulations for "maharem", this would most probably have been an

extended family. Based on the Quran, "maharem" refers to the conditions when women do not wear the hijab. This involves relationships such as father/daughter, mother/son, brothers/sisters, uncle/niece, aunt/nephew, father-in-law/daughter-in-law, mother-in-law/son-in-law, grandmother/grandson and grandfather/granddaughter. This is also the reason why only boys of an extended family live in their parental house, with girls going to their husband's family house. When a boy of the family married, he could live with his wife and any children in one of the rooms of the house for some years up to the time that he could make his own house (Shabani et al., 2011). Consequently there is no accurate information on how many families used to live in each of these houses because this was completely dependent on the size of the house and the financial condition of the owner.

Table 1
Different types of Bushehr central court house.

	One Side	Two Sides	Three Sides	Four Sides
One storey				
Two storeys				 *
Three storeys				

*This is one of the most popular forms and all case studies are like this.

4.2. Bushehr

A typical central court house in Bushehr is formed by building on at least two sides, but most have three or four built sides (Rasaie-Kashuk, 2005). Walls are made of coral stone covered with a white plaster (Rasaie-Kashuk, 2005). Wall thickness is between 40 and 50 cm. Flat roofs are made from timber poles with wooden boards or a hand woven carpet made with leaves of the palm tree (called "hasir") on top with a covering of mud (Rasaie-Kashuk, 2005). All houses have several openings both into the public space and the court which are used to facilitate natural ventilation (Memarian and Brown, 2006). Openings to public spaces are usually covered by wooden blinds to control views from outside to inside while allowing wind into the rooms. These are also equipped with shutters to control solar over heating (Ragette, 2003). Most houses have wooden balconies on to the public space called "Shenashil", which is a Middle Eastern Arabic term (Memarian and Brown, 2006). All houses have spaces like a veranda adjacent to the central court called "tarme" (Memarian and Brown, 2006).

Most central houses have two storeys although there are also some three and one storey variants. The number of three storey houses is very small and they all belong to rich families. The hot humid weather for more than 7 months of the year (April–October) needs houses that catch more wind and are more in shadow. The form of the central court is usually a four sided square with very high surrounding walls making more shadow, although there are also rectangular houses. Some houses have two storeys to all four sides while others have only one, two or three double storey sides (see Table 1). The direction of Bushehr's central court houses with regard to North is varied and seems not to obey a particular rule. There are rooms in each side of the court. The rooms located in the upper level are mostly used as major spaces and those on the ground floor for servicing and water storage. The largest and most beautiful room in the upper level is used for guests and is called "majlis" (Memarian and Brown, 2006).

Table 1 shows the different types of Bushehr central court house. As explained most are the double storey type as one and three storey houses are very rare.

Like Yazd, Bushehr's central court houses were used by several families at the same time (those of the Father and his sons), the number depending on the size of the house and the financial condition of the owner.

4.3. The climate in Yazd and Bushehr

The city of Yazd is located in the central desert of Iran in a hot and dry climate. There is a big temperature difference between night and day and this is the same winter and summer (see Fig. 6). In this climate, absorbing most sunshine on winter days and least sunshine on summer days is important for thermal comfort. Over a year, the temperature typically varies from −1 °C to 41 °C and is rarely below 5 °C or above 42 °C (Weather spark, 2013). The relative humidity in Yazd typically ranges from 6% to 74% over a year which can be categorised as very dry to humid (Weather spark, 2013). Humidity in Yazd can drop as low as 3% (very dry) and reaches as high as 96% (very humid) (Weather spark, 2013).

In contrast, Bushehr is located in the south of Iran in a hot and humid climate. For more than 8 months of the year the outdoor temperature is very high and as a result, absorbing the least sunshine is needed (see Fig. 7). Over a year, the temperature typically varies from 11 °C to 38 °C and is rarely below 7 °C or above 39 °C (Weather spark, 2013). Controlling the high level of humidity is another problem in this region. The relative humidity of Bushehr typically ranges from 34% to 88% over a year which can be categorised as comfortable to very humid (Weather spark, 2013). It rarely drops below 18% (dry) but it can reach as high as 98% which is very humid (Weather spark, 2013).

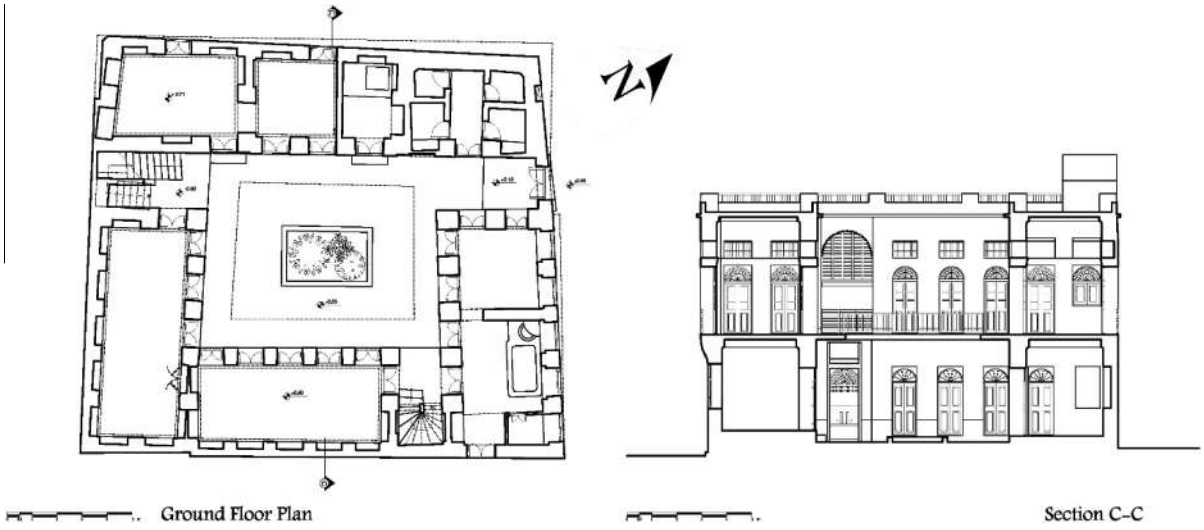


Figure 4. Ground floor plan and Section C–C, Rashidi house, Bushehr (*source:* Khajehzadeh and Yavari (2012)).

Figure 5. Central Court view, Rashidi House, Bushehr (*source:* Khajehzadeh and Yavari (2012)).

5. Analysis

5.1. Case studies

Ten houses (Amirieh house, Rashidi house, Golshan house, Farkhondeh house, Payambarifar house, Rowghani house, Taheri house, Mandanipour house, Nowzari house and Rafiei house) were selected as Bushehr case studies (Khajehzadeh and Yavari, 2012). All are four sided two storey central court houses of the same shape but not the same size. A table of characteristics was prepared for each house (Table 2).

Ten houses (Arabha house, Mortaz house, Rasoulian house, Tehraniha house, Olumiha house, Rismanian house, Semsar house, Shafipour house, Arab (Bibi Rghayeh) house and Arab (Alireza) house) were selected as Yazd case studies (Haji-Qassemi, 2005). All are four sided one storey central court houses of the same shape but not the same size. Again, a table of characteristics was prepared for each house (Table 3).

To make a clear comparison, the data for all ten houses in each group were averaged. The Bushehr average is shown in Table 4 and the Yazd average in Table 5.

Comparing Tables 4 and 5 shows that:

- There is not a big difference between the density of built space in Bushehr and Yazd although that of Bushehr (78.0%) is a bit higher (Yazd is 70.2%).

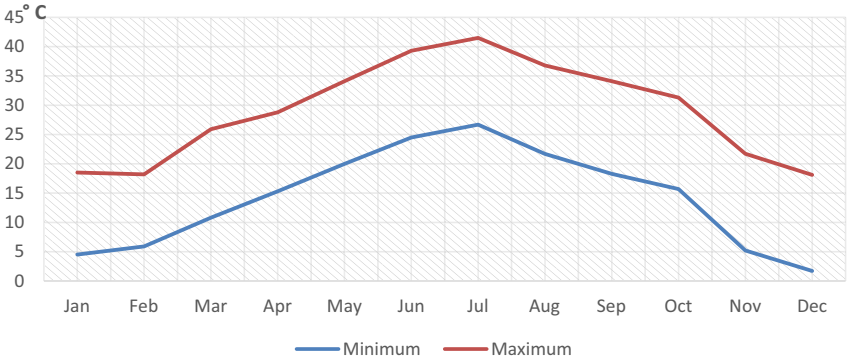


Figure 6. Average Minimum/Maximum temperatures for Yazd-2010 (*source:* Yazd Meteorological Organization (2014)).

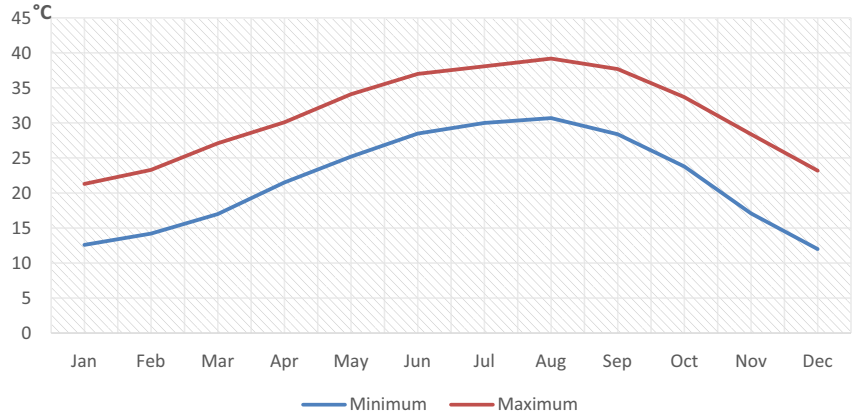


Figure 7. Average Minimum/Maximum temperatures for Bushehr-2010 (*source:* Yazd Meteorological Organization (2014)).

Table 2
Characteristics of a typical house in Bushehr (Amirieh house).

	Length (m)	Width (m)	Height (m)	Area (m2)	BA/BFP (Percent)	CCA/BFP (Percent)	Width/Length central court (Percent)	Width/Height central court (Percent)	Length/Height central court (Percent)
Central court area	12.2	8.8	8.7	107.4	86.5%	13.5%	72.1%	101.1%	140.2%
Built area	32.6	25	8.7	692.6				Average $[(a+b) \div 2] \div c = 120.6\%$	
Building foot print	32.6	25	–	800.0					

Note: BA, built area; BFP, building foot print; CCA, central court area.

Table 3
Characteristics of a typical house in Yazd (Arabha house).

	Length (m)	Width (m)	Height (m)	Area (m2)	BA/BFP (Percent)	CCA/BFP (Percent)	Width/Length (Percent)	Width/Height (Percent)	Length/Height (Percent)
Central court area	24.8	17.1	5.7	423.8	57.9%	42.1%	68.9%	300.0%	435.1%
Built area	39.6	26.8	5.7	583.3				Average = 367.5%	
Building foot print	39.6	26.8	–	1007.1					

Table 4
Average characteristics for 10 Bushehr houses.

Built area/building foot print (Percent)	Central court area/building foot print (Percent)	Width/length for open spaces (Percent)	Width/height for open spaces (Percent)	Length/height for open spaces (Percent)
78.0%	22.0%	79.5%	88.9% Average = 100.8%	112.8%

Table 5
Average characteristics for 10 Yazd houses.

Built area/building foot print (Percent)	Central court area/building foot print (Percent)	Width/length for open spaces (Percent)	Width/height for open spaces (Percent)	Length/height for open spaces (Percent)
70.2%	29.8%	68.6%	220.1% Average = 270.4%	320.7%

- The form of the Bushehr central court is very near to a cube while that of Yazd is more rectangular. Additionally, the Bushehr central court is much higher than that of Yazd. Using a for width, b for length and c for height then:

  For Bushehr central court $b = 1.25a$ $c = 1.12a$

  For Yazd central court $b = 1.45a$ $c = 0.45a$

- Using the analysed data, typical forms for Yazd and Bushehr central court houses were created and are shown in Fig. 8.

5.2. Exploring reasons for different central court forms

According to the dimensional analysis, although both are based on a rectangular form the proportions of the

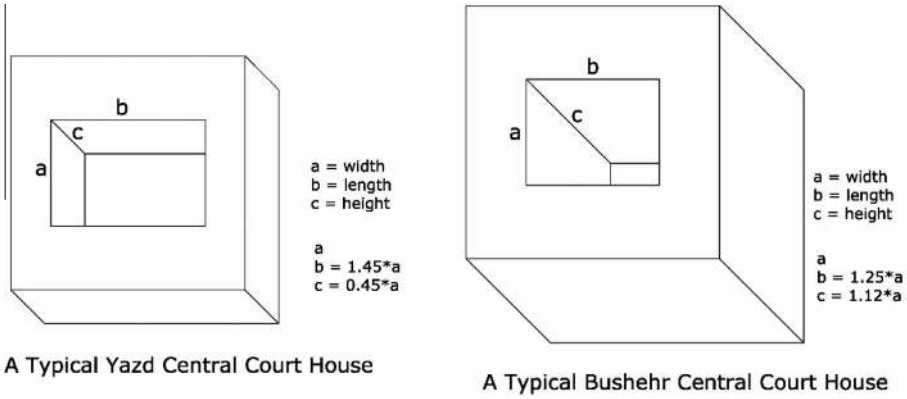


Figure 8. Typical central court houses of Yazd and Bushehr.

central courts of the Bushehr and Yazd houses have significant differences. This could be related to the level of direct sunshine needed in each of these two cities in summer and winter. As mentioned, Bushehr is located in a climate which needs more shade during the 8 hot months but Yazd needs more sun during winter as well as shade in summer. A study by Mohsen (1979:105) concludes the proportions of a central court "can affect the initial irradiation load received on the surfaces of the form".

Fig. 8 shows the central court houses in both cities potentially generate four external and four internal facades. In Yazd, external facades are usually blocked by the attached neighbouring houses to reduce the external surfaces being affected by sun and wind. There is no opening to the exterior apart from an entrance door (see Figs. 1–3). In contrast, Bushehr central court houses have several openings in the interior and exterior facades (Figs. 4 and 5). Having openings in two opposite sides of a room assists natural cross ventilation, which is important in a hot and humid climate. At the urban scale, unlike Yazd, Bushehr central court houses were not usually attached on all sides, but were built very close to each other making very narrow alleys creating shadow on the external surfaces for most of the day (Fig. 9). As a consequence in neither city do the external surfaces receive much direct solar radiation. This is not true of the internal courtyard as the internal facades are the main receivers of solar radiation, although this differs with the season and time of day. As a result this study is limited to exploring sun and shadow on the internal facades of the central court houses of both cities.

To find the level of sun and shadow on the internal facades of the typical Yazd and Bushehr central court houses each was modelled in "Archicad" to create a "sun study" for all internal facades. These were modelled for every 30 min from sunrise to sunset in winter and summer. To avoid confusion internal facades in this study were named according to the direction they face (i.e. north facing façade, south facing façade, east facing façade and west facing façade). The average shadow density for each internal facade in summer and winter was then calculated (Table 6).

Figure 9. Narrow alleys created between central court houses of Bushehr (*source:* (Khajehzadeh and Yavari (2012)).

Table 6 shows that the shadow density on all internal facades except the west facing internal facade of a Bushehr central court house is greater than for a Yazd house. This situation indicates a better situation in summer and a worse situation for winter in Bushehr in comparison to Yazd, which is perhaps useful for a city with 8 hot months. Further comparison shows that some internal facades provide better shadow and sun for the residents in summer and winter. Assuming that, in both cities, the best internal facades of the central court are those receiving more sun

Table 6
Average shadow density on different sides of a typical central court in Yazd and Bushehr on the hottest summer day (22nd of July) and coldest winter day (22nd of December).

	Central Court (the yard area)		South facing facade		North facing facade		West facing facade		East facing facade	
	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)
Yazd	55.97	82.94	61.38	41.69	69.28	98.38	66.79	93.02	58.24	44.66
Bushehr	77.44	100.0	70.73	62.97	83.54	100.0	66.28	86.41	68.80	84.96

Table 7
Best internal facades for summer living in a Yazd and Bushehr central court house.

Yazd	Side of the central court and Shadow Density	North facing facade 69.28%	West facing facade 66.79%	South facing facade 61.38%	East facing facade 58.24%
Bushehr	Side of the central court and Shadow Density	North facing facade 83.54%	South facing facade 70.73%	East facing facade 68.80%	West facing facade 66.28%

Table 8
Best internal facades for winter living in a Yazd and Bushehr central court house.

Yazd	Side of the central court and sun density	South facing facade 58.31%	East facing facade 55.34%	West facing facade 6.98%	North facing facade 1.62%
Bushehr	Side of the central court and sun density	South facing facade 37.03%	East facing facade 15.04%	West facing facade 13.59%	North facing facade 00.00%

Note: For each façade: sun density = 100 – shadow density.

in winter and more shadow in summer, Tables 7 and 8 are created.

5.2.1. Summer

Table 7 indicates that north and west facing internal facades are the best in Yazd and north and south facing internal facades the best for Bushehr. The average shadow density of the Bushehr internal facades is much higher in comparison to Yazd. Although the shadow density on the north facing internal façade in Bushehr is much more than in Yazd, wind catchers in the southern part of the Yazd central court house should help to keep spaces cool during a summer day. In both cities, there is no meaningful difference between the shadow density of the best and worst internal facades.

5.2.2. Winter

Table 8 shows that south and east facing internal facades are the best for both cities. The average sun density on these internal facades in the Yazd house is much higher, which indicates a good situation for Yazd but not so good for Bushehr.

5.3. Moving to different sides of the house for thermal comfort

The big difference between the sun density average of the two best (56.82%) and two worse (8.6%) internal facades for a winter day in Yazd reinforces the belief that past residents of central court houses used to move from one side to the other to achieve their desired thermal comfort. Although the difference between the shadow density average of the two best (68.03%) and two worse (59.81%) internal facades for a summer day is not as big as in the winter, it also offers proof of this traditional practice. This supports Roaf (1988), Nicol et al. (2012) and Foruzanmehr (2014) who reported movements between different parts of a desert house during a summer day, noting this as an adaptive trend. Roaf et al. (2005, 2009 ed.:185) called this trend a search for an "optimal micro climate". Prior studies by Bonine (1980), Madanipour (1998) and Memarian and Brown (2006) also confirm the presence of summer and winter rooms in traditional Yazd houses. Another study by Heidari et al. (2000) on Iranian central court houses in Ilam shows movements from one place to another within a courtyard house were one of the main forms of climate adaptation. A recent questionnaire survey by Foruzanmehr (2014) also proves this trend still exists in traditional Yazd houses, as 69% of the respondents living in these houses said they had "distinct seasonal rooms".

To find out the benefit of moving from one side to another in a Yazd central court house, a graph was prepared showing the shadow and sun percentage for each of the internal facades for the chosen summer and winter day. Looking at these charts together with Tables 7 and 8, shows that combining the table of shadow/sun density on the two best internal facades for a summer day (north facing (Fig. 10) and west facing (Fig. 11) internal facades) gives shadow all day long for the residents. On the other hand combining the table of shadow/sun density on the two best internal facades for a winter day (south facing (Fig. 12) and east facing facades (Fig. 13)) gives sun all

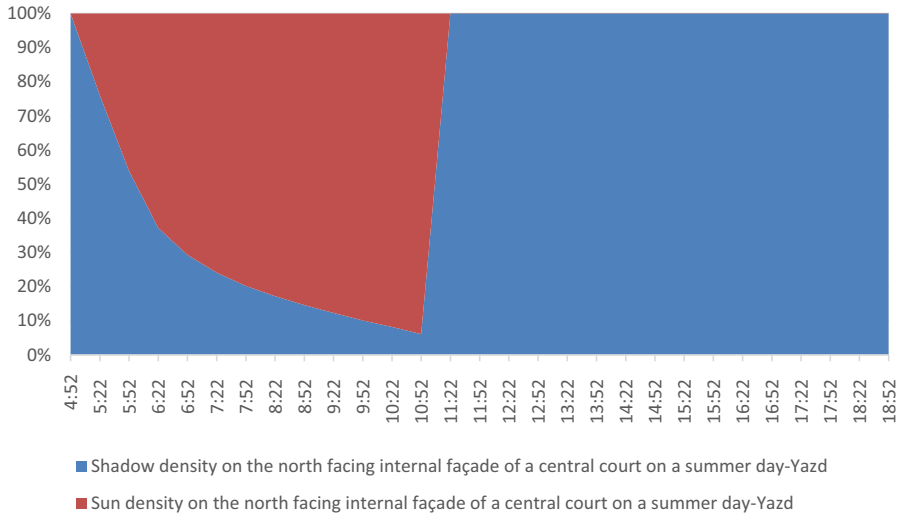


Figure 10. Sun and shadow densities on north facing internal facade of a central court on a summer day in Yazd.

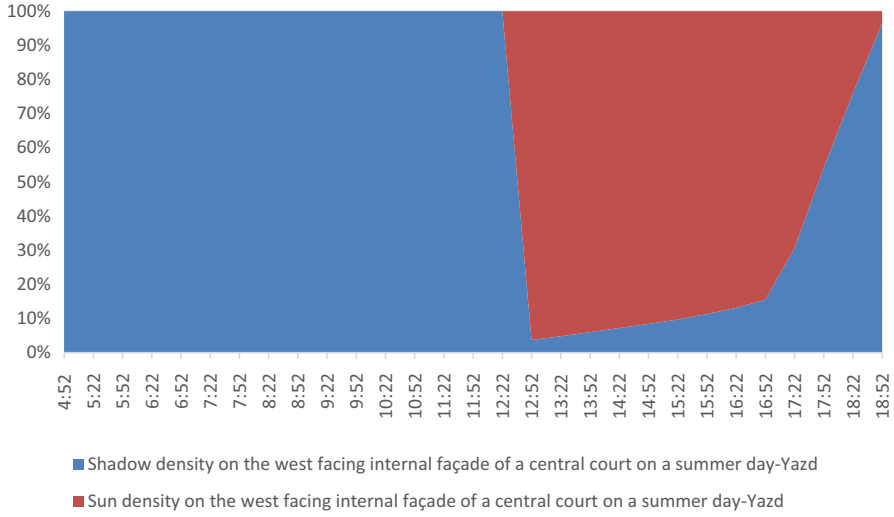


Figure 11. Sun and shadow densities on west facing internal facade of a central court on a summer day in Yazd.

day long for the residents. It seems that residents of these houses must follow the sun's movement over the day to reach comfort. This supports Foruzanmehr (2012:61) who found comfort in ancient Yazd houses could only be achieved "by moving around the house to take advantage of the most suitable of the diverse climates in the house at any particular time of a day". Although as Foruzanmehr (2014:3) says, a traditional family in Yazd is always "in a continual motion around the house both horizontally and vertically in search of an optimum climatic environment".

In Bushehr, the situation is different. The difference between the sun density average of the two best (26.03%) and two worse (6.79%) internal facades for a winter day in Bushehr is not as big as in Yazd and additionally, the sun density on the best side for Bushehr is not as large, meaning the Bushehr central court house does not create such a good situation for winter, so movement from one side to another is not a good answer. Examining the façade images of Bushehr shows the existence of varying shadow densities on the different levels of the internal façade. It seems the ground floor gets more shadow and the first floor more sun during the day, making vertical movement a good answer for Bushehr. This supports Nicol et al. (2012:34) asserting that temperatures in Iranian houses vary on different levels and inhabitants "can move around the building to optimise their comfort". Memarian and Brown (2006:25) also report the presence of vertical rather than horizontal movements in Iran and Iraq. To see the exact shadow and sun density on each part of an internal façade, the images were reanalysed for Bushehr (see Table 9).

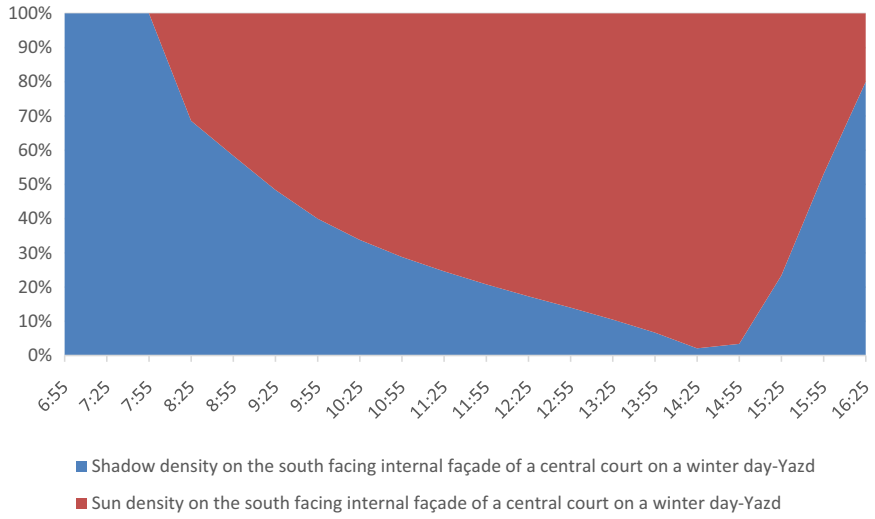


Figure 12. Sun and shadow densities on south facing internal facade of a central court on a winter day in Yazd.

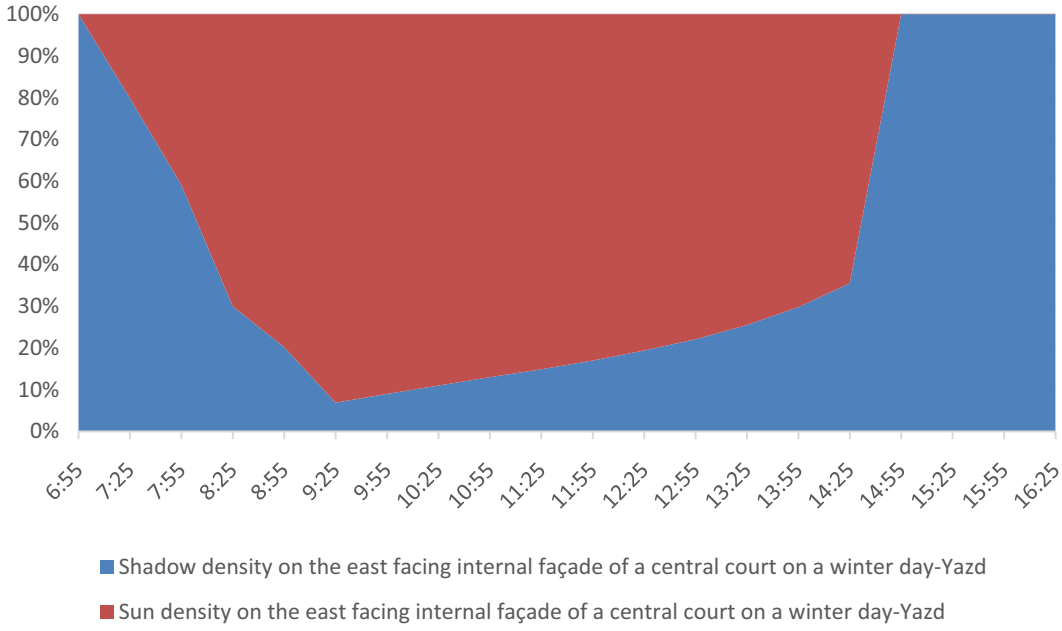


Figure 13. Sun and shadow densities on east facing internal facade of a central court on a winter day in Yazd.

Table 9
Shadow density on each level of each internal façade of a central court in Bushehr for summer and winter days.

		Central court		South facing facade		North facing facade		West facing facade		East facing facade	
		Summer day	Winter day	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)	Summer day (%)	Winter day (%)
Bushehr	Whole facade	77.44%	100.0	70.73	62.97	83.54	100.0	66.28	86.41	68.80	84.96
	Ground Floor level of facade	NA	NA	73.83	81.04	95.19	100.0	72.98	97.25	75.44	96.76
	First Floor level of facade	NA	NA	67.57	44.90	71.90	100.0	59.57	75.57	62.17	73.15

From Table 9, the best internal facade and level for summer and winter can be created for a Bushehr central court house (Tables 10 and 11).

Table 10 shows the difference in shadow density for the best (95.19%) and the worst internal facades (59.57%) is 35.62%. Such a big difference indicates the logical movement from first floor level to ground floor level of a Bushehr central court house in summer.

Table 11 reveals the difference in sun density for the best (55.10%) and worst side (0%) is 55.10%. Such a big

Table 10
Best internal facades for living in a Bushehr central court house in summer.

	First side	Second side	Third side	Fourth side	Fifth side	Sixth side	Seventh side	Eighth side
Best internal facade and level in the central court + shadow density in Bushehr	Ground Floor level of north facing facade 95.19%	Ground Floor level of east facing facade 75.44%	Ground Floor level of south facing facade 73.83%	Ground Floor level of west facing facade 72.98%	First Floor level of north facing facade 71.90%	First Floor level of south facing facade 67.57%	First Floor level of north facing facade 62.17%	First Floor level of west facing facade 59.57%

Table 11
Best internal facades for living in winter in Bushehr central court house in winter.

	First side	Second side	Third side	Fourth side	Fifth side	Sixth side	Seventh side	Eighth side
Best side and level in the central court + sun density in Bushehr	First floor level of south facing facade 55.10%	First floor level of east facing facade 26.85%	First floor level of west facing facade 24.43%	Ground floor level of south facing facade 18.96%	Ground level of east facing facade 3.24%	Ground floor level of west facing facade 2.75%	First floor level of north facing facade 0%	Ground floor level of north facing facade 0%

difference indicates the logical movement from ground floor to first floor of a Bushehr central court house in winter. This is the same trend described as "seasonal shifting from ground to first floor" in Gulf coastal towns by Ragette (2003:85).

To find out the benefit of moving from one level to another one, a graph showing the shadow and sun percentage over the chosen day was prepared for each of the ground and first floor facades. Fig. 14 shows that residents would mostly be in shadow (north facing internal facade) all day if they moved downstairs in summer. On the other hand, Fig. 15 shows residents would mostly be in sun (south facing internal facade) all day if they moved upstairs in winter.

6. Discussion

A comparison of the less well documented central court houses of Bushehr and the better known houses of Yazd indicates that the form of Bushehr central courts is well designed on the basis of getting more shadow on hot summer days but also allowing good sunshine for rooms in the first floor level during winter days.

The form of Yazd central courts, however, is designed on the basis of receiving sunshine for some internal facades on cold winter days and sufficient shade on others for hot summer days. To take advantage of this, past residents of Yazd central court houses used to move within the house seasonally for their desired thermal comfort. They would live in rooms located behind south and east internal facades for more sunshine during winter and in rooms behind north and west internal facades for more shadow during summer. Similarly, past residents of Bushehr central court houses used to move vertically for their desired thermal comfort, living in rooms located at first floor level for more sunshine in winter and rooms on the ground floor for more shadow during summer. These behaviour patterns are supported by the architectural form in both climatic contexts.

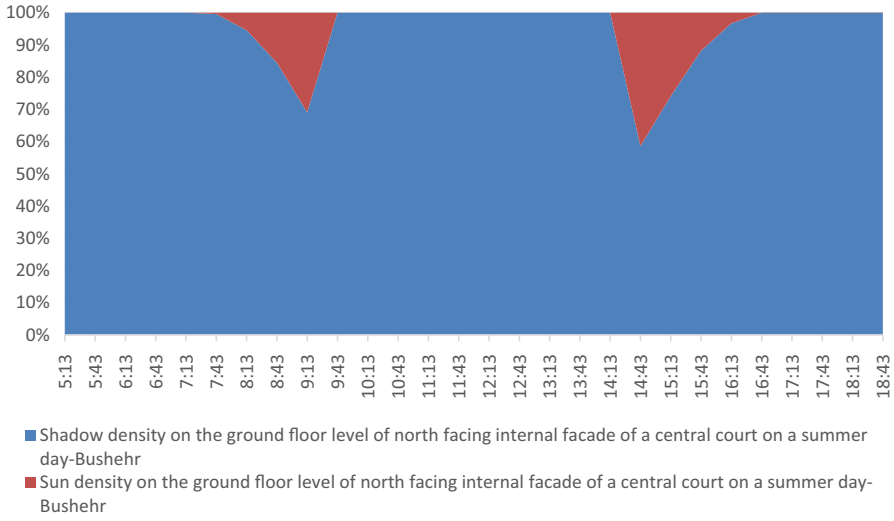


Figure 14. Shadow and sun densities on ground floor level of north facing internal facade on a summer day in Bushehr.

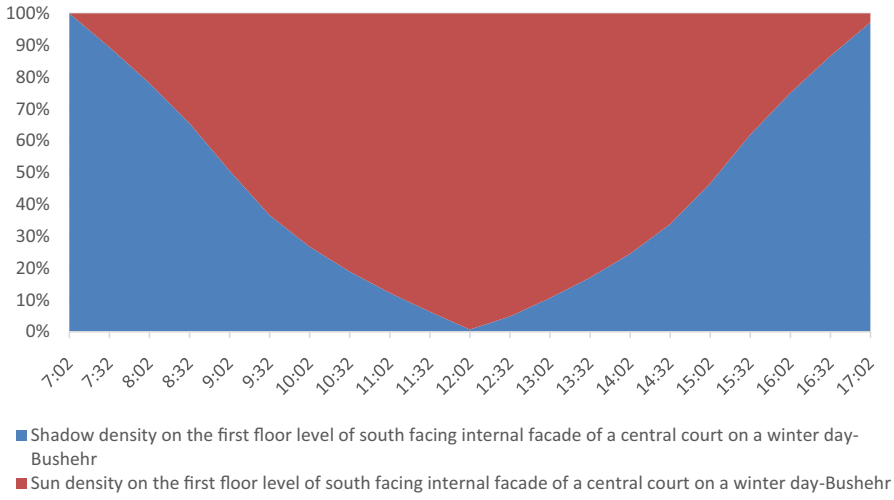


Figure 15. Shadow and sun densities on first floor level of south facing internal facade on a winter day in Bushehr.

Though the internal court forms are different in Yazd and Bushehr, shadow densities on the best internal facades in both cities in summer are comparable. The shadow density on the north facing internal facade of a Yazd central court house is 69.28% (see Table 7) and 95.19% (see Table 10) for the ground floor level of the north facing internal facade of a Bushehr central court house. Similarly, the sun densities on the best sides in both cities in winter are comparable. The sun density on the south facing internal facade of a Yazd central court house is 58.31% (see Table 8) and 55.10% (see Table 11) for the first floor level of the south facing internal facade of a Bushehr central court house. Different sun densities can lead to different indoor temperatures in the rooms located behind each internal façade of a central court, supporting the findings of Roaf (1988), who found that "different rooms had quite different thermal environments, and the occupants were chasing the best living conditions" (Foruzanmehr, 2014:4 from Roaf, 1988).

It seems a combination of form and behaviour made Iranian central court houses comfortable places to live in difficult climates. This supports Foruzanmehr and Vellinga (2011:284) who found traditional cooling systems in Yazd traditional houses "can only really work if the various strategies that make it up complement one another and if the inhabitants are willing and able to adapt their lifestyle and behaviour to the system".

Considering the current global population and availability of land in a time of increasing growing urbanisation the chance of having such large houses which allow for seasonal movement in search of comfort is very low. Additionally, people are probably less willing to share and live together as extended families. The question arises of how one might tackle modern cultural expectations that typically do not expect occupants of modern buildings to move around.

While the idea of having large houses is less realistic there are spaces in modern houses which can support similar movements in search of comfort. In many parts of the world, gardens, balconies and decks, if designed properly, can provide comfortable spaces for some times of the day over the year. For instance, while the temperatures inside modern Iranian houses are quite high in summer, gardens provide a desirable temperature in the evening and also at night. Some people in Iran still use the garden for an evening chat/dinner or for sleeping in preference to being indoors and using air conditioners. Flat roofs are also still used for nightly conversation and sleeping over summer in some parts of Iran. This trend could be supported by wise location and better design of open spaces (gardens, decks and balconies) and better use of flat roofs to serve as summer night/evening living rooms/bedrooms. This would help reduce energy use in summer by less use of air conditioners. This also suggests designers of sustainable buildings need to know that a successful sustainable building can only be achieved through the coming together of users (human behaviour) and technical/design features.

7. Conclusion

This comparative study of Iranian central court houses in two different climatic zones shows that though superficially similar in form the significant difference in proportions of the courts is deliberate. These differences led to different sun/shadow densities on the internal facades of houses in both cities over summer and winter. Modelling the shadow/sun density on the internal facades over summer and winter in both cities shows that occupants had to move (horizontally in Yazd and vertically in Bushehr) in search of ideal levels of shadow/sun over summer/winter. Analysis also shows that a similar architectural form (the central court) of different proportions supports this behaviour in both cities. Obviously it is no longer possible to copy these houses from the past in the search for more sustainable house forms that rely on natural energy sources. However, the results of this study do indicate that through better design of the open spaces of a house, modern architecture could provide opportunities for moving in the house in search of the desired level of thermal comfort, obviating the need to run air conditioners. This study also shows that successful sustainable buildings can only be achieved through a symbiosis of users (human behaviour) and technical/design features.

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