Thermal conditions and daylight availability in different zones of courtyard buildings; a study in Iran

Seyedehraziyeh Khastar [1], Mohammad Taleghani [2 *]

[1] **Massey University, Auckland, New Zealand**
[2] **Leeds Beckett University, Leeds, UK**

Abstract

Passive design strategies enhance indoor thermal comfort and reduce energy consumption in buildings located in hot climates. Thus, exploring the various zones of a house's yard can yield valuable insights for devising a plan that achieves high energy and lighting efficiency. This study examines the climate-responsive design strategies of 20 traditional courtyard buildings in Birjand's hot and dry climate. These courtyard houses informed modelling a new hypothetical house in DesignBuilder. Two main orientations (45° = NE-SW, and 315° = NW-SE) were used for comparing their impact on indoor air temperature, solar gain, and daylight factor across various courtyard zones. The findings indicate that during winter, the interiors of courtyard houses maintain a temperature higher than the exterior, while in summer, they remain cooler than outside conditions. Concerning the influence of orientation on indoor climates, the NE-SW orientation yielded the greatest solar gains for windows in the northern and western zones. Conversely, in the NW-SE orientation, the most substantial solar gains were recorded for windows in the northern and eastern zones. Additionally, the study noted a marginal variation in the daylight factor across different zones of the courtyard houses when comparing the two orientations.

Keywords: Courtyard buildings, thermal comfort, energy efficiency, building orientation, microclimate.

1. Introduction

With the increased consequences of climate change and global warming on human health, mitigation of the urban heat islands in cities is of great importance (Sailor, 2014; Rosenfeld et al., 1995). The urban heat islands increase the cooling energy load of buildings in summer time, and reduce the heating load in winter (Santamouris et al., 2011). Passive strategies can reduce the negative effects of climate change and they could be used for reducing the cooling load of buildings (K. Huang & Hwang, 2016). Many studies have looked at the passive design strategies used in

[*] Corresponding author's contact:
Mohammad Taleghani: m.taleghani@leedsbeckett.ac.uk

traditional dwellings around the world. For example, Hacker (2008) created a century-long hourly weather dataset (1980–2080) to study global warming's impact on energy consumption in buildings with passive design features such as thermal mass, controlled ventilation, and shading. The study concluded that these passive strategies could delay the necessity for mechanical cooling in English homes well into the mid-21st century. In another study, Ouedraogo et al. (2012) developed projections for Burkina Faso's hourly weather patterns extending from 2010 to 2080 and examined the fluctuating cooling energy requirements of the nation's public structures. Their forecasts indicated that cooling energy needs could rise by 59% by 2050 and by 99% by 2080. After assessing different passive building adaptations, they determined that external shading stands out as the most efficient energy-saving adaptation to address the anticipated climatic shifts. Globally, numerous studies have been carried out in regions including Netherland (Ploker et al., 2009), Portugal (De Aguiar et al., 2002), China (Lam et al., 2006), India (Singh et al., 2007), Switzerland (Christenson et al., 2006), and Iran (Soflaei et al., 2016a), focusing on the impact of climate change on building design. A key finding across these studies is the substantial contribution of various passive design strategies to sustainable energy management in buildings, underscoring their importance in adapting to climatic variations.

This study extends the body of work on passive residential building design by examining the impact of two orientations—45 degrees (northeast-southwest) and 315 degrees (northwest-southeast)—on the thermal performance and daylight conditions in traditional house courtyards. Birjand, a city situated in Iran's eastern tropical region, was selected as the case study to explore these effects. Therefore, the main contribution of this study lies in its detailed examination of the yard's impact on various zones within the house. Unlike prior research that treated the house's interior as a single zone, this study distinguishes between different areas of the courtyard house. It offers a comparative analysis of these zones, yielding a more nuanced understanding of the yard's influence on each part of the house.

The remainder of this paper is organized as follows: Section 2 provides the literature background of the study; Section 3 describes the methodology and details of the case study area; Section 4 presents the results and discussion; and finally, Section 5 concludes the study.

2. Literature review

This section establishes the background of research in the field of passive building design. To enhance the organization of the existing literature, the review is divided into two subsections: traditional architecture and daylight.

2.1. Traditional architecture

The lack of attention into climatic needs has led to significant increased energy consumption in modern buildings (Abdulkareem, 2016). The traditional buildings in Kerala have an efficient natural system that provides a comfortable environment inside the buildings. Indigenous native dwellings in northeastern India provide good thermal conditions for their residents all year round except for winters (Dili et al., 2011; Singh et al., 2010). Passive solar strategies used in indigenous Indian buildings can be used in the contemporary design of buildings (Singh et al., 2009). The study of traditional rural homes in China shows that these buildings are well suited to hot summer weather, but these strategies are not effective against cold weather in winter (Gou et al., 2015). Shading and insolation have been used as the main solutions in traditional Chinese homes (Lin et al., 2004).

Courtyards have been used for a long time throughout the world as a balancing of climatic conditions and passive strategies to reduce energy consumption and to improve the living conditions of the dwellers (Toe & Kubota, 2015). Courtyard plays an effective role in reducing the indoor air temperatures (Rajapaksha et al., 2003). Courtyards in the temperate climate of the Netherlands reduce the energy consumption of the dwellings and reduce the heat stress of the residents (Taleghani et al., 2013). The building form significantly affects shading within courtyards (Okeil, 2010). Soflaei et al. (2017a) conducted research in Kerman, Iran, to investigate how the geometry and orientation of courtyards affect indoor thermal conditions. Their findings indicated that courtyards with a square configuration offer superior thermal efficiency compared to those with a rectangular layout. Additionally, they discovered that courtyards elongated from north to south are less conducive to thermal comfort. In a recent study in the Netherlands, DesignBuilder was used to evaluate the effect of orientation of the courtyard on the indoor thermal comfort. The results showed that a courtyard with East-West orientation, in contrast to North-South orientation, provides the best indoor thermal conditions. In this study, the effects of using greenery on the roof and within the courtyard have been investigated, and showed reduction of heat stress for the dwellers (Taleghani et al., 2014a). By comparing the energy performance of the courtyard and the atrium in four different climates, it has been shown that buildings with a courtyard have a better thermal performance than the atrium (Aldawoud & Clark, 2008). The study showed that in some cases, atrium plays a better role in the high-rise buildings than a courtyard. In another study, the thermal performance of an atrium and a courtyard was compared, and it was recommended to improve the conditions by converting the courtyard to an atrium between November and April. (Taleghani et al., 2014b)

Soflai et al. (2016a) highlighted that courtyards are a key element in enhancing cooling by taking into account the house's orientation and geometry. Further research by Soflai et al. (2016b) on six traditional courtyard homes in Iran's BWks climate zone revealed that the right orientation, size, and shape can significantly improve a dwelling's thermal environment. These design principles are not only applicable to traditional homes but can also inform the design of modern residences. Additionally, Soflai et al. (2017b) found that in both Iran and China, traditional homes are well-adapted to local climates, offering their inhabitants comfort both physically and psychologically. Muhaisen and Gadi (2006) studied the shading effect of courtyards in different geometries and proportions using computer modeling. Their results indicated that geometry and proportions affect the shaded areas within courtyards. Deep courtyards have more shadows, while in the shallow ones, the solar gain is lower and more suitable for the winter. Muhaisen by using shadow modeling, examined various forms of the courtyard in different climates. The results indicated that the characteristics of the form, latitude, and climatic conditions affect the shading of the courtyard (Muhaisen, 2006). Yang et al. (2012) examined the impact of geometry and material on the microclimate of the courtyards in Beijing. The results showed that the increase in thermal mass, surface albedo, and material conductivity reduce the peak temperature during the day. Berkovic et al. (2012) examined comfort within courtyards with ENVI-met (as a simulation software). The results showed that the eastern zone of the rectangular courtyard had the least shadow, thus it had the worst comfort conditions in the building. Adding a porch and trees improved the thermal conditions.

2.2. Daylight

Nowadays, reducing energy consumption through building design and lighting system is of great importance (Pérez-Lombard et al., 2008). Window glass management and shading tools, window level checking and daylight control can significantly improve daylight and visual comfort (Hee et al., 2015; Lim et al., 2012; Ihm et al., 2009).

Daylight is known as the best light source, allowing high-quality colors to be seen (Alrubaih et al., 2013). The proper design of lighting and the use of daylight diminishes the energy use of buildings (Li, 2010). Tzempelikos and Athienitis (2007) found that shading control and interior lighting can reduce energy consumption for cooling and lighting. Persson et al. (2006) reviewed the size of windows and their impact on energy consumption in Gothenburg, Sweden. The results showed that optimal window size does not significantly affect winter heat load but large windows affect the energy consumption in summer time. Therefore, the use of large windows on the northern wall is recommended to get more light and not to use large-sized southern windows to reduce the cooling load in summer. Acosta et al. (2016) examined the geometry and position of the window to reduce the energy consumption of the buildings. The results show that horizontal windows reduce energy consumption more than other types of openings, and the window-to-wall ratio affects energy consumption. The windows in the south light up the windows in the north of the room three times more, and windows in the east and west of the room double the window of the north enter light of the day. Mangkuto et al. (2016) examined the optimal window size, orientation and reflection of the wall to obtain adequate light and optimal energy consumption in the tropical areas. The results show that the window-to-wall ratio is 30%, the reflectance is 8.0%, and the southern direction provide the best performance for the buildings. Krarti et al. (2005) studied the impact of geometry of the building, the size of the window and the type of glass on the daylight availability of commercial buildings in four American cities. The results indicated that the window size and the type of glass affect the amount of daylight. They also showed that the geographic area has a very little impact on reduction in energy consumption.

Chen et al. (2014) examined the reduction in energy consumption using controllers in a commercial building. The results showed that dimming control, along with the use of daylight had a greater impact on building energy consumption than on/off control. Bodart and DeHerde (2002) in a research in Belgium found that by using daylight, the lighting energy consumption of an office building in this climate could be reduced between 50 to 80 percent.

3. Research Methodology

In this research, thermal performance of courtyard dwellings was studied in the historical urban texture of Birjand in the hot and dry climate of Iran. The average dimensions and proportions of the houses, the openings, and the walls of the courtyard were measured on site. A computer model was made based on the measured dimensions. After validating the results of DesignBuilder (by comparing the simulation data with field measurements), thermal and daylight analyses were done for two orientations of Northeast-Southwest (45°) and Northwest-Southeast (315°).

3.1. Study area

Birjand is the capital of Southern Khorasan province, located in the east of Iran. According to Koppen classification, Birjand (59˚22'N, 32˚86'E) has a hot and dry climate and 1491 meters above the sea level (Saghafi, 2018). The climate of the city is affected by several factors such as low pressure and high pressure systems, air masses, distance and proximity to moisture sources, and being adjacent to the inner deserts and highlands. On a smaller scale, the climate of the city is influenced by micro-climatology, including green spaces, rivers, factories and industries, buildings and streets (Yasoori, 2004). The geographical location of the Southern Khorasan province and the city of Birjand is shown in Figure 1- top.

In this research 20 traditional courtyards were selected randomly within the historical area of Birjand. Some of these traditional houses have been recently refurbished as a museum and the rest of the houses are still the place of residence (Figure 1- bottom). All selected buildings have a rectangular courtyard.

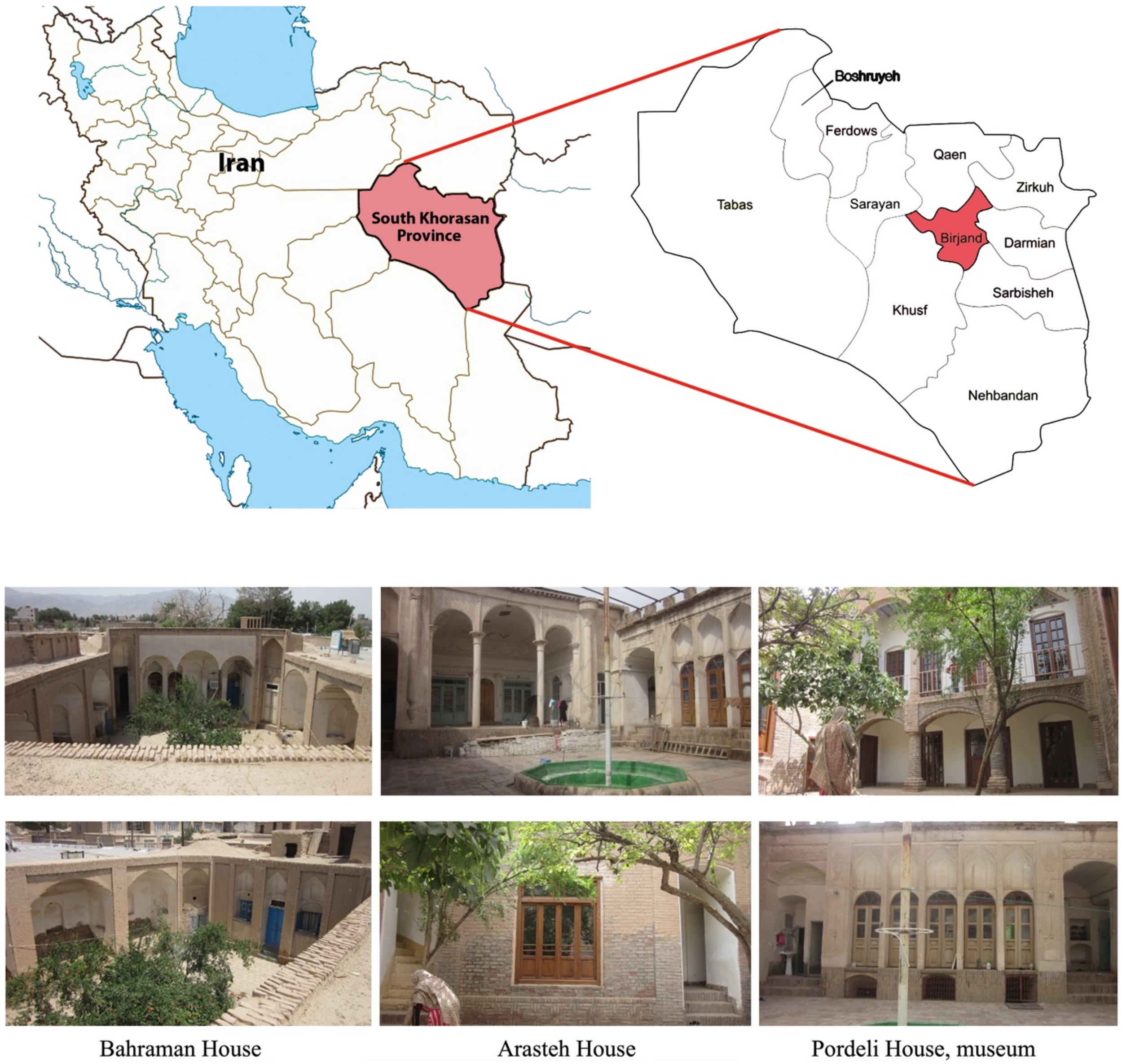


Figure 1. Top, the geographical location of Southern Khorasan province and Birjand [66]. Bottom, views of three traditional courtyard houses in Birjand.

The locations of the selected case studies are shown in Figure 2. Figure 3 shows the plan of the courtyard houses.

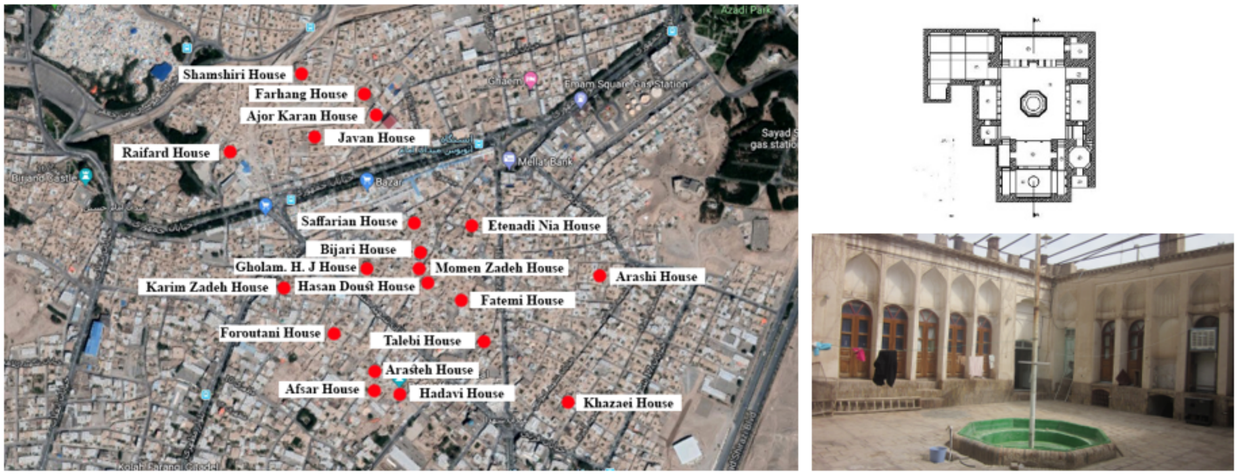
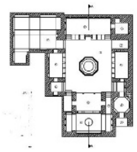
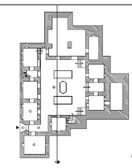
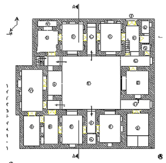
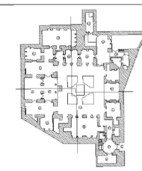
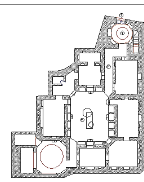
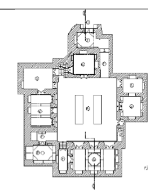
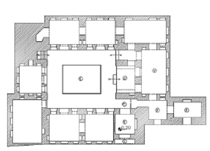
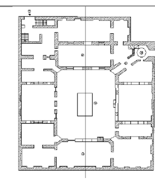
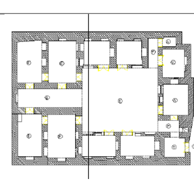
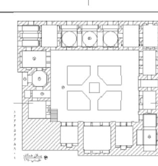


Figure 2. Locations of the case studies in Birjand.

House Name	House plan	House Name	House plan
Arasteh House		**Hasan Doust House**	
Arashi House		**Farhang House**	
Saffarian House		**Momen Zadeh House**	
Foroutani House		**Hadavi House**	
Khazaei House		**Etemadi Nia House**	

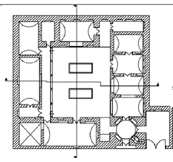
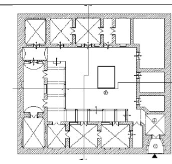
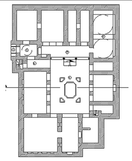
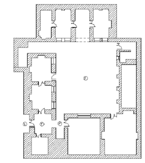
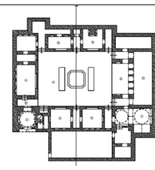
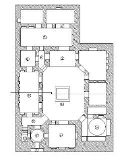
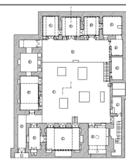
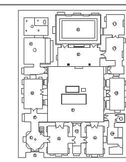
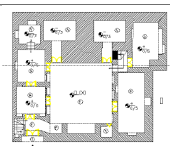
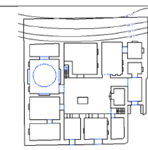
Pordeli House		**Javan House**	
Talebi House		**Fatemi House**	
Gholam. H. J House		**Karim Zadeh House**	
Ajor Karan House		**Shamshiri House**	
Bijari House		**Afshar House**	

Figure 3. The plans of the examined houses.

3.2. Simulation software

DesignBuilder was used to model indoor cooling, heating, and lighting systems (DesignBuilder Documentation, 2006). The engine model for this software is EnergyPlus built by the US Department of Energy which is among the most accurate tools to predict building energy use (EnergyPlus Documentation, 2007). In the software, the annual and hourly climatic data of the location of the building are given as the input. The thermal and lighting performance of different building zones are simulated in a given time period.

3.2.1. Simulation assumptions

To model the physical characteristics, a simplified courtyard house was designed with 8 thermal zones. The area of the building and the courtyard are 334 and 100 m^2, respectively. The length to width ratio of all zones is 1.2 and the length to width ratio of the courtyard is 1.16. The thickness of the internal walls is 0.6 m, and the thickness of the external walls is 0.9 m. These thicknesses are based on measurements (and are common in the traditional courtyards of Birjand). The window to wall ratio is assumed 30% for all facades. Due to the compact urban texture of the old neighborhoods of Birjand, the outdoor facades have no openings.

3.2.2. Thermal specifications of building components

Details of the walls were also obtained from the interviews with the cultural heritage researchers of Birjand (Cultural Heritage, 2018). For the roof materials, we used the most common materials in Birjand (tiles). The thermal characteristics of the simulated model are shown in Table 1. It should be noted that the walls and roofs are constructed from a combination of various materials. The external walls consist of layers of clay straw, adobe, clay, clay straw and plaster, in that order. Similarly, the internal walls are composed of alternating layers of plaster, clay straw, adobe, clay straw and clay. The roof is constructed with multiple layers of clay and silt, clay straw, separated by an air gap, clay straw, adobe, and finished with a layer of plaster.

Table 1. Characteristic of simulated house and building components.

location	Birjand, Iran (59˚22'N, 32˚86'E)	
Running model	Free- running	
Natura ventilation	Natura ventilation- no heating/cooling, calculated, constant.	
External wall	R-value = 1.10 (m^2K/W); U-value = 0 .7 (W/m^2K)	
External wall	R-value = 2.56 (m^2K/W); U-value = 0.9 (W/m^2K)	
Roof	R-value = 2.56 (m^2K/W); U-value = 0.39 (W/m^2K)	
Floor	R-value = 2.92 (m^2K/W); U-value = 0.34 (W/m^2K)	
Air tightness	Model infiltration	2 (ac/h)
window	Glazing type	Single glazing clear glass 6mm
	Dimension	Various
	Window to wall ratio	30%
	Sill height	0.8 m
Frame	Type	Painted wooden window frame
	Width	0.4 m
Divider	Type	Divided lite
	Horizontal divider	1

3.2.3. Field measurements

Air temperature was measured by the ST-174B Standard Sensor (S. i. C. LTD., 2018) at a height of 1 meter from the ground in one of the historic courtyard dwellings in Birjand. The results were compared with the simulation outputs. The measurement accuracy of the data logger was ±1 °C, and its measurement range was -40 to 70 °C. This device is compliant with ISO 7726 (I. O. f. Standardization and I. E., 1998). The images of the sensor and its location in the room are shown in Figure 4.

Figure 4. Standard ST-174B sensor for indoor air temperature measurement.

3.2.4. Validation of the DesignBuilder results

Several studies have investigated the accuracy of DesignBuilder outputs (Mohammadi et al., 2018; Rahman et al., 2010). In this paper, one of the traditional courtyard houses of Birjand was modelled in DesignBuilder, and the air temperature results were compared with our measurements. The plan of the actual courtyard house and the DesignBuilder model are illustrated in Figure 5.

Figure 5. Left: The plan of the actual courtyard house in Birjand. Right: The simulated courtyard house in DesignBuilder.

The measured air temperatures and the corresponding results of DesignBuilder for one of the thermal zones of the house (Zone 6) are compared in Figure 6-a. The R^2 value from the scatterplot of the simulation versus measurement data (Figure 6-b) is 0.72. This value represents the correlation between the measured and simulated air temperature data sets of the house.

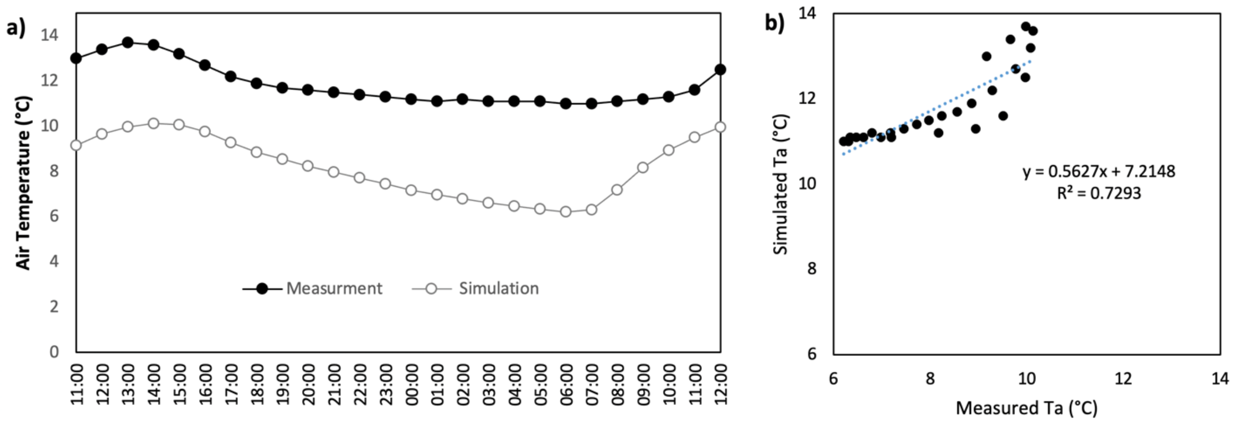


Figure 6. a: Comparison of simulated (DesignBuilder) vs measured (ST-174B sensor) air temperatures, b: The scatterplot of the measured versus simulated air temperatures.

The deviation occurred between measured and simulated results could be attributed to the weather data for DesignBuilder. The weather data is recorded from the weather station located in Birjand airport. The distance between the airport and the simulated house is 9.8 km. Local materials surrounding the simulated house could change the local microclimate and affecting indoor temperature. The airport is not affected by the urban heat island impact of the city. Therefore the measured data in the house are higher than the simulated results.

4. Results

4.1. Courtyard houses analysis

4.1.1. Analysis of geometries and orientation of the courtyard houses

Geometry and orientation could significantly affect the thermal conditions of indoor spaces. In this section, the orientations of the houses surveyed are shown relative to the north. Appropriate orientation could provide more sunlight in the winter and the best natural ventilation for the summer period. Figure 8 illustrates the orientation of 20 courtyard dwellings that were highlighted in Figure 4. 60% of the buildings have orientations in the northeast-southwest, and 40% of home are in the northwest-southeast direction.

4.1.2. Dimensions and characteristics of the home spaces

Dimensions and geometry of spaces play important roles in improving the thermal conditions and energy consumption of buildings (Soflaei et al., 2017a). The average area of each traditional house is 444 m^2, of this, 100 m^2 is dedicated to the courtyard (open space) and 344 m^2 of the area is the solid building. Generally, the northern courtyard spaces have the largest area than other fronts. In the northeast-southwest orientation courtyards, the northern and western zones with the mean of 100 and 86 m^2 are the largest closed spaces, respectively; and the eastern zone with 76 m^2 has the lowest proportion of the closed space. In the northwest-southeast orientation, the northern, southern and eastern spaces with 88, 89 and 89 m^2 are the most closed spaces and the western space with 70 m^2 has the lowest proportion of the closed space. In Figure. 7, the average areas of the various fronts of the courtyard houses in this study are presented in two orientations of 45 and 315 degrees.

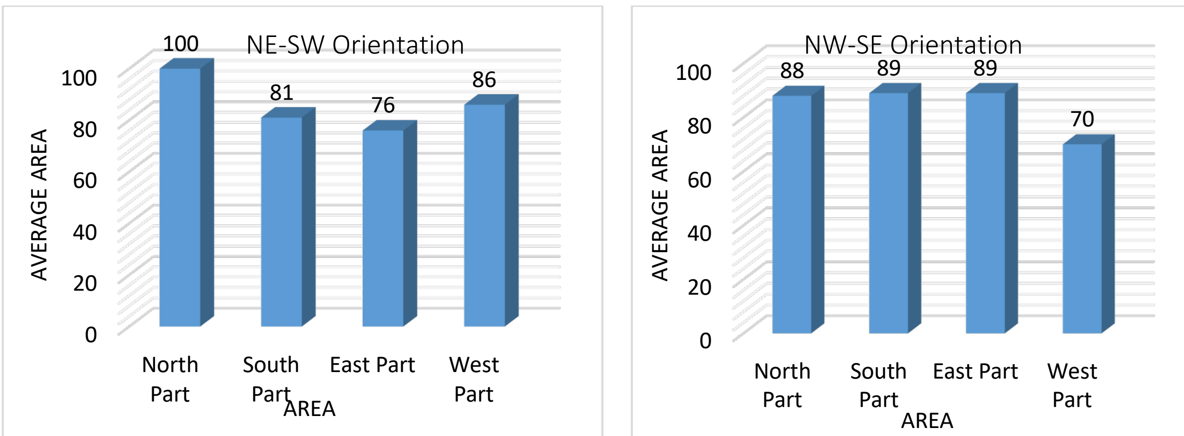


Figure 7. Dimensions and proportions of the open spaces of courtyards.

Overall, the courtyard's open space comprises 22% of the total area of the house. The average height of the courtyards is 4.8 m, the H/W ratio is 0.6 in both orientations, and the average length and width of the courtyards are 10 and 9 m, respectively.

The ratio of openings to the walls are calculated for both orientations, and shown in Figure 8. In the 45° orientation courtyards, the western wall with a ratio of 30% and the northwest with a ratio of 22% have the lowest level of the window to wall ratio. In the 315° orientation courtyards, the northern and eastern fronts with 34 and 19 percent have the highest and lowest levels of the window to wall ratio, respectively.

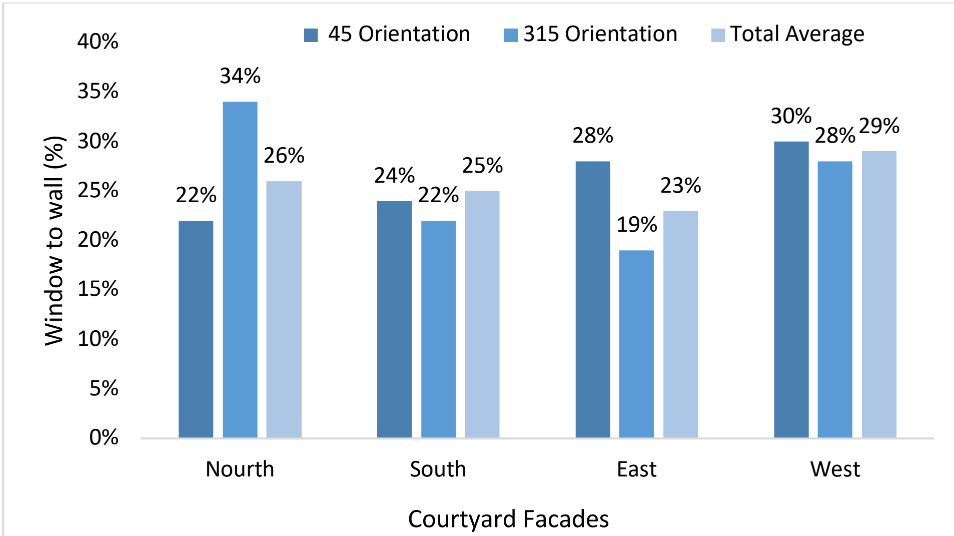


Figure 8. Area and proportion of the openings in courtyard facades.

4.2. Simulation results

In this section, the indoor air temperature of the courtyard house with two orientations (Northeast-Southwest and Northwest-Southeast) are compared. The activities of dwellers were identical in both buildings. The average indoor air temperatures of these buildings (for all thermal zones) are shown in Figure 9.

In cold months, the indoor air temperatures in both courtyard buildings are higher than the outdoor temperatures; and in warm seasons, the indoor air temperatures are cooler than outside. This shows that regardless of the courtyard orientation, the indoor environments of the courtyard houses are more favourable than outside.

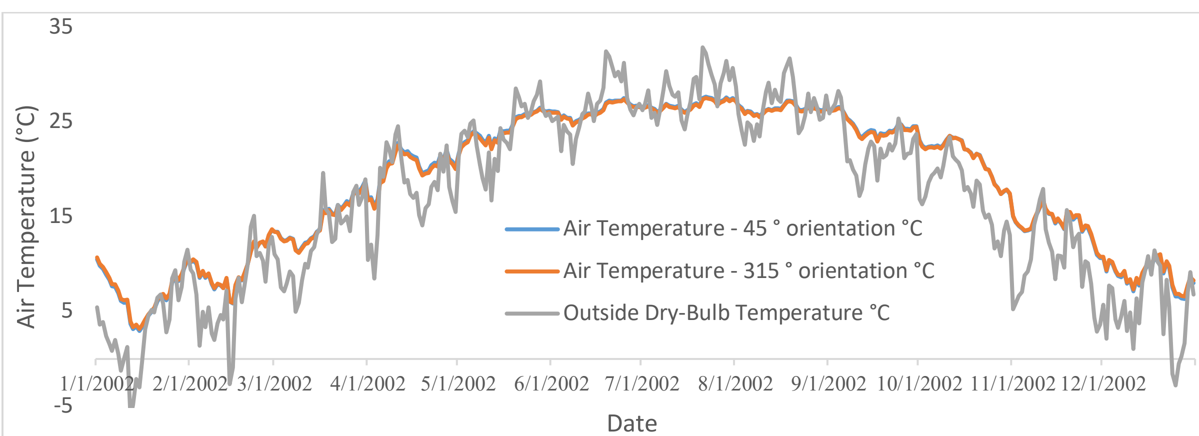
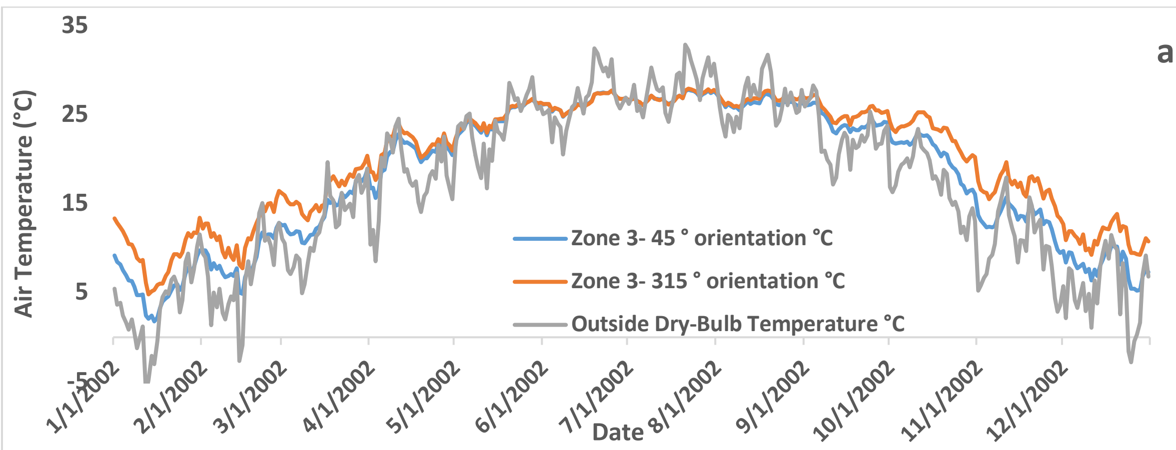
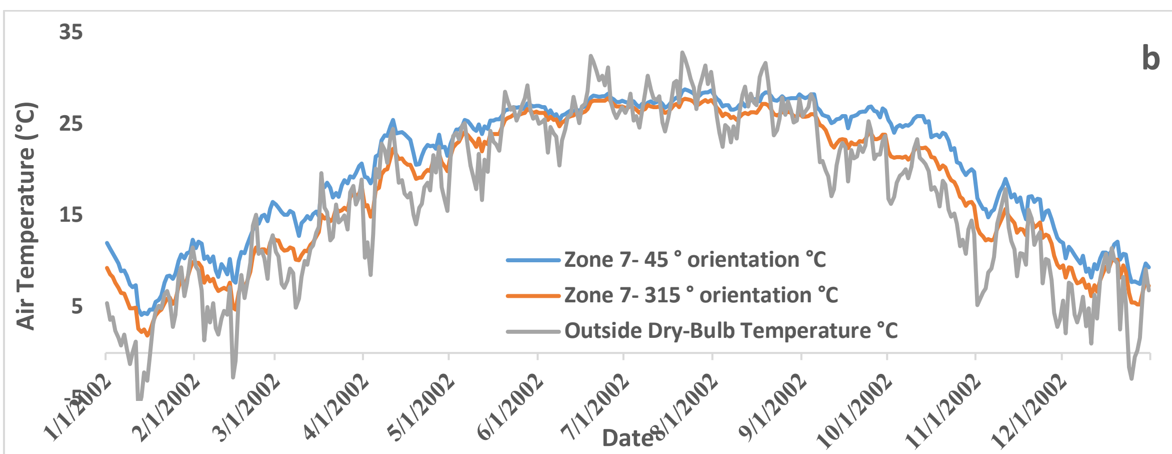


Figure 9. Building temperatures for two courtyard orientations of 315 and 45 degrees.

The third thermal zone (east front) in the 45° orientation has lower air temperatures than the 315° orientation during the year. This difference is higher during the cold months. In summer, the temperature difference is negligible (almost zero), and during cold months it reaches to a maximum of 4.7 °C (Figure 10-a). The seventh thermal zone (west front), in the 45° orientation, has a higher temperature than the 315° orientation. In the warm months, the air temperature difference reaches to a minimum of zero and during cold months it increases by up to 4 °C (Figure 10-b). The first thermal zone (north front) in the 315° orientation with a very small difference (maximum 0.5 °C) has a higher temperature than the 45° orientation in the warm months (Figure 10-c). The fifth thermal zone (south front) has a temperature of 45 °C with a very small difference (maximum 0.5 °C) than the orientation of 315° during the warm months (Figure 10-d).





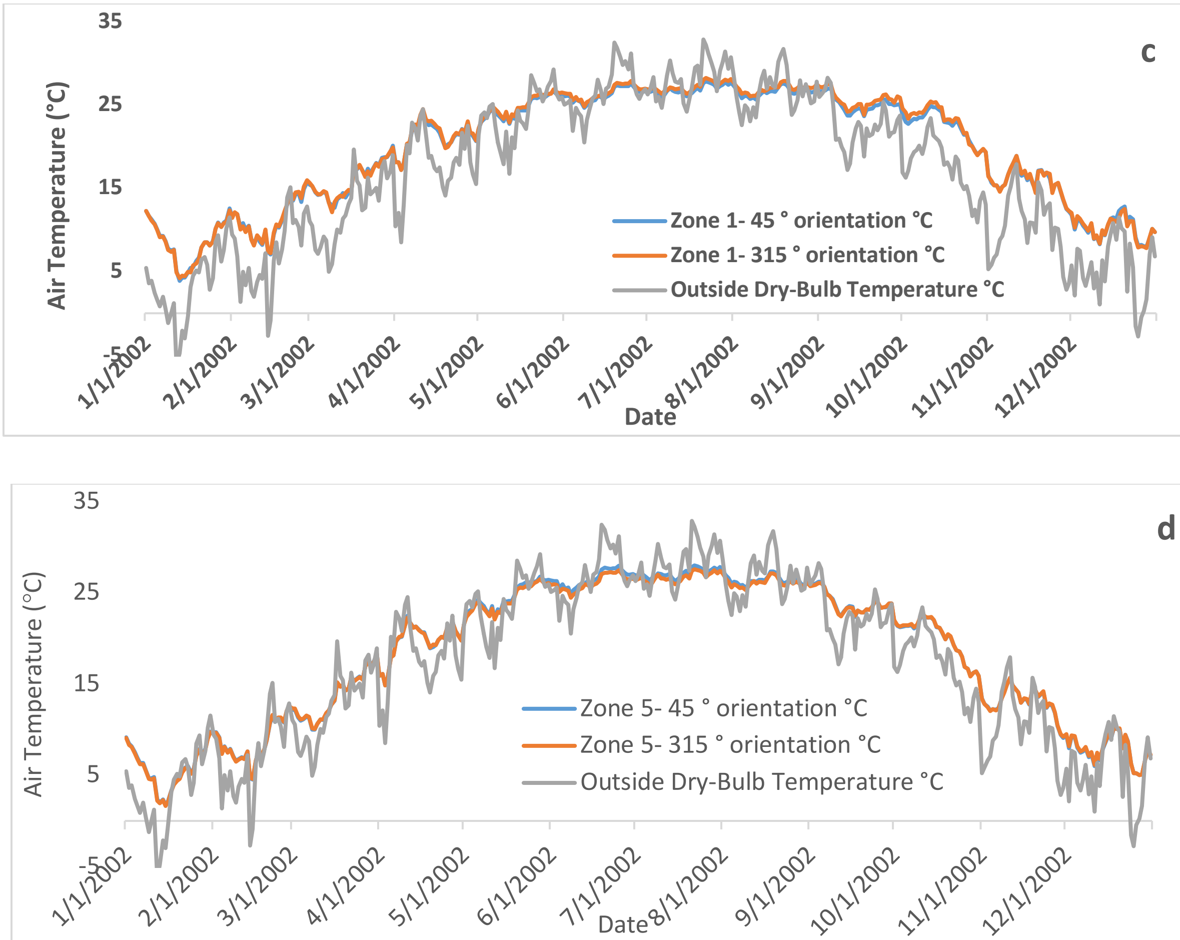


Figure 10. Comparison of the air temperature in different thermal zones.

The eastern front in the direction of 45° compared to the orientation of 315° shows uncomfortable conditions in winter. The western front in 315° orientation also shows less favourable thermal conditions than the 45° orientation in the winter. In warm months, there is a slight difference in air temperature between these two orientations.

The first and seventh heat zones (north and west rooms of the courtyard, respectively) have higher solar gains in the 45° orientation than other zones. The fifth heat zone (South front) has the lowest amount and reaches to the lowest amount during the cold days. The difference between solar gains in different zones reaches to its peak in the winter, and is reduced in summer time. Figure 11-a shows solar gains through windows in different fronts of the house with 45° angle.

In the 315° orientation house, windows in the first and third heat zones (the northern and eastern fronts) have the highest solar gains. The windows on these fronts have the highest solar gains in the cold months of the year and receive the lowest amount during the warm months of the year. The differences in solar gains are minimum during the hottest days of the year (Figure 11-b).

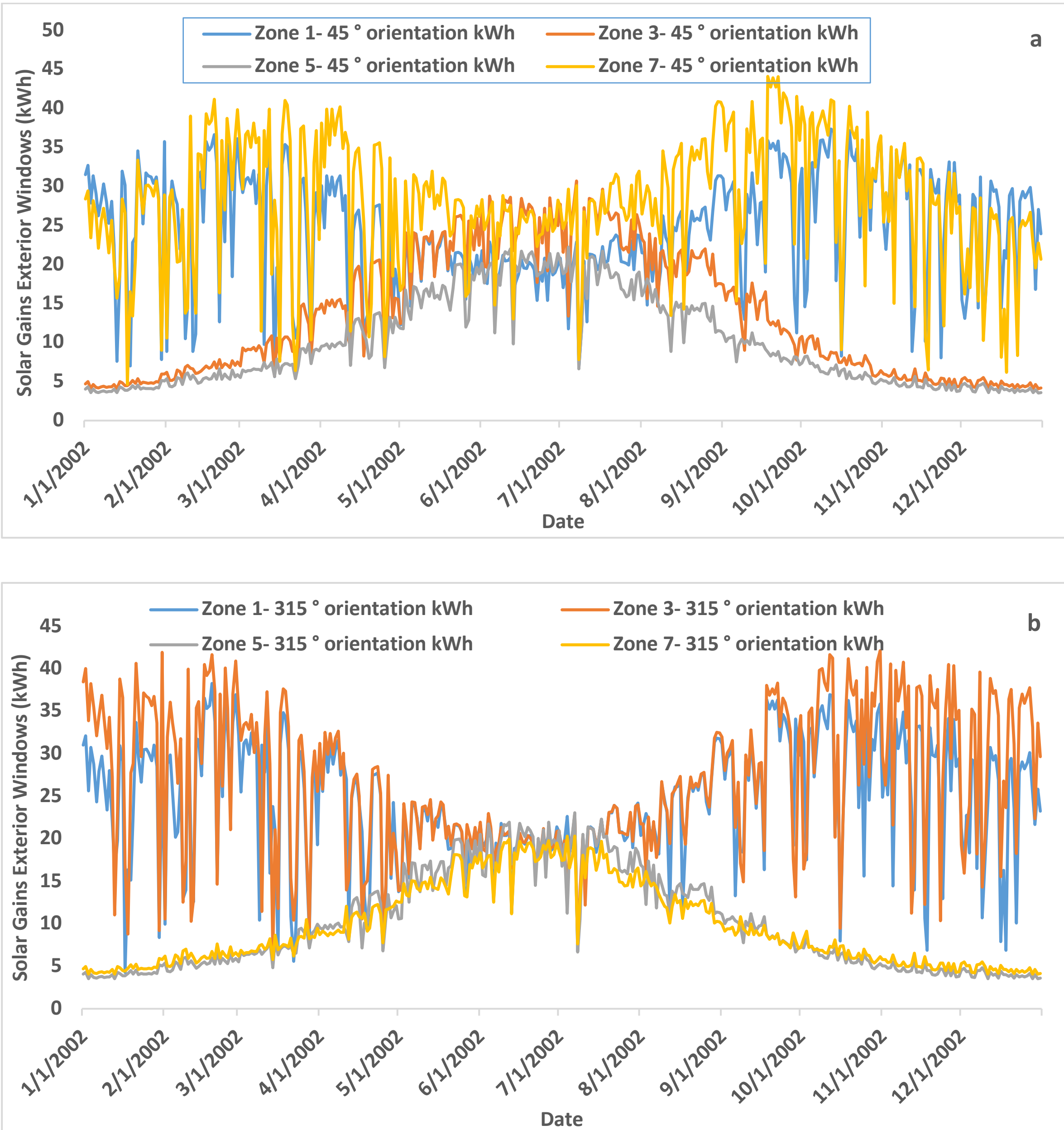


Figure 11. Solar windows receive different fronts of the house during the days of the year

It could be concluded that for both courtyard elongations (45° and 315°), indoor environment of the courtyard buildings (average of all zones) is warmer than the courtyard in cold months, and it stays cooler than the courtyard in warm months. Solar gain directly affects indoor air temperature, and consequently indoor thermal comfort of the users. This shows the importance of solar gain assessment for new construction (courtyard or other building morphology).

4.3. Daylight analysis

Different computer simulation tools are developed to analyse daylight availability and they can estimate the energy use for artificial lighting in buildings (Krarti et al., 2005; Li & Wong, 2007). Daylight factor is an index used to specify the daylight conditions in a building (Alrubaih et al., 2013). In this study, daylight simulation was conducted by DesignBuilder for different zones of the courtyard. The results are shown for both orientations of 45 and 315 degrees in Figure 12.

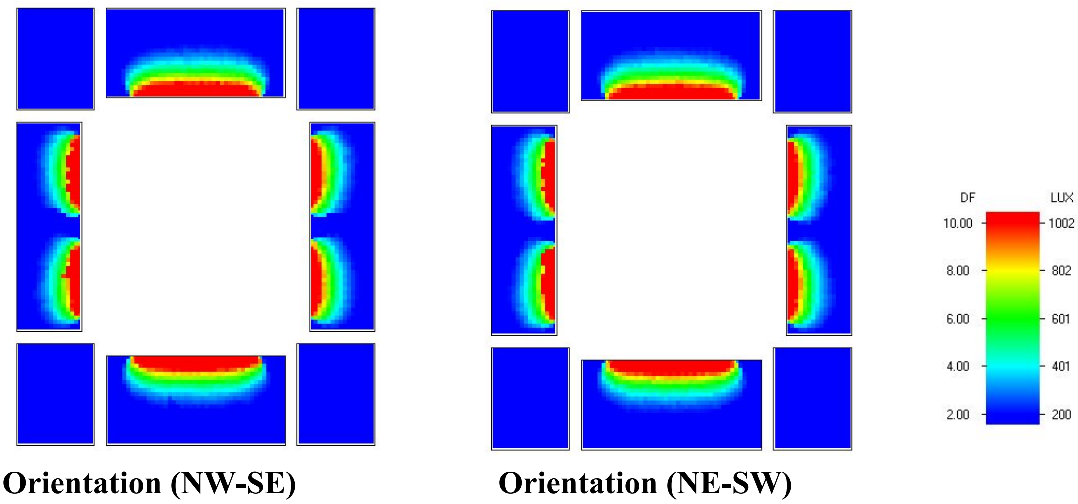


Figure 12. Different zone daylight factor plan for two orientations of 45 (NW-SE) and 315 (NE-SW) degrees.

The thermal zones in the orientation of 45 and 315 degrees have very little differences, but the western zone has the highest average of daylight factor and then the eastern front has the highest amount of daylight factor. The lower depths of the eastern and western fronts affect the daylight factor of these spaces.

Compared to previous studies on daylight analysis in courtyards, this study divides the indoor environment to different zones to have a more realistic approach for daylight availability. Other studies like (Asfour, 20220) considered the entire interior environment as a single zone. In other studies like (Aldawoud, 2014), experimented courtyards received solar radiation from both facades of each zone (from outside of the house and inside of the courtyard). This situation is rare in Iranian courtyard houses were all openings are through the courtyard space.

Analysing daylight factor could help indoor space allocation not only for residential buildings, but also in spaces like schools or offices. In the case of courtyards with 45 or 315 degree orientations, this could allow better resource management to reduce lighting energy use by understanding the fact that western zone receives the highest natural daylight. Interior designers could benefit from this type of analysis prior to planning for indoor activities.

5. Conclusions

In this paper, thermal performance of courtyard houses within the historical texture of the hot and dry climate of Birjand (Iran) were studied. The average dimensions and proportions of the courtyard houses, and the size of the openings and the walls of the courtyards were calculated and a hypothetical model was designed as the final case study. Thermal and daylight analyses were performed for two courtyard orientations of 45 and 315 degrees.

In the cold months of the year, the indoor air temperatures of the house were warmer than the outdoor dry-bulb temperatures; and in the warm seasons the indoor environments were much cooler than the outdoors. On average, the east thermal zone in the 45° orientation, had lower air temperatures than the 315° orientation during the year. The west heat zone, in a 45° orientation, had higher air temperatures than the 315° orientation. The temperatures in the north and south thermal zone were almost identical in both orientation (~ 0.5°C).

East zone in the 45° courtyard had much lower air temperatures in winter in comparison with the 315° courtyard. The west zone of the 315° courtyard was cooler than the 45° orientation in winter. In warm months, a slight difference was found in temperature between these two orientations.

In the 45° courtyard, the windows of the north and west heat zones had higher solar gains than the other spaces. The south thermal zone had the least solar gain. In the 315° orientation, the north and east zones had the highest solar gains. These fronts had the most solar gains through windows in the cold months of the year and received the lowest amount during the summer.

The orientations showed a very small impact on the daylight factor of the building zones. Comparison between different zones of the model showed that the western zone has the highest average daylight factor than the other zones. These results could be used for planning indoor spaces in naturally ventilated buildings to improve users' satisfaction and comfort.

References

Abdulkareem, H. A. (2016). Thermal Comfort through the Microclimates of the Courtyard. A Critical Review of the Middle-eastern Courtyard House as a Climatic Response. *Procedia - Social and Behavioral Sciences*, *216*, 662–674. https://doi.org/10.1016/j.sbspro.2015.12.054

Acosta, I., Campano, M. Á., & Molina, J. (2016). Window design in architecture: Analysis of energy savings for lighting and visual comfort in residential spaces. Applied Energy, 168, 493–506. https://doi.org/10.1016/j.apenergy.2016.02.005

Aldawoud, A., & Clark, R. (2008). Comparative analysis of energy performance between courtyard and atrium in buildings. Energy and Buildings, 40(3), 209–214. https://doi.org/10.1016/j.enbuild.2007.02.017

Alrubaih, M. S., Zain, M. F. M., Alghoul, M. A., Ibrahim, N. L. N., Shameri, M. A., & Elayeb, O. (2013). Research and development on aspects of daylighting fundamentals. Renewable & Sustainable Energy Reviews, 21, 494–505. https://doi.org/10.1016/j.rser.2012.12.057

Berkovic, S., Yezioro, A., & Bitan, A. (2012). Study of thermal comfort in courtyards in a hot arid climate. Solar Energy, 86(5), 1173–1186. https://doi.org/10.1016/j.solener.2012.01.010

Bodart, M., & De Herde, A. (2002). Global energy savings in offices buildings by the use of daylighting. Energy and Buildings, 34(5), 421–429. https://doi.org/10.1016/s0378-7788(01)00117-7

Chen, Y., Liu, J., Pei, J., Cao, X., Chen, Q., & Jiang, Y. (2014). Experimental and simulation study on the performance of daylighting in an industrial building and its energy saving potential. Energy and Buildings, 73, 184–191. https://doi.org/10.1016/j.enbuild.2014.01.030

Christenson, M., Manz, H., & Gyalistras, D. (2006). Climate warming impact on degree-days and building energy demand in Switzerland. Energy Conversion and Management, 47(6), 671–686. https://doi.org/10.1016/j.enconman.2005.06.009

De Aguiar, R. a. A., Oliveira, M. J., & Gonccedilalves, H. (2002). Climate change impacts on the thermal performance of Portuguese buildings. Results of the SIAM study. Building Services Engineering Research and Technology, 23(4), 223–231. https://doi.org/10.1191/0143624402bt045oa

DesignBuilder Documentation, DesignBuilder User Manual, Version 1.2, UK: DesignBuilder Software Limited (2006).

Dili, A., Naseer, M., & Varghese, T. Z. (2011). Passive control methods for a comfortable indoor environment: Comparative investigation of traditional and modern architecture of Kerala in summer. Energy and Buildings, 43(2–3), 653–664. https://doi.org/10.1016/j.enbuild.2010.11.006

EnergyPlus Documentation, EnergyPlus Manual, Version 2, U.S. D (2007). epartment of Energy.

Gou, S., Li, Z., Zhao, Q., Nik, V. M., & Scartezzini, J. (2015). Climate responsive strategies of traditional dwellings located in an ancient village in hot summer and cold winter region of China. Building and Environment, 86, 151–165. https://doi.org/10.1016/j.buildenv.2014.12.003

H. a. T. O. o. S. K. SKCHTO - Cultural Heritage. (2018, December 18). http://www.skchto.com/en/.

Hacker, J. N. (2008). Modelling passive and active cooling strategies for housing under present and projected future climate–A case study of London. In Proceedings from Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK.

Hee, W. J., Alghoul, M. A., Bakhtyar, B., Elayeb, O., Shameri, M. A., Alrubaih, M. S., & Sopian, K. (2015). The role of window glazing on daylighting and energy saving in buildings. Renewable & Sustainable Energy Reviews, 42, 323–343. https://doi.org/10.1016/j.rser.2014.09.020

Huang, K., & Hwang, R. (2016). Future trends of residential building cooling energy and passive adaptation measures to counteract climate change: The case of Taiwan. Applied Energy, 184, 1230–1240. https://doi.org/10.1016/j.apenergy.2015.11.008

Ihm, P., Nemri, A., & Krarti, M. (2009). Estimation of lighting energy savings from daylighting. Building and Environment, 44(3), 509–514. https://doi.org/10.1016/j.buildenv.2008.04.016

Krarti, M., Erickson, P. M., & Hillman, T. C. (2005). A simplified method to estimate energy savings of artificial lighting use from daylighting. Building and Environment, 40(6), 747–754. https://doi.org/10.1016/j.buildenv.2004.08.007

Lam, J. C., Yang, L., & Liu, J. (2006). Development of passive design zones in China using bioclimatic approach. Energy Conversion and Management, 47(6), 746–762. https://doi.org/10.1016/j.enconman.2005.05.025

Li, D. H. (2010). A review of daylight illuminance determinations and energy implications. Applied Energy, 87(7), 2109–2118. https://doi.org/10.1016/j.apenergy.2010.03.004

Li, D. H., & Wong, S. (2007). Daylighting and energy implications due to shading effects from nearby buildings. Applied Energy, 84(12), 1199–1209. https://doi.org/10.1016/j.apenergy.2007.04.005

Lim, Y. W., Kandar, M. Z., Ahmad, M. H., Ossen, D. R., & Abdullah, A. (2012). Building façade design for daylighting quality in typical government office building. Building and Environment, 57, 194–204. https://doi.org/10.1016/j.buildenv.2012.04.015

Lin, B., Tan, G., Wang, P., Song, L., Zhu, Y., & Guangkui, Z. (2004). Study on the thermal performance of the Chinese traditional vernacular dwellings in Summer. Energy and Buildings, 36(1), 73–79. https://doi.org/10.1016/s0378-7788(03)00090-2

Mangkuto, R. A., Rohmah, M., & Asri, A. D. (2016). Design optimisation for window size, orientation, and wall reflectance with regard to various daylight metrics and lighting energy demand: A case study of buildings in the tropics. Applied Energy, 164, 211–219. https://doi.org/10.1016/j.apenergy.2015.11.046

Mohammadi, A., Saghafi, M. R., Tahbaz, M., & Nasrollahi, F. (2018). The study of climate-responsive solutions in traditional dwellings of Bushehr City in Southern Iran. Journal of Building Engineering, 16, 169–183. https://doi.org/10.1016/j.jobe.2017.12.014

Muhaisen, A. S. (2006). Shading simulation of the courtyard form in different climatic regions. Building and Environment, 41(12), 1731–1741. https://doi.org/10.1016/j.buildenv.2005.07.016

Muhaisen, A. S., & Gadi, M. B. (2006). Shading performance of polygonal courtyard forms. Building and Environment, 41(8), 1050–1059. https://doi.org/10.1016/j.buildenv.2005.04.027

Okeil, A. (2010). A holistic approach to energy efficient building forms. Energy and Buildings, 42(9), 1437–1444. https://doi.org/10.1016/j.enbuild.2010.03.013

Ouedraogo, B. I., Levermore, G., & Parkinson, J. (2012). Future energy demand for public buildings in the context of climate change for Burkina Faso. Building and Environment, 49, 270–282. https://doi.org/10.1016/j.buildenv.2011.10.003

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. Energy and Buildings, 40(3), 394–398. https://doi.org/10.1016/j.enbuild.2007.03.007

Persson, M., Roos, A., & Wall, M. (2006). Influence of window size on the energy balance of low energy houses. Energy and Buildings, 38(3), 181–188. https://doi.org/10.1016/j.enbuild.2005.05.006

Plokker, W., Evers, J. E. J., Struck, C., Wijsman, A. J. T. M., & Hensen, J. L. M. (2009). First experiences using climate scenarios for The Netherlands in building performance simulation. In 11th IBPSA Building Simulation Conference, 27-30 July (pp. 1284-1291). International Building Performance Simulation Association (IBPSA).

Rahman, M. M., Rasul, M., & Khan, M. (2010). Energy conservation measures in an institutional building in sub-tropical climate in Australia. Applied Energy, 87(10), 2994–3004. https://doi.org/10.1016/j.apenergy.2010.04.005

Rajapaksha, I., Nagai, H., & Okumiya, M. (2003). A ventilated courtyard as a passive cooling strategy in the warm humid tropics. Renewable Energy, 28(11), 1755–1778. https://doi.org/10.1016/s0960-1481(03)00012-0

Rosenfeld, A. H., Akbari, H., Bretz, S., Fishman, B. L., Kurn, D. M., Sailor, D. J., & Taha, H. (1995). Mitigation of urban heat islands: materials, utility programs, updates. Energy and Buildings, 22(3), 255–265. https://doi.org/10.1016/0378-7788(95)00927-p

Saghafi, M. (2018). Evaluating and classifying restrictions and hydrogeomorphic hazards for sustainable urban development planning in dry areas (case study: Birjand, South Khorasan Province, Iran). Natural Hazards, 93(1), 219–236. https://doi.org/10.1007/s11069-018-3296-x

Sailor, D. J. (2014). Risks of summertime extreme thermal conditions in buildings as a result of climate change and exacerbation of urban heat islands. Building and Environment, 78, 81–88. https://doi.org/10.1016/j.buildenv.2014.04.012

Santamouris, M., Synnefa, A., & Karlessi, T. (2011). Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. Solar Energy, 85(12), 3085–3102. https://doi.org/10.1016/j.solener.2010.12.023

Singh, M. K., Mahapatra, S., & Atreya, S. (2009). Bioclimatism and vernacular architecture of north-east India. Building and Environment, 44(5), 878–888. https://doi.org/10.1016/j.buildenv.2008.06.008

Singh, M. K., Mahapatra, S., & Atreya, S. (2010). Thermal performance study and evaluation of comfort temperatures in vernacular buildings of North-East India. Building and Environment, 45(2), 320–329. https://doi.org/10.1016/j.buildenv.2009.06.009

Soflaei, F., Shokouhian, M., & Shemirani, S. M. M. (2016a). Investigation of Iranian traditional courtyard as passive cooling strategy (a field study on BS climate). International Journal of Sustainable Built Environment, 5(1), 99–113. https://doi.org/10.1016/j.ijsbe.2015.12.001

Soflaei, F., Shokouhian, M., & Shemirani, S. M. M. (2016b). Traditional Iranian courtyards as microclimate modifiers by considering orientation, dimensions, and proportions. Frontiers of Architectural Research, 5(2), 225–238. https://doi.org/10.1016/j.foar.2016.02.002

Soflaei, F., Shokouhian, M., & Zhu, W. (2017b). Socio-environmental sustainability in traditional courtyard houses of Iran and China. Renewable & Sustainable Energy Reviews, 69, 1147–1169. https://doi.org/10.1016/j.rser.2016.09.130

Soflaei, F., Shokouhian, M., Abraveshdar, H., & Alipour, A. (2017a). The impact of courtyard design variants on shading performance in hot- arid climates of Iran. Energy and Buildings, 143, 71–83. https://doi.org/10.1016/j.enbuild.2017.03.027

Taleghani, M., Tenpierik, M., & Van Den Dobbelsteen, A. (2014a). Indoor thermal comfort in urban courtyard block dwellings in the Netherlands. Building and Environment, 82, 566–579. https://doi.org/10.1016/j.buildenv.2014.09.028

Taleghani, M., Tenpierik, M., & Van Den Dobbelsteen, A. (2014b). Energy performance and thermal comfort of courtyard/atrium dwellings in the Netherlands in the light of climate change. Renewable Energy, 63, 486–497. https://doi.org/10.1016/j.renene.2013.09.028

Taleghani, M., Tenpierik, M., Van Den Dobbelsteen, A., & De Dear, R. (2013). Energy use impact of and thermal comfort in different urban block types in the Netherlands. Energy and Buildings, 67, 166–175. https://doi.org/10.1016/j.enbuild.2013.08.024

Toe, D. H. C., & Kubota, T. (2015). Comparative assessment of vernacular passive cooling techniques for improving indoor thermal comfort of modern terraced houses in hot–humid climate of Malaysia. Solar Energy, 114, 229–258. https://doi.org/10.1016/j.solener.2015.01.035

Tzempelikos, A., & Athienitis, A. (2007). The impact of shading design and control on building cooling and lighting demand. Solar Energy, 81(3), 369–382. https://doi.org/10.1016/j.solener.2006.06.015

Yang, X., Li, Y., & Yang, L. (2012). Predicting and understanding temporal 3D exterior surface temperature distribution in an ideal courtyard. Building and Environment, 57, 38–48. https://doi.org/10.1016/j.buildenv.2012.03.022

Yasoori, M. (2004). Reconstruction of the environment for sustainable development of the Khorassan region. The Journal of Environment & Development, 13(4), 425–437. https://doi.org/10.1177/1070496504266382