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Investigating the Interaction between the Residential Architecture Principles in Muzaffarids and Qajar Eras in Yazd from the Perspective of the Solar Energy Orientations*

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ABSTRACT

Yazd is one of the country's regions with the arid and hot climate in which the solar irradiation plays an important role in the formation of its residential architecture. The present article uses a historical-comparative method to investigate the interaction between the principles of residential architecture's principles governing the houses during Muzaffarids and Qajar Eras with the solar energy from the perspective of orientation. The questions raised herein are: 1. have the houses been formed based on the interaction with solar energy during Muzaffarids and Qajar Eras? 2. In which period of time and for what reasons the residential architecture shows a better interaction with the solar energy? 3. Is the better interaction with climate associated with the proportions between the central yard and the walls and how the aforementioned proportions cause such an interaction? To do this research, 3D models were constructed for Karimi House (Muzaffarids) and Shokuhi House (Qajar) in the environment of ECOTECT Software and the climatic data of Yazd were utilized in simulation operation. Then, the models were analyzed based on a corresponding solar protractor and the behavioral trends of the houses; they were subsequently expanded to the longest and shortest days of the year. The results indicate that the proper orientation has caused the apportionment of solar energy during the entire year between all the four fronts. The summerside parts have favorable shades during the hot months of the year and the winterside parts provide part of the thermal energy through receiving a good deal of light during the cold months of the year; but, this front was found having a better performance in Shokuhi house because the development in the dimensions of the yard causes an increase in the area of this wall enabling it to receive more energy. Moreover, the yard in Shokuhi House has a better performance during the cold months. The increase in the yard's vastness gives the possibility of creating microclimate in the interior spaces of the house and this is accompanied by pleasant comfort. Thus, it can be stated that the residential architecture of both periods has been created subject to the interaction with the solar energy but Shokuhi House has better interaction with the climate in Yazd and this is closely associated with the present proportions in the building.

Keywords: Residential Architecture, Solar Energy, Yazd Region, Muzaffarids Era, Qajar Era.

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1. INTRODUCTION

The weather is arid and hot in Yazd and it exerts a large deal of effect on the principles governing the region's residential architecture. In this region, there are two critical cold and hot seasons with the latter being longer than the former. Amongst the various climatic factors, sun always plays an important role in the creation of thermal comfort for the residents and, due to the same reason, the architects try to use different methods for creating the best interaction with this source of energy in various periods because the buildings should be architecturally designed so that the intensity of the solar irradiation can be reduced in line with providing the residents with thermal comfort during the days of the hot seasons of the year, i.e. May, June, July, August and September, and the sunlight can be put into practical use during the days of the cold months, i.e. November, December, January and February (Kasmaei, 1984, p. 206).

Houses' orientation was one of the principles selected for the correct use of the sunlight. In line with this, a great percentage of the houses have been constructed with perpendicular postures (northeast-southwest orientation) and a few percentages of them were built with Isfahani sides (northwest-southeast orientation) and this has had a large effect on the creation of thermal comfort because buildings' orientation is one of the important factors in determining the amount of sun irradiation received. In the hot climates, the minimum solar energy is needed hence the building has to be oriented towards a direction that the least irradiation could be received. In the cold seasons, as well, the building's orientation has to be in such a way that the intensity of irradiation on the walls could be maximized and it could be possible for the sun rays to enter into the interior spaces (Lashkari, Moozermi, Solki, & Lotfi, 2011, p. 49).

The MuzaffaridsEra's houses in the Yazd region had courtyards with elevated porches towards the summerside front and the heights reached eight meters in some samples. On the opposite side of them, there was a small platform that formed the winterside front of the house and it was less elevated in contrast to the primary platform. The yards of these houses had a small area. For example, the yard of Muhammad Jawkar's house in Khavidak Village features a dimension of about 4.60 × 3.92 meters and Bagherdashti House's yard is about 4.33 × 4.10 meters. This same issue caused the impossibility of creating microclimates inside the houses through planting of trees and construction of water ponds because it would otherwise disrupt the daily activities of the residents.

In spite of enjoying an identical orientation, Qajar Era's houses are largely different from the MuzaffaridsEra's specimens in some of the cases like the relatively equal heights of the summerside front to the other fronts, vaster dimensions of the courtyards and creation of microclimates through planting of trees and construction of water ponds. These same issues caused the different interactions between the architectural principles commonly used in the residential buildings of Muzaffaridsand Qajar Eras. In the present study, through simulating the case studies of each era, it was tried to analyze their interactions with solar energy in an objective way and close-to-reality manner.

2. STUDY BACKGROUND

The interaction between architecture and climate is one of the highly important issues dealt with in various studies. The book "climatic investigation of Iran's traditional buildings" is one of the works that introduces the various climates in Iran and investigates their effects on the traditional architecture (Ghobadian, 2014). The book "comfort by the support of a climate-compliant architecture" expresses the scientific principles and foundations in various chapters and the awareness of them is necessary as a basic knowledge for those who work with climate-compliant designing (Razjouyan, 2009). The book "comfort by protection from the wind", as well, deals with the role of these factors in providing comfort to the human beings or disordering of it in the external and internal environments of the buildings and it is of a great importance in climatic terms (Razjouyan, 2000). The book "climate and architecture" deals with the investigation of the conditions in each of the Iranian cities based on the statistical data and offers a psychrometric table based thereon. The book is a source of information that can be used as scales in the preliminary calculations (Kasmaei, 1984). Taban et al. (2013) used simulation software packages to determine the optimum pattern of the central yard in the traditional houses in Dezful.

Nowadays, the use of simulator has gained a lot of importance in designing buildings and the method of their interactions with climate. The most important advantage of such software packages is their savings in time and costs of designing and proper use of them can lead to the creation of a design that interacts with the climate in the best possible way and enables the provisioning of the comfortable conditions with the lowest cost due to the proper use of the capacities of each climate (Qiaei, Mahdavinia, Tahbaz, & Mofidi, 2013, p. 46). Some of the researchers have used ECOTECT Software in their studies. Sohailifard et al. (2013) studied the interaction of Abbasian House in Kashan with solar energy. Yang et al. (2014) attained important findings in the designing stage and suggested a model having the best interaction with the studied' region's climate through paying attention to the environmental factors and analyzing some of the factors like building orientation, natural ventilation and night and day lighting and this enabled the availability of the best thermal comfort with the lowest amount of energy consumption. Asfour and Al-Ashouf (2015) studied the effect of the density of the residential units in energy productivity in the buildings in consideration of the hot climatic conditions. The numerical analysis performed in the environment of the ECOTECT's simulator software demonstrates that energy productivity in the residential buildings is directly associated with their density. Fayyazi et al. (2011) investigated the effect of building orientation on the thermal comfort in various Mehr Housing Complexes in Tehran. Monshizadeh et al. (2013) examined the effect of microclimatic factors on the thermal and environmental comfort in the urban spaces and their relationship with the buildings' heights as walls influencing the microclimate. Paramita and Kourniavan (2012) dealt with the exploration of the relationship between the sun's irradiation and the building's orientation and latitudes in Bandung, Indonesia. Canters and Herawat (2012) investigated the relationship between the optimum use of solar energy and the building's geometrical form in Lund in the southern part of Sweden.

Zomorrodian and Tahsildoust (2015) dealt with the evaluation of two Software Packages, named ECOTECT and Design Builder, for the prediction of the amount of energy consumption and the internal temperature of the spaces. Ghia'ei et al (2013) compared some of the energy simulation software packages and chose ECOTECT and ICOST as the optimum software packages for the architects. Furthermore, the results of the research by Hensen (2002) indicate that ECOTECT is one of the widely used simulation software applied by architects in the US.

In some of the studies, as well, the software's validation has been conducted amongst which the researches by Ali et al. (2016), Ali et al. (2015), Al-Tamini and Fazil (2011) and Marsh (2003) can be pointed out.

3. RESEARCH THEORETICAL FOUNDATION

The sun irradiation status in the Yazd region has transformed it into an important issue in regard of the climate-based designing of the buildings (Jahanbakhsh & Esmaeilpoor, 2004, p. 38) and this has had a large deal of effect on the formation of the residential architecture from various perspectives. Buildings' orientation is one of the principles selected by the architects according to the required thermal, sanitary and psychological conditions for achieving the highest practical use of the sunlight because this principle can determine the amount of sun irradiation absorption. Due to the same reason, the building designers calculate the sun's irradiation flux for various hours of the day and different days of the year considering the changes in the sun irradiation's place and angle to choose an orientation for the building so that the amount of the absorbed irradiation does not give rise to the extreme heat in the building (Shams Tabrizi & Khodakarami, 2010, p. 100) because the extreme irradiation of the sun into the internal rooms should be prevented during the hot occasions and, conversely, it has to be usable during the cold occasions (Jahanbakhsh & Esmaeilpoor, 2004, p. 30).

Simulation software packages are amongst the instruments by means of which the interaction between architecture and the region's climate can be investigated. These software packages create virtual environments so as to make it possible for the building's functional predictions to be close to the reality as much as possible (Qiaei et al., 2013, p. 46). "ECOTECT is one of the simulator software packages and a comprehensive energy, light and sound analysis instrument that can perform the corresponding analyses in a completely graphical environment by means of 3D models that are either made in the environment of the program or constructed in the other software packages and inserted into the program which is capable of offering the related numerical and visual analyses in the form of table, diagram, image and/or animation. Amongst the notable attributes of this software, the ability of performing all of the drawing stages, calculations and results' analyses in the program's environment and carrying out the modifications and re-running the calculations without any wastage of time and in a simple way can be pointed out (Ghiabaklou, 2009, p. 9).

In this article, the architectural principles of the residential buildings in Yazd region during Muzaffarids and Qajar Eras were investigated in terms of interaction with solar energy by means of ECOTEC simulator software and, as it was mentioned in the previous section, the software is widely applied by the architects (Hensen, 2002, p. 6).

4. STUDY QUESTIONS

1. Are the houses from Muzaffarids and Qajar Eras formed based on the interaction with solar energy?
2. In which period and for what reason the residential architecture shows a better interaction with solar energy?
3. Is the better interaction with the climate associated with the proportions of the courtyard and walls and how do the aforementioned proportions cause such an interaction?

5. STUDY METHOD

The present study has been conducted through a historical-comparative method based on the field investigations and notes to investigate the residential architecture principles governing the houses in the Muzaffarids and Qajar Eras in Yazd. To do so, a house was selected from each of the Muzaffarids and Qajar Eras and the 3D model of each of them was prepared in the ECOTECT Software Environment (Figs. 1 & 2). The climatic data of Yazd, as well, were inserted into the simulation operation and all of the calculations for the solar energy adsorption and reception were carried out based on the climatic information of Yazd Region

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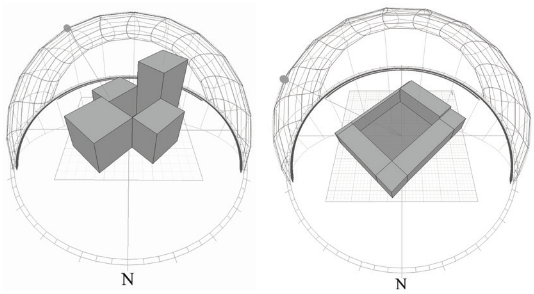
during the recent 30 years in consideration of the longitudes and latitudes (31.9º of the northern latitude and 54.3º of the eastern longitude) and elevation from sea level (1230m). In addition, the climatic data were inserted into the model in the form of 2TMY. "These data were calculated based on the Sandia Method by Abd Al-Salam Ibrahim Pour and introduced to the energy department of the US" (Soheilifard, Akhtarkavan, Fallahi, & Mohammad Moradi, 2013, p. 77). Then, the prepared model was matched with solar protractor and the behavioral trends of the houses were analyzed in the course of year on an hourly basis. These investigations were generalized to the longest and the shortest days of the year (summer revolution and winter revolution). The constructional materials used in the walls were considered to be sun-dried bricks with conductance coefficient of 0.711w/m.k and specific heat of 838.80J/kg.k. The wall's thicknesses were set at 900mm and 500mm respectively for Karimi House and Shokuhi House. It is worth mentioning that the reflectance from the other fronts does not have any effect on the results.



Figs. 1 & 2. 3D Models of Shokuhi (Right) and Karimi (Left) Houses

6. SOFTWARE VALIDATION

In order to validate ECOTECT software, the field calculations were carried out in Shokuhi House. The reason for selecting this house was the access to the investigated sample which was not possible for Karimi House. In line with the validation of the software, the amount of shading by the walls in the central yard was investigated for three days, 26th to 28th of July, at 12:00 A.M., 01:00 P.M. and 02:00 P.M. Then, the mean rates of the various walls' shading were calculated at each hour and presented in chart 1. This process was also performed for the information obtained from the software and displayed in the foresaid diagram.

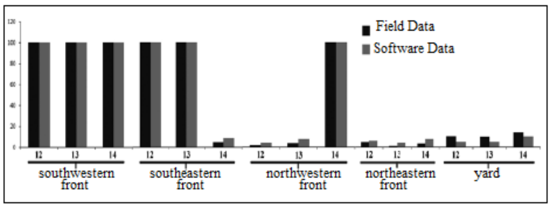


Chart 1. Comparison of the Data Obtained from Field Note-taking and ECOTECT Software

Comparison of the obtained results with one another shows that ECOTECT Software has the required validity for the calculation of the solar energy irradiations because the results obtained from the software trivially differ from the results obtained from the field investigations with the difference being less than 5% in the majority of the cases and this is reflective of the ECOTECT Software's high accuracy.

7. THE REASONS FOR SELECTING THE STUDY SAMPLES

One of the important goals of the present article is the comparison of the various kinds of courtyard's behaviors with respect to the dimensions and proportions in the two studied eras' houses that have been constructed in such an arid and hot climate as Yazd. Due to the same reason, Karimi House was selected from Muzaffarids Era. Based on the Pirniya's definition (Memarian, 2013, p. 226), Karimi House is a building with a micro-module system and a courtyard reaching tothe area to about 16.8 square meters. The house enjoys a relatively suitable situation and it is amongst the few Muzaffarids Era houses that many parts of which have been left intact and presenting unchanged preliminary proportions and it is not possible to access the preliminary proportions of the building in the other samples due to the destructions or the changes and repairs.
Shokuhi House was also selected from Qajar Era and the house features a macro-level module considering the aforementioned definition (Memarian, 2013, p. 224). The yard reaches to 378 square meters in area and the expansion of the dimensions of the courtyard has caused changes in the present proportions between the yard and the walls. So, the abovementioned houses were selected for finding answers to the study questions and investigate the role of proportions in the interaction with the climate.

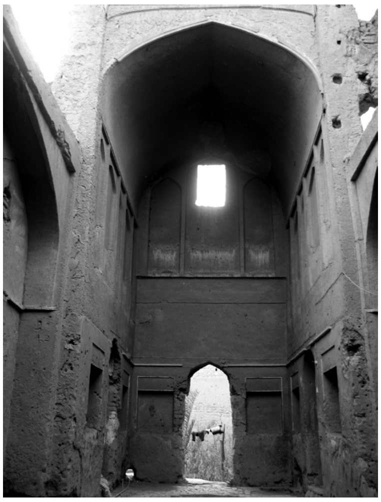
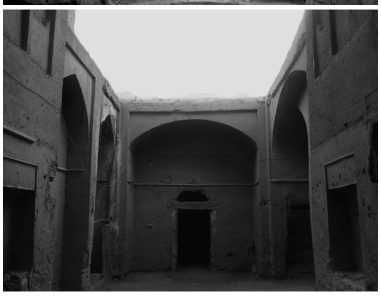
Fig. 3. Karimi House
(Khademzadeh, 2008, p. 277)

8. INTRODUCING THE STUDIED SAMPLES

8.1. Karimi House

Karimi House is a building from Muzaffarids Era and it is situated in Sheikhdad Neighborhood in Yazd (Figs. 1 & 2, Left Side). The house's entry is located on the

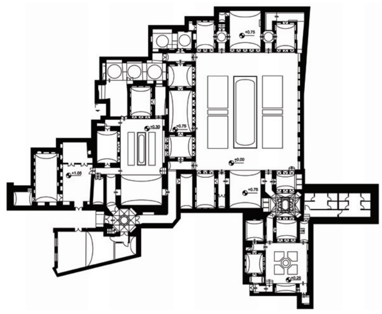
northwestern side of the building which is connected to the courtyard in a 90-degree turn through one of the small porches. The yard is small and rectangular and it has been built with a perpendicular posture; the summerside porch is positioned on the southwestern side and the winterside, as well, is on the northeastern side. On the other two sides of the yard, small porches have been placed that enable access to some other spaces and roof.
The main porch has eight meters height that shows a large elevation difference with respect to the other parts of the house. Behind the porch, there has been a garden part of which is still remaining and a platform, approximately 1.5 m in height, has caused the elevation of the porch and the peripheral residential rooms' floors from the garden level (Figs. 4 & 5). The small porch that is situated in the northeastern side of the courtyard enjoys a lower elevation as compared to the main porch and there is another room behind it with its entry door being located in the shield frame of the small porch (Khademzadeh, 2008, pp. 276-282).

Figs. 4 & 5. Main Porch of Karimi's House
(Archive of Cultural Heritage, Handicrafts & Tourism Organization of Yazd Province, 2005)

8.2. Shokuhi House

This house is one of the monuments dating back to the Qajar Era and it is positioned in Chaharsough Neighborhood in Yazd (Fig. 6). The house has four yards the largest of which is in the innermost part of the house. The summerside hall is situated in the southwestern front of the house and there is a five-door room for wintersideon the opposite front (Fig. 7).
The exterior part of the house contains a small yard enjoyingsummerside and winterside spaces. There is another small yard in the external part that made it possible to have access to some of the lateral spaces like stable. Shokuhi House has an octagonal wind-catching room behind which there is an orangery with rooms on its both fronts.




Figs. 6 & 7. Shokuhi House
(Archive of Cultural Heritage, Handicrafts & Tourism Organization of Yazd Province, 2005)

9. INVESTIGATING THE INTERACTION BETWEEN THE RESIDENTIAL ARCHITECTURE AND SOLAR ENERGY

Enjoying the rectangular forms of construction, the Iranian house showcases the emphases on its geometrical capabilities. Based thereon, it uses a semi-open filter, named central yard, to divide the house's space into two parts of summerside (southview rooms) and winter-stay (northview rooms). To investigate the interaction between residential architecture in Yazd region with solar energy, models were prepared with consideration of the proportions in both of these two houses so that the various walls can be investigated. Both of the models were in a 135-degree angle with respect to the geographical north due to the fact that they have been built with a perpendicular posture. Also, the irradiation on each of the walls and yard's floor was investigated.

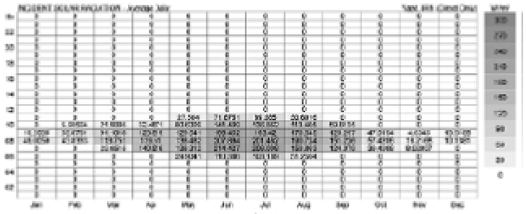
9.1.The Wall Facing the Northeastern Side (Summer-Stay Front)

The wall facing the northeast in both of the houses is subjected to sun irradiation during the hot months (May, June, July, August, & September) from the early morning hours till noon and it goes under shadow till the end of the day (Tables 1 & 2). Although the energy received by this wall is relatively high, it takes place during the early morning hours and it stops receiving any irradiation in the peak hours, i.e. from 11:00 A.M.

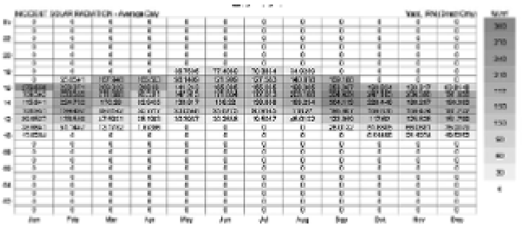
till 02:00 P.M. The amounts of energy received during the aforesaid months in Karimi and Shokuhi Houses are 349 w/m^2 and 757 w/m^2 on average, respectively. The highest amount of energy, as well, is received during June for 1020 w/m^2 for Shokuhi House and 949 w/m^2 for Karimi House.

The energy adsorbed by sun-dried bricks during the day would be kept therein for about 8 to 10 hours (Behyar, Parvaneh Khoozani, & Baqeri, 2002, p. 1). The energy is transmitted gradually from one side of the wall to the other side during the night as a result of which the residents are provided with part of the heat required for the night. Such a type of heat transfer is appropriate for the arid and hot regions wherein the temperatures largely differ between day and night (Balaras, 1996, p. 2).

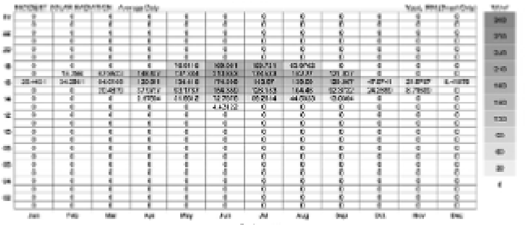
Table 1. Analyses of the Four Fronts from Internal Viewpoints of the Courtyard in Shokuhi House



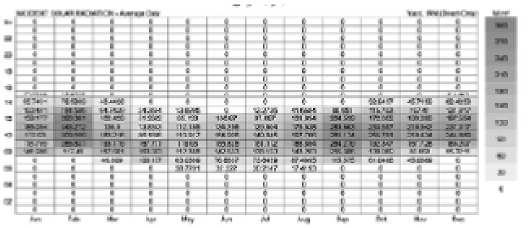
Southwest



Northeast



Southeast



Northwest

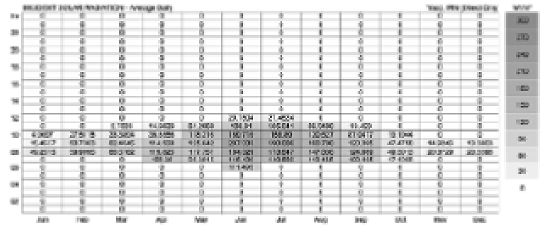
The wall facing the northeast is in shade during the cold months (November, December, January and February) for most of the hours and it does not receive any irradiation except during the early morning hours. Although the reception is comparable in both of the houses, Karimi House receives more irradiation due to the proportion of the southern porch in contrast to the other walls. According to charts 8 and 9, this trend holds during the early morning hours and the proper shading by the wall prevents the energy adsorption during the critical hours of the hot months of the year. This way, it can be discerned that the favorable form is created by an element named courtyard in the traditional architecture of Iran that gives a special definition for shading. The amount of shade depends on the proportions of the three dimensions of the yard and the building's rotation angle. In fact, Iran's traditional architecture creates a proportionate form that is indicative of a special behavior for every front of the building (Soheilifard et al., 2013, p. 77).

9.2. Wall Facing the Southwest (Winterside Front)

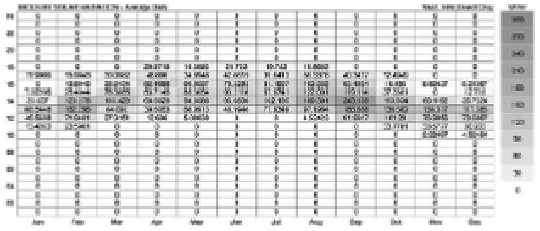
The wall facing the southwest (Winterside) receives a relatively good deal of sunlight during the cold months for a long period during the day (Tables 1 & 2). But, the front was found having a better performance in Shokuhi House because a greater area of the front receives irradiation due to the better proportion between the yard and the walls and this same issue causes the absorption of more energy hence more thermal comfort of the residents. The highest amount of energy received during the cold belongs to February in Shokuhi House for an amount of 1139 w/m^2 whereas it was calculated 436 w/m^2 for Karimi House and this is reflective of the better reception of the sunlight by the wall in Shokuhi house.

On winter days, the walls store the thermal energy received from the sun irradiation and entered and captured through the openings and subsequently give it slowly back to the interior spaces with the sunset and upon the elimination of the heat source when the need for heat is increased in the interior spaces of the house. This causes a reduction in the heating load of the building (Mohammad, 2013, p. 71). The process was found showing off better in Shokuhi House because the existence of a five-door room causes the infiltration of the sun into the interior spaces of the room that would be accompanied by better comfort at night. But, in Karimi House, only the extant opening is the room entry door in the backside of the small platform; however, no exact idea can be expressed about this room due to the absence of archaeological data but it is deemed quite likely that the sunlight could enter the room through the glasses because the use of the colorful glass for buildings' decoration had been completely customary (Katib, 1965, p. 203). During the hot months of the year, the aforementioned wall has been under thermally uncomfortable conditions and, though it is in the shade almost till 11:00 AM, it receives sun irradiation during peak hours in Yazd Region.

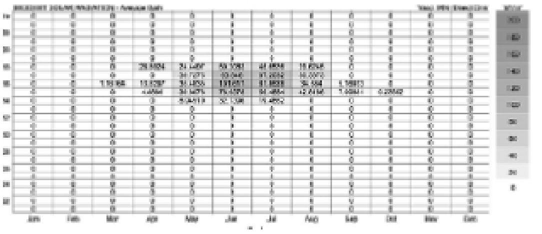
Table 2. Analyses of the Four Fronts from Internal Viewpoints of the Central Yard in Shokuhi House



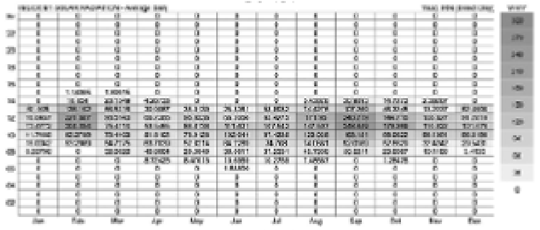
Southwest



Northeast



Southeast



Northwest

9.3. The Wall Facing the Northwest (Southeast Front)

The wall facing the northwest is in thermally uncomfortable conditions during the entire year. Although it receives little irradiation in Shokuhi House, it is in the shade during the cold months for a long time of the day and receives no irradiation. In Karimi House, as well, the wall does not receive any irradiation during the cold months of the year.

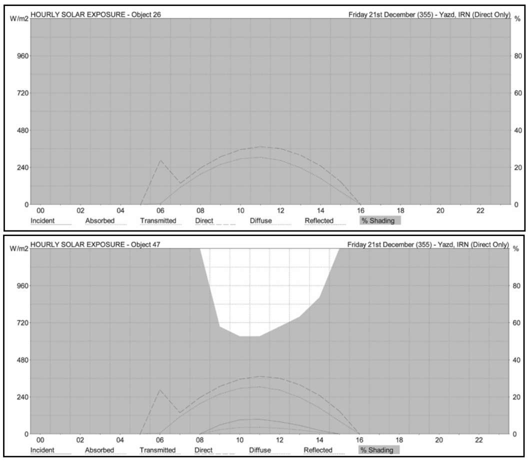
During the hot months, as well, although it is in the shade during the early morning hours, it is subjected to the irradiation afterwards and this same issue causes the absorption of a relatively high amount of energy for such a reason as the reception of light from the northwest that is recognized as unfavorable light in Yazd Region (Jahanbakhsh & Esmaeilpoor, 2004, p. 38). This same issue is more likely to have been the cause of the absence of any residential spaces in the southeastern front in Shokuhi House (Tables 1 & 2).

9.4. The Wall Facing the Southeast (Northwest Front)

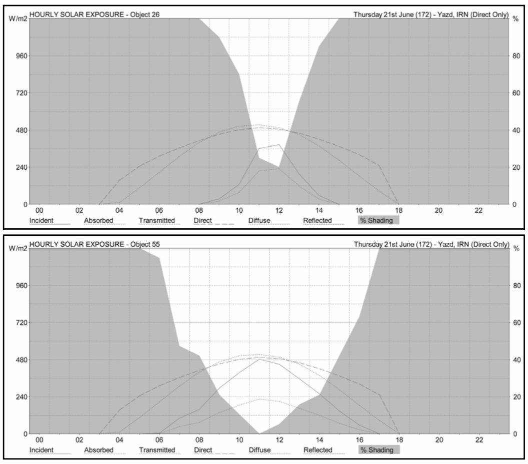
The wall facing the southeast, unlike the formerly described one, is in thermally favorable conditions during the entire length of the year (Tables 1 & 2). This wall receives irradiation during the cold months from the early hours of the day and it remains the whole day. In hot months, as well, the wall receives the early morning hours' irradiation that is continued till noon and it subsequently goes under the shade during the peak hours. This issue comes about due to the reception of the light from the southeast side which is recognized as the most favorable light in the Yazd Region (Jahanbakhsh & Esmaeilpoor, 2004, p. 31). This wall has a better performance in Shokuhi House than in Karimi House because it receives about 1600w/m2 energy during February whereas the energy absorption rate is about 730w/m2 in Karimi House. This same issue along with the constant irradiation during the cold months causes the creation of a better thermal comfort in comparison to the Muzaffarids sample. Although Shokuhi House receives more energy during the hot months, it mostly occurs during the early morning hours and the wall is in the shade during the peak irradiation hours (Chrats 6 & 7). In Shokuhi House, the creation of spaces in this front serves the utmost utilization of light from the southeast but there are small porches in the northwest front in Karimi House and, considering the current status, the existence of the other spaces seems to be not so much worth of mentioning. However, in some of the houses, a room was created in the backside of the small porches that served different functions; for instance, in Sheikh Ismail House in Maibod, the existence of black soot on the wall and ceiling and the existence of an earthen oven are suggestive of the fact that it has been a kitchen; or, the existence of the numerous shelves in Boruni and Rafi'eis' Houses are indicative of the vitality during certain hours of the year (Zakerameli & Esfanjari Kenari, 2006, p. 202).

9.5. Yard

The courtyard was used in the arid and hot climate for a long time in Iran's traditional architecture. Additionally, this courtyard was of great importance in social terms for it created a microclimate inside the building that provided cold and humid air and reduced the amount of energy required for chilling the building. This element organized the various architectural spaces like doors and windows all of which were opened thereto (Khalili & Amindeldar, 2014, pp. 172-173).



Charts 2 & 3. The Hours of the Courtyard's Exposure to the Sunlight on the 1st of January in Karimi House (Top) and Shokuhi House (Bottom)



Charts 4 & 5. The Hours of the Courtyard's Exposure to the Sunlight on the 1st of July in Karimi House (Top) and Shokuhi House (Bottom)

Alongside with the organization of the various spaces around it, this space caused the various parts of the house to be dedicated to a season of the year considering the sun's movement in the sky and a sort of seasonal movement had been created in the houses (Memarian, 2013, p. 16).

In hot regions, various strategies were employed for controlling the irradiative energy in the exterior spaces amongst which the use of the bright colors for the external bodies, application of shades of various kinds and improvement of the thermal properties of the masonry utilized in the walls can be pointed out. But, before putting these strategies into the practical use, the important thing has been the proper proportion of the exterior spaces like yards in such a way that they could have the best performance in regard of the sun's irradiation in terms of the occasions that shade was needed and vice versa (Taban, Pourjafar, Bemanian, & Heidary, 2013, p. 40).

The yard in Karimi House does not receive any irradiation on the first of January (winter revolution). This can have a direct relationship with its dimensions and proportions of the walls that prevented the irradiation of the sun (Chart 2).

Tables. 3 & 4. The Amount of Shading in Yard During the Year in Karimi House (Top) and Shokuhi House (Bottom)

PERCENTAGE SHADING - Average Daily — Yazd, IRN (Direct Only)

Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
22	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
20	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
18	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
16	100	100	100	100	95	100	100	100	100	100	100	100
	100	100	100	100	95	85	70	90	100	100	100	100
14	100	100	100	85	75	55	60	70	95	100	100	100
	100	100	80	60	35	25	40	50	75	100	100	100
12	100	100	95	75	40	25	40	55	85	100	100	100
	100	100	100	90	70	70	70	90	100	100	100	100
10	100	100	100	100	95	90	95	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
08	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
06	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
04	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
02	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100

%: 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 0

PERCENTAGE SHADING - Average Daily — Yazd, IRN (Direct Only)

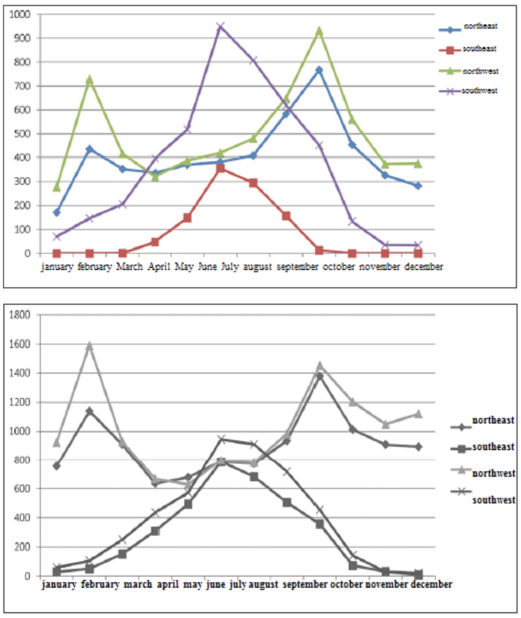
Hr	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hr	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
22	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
20	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
18	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	94.7368	78.9474	63.1579	63.1579	63.1579	63.1579	89.4737	100	100	100
16	100	73.6842	73.6842	57.8947	47.3684	42.1053	42.1053	47.3684	57.8947	73.6842	94.7368	100
	68.4211	47.3684	36.8421	36.8421	31.5789	31.5789	31.5789	31.5789	36.8421	52.6316	68.4211	68.4211
14	42.1053	31.5789	31.5789	21.0526	21.0526	15.7895	10.5263	15.7895	26.3158	31.5789	47.3684	63.1579
	42.1053	36.8421	21.0526	5.26316	5.26316	5.26316	5.26316	5.26316	10.5263	31.5789	36.8421	57.8947
12	42.1053	31.5789	15.7895	10.5263	0	0	0	0	10.5263	15.7895	42.1053	52.6316
	52.6316	42.1053	21.0526	5.26316	5.26316	10.5263	10.5263	5.26316	10.5263	26.3158	42.1053	52.6316
10	57.8947	52.6316	42.1053	31.5789	21.0526	21.0526	21.0526	26.3158	26.3158	36.8421	52.6316	57.8947
	100	84.2105	68.4211	47.3684	42.1053	36.8421	36.8421	42.1053	42.1053	63.1579	78.9474	100
08	100	100	89.4737	63.1579	57.8947	47.3684	47.3684	57.8947	78.9474	94.7368	100	100
	100	100	100	100	89.4737	94.7368	94.7368	100	100	100	100	100
06	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
04	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100
02	100	100	100	100	100	100	100	100	100	100	100	100
	100	100	100	100	100	100	100	100	100	100	100	100

%: 100, 90, 80, 70, 60, 50, 40, 30, 20, 10, 0

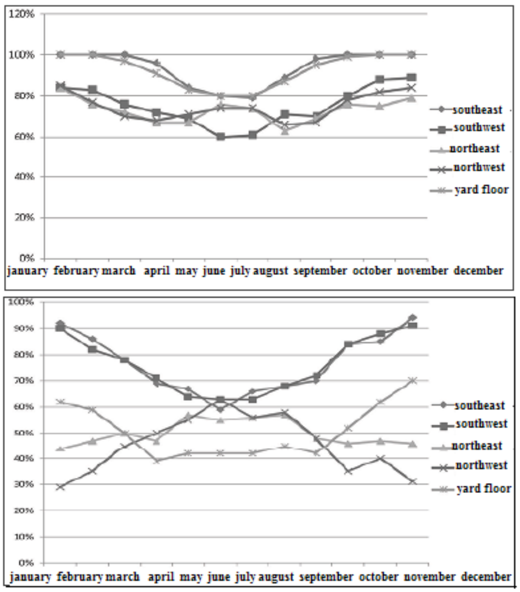
According to chart 7, this shading trend is repeated for the cold months of the year. Although the length of the hot period is larger than the cold period in the Yazd Region, Yazd should be categorized based on the climatological chart of Amberge as a region with arid and cold climate (Sadeghi Ravesh, 2010, p. 90) for it has cold and dry winters and the use of sun can somewhat reduce the coldness of the air. Shokuhi House receives irradiation on the 1st of January from 09:00 A.M. and it is continued till 02:00 P.M. (Chart 3). According to charts 2 and 3, the yard receives irradiation during the cold months of the year (December, January and February) and this same issue causes the gradual heating of part of the yard's space during the day. These results are reflective of the better performance of the central yard in Shokuhi House because it is followed by better thermal comfort with the better reception of irradiation during the cold months.

On the first day of July (summer revolution), the irradiation on the yard in Karimi House begins from 09:00 A.M. and continues till 03:00 P.M. (Chart. 4). The highest amount of irradiation occurs at 12:00 at noon that only 20% of the yard's area is shaded. This trend is repeated with a little difference for the entire length of the hot period (Chrat 8). It is worth mentioning that the change in the orientations of Muzaffarids Houses, as well, has not had much of an effect on the amount of the irradiation received by the yard during the year because the authors' calculations on Abd Al-Hussein Reza's House in Khavidak Village that has been built based on Isfahani Posture also show a similar performance for it.

Irradiation lasts in Shokuhi House on the first of July for the entire length of the day. The highest amount of irradiation occurs at 11:00 A.M. and it encompasses almost the entire level of the yard (Chart 5). The trend is continued for the hot months of the year and, due to the proportions presentbetween the yard and the walls in Shokuhi House, the irradiation is stretched over a larger area (Chart 9). But, the planting of trees in the yard's space has probably been for the purpose of preventing the direct sun irradiations and the water pond in the middle has surely been serving the moderation of the temperature. Moreover, the existence of the wind-catchers and the spaces connected to them could largely provide the residents with appropriate thermal comfort conditions.



Charts 6 & 7. The Amount of the Energy Received By All of the Four Internal Fronts; Shokuhi House (Top) and Karimi House (Bottom)



Charts 8 & 9. The Amount of Shading in All of the Four Internal Fronts; Karimi House (Top) and Shokuhi House (Bottom)

10. CONCLUSION

Climate is one of the important factors in the formation of the principles governing the residential architecture in Yazd region; in between, the solar energy plays an influential role since, due to the existence of long hot periods, the architectural designing should be in such a way that the irradiation be blocked during the hot seasons and it can be practically applied in cold periods.

According to the analyses, it can be concluded that the residential architecture of both periods has been developed in the interaction with the solar energy because considering the appropriate orientation in building the houses, they have caused that in proportion to their spatial landuse, four internal fronts divide the solar energy received during the year. The summerside space prevents the irradiation reception during the peak hours with its proper application of walls' shading and the winterside space provides the building with part of its required thermal energy during the cold months of the year through its appropriate reception of sufficient amount of irradiation but this front exhibits better performance in Shokuhi House because the yard's aspectshave been increased and cause an increase in the area of the front as a result of which more solar energy is received during the cold months of the year. Moreover, yard, unlike the Karimi House, performs better in this house because it receives part of the sun's irradiation that could have had a direct effect on the creation of thermal comfort conditions.

On the other hand, the increase in the yard's area provided the creation of a microclimate in the internal spaces of the house for it prevented the sun's irradiation during summer and the existence of a water pond, as well, caused the humidification of the interior spaces of the yard. This can be reflective of the importance of microclimate in the houses in Yazd and generally desert regions. That is because it played an important role in the creation of the comfortable conditions for the residents during the hot periods through providing proper shading and humidifying the interior spaces of the yard and this same issue has caused Karimi House to have a better interaction with the arid and hot climate in Yazd considering the entire conditions; it is additionally closely associated with the building's form and the proportions present therein. This is due to the increase in the yard's and the walls' areas and as a resultant, a better reception during the cold months of the year. The above-described plan can be utilized by the today's designers as a pattern because they can consider the proper proportions of the building so as to create a good interaction with the climate that plays a considerable role in reducing the costs stemming from energy consumption in the building.

The results of the present study indicate that the proportions of the micro-module system that was commonly practiced in Muzaffarids period do not fit Yazd region's climate. On the other hand, although the houses built with large modules can provide better interaction with solar energy but this could contrarily cause thermally uncomfortable conditions during the storm occasions because the wind speed in the internal space of the central yard is increased as compared to the micro-module system and this results in thermally uncomfortable conditions. The houses built with small modules can be possibly considered as providing the best proportions for Yazd's climate; however, the aforesaid assumption needs separate study and research.

Microclimate in Yazd region plays an important role in the creation of thermal comfort. This plan can be taken into account as a pattern by the designers who can apply it in their architectural designing of the buildings in similar climates. Furthermore, the high potentials of the energy simulation software packages can be also taken into consideration for the study of the historical buildings from various perspectives because the results of the analyses feature high accuracies and are obtained through spending relatively large deal of time but small costs. This principle becomes very much important for the buildings, parts of which have been destroyed but having their previously extant proportions still remaining. The study of them can be greatly helpful in the better recognition of the architectural styles of the various periods and the past experiences can be employed for today's designs and plans.

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