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Typology and Solar Gain Analysis: Vernacular Courtyard Houses of Tabriz, Iran

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Abstract

The study presents the results of typological analysis and simulation modeling analysis of traditional courtyard residential houses in the cold semi-arid climate of Iran. The purpose of the research has been to analyze and evaluate traditional passive environmental strategies and their elements to provide implications for the design of sustainable residential buildings in contemporary time. Five existing traditional courtyard houses in the city of Tabriz, Iran, are used as case-studies to analyze the typology and the solar zoning conditions and to develop simulation models. The Ecotect simulation program is used to calculate the solar gains of the buildings and to analyze the effectiveness of the natural passive systems along with native design strategies in terms of potential solar gains of main and secondary living spaces. However, in the vernacular, not only the awareness of the climatic and topological considerations is important, but also the values, rituals, and beliefs that shape the design of the dwellings need to be considered. The research is based on the hypothesis that vernacular buildings (courtyard houses) of Iran have been environmentally sustainable structures. However, an important challenge of the study has been to avoid the technological bias and to consider the cultural and social aspects and embodiment of the studied houses, as well. The study also addresses the potential shortcomings that limit the reliability of Iranian vernacular architecture at present in order to arrive at a more holistic understanding of the sustainability of the vernacular architecture in the country.

Keywords

Courtyard Housing; Solar Gains Analysis; Sustainability; Typological Analysis; Vernacular Architecture

1. Introduction

The environmental focus in regard to the sustainability and built environment is growing because of the immense importance of environmental issues in a time of rapid climate change, global warming, environmental pollution and the depletion of natural resources. Sustainability in the world of architecture is regarded as one of the most important and internationally endorsed principles of the environmental ethic of the twenty-first century (Asquith & Vellinga, 2006). In this manner, sustainability in the building practices has now become a major criterion in the judgment of architectural and planning practices. According to the United Nations Environment Program of Sustainable Buildings & Climate Initiative (UNEP SBCI, 2009), buildings consume up to 40% of the energy use in the world and they are responsible for one third of global Greenhouse Gas (GHG) emissions in most countries.

Concurrently, most big cities in Iran produce high level of air pollution, which is far exceeding the standards set by the World Health Organization (WHO) and posing considerable health problems (Sarbib et al., 2001). Hence, the reduction of energy consumption and preservation of energy are important for Iran. The specific problems that signify the importance of designing environmental friendly houses in Iran are as follows:

- Building sector emissions in Iran: the pollutant and GHG emissions by Residential sector are overrepresented in Iran (Iran's Deputy for Power & Energy Affairs Power & Energy Planning Department, 2013).
- High energy use of residential buildings in Iran: Residential sector has been responsible for almost 38% of final energy consumption during 1974-2013. Of this amount, the operation phase is responsible for approximately 85% of a building's total energy use (Ibid).
- The dependency on fossil fuels for heating buildings: the energy consumption for the building sector in Iran is mainly provided by the natural gas, petroleum products, coal, and electricity. Natural gas and electricity final consumption by the building sector in Iran has increased considerably during 1974-2013 (Ibid). According to Iran's ministry of Energy, residential buildings have consumed 41% of the total Iran's energy consumption of natural gas during the previous nine years (Iran Ministry of Energy, 2017). Fossil fuels are used in Iran without consideration; accordingly, 98.8 % of the country's total residential energy consumption is supplied from oil products and natural gas (Nasrollahi, 2009).
- Increased rate of energy price: the average electricity sale price for residential buildings in Iran has increased from 2.3 Rial/kWh in 1974 to 346.7 Rial/kWh in 2013 (Iran's Deputy for Power & Energy Affairs Power & Energy Planning Department, 2013).
- Energy supply depletion: the majority of Iran's oil resources are in the second half of their life span and other resources are inefficient. Renewable energies are not practically used in Iran. However, the use of renewable energies such as wind and solar energy is going to be increased. Currently, only a small-scale conversion is being made to nuclear energy for the electricity's production in an effort to counter the aforementioned consumption (Nasrollahi, 2009).

A reduction in energy consumption and the introduction of energy efficient houses, hence, would have a significant impact on the overall energy consumption of Iran. One way to meet the need for sustainable buildings is to raise the awareness of the importance of vernacular architecture. This is because in architectural theory the factors that surround the art of building, is embedded in the society, and is passed on from one generation to the next through tradition (Asquith & Vellinga, 2006). This cyclical period of sustention is broken by outside forces and changes that ignore the complex nature of social and environmental forces and result in inappropriate architecture. While globalization has brought convenience in living and communication, it has threatened the architecture and the built environments we live in (Ibid). In a world that the scarcity of energy resources and environmental pollutions is likely to increase, the durable and conscious vernacular architecture needs to be raised.

1.1. Objective of the study

The objective of the present study has been to advocate for more awareness of vernacular architecture of the cold climatic region of Iran, not so much as museum components but as viable housing environments, which can contribute to a healthy and rewarding twenty-first century life style. This study recognizes buildings with environmental adoptive patterns that have proven their worth and efficiency over the centuries in Iran. Five vernacular houses in the city of Tabriz, Iran are analyzed in regard to their typology and solar zoning strategies. In that way, the study aims at exploring the possible strategies for increasing the sustainable design strategies in contemporary houses of Iran. Moreover, this study takes into consideration that the design of houses cannot be divided from those who eat, sleep, cook, and play in them. In the vernacular, not only the awareness of the climatic and topological considerations is important, but also the values, rituals, and beliefs that shape the design of the dwellings need to be considered (Asquith & Vellinga, 2006). The present research aims to avoid a romanticized approach towards the studied vernacular houses. As, Vellinga (2015) suggests, many of the recent publications emphasize the "harmonious" ways in which vernacular traditions relate to their environmental contexts (P.6). But a romanticized approach to vernacular reveals the tendency to draw conclusions based on limited or partial evidence (Ibid).

While, this study is based on the hypothesis that vernacular buildings (courtyard houses) of Iran are environmentally sustainable structures; an important challenge is to avoid the technological bias and to consider the cultural, social, and economical sustainability and embodiment of the studied houses. Thus it is intended to address the potential shortcomings that limit the reliability of Iranian vernacular architecture at present in order to arrive at a more holistic understanding of the sustainability of the vernacular architecture in Iran.

2. Vernacular architecture

The interest in vernacular architecture started in the eighteenth century, though the first scholarly analyses of vernacular buildings started in the late nineteenth century (Upton, 1990; Oliver, 1997). However, many of these early studies were used to criticize contemporary architectural practices, rather than paying attention to the way in which the traditions might contribute to the future built environments. The main interest in studying vernacular architecture during the eighteenth and nineteenth centuries was to document and classify the historic and traditional forms and styles, most of them especially in the case of non-western traditions, were considered as destined to disappear. Many of these studies were conducted in Europe and the US by historians and architects who were influenced by the Arts and Crafts movement (Asquith & Vellinga, 2006). Consequently, Arthur Upham Pope[1] and Robert Hillenbrand[2] are among the Western experts and professors who have studied vernacular art and architecture in Iran.

Since the beginning of the twentieth century, the dominant paradigm in architecture has been Modernism (Özkan, 2006). Modernism over time has become diversified and has developed a plurality of its own, which can be categorized within seven groups. Conservatives as one of these groups developed into two fundamentally different sub-groups: classicists and traditionalists. While, classicists believe that whatever that was built in the past is good enough for the urbanized world to repeat in most loyal form, traditionalists such as Hassan Fathy are more geared to appropriate technologies and social concerns present in the traditional architecture (Ibid). The most influential reaction to Modernism in architecture is traditionalism, which focuses on research in vernacular architecture and the revitalization of traditional building practices. Later, in 1964 the Venice Charter was approved by International Council on Monuments and Sites (ICOMOS), which called for the international recognition of the value of vernacular architecture, stated that not only the great works of art but also the modest works of the past should be considered as historic monuments (Ikuga et al., 2012). ICOMOS created a special committee in 1976 to promote a coordinated international effort in order to identify, study, and protect vernacular architecture (Ibid).

2.1. Vernacular housing and sustainability

The scholarly effort in the sustainability of vernacular architecture remained marginal until the late 1990s, when sustainability emerged as a topic of political, academic, and popular interest (Vellinga, 2015). Most of the new studies on vernacular architecture endeavor actively to evaluate the properties of particular building types and investigate how the layout, form, and materials of the vernacular buildings relate to local climatic and geographical conditions. On the other hand, in learning from the vernacular buildings, the focus must not be just the buildings or the "physical shells", but the sustenance of vernacular knowledge, skills, and experiences (Asquith & Vellinga, 2006, p. 11). With a critical and forward-looking perspective towards vernacular architecture, it will be possible to cling to the vernacular and to claim that there still is a place for vernacular architecture in the twenty-first century.

In 1987, the World Commission on Environment and Development of the United Nations in its report "Our Common Future" also known as the Bruntland Report defines sustainable development as a development that "meets the needs and improves human conditions of this generation without compromising the ability of future generations to do the same" (World Commission on Environment and Development [WCED], 1987, P.8; Chiu, 2012, p. 91). Cities, where most of economic activities, employment, and educational activities take place are considered as the focal point. Likewise, the role of housing in the pursuit of sustainable development of the cities has been explored by governments, professionals, and academies since the early 1990s.

[1] Arthur Upham Pope (1881-1969) is best known as a pioneering American expert on Persian/Iranian art, architecture and archaeology.
[2] Professor Robert Hillenbrand is educated at the universities of Cambridge and Oxford (D.Phil. 1974). He has been teaching at the Department of Fine Art, University of Edinburgh focusing on (Persian/Iranian) Islamic art and architecture.

The International Encyclopedia of Housing and Home (2012) puts forward that sustainable housing development refers to a housing development that "meets the housing needs and improves the housing conditions of this generation without compromising the ability of future generation to do the same" (Smith, 2012, Vol. 7, p. 92). Accordingly, sustainable architecture needs to recognize the energy consumption and polluting side effects caused by buildings and the relationship that exists between the buildings and the behavior of their occupants (Ikuga et al., 2012). That is the only way not to compromise future generations' wealth in housing. Likewise, vernacular architecture is invaluable as a technical and conceptual source of sustainable architecture. Vernacular architecture in each instance around the world ensures the habitability of buildings and has provided functional strategies that are compatible with the locally available resources and functions of the buildings (Ibid).

3. Traditional built environment of Iran

The notion "traditional city" refers to the city before the modernization of Iranian society, which began after World War II (WWII) (Kheirabadi, 1991, p.6). However, traditional cities and houses still form the old parts of many contemporary Iranian cities and built environment, and planners can learn a great deal from a close observation of their forms and the logic behind them. The physical morphology of the traditional Iranian city is a cultural-historical response to the climatic condition of the country. Contrary to modern Iranian cities, which are copies of the contemporary European and American cities, the traditional Iranian city is compact with a high density of residential areas, which is homogeneous in its buildings. The compact traditional city has had the potential to minimize the climatic stress greatly and mitigate microclimatic conditions. Accordingly, traditional Iranian city minimized empty spaces, had buildings of uniform heights, contained narrow streets, provided covered bazars, and considered proper orientation to the wind and sun. In traditional Iranian cities, residential areas as the private sections were connected to the bazar as the public section of the city by small and narrow covered or uncovered alleys. The plan of Iranian traditional houses has been an open rectangular courtyard, with rooms around two or more sides. Traditional houses were designed to give a compact and organic appearance to the cities. Looking from the outside, they look similar having the same height and design; however, the Iranian traditional houses do vary in internal design strategies and architecture. Normally, size and internal decoration of these houses reveal the owner's taste and financial condition. Walls and roofs of an Iranian courtyard house are thick and the courtyard acts as a temperature moderator. The center of the courtyard normally has a pool of water and small gardens containing flowers, vegetables, and fruit trees surrounding the water. Courtyard houses existed in pre-Islamic Iran and also in non-Islamic regions of the world. Even though, the origin of courtyard housing is related to the necessity for defence and climatic considerations, because of its conformity with Islamic requirements, this typology remained as the dominant pattern for houses in many Muslim cities. Therefore, defense and climate should be considered as equal importance to religion or other social beliefs in the separation of physical spaces by walls and courtyards (Ibid).

One aspect of the courtyard house is that it has wings, which have different orientations allowing differentiation and segregation of functions that can be alternated in accordance to a daily or seasonal cycle (Samizay, 2012). In order to achieve comfort, life is circulated in an Iranian traditional courtyard house both vertically between levels and around the open yard on daily basis or between wings on seasonal basis. Thus, the cool north-facing wing of the house is used for the summer, while the warm south-facing wing of the house is used in the winter. North and south wings of the house provide the two crucial sets of "climate-conscious" rooms (Ibid, p.133). Traditional Iranian cities and houses have been built in such a way to harmonize the surrounding environment and to provide better living conditions for their inhabitants. Contrary to the tendencies of present planners, the traditional builders in the process of forming the physical urban and housing design have tried to work with and not against the forces of nature.

3.1. The city of Tabriz

Tabriz is the fourth largest city of Iran and the capital of the East Azerbaijan province, which is located in the northwestern part of the country (see table 1) (Fig. 1).

Table 1. General geographical information of Tabriz (Source: Iran Meteorological Organization, 2018; Encyclopedia Britannica, 2018)

Latitude	Longitude	Elevation	Current Population
38 5 N	46 17 E	1361.0 M	1.6 Million

Figure 1 Tabriz on Iran's map (Source: www. iranmap.com/)

Tabriz has a long history that dates back to 1,500 BC and contains many historical monuments, which represents the transition of Iranian architecture in its long historical timeline (Encyclopedia Britannica, 2018). The city of Tabriz has been destroyed severely by very strong earthquakes in the years 858, 1034, 1272, and 1780 (Omrani & Esmaili Sangari, 2006). Considering the disastrous earthquake of 1780, Tabriz has been probably rather a shabby town at the time when it was taken over by the Qajars[3] (Werner, 2000). However, soon after 1820s, Tabriz started to have a fast rise. Accordingly, Fraser and Southgate in their reports during 1820s and 1830s state that Tabriz is the most agreeable city in Persia (Ibid).

3.2. Climate

Tabriz is located in the cold and mountainous climatic region of Iran. Iran has several different climatic regions and climatic divisions of the country is based on climate classification of W. Köppen (Kasmaei, 2004). Cold climatic region of Iran is generally characterized by warm and dry summers and cold winters, where winters are harsh and snowy (Ibid). Based on Köppen's classification, Tabriz has a BSk climate type (Nasrollahi, 2009), which means a cold semi-arid climate. According to Meteorological Organization of Iran, the average air temperature of Tabriz differs from -2.4 to 25.6 °C from January to July and the average maximum temperature for these two months are 2.2 and 32.7 °C respectively and the average minimum temperature varies from -5.7 to 19.2 °C (Ibid).

3.3. Urban fabric

The traditional urban fabric and houses in Tabriz are mainly inwardly oriented and the buildings in the whole city make an inter-connected structure. Traditional Iranian cities are not simply "tangle of blocks badly ventilated by labyrinth of twisted alleys and dark courts", however, they have been planned to satisfy the cultural needs of their inhabitants and to deal with the pragmatic realities of the environmental conditions (Kheirabadi, 1991, pp. 87-8). One important reason behind the physical form of traditional Iranian cities and houses has been the strong desire for privacy and tranquility. However, the new Tabriz city of the twentieth and twenty-first centuries is the outgrowth of the central old town, which surrounds and spreads out from the traditional town nucleus. It contrasts sharply with the old town and it is sprawling and diffused over a large area, with wide avenues and Western-style houses and apartment complexes.

[3] Qajar Dynasty has been the ruling dynasty of Iran from 1794-1925.

3.4. Traditional courtyard houses

Paul Oliver (2006) writes in his book Built to Meet Needs that vernacular architecture is "the architectural language of the people with its regional and local dialects" (p.17). Courtyard houses in Tabriz have not been just an architectural type, but a way of life. The spatial and formal elements, which fell into an introverted blueprint, reflect the society of its times. This form of architecture met with the requirements of the traditional extended family system and the climate. The anonymous master builders were the architects of these courtyard houses. The architectural tenets were passed from one generation to the next and skills were developed by practical experience from a very young age. The site characteristics and owners' needs were considered and incorporated in the design and construction of these traditional houses. In the traditional part of Tabriz most of the buildings are connected to each other on three sides, with the fourth side facing the street, lane, or alley (Nasrollahi, 2009). The orientation of buildings varies from southwest facing to southeast facing and the most important parts of the buildings are located to the north of the site. Five traditional houses in Tabriz will be investigated in regard to their typology and potential passive solar gains in order to analyze their architectural functions according to climatic condition of the region. This approach is important, since it highlights the effective architectural factors in adapting housing to a given climate.

4. Typological analysis

Five traditional courtyard houses in the city of Tabriz are analyzed in regard to their typology variations. House No. 1 (Alavi House) belongs to the middle of Qajar Era (1794-1925), which is located in the historical urban fabric of Tabriz (Fig. 2). In this period the main spaces of the main structure are located on the northern side of the courtyard facing south for the climatic and sunlight reasons. In house No. 1, the eastern side of the building is also built up, which gives an L-shape to the house. In this house, the main spaces such as reception hall, pool room, side rooms, and ivan (veranda) are located along the main axis of the house.

Figure 2 Courtyard house No.1 (Source: Iran Cultural Heritage, Handicrafts and Tourism Organization)

House No.2 (Qadaki House) is located in the historical urban fabric of Tabriz, belongs to the middle Qajar period (1794-1925). The north section of the house has a reception hall with sash windows on the ground floor, which opens to the north and south parts of the building (Fig. 3). The eastern and western wings of the house have two floors, where the floor above contains the bedrooms and living rooms and the basement contains the kitchen and cistern. These wings have given a U-shape to the house number 2.

Figure 3 Courtyard house No.2 (Source: Iran Cultural Heritage, Handicrafts and Tourism Organization)

House No.3 (Sharbat-Oghli House) belongs to the end of the Qajar period (1794-1925), which is located in the old district of Tabriz. The northern part of house No. 3 is the main side of this house, while the west wings are ranked as second importance (Fig. 4). A two-storey construction is located on the western wing of the south courtyard that has given a T-shape to the house. There is also a private courtyard on the northern side and access is provided through a front door.

Figure 4 Courtyard house No. 3 (Source: Iran Cultural Heritage, Handicrafts and Tourism Organization)

House No.4 (Savojbolaghi House) is located in the historical urban fabric of Tabriz, belongs to the late Qajar period (1794-1925). In this period the northern part of the building, which faces south is still the main side (Fig. 5). In house No. 4, the western side of the building is also built up, which gives an L-shape to the house. In this house, the main parts of the house such as the reception hall, pool room, and veranda are still located in the line of the main axis, though the Iranian architecture was influenced by foreign elements in this period (Keynejad & Shirazi, 2011).

Figure 5 Courtyard house No.4 (Source: Iran Cultural Heritage, Handicrafts and Tourism Organization)

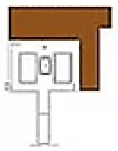
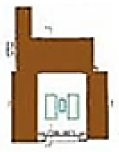
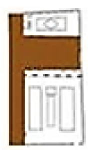
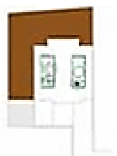
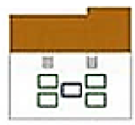
House No.5 (Parvin Etesami House) belongs to the early Pahlavi[4] period (1925-1941), which is located in old district of the city of Tabriz. In house No. 5 the northern section of the building, which faces south is dominant with no other constructed wings (Fig. 6). Therefore, the number of the constructed parts of a house is decreased considerably in this period given the house a line-shape.

Figure 6 Courtyard house No.5 (Source: Iran Cultural Heritage, Handicrafts and Tourism Organization)

[4] The Pahlavi period was the ruling time of Pahlavi dynasty of the imperial state of Iran from 1925 until 1979.

The traditional urban courtyard houses of Tabriz have contributed to the zoning and land pressure requirements of the city. In courtyard dwellings of Tabriz, the courtyard is like a protected garden, an open reception space, a connector between the rooms surrounding it, and a service space where cooking and washing took place. The differences in scales of the courtyards demonstrate the flexibility of the forms, which are surrounded by built space. Not all courtyards are identically enclosed on different sides. Illustrated through Table 2, the typology variation and analyses of these five traditional courtyard houses have been presented.

Table 2. Comparison between 5 traditional courtyard houses of the city of Tabriz and their typology transformation over time (Lcy: Courtyard Length, Wcy: Courtyard width) (Source: Author)

	House 1	House 2	House 3	House 4	House 5
	L-shape (type 1)	U-shape	T-shape	L-shape (type 2)	Line-shape
					
	ca. 1859	ca. 1859	ca. 1890	ca. 1900	ca. 1930
Orientation	South	South	South	South	South
Courtyard	Public	Private	Public & Private	Public	Public
Courtyard shape	Rectangular	Rectangular	Rectangular	Rectangular	Rectangular
Lcy/Wcy (unit.m)	1.92	1.24	2.25 1.36	1.1	1.30
Reception hall	Ground floor, central	Ground floor, central	First floor, central	Ground floor, central	Ground floor, central
Veranda	Overall in southern facade	Overall in southern facade	Overall in southern facade	Overall in southern facade	No
Sash windows	Yes. in south facade	Yes. in north & south facades	No	Yes. in south facade	No
Staircase	hidden	hidden	central	Foreign architectural influence	Foreign architectural influence
Side rooms	Yes	Yes	No	No	No
Pool house	Yes	Yes	-	Yes	No
Ornamentation	Iranian tile & plaster work	Iranian tile & plaster work	Iranian tile & plaster work	Iranian tile & plaster work. Foreign influence decorative pediment	Iranian tile work

Considering the typology analysis highlighted in table 2, all houses face the south with the major reception hall located on the southern side of the building. However, only in house No. 3 this reception hall is located on the first floor, while in other 4 houses this reception space is located on the ground floor of the house. The U-shaped house and the T-shaped house are introverted with the private courtyards, while L-shaped houses and the line-shaped house are semi introverted with public courts. The overall veranda is present in all four houses of Qajar era, while in early Pahlavi era the overall veranda disappears and southern façade is much more dominant. The secondary wings of the house disappear in the early Pahlavi period. Side rooms also disappear towards the early Pahlavi period. In earlier constructed houses of Qajar period, pool houses[5] are one of the most important spaces in the range of main axis on the northern part of the house. However, in later houses and towards the early Pahlavi period, the pool house is completely missing. While earlier Qajar houses have hidden staircases, towards the early Pahlavi period the staircases gain importance in houses (No.3-5) and get influenced by foreign architecture. Moreover, the Iranian ornamentation, plaster, and tile works of the Qajar houses get influences of foreign architecture to the end of this period and in early Pahlavi period the ornamentation is simpler.

5. Potential solar radiation gains analysis

The solar zoning of these five traditional courtyard houses in the city of Tabriz have been done. The analysis procedure does not consider the effect of neighboring houses on the studied houses. Solar zoning in courtyard housing determines “a house layout so that rooms looking into middle court and surrounding spaces are cool in summer and warm in winter” (Land, 2006, p.234). The cold semi-arid climate in the region of Tabriz is characterized by cold & humid with occasional frost periods in winters and warm & dry summer periods; with extreme temperatures of more than 33° C during the day in summer. Therefore, during winter period, living is organized on the north side of the house thus receiving full solar exposure for warming (in northern hemisphere). On the other hand, during summer period living functions need to be organized on the sides of the house, which avoid the high temperature summer sun. Therefore, the studied courtyard houses have to benefit from the living on different wings of the court in accordance to season in order to receive the sun or to exclude it. Accordingly, this design strategy contributes to being warmed by passive solar radiation in winter and avoids excessive summer heat.

The software program Ecotect (Version 11) is used in this study to evaluate the impact of multi parameters on the direct solar gain of the selected courtyard buildings. Ecotect is an environmental analysis tool that allows designers to simulate building performance. Ecotect couples an intuitive 3-D design interface with a comprehensive set of performance analysis functions and interactive information displays (Marsh, 2003). The software has the capacity to generate the most complex building geometry and also offers different visualization facilities such as the sun path diagrams, shadow information, and potential solar gains of the structure in real time (Ibid). Furthermore, software called Origin (version 2015) is used for data analysis and graphing. This software is produced by OriginLab Corporation and runs on Microsoft Windows. It supports 2D/3D plot types and is validated by academic and industrial works worldwide (Originlab, 2017).

Fig. 7 illustrates the geometry of the L-shaped courtyard house No.1, which shows its design strategies about its location, orientation and its relationship to the courtyard. The rotation degree for this house is 29° from north offset. The daily sun path and shadows for the house in the month of January and July (day 15) have been simulated by the software Ecotect (Figs. 8 & 9).

[5] Pool house was a covered area with a basin in middle.

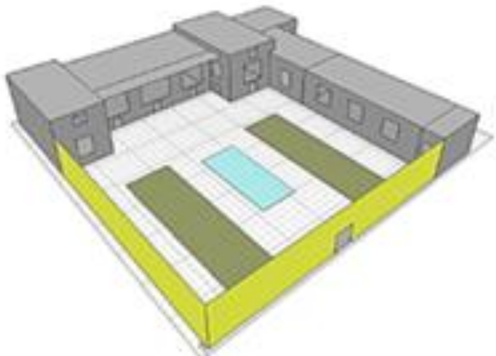


Figure 7 Geometry of house No. 1 (Images 9-23 from the analyses done in software Ecotect) (Source: Author)

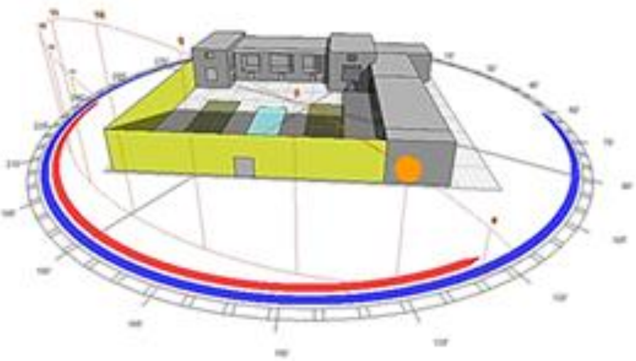


Figure 8 3D view of house No. 1 (7:00 am, January)

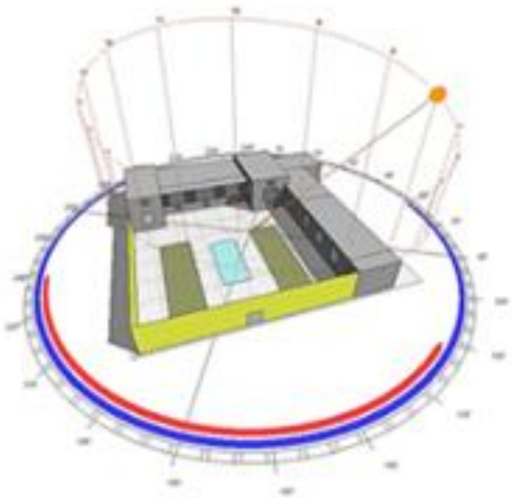


Figure 9 3D view of house No. 1 (7:00 am, July)

Figs. 10 & 11 illustrate the geometry of the U-shaped courtyard house No.2, which shows its design strategies about its location, orientation and its relationship to the courtyard. The rotation degree for this house is 8° from north offset.

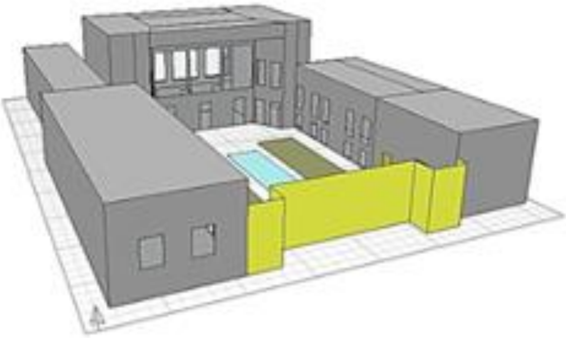


Figure 10 Geometry of house No. 2; south facing façade

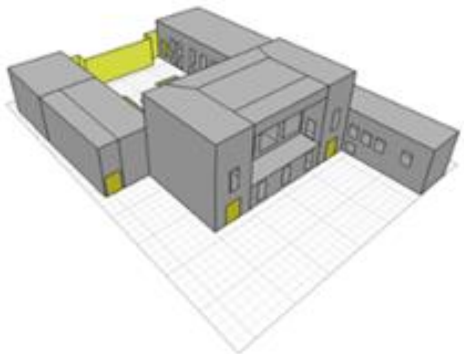


Figure 11 Geometry of house No. 2; north facing façade

Figs. 12 & 13 show the daily sun path and shadows for the house in the month of January and July (day 15), respectively. In month January, the south facing reception hall of the house as the main space of the house receives direct passive solar sun radiation from 8:00 am to 14:30 pm completely. However, in month July the reception hall does not receive direct solar radiation throughout the day.

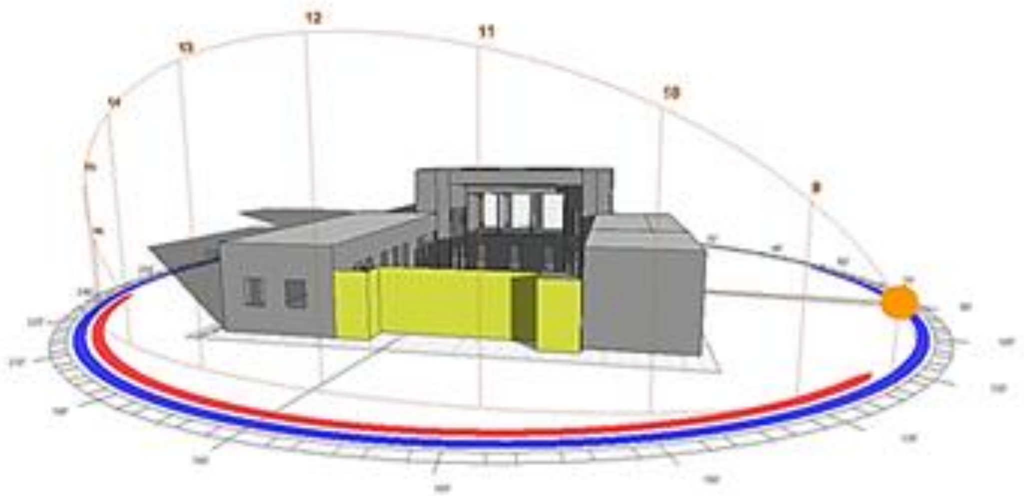


Figure 12 3D view of house No.2 (8:00 am, January)

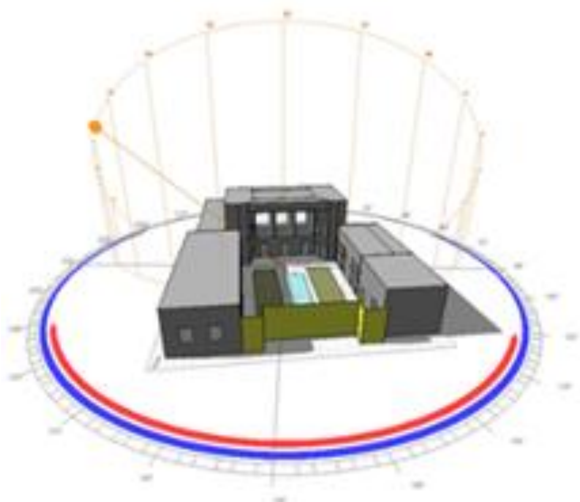


Figure 13 3D view of house No. 2 (16:00 pm, July)

Fig. 14 illustrates the geometry of the T-shaped courtyard house No.3, which shows its design strategies about its location, orientation and its relationship to the courtyard. The rotation degree for this house is 30° from north offset. Figs. 15 & 16 show the daily sun path and shadows for the house in the months of January and July (day 15), respectively.

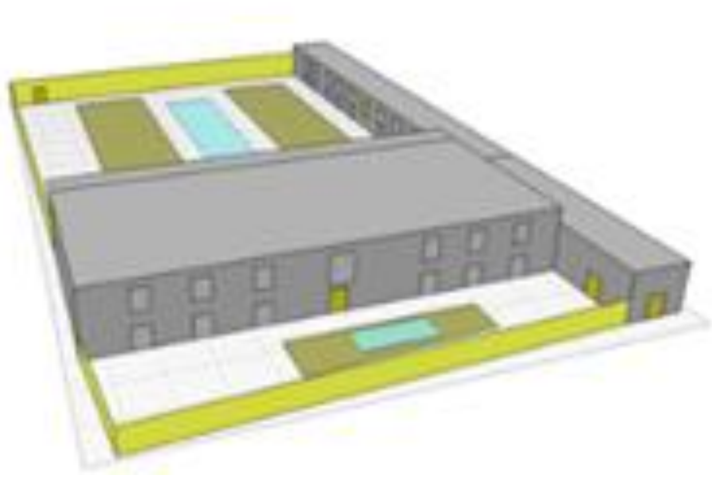


Figure 14 Geometry of house No. 3; north facing façade

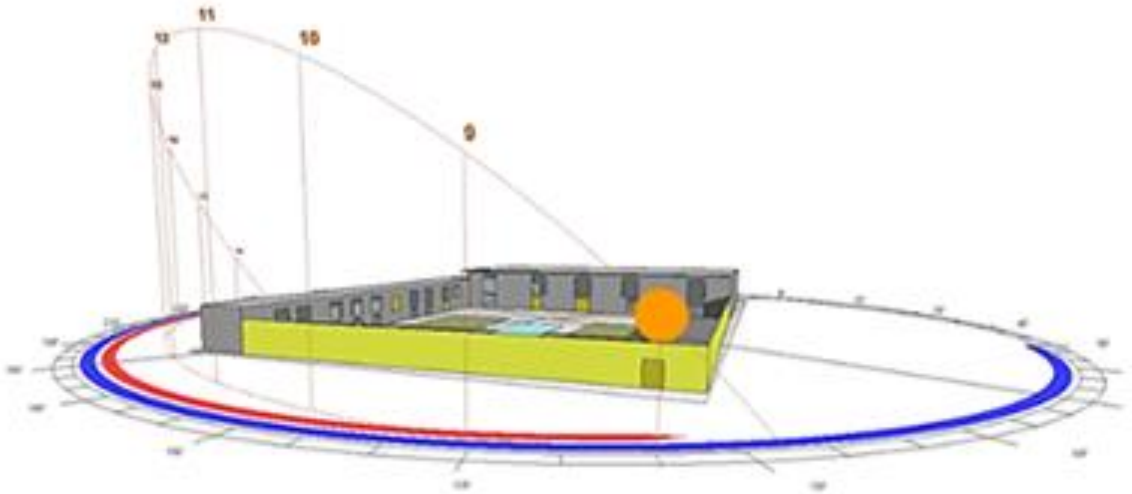


Figure 15 3D view of house No.3 (January, 8:00 am)

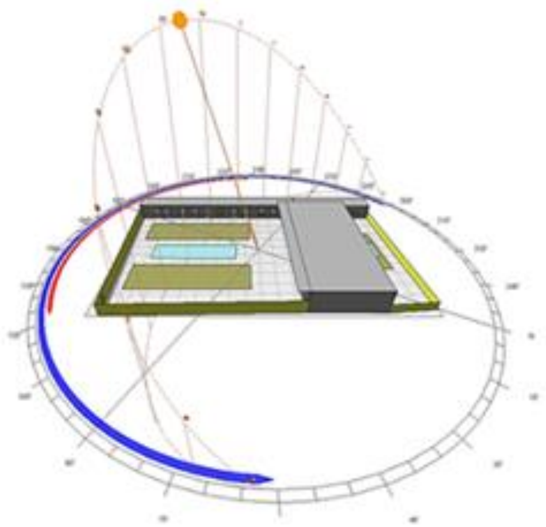


Figure 16 3D view of west wing of house No.3 in shadow (July, 11:30 am)

Fig. 17 illustrates the geometry of the L-shaped courtyard house No.4, which shows its design strategies about its location, orientation and its relationship to the courtyard. The rotation degree for this house is 15° from north offset. Figs. 18 & 19 show the daily sun path and shadows for the house in the month of January and July (day 15), respectively.

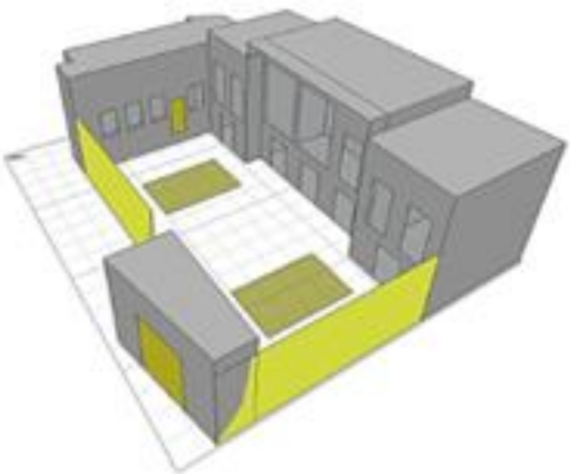


Figure 17 Geometry of house No. 4; south facing façade

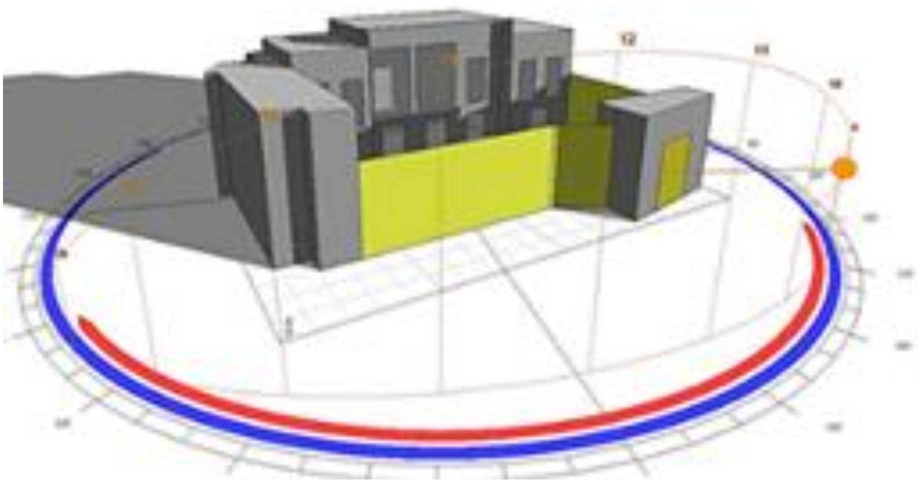


Figure 18 3D view of house No.4 (January, 8:00 am)

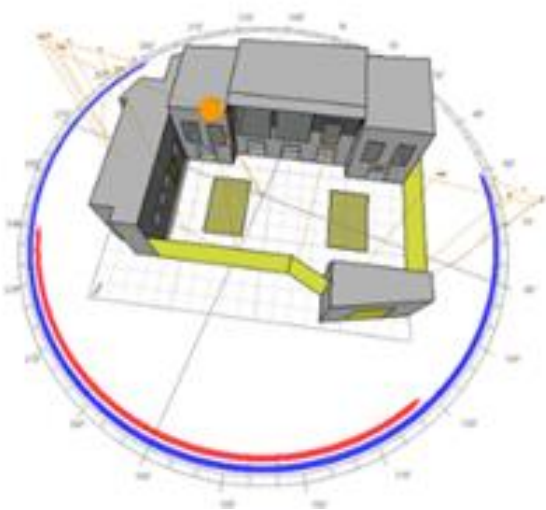


Figure 19 3D view of west wing of house No. 4, (July, 12:00 pm)

Fig. 20 illustrates the geometry of the Line-shaped courtyard house No.5, which shows its design strategies about its location, orientation and its relationship to the courtyard. The rotation degree for this house is 10° from north offset. Figs. 21 & 22 show the daily sun path and shadows for the house in the month of January and July (day 15), respectively.

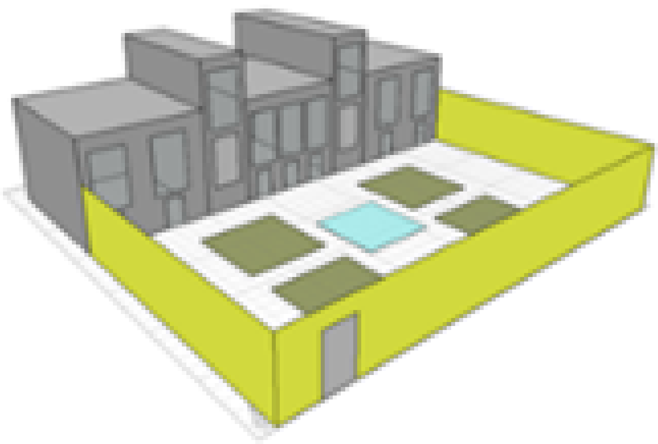


Figure 20 Geometry of house No. 5; south facing façade

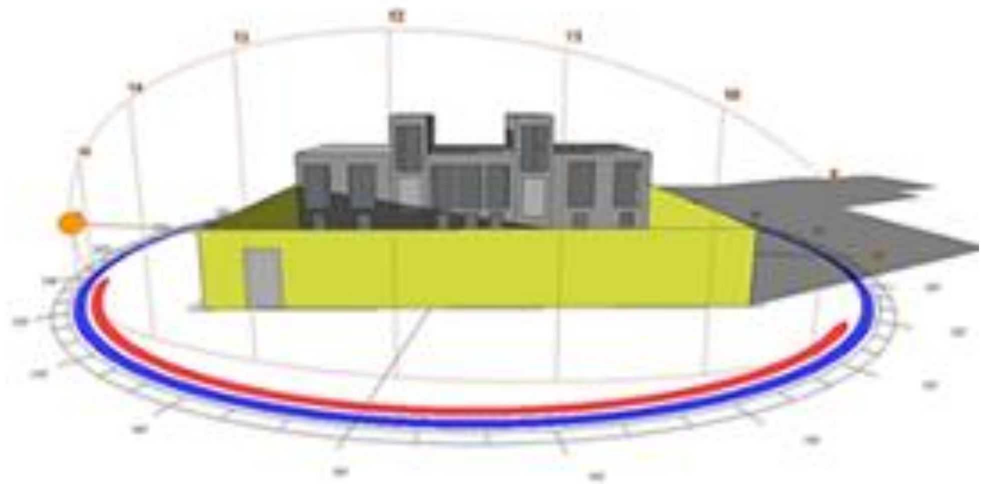


Figure 21 3D view of house No.5 (January, 16:00 pm)

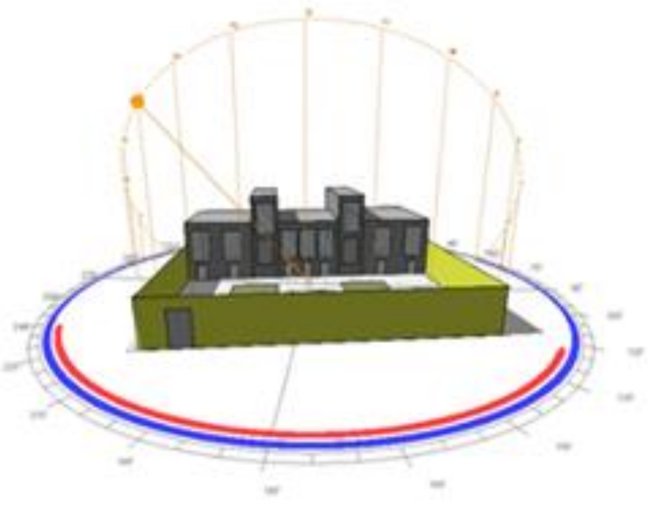


Figure 22 3D view of house No.5 (July, 16:00 pm)

Considering the data from solar analysis, house No.1 gets 4 ½ hours of desirable direct solar radiation in month January for its main living space and 4 ½ hours of desirable direct solar radiation in month January for its secondary living space in the east wing (tables 3 & 4). The main living space of house No.1 does not receive the direct unfavorable solar radiation in July due to roofed veranda in front of it and its climatological orientation. However, the east wing of the house gets 9 hours of unfavorable direct solar radiation in month of July. House No.2 gets 6 ½ hours of desirable direct solar radiation in month January for its main living space and 2 & 3 hours of desirable direct solar radiation in month January for its secondary living space in the west and east wings respectively (tables 3 & 4). The main living space of house No.2 does not receive the direct unfavorable solar radiation in July due to roofed veranda in front of it and its climatological orientation. However, the west and east wings of the house get 4 and 4 ½ hours of unfavorable direct solar radiation in month of July.

Table 3 Hours of direct solar radiation for houses No.1-5 regarding the main living space (Source: Author)

	House No.1 L-shape (type 1) Reception hall	**House No.2 U-shape Reception hall**	**House No.3 T-shape Reception hall**	**House No.4 L-shape (type 2) Reception hall**	**House No.5 Line-shape Reception hall**
Rotation degree	29°	8°	30°	15°	10°
Direct passive solar gain (January)	7:00-11:30 4 ½	8:00-14:30 6 ½	8:00-13:00 5	8:00-14:00 6	8:00-16:00 8
Direct passive solar gain (July)	-	-	-	9:00-12:00 3	8:00-15:30 7 ½

Table 4 Hours of direct solar radiation for houses No.1-5 regarding the secondary living space (Source: Author)

	House No.1 L-shape (type 1) West wing East wing	**House No.2 U-shape West wing East wing**	**House No.3 T-shape West wing East wing**	**House No.4 L-shape (type 2) West wing East wing**	**House No.5 Line-shape - -**
direct passive solar gain (January)	- 10:30-13:30 4 ½	9:30-11:30 2 12:00-15:00 3	8:00-10:00 2 -	8:30-11:00 2 ½ -	-
direct passive solar gain (July)	- 9:30-18:30 9	8:00-12:00 4 12:00-16:30 4 1/2	6:00-11:00 5 -	7:00-11:30 4 ½ -	-

House No. 3 gets 5 hours of desirable direct solar radiation in month January for its main living space and 2 hours of desirable direct solar radiation in month January for its secondary living space in the east wing (tables 3 & 4). The main living space of house No.3 does not receive the direct unfavorable solar radiation in July due to roofed veranda in front of it and its climatological orientation. However, the east wing of house gets 5 hours of unfavorable direct solar radiation in month of July.

House No.4 gets 6 hours of desirable direct solar radiation in month January for its main living space and 2 ½ hours of desirable direct solar radiation in month January for its secondary living space in the west wing (tables 3 & 4).

However, the main living space of house No.4 gets 3 hours of direct unfavorable solar radiation in July and also the west wing of the house gets 4 ½ hours of unfavorable solar radiation in July. House No. 4 has a roof veranda in front of its main space; however the courtyard has smaller dimensions in comparison to other studied houses. Because of the sun's diminished angle in the sky during the winter months, an undersized court for a two-storey structure, which encloses the court makes this outdoor space undesirable and results in darkness of the structure.

Finally, house No. 5 gets 8 hours of desirable direct solar radiation in month January for its main living space in January, while this space gets 7 ½ of unfavorable direct solar radiation in month July (tables 3 & 4). This house does not have any other wings.

Diagram 1 illustrates the comparison of the duration of direct solar gain in month January for houses No.1-5, while diagram 2 shows the comparison of the duration of direct solar gain in month July for houses No.1-5. Considering the duration of hours for favorable direct solar gains in month January, houses No. 2, 1, & 4 demonstrate a good performance (11 ½ hours, 9 hours, and 7 hours respectively distributed between wings). However, they demonstrate 8 ½, 9 hours, and 7 ½ hours of unfavorable direct solar gains in month July respectively.

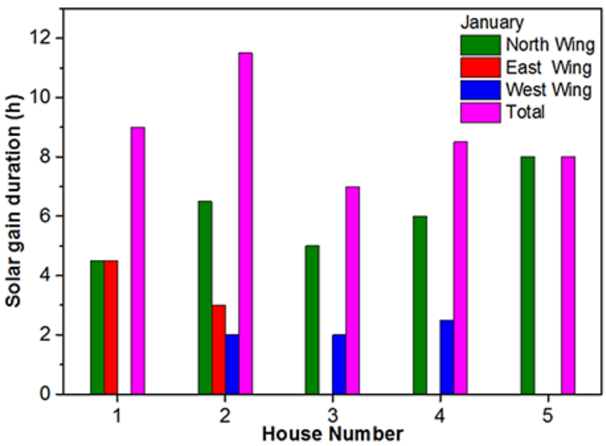


Diagram 1 Comparison of duration of direct solar gain for 5 studied houses in month January (done in software Origin) (Source: Author)

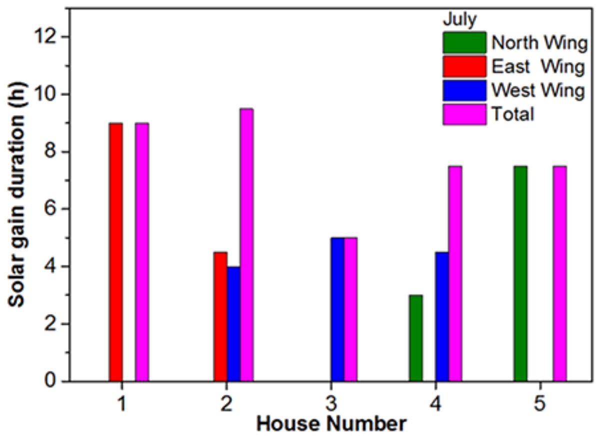
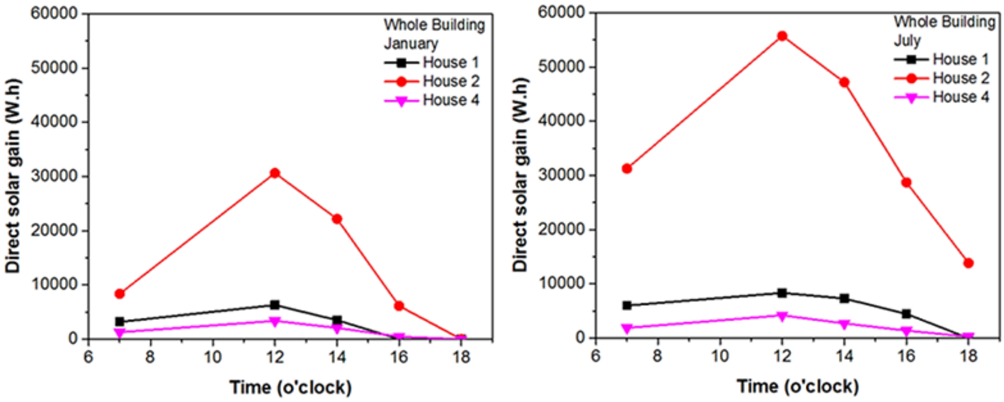


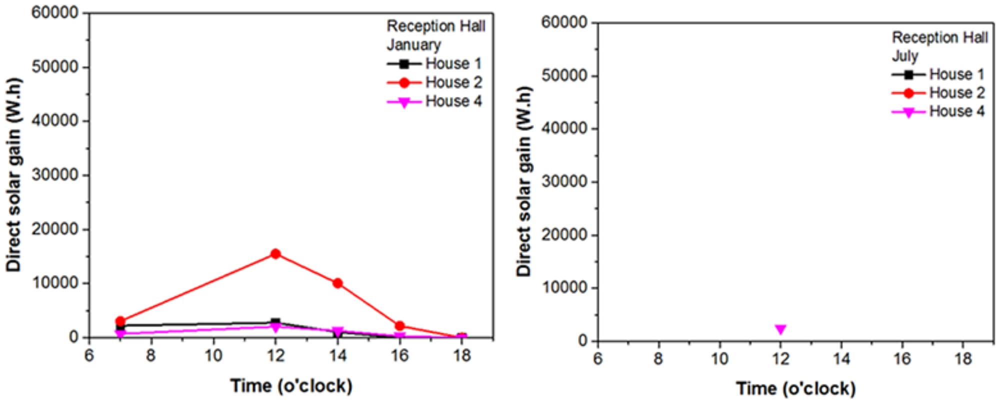
Diagram 2 Comparison of duration of direct solar gain for 5 studied houses in month July (done in software Origin) (Source: Author)

On the other hand, the reception hall of houses 1 & 2 does not get any unfavorable direct hot solar radiation in month of July. The reason is that the angle of the sun's rays during the summer is high and the narrow roofed verandas of houses No.1 & 2 prevent the heat rays of the sun from reaching the main living spaces. Considering house No.5 the reception hall of this house gets 8 hours of favorable direct solar gain in January, while this living space is overheated during month of July since it receives unfavorable direct solar gains for 7 ½ hours daily. Considering the analysis in this part houses No. 3 & 5 are omitted from analysis since they demonstrate a poor seasonal performance in regard to favorable and unfavorable direct solar gains.

The aforementioned analysis has to be coupled with the data analysis from the amount of direct solar radiation for houses No.1, 2, and 4 in months January and July. Diagrams 3 & 4 illustrate the comparison of amount of direct solar gain in months January and July for the whole building for aforementioned studied houses. Accordingly Houses No. 2, 1, and 4 have better performance for the month of January, respectively. This data need to be limited to the direct solar gain of the houses for the reception hall, which is the main living space of the house (Diagrams 5 & 6). Diagrams 5 & 6 illustrate the comparison between the houses 1, 2 & 4 in regard to their direct solar gain for reception hall space in months January and July. Accordingly, houses No. 2 & 1 respectively have better performance in month January and also they do not demonstrate any unfavorable solar gain for month of July (see Appendix A regarding the information and tables).



Diagrams 3 & 4 Comparison of direct solar gain for houses 1, 2 & 4 for the whole building in January and July (done in software Origin) (Source: Author)



Diagrams 5 & 6 Comparison of direct solar gain for houses 1, 2 & 4 for the reception hall in January and July (done in software Origin) (Source: Author)

Still, this data have to be coupled with the data obtained from typology analysis in section 4 of the study and secondary data obtained from previous research in the field. The typology analysis of studied houses revealed that courtyard houses of cold climate region of Iran have south-facing winter rooms, which are located on the north side of the courtyard. These rooms are called “aftab-ru (facing sun) or aftab-gir (sun catcher) in Persian” (Foruzanmehr, 2016, p.4). However, the courtyard houses of cold climatic region of Iran do not contain any north-facing summer rooms and hence south-facing winter rooms are used as living space during summer, as well. The potential solar gain analysis revealed that south-facing rooms of houses No. 1 & 2 are not exposed directly to sun compared to other studied houses in month July. On the other hand, the west-facing façade of house No.1 faces the sun’s rays from sunrise to evening in month July, which consequently causes this east wing of the house overheated and not thermally comfortable for bedrooms. According to Foruzanmehr (2016), “a room with a façade opening to the west is generally the worst case encountered, owing to the heat gain of the surrounding environment during the day and the angle of the sun’s altitude, which allows the sun’s rays to penetrate into the interior” (P.4). Furthermore, the east-facing façade of house No.2 faces sun’s rays from sunrise to moon in month July; hence, it cools down considerably by the evening, making this exposure more suitable for bedrooms. Therefore house No.2 shows proper solar performance for south facing and east facing facades during months of January and July.

6. Conclusion

As the first step, the typological analyses of studied houses are carried out in order to introduce and discuss the transformation of studied cases over the given time period. Secondly, the computer simulation analyses are done for duration and potential direct solar gains of studied houses. The results of this study can help designers in making decisions regarding the orientation, form, and applicability of courtyard housing in BSk climate of Iran. The courtyard house No. 2 (U-shaped) has the best passive solar performance during the months of January and July. It was found out that the south-facing reception hall of house No. 2 as the main living space of the house receives 6 ½ hours of direct solar radiation from sunrise till afternoon in month January. Moreover, considering the thermal mass of thick walls of the structure, the sun heat is stored in thick mud brick walls and earthen floors and then is released within 7-9 hours to keep the inhabitants warm when the sun moves on (meaning after 14:30 pm). During the hot summer months, when heat and excessive light are not desirable, the south facing façade of the house also does not work against our desire. Since the angle of the sun's rays during the summer is high, a narrow eave (in this case the roofed veranda) will prevent the heat rays of the sun from reaching the main living space. Thus, the south-facing section of the house can be called the main solar-conscious living space of house No.2. Furthermore, it was shown that the east-facing façade of house No.2 faces sun's rays from sunrise to moon in month July. Therefore, it cools down considerably by the evening, making this exposure more suitable for bedrooms. As a result, the east-facing wing of the house can be considered as the secondary solar-conscious living space of house No.2. However, the study revealed that the west-facing façade of house No.2 and other studied house (house No.1), are generally the worst cases encountered, owing to the heat gain of the surrounding environment during the day and the angle of the sun's altitude, which allows the sun's rays to penetrate into the interior in month of July.

In Iran, the courtyard house has evolved from the "geographic, topographic, and climatic conditions" of different regions of the country and the "overall arrangement of the interior of such a house was based on kin relations" (Karimi, 2012, p.124). Not only were most traditional houses built according to climatic and geographical features, they were also "self-sufficient micro-communities that raised vegetables and livestock" (Ibid, p.341). But when new products became available in the Iranian market, the "economic self-sufficiency of the traditional Iranian house eroded", and the household turned into a consumer spending habit (Ibid, p.341). Thus, the spatial arrangement of the traditional courtyard house was in harmony with the rituals and living activities of that time. Moreover, women were much more limited to the house and its tasks during the time that courtyard housing was dominant in Iran and women working outside the house were discouraged. However, during the first Pahlavi period (1925-1941) Iran undergoes major infrastructural reforms that affect the look of Iranian cities and residential neighborhoods. The hygiene and domestic improvements in housing have been the focus of such a reform. The real everyday life in Iran from the early 1950s to the late 1970s demonstrates that "there was neither total conformity to Western life styles and commodities nor a steadfast embrace of traditional values" (Ibid, p. 134). In spite of the fact that by the 1960s Iran was moving away from traditional construction methods and traditional lifestyle, there have been some architects who tried to link traditional Iranian architecture with modern technologies and accommodate the unique environmental characteristics of Iranian regions at the same time (Karimi, 2014). Parallel to the rise of the Post-Modern movement in the West that allowed past architectural motifs, there have been a return to traditional Iranian building methods "not only [as] a reaction to the rigidity of the imported Western Modernist styles, but also [as] a timely response to a popular global trend" (Ibid, p.341).

The lessons that can be learned from the studied courtyard houses of Tabriz emphasize not only the optimal orientation and form to use passive solar energy effectively, efficient multi-functional design strategies such as the roofed veranda to create desirable environmental and space solutions, but also emphasizes the adaptation to contemporary Iranian lifestyle. The present-day courtyard house has to be built for a smaller family with a different lifestyle, while, combining the benefits of solar-conscious living spaces and courtyard with the contemporary apartment lifestyle as much as possible.

Appendix A.

Considering the direct solar gains for house No.1, in month January at 7:00 am, 12:00 pm, 14:00 pm, 16:00 pm, and 18:00 pm, it is 3188, 6299, 3507, 0, and 0 W.h respectively for the whole building, while this amount in month July at 7:00 am, 12:00 pm, 14:00 pm, and 16:00 pm increases to 6008, 8330, 7301, 4470 W.h for the whole building (0 W.h at 18:00 pm) (Table 5). Focusing on the reception hall of the house, the direct solar gain of this space in month January at 7:00 am, 12:00 pm, 14:00 pm, 16 pm, and 18: pm is 2229, 2768, 1044, 0, and 0 W.h (Table 5).

Table 5 Direct solar gain of house No.1 (unit: W.h) (Data done in Ecotect, Source: Author)

House No. 1	**7:00 am** **January** **July**	**12:00 pm** **January** **July**	**14:00 pm** **January** **July**	**16:00 pm** **January** **July**	**18:00 pm** **January** **July**
Direct solar gain (whole building)	3188 6008	6299 8330	3507 7301	0 4470	0 0
Direct solar gain (reception hall)	2229 -	2768 -	1044 -	0 -	0 -

Considering the direct solar gains for house No.2, in month January at 7:00 am, 12:00 pm, 14:00 pm, 16:00 pm, and 18:00 pm, it is 8371, 30621, 22171, 6130, and 0 W.h respectively for the whole building, while this amount in month July for the whole building at 7:00 am, 12:00 pm, 14:00 pm, and 16:00 pm increases to 31261, 55715, 47188, 28707, and 13859 W.h (Table 6). Focusing on the reception hall of the house No.2, the direct solar gain of this space in month January at 7:00 am, 12:00 pm, 14:00 pm, 16 pm, and 18: pm is 3056, 15504, 10072, 2177, and 0 W.h (Table 6).

Table 6 Direct solar gain of house No.2 (unit: W.h) (Data done in Ecotect, Source: Author)

House No. 2	**7:00 am** **January** **July**	**12:00 pm** **January** **July**	**14:00 pm** **January** **July**	**16:00 pm** **January** **July**	**18:00 pm** **January** **July**
Direct solar gain (whole building)	8371 31261	30621 55715	22171 47188	6130 28707	0 13859
Direct solar gain (reception hall)	3056 -	15504 -	10072 -	2177 -	0 -

Considering the direct solar gains for house No.3, in month January at 7:00 am, 12:00 pm, 14:00 pm, 16:00 pm, and 18:00 pm, it is 5406, 13384, 7963, 1108, and 0 W.h respectively for the whole building, while this amount in month July for the whole building at 7:00 am, 12:00 pm, 14:00 pm, 16:00 pm, and 18:00 pm increases to 16959, 22818, 16910, 11182, and 5612 W.h (Table 7). Focusing on the reception hall of the house No.3, the direct solar gain of this space in month January at 7:00 am, 12:00 pm, 14:00 pm, 16 pm, and 18: pm is 3577, 10635, 6163, 827, and 0 (Table 7).

Table 7 Direct solar gain of house No.3 (unit: W.h) (Data done in Ecotect, Source: Author)

House No. 3	**7:00 am** **January** **July**	**12:00 pm** **January** **July**	**14:00 pm** **January** **July**	**16:00 pm** **January** **July**	**18:00 pm** **January** **July**
Direct solar gain (whole building)	5406 16959	13384 22818	7963 16910	1108 11182	0 5612
Direct solar gain (reception hall)	3577 -	10635 -	6163 -	827 -	0 -

Considering the direct solar gains for house No.4, in month January at 7:00 am, 12:00 pm, 14:00 pm, 16:00 pm, and 18:00 pm, it is 1286, 3374, 2090, 469, and 0 W.h respectively for the whole building, while this amount in month July for the whole building at 7:00 am, 12:00 pm, 14:00 pm, and 16:00 pm increases to 1884, 4210, 2717, 1387, and 279 W.h (Table 8). Focusing on the reception hall of the house No.4, the direct solar gain of this space in month January at 7:00 am, 12:00 pm, 14:00 pm, 16 pm, and 18: pm is 712, 2055, 1267, 287, and 0 (Table 19). Moreover, reception hall of house No. 4 has direct solar gains from 9:00 am to 12:00 pm in month of July at 9:00 am and12:00 pm as 2035 and 2479 W.h (Table 8).

Table 8 Direct solar gain of house No.4 (unit: W.h) (Data done in Ecotect, Source: Author)

House No. 4	**7:00 am** **January** **July**	**12:00 pm** **January** **July**	**14:00 pm** **January** **July**	**16:00 pm** **January** **July**	**18:00 pm** **January** **July**
Direct solar gain (whole building)	1286 1884	3374 4210	2090 2717	469 1387	0 279
Direct solar gain (reception hall)	712 -	2055 2479	1267 -	287 -	0 -

Considering the direct solar gains for house No.5, in month January at 7:00 am, 12:00 pm, 14:00 pm, 16:00 pm, and 18:00 pm, it is 3406, 10094, 6197, 1315, and 0 W.h respectively for the whole building, while this amount in month July for the whole building at 7:00 am, 12:00 pm, 14:00 pm, and 16:00 pm increases to 4780, 12983, 8360, 4295, and 866 W.h (Table 9). Focusing on the reception hall of the house No.5, the direct solar gain of this space in month January at 7:00 am, 12:00 pm, 14:00 pm, 16 pm, and 18: pm is 776, 3555, 2418, 698, and 0 W.h (Table 20). Moreover, reception hall of house No. 5 has direct solar gains from 8:00 am to 15:50 pm in month of July at 7:00 am, 12:00 pm, 14:00 pm, and 16 pm as 1433, 4560, 3367, and 1497 W.h (Table 9).

Table 9 Direct solar gain of house No.5 (unit: W.h) (Data done in Ecotect, Source: Author)

House No. 5	**7:00 am** **January** **July**	**12:00 pm** **January** **July**	**14:00 pm** **January** **July**	**16:00 pm** **January** **July**	**18:00 pm** **January** **July**
Direct solar gain (whole building)	3406 4780	10094 12983	6197 8360	1315 4295	0 866
Direct solar gain (reception hall)	776 1433	3555 4560	2418 3367	698 1497	0 0

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