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Application of Thermal Comfort Indicators in Climate Design (Case Study: Yazd Township)

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Research Article

Abstract

Climatic and weather conditions have a significant impact on creating a sense of comfort in any architectural space. Therefore, it is essential to know the climatic conditions of each region and the associated measures. In fact, creating thermal comfort for people and providing them with the means of comfort for a better life space in terms of climatic conditions are the bases of the formation of urban and rural residential. Climatic architectural design is possible given the climatic data and thermal needs of the space to be built. The purpose of this study is to identify and investigate the weather conditions of Yazd Township, Iran. To do so, climate type of Yazd province was initially validated and then the range of thermal comfort was measured through different methods followed with the presentation of architectural solutions in accordance with the climate of this city. The present study is descriptive-analytical in terms of methodology and an applied study in terms of the approach. For this purpose, first by visiting the Meteorological Research Center, Meteorological Organization of Yazd Province, the meteorological data of 23 years (1996-2019) of this city was obtained, then using the climatic classification methods (Koppen, Emberger and DeMarton), the type of climate was identified. Next, by determining the thermal comfort indicators of the building and with the help of Olgyay, Mahani and Givoni bioclimatic charts, the intensity and extent of the drought period and the limits of thermal comfort

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were calculated. Finally, recommendations are presented for designing residential spaces in accordance with the climate.

Keywords: Givoni; Mahani; Olgyay; Yazd; Thermal; Climate

1. Introduction

The term ‘climate’ comes from the Greek word ‘klima’ which means bending and curvature and literally means the inclination and deviation of an area of the earth toward the sun. Climatology is equivalent to meteorology (Beer and Higgins, 2004). Architecture and climate are two human-made and natural systems with close correlations with each other, so that it is unavoidable to investigate how climate elements affect architecture. In geography, the two concepts of meteorology and climatology are scientifically distinguished. Meteorology is the daily changes of atmospheric factors which are usually announced by the meteorological organization daily in the public media and are used in areas such as agriculture, aviation, shipping and people's daily affairs. But climatology is the general process of weather conditions of a region in long periods and its application is mostly in fields such as urban planning, architectural design and landscape design (Tahbaz, 2013). Climate is studied as one of the most important factors in the construction of buildings. Considering the geographical conditions of the region and the variety of weather conditions in different seasons of the year, building design, both residential and administrative, is required to have a comfortable climate in order to save energy. In the past, the architecture and urban planning of cities were significantly influenced by climatic factors, so that special attention was paid in the design of buildings.

Nowadays, in most of the urban planning, considering the climate and geographical investigations is the basis of the work. Knowledge of the climate is the most necessary step in examining various human activities. It is necessary to know the climate correctly and create a proper adaptation to it. Since people spend a lot of time at home, it is necessary to ensure its comfort. One of the most important factors that affect the construction of human housing is climate and weather characteristics. Design compatible with the climate means maintaining the microclimate of the house within the comfort range, regardless of the situation outside the building. The comfort range is the situation in which almost 80% of people feel comfortable. Based on this, the six main factors of comfort include temperature, humidity, radiation, air flow, coverage and activity level. undoubtedly, other factors such as age, gender, body shape, health status, diet, clothing color, and adaptation to the environment's climate also affect the level of comfort (Consulting Engineers, 2007).

Each climatic region has an architectural typology appropriate to its corresponding climate (Memamarian, 1996). The significance of the role of climate in structural design is obvious; hence, it is necessary to pay comprehensive attention to the role of climate in architecture.

2. Significance of the Study

Since one of the main concerns of the modern world is saving non-renewable energy sources, the use of natural energies not only will make the living space comfortable, but also will play a significant role in reducing energy consumption (Tavousi, 2011). As a result, it is necessary to consider the climate of different regions in designing buildings. Architectural design without taking into account the climatic factors of the region will be an incomplete and costly practice; hence, the study and consideration of climatic factors is a must do in the design of urban spaces and the associated components including buildings, streets, etc. (Givoni, 1997).

Harmonizing the building and human residential environment with climatic conditions and factors is very important due to the high costs of energy. Climate and architecture is one of the new sciences, which aims to exploit natural gifts and save energy through reducing the consumption of non-renewable energies, including oil and gas, and creating conditions of well-being and comfort for individuals in buildings and housing. Through the studies of various climatic factors and elements, man can design residential spaces and buildings in such a way that provides the most comfort and well-being for him. This shows the interaction between humans, climate and buildings (Givoni, 1997). The present study seeks to find a way to save energy consumption while creating comfort and well-being in the buildings that are designed and built in Yazd Township.

3. Research Background

For the first time in 1986, a commission composed of meteorologists, health and life experts, architects, engineers and urban designers was formed to investigate the climatology of buildings in Geneva, whose goal was to investigate the effects of urban air in order to achieve the best result regarding the urban climate. Moreover, Hovar J. Kuchinlerd (1979) also emphasizes the selection of the building location and considering local microclimatic conditions as a constraint in comfort, arguing the role of factors such as radiation, wind and the direction of the building in controlling the heat of the interior space. Givoni (1998) in his book 'Urban Design in Different Climates' notices macro and micro-scale weather issues (Tavousi, 2011).

KIFA (2004) analyzed the 25-year period of climate elements in Nicosia, Cyprus, using the monthly table, in order to provide general and appropriate information for the optimal use of passive solar energy in urban planning and building design, resulting in presentation of pre-design strategies. Bouden and Ghrab, (2005) investigated the thermal comfort in five Tunisian cities from two climate zones. In their research, they asked two hundred people about their natural living conditions at work and place of residence every month for one year and compared the results with thermal comfort indices. The results of their study indicated a significant relationship between the declared thermal comfort conditions and the thermal comfort indices. Johnson (2006) studied the effect of urban geometry on outdoor thermal comfort in a dry climate in Morocco. He concluded that in a hot and dry climate, intensive urban design should be carried out to provide as much thermal comfort as possible in the city. Tui et al. (2007) investigated and determined the bioclimatic comfort conditions in Erzurum city in three rural, urban and urban forest areas of Turkey and concluded that forest urban areas are more compatible with the thermal comfort index used in (Farajzadeh Assal, 2008).

In our country, due to the reduction of non-renewable oil resources, urban pollution and the irreparable damage of fossil fuels to the environment, climate and climate design were again taken into consideration from the second half of the 1970s. Among the first efforts in this field, one can refer to the research done by Adl (1970). Making changes in the thermal thresholds in the Koppen's method, he evaluated the climatic conditions of Iranian cities and presented the bioclimatic map of Iran for the first time. Tavasoli (2001) studied the influence of climatic and historical factors on the architecture of Yazd, Nain, Zavareh, Tabas, Kashan and some other central regions of Iran. Razjouyan (2014) investigated the comfort conditions and architecture suitable for the climate in different parts of the country while determining and explaining the comfort charts. Kasmai (1999) divided Iran into different climatic regions and specified the principles of architecture compatible with the climate in many parts of Iran according to the monthly criteria, the first bioclimatic table and the structural bioclimatic table. Amiri (2016) investigated thermal comfort in the interior of the building and climate design in Qom city.

Riazi (1977) prepared a map of climatic divisions regarding the construction works based on Olgyay’s index using the climatic data of 43 synoptic stations of the country. Unfortunately, since the role of building elements in controlling the thermal conditions of indoor spaces is not clear in Olgyay’s proposal, Riazi's work has not been fully noticed. Kasmai (1999) used building bioclimatic tables and the statistics of 43 synoptic devices to prepare different climates of Iran for use in housing and architecture. Also using climatic data from 591 meteorological stations, he presented the first climatic zoning of Iran in relation to residential environments using the monthly method, based on which the country is divided into 23 climatic groups (Kasmai, 1999). Razjouyan (2014) has also provided appropriate instructions for the optimal use of climatic potentials in his books Comfort through Climate Compatible Architecture. Among the studies conducted in recent years on Iran's climate and its changes, one can refer to the works of Farajzadeh Assal (2008), Malek-Hosseini and Maleki (2010), Tavousi (2011), Kamyabi (2016).

While studying the literature review on investigation of the climate and solutions to improve the relationship between architecture and climate in design, it is noticeable that no significant study has yet attempted to identify the type of climate in Yazd province according to different international classifications. Hence, the present study attempts to identify the type of climate of Yazd and then the comfort range in this province. Next, according to the identified climate and the comfort range of the study, solutions will be suggested for better relationship between climate and architecture in this province. The innovations of this article are as follows:

- Studying the types of existing climate classifications, in order to verify the climate type of Yazd province with the help of weather data obtained from Yazd Meteorological Department.
- Determining the comfort range of Yazd province according to commonly-used methods in the world and general conclusions regarding the comfort range of Yazd province.
- Providing solutions to optimize the relationship between architectural design and the climate of Yazd province.

4. Methodology

4.1. Geographical Location

Yazd Township is located in a dry and wide valley between Shirkooh and Kharanag mountains. With an area of 99.5 square kilometers, Yazd is located in the center of Yazd province and on the Isfahan-Kerman road at the coordinates of 54.31 north latitude and 23.54 east longitude. The altitude of this city is 1215m, and the air distance to Tehran is 508 kilometers.

4.2. Method

Given that climatic conditions play a determining role in the formation of local architectural features in urban and rural areas, identifying the climatic differences and their effect on the body and buildings of the city is one of the measures which provide useful insights into improving the climate-compatible architecture. The present study is applied research with an analytical-descriptive approach, where the required data was obtained via library method and using the sources and information available in books and articles as well as the information from relevant organizations, including the city's Meteorological Department. Moreover, the statistical data of the synoptic station of Yazd Township in a 23-year period (1996-2019) was obtained from Yazd Meteorological Organization. The data include:

Average maximum and minimum temperature
Average monthly and annual temperature fluctuation
Average maximum and minimum relative humidity
Average relative monthly humidity
Total annual rainfall
Prevailing wind speed and direction

In the next step, Koppen, Emberger and DeMarton's classification methods were used to identify the type of climate of Yazd Township, and various indicators such as Olgyay, Givoni, Mahani, Evans and Szokolay to identify the thermal comfort range of this township. Finally, suggestions were provided to improve climate compatible architectural design in this township. Figure 1 depicts different phases of the study.

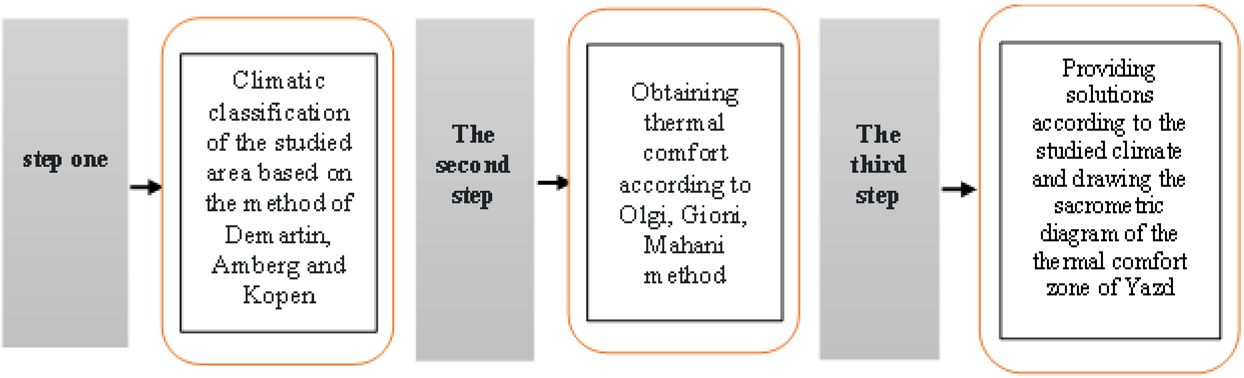

Fig 1 Research process

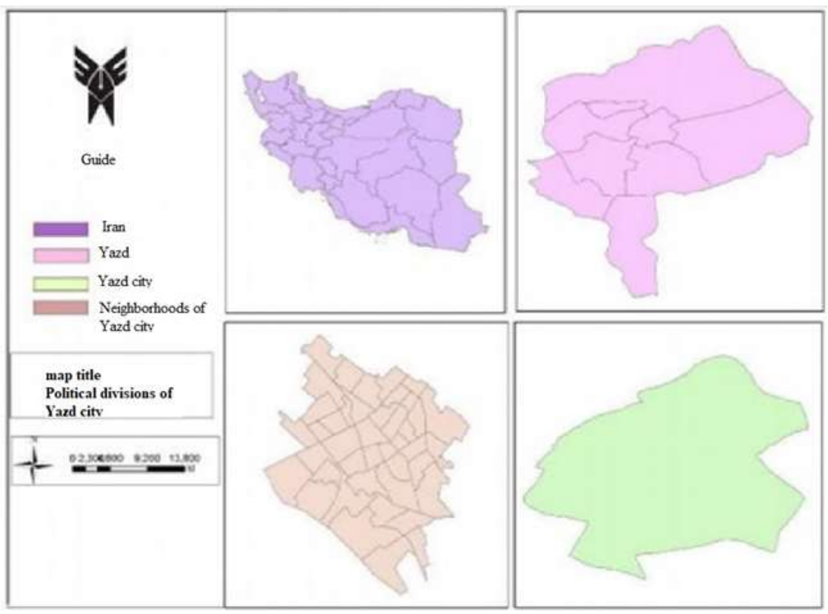

Fig 2 Geographical location of Yazd

Table 1 Climatic data affecting architecture in the 23-year period (1996-2019) Yazd city (source: Meteorological Organization of Yazd Province)

maximum wind		Sun clock	Evaporation (mm)		Ice days	Rainfall (mm)		relative humidity (percentage)		temperature (celsius)					Month
Side	Speed (m/s)				Maximum 24 hours	Total	average	average maximum	average minimum	average	absolute maximum	absolute minimum	average maximum	average minimum	
250	27.0	260.7	259.4	0.0	11.9	7.4	31	47.2	14.6	18.8	35.6	-0.8	25.5	12.0	**April**
280	25.0	299.8	353.5	0.0	7.5	3.2	25	38.2	12.0	24.5	39.4	7.7	31.5	17.5	**May**
290	30.0	358.0	459.8	0.0	10.6	0.9	16	23.8	8.3	29.8	43.8	12.4	37.0	22.6	**June**
260	23.0	353.1	513.9	0.0	3.8	0.3	15	21.4	8.2	33.2	45.6	16.2	40.3	26.1	**July**
220	22.0	360.4	480.7	0.0	0.0	0.0	15	21.3	7.9	31.6	44.8	16.6	38.9	24.2	**August**
320	20.0	343.7	393.2	0.0	0.0	0.0	15	22.9	8.1	28.7	42.2	12.7	36.4	21.0	**September**
230	21.0	299.5	264.4	0.0	2.8	0.2	21	30.4	11.5	23.3	38.2	5.2	30.9	15.7	**October**
330	21.0	245.4	153.1	0.1	12.0	3.2	35	49.2	20.0	16.0	33.0	-1.6	22.9	9.1	**November**
220	35.0	214.2	70.5	5.0	20.1	9.2	46	64.0	27.9	9.8	28.5	-6.8	16.2	3.4	**December**
320	21.0	214.4	23.7	12.6	21.3	9.8	47	66.2	28.8	7.5	27.8	-10.8	13.9	1.2	**January**
210	24.0	230.2	12.5	9.1	20.9	7.8	44	64.9	23.7	9.1	27.8	-10.1	15.5	2.6	**February**
260	25.0	239.0	119.1	1.4	26.9	7.7	34	51.9	16.8	13.6	35.2	-6.0	20.4	6.9	**March**
220	**35**	**3418.2**	**3103.8**	**28.3**	**26.9**	**49.6**	**28.7**	**41.8**	**15.6**	**20.5**	**45.6**	**-10.8**	**27.5**	**13.5**	**yearly**

5. Climate Classification

5.1. DeMarton's Classification Method

In the Demarton's method, Equation (1) is presented as a dryness index and can be used in a period of several days, a month, a season or a year (Alizadeh, 2002).

$$I = \frac{P}{T+10} \qquad (1)$$

where, I denote the dryness index coefficient, P is the average annual precipitation (in millimeters) and T is the average annual temperature (in degrees Celsius). Based on Demarton's method and given that the average annual precipitation of Yazd city is 48.4 mm and the average annual temperature is 20.5°C, the dryness index coefficient is 1.62. Hence, according to Demarton's climate classification (Table 1), the studied area is located in the hyper-arid (desert) zone.

5.2. Emberger's Classification Method

In Emberger's method, Equation (2) is used, where P denotes total annual rainfall in millimeters, M shows average maximum temperature in the hottest month of the year in degrees Kelvin, and m is average minimum temperature in the coldest month of the year in degrees Kelvin. According to this method, and given that the total annual rainfall of Yazd is 48.4 mm, Q will be calculated to be 3.54. According to this chart, the climate of Yazd will be dry and cold.

$$Q = \frac{2000\,P}{M^2 - m^2}\ ) \qquad (2)$$

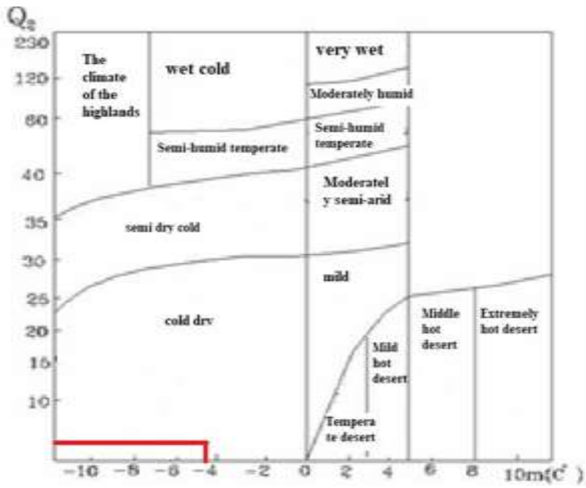

Fig 3 Emberger's climate of Yazd Township

5.3. Koppen's Classification Method

Since the average coldest month of the year in Yazd is between -3 and 18°C and the total annual rainfall during these 23 years has been less than 250 mm and even less than 150 mm, according to Koppne's classification, this township is of Bwh type which means dry and hot. General climate type of Yazd is presented in Table 2.

Table 2 Climate type of Yazd Township

Station name	Climate classification system		
	Demarten	Ambergris	Coupon
Yazd	Very dry (Desert)	Cold dry	Bwh (Dry and warm)

6. Thermal Comfort Indicators

Thermal comfort is a range of temperature and humidity in which the body's thermoregulation mechanism is at minimum (Givoni, 1998). Determining the thermal comfort range has a direct effect on the thermal calculations of the building, the size of the heating and cooling devices, the thickness of the insulation and the materials, and in general on the amount of energy consumption and loss. Considering that people in the same climatic conditions feel the same temperature comfort, it is necessary to determine the thermal comfort range accurately for each climate region (Yang, Wong, and Jusuf, 2013).

6.1. Olgyay's Method

With the help of Olgyay's table and based on the humidity and the intensity of heat and cold, it is possible to understand the climatic conditions of different regions in terms of human comfort, the duration of the annual heat and cold in different cities, the extreme degree of thermal conditions, the type of mechanical system and the need for mechanical systems (Olgyay, 1973). In this diagram, a range has been specified that shows the type of climate regarding the temperature and humidity, and the type of climate of a region can be determined by implementing the thermal conditions in this table. Through the monthly temperature and humidity during a year in the table, while determining the thermal conditions of the area, it is also possible to obtain the critical conditions of the durability of the annual cold and heat (Mahmoud, 2011). Considering the temperature and humidity of Yazd during the given period, the following figure was obtained.

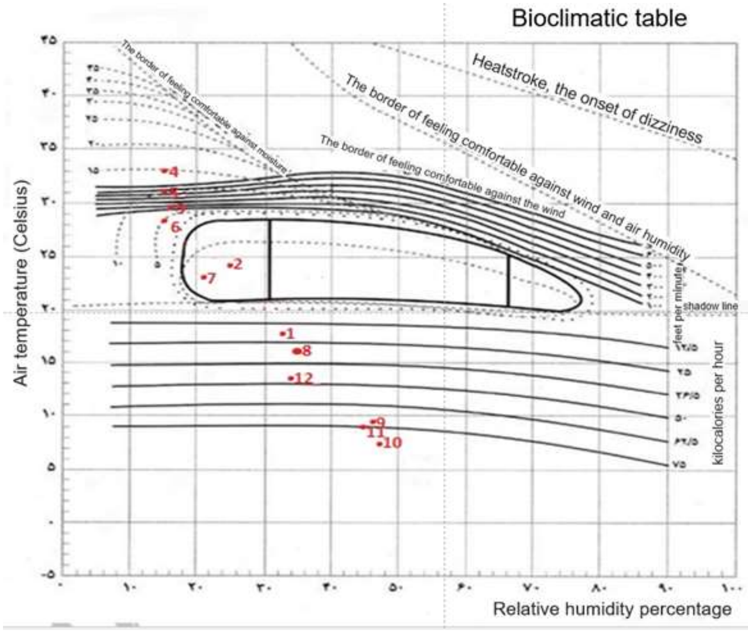

Fig 4 Olgyay of Yazd Township

Table 3 Numbering the 12 months in Olgyay and Givoni charts

March	February	January	December	November	October	September	August	July	June	May	April	Months
12	11	10	9	8	7	6	5	4	3	2	1	numbers

Results of Olgyay chart for Yazd Township:

- May and October are in the comfort range. In this state, a person feels comfortable in the shade and in a situation where the air speed is imperceptible (less than one meter per second).
- April, November, December, January, February and March are in a zone below the level of comfort, and a person does not feel comfortable in the existing conditions, unless exposed to direct sunlight; otherwise, desired comfort is provided using heating devices. However, in December, January and February, the required comfort is provided only by using heating devices.
- June, July, August, and September are above the comfort zone, and it is necessary to provide the necessary comfort both by air flow and by evaporation of water particles in the air.

In Olgyay's method, the type of materials is checked in terms of weight and the amount of thermal insulation in different areas. Since Yazd Township is considered to be a hot and dry region in general, according to Olgyay's model, to determine the range of thermal comfort, relative humidity of the air should also be determined in addition to temperature. According to Olgyay's suggestion, the appropriate relative humidity range is 30-65% and according to the United States standard, this range is 20%-80% (Sadeghi Roshan and Tabatabaei, 2008).

6.2. Givoni's Method

In addition to determining human comfort range more precisely in terms of the temperature and humidity of the air, this method also determines the extent of usefulness of different building elements in regulating the thermal conditions inside the building. Considering the weather conditions of different cities on the building bioclimatic chart, the characteristics of these cities can be checked and classified accordingly (Ghavidel Rahimi and Ahmadi, 2011; Givoni, 1998) (Figure 5).

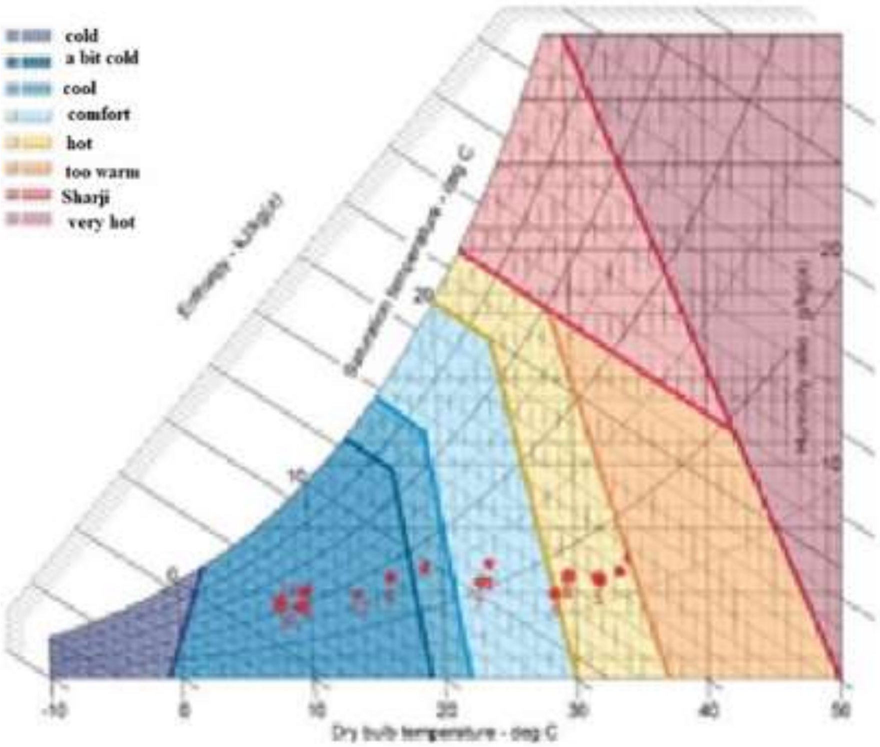

Fig 5 Givoni Chart of Yazd Township

Considering the Givoni chart, it can be seen that in November, December, January, February and March, Yazd is located in a slightly cold region; as a result, in these months, there is a need to receive passive solar heating and increase humidity through water supply.

In April, it is in cool conditions, which requires mild heating and obtaining internal heat along with increasing humidity.

In May and October, the city is in comfort conditions, hence, people feel comfortable both in terms of humidity and temperature.

In September, the city is on the border between comfort and heat and there is a need to reduce heat and ventilation.

In June, July and August, there is a feeling of heat and dryness, and the conditions can be brought closer to the comfort zone with the help of evaporative cooling such as the water-based cooler system.

6.3. Mahani's Method

Mahani chart of the region determines the comfort of night and day in each month according to the average annual temperature of the studied area and the average relative humidity of the same month (Razjouyan, 2014) (Tables 4 and 5).

Table 4 Mahani chart of Yazd

Longitude: 54 17		Latitude: 31 53				Above sea level: 1230 m				Total precipitation mm: 47.4			
Ave.annual temperature: 20.5		Annual fluctuation: 46.7				Max. temperature: 42.3				Lowest temperature: -4.4			
Temperature in Celsius		April	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
Average monthly max. temperature		25.5	31.5	37	40.2	38.9	36.4	30.9	22.9	16.2	13.2	15.5	20.4
Average monthly min. temperature		12	17.5	22.6	26	24.1	20.9	15.7	9.1	3.4	1.2	2.6	6.9
Monthly temperature fluctuation		13.5	14	14.4	14.2	14.8	15.5	15.2	13.8	12.8	12.7	12.9	13.5
Relative humidity	Average monthly max.	47.2	38.3	23.6	21.5	21.4	22.9	30.4	49.2	64	66.2	64.9	51.9
Relative humidity	Average monthly min.	14.6	11.9	8.1	8.1	7.8	7.9	11.5	20	27.9	28.8	23.7	16.8
Relative humidity	Average	30.6	25.1	15.85	14.8	6.52	15.4	20.95	34.6	45.95	47.5	44.3	34.35
Relative humidity group		2	1	1	1	1	1	1	2	2	2	2	2
Rainfall in mm		7.4	3.2	0.9	0.3	0.0	0.0	0.2	3.2	9.2	9.8	7.8	7.7
Wind	Dominant wind	SW	SE	SE	SW	SW	SE	SW	SE	SW	SE	SW	SW
Monthly average max. temperature		25.6	31.5	37	40.2	38.9	36.4	30.9	22.9	16.2	13.9	15.5	20.4
Comfortable day area	Max.	31	36	36	36	36	36	36	31	30	27	30	31
Comfortable day area	At least	25	34	34	34	34	34	34	25	22	20	22	25
Average monthly min. temperature		12	17.5	22.6	26	24.1	20.9	15.7	9.1	3.4	1.2	2.6	6.9
Comfortable night area	Min.	20	23	25	25	25	25	23	20	20	20	20	20
	At least	12	14	17	17	17	17	14	12	12	12	12	12
Thermal status	Day	M	C	H	H	H	H	C	C	C	C	C	C
	Night	M	M	M	H	M	M	M	C	C	C	C	C

Table 5 Mahani's conceptual indicators (source: Kamyabi, 2016)

Concept of indicators	Monthly fluctuation in centigrade	Moisture group	Rain	Thermal condition		Indicators
				Night	Day	
Air flow is essential	Less than 10 degrees	4		Hot		H_1
Air flow is essential		2 & 3		Hot		
Air flow (wind) is favorable		4		Appropriate		H_2
Rain protection			> 200 mm			H_3
Thermal capacity	> 10 degrees	1,2,3				A_1
Free space is essential for sleeping		1 & 2		Hot		A_2
	> 10 degrees	1 & 2		Appropriate	hot	
Protection against cold				Cold		A_3

Table 6 Index of the thermal condition of the months of the year in Yazd Township

	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar
H_1												
H_2												
H_3												
A_1	*	*	*	*	*	*	*	*	*	*	*	*
A_2	*		*	*	*	*						
A_3		*					*	*	*	*	*	*

Table 7 Total humidity indices of Yazd Township

Total humidity indicators					
H_1	H_2	H_3	A_1	A_2	A_3
0	0	0	12	5	7

Table 8 Review of architectural features of buildings in Yazd based on Mahani's method

Suggestions		Checking presence and absence of indicators	Thermal condition indicators					
			A_1	A_2	A_3	H_1	H_2	H_3
			7	5	12	0	0	0
Method of establishing the building								
1	The length of the buildings along the east and west		5-12		0-10			
2	Compact architecture with courtyard		0-4		11-12			
Space between buildings								
3	Wide and open set for wind use							11-12
4	As above, on the condition of avoiding hot and cold wind							2-10
5	Compact collection	*						0-1
Air flow inside the building								
6	Individual rooms for the use of permanent blinds				0-5			1-2
7	Interlocking rooms and air flow forecasting temporarily when necessary				6-12		2-12	0
8	No need for noticeable air flow	*					0-1	
Windows								
9	Large windows, 40-80% of north and south walls		0		0-1			
10	Very small windows, 10 to 20 percent		0-1		11-12			
11	Medium windows, 20 to 40 percent	*						
Walls								
12	Light walls, short lag time				0-2			
13	Heavy walls, internal and external	*			3-12			
Ceilings								
14	Light roofs with thermal insulation	*		0-5				
15	Heavy ceilings, delay time more than 8 hours			6-12				
Night sleep in the open air								
16	The necessity of providing space for night sleep	*		2-12				
Rain protection								
17	The need for protection against heavy rain					3-12		

According to Table 8, buildings in Yazd Township should contain the following conditions:

It is suggested to design the building in the form of a complex and in a dense manner.

It is better to place buildings compactly and individually next to each other; arrangements that cause wind and ice tunnels should be avoided (Razjouyan, 2014: 62).

Suitable surfaces for openings are 20 to 40% of the wall surface. It is better to place the openings on the surfaces that receive the most sunlight (north and south).

The walls must be thick; heavy walls should be used both inside and outside. Light roofs should be designed with proper thermal insulation.

6.4. Evan's Method

Evans' index is one of reliable indices in the field of comfort climate, which examines the conditions of human comfort from the perspective of climate in different times and places (Mohammadi, 2002). In Evans' model, bioclimatic conditions can be obtained separately in the monthly interval and in two parts "day time" and "night time" (Tavousi, 2011), (According to Table 7).

Table 9 The range of day and night comfort temperature with Evans' index in four groups of relative humidity (source: Kamyabi, 2016)

Scale	Thermal conditions	Relative humidity	Daily temperature	Night temperature
A	Temperature comfort zone range with air flow of 1 m/s	0 – 30	29.5 – 32.5	27.5 – 29.5
		30 – 50	28.5 – 30.5	26.5 – 29
		50 – 70	27.5 – 29.5	26 – 28.5
		70 - 100	26 - 29	25.5 – 28
B	The range of temperature comfort zone with light summer clothes and light bedding at night with imperceptible air flow (0.1 m/s)	0 – 30	22.5 – 30	20 – 27.5
		30 – 50	22.5 – 28	20 – 26.5
		50 – 70	22.5 – 27.5	20 – 26
		70 - 100	22.5 - 27	20 – 25.5
C	The range of temperature comfort zone with normal and warm clothes and thick bedding at night (0.1 m/s)	0 – 30	18 – 20	16 – 20
		30 – 50	18 – 20	16 – 20
		50 – 70	18 – 20	16 – 20
		70 - 100	18 – 20	16 – 20

Table 10 Average maximum temperature and minimum relative air humidity and allocation of daytime climatic conditions in Yazd Township based on Evans' index

Month	Ave. max. temp.	Min. relative humidity	Daily bioclimatic conditions of Yazd	Allocation of daily climatic condition of Yazd	Allocation of daily final status of Yazd
April	25.5	14.6	29.5-32.5 22.5-30 18-20	cold Appropriate hot	Appropriate
May	31.5	12.0	29.5-32.5 22.5-30 18-20	Appropriate hot hot	Appropriate
June	37.0	8.3	29.5-32.5 22.5-30 18-20	hot hot hot	hot
July	40.3	8.2	29.5-32.5 22.5-30 18-20	hot hot hot	hot
August	38.9	7.9	29.5-32.5	hot	hot

			22.5-30 18-20	hot hot	
September	36.4	8.1	29.5-32.5 22.5-30 18-20	hot hot hot	hot
October	30.9	11.5	29.5-32.5 22.5-30 18-20	Appropriate Appropriate hot	Appropriate
November	22.9	20	29.5-32.5 22.5-30 18-20	cold cold Appropriate	Appropriate
December	16.2	27.9	29.5-32.5 22.5-30 18-20	Cold cold cold	cold
January	13.9	28.8	29.5-32.5 22.5-30 18-20	Cold cold cold	cold
February	15.5	23.7	29.5-32.5 22.5-30 18-20	Cold cold cold	cold
March	20.4	16.8	29.5-32.5 22.5-30 18-20	Cold cold cold (tend to fit)	Appropriate

Table 11 The average minimum temperature and maximum relative air humidity and allocation of nighttime climatic conditions in Yazd Township based on Evans' index

Month	Ave. min. temperature	Max. relative humidity	Night bioclimatic conditions of Yazd	Allocation of night climate conditions of Yazd	Allocation of the daily final status of Yazd
April	12.0	47.2	26.5-29 20-26.5 16-20	cold cold cold	cold
May	17.5	38.2	26.5-29 20-26.5 16-20	cold cold Appropriate	Appropriate
June	22.6	23.8	27.5-29.5 20-27.5 16-20	cold Appropriate hot	Appropriate
July	26.1	21.4	27.5-29.5 20-27.5 16-20	cold Appropriate hot	Appropriate
August	24.2	21.3	27.5-29.5 20-27.5 16-20	cold Appropriate hot	Appropriate
September	21.0	22.9	27.5-29.5 20-27.5 16-20	cold Appropriate hot	Appropriate
October	15.7	30.4	26.5-29 20-26.5 16-20	cold cold cold	cold
November	9.1	49.2	26.5-29 20-26.5	cold cold	cold

			16-20	cold	
December	3.4	64.0	29.5-32.5 22.5-30 18-20	cold cold cold	cold
January	1.2	66.2	29.5-32.5 22.5-30 18-20	cold cold cold	cold
February	2.6	64.9	29.5-32.5 22.5-30 18-20	cold cold cold	cold

Table 12 Appropriate climatic guidelines of Yazd province

Architectural guidelines for indoor air conditioning	Temperature fluctuations during day and night	Situation under study	Average humidity			Average temperature	Weather conditions
			minimal	maximum	minimal	maximum	
Need for air flow	-	Day is comfortable with A scale and hot with B scale	more than 70%	-	-	More than 27	High temperature and high relative humidity during the day
	10 or less		50-70%	-	-	More than 27.5	
Building components with heat capacity and delay time	-	hot day	0 – 30%	-	-	More than 32.5	High temperature and high fluctuation during the day and night
	-		30 – 50%	-	-	More than 30.5	
	More than 10		50 – 70%	-	-	More than 29.5	
Necessity of mechanical devices for cooling and heating	-	hot day	0 – 30%	-	-	More than 38	Severe discomfort
	-		30 – 50%	-	-	More than 37	
	More than 10		50 – 70%	-	-	More than 35/5	
	10 or less		More than 70%	-	-	More than 32	
Good heat capacity	More than 10	easy days	0 – 30%	-	More than 10	Less than 32.5	Comfortable day and night, but with a large temperature fluctuation during the day and night
	More than 10		30 – 50%	-	More than 10	Less than 30.5	
	More than 10		50 – 70%	-	More than 10	Less than 29.5	
	More than 10		More than 70%	-	More than 10	Less than 29	
Protecting the building from radiation and strong wind	All the conditions that did not come in situations 1, 2, 3, 4, and 6						Presence of daily comfort
Adequacy of building		new	-	-	-	15-18	Low temperature

components with the ability to accumulate heat in themselves							in the day
No need for proper insulation and permanent heating device		cool	-	-	-	10-15	
Need for proper insulation and a permanent heating device		cold	-	-	-	Less than 10	
Need for air flow	-	Hot at night	-	More than 70%	More than 25.5	-	High temperature and high humidity at night
	10 or less		-	50 – 70%	More than 26	-	
Building components with high heat capacity	-	Hot at night	-	0 – 30%	More than 27.5	-	High temperature and low humidity at night
	-		-	30 – 50%	More than 26.5	-	
	More than 10		-	50 – 70%	More than 26	-	
Need for good insulation with a building with medium or high heat capacity		Cold nights	-	-	Less than 29	-	Low temperature at night

6.5. Szokolay's Method

With the help of this method, the comfort range can be presented on the psychometric table according to the following steps (Kamyabi, 2016):

Given that the average annual temperature of Yazd is 20.5, the comfort temperature is equal to:

$T_c = 0.31\ Tm + 17/6c$

$T_c = (0.31 * 20.5) + 17.6_c = 23.95$

$L = 23.95 – 2 = 21.95$

$U = 23.95 + 2 = 25.95$

aL = 0.025 (21.95-14) = 0.19
aU = 0.025 (25.95-14) = 0.29
$T_L = L + (A_c A_H) C$
$T_L = 21.95 + (0.19 * 9) = 23.63$
$T_U = 25.95 + (0.29 * 11) = 29.14$

7. Results and Discussion

The three different methods used for the climatic classification of a region are DeMarton, Emberger and Koppen’s classification methods, all of which were considered in the present study according to the data obtained from the Meteorological Department of Yazd Province. It was concluded that in all three models, the climate of Yazd is characterized as hot and dry.

The range of thermal comfort is a range of temperature and humidity in which the body's thermoregulation mechanism is at minimum activity (Givoni, 1998). In this study, to determine the thermal comfort range of Yazd province, all indices commonly-used in the world were considered, including Olgyay, Givoni, Mahani, Evans, and Zsokolay’s index. Considering the results, a specific range was identified as the comfort range of Yazd province.

8. Conclusion

According to the studies conducted and the validation carried out, the climate of Yazd province is identified as hot and dry, and in this climate, it is better to carry out the architecture of buildings with the following considerations:

- It is suggested to design the building in the form of a complex and in a dense manner.
- It is better to place buildings compactly and individually next to each other; arrangements that cause wind and ice tunnels should be avoided (Razjouyan, 2014: 62).
- Suitable surfaces for openings are 20 to 40% of the wall surface. It is better to place the openings on the surfaces that receive the most sunlight (north and south).
- The walls must be thick; heavy walls should be used both inside and outside. Light roofs should be designed with proper thermal insulation.

In Table 13, according to the hot and dry climate of Yazd, guidelines for architectural and urban planning designers according to the climate of the province are presented. It should be used in the future.

Table 13 The results of climatic classification in the architecture of hot and dry areas of Yazd province (source: authors)

External color	Shadow mask	Building form	Placement direction	Building density	Roof type	Type of material		Plan type	Climate type
						modern	classic		
Color is free but tends to be bright		Expansion of the plan in the east-west direction with 30^{o} deviation to the northwest	30^{o} rotation to southwest and 60^{o} rotation to southeast	High density with minimal external surfaces	Dome shape	High thermal capacity and resistant to thermal stress (false ceiling and iron)	High thermal capacity and resistant to thermal stress of brick materials and wooden coating	Dense and compact	Warm and dry
Underground	Crossing	Door and window	Commonly used elements	Type of window door	Shape of the plan	Building volume		Connection with the earth	Level and number of windows
Basement has many uses	East-west with 30^{o} deviation to northwest	Wooden and crescent face	Fountain and porch in summer	More vertical windows instead of horizontal placement of windows in the upper part	Square plan to minimize side area	Cubic volume		has it	Small and low windows and not placing east and west windows with awnings if necessary
Major objectives of climatic design		Suggested design	Dominant wind	Ventilation		Wall		Plants	View
				winter	Summer				
Reducing building heat loss, using solar energy, using the element of wind and water in urban design and planning			West and North West	Active solar architecture and conventional heating system	Water cooler and suitable materials	Thick walls to delay the entry of heat such as the use of a trompe wall		Planting deciduous and evergreen plants	Not using smooth and unbroken facades

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