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Investigating the Climate Change on Architecture Based on Mahoney Index, Case Study: Tehran Hot and Dry Climates

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ABSTRACT: City and human are two different human-made and natural systems which has an effect on each other. The formation of a residence depends on the climatic conditions. Construction of a residence shows that people have adapted themselves and their activities to it; while the climatic conditions play an important role in comfort in human environments. Thus, the buildings and environmental spaces should have exact and calculated solutions which are compatible with climatic conditions. The geographical region of this study is arid climate of Tehran. Some climatic elements of synoptic station from the beginning of establishment (1981-2013) were studied and analyzed. Then, Mahoney method was used to determine the characteristics which should be considered in climatic building and in relation with environment conditions. The purpose of this study is presenting architecture principles regarding to the climatic changes since global warming has enhanced the importance of these principles more than ever. Except in the northern area which is temperate and humid, Tehran has arid climate. First, the librarian sources and related literatures were reviewed; then using content analysis, the principles of climatic design were extracted. This study suggests that if designing is done based on climatic changes for urban buildings, the buildings can receive their thermal energy from other renewable sources. To examine this hypothesis, the effects of climate on architecture of arid climate of Tehran were investigated. Based on the existing data and survey study for the architecture of Tehran arid climate, some suggestions are presented. Finally, appropriate solutions for compatibility of climate and architecture in Tehran are presented.

Keywords: Level of Comfort, Climatic Architecture, Temperature, Humidity.

INTRODUCTION

Environmental comfort is one of the important human issues so that human societies have formed in more appropriate environments (Mohammadi, 2007). Creating life comfortable based on the environmental conditions and providing the security of residents from tense environmental and atmosphere conditions are among the inseparable principles of architecture and building (Moradi, 2007). Practical planning of urban lands and its effect on the place and density, designing residential areas and neighborhood units have significant effects on reaching sustainable development (Bulkeley and Betsill, 2003). One of the main features of sustainable urban environments is the compatibility and association with local climatic characteristics (IPENZ, 2007).

So, recognizing, understanding and controlling the climatic effects of urban areas are basic preconditions of urban space planning and designing which should be specially regarded by planners and designers before operationalization of the plans and projects (Biket, 2006).

Considering climatic issues in designing the architecture is one of the important dimensions of architecture sustainability and urban planning. Using natural energies in the buildings leads to save fuel consumption and increase the comfort level of quality, sanitation of residential environment and purification of environment. In effect, housing design based on regional climatic conditions is the first defense line against outside threatening factor (Saliqeh, 2004).

Nowadays, coexistence with natural and climatic conditions is one of the main measures of architecture

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and urbanism which makes designers to follow special rules (Zandieh, 2010). The most appropriate method for realizing the ecological city is that every city or an urban collection is limited to ecological area and only using the resources of the area (Bahraini, 2003). On the other side, in recent years, climatic changes have made issues and crises for all parts of the world. Architecture has an important role in the challenge of global warming and climatic changes since the buildings are responsible for producing and disseminating half of greenhouse gas all over the world caused by their high annual energy consumption (Fazli & Madi, 2013). In effect, preparation of every kind of method for reducing, saving and optimizing this amount of consumption in cities and buildings and also declining green-house gas will have a significant effect on preventing climate change trend and global warming (Farshchi, 2010). So, presenting solutions to reduce energy consumption in this sector is really important while observing the smallest details can have great influence on energy consumption reduction. For example, direction of building, positioning of sidereal space and improvement of insulation methods with the least cost can improve the residence efficiency. So, the importance of climate and its effect on human life is obvious for all but high cost of providing comfort inside the buildings through mechanical instruments has added to the importance of climate studies due to continuous climatic changes. The purpose of the present study is reducing the costs of comfort in the buildings through realizing and observing the principles of climatic design.

SIGNIFICANCE OF THE STUDY

Protraction of dry period has been reported as one of the main outcomes of climate change phenomenon (Nicholls, 2000). The evidences show that prolonging the dry season will be pronounced especially in mid latitude (Reilly, 1999). The results of some of the studies show that the effects of climatic change on temperature increase was mostly due to nocturnal temperature raise and generally, nocturnal temperature is affected more by climatic change rather than diurnal. In a city like Tehran as the biggest energy consumer having different kinds of environmental problems, optimization of energy consumption in residential areas is a necessity regarding the changes and protraction of dry period. This can be implemented by observing the architectural urbanism principles and energy optimization of energy consumption like using the climate of the region appropriately and using different kinds of renewable energies which are free and pollution-free.

RESEARCH QUESTION

- How have climate changes happened in Tehran?
- What requirements in architecture of Tehran should be considered for coordination with climatic change and preventing destructive effects on nature?
- How does the trend of architecture design lead to more compatibility of buildings to reduce the energy consumption in Tehran?

RESEARCH METHOD

This study used descriptive-analytical method. The data were collected through extensive library study and referred to main accessible sources. However, a part of data was collected through survey method.
Some climatic elements of synoptic station from the beginning of establishment (1981-2013) were analyzed. Then, to determine the characteristics of environmental climatic conditions for Tehran buildings, Mahoney method was used. At the end, the ways of responding to these needs are suggested.

RESEARCH BACKGROUND

Howard Richfield suggested that the selection of location is important to optimize the use of sub-conditions of local climate. The factors of shining, wind and building direction of settlement in controlling the temperature of interior space are explained and some solutions for using solar shine to warm the building are represented. Morlon Galous et al. (2007), provided the ecological-climatic atlas of Mexico based on the definition and specification of comfort area (suggested equation of Alsimz), biological chart of Ulgi and Giuni diagram for controlling the life of climate inside the building (Karl et al., 1997).

Riazi (1977) suggested a map of climate divisions based on suggested method of Ulgi and Giuni using the information and statistics of 43 synoptic stations aiming at investigating different cities' weather conditions in order to assess the performance of building elements and provide an information collection of climatic design for architects and building engineers. Alijani (1994) in a study investigated weather map for designing by considering shine angle and different methods of compatible house with climate.

CAUSES OF CLIMATE CHANG

- Natural cause: it is caused by the changes of sun axis in milky-way galaxy, pass of meteors, outcome changes of sun and changes in earth axis parameters.

- Human cause: over-emission of greenhouse gas through human activities is among the most significant causes of climate change. Density of greenhouse gas makes a layer in atmosphere like the glass of a greenhouse. The visible sunlight is separated and passes through greenhouse gas and reaches to earth. The infrared light shining out of earth can't pass and is changed to warmth. Over-emission of greenhouse gas makes the earth warmer leading to horrible results (Karl, 1997).

THE WAYS TO PREVENT CLIMATE CHANGE PHENOMENON

Nowadays climate change phenomenon is one of the most critical issues occupying the mind of policy makers and planners. The first step to prevent this trend is understanding climate change phenomenon and accepting its destructive effects. In the next step, increasing or decreasing factors should be considered. Then it should be enculturated to increase public awareness about climate change issue. The most important way to prevent climate change trend is noticing to energy issues. Policy makers should take provoking or stopping plans for decreasing fuel fossils or investment in energy efficient technology and promote the culture of using sustainable energies. This culture is implemented through:

- Sustaining and using renewable energies.
- Saving energy consumption.
- Using mixed energies to lower the use of fuel fossils and their maintenance and increasing resources' life.
- Optimization and increasing energy return for decreasing world consumptive energy (Karl, 1997).

ARCHITECTURE AND URBANISM IN THE AGE OF CLIMATE CHANGE

Increase of world's temperature puts deep effects on climatic phenomena. One of the highest effect of climate change happens in cities (Karl, 1997). The most important effect of climate change on city is the rise of temperature in cities and creation of heat islands. The factors contributing to this issue are in the realm of architects and city planners which include:

- The materials which cities are made up of have high thermal capacity. These materials create an impenetrable surface transferring rainfall quickly out of the city before being evaporated. It prevents wasting heat for evaporation of city humidity.
- Motor vehicles and the heat caused by domestic use releases a great amount of heat in city atmosphere and pollution blocks shining of high waves which are released directly from earth surface to air.
- City over-population includes mostly tiny particles, smoke, vapor and carbon dioxide which are causes for temperature increase.
- Vertical walls of the city buildings do not permit extra radiation as they do for relatively flat areas. Sidereal angels of these three-dimensional structures release the saved heat; and, a part of it shine again among the building instead of going upward and slows down the process of heat waste.
- Over-roughness of city surface reduces the wind speed and slows down the ventilation and stops entering cool air around buildings into the city.
- Urban concrete and asphalt attract and saves high amounts of sunshine in comparison to vegetation and the soil in villages (Karl, 1997).

THE PREDICTED URBAN PROBLEMS CAUSED BY CLIMATE CHANGE PHENOMENON

Climate change trend causes some problems for urban life such as:

- Urban infrastructural system like transportation are unpredictable and damage by movement of earth layers and floods.
- Locating the uses is faced with problems.
- Industrial pollution increases in rivers and coastal areas.
- Destroying the land capabilities.
- Destroying green space (Karl, 1997).

ARCHITECTURE AND ENERGY IN THE AGE OF CLIMATE CHANGE

Regarding energy issue and the most important influencing element on climate change phenomenon is necessary.

Regarding that energy consumption in buildings is more than other industries, some strategies should be taken:

- Reducing non-renewable energies such as fuel fossils and nuclear resources.
- Optimizing energy consumption in buildings.
- Saving energy consumption through the following methods:

a. Insulation of all the roofs, walls, floors, doors and windows.
b. Using high quality two-layered windows or PVC.
c. Using efficient equipment (especially in installations like pumps, fans, etc.).
d. Using day light and natural ventilation.
e. Using durable materials.
f. Using attractive and solar heat saving masses.

- Replacing renewable energy sources such as:
  a. Solar energy.
  b. Wind energy.
  c. Hydro-electric energy.
  d. Geothermal energy.
  e. Biomass energy.
  f. High tide energy.
  g. Energy gained from wastes and trash.

MATERIALS AND METHODS

Regarding climate perspective, four elements of temperature, humidity, wind and shining have fundamental role in the formation of human comfort among which temperature and humidity have the more effect on human health. Because of this, most of human comfort evaluation models are based on these two factors (Alijani, 1993).

GEOGRAPHICAL LOCATION OF THE STUDY

Tehran is located on 510 and 6 minutes to 510 and 38 minutes to Eastern longitude, 350 and 34 minutes to 350 and 51 minutes of northern latitude. The height form high seas is 1800 meters in north, 1200 meters in the center and 1050 meters in south (Tehran History, 2008). The average from sea level is 1400 meters. Tehran is located between central Alborz Chain Mountain from north and semi-desert zones of Qom and Saveh from south. So, Tehran can be divided in three zones including cold and mountainous, hillside and semi-desert. The average of the highest recorded temperature in last ten years was reported in Mehrabad Station, 40.78 in June and July and the least in December-January, -5.78.

The average of annual rainfall was 223.3 and the average humidity during these ten years was between 20-61% showing the relative dryness of air in warm months of the year. Regarding to the average sunny hours from 4.57 in January to 11.26 hours in June, solar shine can have a determining role in climatic characteristics. The prevailing wind of Tehran blows from west and the quickly cold blown wind from west and north-west. Based on this, according to climate classification coupon, Tehran is located in Bsh region and regarding Iran's climate zoning, Tehran is located in 2-5 group in relatively cold of dyr-hot half (Mofidi et al., 2010).

DATA

To consider the comfort in Tehran, parameters of comfort conditions from synoptic stations through the related site, calendars and contact persons were collected from 1982-2013. The statistics were monthly regulated and used in Excel software. Mehrabad station was built in 1942.

Table1. Features of Tehran Station

Statistical Period	Duration	Geographical Features		Height (meter)	Station	Row
		E latitude	N longitude			
1360-1392	32 years	41°,35',35"	51°,18',46"	1191	Mehrabad	1

Mehrabad Meteorology Station of Tehran in 2016

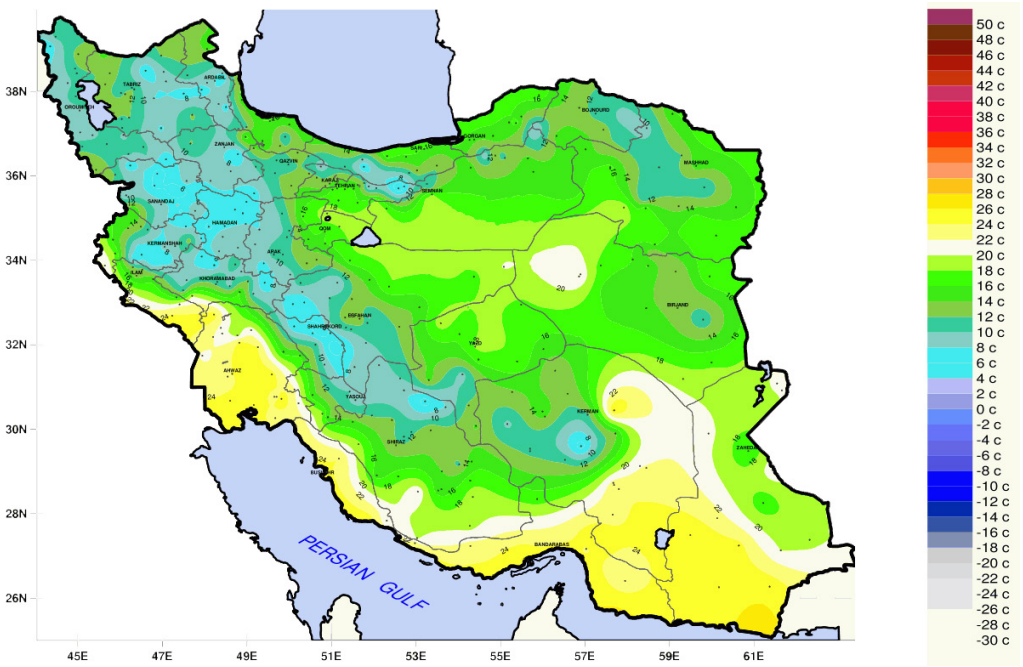

Fig. 1. Minimum Temperature Map of Tehran and Other Iranian Provinces
Mehrabad Meteorology Station of Tehran in 2016

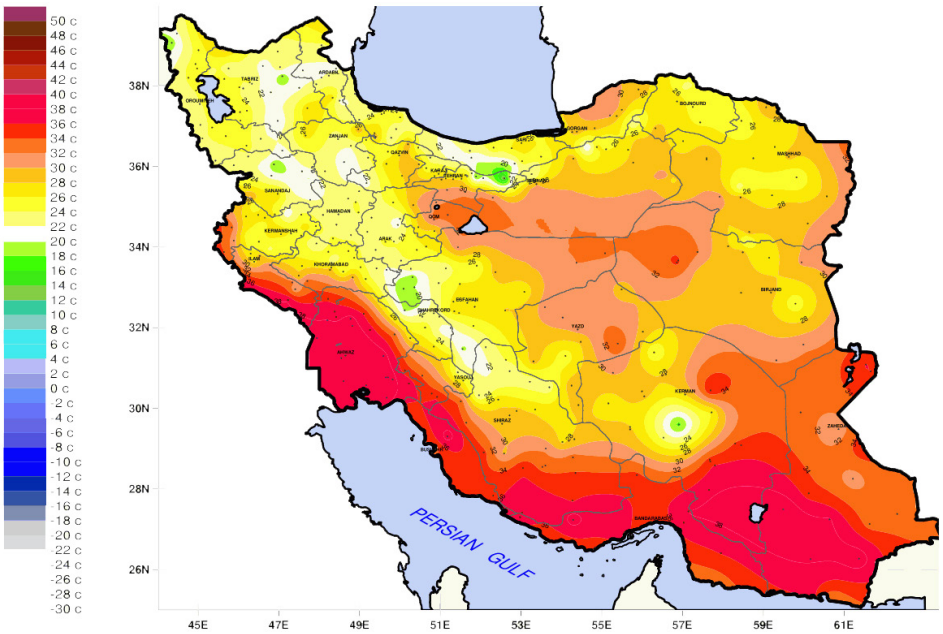

Fig. 2. Maximum Temperature Map of Tehran and Other Iranian Provinces
Mehrabad Meteorology Station of Tehran in 2016

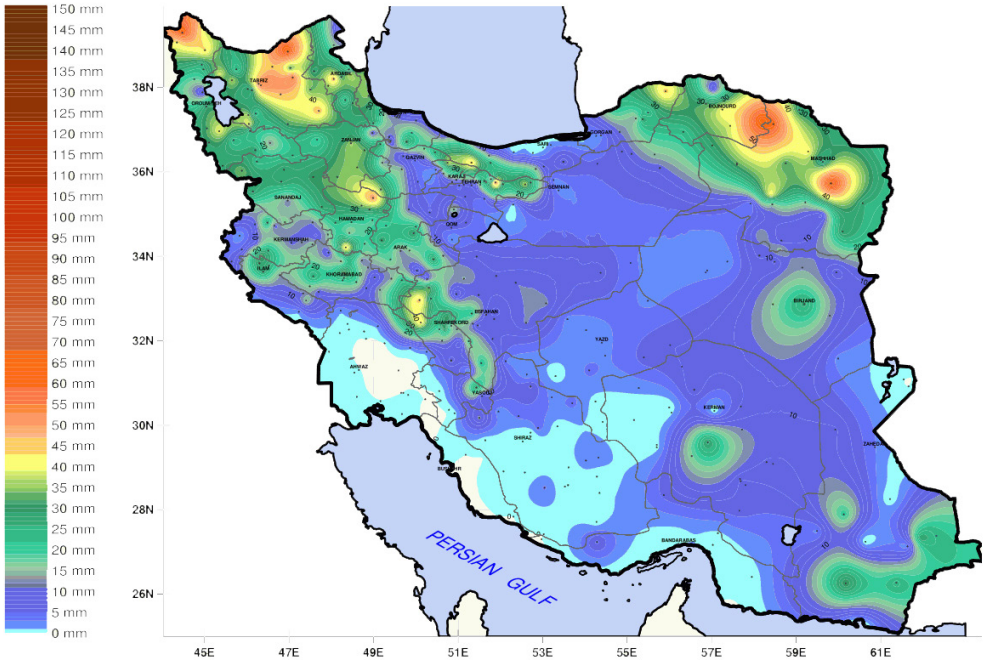

Fig. 3. Precipitation Map of Tehran and Other Iranian Provinces
Mehrabad Meteorology Station of Tehran in 2016

METHODS

Nowadays lots of efforts are being done for discovering and considering the system of thermal feeling of humans from environment. How the simultaneous effect of climatic environmental factors and the effect of physical states of human body are considered in determining the level of comfort. It is tried to determine the thermal comfort range adaptable to human body. To reach compatible relations between environmental weather factors and thermal feeling of human body, Mahoney method is used. Since it is based on the experiential studies with limitations and errors, it cannot be used for all physical and human environment conditions.

DETERMINING COMFORT ZONES THROUGH MAHONEY INDEX

Mahoney method is one of the measurments used for evaluating the thermal range of comfort for day and night of every month introduced first in 1971 by Carl Mahoney. In this method, four temperature groups are represented based on the average annual temperature and the average of relative humidity (Table 2).

Table 2. Mahoney Temperature Group (HG)

Temperature Group	Average of Relative Temperature
1	Under 30%
2	30%-50%
3	50%70-%
4	More than 70%

Since the study case is arid parts of Tehran, comfort zone of is determined by Mahoney as:

First, regarding the parameters of maximum average and minimum of monthly temperature and, average, maximum and minimum of temperature, temperature group of each of Tehran's temperature groups was obtained (Table 5). Three months including August, July and June placed in group 1, March, April and May in group 2, January, February November and December placed in group 3. Group five needs temperature more than 70% which can't be found in Tehran.

In spite of determining monthly temperature group, Mahoney specified the comfort of days and nights of months and separated them in 4 temperature groups and 3 thermal zones (Table 3). The following are the obtained comfort conditions.

- (H) hot: if the average of maximum or minimum of monthly temperature is more than high comfort level.
- (O) proper: if the average of maximum or minimum of monthly temperature is between comfort limit.
- (C) cold: if the average of maximum or minimum of monthly temperature is less than low comfort imit.

Table 3. Comfort Zones

AMT under 15˚C		AMT more than 20˚C- 15˚C		AMT more than 20˚C		HG	Average of Relative Humidity (%)
Night	Day	Night	Day	Night	Day		
12-21	21-30	14-23	23-32	17-25	26-34	1	0-30
12-20	20-27	14-22	22-30	17-24	25-31	2	30-50
12-19	19-26	14-21	21-28	17-23	23-29	3	50-70
12-18	18-24	14-20	20-25	17-21	22-27	4	70-100

Table 4. Weather Temperature

	J	F	M	A	M	J	J	A	S	O	N	D	Max	AMT
Average of Maximum Monthly Temperature	8.3	10.7	15.8	22.8	28.2	34.4	36.9	35.9	31.7	24.6	16.4	10.1		18.9
Average of Minimum Monthly Temperature	0.8	2.3	6.5	12.6	17.3	22.3	24.9	24.4	20.5	14.6	8.1	2.8		36.1
Average Monthly Range	7.5	8.4	9.3	10.2	10.9	12.1	12	11.5	11.2	10	8.3	7.3	min	AMR

Table 5. Humidity, Rain, Wind

Relative Humidity (%)		J	F	M	A	M	J	J	A	S	O	N	D	
Average of Monthly Maximum in the Morning		75.2	70.6	63.4	56.3	49	39.6	39.6	39.6	41.4	51.1	65.1	75.4	
Average of Monthly Maximum in the Evening		45.2	38.1	31.3	25.3	20.7	15.8	17	18.1	19.1	25.6	35.7	45.4	Total 243.2
	Mean	60.2	54.4	47.4	40.8	34.9	27.7	28.3	28.9	30.3	38.4	50.4	60.4	
Temperature Group		3	3	2	2	2	1	1	1	2	2	3	3	
Rainfall (Millimeter)		33	32.9	43	31	15	2.4	2.2	1.7	1.3	14.8	30	35.9	
Wind	Prevailing	W	W	W	W	W	W	SE	SE	W	W	W	W	
	Sideway	W	W	NW	NW	NW	NW	W	NW	SE	W	W	W	

DISCOMFORT INDEX OF HUMID CONDITION

In Mahoney method, in spite of determining humidity group, discomfort climatic indices are suggested in 3 humidity groups including H_1, H_2, H_3 and dry groups including A_1, A_2, A_3. Moreover, some suggestions were provided to obviate the discomforts.

The results of separating limits of day and night comfort are shown in table 7. Based on the table, March, February and January is placed in cold group (C), September, August, July and June in hot group (H) and April, May and October is placed in proper group (O). Thermal comfort condition in nights of December, November, April, March, February, January is placed in (C), September, August and July in hot conditions (H) and October, September, June and May in (C) condition.

H_1: it shows that air flow is necessary. It is enforced when high temperature (H- nocturnal thermal tension) comes with high humidity (HG-4) or when high temperature (H – nocturnal thermal tension) is combined with mean humidity (HG-2 or 3) and the low diurnal range of change (DR less than 100 C). In spite of high temperature of Tehran, the index of discomfort does not exist because of lacking high humidity in these months.

H_2: it shows that air flow is proper. It is enforced when the temperature inside the comfort limit comes with high humidity (HG-4). In Tehran, due to total lack of discomfort index in all the months, Mahoney climatic discomfort is not observed.

H_3: it announces that prevention against rain is obligatory. The problems may even happen with low rainfall but when rainfall is more than 20 millimeters a month, it becomes inevitable. Arid climate of Tehran lacks this discomfort due to not having high amount of rainfall. Generally, as this part of Tehran is arid and away from humidity resources, it lacks this discomfort.

A_1: it shows the need to thermal accumulation. It is enforced when a big range of diurnal changes (100 C or more) is concurred with mid or low humidity (HG-1, 2 or 3). Since Tehran is located in arid region having this discomfort in October, April to September. To obviate the discomfort, using appropriate materials and cooling equipment compatible with the region's climate is suggested.

A_2: it announces the favorable conditions of outer environment. It is needed when nocturnal temperature is high (H-nocturnal thermal tension) and humidity is low (HG-1 or 2). It may be needed when there is nocturnal outer comfort but, as a result of high heat accumulation the internal condition is hot (e.g. H-day, -1 humidity group or 2 and when the changes of diurnal temperature is under 100 C).

Tehran is placed in this discomfort condition in October, September, August, July, June and May. To sleep under open air it is suggested to obviate the discomfort.

A_3: it refers to the problems of winter of cold seasons which occur when diurnal temperature falls under comfort limit (C- diurnal thermal tension).

This condition in Tehran happens in from November, January to March. To obviate the problems, using appropriate thermal systems and thermal insulation is suggested.

Table 6. Realization

		J	F	M	A	M	J	J	A	S	O	N	D
Humidity Group		3	3	2	2	2	1	1	1	2	2	2	3
Temperature AMT		18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9	18.9
Monthly Maximum Average		8.3	10.7	15.8	22.8	28.2	34.4	36.9	35.9	31.7	24.6	16.4	10.1
Diurnal Comfort	Max	21	21	22	22	22	23	23	22	22	22	21	21
	Min	28	28	30	30	30	32	32	32	30	30	28	28
Monthly Minimum Average		0.8	2.3	6.5	12.6	17.3	22.3	24.9	24.4	20.5	14.6	8.1	2.8
Nocturnal Comfort	Max	14	14	14	14	14	14	14	14	14	14	14	14
	Min	21	21	22	22	22	23	23	23	22	22	21	21
Thermal Tension													
	Day	C	C	C	O	O	H	H	H	H	O	C	C
	Night	C	C	C	C	O	O	H	H	O	O	C	C

Table 7. Indices

		J	F	M	A	M	J	J	A	S	O	N	D	Total
Humidity														
H_1	Air Handling (Obligatory)													0
H_2	Air Handling (Obligatory)													0
H_3	Protecting Rain													0
Dryness														
A_1	Thermal Accumulation				✓	✓	✓	✓	✓	✓	✓			7
A_2	Sleeping Outside					✓	✓	✓	✓	✓	✓			6
A_3	Problems of Cold Season	✓	✓	✓								✓	✓	5

THE SUGGESTIONS OF SKETCH DESIGN FOR TEHRAN ARID REGION BASED ON MAHONEY METHOD

After completing the table of indices (7), the plan is ready to specify the needed characteristics. The suggestions depend on the months were one or some of A or H indices happen.

Table 8 helps in regulating the suggestions for some forms of the buildings which should be decided upon in sketch design stage. The suggestions are classified in eight categories: locating, spacing, air handling, outer repentant, openers, walls, ceilings, and rain protection.

Table 8. The Suggestions for Design Sketch for Tehran Arid Climate

Suggestions	**Sum of Indices from Table 4**					
	Dry			**Humid**		
	A_1	**A_2**	**A_3**	**H_1**	**H_2**	**H_3**
	7	6	5	0	0	0
Locating						
1. The buildings should be oriented to east-west direction not to be exposed to sun as possible. ✓	0-10					
	11Or12		5-12			
2. Compact design around a central yard.			0- 4			
Spacing						
3. Open spacing for wind penetration.						
4. Like 3, but preventing hot/cold wind.				11 Or 12		
5. Compact Design. ✓				2-10		
Air Handling				0 Or 1		
6. One-layer rooms, eternal conditions for air handling.						
	0-5			3-12		
7. Double-layered rooms with temporary conditions for air handling. ✓	6-12			1 Or 2		
				0	2-12	
8. No air handling is needed. ✓					0 Or 1	
Wall's openers						
9. Big openers, 40-80% from northern and southern walls.	1 - 0		0			

10. Very narrow openers, 10-20%.	11 Or 12		0 Or 1			
11. Mid openers, 20-40%. ✓	Any other Condition					
Walls						
12. Light walls, short delay time.	2 - 0					
13. Interior and exterior heavy walls. ✓	12 - 3					
Ceiling						
14. Insulated ceiling.	5 - 0					
15. Heavy ceiling. More than 8-hour delay. ✓	12 – 6					
Outside sleeping						
16. A space for sleeping outside is needed. ✓		12 - 2				
Rain protection						
17. Protection against heavy rain is needed						12 - 3

CONCLUSION

Climate change phenomenon can be strengthened as human activities and unsustainable developments in short terms intensify it so that negative effects are worsen day by day. We become aware that if climate change phenomenon continues with this trend, the most important achievement of human civilization which is urbanization is destroyed. The importance and the necessity of noting climatic changes has been verified in designing and constructing all buildings. In Tehran, noticing climatic characteristics and their effects on building formation is significant from to viewpoints: first, compatible buildings with climate or the buildings having a better quality with climatic design regarding human thermal comfort. Second, compatibility of a building with climatic conditions causes saving the energy consumption for controlling the comfort of these buildings. So, using the methods of architecture design and urbanism for saving energy and fuel consumption in buildings are an unalienable principle from every perspective which have a great importance in national and international level.

Based on the existing data and survey study done for the architecture of Tehran arid climate, some suggestions are presented. At the end, for higher compatibility of Tehran architecture with arid climate some suggestions are represented.

- If thermal accumulation is needed for ten months, the buildings should be laced in eastern-western direction toward north and south to reduce exposure to sun. The buildings may rotate a little to receive the prevailing wind or take a limited amount of heat from sun during the A3 cold season.
- If air handling (H_1) is needed for less than two months, the condensed designing is necessary.
- If air handling (H_1) is needed for less than two months, compact design is obligatory.
- If air handling (H_1) is needed for less than two months, the rooms may become double-layered. If there are months in which air handling is not necessary but desirable (H_2), the plan should provide temporary ventilation (e.g. plan can be double-layered while having connected and big doors). If the prevailing wind is uncertain or if site limitations stops the plan from air handling, roof fans should be installed. It should be done in sketch stage of designing because this height creates the rooms not less than 1.7 cubic meter.
- If air handling is not needed for gaining comfort or is needed for keeping comfort for one month, the rooms should be double-layered.
- In all other conditions, mid openers should be used (15-40% of the area of northern and southern walls). Until cold season gets long, the openers in eastern walls are appropriate. The openers of western walls are appropriate in cold and mild climates, but they should be avoided in hot areas.
- Sometimes thermal accumulation (A_1) is needed for three to twelve months. The interior and exterior walls should be heavy with high thermal capacity.
- If thermal accumulation (A_1) is needed for six to twelve months, a heavy ceiling should be used. Glass roof windows or roof skylight should never be used in hot regions.
- When A_2 index is enforced for more than one month, a space for sleeping out should be provided. The sleeping space on the ceiling, balcony or patio should be opened to sky in the coldest part of night to let the thermal waste be done by reverse shining.

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