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Research Paper

Investigating the Time Range of Architecture Compatible with Climate

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Abstract
Thermal comfort conditions include a range of temperature and moisture in which the regulatory mechanism of body temperature is at the lowest level of activity. This paper evaluates the thermal human comfort of bioclimatic conditions according to human comfort with analysis software. In this research, a descriptive-analytical method was utilized. Most of the data were gathered through library studies and required climate information was extracted from the data according to the weather station. In conclusion, the fall and winter seasons and the month of April have cold conditions. Therefore, applying mechanical heating and high thermal mass is needed for most of the year. One-third of a year has human comfort conditions. In this regard, natural and mechanical cooling is required for three months of the year due to warm conditions.

Keywords: *Time range, Architecture, Climate, Design, Zone.*

INTRODUCTION

Thermal comfort conditions include a range of temperature and moisture in which the regulatory mechanism of body temperature is at the lowest level of activity. Determining the thermal comfort zone has a direct impact on the thermal calculations of a building, the size of heating and cooling devices, insulation thickness, type of materials and consumption and waste of energy. Since individuals have the same thermal comfort in similar climatic conditions, the thermal comfort zone must be determined accurately for each climatic region (Kamyabi, 2015).

DEFINITIONS

Olgyay Bioclimatic Chart

One of the most useful factors for examining air temperature conditions in terms of comfort is the Olgyay bio-climatic table. In the 1960s, Olgyay presented a diagram in which the characteristics of the human comfort zone were determined in terms of dry temperature and relative humidity (Eskandarian, 2015).

The Olgyay Bioclimatic chart is the first bioclimatic chart that connects temperature and relative humidity to define a comfort zone (Santy, 2017). The durability of annual hot and cold weather in different cities, the degree of seriousness of thermal conditions, the type of mechanical systems, and the need for mechanical systems are determined according to the amount of moisture and the intensity of heat or cold (Kamyabi, 2015).

Terjung Index

This index is one of the most important bioclimatic indexes for assessing human comfort. One of the most important advantages of this index compared with other indexes is the simultaneous use of the highest number of climatic indexes which control

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the human body temperature. Using this index one can indicate the most preferable region for staying and living of people who suffer from climatic illnesses. Terjung is based on the comfort coefficient and wind cooling coefficient (Mogholi, 2014).

Thermo-hygrometric Index

The condition of thermo-hygrometric comfort or well-being can be defined, from the psychological point of view, as the psychophysical state in which the subject expresses satisfaction with the thermal environment, or, from the thermo-sensory viewpoint, such as the condition in which the subject does not feel sensation nor of hot or cold (that is a neutral thermo-hygrometric condition) (Cannistraro, 2015).

Dry bulb temperature and dew point temperature are used in this index. This index is used more in warm areas and does not work with windflaw. The thermo-hygrometric index is calculated by the following formula (Mogholi, 2014):

Equation 2: $DI=0.99T_d+0.36T_{dp}+41.5$

In this relation DI is the thermo-hygrometric index, Td is dry bulb temperature in degrees Celsius, and Tdp is dew point temperature in degrees Celsius (Hessari, 2018).

Wind-chill Index

Another coefficient of human comfort is the Wind-chill index or indeed the effect of wind drying. This index represents the amount of energy excretion in terms of kilocalories per hour from the surface of one square meter of the body and normal conditions, which means lack of physical activity and normal skin temperature, i.e. about 33 degrees Celsius (Ahmadi, 2013). The following formula is proposed to calculate the value of the Wind-chill index.

Equation 3: $H= (10.45+10\sqrt{V}-V)\times(33-T)$

V: The average wind speed in meters per second

T: The average temperature in degrees Celsius (Ghanbari, 2010).

Neurotic Pressure Index

This index is aimed to explain the level of comfort using temperature, humidity, and wind (Molanejad, 2015).

The Neurotic pressure index for temperatures below 20°C is:

Equation 4: $H=(0.57\times V^{0.42})(36.5-T)\times 36$

Where H is cooling power in kilo calories per hour per meter squared; T is air temperature in degrees Celsius; V is wind speed in meters per second (Ghalhari, 2019).

Location

Tehran is located at 35.41 north latitude and 51.15 east longitude and 1,200 meters above sea level (Affairs, 2017). Tehran is the capital of Iran and Tehran Province. With a population of around 8.7 million in the city and 15 million in the larger metropolitan area of Greater Tehran, Tehran is the most populous city in Iran and Western Asia and has the second-largest metropolitan area in the Middle East (after Cairo) (Wikimedia Foundation, 2021). The location of Tehran province is shown in Figure 1 and Figure 2.

Fig 1. Location of Tehran province in Iran (Yamaha5., 2013)

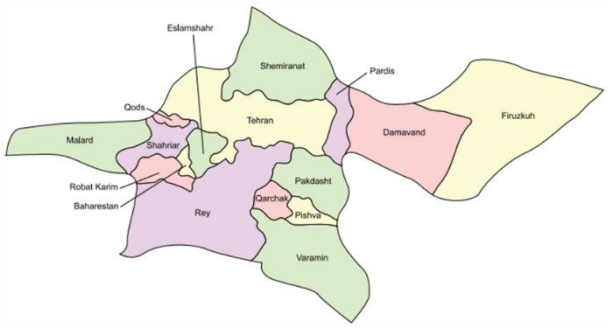


Fig 2. Map of Tehran Province (Affairs, 2017)

RESEARCH METHODOLOGY

In this study most of the data were gathered through library studies and required climate information was extracted from the data related to the weather station (Mehrabad Airport) in Tehran throughout a 10-year time period (2009-2019). Based on the data obtained from the mentioned station, required suggestions and solutions were presented. Table 1 indicates climate weather elements of rainfall, temperature, relative humidity and wind speed. Noted that the accuracy of dates shown as one month which includes more days due to simplifying analysis.

Table 1. Climate Data for Tehran City (Source: Authors)

Monthly amount of rainfall (mm)	Monthly average air temperature (°C)			Monthly average relative humidity (%)			Wind speed (m/s)	Month
	Monthly average range (°C)	Monthly average minimum (°C)	Monthly average maximum (°C)	Monthly average range (%)	Monthly average minimum (%)	Monthly average maximum (%)		
18.32	18.43	13.48	23.37	37.18	22.00	52.36	14.57	Annual
22.42	5.87	1.87	9.88	51.45	34.69	68.2	14.5	Dec 21-Jan 19 (Jan)
29.8	6.37	2.35	10.38	51.44	33.58	69.3	13.7	Jan 20-Feb 18 (Feb)
28.03	10.53	5.97	15.1	42.99	25.07	60.9	14.1	Feb 19-Mar 20 (Mar)
39.5	15.84	11.08	20.57	38.61	21.22	56	18.3	Mar 20-Apr 19 (Apr)
16.06	21.61	16.24	26.97	33.59	18.58	48.6	20.89	Apr 20-May 20 (May)
5.14	27.73	21.84	33.63	23.14	10.18	36.1	18.8	May 21-Jun 20 (Jun)
2.94	31.34	25.27	37.45	23.15	10.69	35.6	12.6	Jun 21-Jul 21 (Jul)
0	30.89	25.07	36.7	22.57	11.14	34	10	Jul 22-Aug 21 (Aug)
2.49	27.61	22.1	33.09	25.98	13.35	38.6	13	Aug 22-Sep 21 (Sep)
4.41	21.91	16.60	27.20	30.91	16.62	45.20	14.50	22 Sep- 21 Oct (Oct)
45.52	13.62	9.46	17.75	49.45	32.59	66.3	12.1	Oct 22-Nov 20 (Nov)
23.47	7.80	3.85	11.71	52.92	36.33	69.5	12.4	Nov 21-Dec 20 (Dec)

Assessing Olgyay Index

The following figure is obtained (derived) based on monthly temperature and moisture transfer over 10 years (2009-2019) using the BcChart v2.0 software.

In Figure 3, the basic bioclimatic chart of Tehran is plotted. This chart illustrates that the comfort zone is in the center with winter and summer ranges indicated separately. The chart also recommends the radiation needed zone, wind needed zone and shading needed zone to make the environment balanced and comfortable.

According to the collected data for the period of 2009-2019 from Mehrabad Airport station. The values of the mean daily minimum and maximum temperatures are combined with the maximum and minimum relative humidity, respectively. The lines are created representing the various months and reflect the external conditions. The bottom point of the straight line is the average minimum temperature with the AM (ante meridiem) relative humidity whereas the upper point of the line is the average minimum temperature with the PM (post meridiem) relative humidity. For better legibility, each month is drawn with a different color.

This chart shows that the daily time and nighttime temperature of November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20) and April (March 20- Apr 19) fall below the comfort zone. Therefore, passive solar heating is needed for the cold months of winter and the month of April.

The chart depicts that May (Apr 20- May 20) and October (22 Sep- 21 Oct) fall into two different zones. Half of these months fall under the comfort zone and the rest fall below the comfort zone. The promotion of passive solar heating and the prevention of heat losses are the main strategies that have to be employed.

About half of June (May 21- Jun 20) and September (Aug 22- Sep 21) fall in the comfort zone, about one-third of these months need utilization of natural ventilation. For the rest, direct evaporative cooling and high thermal mass are required.

A tiny part of July (Jun 21- Jul 21) and August (Jul 22- Aug 21) fall in the comfort zone, more or less than half of these months fall above the comfort zone. Therefore, three solutions can offer comfort conditions for these months. Natural ventilation is a solution to offer comfort for half of these months. Almost one-third of these monthly lines need direct evaporate cooling.

Assessing Evans index

For studying the heat condition of a place with the use of the Evans method we should: 1. For the average minimum relative humidity of each month, the range of comfort zone of the days of that month should be extracted from Table 2. For the average maximum relative humidity of each other, the range of the comfort zone of the nights of that month should be extracted from the same Table 3. The average of the maximum temperature of each month should be compared with the comfort zone of the day, 4. The average minimum temperature of each month should be compared with the comfort zone of the night (Nadimi, 2014). The different scales of Evans are shown in Table 2. The resulting heat conditions based on the Evans index are illustrated in Table 3.

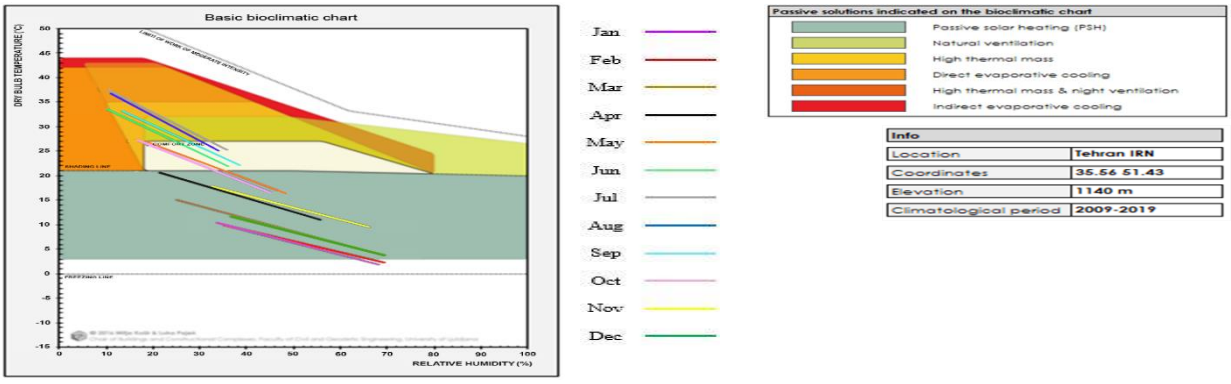


Fig 3. Basic Bioclimatic Analysis for the Location of Tehran (created using BeChart v2.0. Climate data, plotted as monthly daily average minimum and maximum with respect to the selected passive solutions) (Košir, 2017)

As shown in Table 3, the months of November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), and March (Feb 19- March 20) in Tehran is cold based on the Evans index.

April (March 20- Apr 19) in Tehran is cold based on the Evans index during day and night. Whereas, this month is cold at night.

The month of October (22 Sep- 21 Oct) is also cold at night whilst it has comfortable conditions for citizens who use thick blankets at night. This month has climate comfort in scale B (Area rug comfort zones per summer dress or a subtle style in the night air flow (0/1 meters per second)).

The months of June (May 21- Jun 20), July (Jun 21- Jul 21), August (Jul 22- Aug 21) and September (Aug 22- Sep 21) are hot during the day based on the Evans index. However, these months have climate comfort in scale B at night.

The month of May (Apr 20- May 20) has climate comfort in scale B during the day. This month has cold conditions while it has climate comfort in scale C (Per ordinary clothes and warm and comfortable areas of thick blankets at night).

Assessing Backer's index

The degrees of cooling power of the environment's bioclimatic thresholds according to the Backer index are illustrated in Table 4. The estimation of the power of the cooling index and human climate comfort by Backer's method according to Eq. 1, is shown in Table 5. In this table, the backer index is estimated for day and night based on monthly temperature and wind speed over 10 years (2009-2019).

Table 2. Different Scales Used in the Evans' Model (Barahouei Nezhad, 2018)

Daily temperature (°C)	Night temperature (°C)	Relative humidity (%)	Thermal conditions	Scale
29.5-32.5	27.5-29.5	0-30	Groups comfortable air flow per area of 1 meter per second	A
28.5-30.5	26.5-29	30-50		
27.5-29.5	26-28.5	50-70		
26-29	25.5-28	70-100		
22.5-30	20-27.5	0-30	Area rugs comfort zones per summer dress or a subtle style in the night air flow (0/1 meters per second)	B
22.5-28	20-26.5	30-50		
22.5-27.5	20-26	50-70		
22.5-27	20-25.5	70-100		
18-20	16-20	0-30	Per ordinary clothes and warm and comfortable area of thick blankets at night	C
18-20	16-20	30-50		
18-20	16-20	50-70		
18-20	16-20	70-100		

Table 3. Tehran Temperature Based on the Evans Index

Scale	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Period
A	Cold	Cold	Cold	Cold	Cold	Hot	Hot	Hot	Hot	Cold	Cold	Cold	
B	Cold	Cold	Cold	Cold	ok	Hot	Hot	Hot	Hot	ok	Cold	Cold	Day
C	Cold	Cold	Cold	Hot	Hot	Hot	Hot	Hot	Hot	Hot	Cold	Cold	
A	Cold	Cold	Cold	Cold	Cold	Cold	Cold	Cold	Cold	Cold	Cold	Cold	
B	Cold	Cold	Cold	Cold	Cold	ok	ok	ok	ok	Cold	Cold	Cold	Night
C	Cold	Cold	Cold	Cold	ok	Cold	Hot	Hot	Hot	ok	Cold	Cold	

Table 4. Degrees of the cooling power of the Environment Bioclimatic thresholds based on Backer review (Hessari, 2018)

Sign		Amount	Environmental conditions	Human bioclimatic conditions
A		0-4	Hot and humidity and undesirable	Bioclimatic pressure
B	B1	5-9	Bioclimatic welfare	Warm and tolerable
	B2	10-19	Bioclimatic welfare	Desirable moderate
C		20-29	Cool	moderate
D	D1	30-39	Moderate to extreme	Cold and a bit restrainer
	D2	40-49	Restrainer moderate	Very cold
	D3	50-59	Extremely restrainer	Extreme cold

Table 5 reveals that December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), and March (Feb 19- March 20) have extremely cold human bioclimatic conditions. The months of April (March 20- Apr 19) and November (Oct 22- Nov 20) have very cold human bioclimatic conditions. The Human bioclimatic conditions of the months of May (Apr 20- May 20) and October (22 Sep- 21 Oct) are cold and a bit restrainer. The human bioclimatic conditions of the month of August (Jul 22- Aug 21) are warm and tolerable. The month of July (Jun 21- Jul 21) and September (Aug 22- Sep 21) has desirable moderate human bioclimatic conditions. The only month that has moderate human bioclimatic conditions is June (May 21- Jun 20).

Assessing Terjung Index

Figure 4 is used to indicate the comfort coefficient. This graph shows the comfort human obtains in situations of different mixtures of temperature, humidity, and in normal situations in normal clothing and without physical activity (Mogholi, 2014).

In this chart, the horizontal axis indicates the temperature in Fahrenheit, and the curves illustrate the humidity in percentage. Where these two climatic factors encounter happened in different places which are shown by different numbers and symbols in Table 6. According to Figure 4 and Table 6, the human comfort coefficient at the region in which we do research is shown in Table 7.

Mehrabad Airport weather station 10-year statistics are utilized to calculate the Terjung comfort index in Tehran City (Table 7). Calculations reveal that human bioclimatic conditions are keen in the months of November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20), and April (March 20- Apr 19). Another point is that the physiologic changes in fall are almost sudden in a way that between two months of October (22 Sep- 21 Oct) and November (Oct 22- Nov 20) the situation changes from moderate to keen. Moreover, the situation changed inversely from keen to moderate, between two months of April (March 20- Apr 19) and May (Apr 20- May 20). However, the physiologic slow transition in summer makes the living situation pleasant in Tehran in a way that the comfort coefficient changes between the two months of September (Aug 22- Sep 21) and October (22 Sep- 21 Oct) and inversely from warm to moderate between the two months of June (May 21- Jun 20) and July (Jun 21- Jul 21) moderate to warm. The months of July (Jun 21- Jul 21), August (Jul 22- Aug 21) and September (Aug 22- Sep 21) have warm human bioclimatic conditions. The two months of the spring season as well as May (Apr 20- May 20) and June (May 21- Jun 20) have moderate dominant feeling.

Assessing Terjung Index during the Day

The day comfort coefficient from the relative maximum daily temperature average in Fahrenheit and relative minimum daily humidity in percent is utilized to show the day comfort coefficient in different months of the year according to Terjung. Therefore, the day comfort coefficient for Tehran is illustrated in Table 8.

Table 5. Cooling Power of the Environment Bioclimatic Thresholds of the Months of the Year Based on the Backer Index (Source: Authors)

Scale		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum Temperature (°C)		9.88	10.38	15.1	20.57	26.97	33.63	37.45	36.7	33.09	27.2	17.75	11.71
Average minimum temperature (°C)		1.87	2.35	5.97	11.08	16.24	21.84	25.27	25.07	22.1	16.6	9.46	3.85
Average temperature (°C)		5.87	6.37	10.53	15.84	21.61	27.73	31.34	30.89	27.61	21.91	13.62	7.8
Average wind speed (m/s)		14.5	13.7	14.1	18.3	20.89	18.8	12.6	10	13	14.50	12.1	12.4
Cp index (mcal/cm^2/sec)	Night	60.87	52.29	35.64	21.86	19.63	28.51	41.84	51.13	62.99	72.82	69.59	63.21
	Sign	D3	D3	D1	C	B2	C	D2	D3	D3	D3	D3	D3
	Day	38.15	24.60	6.98	-1.85	-0.34	6.75	19.56	35.69	47.83	55.97	53.23	44.31
	Sign	D1	C	B1	A	A	B1	B2	D1	D2	D3	D3	D2
	Total	49.48	38.43	21.32	10.04	9.63	17.60	30.68	43.55	55.37	64.41	61.40	53.77
	Sign	D2	D1	C	B2	B1	B2	D1	D2	D3	D3	D3	D3

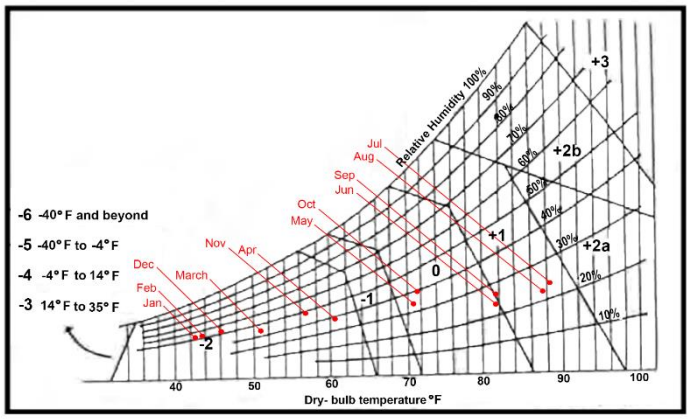


Fig 4. Comfort Limit Coefficient Based on Terjung (Hessari, 2018)

Table 6. Terjung Concepts, Symbols, and Signs (Hessari, 2018)

Symbol	Dominant feeling	Group
-6	Ultra cold	Uc
-5	Extremely cold	Ec
-4	Very cold	Vc
-3	Cold	Cd
-2	Keen	K
-1	Cool	C
0	Moderate	M
+1	Warm	W
+2a	Hot	H
+2B	Very hot	S
+3	Extremely hot	Eh

Table 7. Terjung Index (Source: Authors)

Scale	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average relative humidity (%)	51.45	51.44	42.99	38.61	33.59	23.14	23.15	22.57	25.98	30.91	49.45	52.92
Average temperature (°F)	42.57	43.47	50.95	60.51	70.90	81.91	88.41	87.60	81.70	71.44	56.52	46.04
Comfort coefficient	-2	-2	-2	-2	0	0	+1	+1	+1	0	-2	-2
monthly	Keen	Keen	Keen	Keen	Moderate	Moderate	Warm	Warm	Warm	Moderate	Keen	Keen

Table 8. Terjung Index (source: Authors)

Scale	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum temperature (°F)	49.78	50.68	59.18	69.03	80.55	92.55	99.41	98.06	91.56	80.96	63.95	53.08
Average minimum relative humidity (%)	34.69	33.58	25.07	21.22	18.58	10.18	10.69	11.14	13.35	16.62	32.59	36.33
Comfort index	-2	-2	-2	-1	+1	+1	+2a	+2a	+1	0	-2	-2
Comfort index for day	Keen	Keen	Keen	Coold	Warm	Warm	Hot	Hot	Warm	Moderate	Keen	Keen

In order to calculate the Terjung comfort index during the day in Tehran, Mehrabad weather station 10-year statistics are utilized. As shown in Table 7, the bioclimatic conditions are the same as in Table 8, the dominant feeling is keen during the day in November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18) and March (Feb 19- March 20). Moreover, the physiologic change during the day is almost sudden in a way that between two months of October (22 Sep- 21 Oct) and November (Oct 22- Nov 20) the situation changes from moderate to keen.

But there is a slight change in bioclimatic conditions during the day from cool to warm between April (March 20- Apr 19) and May (Apr 20- May 20) and the inverse progress between June (May 21- Jun 20) and July (Jun 21- Jul 21) from hot to warm. The only month which has moderate conditions during the day is October (22 Sep- 21 Oct).

Assessing Terjung Index at Night

Table 9 indicates Tehran's comfort coefficient of night. The night comfort coefficient during the year based on Terjung is calculated from the average of daily minimum temperature in Fahrenheit and the average of daily maximum relative humidity in percent. The physiologic situation of Tehran is calculated and illustrated again based on Terjung and the results are shown.

Table 9 reveals that according to the Terjung index, the human bioclimatic conditions of October (22 Sep- 21 Oct), November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20), April (March 20- Apr 19) and May (Apr 20- May 20) have keen bioclimatic conditions at night. The human bioclimatic conditions of June (May 21- Jun 20), July (Jun 21- Jul 21), August (Jul 22- Aug 21) and September (Aug 22- Sep 21) have moderate bioclimatic conditions at night.

Assessing Thermo-hygrometric Index

In this index, if the DI is between 60 and 75, the human bioclimatic situation is equal to comfort feeling (A), and if it is less than 60 coldness feeling (B) and more than 75, about 50% of people get irritated of heat (C), and if this coefficient passes 80, all of the people suffer from the heat (Mogholi, 2014).

Monthly statistics of the Mehrabad weather station during a 10-year period from 2009 to 2019 are utilized in this study in order to calculate the Thermo-hygrometric index by Eq. 2 in Tehran City which is shown in Table 10.

Table 10 shows that based on the Thermo-hygrometric index, the months of May (Apr 20- May 20), June (May 21- Jun 20), August (Jul 22- Aug 21), September (Aug 22- Sep 21) and October (22 Sep- 21 Oct) have human bioclimatic conditions that illustrate comfort feeling (A), the human bioclimatic conditions of November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20) and April (March 20- Apr 19) illustrate coldness feeling (B) and July (Jun 21- Jul 21) is the only month with the bioclimatic conditions which people feel warm in (C).

Assessing Wind-chill index

For calculating the Wind-chill index of Tehran City Monthly statistics of Mehrabad weather station for 10 years from 2009 to 2019 are utilized which is shown in Table 12 that is based on Table11 that illustrates the dominant feeling of the Wind-chill index, in accordance with Equation 3.

Table 9. Terjung Index (Source: Authors)

Scale	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average maximum relative humidity (%)	68.2	69.3	60.9	56	48.6	36.1	35.6	34	38.6	45.20	66.3	69.5
Average minimum temperature (°F)	35.37	36.23	42.75	51.94	61.23	71.31	77.49	77.13	71.78	61.88	49.03	38.93
Comfort index	-2	-2	-2	-2	-2	0	0	0	0	-2	-2	-2
Comfort index for night	Keen	Keen	Keen	Keen	Keen	Moderate	Moderate	Moderate	Moderate	Keen	Keen	Keen

Table 10. Thermo-hygrometric index (Source: Authors)

Scale	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average dew point temperature (°C)	-3.38	-2.92	-1.54	1.76	4.90	4.80	7.83	7.08	6.37	3.97	3.23	-1.21
Average temperature (°C)	5.87	6.37	10.53	15.84	21.61	27.73	31.34	30.89	27.61	21.91	13.62	7.8
symbol	B	B	B	B	A	A	C	A	A	A	B	B
Thermo-hygrometric index	46.09	46.75	51.37	57.82	64.66	70.68	75.34	74.63	71.13	64.62	56.15	48.79

Table 11. Dominant feeling of Wind-chill index (Hessari, 2018)

Amount	Symbol	Dominant feeling
< -1400	-h	Meat freezes at this temperature
-1400 to -1200	-g	Extremely cold
-1200 to -1000	-f	uncomfortably cold
-1000 to -800	-e	Cold
-800 to -600	-d	Too cool
-600 to -300	-c	Cool
-300 to -200	-b	Comfortable and pleasant
-200 to -50	-a	Warm
-50 to 80	N	Not warm, not cold
80 to 160	A	Warm feeling on skin
80 to 160	B	feeling of unpleasant heat
160 >	C	Feeling of very unpleasant extra heat

Table 12. Dominant feeling of the months of the year according to the Wind-chill Index (Source: Authors)

Scale	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average Maximum temperature (°C)	9.88	10.38	15.1	20.57	26.97	33.63	37.45	36.7	33.09	27.2	17.75	11.71
Average Minimum temperature (°C)	1.87	2.35	2.97	11.08	16.24	21.84	25.27	25.07	22.1	16.6	9.64	3.85
Average temperature (°C)	5.87	6.37	10.53	15.84	21.61	27.73	31.34	30.89	27.61	21.91	13.62	7.8
Average Wind Speed (m/s)	14.5	13.7	14.1	18.3	20.89	18.8	12.6	10	13	14.5	12.1	12.4
H at night	1059.32	1034.85	1018.02	765.63	591.05	390.70	257.77	254.34	365.21	558.07	774.03	969.63
Sign	C	C	C	C	C	C	C	C	C	C	C	C
H for day	786.75	763.73	606.81	434.16	212.65	-22.06	-148.39	-118.67	-3.02	197.37	505.31	708.18
Sign	C	C	C	C	C	N	-a	-a	N	C	C	C
H for each month	923.20	899.12	761.73	599.37	401.67	184.50	55.36	67.67	180.59	377.38	642.16	838.24
Sign	C	C	C	C	C	C	N	N	C	C	C	C

Table 12 shows that based on Wind-chill index, the months of April (March 20- Apr 19), May (Apr 20- May 20), June (May 21- Jun 20), July (Jun 21- Jul 21), August (Jul 22- Aug 21), September (Aug 22- Sep 21), October (22 Sep- 21 Oct), November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20) have human bioclimatic conditions that people feel very unpleasant extra heat at night.

The human bioclimatic conditions of the months of October (22 Sep- 21 Oct), November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20), April (March 20- Apr 19) and May (Apr 20- May 20) are very unpleasant extra heat during the day. The human bioclimatic conditions of the two months of June (May 21- Jun 20) and September (Aug 22- Sep 21) are not warm, nor cold (moderate) during the day. The two months of July (Jun 21- Jul 21) and August (Jul 22- Aug 21) have human bioclimatic conditions that people feel warm during the day.

Ten months in a year have human bioclimatic conditions in which citizens feel very unpleasant extra heat. These months are sequence are September (Aug 22- Sep 21), October (22 Sep- 21 Oct), November (Oct 22- Nov 20), December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), March (Feb 19- March 20), April (March 20- Apr 19), May (Apr 20- May 20), June (May 21- Jun 20). The bioclimatic conditions of the two months of July (Jun 21- Jul 21) and August (Jul 22- Aug 21) are moderate (not warm, not cold).

Assessing Neurotic Pressure Index

Degrees of Neurotic Pressure comfort index are indicated in Table 13. Additionally, the results derived from calculating the neurotic pressure index of Tehran City based on Monthly statistics of the Mehrabad weather station during a 10-year period from 2009 to 2019 are shown in Table 14. These results are by Equation 4 and Equation 5.

As shown in Table 14 based on the Neurotic Pressure comfort index (Equation 3 and Equation 4), the human bioclimatic conditions in December (Nov 21- Dec 20), January (Dec 21- Jan 19), February (Jan 20- Feb 18), and March (Feb 19- March 20) are in a way that skin freezes fast.

The comfort coefficients of April (March 20- Apr 19) and November (Oct 22- Nov 20) show that the human bioclimatic conditions are extremely cold.

The month of May (Apr 20- May 20) is cool with uncomfortable bioclimatic conditions.

The months of July (Jun 21- Jul 21) and August (Jul 22- Aug 21) are warm with uncomfortable bioclimatic conditions. The human bioclimatic conditions in June (May 21- Jun 20), September (Aug 22- Sep 21) and October (22 Sep- 21 Oct) are warm with comfortable.

Assessing comfort zone according to the Givoni index using the psychometric chart in Climate Consultant software

In accordance with statistical information, by transferring the average maximum monthly temperature over 10 years (2009-2019) and average minimum monthly temperature on the chart and also finding monthly relative humidity on it, the following results in Table 16 are obtained. Climate Consultant software proposes sixteen passive strategies in this chart, as shown in Table 15. Based on Table 15, we can attempt to achieve the necessary comfort conditions inside the building based on the climatic and constructional characteristics of the region.

Figure 5 shows that April (March 20- Apr 19) and November (Oct 22- Nov 20) require internal heat gain. The months of January (Dec 21- Jan 19), February (Jan 20- Feb 18) and December (Nov 21- Dec 20) require two design strategies as well as heating, and humidification if needed and wind protection of outdoor spaces.

The month of March (Feb 19- March 20) also requires heating, and adding humidification if needed.

The months of April (March 20- Apr 19) and November (Oct 22- Nov 20) need internal heat gain.

The months of May (Apr 20- May 20) and October (22 Sep- 21 Oct) are in the human comfort zone if people wear winter clothing. Furthermore, the months of June (May 21- Jun 20) and September (Aug 22- Sep 21) have human comfort conditions if people wear summer clothing.

The months of July (Jun 21- Jul 21) and August (Jul 22- Aug 21) need natural ventilation cooling. The results are also illustrated in Table 16.

Table 13. Dominant Feeling of the Months of the Year According to the Wind-chill Index (Source: Authors)

Comfort coefficient for temperatures above 20 °C		**Comfort coefficient for temperatures below 20 °C**	
Comfort coefficient	**Heating condition**	**Comfort coefficient**	**Heating condition**
<-5	Cool with uncomfortable condition	395 to 540	Cool
-5 to -1	Cool with uncomfortable condition	540 to 790	Too cool
0	Comfortable	790 to 1000	Cold
1 to 5	Warm with comfortable	1000 to 1200	Too cold
5 to 10	Warm with uncomfortable	1200 to 1440	Extremely cold
10 to 15	Extremely uncomfortable	+1440	Skin freezes fast
+15	Totally uncomfortable	-	-

Table 14. Heating Conditions of the Months of the Year Based on Neurotic Pressure Comfort Index (Source: Authors)

Scale	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average temperature (°C)	5.87	6.37	10.53	15.84	21.61	27.73	31.34	30.89	27.61	21.91	13.62	7.8
Average wind speed (m/s)	14.5	13.7	14.1	18.3	20.89	18.8	12.6	10	13	14.50	12.1	12.4
Comfort coefficient (kcal/h/m^2)	1932.41	1856.09	1619.28	1437.27	-3.31	2.47	6.07	5.56	2.59	-3.07	1337.84	1695.49
Comfort degree	Skin freezes fast	Skin freezes fast	Skin freezes fast	Extremely cold	Cool with uncomfortable condition	Warm with comfortable	Warm with uncomfortable	Warm with uncomfortable	Warm with comfortable	Warm with comfortable	Extremely cold	Skin freezes fast

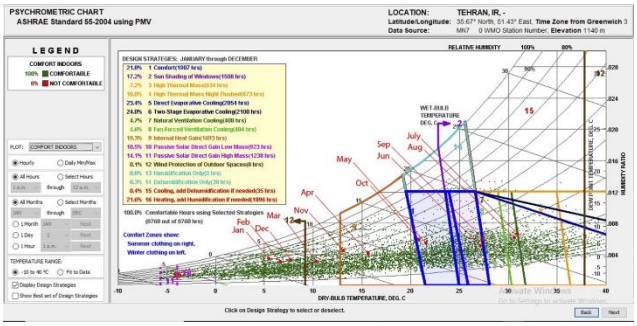
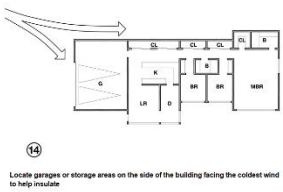
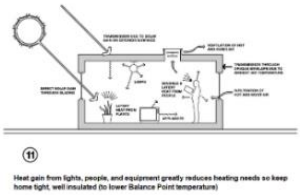
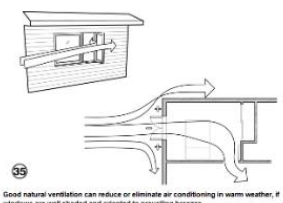


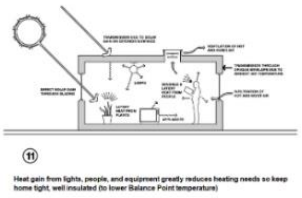
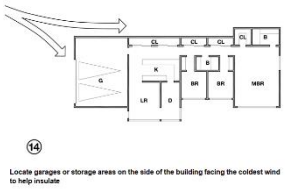
Fig 5. Climate Consultant Display of the Building Bioclimatic Chart for Tehran City (Climate Consultant 6.0)

Table 15. Design Strategies of Climate Consultant (Climate Consultant 6.0)

Number	Design Strategies	Percentage
1	Comfort	21.8%
2	Sun shading of windows	17.2%
3	High thermal mass	7.2%
4	High thermal mass night flushed	10%
5	Direct evaporative cooling	23.4%
6	Two-stage evaporative cooling	24%
7	Natural ventilation cooling	4.7%
8	Fan-forced ventilation cooling	4.6%
9	Internal heat gain	19.3%
10	Passive solar direct gain low mass	10.5%
11	Passive solar direct gain high mass	14.1%
12	Wind protection of outdoor spaces	0.1%
13	Humidification only	0%
14	Dehumidification only	0.3%
15	Cooling, add dehumidification if needed	0.4%
16	Heating, add humidification if needed	21.6%

Table 16. Design Strategies for all Months According to Climate Consultant (Source: Authors)

Month	Examples of strategies	Number	Relative humidity (%)	Temperature (°C)
Jan		12-16	51.45	5.87
Feb		12-16	51.44	6.37
Mar		12-16	42.99	10.53
Apr		9	38.61	15.84
May		1	33.59	21.61
Jun		1	23.14	27.73
Jul		7	23.15	31.34
Aug		7	22.57	30.89

Month	Examples of strategies	Number	Relative humidity (%)	Temperature (°C)
Sep		1	25.98	27.61
Oct		1	30.91	21.91
Nov		9	49.45	13.62
Dec		12-16	52.92	7.80

Assessing Ecotect Analysis

The wind analysis graphs in Figure 6 display wind frequency, direction and speed, average wind temperature, average relative humidity and average rainfall. This is analyzed over the year, so it is possible to determine the predominant wind direction during a year.

The calculation in Figure 7 is done for the full 360 degrees. Under-heated/overheated values indicate the most favorable range of orientations for passive solar heating, whilst still considering the effects of unwanted solar gains in summer. The best orientation is 180°.

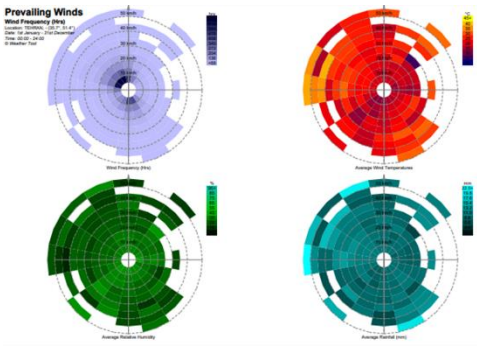


Fig 6. Multiple Information Graphs of Prevailing Winds of Tehran City (Autodesk Ecotect Analysis 2011)

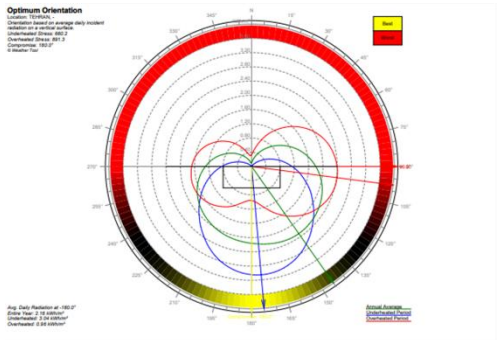


Fig 7. Optimum Orientation Based on Average Daily Incident (Autodesk Ecotect Analysis, 2011)

CONCLUSION

Monthly statistics of Mehrabad weather station in 10 years from 2009 to 2019 are utilized in this study to calculate the indices as well as Olgyay, Evans, Backer, Terojung, Thermo-hygrometric, Wind-chill and Neurotic Pressure comfort index and Climate consultant analysis tool.

Table 17 illustrates the comparison between human bioclimatic conditions in Tehran for all months of the year according to bioclimatic indices and climatic analysis tools. In this table, the eight indices are placed in the first column and 12 months are placed in the other columns. In the description of the results of these indices, to simplify the comparison of the results, they are named in three classifications warm, moderate and cold. For each month, bioclimatic conditions are determined by more the same classifications of the results derived from indices that special month has. For instance, the month of April (March 20- Apr 19) from the point of view of seven indices has cold conditions but from the point of one index, it has warm bioclimatic conditions. Accordingly, this month has cold bioclimatic conditions.

The Olgyay chart depicts that the winter season and the months of November, December, and April have cold conditions. Half of the months of May and October are in the comfort zone and the rest need the promotion of passive solar heating and the prevention of heat losses. Nearly half of June and September fall in the comfort zone, and the rest require utilization of natural ventilation and direct evaporative cooling and the others require high thermal mass. A tiny part of July and August fall in the comfort zone. For the rest, natural ventilation and direct evaporate cooling should be employed. So, according to the Olgyay index, more than half of the year has cold conditions and it needs passive solar heating, and the rest needs natural ventilation and cooling. And more or less than four months of a year have human comfort conditions. Considering the Evans index, the winter season and the months of November, December, April, and May have cold bioclimatic conditions. The months of June, August, and October have human comfort. Whereas, the months of July and September have warm conditions. Therefore, based on the Evans comfort index, more than half of the year is cold and needs heating and the rest of the year has human comfort. According to the Backers index, the winter and fall seasons and the months of April and May have cold bioclimatic conditions. However, the only month that has warm conditions is August. Months of June and September have human comfort conditions. So, based on the Backer index, this city has a cold and a little comfortable bioclimatic condition. In accordance with the Terjung index, the winter season and the months of November, December, and April have cold conditions. Whilst the summer season has warm conditions. Furthermore, bioclimatic conditions of the months of May, June, and October are comfortable. Thus, most of the year in Tehran City has cold conditions and the rest are warm and comfortable.

Table 17. Comparison of Bioclimatic Conditions in Tehran City (Source: Authors)

Scale	Jan (Dec 21- Jan 19)	Feb (Jan 20- Feb 18)	Mar (Feb 19- Mar 20)	Apr (Mar 20- Apr 19)	May (Apr 20- May 20)	Jun (May 21- Jun 20)	Jul (Jun 21- Jul 21)	Aug (Jul 22- Aug 21)	Sep (Aug 22- Sep 21)	Oct (22 Sep- Oct 21)	Nov (Oct 22- Nov 20)	Dec (Nov 21- Dec 20)
Backer	Extremely cold	Extremely cold	Extremely cold	Very cold	cold	Moderate	Moderate	Warm	moderate	cold	Very cold	Extremely cold
Climate consultant	Very cold	Very cold	Very cold	cold	comfortable	comfortable	warm	warm	comfortable	comfortable	cold	Very cold
Evans	cold	cold	cold	Cold	cold	comfortable	Warm and comfortable	comfortable	Warm and comfortable	comfortable	cold	cold
Neurotic Pressure	Skin freezes fast	Skin freezes fast	Skin freezes fast	Extremely cold	Cool with uncomfortable condition	Warm with comfortable	Warm with uncomfortable	Warm with uncomfortable	Warm with comfortable	Warm with comfortable	Extremely cold	Skin freezes fast
Olgyay	Extremely cold	Extremely cold	Extremely cold	Cold	cold and comfortable	Warm and comfortable	Warm	Warm	Warm and comfortable	cold and comfortable	Cold	cold
Terjung	Keen	Keen	Keen	Keen	Moderate	Moderate	Warm	Warm	Warm	Moderate	Keen	Keen
Thermo-hygrometric	Cold	Cold	Cold	Cold	comfortable	comfortable	warm	comfortable	comfortable	comfortable	Cold	Cold
Wind-chill	extremely hot	extremely hot	extremely hot	Extremely hot	Extremely hot	Extremely hot	Moderate	Moderate	extremely hot	extremely hot	extremely hot	extremely hot
Result	cold	cold	cold	cold	Cold-comfortable	comfortable	warm	Warm	Warm-comfortable	comfortable	cold	cold

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