INVESTIGATION OF APPARENT TEMPERATURE IN DIFFERENT CLIMATES
(case study: Yazd and Coastal Bushehr)

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ABSTRACT
Evaluating of climate situations related to human comfort is the major concern of architecture, urbanization and tourism. Therefore, estimating and comparison human comfort in different climates would be necessary. In this research, in order to the assessment of human comfort, two different climates of Iran(central parts and humid coastal of Persian Gulf) were considered by using of Apparent Temperature index (AT) .Yazd and Bushehr are two cities that were selected as a sample of arid and humid climates, respectively. Mean temperature, mean highest temperature, mean relative humidity and mean lowest relative humidity during two decades (1991-2010) from Iran Meteorological Organization were obtained. The results show that during warm months, due to increasing temperature the risk of heat stroke and other health problems is imminent.

Keywords: *human comfort, apparent temperature, bioclimatic indices, Yazd, Bushehr.*

1. Introduction
Urban climate studies have a strong potential to provide vital information around improvement of human thermal comfort conditions in cities. Today, bioclimatic studies are the basis for architectural activities, urban planning and tourism (Olgyay, 1963; Schiller and Evans, 1999; Johansson, 2005; Ali-Toudert and Mayer, 2006; Matzarakis, 2006; De Cosata Silva at el., 2008; Farajzdeh and Matzarakis, 2011; Matzarakis et al., 2011; Berkovic et al., 2012; Yilmaz et al., 2013; Taleb, 2014).
Researchers have a long recognized that the human thermal comfort is not assessment only by temperature, but other meteorological parameters have involved in the temperature that a person feels. For this purpose, numerous studies have been done over years that give a measure of how comfortable a person feels based on current weather conditions (Hevener, 1959; Thom, 1959; Rackliff, 1965; Houghes, 1967; Masterton and Richardson, 1979; Steadman 1979; Steadman 1984; Hoppe 1999; Jendritzky et al. 2001, Matzarakis, 2012). The indices which is produced through bioclimatic branch, present the complicated (and elaborate) effect of climate variables on mankind. The indices are shown as numerical values to become understandable for people, and to provide comparisons for different climates and areas through bioclimatic concepts. The results of such studies lead to three group of indices. The first group called empirical indices like heat index (Steadman, 1984), wind chill (Siple and Passel, 1945; Steadman, 1971). The second group is synthetic and bioclimatic indices, such as Terjung index (Terjung, 1968) and Olgyay index (Olgyay, 1973). And the tired set was derived from thermo-physiology, and the most renowned ones are Physiological Equivalent temperature PET(Matzarakis and Mayer 1996; VDI 1998; Ho¨ppe 1999; Matzarakis at al. 1999), Predicted mean vote PMV (Fanger 1972), Standard Effective Temperature SET* (Gagge et al. 1986), and Outdoor Standard Effective Temperature OUT_SET* (Spognolo and De Dear 2003), Universal Temperature Climate Index (UTCI) (Jendritzky et al., 2001; Sookuk et al., 2014).
One of well-known index which is developed by Steadman (1984) is heat index or apparent temperature (AT). The heat index which is reported by National Weather Service (NWS) is an approximation of Steadman (1979a, 1979b, 1984) AT tables (NWS, 1992). This index after modification from summer 1987 was used by International Weather Organization of USA (National Oceanic Atmospheric Administration) (NOAA) (Climate Analysis Center, 1987). And then, the index in order to analysis of the human thermal comfort conditions due to climatic parameters was interested in using by other Countries Weather Organization services such as England and New Zealand (Dioxin, 1991).
In fact, there are “no” true equation for calculating heat index. Heat index are gained from a combined equations and assumptions based on extensive biometeorological studies (Steadman, 1979a, 1979b). Each of its below assumptions obtained by separate equation, but in below in order to simplify, try not to define these equation and also the amounts which are seen in parentheses assumed magnitude (Steadman, 1979a). These assumptions are as follow:
1-ambient vapor pressure of atmosphere (1.6Kpa), 2-dimension of human body, 3- effective radiation area(0.8), 3-significant diameter of human body (15.3 cm), 4-clothing cover (assumed 84% coverage), 5- core body temperature

(37^0 C), 6-core body vapor pressure and salinity(5.65 kPa), 7- heat transfer from the skin's surface either by radiation or convection, 8- effective wind speed, 9- level of activities which is assumed 180 Wm^{-2} for a person walking outdoors at a speed of 1.4 ms^{-1}, 10- clothing resistance to heat transfer according to the assumption of 20% fiber and 80% air,11- clothing to moisture heat transfer, 12- radiation from the skin surface, 13- sweating rate
Other assumptions that must be taken into account are: 1- Ventilation rate: the amount of heat lost via exhaling (2-12%, depending upon humidity). 2- Skin resistance to heat transfer as function of activity and skin temperature. 3- Skin resistance to moisture transfer as function of the vapor pressure difference across the skin. This value decreases with increasing activity. 4- Surface resistance to heat transfer, this value decreases if radiation and convection from the skin increases. 5- Surface resistance to moisture transfer: the value is similar to heat transfer resistance but also depends upon conditions in the boundary layer just above skin's surface.
Some of these assumptions may seem insignificant and trivial but a forecaster must be able to use them when writing public information statement in regard to heat stress, heat stroke, etc. The last five parameters are explicitly used in heat index equation. By an iterative procedure which depends upon the first assumptions, the model is able to reduce itself to a relationship between dry bulb temperature at different humidity and the skin's resistance to heat and moisture transfer. Ultimately, we have a relationship between ambient temperature and relative humidity (Rothfuz, 1990). Increasing or decreasing in humidity and temperature result in increasing or decreasing in AT values. Note that AT could be less than air temperature. According to these assumptions and the relationship, Steadman (1979) developed a table for reporting AT values in different temperature and humidity. But the table published after modification that was done by Steadman (1994) is the same table that was done by him (table2).
Note that AT depends on the ability of human body to release heat load from itself and also depends on water vapor pressure difference between the evaporative skin surface and its surroundings. Increasing humidity in the air result in decreasing evaporation from the skin, consequently the body feels discomfort. Such a perceived temperature is AT which heavily depends upon the amount of water vapor in the air.
Since weather organizations and also other related organizations in Iran report none of such these indices; so, the importance of such a research for different climatic areas in Iran cannot be ignorable.

2. DATA

Case studies

2.1. Yazd

Yazd is the administrative of its Province, with geographical location of 31^0 54' N, 54^0 24' E, and 1230m elevation (Fig.1) and with only mean annual 60mm precipitation (Fig.2) known as the major driest part in north of Persian Gulf (Fig.1).
In regard to geographical location of Yazd, The climate of the city is associated with the climate of central Iranian Plateau, although the Shirkooh height which is located not far from the city, have great impact on its harsh climatic conditions and its influence on continuing of the city's life cannot be ignorable. The most influenced factors on climatic the city are as follow:

a- Its location and near to the Salt Desert -very dry and vast desert in Iran- (this factor causes great fluctuations in temperature, So that the difference between the temperature during the day and night in various seasons are noticeable).
b- The effect of subtropical high pressure
c- Far from seas (Persian Gulf, Caspian Sea and Oman sea), and also lack of internal lakes
d- Having very low precipitation , relatively low humidity, overheating and intense evaporation

Because of all of these factors this part of Iran turned to the driest parts.

2.2. Coastal Bushehr

Bushehr lies in a vast plain running along the coastal region on the Persian Gulf, southwestern Iran (Fig. 1). It was the main seaport of the country and is the administrative center of its province. Bushehr city divided two parts, coastal parts and the other parts. Coastal bushehr is the old parts of the city and almost the major markets and industries established there. The local climate is humid.
The area was located in 28^0 54' N and $50^0$49' E with 8.4m elevation (Fig.1). Annual mean humidity is around 71% and annual mean temperature is around 25^0 C and means precipitation was 217 mm recorded (Fig. 3). During hot summer time the temperature goes 50^0 C and the minimum temperature in winter is about 6^0 C recorded.
Sultry phenomenon is the most significant climatic feature of the city. High humidity due to the Persian Gulf is the vital factor for preventing temperature from falling dramatically in cold months and going up sharply during hot months. And also cause of this phenomenon the temperature differences(fluctuations) during day and night are not noticeable.

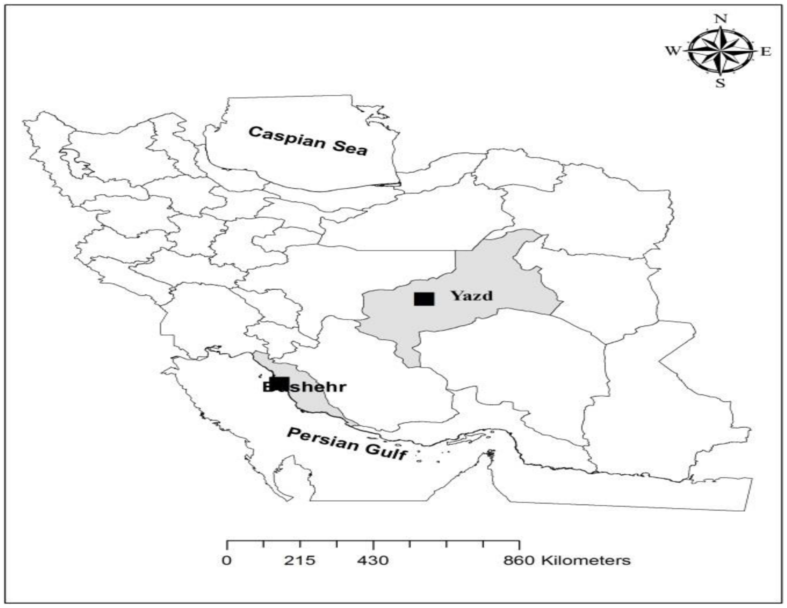

Figure 1. The location of costal Bushehr and Yazd in Iran

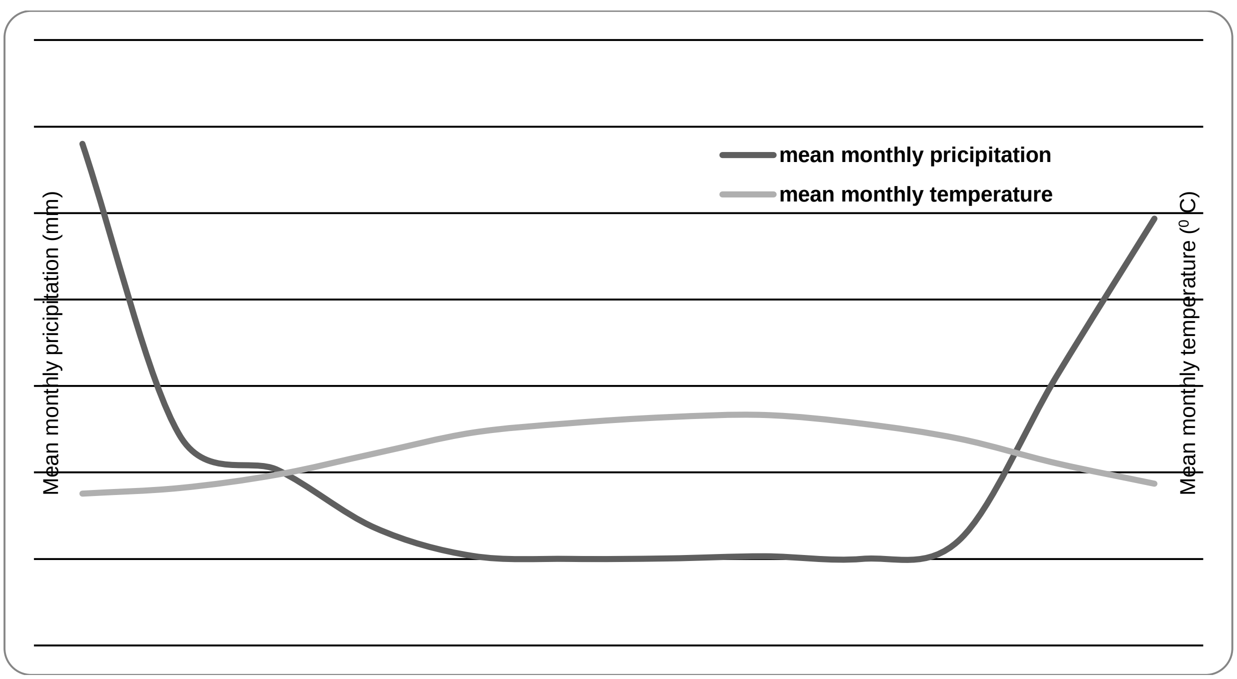

Figure 2. Costal Bushehr (1991-2010)

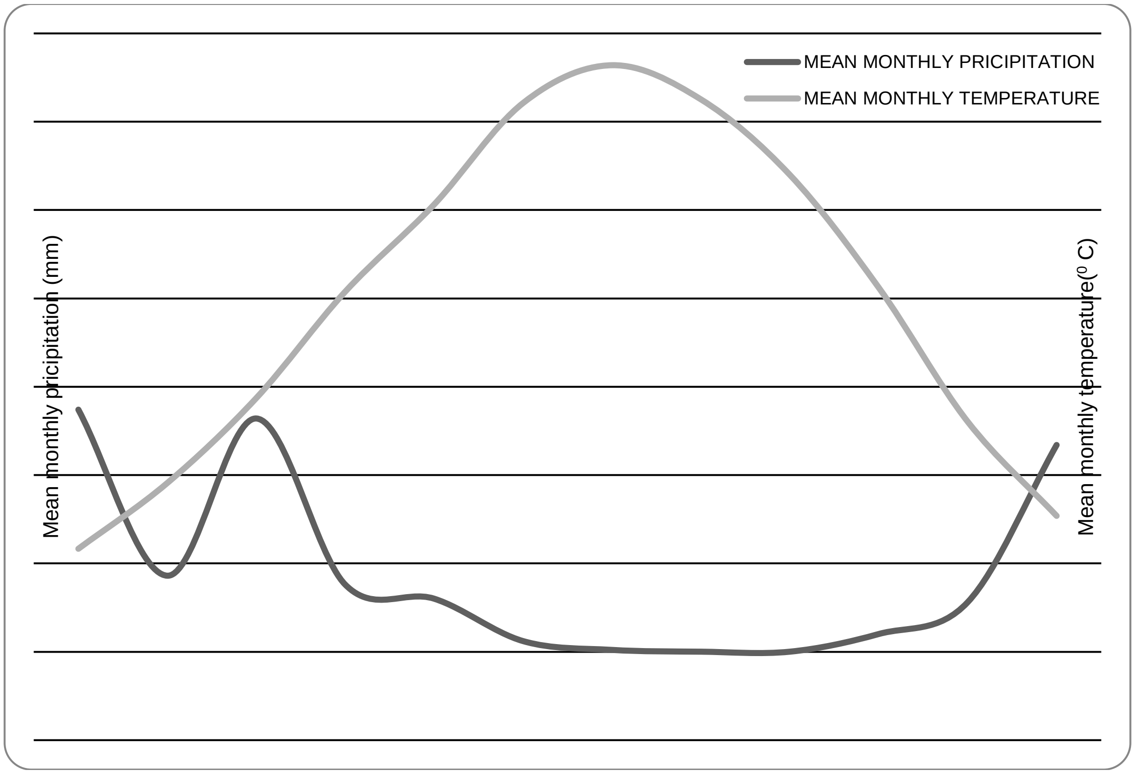

Figure 3. Yazd (1991-2010)

3. METHODOLOGICAL APPROACHES

AT is defined by a set of computational formulas which try to describe the combined effect of temperature, humidity, wind and solar radiation by considering the thermal comfort of an adult walking at 1.4 ms^{-1} and generating 180 wm^{-2} (Steadman, 1979a, 1979b; 1984). Since AT is usually expresses in degrees Celsius, understating it by general users is so easy.

The tree versions of AT indices exist as follow (Steadman, 1994):

i) The indoor AT (AT_{in}) which only takes into account the combined effect of air temperature and humidity. This index was defined by following formula:

$$AT_{in} = o.89\ T_{air} + 0.382\ e – 2.56,$$

Where 'T_{air}' is air temperature (^{0} C) and 'e' is water vapor pressure (hPa).

ii) The shade AT (AT_{shade}) takes the wind effect into consideration. This index is evaluated by:

$$AT_{shade} = T_{air} + 0.33\ e – 0.70\ V_{10} – 4.0,$$

Where 'V_{10}' is wind speed (ms^{-1}) in the height of 10 m.

iii) The outdoor AT (AT_{out}) which takes into account a walking and clothed person to all meteorological variables: air temperature, humidity, wind speed and solar radiation. This index is defined as follow:

$$AT_{out} = T_{air} + 0.384\ e – 0.70V_{10} + 0.7(Q_g /V_{10}+10) – 4.25,$$

Where 'Q_g' heat follow rate per unit area of human body due to extra radiation, and 'e' was obtained by following equation:

$$e = (RH/100)\ 6.105\ \exp\ (17.27 \times T_{air} / 237.7 + T_{air})),$$

Where RH is relative humidity in percent.

But the equation introduced by National weather Service (NWS) is the equation that was obtained by multiple regression analysis performed by Rothfusz (1990). The regression was performed on the data of Steadman, and then the ersatz equation is achieved as follow:

$HI = - 42.379 + 2.04901523\ T + 10.14333127\ RH – 0.2247551\ T\times RH – 6.83783\times10^{-3}\ T^2 – 5.481717\times10^{-2}\ RH^2 + 1.2287\times10^{-3}\ T^2\ RH + 8.5282\times10^{-4}\ T \times RH^2 – 1.99\times10^{-6}\ T^2\ RH^2$,

Where T is air temperature in degrees Fahrenheit (F) and RH is relative humidity in percent. HI is the heat index (or AT) in degrees F. This formula has an error $\pm1.3^0$ F (Rothfusz, 1990). As completely seen in this formula, only humidity and temperature taken into consideration although other variable which mentioned earlier are implied (Rothfusz, 1990).

If the RH is less than 13% and the temperature is between 80^0-112^0 F (or 26.67^0 – 44.44^0 C), then the following adjustment of is:

heat index Adjustment = (13-RH/4) ×SQRT [{17- ABS (T-95.0)}/17],

Where ABS and SQRT are the absolute value and square root functions, respectively.

On the other hand, if the RH is greater than 85% and the temperature is between 80^0 – 87^0 F (or 26.67^0 -30.56^0C), then the following adjustment of heat index turned as follow:

heat index Adjustment = [(RH-85)/10] * [(87-T) /5],

The Rothfusz regression is not valid when temperature and humidity allowance a heat index value below 26.67^0 C. In practice, at first, the simple formula is calculated and then the result averaged with the temperature. If this AT value is 80 ^{0}F (or 26.67^0 C) or higher, the full regression equation along with any adjustment equations as defined above is used. The Rothfusz regression is not logical for extreme temperature and relative humidity beyond the range of Steadman's data.

Table 1, which is introduced by NOAA, expresses AT (^{0}F) values based on temperature (^{0}F) and relative humidity (%). In fact, it is just a table which tries to inform people about AT and its effect on their health. And table2 is a table which is introduced by Steadman (1994) and including AT values in degrees C.

But in this paper the outdoor AT (AT_{out}) used which is produced by Steadman AT (1994). Meteorological variables: Mean temperature, mean highest temperature, mean relative humidity and mean lowest relative humidity during two decades (1991-2010) from Iran Meteorological Organization in order to the assessment human thermal comfort in two cities from different climatic areas in Iran (Yazd and Bushehr) by using AT indices, was obtained.

In this research, two methods for computation of AT was applied:

1- Calculating AT according to mean monthly temperature and mean relative humidity in the period of 1991-2010.

2- Computing the highest values of AT based on maximum temperature and minimum relative humidity at 12:30 at the local time. In fact, maximum AT has a better expression to heat stress.

The amounts of AT values for two mentioned cities were achieved. For example if the air temperature and humidity for an area is 38^0 C and 50%, respectively, so that the AT value will be 48^0 C. It means that the temperature that a person feels 48^0 C. The results of the obtained AT of the two cities for various months were assessed. Based on the table 3, the risk point was started in the AT of 27^0 C. The maximum hazardous effect of heat stress started when the AT is more than 54^0 C which is accompanied with heat stroke (category IV). Based on this classification, the AT between 22^0 to 27^0 C is called comfort zone.

Table1. Apparent Temperature based on humidity and temperature (Noaa)

Temperature (^{o}F)

Relative Humidity (%)	80	82	84	86	88	90	92	94	96	98	100	102	104	106	108	110
40	80	81	83	85	88	91	94	97	101	105	109	114	119	124	130	136
45	80	82	84	87	89	93	96	100	104	109	114	119	124	130	137	
50	81	83	85	88	91	95	99	103	108	113	118	124	131	137		
55	81	84	86	89	93	97	101	106	112	117	124	130	137			
60	82	84	88	91	95	100	105	110	116	123	129	137				
65	82	85	89	93	98	103	108	114	121	128	136					
70	83	86	90	95	100	105	112	119	126	134						
75	84	88	92	97	103	109	116	124	132							
80	84	89	94	100	106	113	121	129								
85	85	90	96	102	110	117	126	135								
90	86	91	98	105	113	122	131									
95	86	93	100	108	117	127										
100	87	95	103	112	121	132										

Likelihood of Heat Disorders with Prolonged Exposure or Strenuous Activity

Caution   Extreme Caution   Danger   Extreme Danger

Tabel2. Apparent Temperature according to humidity and temperature (Steadman, 1994)

Temperature (°C)

Relative Humidity (%)	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46
5	16	17	18	19	20	21	22	23	24	25	26	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	44	45	46	47	48
10	17	18	19	20	21	22	23	24	25	26	27	28	29	31	32	33	34	35	36	37	38	39	41	42	43	44	45	46	48	49	50
15	17	18	19	20	21	22	24	25	26	27	28	29	30	31	33	34	35	36	37	38	40	41	42	43	45	46	47	48	50		
20	17	18	20	21	22	23	24	25	26	28	29	30	31	32	33	35	36	37	38	40	41	42	43	45	46	47	49	50			
25	18	19	20	21	22	24	25	26	27	28	29	31	32	33	34	36	37	38	40	41	42	44	45	46	48	49					
30	18	19	21	22	23	24	25	26	28	29	30	31	33	34	35	37	38	39	41	42	43	45	46	48	49						
35	19	20	21	22	23	25	26	27	28	30	31	32	34	35	36	38	39	40	42	43	45	46	48	49							
40	19	20	21	23	24	25	26	28	29	30	32	33	34	36	37	39	40	41	43	44	46	48	49								
45	19	21	22	23	24	26	27	28	30	31	32	34	35	37	38	40	41	43	44	46	47	49									
50	20	21	22	24	25	26	28	29	30	32	33	35	36	38	39	41	42	44	45	47	49	50									
55	20	22	23	24	25	27	28	30	31	32	34	35	37	38	40	42	43	45	46	48	50										
60	21	22	23	25	26	27	29	30	32	33	35	36	38	39	41	42	44	46	48	49											
65	21	22	24	25	27	28	29	31	32	34	35	37	39	40	42	43	45	47	49												
70	21	23	24	26	27	28	30	31	33	35	36	38	39	41	43	44	46	48	50												
75	22	23	25	26	28	29	31	32	34	35	37	38	40	42	44	45	47	49													
80	22	24	25	27	28	30	31	33	34	36	38	39	41	43	45	46	48	50													
85	23	24	26	27	29	30	32	33	35	37	38	40	42	44	45	47	49														
90	23	25	26	28	29	31	32	34	36	37	39	41	43	45	46	48	50														
95	23	25	26	28	30	31	33	35	36	38	40	42	43	45	47	49															
100	24	25	27	29	30	32	33	35	37	39	41	42	44	46	48	50															

AT above 50°C

Table 3. the risks of heat stress (Moran and Morgan 1995)

Group	heat index (° C)	general effect on human body
I	27-32	Fatigue is likely with continued exposure
II	32-41	Sunstroke, heat cramps and heat exhaustion are likely with continued physical activity
III	41-54	Sunstroke, heat cramps and heat exhaustion are possible. Heat stroke is likely with continued physical activity
IV	>54	Heatstroke/sunstroke is highly possible with prolonged exposure

4. RESULTS

Mean Annual temperature and humidity during two decades (1991-2010) for Coastal Bushehr and Yazd are 25.1^{0} C, 69% and 19.9^{0} C, 29%, respectively. Comparisons these numbers show us Bushehr is generally 5.2^{0}C warmer and 40% more humid.

Fig. 4 and 5 give a comparison between monthly air temperature and AT values for two cities of Bushehr and Yazd, respectively. Fig. 4 shows that particularly during summer time (Jun, July and August) the differences between monthly mean air temperature values for two cities are not much highlighted and even in July the air temperature in Yazd is slightly higher. But based on Fig. 5 we noticed that in almost all months the differences between AT in two cities are noticeable. In regard to 40% differences in humidity, such this high differences in AT values seem reasonable.

Finding maximum heat stress in hot summer afternoon days on residents of the two mentioned cities is the most mainly objective of this research. Because maximum air temperature cannot be able to describe the heat stress, computation of maximum AT values seems better solution. In order to calculating maximum AT, maximum air temperature and minimum relative humidity (at 12:30 in local time) was used, and the results are shown in Fig.5 and 6.

Investigation of Fig. 6 releases that just only in summer months (Jun, July and August) maximum air temperature in Yazd is higher. This result is truly logical, because high humidity in Bushehr during summer times does not allow the temperature to increase dramatically. Although in October, November, December, January, February and March (cold months) air temperature in Bushehr is higher. The reason of this fact is high humidity in Bushehr prevents from falling the temperature dramatically. Despite the fact that maximum air temperature in some months in Yazd is higher, but AT values in Bushehr almost in all months are greater (Fig.7).

Although there are not significant differences in the air temperature of Yazd and Bushehr (Fig.6) and even in some months the air temperature in Yazd is greater (Fig. 6), but because of geographical location of Bushehr which laid along the coastal region of Persian Gulf, its residents in all warm months feel more heat stress (Fig.7).

As was completely illustrated in Fig.7, maximum AT for Yazd is around 37^0C and occurs in July, whereas for Bushehr maximum AT occurs in August and equals 48^0 C. Investigation of Fig.5 and Fig.7 and with considering Table 3 found that At values in Yazd never exceed than category (II), while these values in Bushehr in July, August and September (Fig.7) lie in the group (III). So, by contribution of these results can be said with relative high certainty, during warm months residents of Bushehr more suffer from heat stress and prolong activity in outdoor can even result in death, so paying attention to medical and psychological description in order to relieve mentally and physically hurt seems necessary.

Heat stress except temperature was affected by other significant factor, called humidity. So that, in order to provide relative comfort situation for residents, considering these results would be necessary. Also, the results of such researches can be available for tour guiding in order to guide tourists in appropriate areas through the appropriate time. And of course such these results in development of urban spaces, recreational facilities, and establishing new residences especially along the coast can be considered. From other point of view, these results in architecture and preventing from wasting energy especially inside the buildings have a special importance.

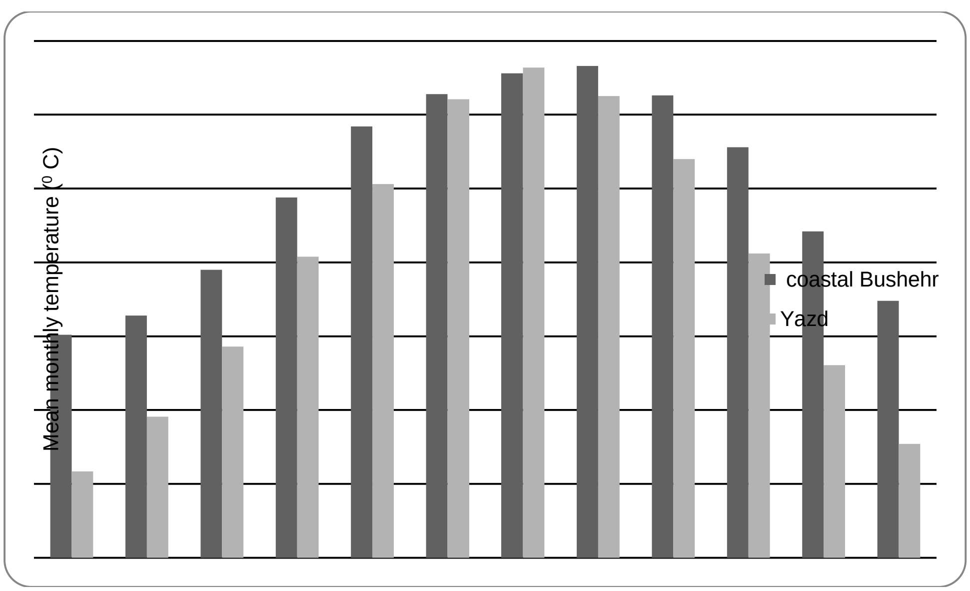

Figure 2. A 20-year Mean Temperature of Coastal Bushehr And Yazd

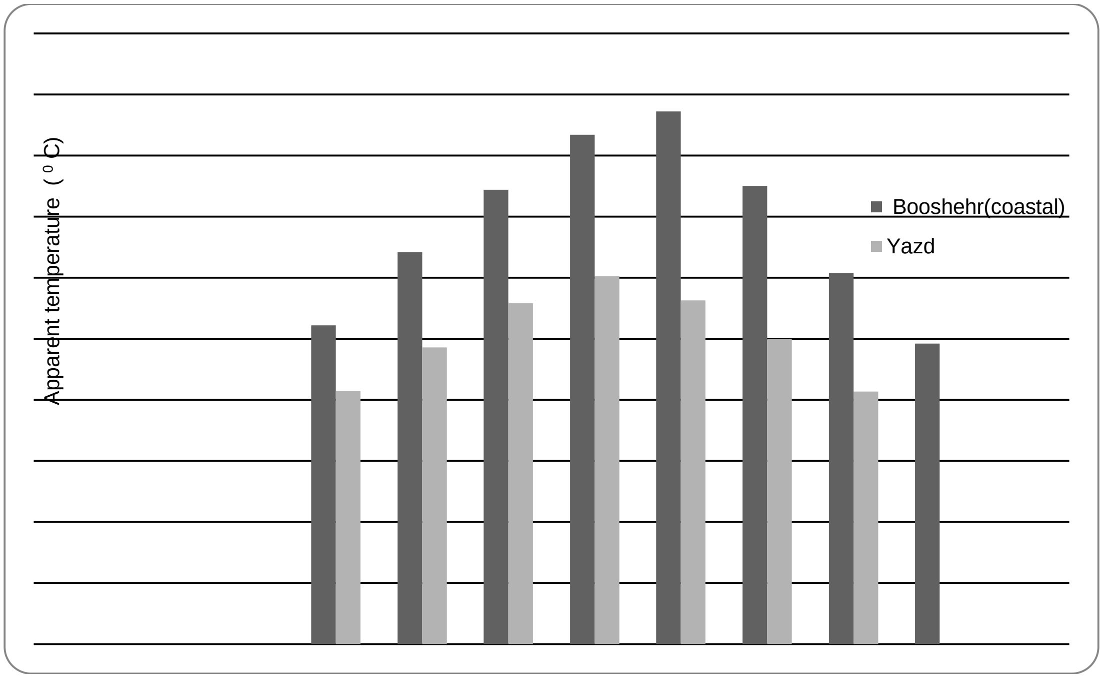

Fig. 5. A 20-year Mean Apparent Temperature of coastal Bushehr and Yazd

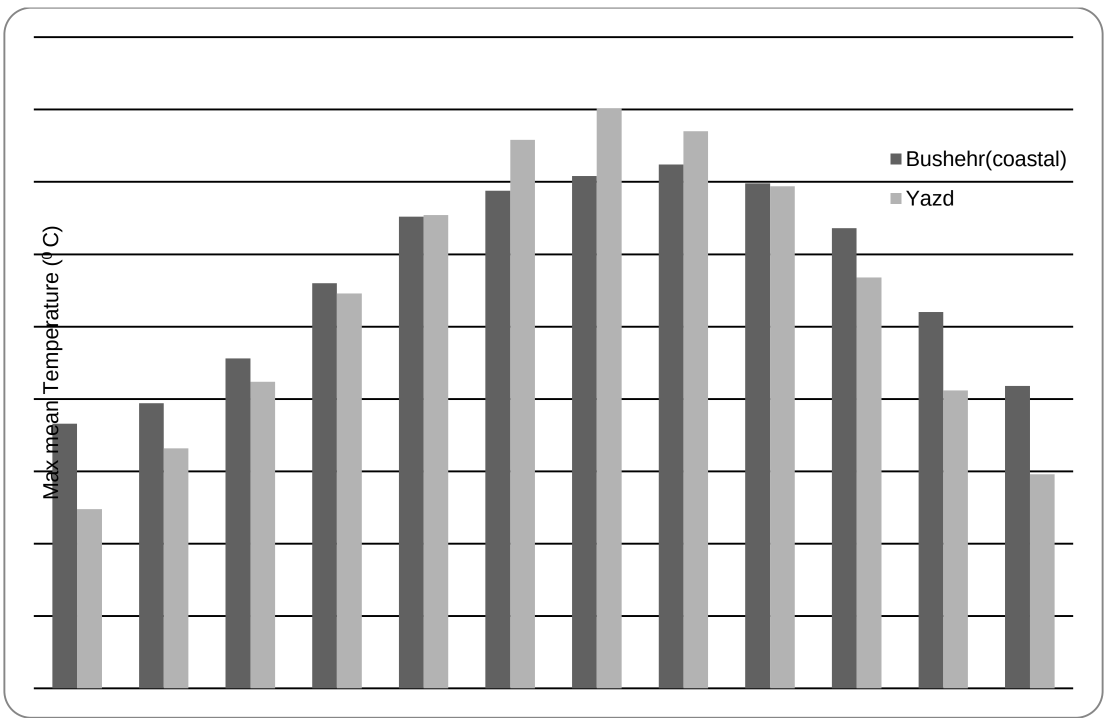

Fig.6. A 20-Year Max air temperature of Bushehr (coastal) and Yazd

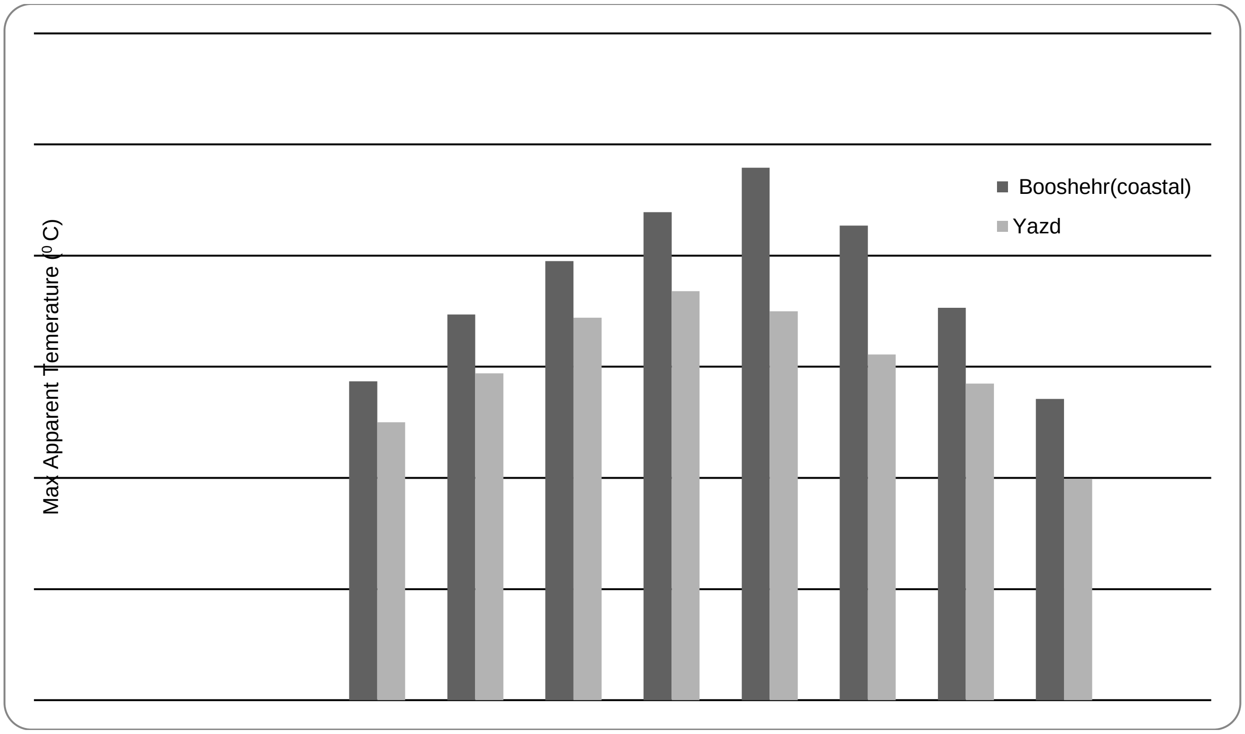

Fig. 7. A 20 Year Max Apparent Temerature og Coastal Bushehr and Yazd

5. DISCUSSION

In our analysis, outdoor thermal comfort conditions in order to determine thermal perception in period of 1991-2010 for different months. Heat index uses the main climatic factors in unit of ^{0} C which is easy to understand for ordinary users. Furthermore, the results of the research show that the interpretation of the index in assessing of human thermal comfort.

The findings of this study are valuable for tourism, architecture activities and urban planning in Bushehr and Yazd. Based on Fig.5 and this index, the number of days that faced heat stress in Bushehr is 184 days (from May to October) and in Yazd is around 92 days (from Jun to August).

For gaining better view, charts for fluctuation of temperature were drawn (Fig. 8-11). Fig.8 and 9 shows air temperature and maximum air temperature fluctuations, respectively. In both figures can be obviously seen that the temperature fluctuation of Yazd is grater, and the main reason for this issue is certainty due to existence of low humidity in Yazd. Fluctuation of mean-AT and Max-AT was shown in Fig. 10 and 11, respectively. Base of these two illustrations AT in Bushehr is greater than Yazd. Without any skeptical, existence of high amount of humidity in coastal Bushehr, is the only reason for this issue.

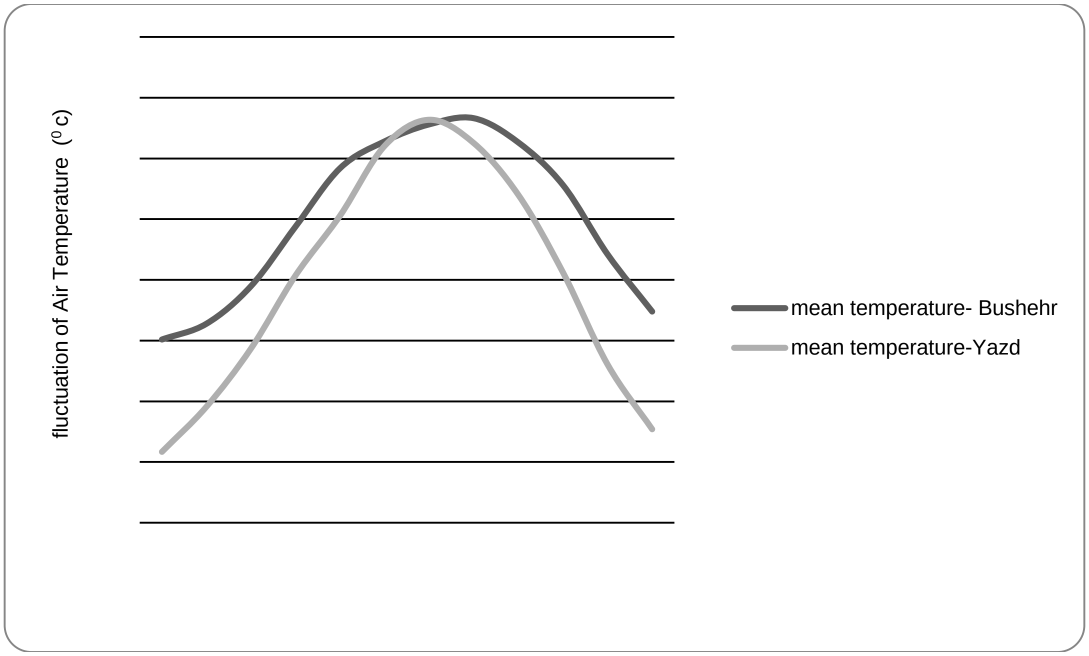

Fig. 8. Fluctuation of mean air temperature in Bushehr (coastal) and Yazd

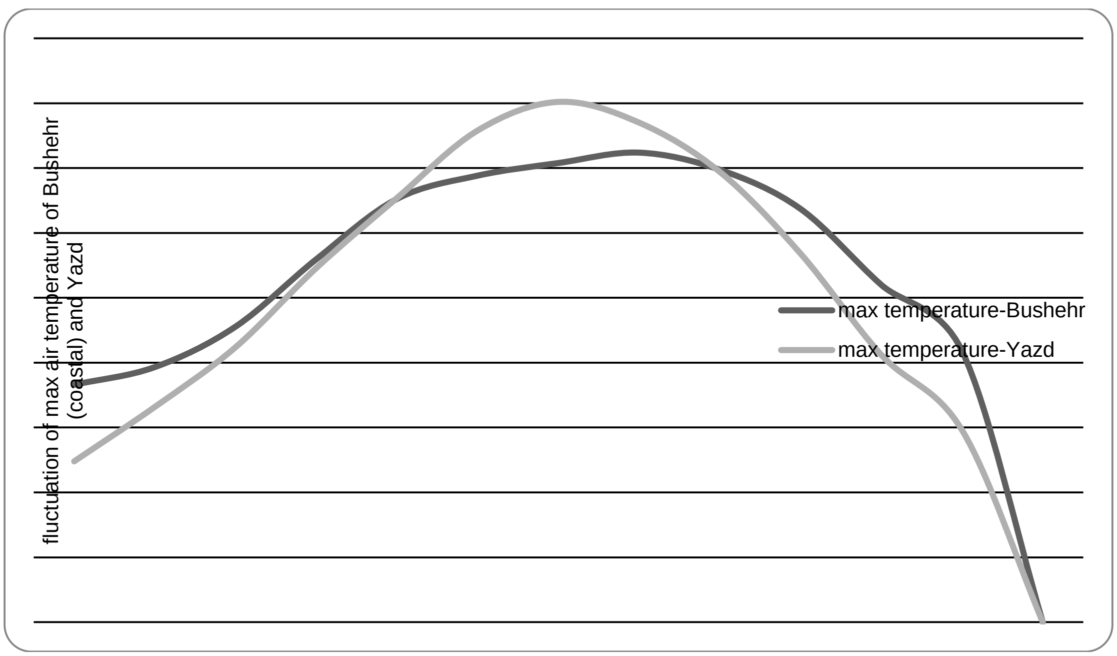

Fig.9. Fluctuation of Max air temperature of Booshehr (coastal) and Yazd

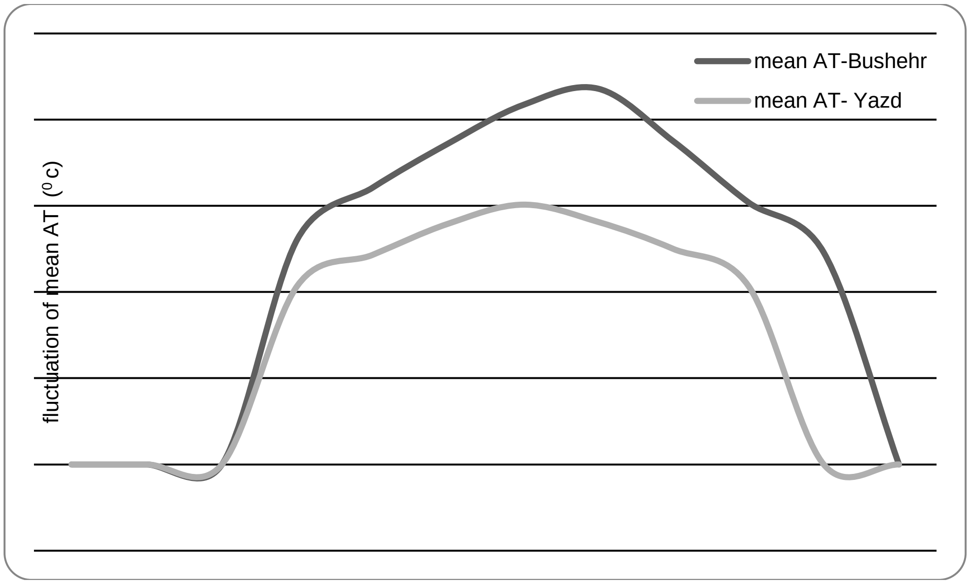

Fig. 10. Fluctuation of mean AT for Bushehr (coastal) and Yazd

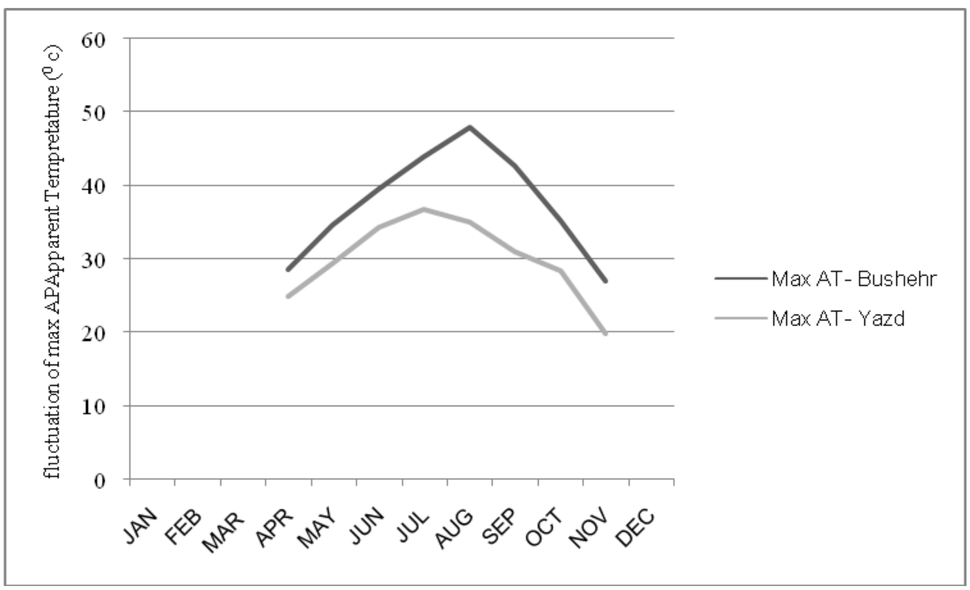

Fig.11. Fluctuation of Max AT for Bushehr (coastal) and Yazd

6. CONCLUSIONS

Yazd is considered among the top host cities in the Country because of especial conditions in development industries and factories, various mines, establishing varied universities and etc. So, cause of all these reasons the population of the city especially in the last decade is increased. Moreover, the city is among the top cities in Iran that attracts tourists each year because of old and breathtaking architecture, its old historic and culture.

And Bushehr is known the chief seaport in Iran; so, shipbuilding industry includes the main industry in the city. Furthermore, there are many big companies related to Oil &Gas in the city or near it. For example, Asaloyeh is an area near the city which is well-known area to produce Oil & Gas for domestic consumptions and also for export purposes. Another industry which is located near the city is Nuclear Power Planet. Moreover the city contains the oldest seaport in the Country and has unique historic, culture and even unique nature. So, the city has a strong potential to attract tourists from different parts toward itself every year.

Because of all these reasons many people from other parts and climates attracted toward these two cities. Trying to assess outdoor thermal conditions in two cities of Bushehr and Yazd seem imperative. Meteorological parameters in the period 1991-2010 were analyzed in order to calculate heat index. The results show us the temperature which is measured by thermometer cannot be an appropriate index in assessing bioclimatic comfort. For evaluating bioclimatic comfort, considering simultaneous variables give us relative true perception about thermal outdoor condition.

With comparison the air temperature and AT charts found that only in July the mean air temperature in Yazd is slightly greater but in all warm months in Bushehr ATexceeds with noticeable difference. While with comparison maximum air temperature and max-AT noticed that only in summer time maximum mean air temperature in Yazd surpasses, but max-AT in Bushehr having the greater values in all warm months, yet.

Based on Fig.7 we notice that during Jun, July and August in Bushehr the AT values lie in the category III (Table 2), but in Yazd even in summer months (Jun, July and August) the AT values never exceed than category II (Table 2). So, people who live in Bushehr faced more the risk of heat stroke. The awareness of such results can be the basis for a successful strategy in urban planning, architectural activities, and tourism or even in other industries.

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