Thermal discomfort analysis using UTCI and MEMI (PET and PMV) in outdoor environments: case study of two climates in Iran (Arak & Bandar Abbas)

Weather – Month 9999, Vol. 99, No. 99

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Introduction

It is generally accepted that different weather conditions are the most important factors affecting daily and long-term human activities. Today, the effects of weather conditions on human life, human behaviour and human comfort are examined by a scientific branch called human bioclimate. Bioclimatology is the science of examining and evaluating the impact of weather on creatures, both animals and human beings (Fallah Ghalhari *et al.*, 2015). Thermal comfort refers to a set of conditions that is thermally suitable at least for 80% of the people. In other words, it is set of the conditions in which human beings do not feel cold or hot. In such a condition, the human organism can maintain its thermal balance in the best possible way, without facing energy shortage or energy surplus (Streinu-Cercel *et al.*, 2008). Human beings, in any conditions, are affected by the heat of the surroundings, so climatic factors with their desirable and sometimes undesirable effects cause changes in human bodies, such as hypothermia, influenza, heart disease, brain stroke, asthma, etc. With respect to medical studies, an increase or decrease in environmental temperature or season changes causes the break out of various diseases (Fallah Ghalhari *et al.*, 2015). Furthermore, many studies have reported the side effects of heat and cold stresses on mortality (Nastos and Matzarakis, 2012).

Environmental studies, particularly bioclimatic studies, play a vital role in comprehensive and sustainable development. Identifying bioclimatic conditions of a location can be the first step in many environmental studies. In fact, being aware of bioclimatic capability improves planning and management of human activities. For example, analysing climate conditions from an economic point of view is noteworthy for energy consumption patterns and, from an urban point of view, is noteworthy for civil planning and tourism (Çalışkan *et al.*, 2012).

From a climatic point of view, four elements – temperature, wind, humidity and radiation – play a major role in the formation of human comfort conditions (de Freitas and Grigorieva, 2017). Of these elements, temperature and humidity have a greater effect on human health and well-being. Accordingly, most models and indices measuring human comfort are based on these two elements (empirical indices) (Asghari *et al.*, 2017). It should be noted that human thermal comfort is the result of energy balance between body surface and environment that affects people's physiology, psychology and behaviour. On the other hand, thermal comfort models, besides using atmospheric parameters such as temperature, vapour pressure, wind speed and average radiant temperature, use complex metabolic processes such as the level of physical activity and clothing coverage (Jendritzky *et al.*, 2012; Nassiri *et al.*, 2017). These indices provide climate data in a way that reflects people's response to climate conditions and, in a numerical classification, range from very appropriate to very inappropriate (de Freitas, 2003). These indices facilitate interpreting the complex effects of atmospheric elements on human comfort and allow comparison of different places from a climatic comfort point of view (Ghalhari *et al.*, Blazejczyk *et al.*, 2012; Nassiri *et al.*, 2018). It should be noted that the empirical and simple parameters (including temperature and relative humidity), on the one hand, are very limited as a result of ignoring temperature–physiological relations and cannot meet the essential needs of the researchers, and on the other hand, their results are frequently not comparable, and the temperature thresholds they use arbitrarily are defined by the researchers and do not fully reflect the effect of the outside environment on human beings (Nassiri *et al.*, 2018). Today, it is believed that bioclimatic evaluations should involve the effects of all climatic elements and thermal components of the environment. Moreover, for the evaluation of an ideal bioclimatic index, the balance of energy between the human body and environment must be taken into consideration, which can lead to the presentation and development of human energy balance models (Thomson *et al.*, 2008). In designing thermal comfort models, especially since 1979 when the Klima Michel Model (KMM) was invented, special attention has been paid to the energy balance of the human body. The KMM is extracted from the Fanger model – a shortwave radiation model that calculates the average radiant temperature (Kim *et al.*, 2009). In 1999, Hoppe proposed the Munich Energy-Balance Model for Individuals (MEMI) based on the previous studies (Höppe, 1999). The MEMI measures sweat and regulating heat fluxes, the temperature emitted from the body with clothing and without clothing (Höppe, 1999; Thomson *et al.*, 2008). In this model, skin heat dissipation is assumed to be equal to the heat produced by the blood and the heat transferred from the centre to the surface of the skin. From major outputs of this model, derived from the energy balance of the human body, the physiological equivalent temperature (PET) and the predicted mean vote (PMV) indices can be obtained. These indices are two of the most important physiological–temperature indices (Thomson *et al.*, 2008; Fallah Ghalhari *et al.*, 2016). In 1999, the International Bioclimatology Commission set up a commission for the development of the Universal Thermal Climate Index, whose purpose was to extract a thermal index based on the most advanced thermophysiological (temperature–physiological) models. Since 2005, these efforts have been strengthened by the COST Action7300 Group (European Technology and Science Development Cooperation Organization). The COST research team consists of prominent climatologists, meteorologists and experts of human thermophysiological models who cooperated to develop the Universal Thermal Climate Index (UTCI), which was named at the completion of the group activity in February 2009 (Bröde *et al.*, 2012).

Today, bioclimatic studies, from a human comfort point of view, are the basis of many management plans, especially health and treatment. Therefore, given this approach, the present study aims to use the databases of the meteorological organisation and environmental variables registered by this organisation to analyse thermal energy balance data in two climates of Iran, using PET and PMV indices along with the thermophysiological UTCI. It should be noted that these data can be used for future planning, preventive strategies and control measures to protect people in outdoor spaces.

Methodology

Studied climates

According to the Köppen climate classification (Koppen, 1936; Kottek *et al.*, 2006), there are 10 different climates in Iran. Based on this classification, 80% of Iran's regions have dry climate, 16.7% mild climate and 3.2% cold climate (Fallah Ghalhari *et al.*, 2016). In the present study, the meteorological data recorded by the Iran Meteorological Organization (the national weather service of Iran) in a 15-year period were surveyed, and two cities from two different climatic regions of Iran were studied. To that end, Arak in the centre of Iran, as a representative of the warm and dry climatic areas of the country, and Bandar Abbas in the south, as a representative of the semi-arid and cold climates of to the country, were selected (Fallah Ghalhari *et al.*, 2016). Figure 1 presents the studied cities from two different climatic regions of Iran.

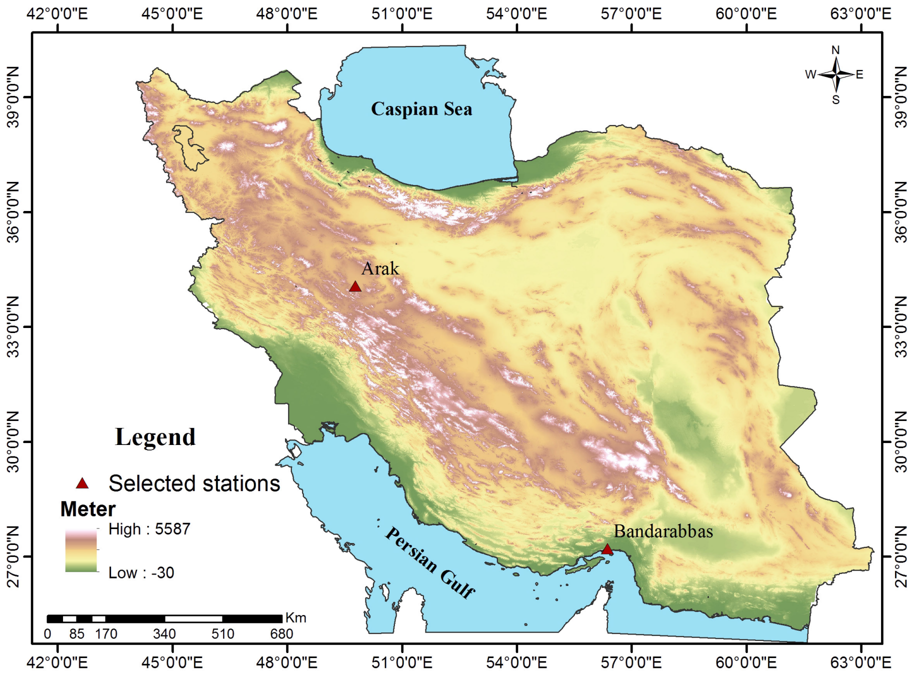

Figure1. The studied cities of two different climatic regions in Iran.

Arak is located in the centre of Iran, and its geographic coordinates are latitude 34°06′N, longitude 49°42′E, and elevation above sea level is 1708 meters. Bandar Abbas is located in the south of Iran, and its geographic coordinates are latitude 27°13′N, longitude 56°18′E, and elevation above sea level is 16 meters. This city overlooks the Strait of Hormuz and has a hot and dry climate (Roshan *et al.*, 2010). It should be noted that Arak and Bandar Abbas are two of the most important cities in Iran in terms of economic activities. These two cities have high capacity for agriculture, tourism industry, large industries, refineries and petrochemicals, transit, ports, fishing, fisheries, services, etc. Therefore, they are of high importance from the perspective of occupational and outdoor activities.

Thermal comfort indices

In the present study, daily weather data, including temperature, wind speed, cloudiness, relative humidity and water vapour pressure, in Bandar Abbas and Arak from 2000 to 2014 (15 years) were used. In the first step, the averages of the mentioned variables were calculated daily for 15 years. Considering the need for the mean radiant temperature (Tmrt) in this study, this parameter was calculated using Equation 1 and RAYMAN 1.2 software (Matzarakis and Rutz 2007). This parameter represents the thermal effect of solar radiation and temperature on humans and indicates the temperature of a uniform surface from a hypothetical area that surrounds the person.

$$Tmrt = \left[\left(\left(R' + 0.5La + 0.5La\right)\Big/ S_h.s\right)\right]^{0.25} + \left(-273\right) \qquad (1)$$

where

R′: solar radiation absorbed by a nake person

Lg: the Earth's radiation

La: reflected radiation

S: Stephen Boltzmann constant, and

Sh: the emissivity factor that is 0.95 for the human body (Błażejczyk, 2011).

PET and PMV indices

These two indices have been derived from the important outputs of the human energy balance model (Fröhlich and Matzarakis, 2013). This model is an appropriate basis for evaluating the thermal conditions of the climate of an environment (Esmaili and Montazeri, 2013). The equation of the model is as follows:

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0$$

where M = body metabolism rate; W = output of physical work; R = pure body radiation; C = convective heating current; E_D = the flow of latent heat of evaporation from the skin; E_{RE} = total heat flows effective in heating, evaporation and sweating; and E_{SW} = effective air flow in body evaporation and perspiration.

All statements are in watts, and frequently, M is positive, and W, E_D and E_{SW} are negative. In this equation, if the human body is gaining energy, the equation will be positive entirely, and if it is losing energy, the statements of the equation will be negative.

The PET index is one of the most comprehensive and most widely used indices for evaluating bioecological conditions in which the temperature of the centre and skin of the human body within an indoor environment, with an 80W activity style, basal metabolism and thermal resistance

Table 1

Classification of the numerical thresholds for the thermal indices along with physiological conditions and thermal perception.

Thermal perception	PMV	PET	UTCI
Very cold[1] (extreme cold stress[1,2])	−3	< 4	< −40
(Very strong cold stress[2])			−40 to −27
Cold[1] (strong cold stress[1,2])	−2.5	4–8	−27 to −13
Cool[1] (moderate cold stress[1,2])	−1.5	8–13	−13 to 0
Slightly cool[1] (slight cold stress[1,2])	−0.5	13–18	0 to +9
Comfortable[1] (no thermal stress[1,2])	0	18–23	+9 to +26
Slightly warm[1] (slight heat stress[1])	0.5	23–29	
Warm[1] (moderate heat stress[1,2])	1.5	29–35	+26 to +32
Hot[1] (strong heat stress[1,2])	2.5	35–41	+32 to +38
(Very strong heat stress[2])			+38 to +46
Very hot[1] (extreme heat stress[1,2])	3	>41	>+46

(Indices range: PMV, PET, UTCI)

[1]PET and PMV
[2]UTCI

of clothing of 0.9 Clo, is equivalent to the outdoor temperature (Roshan *et al.*, 2019). Table 1 presents the numerical thresholds for classifying this index along with a descriptive state of physiological conditions and thermal sensitivity (Höppe, 1999; Blazejczyk *et al.*, 2012; Fang *et al.*, 2019).

The data needed to calculate the PET index can be presented in four categories of variables:

1. The first category includes situational variables, such as length, width and height.
2. The second category includes climatic elements such as dry air temperature, vapour pressure, relative humidity, wind speed and cloudiness.
3. The third category consists of individual variables, including effective physiological features such as height, weight, age and gender.
4. The fourth category includes the variables related to the type of coverage and activity (Roshan *et al.*, 2019).

The PMV was developed by Fanger in 1970. This index considers four physical variables, including air temperature, mean radiant temperature, air velocity and relative humidity, and two personal variables, including clothing resistance and activity level, as a composite index to measure thermal comfort. The PMV index determines coefficients that will be measured according to the American society of heating refrigerating and air-conditioning engineers (ASHRAE) 7-point thermal sensation scale and indicates a moderate thermal sensation by a large group of people in a given space (Yau and Chew, 2014). The aforementioned index provides thermal comfort as an imbalance between the actual heat of the body in a given thermal environment and the required heat flow for optimal conditions (such as neutral conditions) in a given activity (Zare *et al.*, 2018; Fang *et al.*, 2019). The values of PMV and PET indices were extracted using Rayman 1.2 software.

Universal Thermal Climate Index

One of the most advanced models, based on the latest achievements in all disciplines such as thermal physiology, occupational health, physics, meteorology, biological meteorology and environmental sciences, to adjust and balance human body heat is the Fiala multi-node model, a model from which the global index of thermal climate was derived (Psikuta *et al.*, 2012). This index was developed to create a standard benchmark for appropriate heat conditions in the major field of human biometeorology and is more sensitive to trivial changes in temperature, solar radiation, humidity and wind speed compare with other indices and provides a better description of different climatic conditions (Vatani *et al.*, 2015; Nassiri *et al.*, 2017). The value of the index depends on the temperature, wind speed, relative humidity and mean radiant temperature. These classifications have, in fact, been based on the physiological responses of the living organism to the conditions of real environment in such a way that these responses are created under reference conditions and with the reduction of heating or cooling loads. This index, in the form of a temperature range of −40 to +46, categorises thermal stresses into 10 classes ranging from extreme cold stress to extreme heat stress (Bröde *et al.*, 2013; Fallah Ghalhari *et al.*, 2015). The numerical thresholds for classifying the UTCI index along with physiological conditions and thermal perception are presented in Table 1. The values of UTCI were calculated using BioKlima 2.6 software (Błażejczyk, 2011).

All statistical analyses were performed using Microsoft Office Excel 2010 and Spss 21 statistical software (v.18). Significance level was set at 0.05.

Results

Table 2 illustrates the mean and standard deviation of environmental variables affecting thermal comfort in different months of the year based on 15 years of data in two studied climates. As can be seen from Table 2, in Arak during the surveyed years, the highest average temperature (28.1 ± 0.65) was observed in July, and the lowest average temperature (−1.14 ± 1.94) was seen in January. In addition, the highest humidity rate (70.67 ± 3.87) was observed in January, and the lowest humidity rate (22.96 ± 1.25) was seen in July. In Bandar Abbas, the highest average temperature (34.27 ± 0.26) was observed in July, and the lowest average temperature (17.44 ± 0.62) was seen in January. Likewise, the highest humidity rate (68.39 ± 2.41) was seen in August, and the lowest humidity rate (57 ± 4) was observed in December.

Table 3 indicates the means and standard deviations of thermal comfort indices in two climates. In Arak – the representative of a semi-cold and cold climate – the mean of the UTCI for the surveyed years was 14.41 ± 11.5; the maximum mean of the index was observed in July (30.36 ± 0.74), and the minimum mean of the index was seen in January (−1.99 ± 1.8). In Bandar Abbas – the representative of a hot and dry climate – the mean of the index was 22.56 ± 9; the maximum mean of the index during the surveyed years was observed in July (33.87 ± 0.72), and the minimum mean of the index was seen in January (8.51 ± 1). Due to the UTCI base, perceived thermal sensations of individuals are expressed between extreme cold stress (< −40; dark blue), very strong cold stress (−40 to −27; muddy blue), strong cold stress (−27 to −13; sky blue), moderate cold stress (−13 to 0; lead grey), slight cold stress (0 to +9; bright grey), no thermal stress (+9 to +26; white), moderate heat stress (+26 to +32; lemon), strong heat stress (+32 to +38; yellow), very strong heat stress (+38 to +46; brown) and extreme heat stress (>+46; red), which are shown in Table 1.

As seen in Table 3, regarding the UTCI for Arak, the cold stress is moderate in January, and it is low in February, March, November and December; April, May, September and October have no thermal stress, and June, July and August have moderate heat stress. In Bandar Abbas, January months have slight cold stress; February, March, April,

Table 2

The mean and standard deviation of environmental variables affecting thermal comfort in different months of the year based on data of 15 years.

Month	Station	Temperature (°C)	Humidity (%)	Air velocity (ms^{-1})	Cloudiness (okta)	Mean radiant temperature (°C)
January	Arak	−1.14 ± 1.94	70.67 ± 3.87	0.97 ± 0.3	3.74 ± 0.57	2.28 ± 1.84
	Bandar Abbas	17.44 ± 0.62	63.1 ± 4.4	2.73 ± 0.17	2.57 ± 0.61	9.37 ± 0.81
February	Arak	2.84 ± 2.48	60.54 ± 6.7	1.76 ± 0.46	3.13 ± 0.44	11.92 ± 4.0
	Bandar Abbas	19.75 ± 1.22	65.1 ± 4.2	3.11 ± 0.24	2.56 ± 0.4	11.92 ± 1.44
March	Arak	9.13 ± 1.16	46.1 ± 2.73	2.43 ± 0.43	3.07 ± 0.3	23.55 ± 2.74
	Bandar Abbas	23.19 ± 1.0	64.40 ± 2.71	3.33 ± 0.2	2.33 ± 0.47	15.4 ± 1.2
April	Arak	13.9 ± 1.53	46.5 ± 340	2.33 ± 0.37	3.56 ± 0.35	31.85 ± 2.25
	Bandar Abbas	27.5 ± 1.18	59.68 ± 2.2	3.48 ± 0.16	2.34 ± 0.56	19.7 ± 1.0
May	Arak	19.1 ± 2.0	36.93 ± 5.41	2.32 ± 0.24	2.5 ± 0.77	39.72 ± 3.1
	Bandar Abbas	31.6 ± 0.9	57.4 ± 2.33	3.5 ± 0.13	0.83 ± 0.41	23.33 ± 0.9
June	Arak	25.2 ± 1.37	24.7 ± 1.55	2.1 ± 0.17	1.06 ± 0.26	47.7 ± 1.27
	Bandar Abbas	33.73 ± 0.5	60.3 ± 3.37	3.62 ± 0.13	0.91 ± 0.35	25.5 ± 0.52
July	Arak	28.1 ± 0.65	22.96 ± 1.25	2.04 ± 0.18	1.38 ± 0.3	49.05 ± 0.98
	Bandar Abbas	34.27 ± 0.26	66.51 ± 2.46	3.86 ± 0.17	2.0 ± 0.4	26.26 ± 0.37
August	Arak	26.8 ± 1.11	23.1 ± 2.44	1.75 ± 0.19	1.12 ± 0.26	46.35 ± 1.87
	Bandar Abbas	33.58 ± 0.56	68.39 ± 2.41	3.83 ± 0.16	2.12 ± 0.27	25.75 ± 0.6
September	Arak	22.2 ± 1.84	25.25 ± 2.80	1.66 ± 0.24	0.63 ± 0.31	38.76 ± 3.1
	Bandar Abbas	32.12 ± 0.61	67.22 ± 2.27	3.37 ± 0.21	1.37 ± 0.39	23.93 ± 0.72
October	Arak	15.60 ± 2.38	39.22 ± 8.0	1.49 ± 0.26	2.02 ± 1.0	25.3 ± 4.69
	Bandar Abbas	29.23 ± 1.2	64.97 ± 2.66	2.98 ± 0.20	0.89 ± 0.25	21.05 ± 1.19
November	Arak	7.04 ± 2.1	62. 3 ± 3.53	1.05 ± 0.24	3.18 ± 0.5	10.76 ± 3.4
	Bandar Abbas	23.83 ± 1.8	58.96 ± 2.8	3.04 ± 0.25	1.83 ± 0.39	15.77 ± 1.94
December	Arak	2.26 ± 1.21	68.66 ± 2.21	0.93 ± 0.27	3.34 ± 0.61	3.35 ± 1.32
	Bandar Abbas	19.35 ± 1.16	57.0 ± 4.0	2.91 ± 0.32	2.08 ± 0.59	11.2 ± 1.45

October, November and December have a thermal comfort condition; May, June and September have moderate heat stress; and July and August have strong heat stress.

In Arak, the mean PET index for surveyed years was 15.81 ± 1.23. According to Table 3, the maximum value of the index was seen in July (33.94 ± 0.95), and the minimum value of the index was observed in January (−1.26 ± 2.45). In Bandar Abbas, the mean of the index was 22.73 ± 7.7; the maximum mean of the index for the surveyed months was seen in July (32.3 ± 0.59), and similarly, the minimum mean of the index was observed in January (1.95 ± 0.77). The PET index provided different temperature thresholds with the same meaning of thermal sensations or alert physiological stress. Thermal perception is between very cold (<4; dark blue), cold (4–8; sky blue), cool (8–13; lead grey), slightly cool (13–18; bright grey), comfortable (18–23; white), slightly warm (23–29; cream), warm (29–35; lemon), hot (35–41; yellow) and very hot (>41; red) (Table 1).

Using the PET index for Arak, the cold stress is very strong for January, February and December; November has a strong cold stress; March has a moderate cold stress; April and October have slight cold stress; May has a comfort condition; September has slight heat stress; and June, July and August have moderate heat stress, whereas in Bandar Abbas, January has strong cold stress; February, March, November and December have slight cold stress; April lacks thermal stress; May and October have slight thermal stress; and June, July, August and September have moderate heat stress.

In Arak, the mean of PMV index for surveyed years was −0.77 ± 2.15; the maximum value of the index was seen in July (2.33 ± 0.17). As observed in Table 3, the minimum value of the index was observed in January (−3.67 ± 0.45). In Bandar Abbas, the mean of the index was 0.73 ± 7.7; the maximum of the mean was observed in July (2.67 ± 0.12), and the minimum of the mean was seen in January (−1.82 ± 0.17). Based on the PMV index, the thermal sensations are defined from very cold to very hot conditions, as presented in Table 1. Thermal perception is between very cold (−3), cold (−2.5), cool (−1.5), slightly cool (−0.5), comfortable (0), slightly warm (0.5), warm (1.5), hot (2.5) and very hot (3); the order of colours order is similar to the PET index.

Using the PMV index for Arak, January has a very strong cold stress; February and December have strong cold stress; March and November have a moderate cold stress; April and October have slight cold stress; May lacks thermal stress; June, July and August have moderate heat stress; and September has slight heat stress, whereas in Bandar Abbas, January has a moderate cold tress; February and December have slight cold stress; March and November have thermal comfort condition; April and October have slight thermal stress; May, June and September have moderate heat stress; and July and August have strong heat stress.

Figure 2 shows thermal stress percentages of the indices examined during the surveyed years. The results of the UTCI indicated that, in Arak, 25.7% of the days have moderate heat stress. The percentage of the days with thermal comfort was 37%. On the other hand, 25% and 12.3% of the days have slight cold stress and moderate cold stress, respectively, whereas in Bandar

Table 3

The means and standard deviations of thermal comfort indices in two climates.

Month	*Arak*			*Bandar Abbas*		
	UTCI (°C)	PET (°C)	PMV	UTCI (°C)	PET (°C)	PMV
January	−1.99 ± 1.8	−1.26 ± 2.45	−3.76 ± 0.45	8.51 ± 1.0	1.95 ± 0.77	−1.82 ± 0.17
February	0.26 ± 3.46	1.7 ± 2.55	−3.38 ± 0.46	11.63 ± 2.3	13.48 ± 1.46	−1.21 ± 0.36
March	6.38 ± 3.4	8.26 ± 2.0	−2.22 ± 0.4	16.39 ± 1.7	17.21 ± 1.22	−0.34 ± 0.29
April	13.7 ± 1.55	14.64 ± 1.9	−0.89 ± 0.37	22.3 ± 1.63	22.3 ± 1.6	0.77 ± 0.3
May	20.21 ± 2.9	21.44 ± 3.11	0.31 ± 0.48	28.14 ± 1.66	28.1 ± 1.4	1.82 ± 0.26
June	27.53 ± 1.5	30.42 ± 1.9	1.7 ± 0.33	31.93 ± 0.94	31.36 ± 0.78	2.45 ± 0.15
July	30.36 ± 0.74	33.94 ± 0.95	2.33 ± 0.17	33.87 ± 0.72	32.3 ± 0.59	2.67 ± 0.12
August	28.68 ± 1.22	31.73 ± 1.59	1.96 ± 0.26	33.17 ± 0.87	31.52 ± 0.88	2.55 ± 0.15
September	23.42 ± 2.59	24.86 ± 3.2	0.8 ± 0.5	30.38 ± 1.25	29.1 ± 1.0	2.05 ± 0.2
October	15.82 ± 2.95	15.76 ± 2.86	−0.69 ± 0.46	25.7 ± 1.9	24.93 ± 1.8	1.26 ± 0.435
November	6.82 ± 2.62	6.3 ± 2.48	−2.29 ± 0.46	17.7 ± 2.8	17.94 ± 2.1	−0.19 ± 0.5
December	0.88 ± 2.0	1.04 ± 2.16	−3.27 ± 0.4	10.82 ± 2.0	13.03 ± 1.33	−1.33 ± 0.31

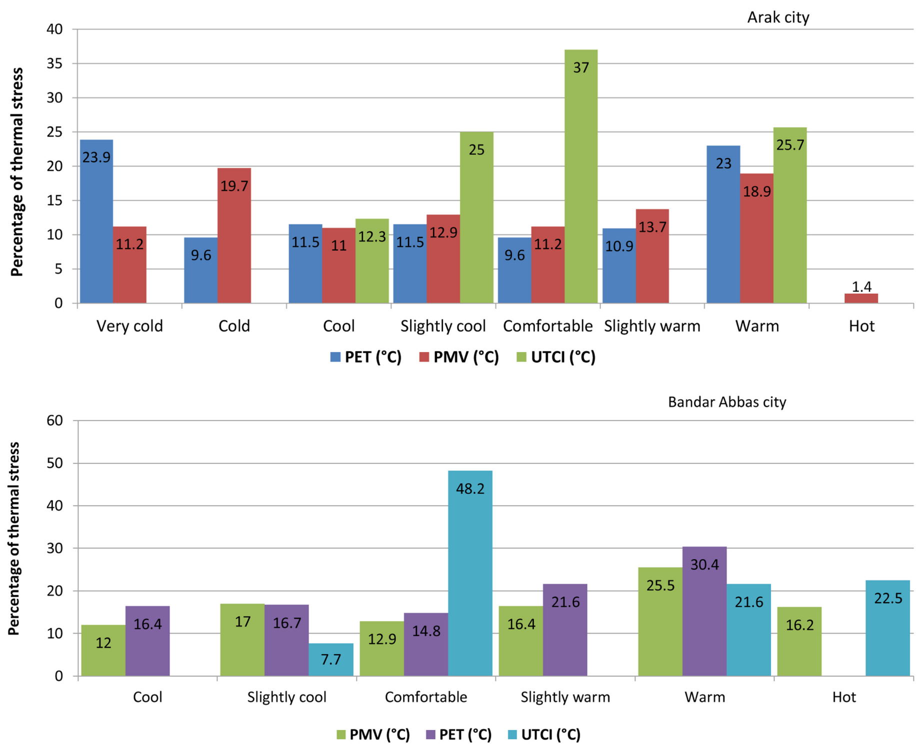

Figure 2. Percentages of thermal stress based on examined indices during the surveyed years.

Abbas, 22.5% and 21.6% of the days have strong heat stress and moderate heat stress, respectively. The days with thermal comfort were 48.2%, and 7.7% of the days have slight cold stress. Using the PET index, the results demonstrated that, in Arak, 23.9%, 9.6%, 11.5% and 11.5% of the days exhibited very strong, strong, moderate and slight cold stress, respectively. The percentage of the days with thermal comfort was 9.6%. On the other hand, 10.9% and 23% of the days had slight and moderate heat stress, respectively. In comparison, the percentage of the days with moderate (16.4%) and slight (16.7%) cold stress in Bandar Abbas was close to the days lacking thermal stress (14.8%), although 21.6% and 30.4% of the days had slight and moderate heat stress, respectively. Correspondingly, using the PMV index, the thermal comfort analysis of Arak showed that 11.2%, 19.7%, 11% and 12.95% of the days have very strong cold stress, strong cold stress, moderate cold stress and slight cold stress, respectively. The percentage of the days with a lack of thermal stress was 11.2%. On the other hand, 13.7%, 18.9% and 1.4% of the days have slight heat stress, moderate heat stress and strong heat stress, respectively. In Bandar Abbas, 12% and 17% of the days have moderate cold stress and slight cold stress, respectively; 12.9% of the days lack thermal stress; and 16.4%, 25.5% and 16.2% of the days have slight heat stress, moderate heat stress and strong heat stress, respectively.

Figure 3 illustrates scatterplots and regression lines for the relationship between examined indices in two surveyed climates. There are very strong correlations between the indices used for the two different climates.

Discussion

Awareness of the effects of climate attributes on different aspects of human life is of high importance for more accurate planning at different time and spatial situations. One of these aspects is climate comfort. Today, bioclimatic investigations, from a

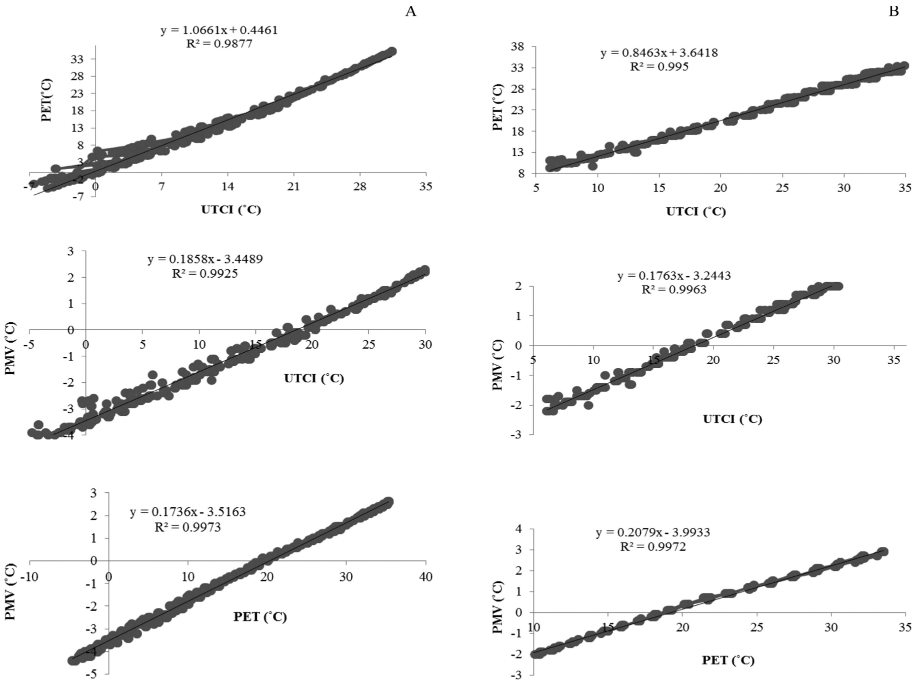

Figure 3 Comparing correlation between examined indices: (a) semi-dry and cold climate (Arak city), (b) hot and dry climate (Bandar Abbas city).

human comfort point of view, are the basis of management planning, especially healthcare planning (Horanont *et al.*, 2013). Such data can be used for future planning, preventive approaches and control measures in order to protect people in outdoor spaces.

In the current study, using the databases of the meteorological organisation to evaluate thermal comfort in different months of the year, a body energy balance model (PET & PMV indices) and the Fiala multi-node model (UTCI) were used in two climates of Iran: semi-dry and cold and hot and dry climates. The results of the study showed that the maximum and minimum temperatures in two examined climates during the surveyed years were observed in July and January, respectively. In the above-mentioned months, people could be at greater risk of heat stress and heat-related diseases compared with other months of the year (Maeda *et al.*, 2006). Appropriate protective measures, especially for people working outdoors with high physical activity, can protect people against heat stress and can reduce irreparable effects on them (Basu and Samet, 2002; Na *et al.*, 2013).

In this study, for Arak, a representative of semi-dry and cold climates, the maximum and minimum values of thermal indices of UTCI, PET and PMV during the surveyed years were observed in July and January, respectively. For Bandar Abbas, a representative of hot and dry climates, the maximum and minimum values of thermal indices for the surveyed years were observed in July and January months, respectively. A rising trend was observed in all indices from January to July. Then, these thermal indices demonstrated a decreasing tendency over other months of the year (Table 3). This was consistent with findings of the study by Zare *et al.*, which compared the UTCI and other heat indices (standard effective temperature [SET], PET, PMV, PPD and WBGT) during the year in the Kerman climate, and results demonstrated that the most severe stressful conditions occurred in June. All indices' values increased from January to June, and then, a descending trend was observed over the other months of the year for all indices (Zare *et al.*, 2018).

According to the UTCI, on some days of the year in Arak, there were moderate heat stress to moderate cold stress. According to the PET index, the days enjoy a very high cold stress to a moderate heat stress, and very cold to cold stress conditions prevailed according to the PMV index during the year. In contrast, based on the UTCI for Bandar Abbas, the days had a strong heat stress to low cold stress, and the day conditions were between moderate cold stress and moderate heat stress for the PET; for the PMV index, the days enjoy moderate cold stress to strong heat stress (Figure 2). Fallah Qalhori *et al.* used the UTCI to assess human thermal comfort in the Kurdistan province; they showed that the lowest and highest values of this index were observed in February and July, respectively. In addition, the results obtained from the zoning index values showed that areas at a higher altitude have very strong cold stress in winter, especially in February, and severe heat stress occurred in the summer, from June to August (Fallah Ghalhari *et al.*, 2015). A more severe cold stress condition, compared to that of the present study, is due to the high altitudes of the region, the length of ice age and the winds of the west on cold days in the Kurdistan region. It should be noted that, in the summer season, the entire country of Iran is located under the prevailing high pressure of the subtropical Azores, which is associated with hot and dry weather and causes severe heat stress that can increase in low-lying and southern areas such as Bandar Abbas and or Kerman (Zare *et al.*, 2018). Omonijo *et al.* evaluated the thermal perception of Nigeria using the PET index. The results indicated that, in a humid forest zone, 61% of the total study period has moderate heat stress, 33.8% slight heat stress, 2.6% no thermal stress and 2% strong heat stress, whereas in the derived savannah region of Ondo State, the environmental condition is as follows: 32.6% strong heat stress, 57.5% moderate heat stress and 9.8% slight heat conditions (Omonijo *et al.*, 2013). The climatic conditions studied by Omonijo *et al.* were warmer than our study climate. Bartzokas *et al.* investigated human thermal discomfort in Athens for the period 1954–2012 in terms of the PMV index. The discomfort period was recorded around the beginning of July to the end of August, and from the mid-1980s, the summer discomfort period was increased (Bartzokas *et al.*, 2013).

Regarding thermal perception, a comparison of thermal indices during all months of the year showed that all indices had similar thermal perceptions (moderate) in the Arak climate from June to August; in May, comfort conditions prevailed, and in the cold months of the year, a more severe cold perception was observed for the PET and PMV indices compared to the UTCI from December to February. In addition, in the Bandar Abbas climate, the months of June and September experienced a moderate heat perception; in July and August, more severe heat conditions prevailed, and in the cold months of the year, there was a more severe cold perception in January, with the highest mean scores for the PET index (Table 3). Furthermore, at the same time, the UTCI had estimated warmer environmental conditions in the two climates than the two other indicators and showed the highest percentage of comfort conditions throughout the year (Figure 2). This is probably due to high correlation between the UTCI and the dry temperature parameter (Matzarakis *et al.*, 2014; Zare *et al.*, 2018).

Previous studies have applied the PET index to locations in Iran (Daneshvar *et al.*, 2013; Roshan *et al.*, 2018). In the study by Daneshvar *et al.* the highest and lowest average values of the PET were observed in July and January, respectively. In the summer months, from July to August, most areas of the country experienced thermal discomfort conditions, which is in accordance with our findings (Daneshvar *et al.*, 2013). Values in the present study appear to be much lower than the values of Roshan *et al.* at both Arak and Bandar Abbas. The years included in the analyses differ (1961–2010 for Roshan *et al.*, 2018 and 2000–2014 for the present study), which may explain this disagreement (Roshan *et al.*, 2018). Hadianpour *et al.* (2018) found that, for an outdoor space in Tehran, the PET and UTCI were more strongly correlated with thermal sensation votes than other indices and that the PMV index tended to overestimate thermal stress (Hadianpour *et al.*, 2019). The results of a study by Mohammadi *et al.*, which aimed to develop a bioecological map for Iran using the PMV index, indicated that, considering the whole spatial and temporal range of Iran, the country enjoys a diverse bioecological condition, so a given place in Iran during the year enjoys both very cold and very hot conditions. However, such a contradiction can also be observed at a certain point of the time across the country (Mohammadi *et al.*, 2017).

The results of this study indicated a significant relationship between examined indices in these two surveyed climates, which shows the appropriateness of using these indices to evaluate thermal comfort in different climates. In previous studies, significant correlations were found between the UTCI with SET (r = 0.97) and the PET index (r = 0.96) (Blazejczyk *et al.*, 2012), in addition to a significant relationship between the UTCI and PET index (r = 0.936) (Matzarakis *et al.*, 2014). Park *et al.* examined human thermal sensation on human biological maps in summer, demonstrating that UTCI registered correlation coefficients of 0.983, 0.979 and 0.957 with PET, PMV and SET, respectively (Park *et al.*, 2014). Farajzadeh *et al.* evaluated the thermal indices in northern Iran from 1986 to 2007; the results demonstrated that UTCI strongly connected with PET and SET with r = 0.9 and r = 0.94, respectively (Farajzadeh *et al.*, 2015). Furthermore, Zare and colleagues demonstrated that there is a higher relationship between PET thermal index with UTCI (r = 0.96) than the WBGT thermal index (r = 0.88) (Zare *et al.*, 2018), which is similar to our findings. A high correlation between thermal indicators can be due to common parameters such as air temperature, relative humidity, air velocity, etc.

With respect to a longitudinal study by Farajzadeh *et al.*, PET and UTCI were appropriate indices to examine thermal comfort (Farajzadeh *et al.*, 2015). In a study by Abdel-Ghany, the PET index and UTCI were successfully used to evaluate thermal sensation and heat stress (Abdel-Ghany *et al.*, 2013). It should be noted that thermal indices have their pros and cons, and we cannot achieve acceptable results simply by investigating a single index. On the other hand, examining and comparing the indices for a single environment can provide more accurate and better evaluations. Therefore, the studies try to use several indices simultaneously.

According to the results obtained from surveyed indices, it appears that cold stress is more important in Arak. Likewise, special attention should be paid to people with underlying diseases like cardiovascular diseases. The pollution of Arak should also be added to these items because it exacerbates the effects. The results of a study by Wenjuan titled 'Investigating the relationship between mortality rate and cold weather in Shanghai' showed a 13% increase in the mortality rate due to cardiovascular diseases in the short term among people older than 11 years in cold months of the year (Ma *et al.*, 2013), whereas in Bandar Abbas, heat stress has a higher priority. Therefore, in order to prevent undesirable effects of the climate, appropriate measures should be adopted.

Conclusion

The results of the study showed that the surveyed regions enjoy a bioclimatic diversity; so, the thermal conditions vary from very hot to very cold during the year. In Arak, the condition of cold stress is a higher priority, similar to heat stress in Bandar Abbas. Based on these results, the bioclimatic comfort indices used demonstrated comfort and discomfort conditions of people during different months of the year in two surveyed climates, and despite trivial differences in the estimation of comfort conditions, they provided relatively uniform representations of climate comfort for the surveyed cities. Regarding the advantages of using these indices, it should be noted that the data measured by meteorological organisations can be used for the forecast and timely announcement of heat and cold stresses, as well as thermal comfort, in different regions. It should be noted that thermal comfort varies with respect to the race, age, type of activity, clothing, metabolism rate, accommodation, etc. Evaluating the trend of thermal comfort indices can identify high-risk areas that, in this context, includes the presence of comprehensive and innovative policy making and planning according to the climate changes and the ability to forecast and control the risks resulting from these changes, seems necessary for community members.

Acknowledgements

This study was funded and supported by Arak University of Medical Sciences; Grant no. 3369. The authors gratefully acknowledge the assistance provided by the Iran Meteorological Organization.

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doi:10.1002/wea.3612