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Assessing thermal comfort in tourist attractions through objective and subjective procedures based on ISO 7730 standard: A field study

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ABSTRACT

Thermal comfort is a subcategory of environmental comfort measured in the light of climatic conditions. Having a good climate is regarded as an advantage for any tourist attraction. The present study aimed at assessing thermal comfort of tourist attractions in Kerman. This cross-sectional descriptive-analytical study used ISO 7730 to evaluate thermal comfort in Kerman through both subjective and objective procedures. Data were collected on three different days of the six months of summer and winter. Three time intervals (8–9 AM, 11–12 PM, and 6–7 PM.) were set for data collection on each day. The results indicated that subjective and objective PMV had the highest correlation with dry temperature (r = 0.88 and r = 0.94, respectively). There was also a significant correlation between objective and subjective PPD (r = 0.91) and objective and subjective PMV (r = 0.97). According to the obtained results, subjective PMV is greater than objective PMV. In other words, subjective dissatisfaction is greater than objective dissatisfaction. Furthermore, according to the obtained values for subjective and objective PMV, thermal comfort is at the maximum level at 6–7 PM (during summer) and 11–12 AM (during winter). Policy makers should plan to attract a larger number of tourists in these times.

1. Introduction

Thermal comfort, which is an important subject, is a subcategory of environmental comfort measured in the light of climatic conditions (da Silveira Hirashima et al., 2016). It is not easy to provide a definition of thermal comfort; however, it is generally defined as individuals' sensation of comfort after being positioned in an artificial environment. People have different sensations of comfort in various conditions. Thus, thermal comfort differs from person to person. Although individuals can adapt themselves to new conditions, some environmental conditions are more suitable for some specific people. Humans' thermal discomfort is measured based on numerous theoretical and experimental indices (Coccolo et al., 2016; Zare et al., 2018a). For many of these indices, the input data consist of climatic elements including air velocity, air temperature, humidity, and solar radiation (Golbabaei et al., 2014; Tseliou et al., 2010). Humans are influenced by the environmental heat under various conditions (Hemmatjo et al., 2017b, c; Zare et al., 2018b). Heat stress, which is the output of different heat loads, is imposed on human body through various environmental and

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personal factors (Kunst et al., 1994). Thermal comfort is the result of thermal balance between human body and the surrounding environment. It influences human's physiological and psychological behavior (Hemmatjo et al., 2017a; Jendritzky et al., 2012; Lam et al., 2016). On the other hand, thermal comfort models utilize not only environmental parameters (e.g. temperature, water vapor pressure, air velocity, and average radiation temperature) (Kántor and Unger, 2011), but also complicated metabolic processes (e.g. physical activity level and clothing) (Jendritzky et al., 2012). These models are also regarded as efficient instruments to summarize the mutual effect of environmental stressors and human reactions. These effects are presented in the form of experimental or rational categorizations based on human thermal balance calculations (Blazejczyk et al., 2012; Steadman, 1979). ISO 7730 is a universal standard for estimating thermal comfort and the dissatisfaction of people in environments with moderate temperature (ISO 7730, 2005). According to this standard, thermal comfort is obtained through calculating Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD), two indices introduced to determine thermal comfort. PMV, which was introduced by Fanger in 1970, is the most appropriate thermal comfort index for environments with moderate temperature (Fanger, 1970). This index takes into consideration the following six factors: metabolism, clothing, air temperature, air velocity, relative humidity, and average radiation temperature. PPD is based on PMV and determines the percentage of predicted dissatisfaction (ISO 7730, 2005). It is commonly used by a large number of experts.

Nowadays, tourism is becoming the most lucrative industry in the world. In total, 10% of gross production in the world is generated in tourism and 10% of world businesses are active in this area. According to the World Tourism Organization, by 2020, the population of tourists in the world will have reached 1 billion and the tourism-related revenue will have exceeded 6 billion (Nadim et al., 2016). Climate is an important factor in attracting tourists to a particular destination, which has a significant impact on travel planning and travel experience. In fact, it is an important piece of information for tourists and those who plan tourist destinations take climate into account in making decisions. From the perspective of tourism programming, climate has a crucial significance and tourists usually visit regions with good climate where they feel comfortable. In such areas, tourists do not have any dissatisfaction and enjoy utmost thermal and climatic comfort. Therefore, climatic conditions play an important role in selecting tourism destinations. There is a close connection between climate and tourism. More specifically, having a good climate is an essential advantage for any destination. Most of the tourists pay attention to climate when they want to select a particular destination (Ataei and Hasheminasab, 2012). There are few studies focusing on thermal comfort of tourist attractions in Kerman. Being inspired by this scarcity of research, the present study was designed to:

1. Estimate the mean score and standard deviation of environmental parameters in the summer and winter of 2016.
2. Assess PMV and PPD values in the summer and winter of 2016 through objective and subjective procedures.
3. Assess the correlation between PMV, PPD, and environmental parameters through objective and subjective procedures in the summer and winter of 2016.

2. Methods

2.1. Study area

This study aimed at assessing thermal comfort in tourist attractions of Kerman, including Kerman Central Mosque known is Mozaffari Central Mosque, Prince's Garden, Ganjalikhan Bath, and Kerman Temple. Fig. 1 illustrates the geographical location of Kerman in Iran.

2.2. Time of the study

The thermal comfort of Kerman's tourist attractions was assessed during three different days using both objective and subjective procedures. Assessments were conducted in three occasions (8–9 AM, 11–12 AM, and 6–7 PM) during the summer and winter of 2016.

2.3. Calculating the sample size and the number of participants

In order to calculate PMV through an objective procedure, environmental parameters (air velocity, relative humidity, and dry temperature) were used. Data were collected on three days at 8–9 AM, 11–12 AM, and 6–7 PM during the summer and winter. In total, 162 environmental parameters were fed into Rayman version 1.2, followed by calculating mean scores for each sampling time (Matzarakis et al., 2007, 2010). This yielded 30 objective indices for the two seasons. Furthermore, to calculate PMV through a subjective procedure, a survey on thermal comfort was distributed among 3 tourists in each of the above mentioned tourist attractions. The participants were requested to assess environmental conditions based on a 7-point Likert scale. Like the objective procedure, subjective data were collected at 8–9 AM, 11–12 AM, and 6 to 7 PM on three days during the summer and winter. In total, 27 respondents filled the questionnaire in each month and the overall number of participants amounted to 162 people. The mean scores of subjective PMV were calculated for each sampling time; therefore, 30 subjective indices were presented for the six months.

2.4. Rayman software

The RayMan model applied here is utilized for the estimation of the radiation fluxes in simple and complex environments based on several parameters including temperature, humidity, wind speed, and short, and long solar radiation. It has been used in tourism

Fig. 1. The geographical location of Kerman, Iran.

or any kind of human climatic activity, because it takes into consideration various complex horizons. The Rayman model was originally developed by Matzarakis and the main purpose of RayMan software is to compute radiation flux densities, sunshine duration, shadow spaces, and thermo-physiologically related assessment indices using only a limited number of meteorological and other input data. A comparison between measured and calculated values for mean radiant temperature indicates that the simulated data closely resemble measured data (Matzarakis et al., 2007, 2010).

2.5. Data collection

Environmental parameters (air velocity, relative humidity, and dry temperature) were obtained from the meteorological organization to calculate PMV through an objective procedure. In addition, a survey was distributed among tourists to calculate OMV through a subjective procedure. The survey contained a section on demographic information and a 7-point Likert scale questionnaire which was designed based on ISO 7730 (ISO 7730, 2005).

2.6. Requirements of ISO 7730 ergonomic standard

In the present study, ISO 7730 ergonomic standard was used to calculate PMV and PPD in the tourist attractions of Kerman (ISO 7730, 2005).

ISO 7730 is a universal standard used to estimate general sensation of comfort and dissatisfaction of individuals who are exposed to environments with moderate temperature. This standard provides the opportunity to interpret thermal comfort based on PMV and PPD. These two indices are used to estimate thermal comfort.

2.7. Calculating objective PMV

Predicted Mean Vote (PMV) was introduced by Fanger in 1970 (Fanger, 1970). It is one of the major temperature-physiologic indices which is used in both urban and regional planning and applied meteorological studies. This index predicts the average value of collective sensation of a group of people who are exposed to a similar environment. Dry temperature, average radiation temperature, relative humidity, air velocity, metabolism, and clothing are taken into account in calculating objective PMV.

Threshold values of the thermal indices, Predicted Mean Vote (PMV) for different grades of thermal sensivity of human beings and physiological stress on human beings, internal heat production: 80 W, heat transfer resistance of clothing: 0.9 clo (Table 1).

In the current study, Rayman version 1.2 was exploited to calculate objective PMV.

Table 1
Categorization of PMV for different levels of thermal perception and physiological stress.

PMV	Thermal Sensivity	Grade of Physiologic Stress	Color code
> -3.5	very cold	extreme cold stress	
-3.5 up to -2.5	Cold	strong cold stress	
-2.5 up to -1.5	Cool	moderate cold stress	
-1.5 up to -0.5	slightly cool	slight cold stress	
-0.5 up to 0.5	Comfortable	no thermal stress	
0.5 up to 1.5	slightly warm	slight heat stress	
1.5 up to 2.5	Warm	moderate heat stress	
2.5 up to 3.5	Hot	strong heat stress	
> 3.5	very hot	extreme heat stress	

2.8. Calculating subjective PMV

In order to calculate subjective PMV, individuals should evaluate environmental conditions based on a 7-point Likert scale. The mean score of the collected data presents the PMV value. Table 2 illustrates the 7-point Likert scale used in this study.

2.9. Calculating objective PPD

The PPD predicts the percentage of the people who felt warm or hot (or cool and cold) (i.e. the percentage of the people who inclined to complain about the environment). The seven-point likert scale used in the survey ranged from −3 to +3 (ISO 7730, 2005).

All those who responded ± 2 and ± 3 were considered as feeling uncomfortable. Those who responded ± 1 and 0 were declared comfortable. The percentages of subjects who responded ± 2 and ± 3 were determined for each class of PMV; that variable was called PPD. The relationship between PPD and PMV is given by the following Eq. (1).

$$PPD = 100\text{–}95\ \exp.[-(0.03353\ PMV^4 + 0.2179\ PMV^2)] \tag{1}$$

2.10. Calculating subjective PPD

Subjective PMV values were used to calculate subjective PPD. Table 3 displays the subjective PPD percentages corresponding to each PMV value.

Depending on the ranges of PPD and PMV, three kinds of comfort zones can be accessed as reflected in Table 4.

2.11. Ethical considerations

Ethical approval was obtained from the Ethics Committee of Kerman University of Medical Sciences (ID: IR.KMU.REC.1395.225). All participants signed a consent form.

2.12. Statistical analysis

Collected data were analyzed by Statistical Package for the Social Sciences (SPSS) 20 (SPSS Inc., Chicago, IL, USA) using statistical tests such as Pearson correlation coefficient and linear regression.

3. Results

3.1. Age and body mass index of participants

The mean score and standard deviation of participants' age and body mass index were 7.35 ± 29.15 years and 3.15 ± 23.11 kg/m^2, respectively. Furthermore, clothing resistance was considered to be 0.7 K during the summer and 1.2 K in the winter.

Table 2
The 7-point Likert scale used for calculating subjective PMV.

−3	−2	−1	0	+1	+2	+3
Cold	Cool	Slightly cool	Moderate	Slightly warm	Warm	Hot

Table 3
Subjective PPD percentages corresponding to each PMV value.

Type of sensation	Cold	Slightly cool	Cool	Moderate	Slightly warm	Warm	Hot
PMV value	−3	−2	−1	0	1	2	3
PPD (%)	100	75	25	5	25	75	100

Table 4
Predicted percentage of dissatisfied (PPD) based on the predicted mean vote (PMV).

Comfort	PPD	Range of PMV
1	< 6	−0.2 < PMV < 0.2
2	< 10	−0.5 < PMV < 0.5
3	< 15	−0.7 < PMV < 0.7

3.2. Mean score and standard deviation of environmental parameters for the six months of the summer and winter

Table 5 presents mean scores and standard deviations of environmental parameters (air velocity, relative humidity, and dry temperature) in various sampling times during the six months of the summer and winter of 2016. The highest dry temperature (measured by degrees of Celsius) was recorded at all sampling times in June, while the lowest dry temperature was registered at 8–9 AM in January (8.27 ± 5.43), 11–12 AM in February (12.53 ± 5.43), and 6–7 PM in December (6.03 ± 0.19).

3.3. Objective and subjective PMV and PPD measured during the summer and winter

Table 6 displays the mean scores and standard deviations of objective and subjective PMV and PPD calculated for different sampling occasions during the six months of the summer and winter of 2016.

3.4. The correlation between thermal indices (subjective/objective PMV and PPD) and environmental indices

As observed in Table 7, there were significant correlations between objective/subjective PMV and environmental parameters (air velocity, relative humidity, and dry temperature) ($P < 0.05$). Also, objective and subject PMV had strong correlations with dry temperature, with coefficients of 0.88 and 0.94 respectively. Furthermore, both objective and subjective PMV had inverse, small correlations with relative humidity and air velocity.

On the other hand, objective and subjective PPD did not have any significant correlation with environmental parameters ($P > 0.05$) (Table 7).

In addition, objective and subjective PPD had low correlations with environmental parameters. However, there was a significant association between objective and subjective PMV ($P < 0.0001$). Likewise, there were statistically measurable relationships between objective PMV, on the one hand, and objective and subjective PPD, on the other ($P < 0.05$).

Fig. 2 shows the correlations between objective and subjective PMV. It is observed that these two indices were significantly

Table 5
Mean scores and standard deviations of environmental parameters during various sampling times in the six months of summer and winter.

Sampling time	Environmental parameters		JUN	JUL	AUG	DEC	JAN	FEB
8:00–9:00 AM	Air velocity (m/s)	Mean	4.23	4.57	3.97	2.27	0.97	0.97
		SD	0.57	1.06	1.48	1.16	0.29	0.33
	Humidity (%)	Mean	5.73	5.50	9.90	22.57	23.73	43.97
		SD	1.73	2.06	2.73	4.78	5.82	4.38
	Air temperature (°C)	Mean	34.83	33.07	31.00	13.53	8.27	9.87
		SD	0.82	0.91	1.14	3.23	5.43	4.15
11:00–12:00 AM	Air velocity (m/s)	Mean	4.57	5.43	4.67	1.63	2.73	2.80
		SD	0.45	2.27	0.53	0.33	2.59	1.53
	Humidity (%)	Mean	4.97	4.27	8.23	23.30	13.20	28.73
		SD	2.17	1.36	2.50	8.39	6.05	10.34
	Air temperature (°C)	Mean	35.33	34.17	32.53	14.50	16.43	12.53
		SD	1.02	1.39	0.74	4.45	2.67	5.45
6:00–7:00 PM	Air velocity (m/s)	Mean	2.40	2.97	3.17	2.63	2.03	4.30
		SD	0.28	0.25	0.74	1.73	1.27	1.77
	Humidity (%)	Mean	9.53	9.03	12.67	50.57	13.93	31.00
		SD	1.72	0.95	2.75	7.22	8.66	13.82
	Air Temperature (°C)	Mean	28.10	25.63	24.63	6.03	12.57	10.47
		SD	0.24	1.83	1.35	0.19	3.47	4.48

Table 6
The mean scores and standard deviations of objective and subjective PMV and PPD calculated for different sampling occasions during the six months of the summer and winter of 2016.

Sampling time	Indices			JUN	JUL	AUG	DEC	JAN	FEB
8:00–9:00 AM	PMV	Objective	Mean	1.51	2.11	1.47	−1.70	−1.49	−1.60
			SD	0.08	0.17	0.27	4.64	0.20	0.26
		Subjective	Mean	2.00	3.00	2.50	−1.83	−2.00	−2.00
			SD	0.13	0.42	0.71	0.62	0.38	0.14
	PPD (%)	Objective	Mean	51.30	81.10	49.67	61.47	50.20	56.33
			SD	4.49	7.41	14.41	15.77	10.34	13.38
		Subjective	Mean	80	100	83.33	75	80	80
			SD	0.25	0.00	23.57	18.71	0.17	0.45
11:00–12:00 AM	PMV	Objective	Mean	3.17	4.19	3.97	−0.72	−0.36	−0.61
			SD	0.51	0.53	0.32	0.21	0.27	0.11
		Subjective	Mean	3.00	3.00	3.00	−1.17	−1.00	−1.00
			SD	0.24	0.53	0.36	0.24	0.27	0.42
	PPD (%)	Objective	Mean	97.27	99.97	100.00	16.97	9.20	13.87
			SD	3.72	0.05	0.00	7.08	4.84	2.25
		Subjective	Mean	100.00	100.00	100.00	30.00	20.00	20.00
			SD	0.00	0.00	0.00	14.14	3.04	6.07
6:00–7:00 PM	PMV	Objective	Mean	0.39	0.11	−0.08	−2.89	−2.04	−1.73
			SD	0.10	0.63	0.13	0.03	0.08	0.61
		Subjective	Mean	1.50	1.00	1.33	−3.00	−3.00	−2.17
			SD	0.32	0.14	0.24	0.00	0.00	0.62
	PPD (%)	Objective	Mean	8.43	13.53	5.47	98.50	78.53	59.67
			SD	1.96	3.12	0.21	0.22	3.55	26.54
		Subjective	Mean	50.00	20.00	40.00	100.00	100.00	76.67
			SD	3.06	2.04	14.14	0.00	0.00	14.55

Table 7
The correlations between thermal indices, objective/subjective PMV, objective/subjective PPD, and environmental parameters.

Parameters		PMV		PPD	
		Objective	Subjective	Objective	Subjective
Wind speed	R	0.53	0.52	0.24	0.18
	Slope	0.46	0.42	0.01	0.01
	P-value	< 0.0001	< 0.0001	0.08	0.20
Relative humidity	R	−0.72	−0.75	0.04	0.01
	Slope	−5.01	−4.88	0.02	0.003
	P-value	< 0.0001	< 0.0001	0.77	0.97
Air temperature	R	0.88	0.94	0.13	0.14
	Slope	4.78	4.77	0.04	0.05
	P-value	< 0.0001	< 0.0001	0.36	0.31
PMV objective	R	1	0.93	0.30	0.24
	Slope		0.86	0.001	0.02
	P-value		0.001	0.03	0.08
PMV subjective	R	0.93	1	0.13	0.15
	Slope	0.995		0.01	0.01
	P-value	< 0.0001		0.36	0.28
PPD objective	R	0.30	0.13	1	0.91
	Slope	4.99	2.02		1.01
	P-value	0.03	0.36		0.001
PPD subjective	R	0.24	0.15	0.91	1
	Slope	3.72	2.12	0.82	
	P-value	0.08	0.28	< 0.0001	

connected ($r^2 = 0.859$).

Fig. 3 illustrates the correlation between objective and subjective PPD. It is observed that these two indices were significantly correlated ($r^2 = 0.829$).

3.5. Comparing thermal comfort based on objective/subjective PMV obtained during the six months of the summer and winter

Table 8 contains a comparison of thermal stress based on objective/subjective PMV values for various levels of thermal perception and physiological stress for different months of the summer and winter.

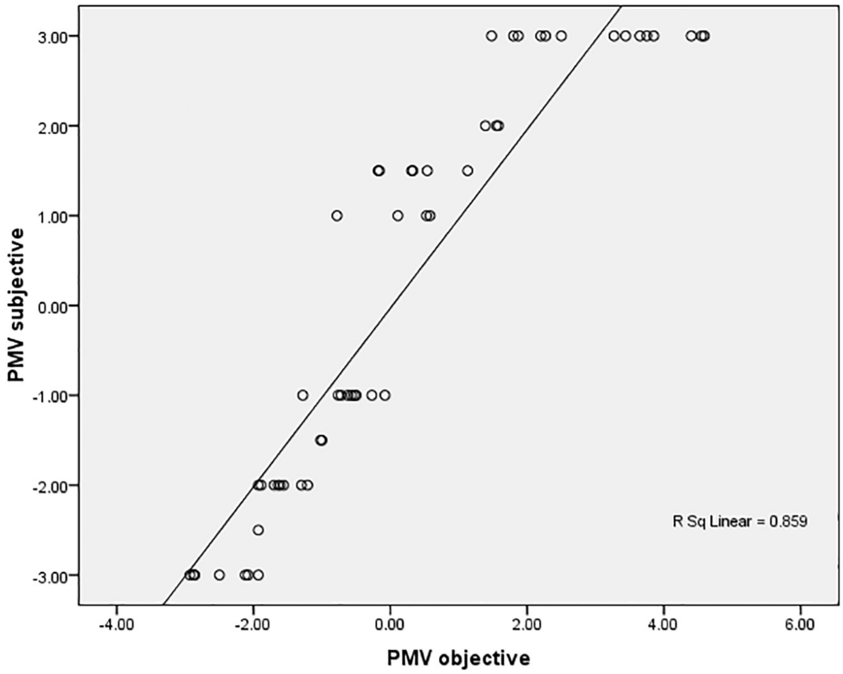

Fig. 2. The correlation between objective and subjective PMV.

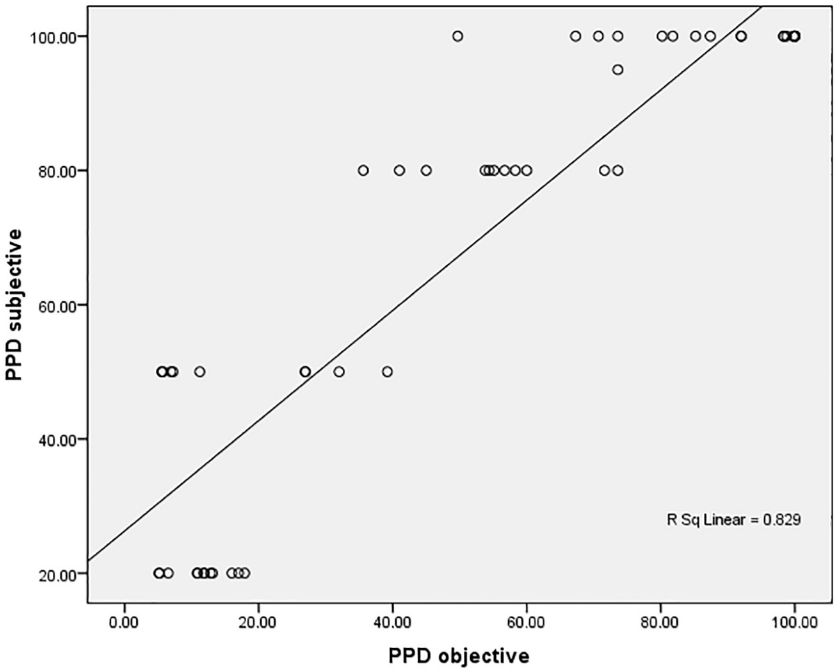

Fig. 3. The correlation between objective and subjective PPD.

4. Discussion

This study used both objective and subjective procedures to investigate thermal comfort in tourist attractions of Kerman based on ISO 7730 ergonomic standard (ISO 7730, 2005). The results showed that the highest dry temperature was recorded in all sampling times of June, while the lowest dry temperature was registered in various sampling times of December.

It was also found that mean score of subjective PMV was higher than that of the objective PMV. In particular, subjective PMV obtained at 8–9 AM in July and Augusts were greater than mean score of objective PMV obtained at the same time. On the other hand,

Table 8
Comparing thermal stress based on objective/subjective PMV in various levels of thermal perception and physiological stress.

Sampling time		JUN	JUL	AUG	DEC	JAN	FEB
8:00-9:00 AM	Objective	1.51	2.11	1.47	-1.7	-1.49	-1.6
	Subjective	2	3	2.5	-1.83	-2	-2
11:00-12:00 AM	Objective	3.17	4.19	3.97	-0.72	-0.36	-0.61
	Subjective	3	3	3	-1.17	-1	-1
6:00-7:00 PM	Objective	0.39	0.11	-0.08	-2.89	-2.04	-1.73
	Subjective	1.5	1	1.33	-3	-3	-2.17

the mean score of subjective PMV was lower in January, and both indices yielded similar values for other months. Both subjective and objective PMV showed similar values (hot) when data were collected from 11 to 12 AM during the summer. In winter, both indices had similar values (slightly cool). Considering the data collected at 6–7 PM, subjective PMV is greater than objective PMV and, in January, the situation was the other way round. Both indices showed similar values in December and February.

Azizpour et al. (2013) examined thermal comfort in one of the hospitals in Malaysia, which has a hot and humid climate. They reported that subjective PMV was greater than objective PMV. Maiti (2014) investigated the response and thermal comfort of 40 Indian university students, concluding that subjective PMV overestimates thermal sensation. In their study, the mean subjective PMV was always greater than the mean objective PMV. In our study, the comparison of subjective and objective PMV values showed that thermal sensation measured through these two procedures was similar in most of the months. Also, in some hot months, subjective PMV was greater than objective PMV, while in cold months, subjective PMV was smaller than objective PMV, hence indicating colder weather. This might be attributed to the fact that most of the participants came from other cities of Iran and were not used to the climatic condition in Kerman. Thus, they overestimated climatic condition measured through subjective PMV.

The results further showed that the highest level of dissatisfaction was recorded at 11–12 AM in the summer in both subjective and objective procedures, whereas the highest level of satisfaction in the same season was observed at 6–7 PM through both objective and subjective measures. Subjective measures also indicated greater satisfaction than objective ones. In winter, the highest level of dissatisfaction was registered at 8–9 AM and 6–7 PM in both objective and subjective procedures, while the highest level of satisfaction was recorded at 11–12 AM in both measures. The subjective measure, however, indicated greater satisfaction than the objective one (Table 4).

Najafi and Najafi (2012) studied thermal comfort in Vakil Market in Shiraz through subjective and objective PMV and PPD at 10 a.m., 12 at noon, and 2 PM. They found that < 15% of people in this market were satisfied with environmental condition in January. Considering subjective and objective procedures respectively, we found that, at 8–9 AM, 56.33% and 80% of the participants were not satisfied. Also, at 11–12 AM, 13.87% (subjective) and 20% (objective) of respondents were not satisfied. Finally, at 6–7 PM, 59.67% (subjective) and 76.67% (objective) were dissatisfied.

Alcobia and Silva (1999) studied thermal stress in mini-buses and tourism buses in Portuguese roads, indicating that objective PPD values were greater than subjective PPD scores. In contrast, we found that subjective PPD was higher than objective PPD (Table 6).

In the current study, there was a significant relationship between subjective/objective PMV and environmental parameters (air velocity, relative humidity, and dry temperature) ($P < 0.05$). The highest correlation coefficients were recorded for the relationship between objective and subjective PMV and dry temperature with Pearson coefficients of 0.88 and 0.94 respectively. Also, the slope of both relationships was 4.77. Nonetheless, subjective/objective PPD did not significantly correlate with environmental parameters ($P > 0.05$). The coefficients of the associations between subjective/objective PPD and environmental parameters were small.

Alcobia and Silva (1999) indicated a strong correlation between subjective and objective PPD ($r = 0.83$) (22). A similar, strong relationship was found between subjective and objective PPD in this study ($r = 0.91$). The association between these two variables was statistically significant ($P < 0.0001$).

Azizpour et al. (2013) who investigated thermal comfort in a hospital in Malaysia with hot and humid weather, found that there was a strong relationship between subjective and objective PMV obtained through linear regression ($r = 0.97$) (28). Maiti (2014) showed that there was a strong relationship between PMV and response to thermal perception (subjective) ($R^2 = 0.835$) (30). A similar result was obtained in this study; that is, the correlation between subjective and objective PMV was significant ($P < 0.0001$). It was also discovered that the relationship between objective PMV and objective PPD was statistically measurable ($P < 0.05$).

4.1. Limitations of the present study

There were some limitations in this study. For example, we did not have access to weather data before 2016. Also, a number of tourists did not cooperate in completing the questionnaires, and the researchers were restricted to a limited number of city attractions.

5. Conclusion

Overall, according to the obtained results, subjective PMV is greater than objective PMV. In other words, subjective dissatisfaction is greater than objective dissatisfaction. Furthermore, according to the obtained values for subjective and objective PMV, thermal comfort is at the maximum level at 6–7 PM (during the summer) and 11–12 AM (during the winter). Policy makers should plan to attract a larger number of tourists in these times.

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Conflicts of interest

There are no conflicts of interest.

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