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Assessing The Thermal Comfort Conditions In Open Spaces: A Transversal Field Survey On The University Campus In India

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ABSTRACT

Outdoor thermal comfort (OTC) promotes the usage frequency of public places, recreational activities, and people's wellbeing. Despite the increased interest in OTC research in the past decade, less attention has been paid to OTC research in cold weather, especially in arid regions. The present study investigates the OTC conditions in open spaces at the campus area in the arid region. The study was conducted by using subjective surveys(questionnaire) and onsite monitoring (microclimate parameters). The study was conducted at the Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Haryana-India campus during the cold season of 2019. The timings of surveys were between 9:00 and 17:00 hours. The authors processed the 185 valid questionnaire responses of the respondents to analyze OTC conditions. Only 8.6% of the respondents marked their perceived sensation "Neutral." Regression analysis was applied between respondents' thermal sensations and microclimate parameters to develop the empirical thermal sensation model. The air temperature was the most dominant parameter affecting the sensations of the respondents. The empirical model indicated that by increasing air temperature, relative humidity, and solar radiation, the thermal sensations also increased while wind speed had an opposite effect. Physiological equivalent temperature (PET) was applied for assessing the OTC conditions; the neutral PET range was found to be 18.42-25.37°C with a neutral temperature of 21.89°C. The preferred temperature was 21.99 °C by applying Probit analysis. The study's findings could provide valuable information in designing and planning outdoor spaces for educational institutions in India's arid regions.

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1. Introduction

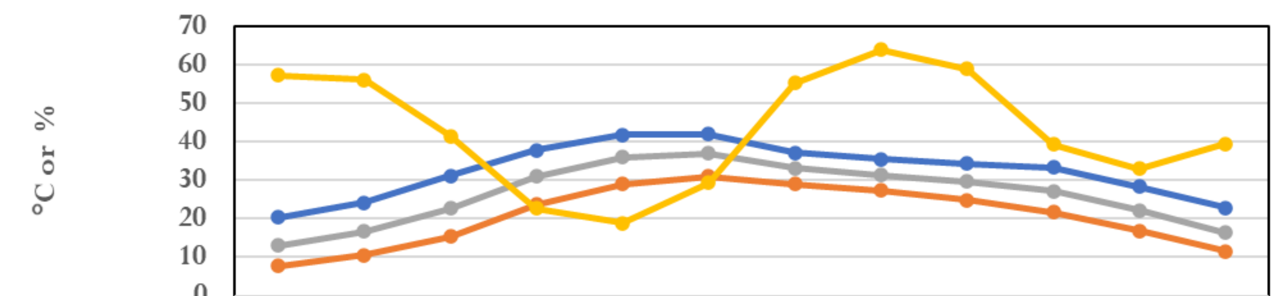
With climate change, the globe's population suffers from extreme weather events(Li & Zha, 2020). The availability of conducive OTC conditions is necessary to be a sustainable, liveable outdoor space (Altunkasa & Uslu, 2020). Urban livability relates to the early 1980s due to climate change and growing competition among the world's economies to attract investors and tourists (Kashef, 2016). Climate change negatively impacts cities' livability status (Fong, Aghamohammadi, Ramakreshnan, Sulaiman, & Mohammadi, 2019; Nazarian, Sin, & Norford, 2018) as urbanization is increasing rapidly, which causes a reduction in urban green spaces and changes in microclimate. So, the population can experience harsh weather conditions in open urban areas (Ketterer & Matzarakis, 2014; Kong et al., 2017). Due to this, the urban population prefers to stay indoors and is bound to opt for sedentary lifestyles (Salata et al., 2018). Urban planners have a big task to encourage people to use outdoor spaces, which are essential from social, environmental, and health perspective (Shooshtarian & Ridley, 2016). The urban areas' microclimate impacts the open spaces' usability frequency (Ali & Patnaik, 2018). The outdoor thermal environment's development promotes public places and ultimately improves life quality (Smith & Henríquez, 2019). Physiological and psychological health is directly linked to outdoor activities (Jianlei Niu et al., 2015; Yao, Yang, Zhuang, Shao, & Yuan, 2018). In the last decade, outdoor thermal comfort gaining more attention through microclimate studies conducted in many parts of the world; this gain is happening even though there are complex unsteady outdoor conditions. However, outdoor thermal comfort studies are still far less than indoor studies (Amindeldar, Heidari, & Khalili, 2017). Over the century, researchers were developed thermal comfort indices to evaluate the thermal environment(both indoor and outdoor) (Coccolo, Kämpf, Scartezzini, & Pearlmutter, 2016; de Freitas & Grigorieva, 2017; Johansson, Thorsson, Emmanuel, & Krüger, 2014; Pardeep Kumar & Sharma, 2020; Potchter, Cohen, Lin, & Matzarakis, 2018). Although thermal comfort indices are used to evaluate the thermal environment, ultimately, it relates to the impact on the human occupant (Kumar and Sharma., 2020).

Thermal comfort indices were developed based on a single node, two-node, and multiple node models to determine comfort conditions. One node model is based on the heat balance equation. It can be calculated by giving input of six basic parameters, i.e., air temperature, mean radiant temperature, relative humidity, wind speed, clothing, and metabolic rate. The two-node model includes the effects of skin temperature and core temperature on the heat balance. In the multi-node model, the whole human body was divided into many sections to consider the effect of skin temperature, core temperature, and rate of change of skin temperature on heat balance (Fang, Feng, et al., 2019).The use of thermal indices is essential to assess human thermal comfort conditions (Coccolo et al., 2016; Hirashima, Katzschner, Ferreira, Assis, & Katzschner, 2018). Several thermal comfort indices were developed intended for the outdoor environment (Coccolo et al., 2016; de Freitas & Grigorieva, 2017; Johansson et al., 2014; Pardeep Kumar & Sharma, 2020; Potchter et al., 2018). PET is the most frequently used thermal index to evaluate the OTC conditions (Kumar and Sharma., 2020). PET was developed based on the two-node model, which includes skin and core temperature of the human body(Höppe, 1999).In the previous studies, the study area selected was public open or semi-open outdoor spaces. According to the study of (Canan, Golasi, Ciancio, Coppi, & Salata, 2019), university campuses have always played a significant role in investigating outdoor thermal comfort conditions for various landscapes because of the availability of plenty of open spaces and semi-open spaces that provide ample space for outdoor activities. In the past decade, several researchers carried out OTC studies to examine the university campus's comfort conditions in different climate zones globally; those studies are given in Table 1. It was inferred from the literature survey that none of the studies (to the best of the author's belief) investigated the hot semi-arid(Bsh) climate zone in the winter season at the campus area.

Table 1 OTC studies carried out at various university campus

Source	Location	Climate	Season	Sample size
Xi et al.,(2012)	Guangzhou, China	Humid subtropical (Cfa)	Summer	114
Makaremi et al., (2012)	Malaysia	Tropical rainforest(Af)	Spring	200
Liu et al., (2016)	Changsha, China	Humid subtropical (Cfa)	Summer& Winter	7851
Zhao et al., (2016)	Guangzhou, China	Humid subtropical (Cfa)	Summer	1582
Salata et al., (2016)	Rome, Italy	Hot-summer Mediterranean (Csa)	All seasons	941
Wang et al., (2017)	Groningen, Netherlands	Temperate oceanic (Cfb)	Spring & summer	387
Canan et al.,(2019)	Konya, Turkey	Cold semi-arid(Bsk)	Summer	315
Huang et al., (2019)	Sichuan, China	Monsoon-influenced humid subtropical (Cwa)	Summer &Winter	523
Fang et al., (2019)	Guangzhou, China	Humid subtropical (Cfa)	Summer	1100
Niu et al.,(2020)	Xi'an, China	Monsoon-influenced Humid subtropical(Cwa)	Summer	54
He et al.,(2020)	Xi'an, China	Monsoon-influenced Humid subtropical(Cwa)	Winter, Spring, and summer	1691

The majority of OTC studies were carried out in tropical and temperate climate zone regions(Kumar and Sharma.,2020), with less focus on the cold weather conditions (Xu, Hong, Mi, & Yan, 2018). Thermal comfort conditions need to be improved to promote the usage frequency of outdoor spaces in cold-weather regions. In the arid regions, mild winter can be experienced by the people. People in the campus area are not provided with a recreational place where people can relax, social interact, and come close to nature, etc., in extreme weather conditions. People mostly preferred spending time indoor. They came outside only for some urgent work. Outdoor activities are prevalent only in transition season/weather. This kind of lifestyle is harmful to wellbeing. The present study was carried out to determine the outdoor thermal comfort conditions at the campus area so that campus areas can be developed to provide comfortable outdoor places in cold weather. The monthly variation of air temperature and relative humidity over a period of 10 years is shown in Figure 1. The Bsh climate of Northern plains of India includes parts of states like Punjab, Haryana, New Delhi, and Utter Pradesh (Britannica.com, n.d.). This study was conducted at a university campus in Sonepat, Haryana



	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Tmax(°C)	20.3	24.1	31.1	37.8	41.8	41.9	37.1	35.4	34.3	33.3	28.3	22.8
Tmin(°C)	7.7	10.6	15.4	23.6	28.9	30.9	28.9	27.3	24.9	21.6	16.9	11.6
Tavg(°C)	13.09	16.64	22.73	30.91	35.91	36.91	33.09	31.27	29.64	27.1	22.1	16.3
RHavg(%)	57.18	56	41.45	22.73	18.91	29.27	55.18	63.91	58.82	39.3	33	39.5

Figure 1 Monthly variation of Maximum temperature, Minimum temperature, Average temperature, and average relative humidity from 2010-19(WWO, 2020)

The present study's driving force targets the research question: What is the cold season's influence on the people's perceptions at the university campus? What are the microclimate parameters which are significantly affecting thermal perceptions at campus? What is the neutral and preferred temperature at campus area? Based on the research question, the objectives of the present study are-

1. To investigate the OTC conditions during winters based on the transversal field surveys.
2. To develop the empirical TSV model based on thermal sensations of the people and meteorological parameters.
3. To determine the neutral temperature range, neutral temperature, and preferred temperature for the study area.

2. Methodology

2.1 Description of Study Area

The authors conducted this study at the campus of Deenbandhu Chhotu Ram University of Science and Technology, Murthal, Sonepat-India, which spreads across 273 acres of land and falls in the northern plains of India. This campus is a governmental university, and the majority of the people from different locations of Haryana and India's national capital region are studying and staying at the campus. The geographical location of the investigated site is shown in Figure 2. The authors selected the mentioned site for investigation because of the usage frequency of the sites. People visit the investigated sites for relaxing/taking a break from their academic activities/studies. The usage frequency of outdoor spaces is directly linked with the OTC conditions, and the microclimate of the site has a direct impact on the thermal comfort conditions(Lai, Guo, Hou, Lin, & Chen, 2014).Sonepat (28.99°N, 77.01° E) is characterized as the hot semi-arid climate (Bsh) zone as per Köppen climate classification(Peel, Finlayson, & Mcmahon, 2007) at the altitude of 219m from sea level. The air temperature varies from 45°C in summers to 4°C in winters. Relative humidity in the region range from 20-50% in summers and 50-90% in winters(Parveen Kumar, 2014).

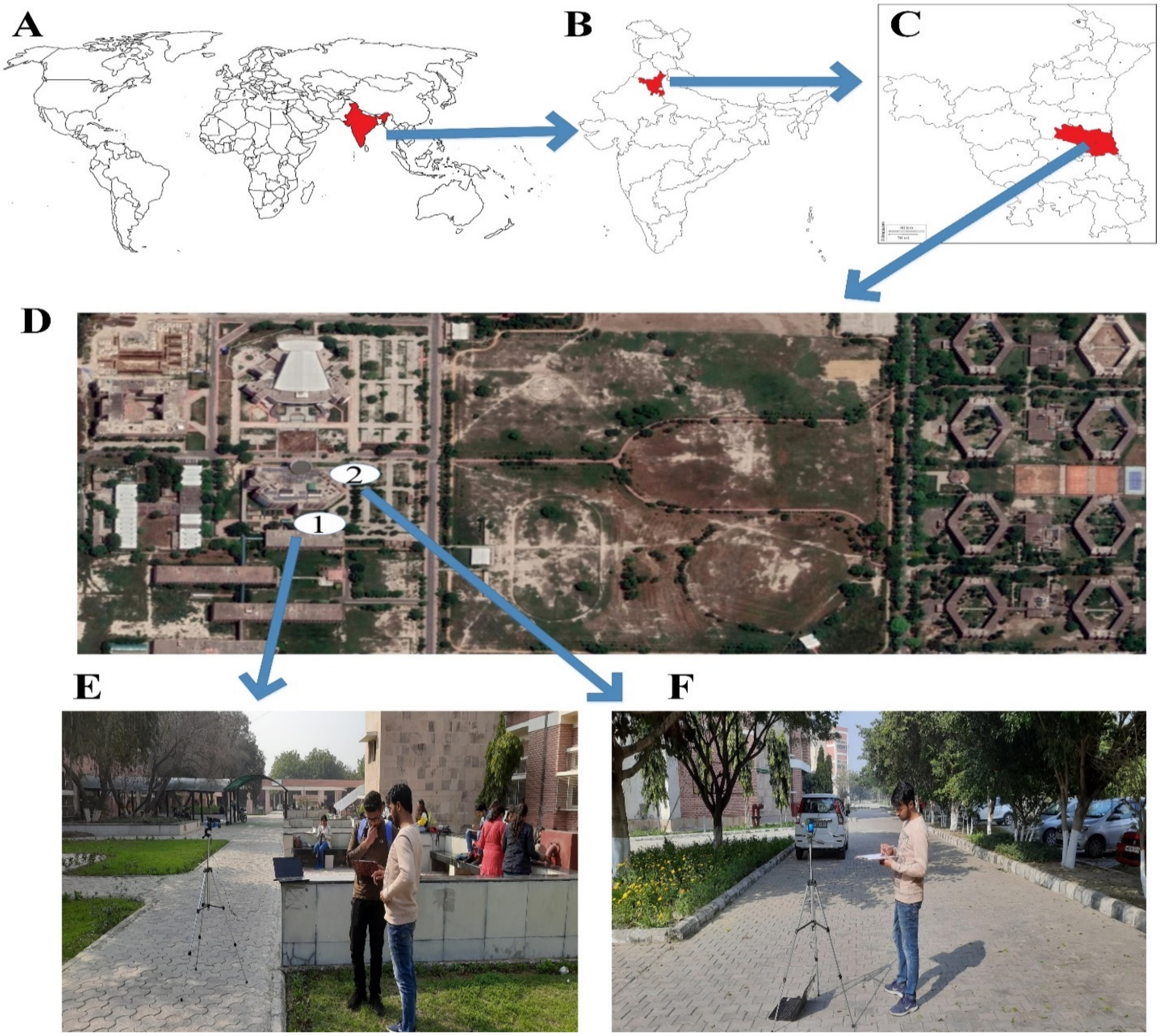


Figure 2 Geographical location of the study area A) India's location in world map B) Haryana's location in India map C) Sonepat's location in Haryana map D) Satellite image of the university campus in Sonepat E&F) Sites investigated in the present study

2.2 Field Survey

In this investigation, the authors conducted a field survey in the winter season during the five typical days from December 23, 2019, to December 31, 2019, that involved subjective surveys and objective measurements between 9:00 and 17:00 hours. During the field survey, the respondents were asked to stay at the investigated sites for 10 to 15 minutes so that they could adapt to the thermal environment. The questionnaire was designed as per ISO 10551 (ISO, 2001) and used to record subjective data like- personal information, current activity, clothing type, thermal sensation scale, thermal preference with regards to microclimate parameters, and overall preference. The authors used the ASHRAE Seven-point sensation scale(ANSI/ASHRAE Standard 55, 2010) to record the respondents' thermal sensations. The overall comfort of the respondents was recorded on the three-point scale, i.e., Uncomfortable (-1), Acceptable (0), and Comfortable (+1). The overall preference of the respondents was recorded on the three-point scale, i.e., Cooler (-1), Neutral (0), and Warmer (+1). The preference of the meteorological parameters Air temperature (T_a), Relative humidity (RH), Wind Speed (Ws), and Global solar radiation(G) were recorded on the three-point scale, i.e., T_a preference: Higher (+1), Unchanged (0), Lower (-1); RH preference: Damper (+1), Unchanged (0), Drier (-1); Ws preference: Stronger (+1), Unchanged (0), Slower (-1); G preference: Stronger (+1), Unchanged (0), Weaker (-1). The authors presented a demonstration about the purpose of the investigation and questions in the questionnaire to each respondent before recording their responses. A total of 209 questionnaires were filled by the respondents by the transversal survey. Due to some left out questions from the respondents, 185 valid questionnaires were processed.

2.3 Physical Measurement

The Onsite monitoring was conducted in parallel with the subjective survey to record the meteorological parameters. The sensors used in the present study are given in Table 2. All the instruments used were compiled with ISO 7726(ISO 7726, 1998). The global solar radiation (G) data were retrieved from the meteorological observatory center located at the university campus.

Table 2 The sensor used in the present study for onsite monitoring of meteorological parameters

Meteorological Parameters	Sensor	Range	Accuracy
T_a	Extech HT30 WBGT meter	0 to 50°C	±1.8°F/1.0°C
RH	Extech HT30 WBGT meter	0 to 100%RH	±3%RH
Ws	Meterevi Digital anemometer (AVM-01)	0 - 30m/s	±(5%rdg+0.5)

2.4 Thermal Comfort Index

In the present investigation, the PET was applied to investigate the thermal comfort conditions. Several studies in the literature have used PET to determine the neutral temperature and neutral temperature range(Kumar & Sharma, 2020). It is based on the Munich Energy-balance Model for Individuals (MEMI), which models the human body's thermal needs physiologically. It is defined as the physiological equivalent temperature at any given place (outdoors or indoors) and equivalent to the air temperature at which, in a typical indoor setting (without wind and solar radiation), the human body's heat balance is maintained with core and skin temperatures equal to those under the conditions being assessed. This way, PET enables a layperson to compare the integral effects of complex thermal conditions outside with their own experience indoors(Höppe, 1999). The heat balance of the PET is given in Eq.1 :

$$M + W + R + C + E_D + E_{Re} + E_{Sw} + S = 0 \quad (1)$$

Where M: Metabolic rate
W: Physical work output
R: Net radiation of the body
C: Convective heat flow
E_D: Latent heat flow to evaporate water into water vapor diffusing through the skin
E_{Re}: Sum of heat flows for heating and humidifying the inspired air
E_{Sw}: Heat flow due to evaporation of sweat
S: Storage heat flow for heating or cooling the body mass
Watt is the unit for all heat flow.

Table 3 Description of physiological stress based on PET (Matzarakis & Mayer, 1996)

PET(°C)	Thermal Sensation	Grade of physiological stress
<4°C	Very cold	Extreme cold stress
4-8°C	Cold	Strong cold stress
8-13°C	Cool	Moderate cold stress
13-18°C	Slightly cool	Slight cold stress
18-23°C	Comfortable	No thermal stress
23-29°C	Slightly warm	Slight heat stress
29-35°C	Warm	Moderate heat stress
35-41°C	Hot	Strong heat stress
>41°C	Very hot	Extreme heat stress

A user-friendly software package RayMan Pro 3.1 (Matzarakis, Rutz, & Mayer, 2007, 2010) was used to calculate PET's value based on MEMI. The mean radiant temperature (Tmrt) was also calculated by using RayMan. For calculation of PET, RayMan requires the input of the meteorological parameters (air temperature, relative humidity, wind speed, and Tmrt), personal data (Height, Weight, Age, Gender, clothing insulation, and metabolic rate), and geographic data (latitude, longitude, and altitude), date and time of filling the questionnaire. The description of the physiological stress based on the PET is given in Table 3. The correlation was established between the respondents' thermal sensations and PET to determine the neutral temperature and neutral temperature range. Thermal sensation votes differ amongst the individual respondents' even when they are exposed to the same thermal environment(Lin & Matzarakis, 2008). For balancing these individual differences in thermal sensations, a method was developed by (Richard J. de Dear & Gail Schiller Brager, 1998) to calculate the subjective thermal sensation responses for each 1°C bin. By applying the developed method, PET was divided into a total of 14 bins with an increment of 1°C. The mean thermal sensation vote (MTSV) was calculated corresponding to each bin. By applying linear regression, a linear equation was developed between MTSV and PET. Neutral PET is determined when MTSV =0 in the linear equation(Eq.5). In this study, the neutral temperature range was determined when the comfort interval falls in the range -0.5 ≤TSV≤ +0.5 in the linear equation (Eq.5). Although the respondents' neutral temperature represents comfort temperature, this temperature may differ from the respondents' actual preference. Hence, the preferred temperature should also be determined to assess the thermal perceptions based on the respondents' thermal preference votes (TPV)(Wang et al., 2017). TPV was grouped into 14 bins for 1°C PET intervals. Probit analysis (Ballantyne, Hill, & Spencer, 1977) was applied to fit these data bins with "prefer it to be warmer" and "prefer it to be cooler" against PET. Curve fitting was done for the estimated probability for the "prefer it to be warmer" and "prefer it to be cooler" temperatures against PET. These two models' intersection point was assumed as the preferred temperature(Wang et al., 2017). The significance of fitting was checked by applying the Chi-square test in SPSS. The research methodology framework adopted in the present study is shown in Figure 3.

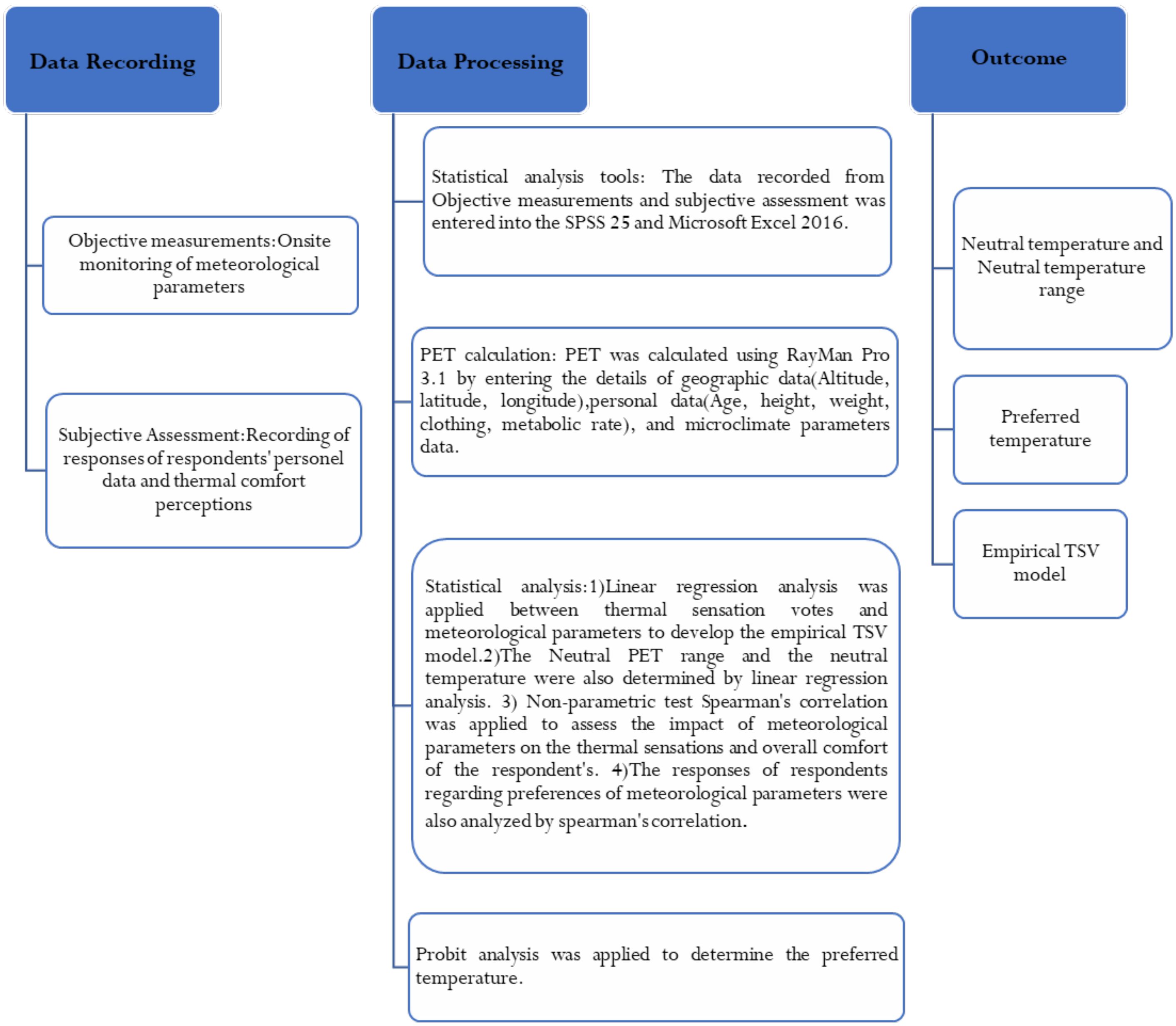


Figure 3. The research methodology framework adopted in the study

2.5 Empirical TSV model

By referring the previous studies like (Cheng, Ng, Chan, & Givoni, 2012; Coccolo et al., 2016; Lai, Zhou, et al., 2014; Nikolopoulou, 2004), the relationship between TSV and meteorological parameters were determined by applying linear regression. The empirical TSV model can be expressed as Eq. (2)

$$\mathrm{TSV} = \mathrm{aT_a} + \mathrm{bG} + \mathrm{cRH} + \mathrm{d}V_a + \mathrm{e} \quad (2)$$

In Eq.2, Ta, G, RH, and Ws are meteorological parameters, whereas a-e is the regression coefficients.

3 Results

The respondents' descriptive, meteorological parameters, thermal index, and thermal sensation votes' statistics, the empirical TSV model showing the relationship between TSV and meteorological parameters, the relationship between overall comfort and thermal sensation votes, the impact of meteorological parameters on OC and TSV, respondents' preferences regarding meteorological parameters, determination of the neutral temperature range, neutral temperature, and preferred temperature are presented in this section.

3.1. Respondent's Statistics

In the present study, 209 questionnaire responses were recorded from the respondents, out of which 185 valid questionnaires were selected and used for statistical analysis. Among all the respondents, females were 36.8 %(68), and males were 63.2 %(117). The respondents marked their clothing responses added all together to get one Clo value by referring to ASHRAE Standard 55. Out of 185 respondents, 85% of the respondents' clothing insulation was calculated to be 1.01Clo, and the rest 15 % of respondents clothing insulation calculated to be 1.3 Clo. The average metabolic rate (Met) of the respondents' is assumed to be 70 Watt. The Clo and Met values are according to reference (ANSI/ASHRAE Standard 55, 2010) by checking the response of respondents in the questionnaire. The descriptive statistics of the respondents can be observed in Table 4. The values of meteorological parameters and PET are given in Table 5

Table 4 Descriptive statistics of the Gender, Age, and Activity of the respondents'

Gender		Age					Activity				
		>18	18-24	25-34	45-54	<54	Chatting Standing	Chatting Sitting	Exercising	Reading books	Strolling
Male	63.20%	43.5%	42.7%	12%	0.9%	0.9%	43.8%	35.2%	13.5%	4.3%	3.2%
Female	36.80%	42.6%	44.1%	11.8%	1.5%	-	50%	48.5%	1.5%	-	-

Table 5 Meteorological parameters and thermal index data

	Minimum	Maximum	Mean	Standard Deviation
T_a(°C)	9.16	15.48	11.94	1.59
RH(%)	59.22	87.06	76.49	6.56
W_s(m/s)	0.42	4.93	1.85	1.08
G(W/m^2)	35.31	622.73	329.52	165.52
T_{mrt}(°C)	8.60	40.40	29.74	9.007
PET(°C)	4.6	22.5	12.99	4.55

From Figure 4, it was found that the highest TSV percentage is "Cool" (33%), followed by "Slightly cool" (30.8%) and "Cold" (19.5%). The overall mean TSV of 185 samples was -1.45, which is well below neutral, with a standard deviation of 1.20. The percentage distribution of the TSV can be observed from Figure 4

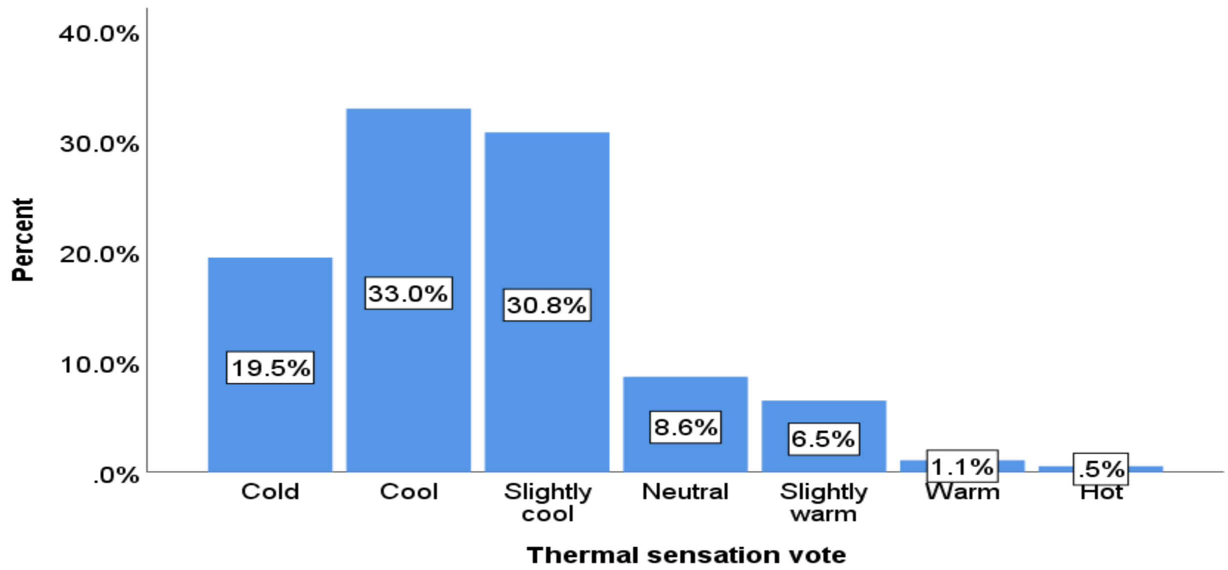


Figure 4 The percentage distribution of the TSV during the survey

3.2 Development of TSV model

In the present study, the empirical TSV model was developed by taking the effect of air temperature, relative humidity, air velocity, and solar radiation as in (Cheng et al., 2012; Coccolo et al., 2016; Lai, Zhou, et al., 2014; Nikolopoulou, 2004). Linear regression technique was applied to drive the relationship between the TSV and the meteorological parameters. The TSV model is expressed in Eq. (3).

$$TSV = 0.390Ta + 0.000431G + 0.016RH - 0.172Ws - 7.158 (R = 0.55, P < .05) \quad (3)$$

3.3 OTC Based On Field Survey

3.3.1 Thermal Sensation Vote And Overall Comfort

OTC may be affected by many factors like extreme weather conditions, physiology, psychology, etc. Thermal comfort is the most crucial factor which is related to the TSV of the respondents (Xu et al., 2018). The proportion of the votes of overall comfort can be observed from Figure 5

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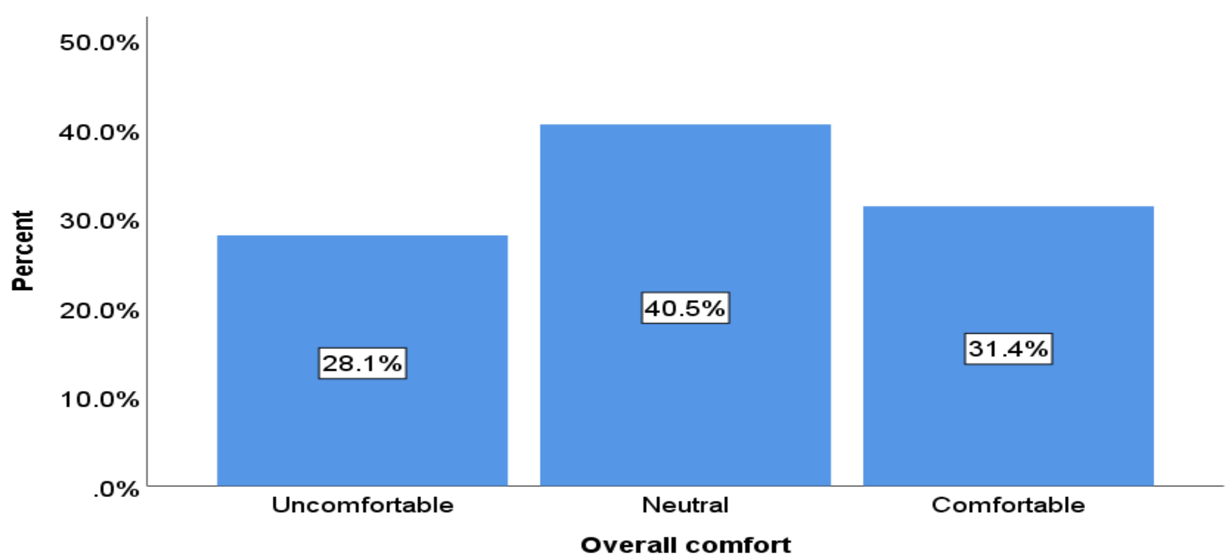

Figure 5 Overall comfort votes during the survey

In this section, overall comfort was correlated with the thermal sensation vote. Data were sorted from the lowest to the highest value of TSV, and corresponding OC responses were sorted automatically. The data sets were separated according to various thermal sensation responses. For example, the OC responses on Cold (-3) sensation forms one data set, Cool (-2) forms secondary data set, slightly cool (-1) forms third data set, and so on. The mean values of OC and TSV of each data set were calculated, and a correlation was established between the two terms. The relationship between OC and TSV can be observed from Figure 6 and Eq. (4).

$$OC = -0.060TSV^2 + 0.110TSV + 0.421 (R^2 = 0.91), p\ value = 0.02 \quad (4)$$

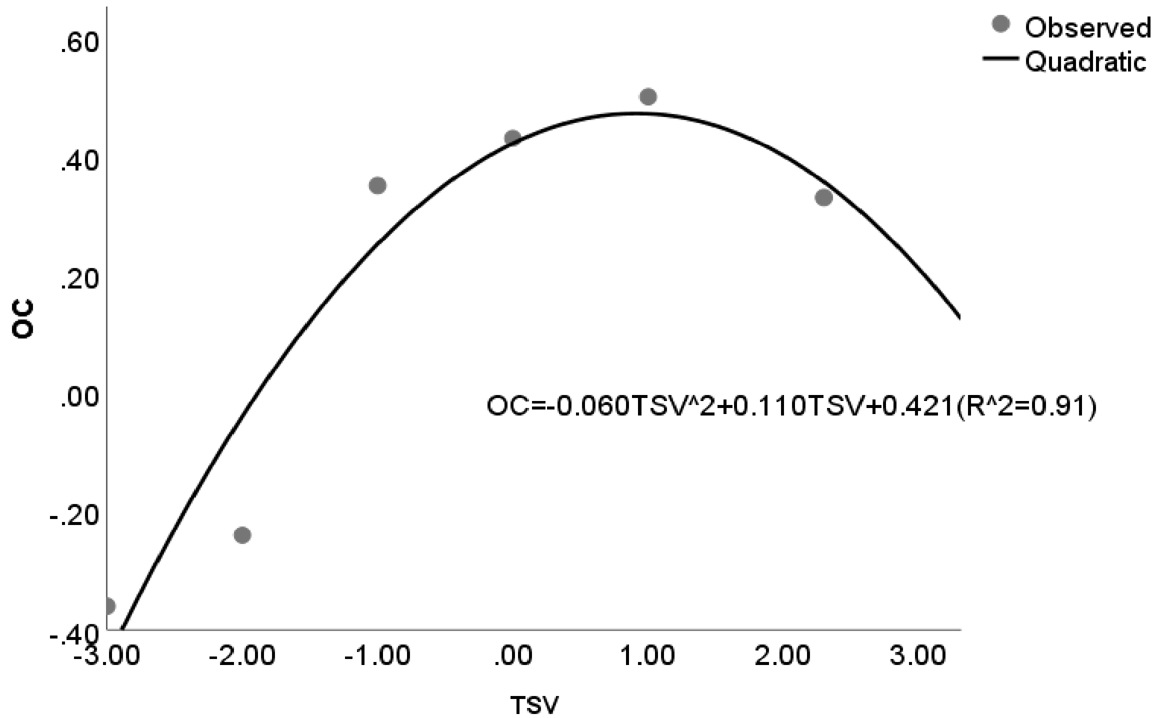

Figure 6 Correlation between the OC and TSV

3.3.2 Impact Of Meteorological Parameters on TSV and OC

Meteorological parameters impact OTC conditions. The impact of microclimate parameters on TSV and OC was investigated by applying Spearman's correlation. A correlation matrix is given in Table 6

Table 6. Correlation of the TSV, OC, and meteorological parameters

	TSV	Ta	RH	Ws	G	Tmrt
OC	.422**	.267**	-0.108	-.248**	.148*	.179*
TSV	-	.524**	-.335**	-.260**	.261**	.310**
Ta	-	-	-.745**	-0.043	.547**	.535**
RH	-	-	-	-.152*	-.727**	-.499**
Ws	-	-	-	-	0.008	-.224**
G	-	-	-	-	-	.844**

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

3.3.3 Thermal Preference Votes

The preferences in the meteorological parameters were generally not normally distributed. So, Spearman's correlation was used to correlate the preference votes with the meteorological parameters. Solar radiation was the most significant parameter that influences the preference votes, as observed in Table 7. The proportion of the preference votes of meteorological parameters recorded from the respondents presented in Figure7

Table 7. Correlation between the preference votes of the meteorological parameters and meteorological parameters

Meteorological parameters	Preferred RH	Preferred W_s	Preferred G
T_a(°C)	-0.073	-0.025	0.144*
RH(%)	-	0.051	-0.168*
W_s(m/s)	-	-	-0.431**

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

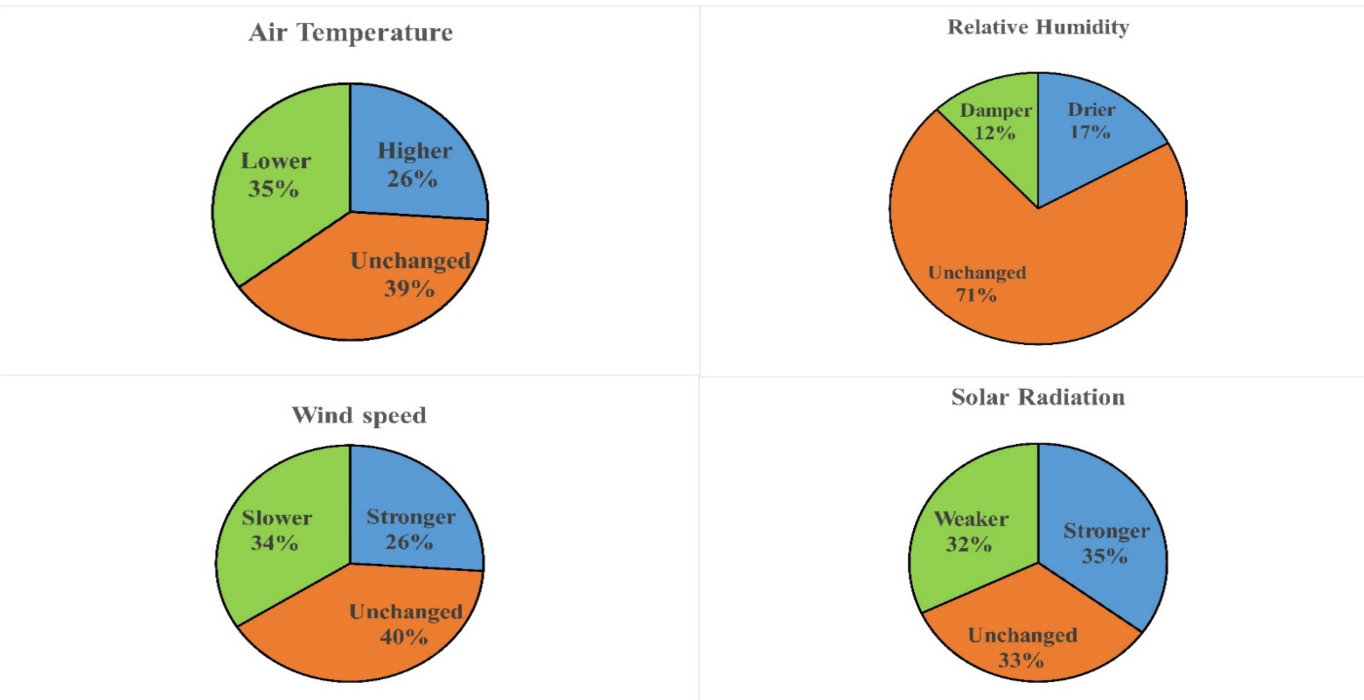

Figure 7 Preference votes of the respondents for different meteorological parameters

3.3.4 Neutral Temperature

Neutral temperature can be defined as the temperature at which the respondents feel neither cool nor hot but feel comfortable(Lin, 2009). As mentioned earlier in the method section, the PET was calculated using RayMan Pro 3.1 software. Figure 8 depicts the relationship between MTSV Vs. PET. The linear relationship can be observed from Eq. (5)

$$MTSV = 0.144PET - 3.153 (R^2 = 0.65), p\ value = 0.0004 \quad (5)$$

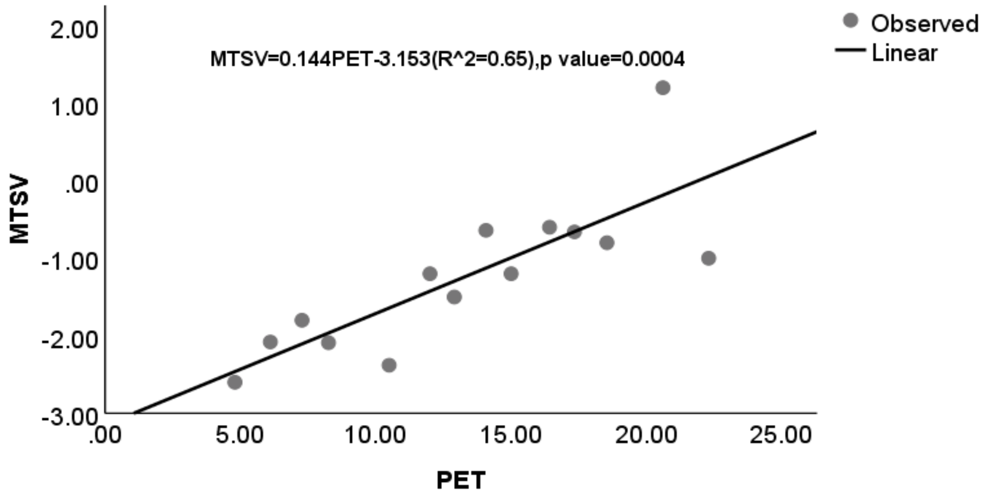

Figure 8 Correlation between the Mean TSV and PET

Neutral PET is determined when MTSV =0 in Eq.(5). In this study, the neutral temperature range was determined when the comfort interval falls in the range -0.5 ≤MTSV≤ +0.5 on the thermal sensation scale. The neutral PET range obtained in the present study is given in Table 8. So, the neutral PET range was found to be 18.42-25.37°C with a neutral temperature of 21.89°C.

Table 8 PET range in the present study

Grade of physiological stress	Thermal sensations	Assumed TSV	PET range
Extreme cold stress	Very cold	<-3.5	<-2.41°C
Strong cold stress	Cold	-3.5 to -2.5	-2.41°C to 4.53°C
Moderate cold stress	Cool	-2.5 to -1.5	4.53°C to 11.47°C
Slight cold stress	Slightly cool	-1.5 to -0.5	11.47°C to 18.42°C
No thermal stress	Neutral	-0.5 to 0.5	18.42°C to 25.37°C
Slight heat stress	Slightly warm	0.5 to 1.5	25.37°C to 32.31°C
Moderate heat stress	Warm	1.5 to 2.5	32.31°C to 39.25°C
Strong heat stress	Hot	2.5 to 3.5	39.25°C to 46.20°C
Extreme heat stress	Very hot	>3.5	>46.20°C

3.3.5 Preferred Temperature

Preferred temperature can be defined as the temperature at which the respondents feel neither cooler nor warmer in the thermal environment(Lin, De Dear, & Hwang, 2011). Probit analysis (Ballantyne et al., 1977) was applied to determine the preferred temperature, as mentioned earlier in the method section. Figure 9 shows the estimated probability for the "prefer it to be warmer" and "prefer it to be cooler" temperatures against PET. The significance of fitting was checked by applying Chi-square test; both the model was found significant (Prefer it to be warmer- $\chi2$=62.25, df=11, Significance=0.000000004, Prefer it to be cooler-$\chi2$=22.84, df=11, Significance=0.01). The preferred temperature was found to be 21.99°C by locating the intersection point of these models

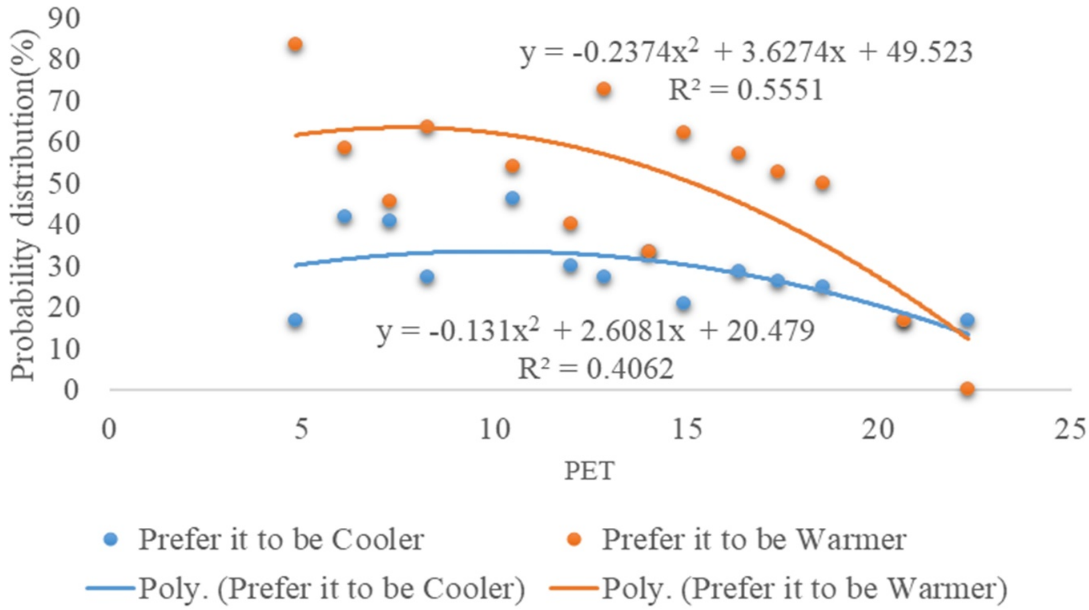

Figure 9 Probit analysis to determine the preferred temperature

4 Discussion

The population's thermal comfort perceptions have a crucial role in extreme climate conditions (hot summer and mild winter) in arid climate zones. So far, less focus has been paid to the outdoor thermal comfort conditions in the cold season. This study investigated people's thermal comfort perceptions at a university campus during the cold season in the Northern plain area of India. This study is the first attempt to investigate the OTC conditions in the cold season using PET in the region.

4.1 Empirical TSV Model

The empirical model in the present study indicated that by increasing air temperature, relative humidity, and solar radiation, the thermal sensations also increased while wind speed had an opposite effect. These findings are in line with investigations carried out in Thessaloniki(Greece), Kassel(Germany), and Combined model for Europe (Nikolopoulou, 2004), São Paulo, Brazil(Monteiro, 2008); Singapore and Changsha, China(Yang, Wong, & Zhang, 2013); Rome, Italy (Salata et al., 2016); Guangzhou, China(Zhao et al., 2016). Since T_a and RH are tough to control in outdoor spaces, blocking Ws and allowing G is a feasible way to improve TSV and, ultimately, OTC conditions. The R-value obtained from the present study is 0.55, which is lower than 0.78 obtained in Tehran, Iran (Hadianpour, Mahdavinejad, Bemanian, & Nasrollahi, 2018), and lies in the range of 0.44-0.58 in European countries (Nikolopoulou, 2004).

4.2 Thermal Sensation Vote, Overall Comfort, And Thermal Preferences

A correlation was established to determine the relationship between overall comfort and thermal sensation vote. It can be observed from Figure 6 and Eq. (4) that there is a robust and nonlinear relationship between OC and TSV; these findings are in line with the results of (Lai, Guo, et al., 2014) and (Xu et al., 2018). As observed from Eq. (4), it was found that the value of TSV is equal to -1.8 at OC =0. It means the respondents' felt overall comfortable when TSV=-1.8. Overall comfort is gradually increasing when the thermal environment approaches warmer conditions. The results indicate that the respondents are adapted to colder weather conditions but value warmer weather conditions to achieve comfort.

Further, a correlation was established among OC, TSV, and meteorological parameters to understand the impact of meteorological parameters on OC and TSV. The results demonstrated that G and T_a directly impact the TSV and OC; these findings are in line with the findings of (Chen, Wen, Zhang, & Xiang, 2015) and (Xu et al., 2018). Ws was found to be inversely proportional to the TSV and OC. RH was found significantly correlated with TSV, but no significant correlation was observed between RH and OC. While analyzing the thermal preferences, it was found that the meteorological parameters' thermal choice is significantly affected by solar radiation. From Table 6, it was inferred that the option for solar radiation found a significant correlation with Tmrt(0.844) followed by RH (-0.727) and T_a (0.547). The correlation coefficient's negative sign reflects the higher the G, the lower the RH. Solar radiation was found to be directly proportional to air temperature, Tmrt, and wind speed.

4.3 Neutral Temperature, Neutral Range, And Preferred Temperature

The basic finding of the present study is that the neutral temperature was found to be 21.89°C. After screening the literature, it was observed that the neutral temperature was found to be more than 20 °C in hot climate zones. The neutral PET was found 28.8°C in Sydney, Australia(Spagnolo & de Dear, 2003); 23.7°C in Taiwan(Lin, 2009); 23.4°C in Damascus (Yahia & Johansson, 2013);26.5°C in Cairo, Egypt(Mahmoud, 2011); 27.85 °C in Boipara and 26.76 °C in Mallickghat (Banerjee, Middel, & Chattopadhyay, 2020).

Further, the neutral range was found to be the 18.42°C-25.37°C PET in the present study. In comparison with the previous studies, the neutral range is comparable with the neutral range in western/middle Europe (18-23°C) and Kassel/Freiburg (18-28°C). The neutral range in Glasgow, UK (9-18°C) is lower than the finding of the present study, but the neutral range in Sun Moon Lake, Taiwan(26-30°C), and Sydney, Australia (26.4-32.4°C), are higher than our finding. The neutral range obtained in various regions of the world is shown in Table 9.

Table 9 Comparison of the Neutral range of the present study with previous studies

Source	Location	Climate(Peel et al., 2007)	Neutral range
Lai et al.,(2014)	Tianjin, China	Dwa	11-24°C
Spagnolo and de Dear,(2003)	Sydney, Australia	Cfa	26.4-32.4°C
Lin and Matzarakis (2008)	Sun Moon Lake, Taiwan	Cwa	26-30°C
Lin, (2009)	Taichung, Taiwan	Cwa	21.3-28.5°C
Mahmoud,(2011)	Cairo, Egypt	BWh	21.6-29°C
Andrade et al.,(2011)	Lisbon, Portugal	Csa	21-23°C
Chen et al.,(2015)	Shanghai, China	Cfa	15-29°C
Krüger et al.,(2013)	Glasgow, UK	Cfb	9-18°C
Hirashima et al.,(2018)	Belo Horizonte, Brazil	Cwa	16-30°C
	Kassel/Freiburg	Cfb	18-28°C
Liu et al., (2016)	Changsha, China	Cfa	15-22°C
Salata et al.,(2016)	Rome, Italy	Csa	21.1-29.2°C
Hadianpour et al.,(2018)	Tehran, Iran	BWk	13.9-20.5°C
Kenawy and Elkadi (2018)	Melbourne, Australia	Cfb	20 -28.4°C
Banerjee et al., (2020)	Boipara, India	Aw	27.8 °C - 36.8 °C
	Mallickghat, India		28 °C -32.3 °C
This study	Sonepat, India	Bsh	18.42 -25.37°C

As inferred from the results section, the preferred temperature was found to be 21.99°C. Compared to our findings, the preferred temperature is lower in Tempe (20.8°C) (Middel, Selover, Hagen, & Chhetri, 2016) and higher in Taiwan (23°C)(Lin, 2009), Sydney(30.9 °C) (Spagnolo & de Dear, 2003), and 25.5°C in Dar es Salaam (Baruti & Johansson, 2020). In addition to the current study results, there are shortcomings and future perspectives of the investigation. Firstly, the present investigation was carried out for only five typical days. Weather conditions for the whole season could be more complicated. Secondly, further research should be carried out in all seasons by examining the various campus area landscapes. Additionally, the majority of respondents were young age group people in the present study, all age group people perceptions can be explored further.

5 Conclusion

For healthy livability in outdoor spaces, people should visit a place without being affected by heat and cold stress. In previous studies, less attention has been paid to investigate the OTC conditions in cold weather. The present study investigated the OTC conditions during the winter season of the hot semi-arid climate of India. The investigation of the OTC conditions was conducted at a university campus in December 2019. Based on the investigation, the following conclusions were drawn from the study: In the cold weather, "Cool" was found to be the most perceived thermal sensation (33%) on the ASHRAE Seven-point sensation scale. Only 8.6% of the respondents marked their perceived sensation "Neutral." The uncomfortable votes were found to be 28.1% of the respondents. A robust and nonlinear relationship was observed between the overall comfort and thermal sensations. Overall comfort is gradually increasing when the thermal environment approaches warmer conditions

In cold weather, overall comfort is significantly affected by the air temperature followed by mean radiant temperature. The air velocity and relative humidity were found to be inversely proportional to the overall comfort. Intensification of the air temperature, mean radiant temperature, and reducing wind speed, relative humidity will improve the overall comfort.

In thermal preferences of the meteorological parameters, solar radiation was found to be the most significant parameter. Higher the value of solar radiation, the higher the value of air temperature, the lower the air velocity and relative humidity, preferred by the respondents, and vice versa.The empirical model in the present study indicated that by increasing air temperature, relative humidity, and solar radiation, the thermal sensations also increased while wind speed had an opposite effect.

The neutral PET range was 18.42-25.37°C with a neutral temperature of 21.89°C. The preferred temperature was 21.99

°C, which is slightly higher than the neutral temperature.

The present study's findings could provide a valuable reference to the urban designers to design/optimize the outdoor environment to improve the thermal comfort of people at university campuses' in the arid regions of India

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