Building and Environment 206 (2021) 108297

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

A comparative study of gender differences in thermal comfort and environmental satisfaction in air-conditioned offices in Qatar, India, and Japan

Madhavi Indraganti [a,*], Michael A. Humphreys [b]

[a] Qatar University, Doha, Qatar
[b] Centre for Religion and Culture, Regent's Park College, University of Oxford, UK

ARTICLE INFO

Keywords:
Thermal comfort field study
Comfort temperature
Gender
Office buildings
IEQ Satisfaction
Qatar

ABSTRACT

Gender differences in the assessment of thermal comfort and indoor environmental quality (IEQ) in the Gulf Cooperation Countries (GCC) have not previously been investigated, despite the prevalence of the overcooling of indoor spaces. This study investigated the effect of sex, age and body mass index on subjective thermal comfort perceptions, comfort temperature and IEQ satisfaction in offices using our thermal comfort surveys in Qatar, India, and Japan. Data from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) databases were used for comparison. We found that females were twice as likely to feel dissatisfied with thermal sensation than males in Doha. Overall, females felt colder than men, and were less satisfied with all IEQ parameters. In Doha, females, younger subjects, and high-BMI subjects had lower comfort temperatures than their counterparts.

Increased indoor air speeds and the provision of personal environmental controls could effectively reduce female dissatisfaction and save energy in Qatar. Women's more stringent thermal comfort preferences could be used to evaluate occupant control provisions and IEQ standards. A robust IEQ complaint redressal system may also be required in offices. This study highlights the need to consider female perspectives and thermal expectations in the environmental design of workplaces as well, not merely privacy concerns.

1. Introduction

The oil-rich states in the Gulf Cooperation Council (GCC) countries have unique socio-political obligations to support low energy tariffs. Standard tariff-based incentives may not be attractive to the Qatari citizenry, as Qatar is the richest nation in terms of GDP (gross domestic product) per capita (purchasing power parity) [1,2]. Further, energy is subsidized in Qatar, which increases its usage [3,4]. Buildings in desert climates require year-round air conditioning, which accounts for approximately 70%–80% of the building's energy usage [5]. Qatar ranks fourth highest in electricity consumption per capita in the world [6] and is concerned about increasing building energy consumption [7]. Researchers in the Gulf region estimated a 16%−68% savings in cooling degree days from moving the indoor setpoint from 18 to 24 °C [8]. In recent years, thermal comfort field studies have gained momentum in the Gulf region [9–11] since their early beginnings in 2002 [12]. Because there are no regional adaptive standards [13], local codes [14] prescribe the predicted mean vote (PMV) method for thermal comfort design [15]. It appeared that the office buildings in this region were overcooled [9,10].

1.1. Review of literature on gender and occupant satisfaction

Gender studies on thermal comfort have come a long way since the classical beginnings of Fanger [16] and Beshir and Ramsey [17] in controlled environments. Interestingly, in these climate chamber experiments, Fanger found no sex differences, while Beshir and Ramsey found differences in preferences by gender. More recent evidence from field experiments in various cities and literature reviews suggests mixed gender differences in occupant perceptions in several dimensions as noted in the following paragraphs.

Research in the hot-humid climate of China investigated college students in a climate chamber and in dormitories and classrooms [18]. They found that both genders were equally satisfied with the temperatures, irrespective of the location. Interestingly, in chamber tests, they

* Corresponding author.
E-mail addresses: madhavi@qu.edu.qa, Madhavi.indraganti@fulbrightmail.org (M. Indraganti), mahumphreys4@gmail.com (M.A. Humphreys).

https://doi.org/10.1016/j.buildenv.2021.108297
Received 13 March 2021; Received in revised form 4 August 2021; Accepted 26 August 2021
Available online 28 August 2021

Nomenclature

T_o	Outdoor daily mean air temperature (°C)	IEQ	Indoor environmental quality
T_i	Indoor air temperature (°C)	SBS	Sick building syndrome
T_g	Globe temperature (°C)	BMI	Body mass index (kg/m^2)
T_{mr}	Mean radiant temperature (°C)	N	Sample size
T_{op}	Indoor operative temperature (°C)	s.d.	Standard deviation
I_{cl}	Clothing insulation (clo)	s.e.	Standard error
T_c	Griffiths Comfort Temperature (°C)	CI	Confidence interval
AH	Absolute humidity (g/kg$_{da}$)	AC	Air conditioned
V_a	Air velocity (m/s)	NV	Naturally ventilated
RH	Indoor relative humidity (%)	MM	Mixed mode
PMV	Predicted mean vote	D	Doha
PMV_{adj}	Adjusted predicted mean vote	C	Chennai
δ	Absolute discrepancy in PMV_{adj} from TSV	H	Hyderabad
ce	Cooling effect	T	Tokyo
TSV	Thermal sensation vote	A	Asia
TP	Thermal preference	Rw	Rest of the world (non-Asia)
TA	Thermal acceptability	ADB	ASHRAE Databases
IAQ	Indoor air quality	OR	Odds ratio
		AOR	Adjusted odds ratio

found higher female dissatisfaction on the cooler side and male dissatisfaction on the warmer side of temperatures. However, when clothing adjustment was allowed (in a field experiment), gender variations equalized.

Karyono's sample included office occupants in Indonesia [19], while Indraganti et al. [20] analyzed gender differences in office buildings in India and reported higher comfort temperatures for females. In everyday environments in Finland, Karjalainen reported that females were less satisfied with room temperatures than males, preferring higher room temperatures and feeling both uncomfortably cold and uncomfortably hot more often in comparison to males [21].

While these are first-hand controlled/empirical studies, some researchers also scrutinized the existing post-occupancy/thermal comfort databases where information on gender and thermal perceptions was available [22,23]. Importantly, a literature review of a large database identified 11 out of 14 projects reporting women as more likely than men to suffer from IEQ/SBS (sick building syndrome) issues such as fatigue and headache [22]. Using the mean difference (size effect) as a parameter, Wang et al. did not find that sex had a strong effect on either neutral temperature or thermal sensitivity [23]. Another researcher carried out a meta-analysis of research results and found that females were more sensitive and 1.74 times more likely to be dissatisfied than males, while the neutral temperature differences were small [24]. Notably, another literature review could not reach a definitive conclusion regarding the significance and size of inter-group differences in thermal comfort (between females and males or between the young and the old) [25]. While claiming that the home thermal environments do not cater to women's preferences, studies on the use of thermostats at home found gender bias in house-wide thermal comfort settings [21,26].

Using exergy analysis of men and women in different clothing and hormonal scenarios, researchers noted that women's comfort temperatures in the luteal phase were similar to men in lighter clothing and lower during the follicular phase, with females having higher comfort temperatures than men overall [27].

That comfortable indoor conditions enhance occupants' health and productivity is well established by researchers such as Wisk and Rosenfeld [28], Akimoto et al. [29], Leaman and Bordass [30], Chen and Chang [31] and Mujan et al. [32]. Self-reported productivity increases with thermal satisfaction [33] and human perception of the thermal environment [34]. While Fisk et al. [35] mentioned that the mechanisms underlying the reductions in performance are unknown, other researchers observed optimum productivity at 400–700 ppm of CO_2 concentration [36]. Given the context of generally overcooled environments, it is important to note the literature review by Sintov et al., which suggests that colder temperatures lower women's cognitive performance, whereas men perform better in such conditions [26].

However, maintaining comfortable environmental conditions to enhance productivity and addressing occupant complaints to assuage user discomfort often rest with the facilities managers in commercial buildings. To be effective, it is important to understand the critical variables of human productivity [30]. With perceived control as their focus, Leaman and Bordass identified four other critical variables: comfort, including personal comfort, responsiveness to need, actual control provision, and the user's ability to control the environment [37].

1.2. Need for the study

The global gender gap index ranks (indicative of gender equality) for Qatar, India, and Japan are very low (142, 140, and 120, respectively, out of 156 countries). [38]. Reduced gender discrimination and an increase in women in the workforce positively impact the economic development of a nation. A recent report noted that "*being passive is the behavior for women*" in Japan [39]. Furthermore, a Singapore study noted that cultural traits skewed certain subjective aspects regarding satisfactory levels and comfort [31].

Due to high female education levels, female labor market participation is high in Qatar. Moreover, public workplaces in Qatar are sex-segregated, and workplaces need to consider the female perspective and expectations in environmental design as well, not merely privacy concerns. More importantly, gender issues relating to thermal comfort and satisfaction in the GCC have not been investigated. Therefore, this study aims to:

1. Study the effects of sex, age, and body mass index on subjective comfort perceptions, indoor environmental satisfaction, and comfort temperature in offices in Qatar.
2. Compare the findings with those from office environments in India, Japan, and other surveys from the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) database [40].

2. Methods

This study uses thermal comfort field-study data collected in offices in Qatar [10], India [41], and Japan [42] in air-conditioned (AC) mode. The surveys are all point-in-time paper-based transverse surveys conducted in open-plan AC offices in Doha (capital of Qatar), Chennai, Hyderabad (two major metropolitan cites in India), and Tokyo (capital of Japan) (Table 1). The research design is illustrated in Fig. 1.

2.1. Data collection

The building level cooling strategy of the surveyed buildings can be categorized into three types as per earlier reports and standards [40,43,44]. These are (a) AC (with a central/split/window unit with no operable windows); (b) naturally ventilated (NV) (with no mechanical cooling but with operable windows); and (c) mixed mode (MM) (mechanical cooling and operable windows that include concurrent, changeover, or zoned operation). Further, we considered data according to the modes of operation in these buildings (operation mode cooling strategies) as NV and AC. In all of the MM and NV buildings, operable windows were available. Window usage was 15% in Tokyo, 3% in Chennai, and 24% in Hyderabad. We noted general (ceiling/pedestal/wall-mounted) fans in one, 12, 10, and four buildings in Doha, Chennai, Hyderabad, and Tokyo, respectively. Doha data were collected only in air-conditioned buildings (AC mode). Therefore, data in AC mode were used for comparison with other surveys and ASHRAE databases (Table 1).

We visited all of the offices monthly and surveyed all voluntary participants available at that time. While the subjects completed the paper questionnaires, a researcher simultaneously noted their clothing and activity using standard checklists and measured the indoor environments with calibrated digital instruments positioned at 1.1 m following ASHRAE Class II protocols [43] (Table 2). We estimated the occupants' metabolic rates from the standard tables and total clothing insulation (I_{cl}) using the summation method [43,45].

The subjects chose their ensembles freely, adapting them to the outdoor and indoor thermal conditions within the local cultural norms. They wore formal shirts and trousers/skirts or local, non-Western attires (e.g., thobe, abaya, hijab, salwar-kameez, sari, shawl, etc.) (Appendix 1).

Reports [10,41], and [42] elucidate methods, building, and other survey details. With the outdoor hourly temperature data collected [46] for Japan and from Ref. [47] for the rest, we estimated the outdoor daily mean and running mean temperatures.

2.1.1. Data from the ASHRAE databases

For wider comparisons, this study uses thermal comfort field data from offices in Asia and the rest of the world made available through ASHRAE Databases I and II (ADB) [40,48]. The ADB is a very large thermal comfort database with 107,583 datasets. First, we selected cases from the ADB using five filter variables: (1) *building type*, (2) *country*, (3) *sex*, (4) *cooling strategy_building level*, and (5) *cooling strategy_operation mode for MM buildings.* This resulted in three initial groups of data: all Asian offices in AC mode with gender information of subjects (Set 1; N = 9640), all non-Asian offices in AC mode with gender information of subjects (Set 2; N = 10206), and all offices in AC mode with gender information of subjects (Set 3; N = 19846). We used these three sets in the analysis of various subjective thermal parameters, using only datasets with valid cases of the subjective parameters under consideration. As several researchers have contributed to the ADB, not all datasets have valid values for the variables of interest in this study. For example, for globe temperature (T_g), we used T_g, operative temperature (T_o), or air temperature (T_i) in that order, as per the availability in the database. Table 3 shows the three sets of data (Sets 1, 2, and 3) selected for analyzing thermal sensation (TSV) and preference (TP). We adopted a similar procedure for the other factors.

2.2. The subject sample

The subject sample consisted of acclimatized subjects working in the surveyed buildings within the age range of 18–70 years. In all of the surveys, a larger portion of the collected sample consisted of males. The female sample was 48.7% of the male sample, similar to the proportion for Asian offices in the ADB (Set 1) (Table 4). To test the sample for normality, we grouped the data by gender and estimated the skewness kurtosis and Kolmogorov-Smirnov statistic for various variables for all four cities using SPSS Ver 27. For example, for TSV, the skewness varied between 0.041 and 0.566, and the kurtosis varied between −0.693 and 0.657. The Kolmogorov-Smirnov statistic values were also non-significant (0.189–0.241 and > 0.05), indicating a normal distribution [49] (p 63).

2.3. Subjective measurements and questionnaires

The three survey questionnaires consisted of three sections: (1) personal identifiers such as code name, age, and gender, (2) thermal comfort responses, such as current thermal sensation, preference, and acceptability, and (3) responses to other environmental parameters, such as air movement and humidity.

Table 5 shows the scales used for subjective warmth (in response to the question "*How do you feel about the temperature now*?"), for thermal preference (in response to the question "*How do you prefer to feel*?"), and for thermal acceptability (in response to the question "*Do you accept the present environmental conditions in this room*?").

We also obtained the sensation and preference for other environmental parameters using the scales shown in Table 6 in various surveys. The questions for sensation and preferences for the other environmental parameters were worded similarly: "*How do you feel about the indoor air movement/humidity/lighting level and background noise level/indoor air quality*? "and "*How would you prefer the air movement/humidity/lighting level and background noise level?*"

Table 1
Details of data collection.

Parameter	Country →	Qatar	India		Japan
	Typology	Doha	Chennai	Hyderabad	Tokyo
Period of survey		January 2016 to January 2017	January 2012 to January 2013	January 2012 to January 2013	July 2012 to September 2012 (summer)
Location		N25° 17′, E51° 32′	N13°04′, E80° 17′	N17°27′, E78° 28′	N35°41′ 22′, E139° 41′ 30′
Köppen climate classification		Bwh	Aw	BSh	Cfa
Nature of climate		Hot desert climate (hot-humid maritime)	Tropical wet savanna (warm, humid, wetland coastal)	Hot semi-arid (composite)	Humid subtropical climate
Cooling strategy at building level: number of buildings (sample size)	AC	10 (3742)	1 (136)	4 (1487)	2 (162)
	MM		12 (2518)	7 (1428)	2 (2209)
	NV			3 (93)	
Cooling strategy at mode operation: number of buildings (sample size)	NV		4 (132)	10 (1220)	2 (432)
	AC	10 (3742)	13 (2522)	11 (1788)	2 (1979)
Ownership: number of buildings (sample size)	Public	4 (892)	6 (804)	5 (1410)	4 (2402)
	Private	6 (2850)	7 (1850)	9 (1598)	

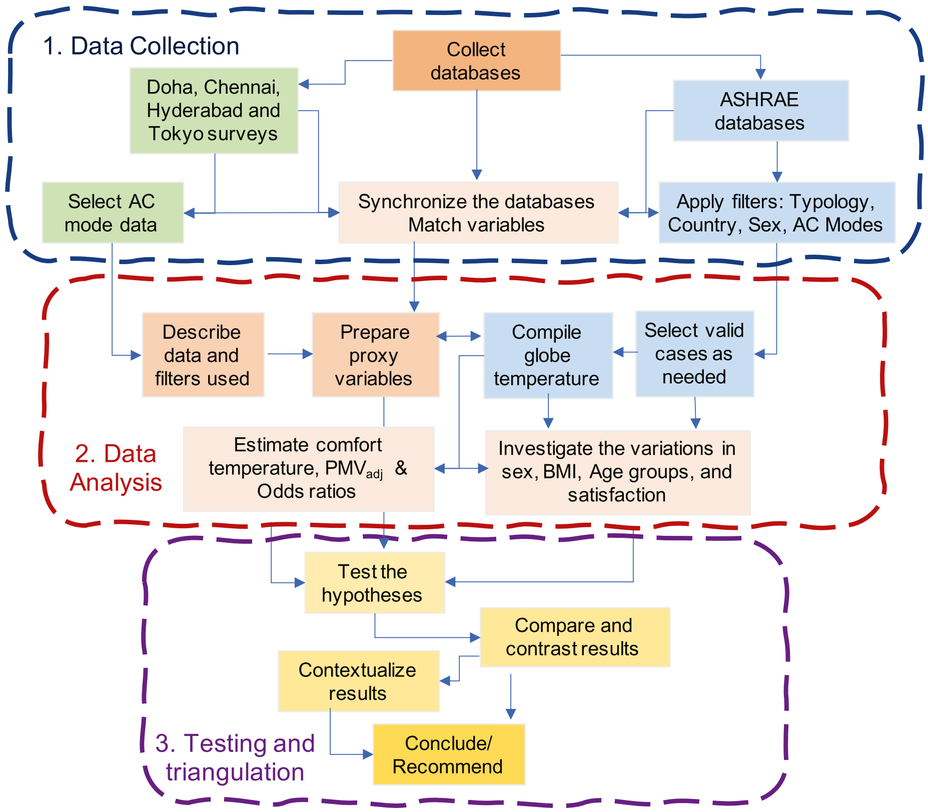

Fig. 1. Structural framework of methods of data collection and analysis.

Table 2
Details of instruments used for field measurements.

Survey	Description	Trade name	Parameter Measured	Range	Accuracy
Doha, Chennai, Hyderabad, and Tokyo	Thermo-hygro-CO_2 meter	TR-76Ui	Air temperature Humidity CO_2 level	0–45 °C 10 to 90%RH 0 to 5000 ppm	±0.5 °C ±5% ±50 ppm
Doha, Chennai, Hyderabad, and Tokyo	Probe thermometer with black painted table tennis ball	Tr-52i	Globe temperature	(- 60 to 155 °C)	±0.5 °C
Doha, Chennai, and Hyderabad	Hot wire anemometer	Testo-450	Air velocity	0.01–50.0 m/s	±0.01 m/s
Tokyo	Omni-directional probe anemometer	Kanomax Climomaster 6531	Air velocity	0.01–50.0 m/s	±0.015 m/s

Table 3
Criteria for selection of datasets from the ASHRAE databases and filter variables and values used.

Set number	Description	Building type	Country	Sex	Cooling startegy_building level	Cooling startegy_operation mode for MM buildings	Sample size for TSV	Sample size for TP
Set 1	All Asian offices running in AC mode	Office	China | India | Indonesia | Iran | Japan | Philippines | Singapore | South Korea | Thailand	Male | Female	Air Conditioned	Air Conditioned	9627	8844
Set 2	All non-Asian offices running in AC mode	Office	Australia | Brazil | Canada | France | Germany | Greece | Italy | Portugal |Sweden | Tunisia | UK | USA	Male | Female	Air Conditioned	Air Conditioned	9974	9959
Set 3	All offices running in AC mode	Office	All	Male | Female	Air Conditioned	Air Conditioned	19601	18803

2.3.1. Forming proxy scales for environmental satisfaction

We formed proxy binary scales for environmental satisfaction using the sensation scales for warmth, air movement, humidity, lighting, noise level, and indoor air quality. We considered the ratings in the three central categories as satisfied (coded as 0) and the rest as dissatisfied (coded as 1), consistent with [50]. For example, those preferring no change in the environment (e.g., air movement, humidity, noise level, etc.) were coded as satisfied (coded as 0) and the rest as dissatisfied (coded as 1). Extending the same logic, we regarded the noise level sensations of "very quiet" and "quiet" as dissatisfied, as very quiet and quiet offices may make people self-conscious and make unwanted noises more pronounced [51].

Table 4
Descriptive statistics of the investigated subject sample.

Survey	Sex	N	Age (years)		Body surface area (BSI) (m^2)		Clothing insulation (I_{cl}) (clo)		Body mass index (BMI)	
			Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Doha (D)	Male	2558	36	8.3	1.88	0.15	0.75	0.14	26.55	4.09
	Female	1184	31.3	7.7	1.65	0.14	0.95	0.31	23.68	4.15
Chennai (C)	Male	2037	29.6	8.6	1.79	0.14	0.67	0.04	23.37	3.93
	Female	870	31.3	9.5	1.56	0.13	0.81	0.11	21.89	3.75
Hyderabad (H)	Male	2394	32.5	9.2	1.79	0.14	0.68	0.04	23.24	3.45
	Female	747	29.3	8.2	1.59	0.13	0.74	0.11	22.43	3.65
Tokyo (T)	Male	1231	38	12.8			0.63	0.06		
	Female	1171	40.8	11.6			0.62	0.09		

Table 5
Scales used in surveys to obtain thermal sensation, thermal preference, and thermal acceptance (all surveys).

Scale value	Description of scale			
	Thermal sensation (TSV)	Thermal preference (TP)	Thermal preference in ASHRAE Database	Thermal acceptability (TA)
3	Hot			
2	Warm	Much Cooler		
1	Slightly warm	A Bit Cooler	Cooler	Unacceptable
0	Neutral	No Change	No change	Acceptable
−1	Slightly cool	A Bit Warmer	Warmer	
−2	Cool	Much Warmer		
−3	Cold			

2.4. Outdoor and indoor environments during the surveys

During the survey period, the outdoor temperature varied widely in Doha (18–39 °C) and moderately in Chennai (25–36 °C), Hyderabad (22–35 °C), and Tokyo (21–30 °C). Indoor environments varied significantly less in the AC mode (Table 7). Mean absolute humidity and air velocity in Doha were lower than the other cities surveyed. A byproduct of metabolism, CO_2 concentration indicates the efficacy of ventilation in diluting indoor pollutants, and Hyderabad offices recorded lower CO_2 concentrations than the other three cities.

3. Data analysis

The Griffiths method [52] is used on raw data to estimate the comfort temperature (T_c) (°C) using the relationship:

$$T_c = T_g + (0 - TSV)/G \tag{1}$$

Consistent with the findings of Humphreys, Nicol and Roaf [53] (p 250), we chose the Griffiths coefficient (G) as 0.5 K^{-1}. A small difference in the choice of coefficient (between 0.3 and 0.5) makes very little difference to the estimates of the comfort temperature. Rupp et al. [54] have drawn attention to some population differences in the value of the coefficient. There are several reasons for a group-estimate of the coefficient to be systematically underestimated, but there is no reason for it to be systematically overestimated. Hence, it is wise to choose a value toward the upper end of the range of the various estimates.

For comparison, we also estimated the neutral temperature (T_n) through linear regression of indoor temperature and TSV.

When air speed (V_a) > 0.20 m/s, ASHRAE suggests the Elevated Air Speed Comfort Zone Method, which considers the cooling effect (*ce*) of the elevated air speed and recommends using adjusted predicted mean vote (PMV_{adj}) instead [43] (p 38). Therefore, we estimated the *ce* for all samples with $V_a > 0.20$ m/s using the CBE Thermal Comfort Tool [55]. With the same tool, PMV_{adj} is estimated inputting *ce*-adjusted radiant and air temperatures and 0.1 m/s air velocity values instead. The cooling effect adjusted thermal index is obtained by subtracting the corresponding cooling effect value from the thermal index. For all cases with $V_a > 0.20$ m/s, we replaced PMV with PMV_{adj} in the analysis.

The gender variations in subjective/proxy scales and comfort temperature were analyzed vis-à-vis other measured parameters from our

Table 6
Scales used to obtain subjective responses to other environmental variables in different surveys.

Scale value	Sensation of					Preference for				Thermal effect on productivity	Air movement satisfaction
	air movement	humidity	lighting level	background noise level	indoor air quality	air movement	humidity	lighting level	noise level		
3	Very low	Very humid	Very bright	Very Noisy	Very good						
2	Low	Humid	Bright	Noisy	Good	Much more air movement	Much drier	Much dimmer	Much quieter	Much higher than normal	
1	Slightly low	Slightly humid	Slightly bright	Slightly noisy	Slightly good	A bit more air movement	A bit drier	A bit dimmer	A bit quieter	Slightly higher than normal	Dissatisfied
0	Neither high nor low	Neither humid nor dry	Neither bright nor dim	Neither noisy nor quiet	Neither bad nor good	No change	No change	No change	No change	Normal	Satisfied
−1	Slightly high	Slightly dry	Slightly dim	Slightly quiet	Slightly bad	A bit less air movement	A bit more humid	A bit brighter	A bit noisier	Slightly lower than normal	
−2	High	Dry	Dim	Quiet	Bad	Much less air movement	Much more humid	Much brighter	Much noisier	Much lower than normal	
−3	Very high	Very dry	Very dim	Very quiet	Very bad						
Surveys	D; C; H; T	D; C; H; T	D	D	D; C; H	D; C; H; T	D; C; H; T	D	D	D; C; H; T	D

D: Doha; C: Chennai; H: Hyderabad; T: Tokyo.

Table 7
Descriptive statistics of outdoor and indoor environmental variables recorded.

Environmental Variable	Doha (N: 3742)		Chennai (N: 2522)		Hyderabad (N: 1788)		Tokyo (N: 1979)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
T_o	30.8	6.5	28.9	2.8	27.5	3.9	28.0	1.7
T_i	23.8	1.2	26.5	1.5	26.1	1.6	27.9	1.1
T_g	23.4	1.2	26.7	1.4	25.6	1.7	27.9	1.1
RH	45.4	6.9	50.1	7.5	45.6	10.8	50.9	4.4
AH	8.2	1.3	10.8	2.0	9.5	2.1	11.9	1.2
V_a	0.04	0.06	0.2	0.20	0.05	0.08	0.3	0.16
CO_2 concentration (ppm)	1337	332	1370	460	962	312	1149	413
Noise level (dB)	57.8	6.7						
Lighting level (lux)	361	280						
T_c	24.0	2.6	26.8	2.9	25.7	2.5	27.4	2.2

(T_o: Outdoor daily mean temperature (°C); T_i = Indoor air temperature (°C); T_g: Indoor globe temperature (°C); RH: Relative humidity (%); AH = Absolute humidity (g_w/kg_{da}); V_a: Air speed (m/s); T_c = Comfort temperature (°C); s.d.: Standard deviation).

surveys and Asia as well as the rest of the world groups from the ADB (Table 3). We further examined the data in the age and body mass index (BMI) subgroups.

We grouped the subjects into two sections: those under and over 25 years of age. This is loosely based on the definition of youth as persons aged 15–24 years by the United Nations for statistical purposes [56].

The subjects were divided into three BMI categories: low (BMI <18 kg/m^2), normal (18 kg/m^2< BMI <25 kg/m^2), and high (BMI >25 kg/m^2) [57] (Table 8).

We relied on a *t*-test to determine whether the mean difference was significant. With sex as a fixed factor, a one-way between-groups analysis of covariance was conducted to compare the effect of T_g (covariate) on TSV (dependent variable). We used a non-parametric (Chi-square) test, which is best suited for ordinal and interval variables with fewer datasets in some categories, to examine the level of significance between gender and TSV. The homogeneity of regression-slopes was also examined using the general linear model (GLM), with TSV as the dependent variable, sex as the fixed factor, and T_g as the covariate.

To predict the likelihood of female respondents reporting environmental dissatisfaction, we estimated the odds ratios (OR) for the proxy satisfaction outcome variables (satisfied: 0, dissatisfied: 1, as mentioned in Section 2.3) using the binary logistic function in SPSS V27. This allows us to assess how well a set of predictors explain the dependent variable. The literature recommends coding variables such that higher values indicate the characteristics of interest [49]. Therefore, females, environmental dissatisfaction, the older age group, the normal and lower BMI groups, private ownership, non-Asian surveys, and Western clothing were all coded as 1, while their respective counterparts were coded as 0. We observed that the age group variable with ages 35 years and above became a significant covariant, while this was not so when 25 years of age was chosen as the dividing point for the groups. Therefore, the research question is "*What is the likelihood of females being dissatisfied*?" An OR less than unity for a significant predictor variable indicates a decreased probability of an increase in the direction of interest in the outcome variable. With multiple significant predictors, adjusted odds ratios (AORs) were obtained.

4. Results

4.1. Clothing insulation

The subjects adapted significantly through clothing, as T_g varied indoors. As shown in Fig. 2a, GLM confirmed the non-homogeneity of regression gradients of both sexes (Levene's F(10029): 2700.5, $p < 0.001$) for all data. The slopes are male: 0.02 clo/K and female: 0.05 clo/K. In all surveys, females had significantly higher clothing insulation than males, except in Tokyo ($p < 0.05$). The mean clothing insulation of subjects in Doha, Chennai, Hyderabad, and Tokyo are (males: 0.75 (0.14) clo, females: 0.95 (0.31) clo), (males: 0.67 (0.04) clo, females: 0.81 (0.11) clo), (males: 0.68 (0.04) clo, females: 0.72 (0.10) clo) and (males: 0.63 (0.06) clo, females: 0.63 (0.09) clo), respectively. In the ADB, the mean clothing differences between the sexes were very small. In both genders, non-Western clothing had a higher mean I_{cl} than Western clothing for all data ($p < 0.05$) (Fig. 2b) (Appendix 1).

4.2. Gender differences in subjective thermal responses

The mean thermal sensation of female subjects was the lowest in Doha among all of the surveys (Fig. 3 a). In Doha and Chennai, gender was significantly associated with TSV (Chi-Square = 183.7 and 45.1, respectively, $p < 0.001$), but this was not the case in Tokyo and Hyderabad.

We noted significant differences in the subjective warmth measurements, that is, estimates of TSV and PMV/PMV_{adj}, in all surveys and ASHRAE databases as well as between sexes in the estimates of PMV/PMV_{adj} (Fig. 3).

More prominently in Asia and in all data, a significantly higher percentage of females voted on the cooler side of discomfort (Fig. 3). Although the mean values are close to 0, the mean TSV of females is significantly lower in Asia (−0.13 (1.29), $t(5688) = -5.72$, $p < 0.001$) and in rest of the world (Rw) (mean: −0.1 (1.07), $t(9919) = -4.361$, $p < 0.001$), with equal variances not assumed.

In the Doha, Chennai, and Hyderabad surveys and in the ADB, but not in the Tokyo survey, the mean TP of female subjects was significantly lower than that of males ($p < 0.05$) (indicative of warmer

Table 8
Sample sizes for BMI, sex, and age groups in the current and ASHRAE databases.

BMI group	Current database					ASHRAE Database				
	Sex		Age group (year)			Sex		Age group (year)		
	Male	Female	≤25	>25	Missing	Male	Female	≤25	>25	Missing
Low	208	254	249	209	4	219	226	88	23	334
Normal	2889	1232	1058	3044	19	3922	1933	1219	1668	2968
High	2370	543	303	2584	26	2322	640	375	1360	1227
Missing	1279	1256	316	1929	290	4732	5852	2161	4981	3442

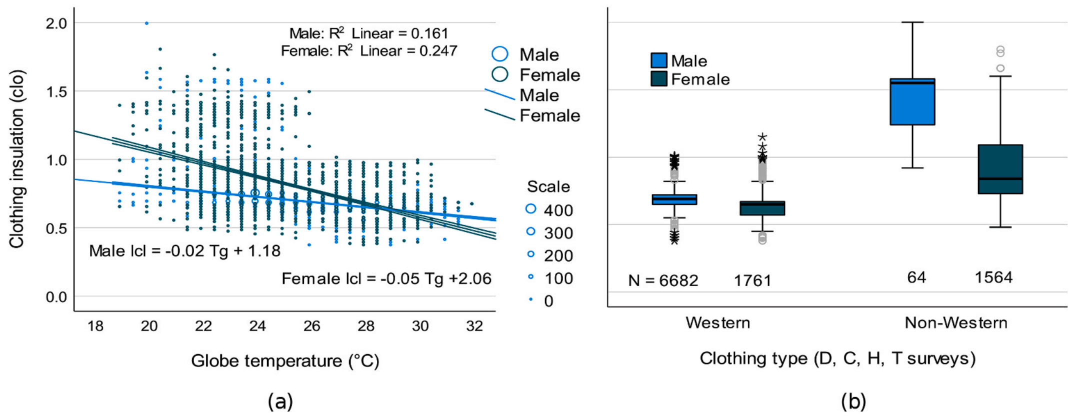

Fig. 2. Sex difference in (a) clothing adaptation (all surveys, N: 6746 (Male), 3285 (Female) $p < 0.001$) and (b) box plot of I_{cl} of Western and non-Western clothing (all data) (D: Doha; C: Chennai; H: Hyderabad; T: Tokyo).

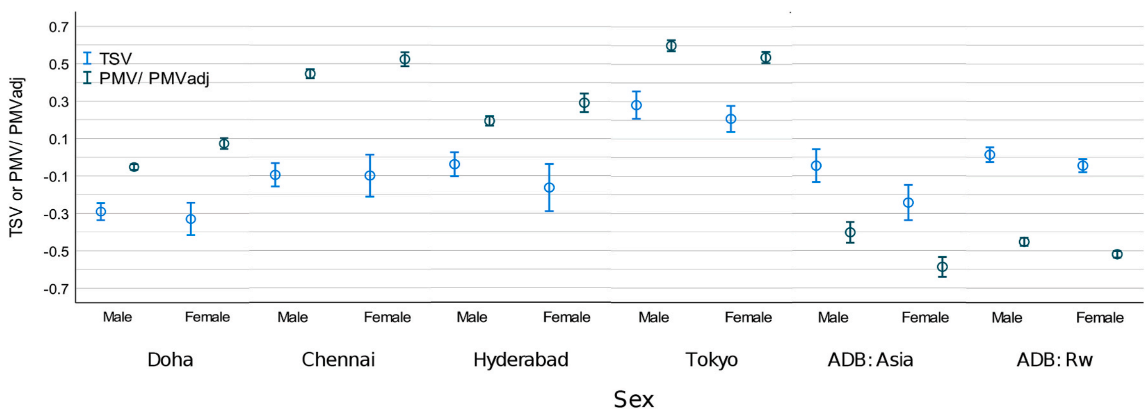

Fig. 3. Gender differences in various surveys and ASHRAE databases in mean TSV and PMV/PMV_{adj} ($p < 0.05$) (D: Doha; C: Chennai; H: Hyderabad; T: Tokyo; A: Asia; Rw: Rest of the world).

environmental preference) (Fig. 4a).

In Doha and Hyderabad, men found the thermal environment to be more acceptable than women, while this was reversed in Chennai and Tokyo (Fig. 4b). Some of the differences were slight. We noted a significant difference in TA between the sexes in the ADB (Rw group, $p < 0.001$) but not in Asia (Fig. 4b).

Linear regression of TSV with indoor globe temperature in Doha and Tokyo returned significantly different gradients for male and female subjects. These gradients are Doha (male: 0.174 K^{-1} standard error (s.e.): 0.020, $p < 0.001$); female: 0.3 K^{-1}, s.e.: 0.033, $p < 0.001$) and Tokyo

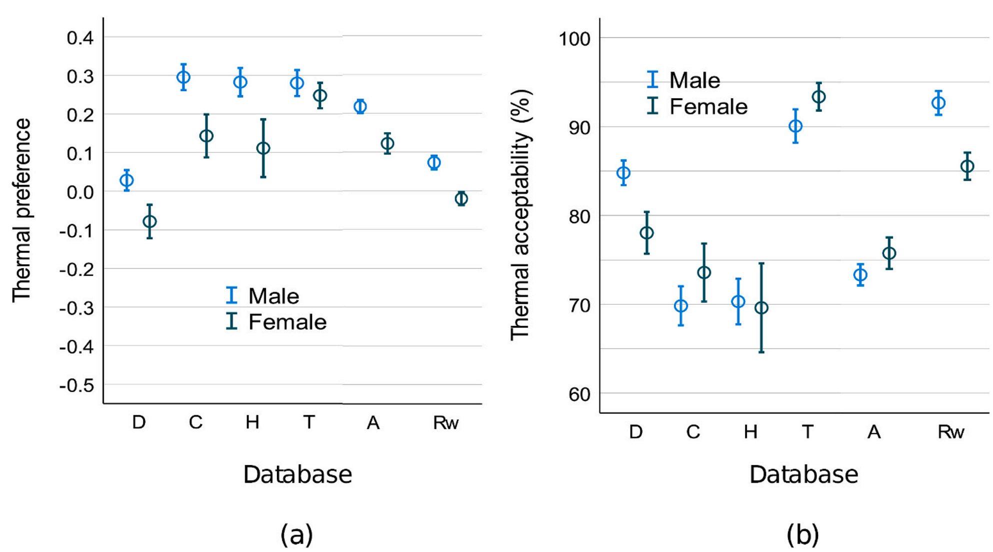

Fig. 4. Gender differences in various surveys and ASHRAE databases in mean (a) thermal preference and (b) thermal acceptability (%), ($p < 0.05$) (D: Doha; C: Chennai; H: Hyderabad; T: Tokyo; A: Asia; Rw: Rest of the world).

(male: 0.359 K^{-1}, s.e.: 0.03, $p < 0.001$; female: 0.26 K^{-1}, s.e.: 0.032, $p < 0.001$).

In Chennai and Hyderabad, GLM confirmed the homogeneity of the gradients of the two sexes. The slopes are Chennai (male: 0.172 K^{-1}, s.e.: 0.023, $p < 0.001$; female: 0.201 K^{-1}, s.e.: 0.038, $p < 0.001$) and Hyderabad (male: 0.228 K^{-1}, s.e.: 0.019, $p < 0.001$; female: 0.278 K^{-1}, s.e.: 0.034, $p < 0.001$).

Running GLM on the ASHRAE database, we found non-homogeneous regression slopes for males and females in Asia and the Rw groups (Asia: Levene's F-test (9618): 22.36, $p < 0.001$; Rw: Levene's F(9967): 73.66, $p < 0.001$). The regressions slopes are Asia (male: 0.181 K^{-1}, s.e.: 0.36, $p < 0.001$; female: 0.221 K^{-1}, s.e.: 0.394, $p < 0.001$) and Rw (male: 0.282 K^{-1}, s.e.: 0.358, $p < 0.001$; female: 0.235 K^{-1}, s.e.: 0.272, $p < 0.001$).

4.3. Comfort temperature: variations by gender, age, and body mass index

In this study, the neutral temperature (T_n) is estimated through linear regression of indoor temperature and TSV and the comfort temperature (T_c) through the Griffiths method as explained in Section 3. We noted significant sex differences in mean T_c ($p < 0.05$) in Doha (males: 24.1 °C (2.4), females: 23.7 °C (3) (Fig. 5). The sex difference in mean T_c in Hyderabad was 0.4 K ($p < 0.05$), and it was not significant in Chennai or Tokyo.

In Doha, the neutral temperature (T_n) obtained by regressing TSV and T_g was 25.1 °C for males and 24.2 °C for females. The difference in T_n between males and females was 0.37 K in Chennai and −0.6 K in Hyderabad; it was negligible in Tokyo. Small but significant sex differences in T_n were also noted in the ADB (Asia-males: 26 °C and females: 26.3 °C; Rw-males: 23.2 °C and females: 23.6 °C).

4.3.1. Effect of age

In Doha, the T_c of younger and older subjects of both sexes varied significantly (Fig. 6). For both sexes, younger subjects had a lower T_c than their older counterparts (0.9–1.5 K lower) ($p < 0.05$).

Overall, in the combined data of all four cities, the younger age group subjects expressed comfort at 26.0 °C (3.3), while the older participants expressed comfort at 25.4 °C (2.9) ($p < 0.05$). However, for males, the mean T_c of the younger age group was 26.5 °C (3.0), while older males had a comfort temperature of 25.5 °C (2.8) ($p < 0.05$). Regarding females, we noted no age group differences in T_c. We noted significant gender differences in T_c in both age groups in Asia and only in the older subjects in the rest of the world from the ASHRAE databases. Overall, these surveys do not show a consistent pattern of the effect of age on comfort temperature, as seen in Fig. 6.

4.3.2. Effect of BMI

Overall, as BMI increased, T_c decreased in our surveys as well as in the ADB (Fig. 7a and b). The comfort temperature of both sexes with normal BMI varied significantly in our surveys and the ADB. A similar difference was noted in younger and older subjects with normal BMI in our data but not in ADB. The Tokyo survey did not record weight data.

4.4. Gender variations in environmental satisfaction

We estimated the proportion of dissatisfied individuals for both genders for each of the several proxy environmental satisfaction scales (Table 6). Females were significantly more dissatisfied with every environmental parameter, other than IAQ ($p < 0.05$). In the Doha data, we noted significant differences in thermal sensation satisfaction, air movement acceptability, air movement preference satisfaction, noise level satisfaction, and lighting level satisfaction between the sexes ($p < 0.05$). A similar trend was noted in other surveys and in the ADB (Fig. 8). For example, in Doha, noise level satisfaction was 76% in males and 68% in females. IAQ satisfaction for all data was 60% and 57% in males and females, respectively.

Table 6 presents the crude odds ratios estimated with sex (male: 0; female: 1) as the single dichotomous independent variable and various proxy variables of environmental satisfaction as categorical dichotomous dependent variables (satisfied: 0; unsatisfied: 1). It also shows adjusted odds ratios (AORs) for sex as the first predictor and age, BMI, clothing type, and ownership as significant covariates (minimum of $p < 0.05$). This table lists the crude OR for Doha, all surveys and data from ADB for comparison, and all significant AORs along with the sex AORs for the other significant covariates.

Sex was the most significant predictor in most cases. For example, an OR of 2.04 for thermal sensation satisfaction indicates that female subjects in Doha are 2.04 times more likely to be dissatisfied with their thermal comfort sensation than men ($p < 0.001$), with a predictive accuracy of 76%. With BMI group as the covariate, the AOR for sex is 2.11, indicating that females are 2.11 times more likely to register dissatisfaction with TS. With sex, age, and BMI as covariates, we observed that females, subjects with normal or low BMI, and subjects older than 35 years were 200% ($p < 0.001$), 24% ($p < 0.05$), and 21% ($p < 0.05$) more

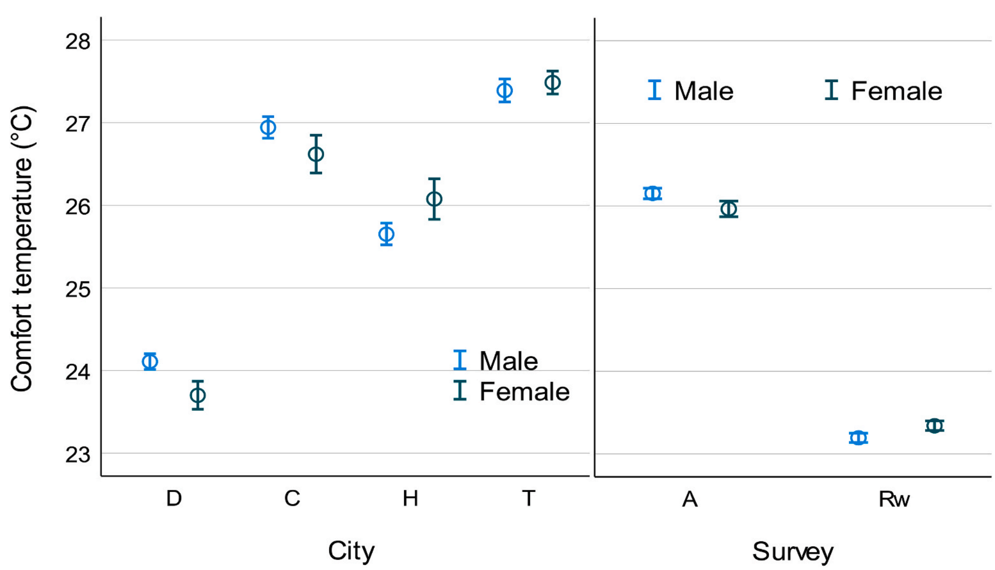

Fig. 5. Gender differences in mean comfort temperature in various surveys and ASHRAE databases ($p < 0.05$) (D: Doha; C: Chennai; H: Hyderabad; T: Tokyo; A: Asia; Rw: Rest of the world).

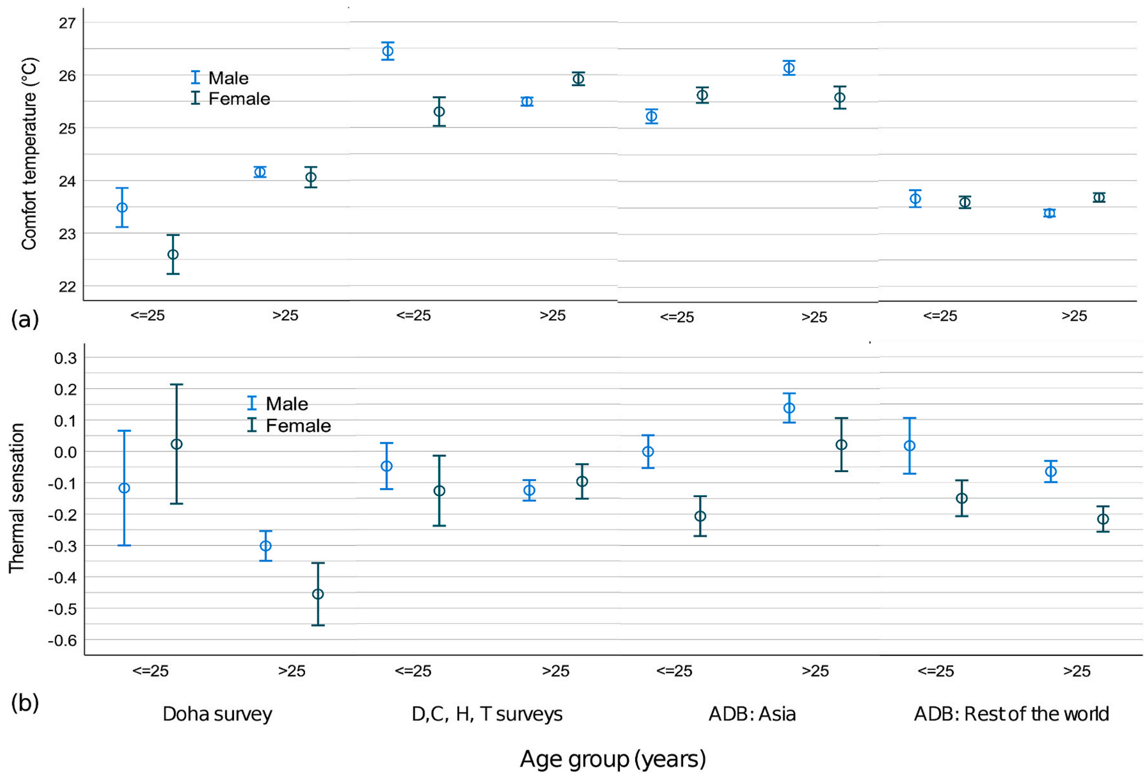

Fig. 6. Differences by age group (years) and sex in mean (a) T_c, (b) TSV in Doha for all four surveys and in the ASHRAE databases ($p < 0.05$).

likely to feel dissatisfied, respectively, than their counterparts in terms of thermal sensation satisfaction, all else being equal, with a predictive accuracy of 76.3%. In Doha, an AOR of 1.64 indicates that noise level satisfaction is a significant response variable with the regressor gender, alongside BMI and age group as co-predictors. Furthermore, subjects in the older age group were 2.3 times ($p < 0.001$) more likely than younger subjects to report reduced self-reported productivity due to thermal effects with 89.7% predictive accuracy.

Females and subjects in private buildings were 73% and 60% more likely to feel dissatisfied with TSV, compared to males and subjects in public buildings ($p < 0.001$), respectively. Similarly, in Doha, subjects in Western clothing were 60% more likely to feel dissatisfied, compared to those in non-Western clothing ($p < 0.001$), with a predictive accuracy of 75.9%. Similar female dissatisfaction was noted in other surveys and the ASHRAE databases. Comparatively, the odds of females expressing dissatisfaction on TSV in Asia is slightly lower than rest of the world (1.3 times and 1.44 times, respectively) ($p < 0.001$). Interestingly, females in surveys outside Asia are 2.14 times more likely to find their thermal environments unacceptable ($p < 0.001$) than males. Outside Asia, the odds of females finding air movement unacceptable is 1.8 times higher in comparison to males ($p < 0.001$). In Doha, an AOR of 1.37 for age group indicates that older subjects (≥35 years) are 65% more likely to find the environment unacceptable at 83% predictive accuracy ($p < 0.001$), all else being equal.

In Doha, the crude odds ratios for age group and ownership were 0.73 and 0.5, respectively ($p < 0.001$), while BMI was not a significant independent predictor.

5. Discussion and limitations of the study

This paper presents the gender differences noted in our field study in Doha and compares the results with data from two more surveys in India and Japan as well as the ASHRAE database. We considered the data collected in AC mode.

5.1. Thermal sensitivity

We noted that in all surveys and in the ADB, females felt non-neutral sensations often, more so on the colder and warmer sides of discomfort, in accordance with past findings. For example, a chamber study found females feeling more uncomfortable than males at both high and low temperature extremes [17] and a Finnish study [21] and an Indian study [58] noted females being uncomfortably cold and hot more often than males. A global database analysis revealed that males perceive the environments significantly warmer than females in all contexts under identical indoor and outdoor conditions [59]. Some researchers have attributed gender differences in comfort to (a) hormonal variations [27] or (b) physiological differences and lower clothing insulation in females [25], while others observed gender differences in sensation equalizing with comparable clothing in controlled experiments [60].

Overall, in our surveys, excepting the case of Tokyo, 24%–39% females voted outside the comfort band on TSV despite having higher clothing insulation (0.79 clo) than males (0.7 clo) (Fig. 2). Other researchers have also observed this phenomenon across all building types and geographies [59]. In this study, we observed that females adapt through clothing more than males do (0.05 as against 0.02 clo/K) (Figs. 2 and 9). These slopes are similar to the 0.04 and 0.03 clo/K slopes noted in a dormitory study [18] and by Zhang et al. [59].

In Doha, the gender difference in clothing is more pronounced at 0.2 clo, which is equivalent to the insulation of a light sweater (or 4 K swing for women). In Middle Eastern offices, women often wear modest clothing (Fig. 9). There were significant differences in mean the I_{cl} of subjects wearing non-Western outfits (e.g., thobe, ghutra, abaya, hijab, salwar-kameez, etc.), compared to those wearing Western outfits. The subjects general dress was more appropriate for the outdoor environment/season.

During the survey, we observed subjects adding extra layers they kept at hand (e.g., shawls, comforters, jackets, and gloves). This adaptation was noted in all buildings, though more frequently in government offices and by women. While it is easy and convenient, clothing

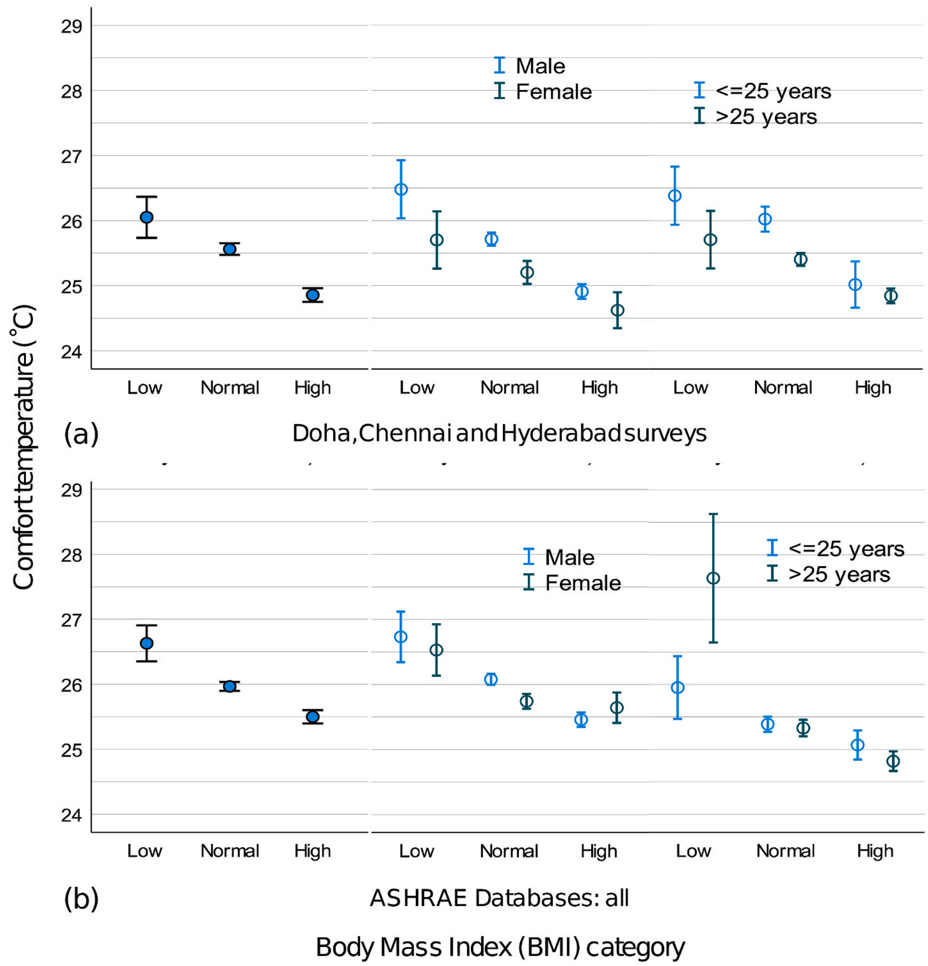

Fig. 7. Differences in mean T_c by BMI category for (a) all Doha, Chennai, and Hyderabad data and (b) all data from the ASHRAE databases ($p < 0.05$).

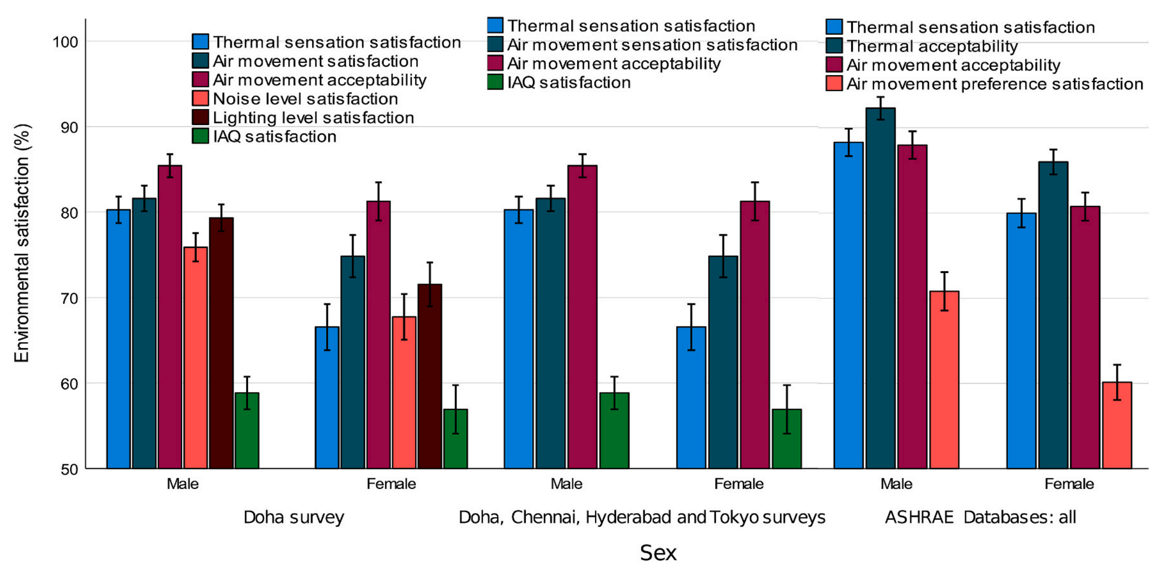

Fig. 8. Gender differences in proportion voting on various environmental parameters in Doha, Doha, Chennai, Hyderabad and Tokyo surveys, and the ASHRAE databases ($p < 0.05$) (D: Doha; C: Chennai; H: Hyderabad; T: Tokyo).

adjustment has practical and cultural limitations [61] (p 27). The adaptive principle holds as long as men and women exercise their freedom to choose thermally suitable clothing [61] (p 255). Unrealized adaptations often lead to dissatisfaction and may lead to complaints to facility managers, and when these are not redressed in time, they lead to a non-neutral sensation and a discomfort vote [37]. Though not as stringent, women in Indian offices had similar modesty requirements in dress.

Fig. 9. (left) Typical women's summer ensembles in a public building in Doha; (right) Subjects keeping jackets and hoodies handy in summer in a private office in Doha.

Female subjects in Doha were more sensitive than males to temperature fluctuations. Women needed 3.3 K and men 5.74 K for a unit sensation vote swing. Many field investigators have reported similar results [59]. On the other hand, it appears that the controlled climate chamber environment eliminated sex differences in thermal sensitivity [16,18]. As Humphreys et al. [61] (p 254, 267) note, the differences in sensitivity between the sexes are of little practical significance, for when adaptation is allowed, both men and women adjust their day-to-day clothing choices to suit the mean thermal environment during a working day. However, in real-life adaptation may not always be practical/possible. For example, too many clothing layers may disrupt the limb movement and ease of physical performance. And too little clothing would be culturally inappropriate.

Even after adjusting for elevated air speeds [43], actual sensation recorded (TSV) was significantly lower than PMV in all our surveys. The compounding effects of the use this metric for comfort prediction are overcooling, energy misuse to the tune of 20%–68% [8,9,27], and continued discomfort for women.

5.2. Comfort temperature

In Doha and Chennai, (younger) females had significantly lower comfort temperatures than males by 4 K (Fig. 5 Fig. 6). A similar trend was noted in the regression neutral temperature and in the ADB. Female T_c in Doha was approximately 3 K lower than that in Chennai and Tokyo. When viewed in conjunction with the indoor air speeds in these two surveys (Table 7), the reasons for the lower comfort temperature in Doha became clear. Chennai and Tokyo had mean air speeds of 0.5 and 0.2 m/s, respectively, whereas Doha had near still-air conditions (0.04 m/s). Overall, there was very little difference in the comfort temperatures of men and women (0.2–0.6 K), in accordance with the summarized findings of Humphreys, Nicol, and Roaf [61] (p 254) [23].

Unlike in other surveys, the comfort temperature of younger females in Doha was the lowest among all four cities studied at 22.6 °C, compared to 24.1 °C for their older counterparts who felt cooler sensations most of the time, possibly due to overcooling (Fig. 6b). In contrast, Thapa [62] reported younger subjects having 3.7 K higher T_c than older subjects in NV spaces in a hilly, colder region in India, where the temperature excursions and adaptive opportunities are notably broader. An increase in BMI significantly lowered comfort temperature overall (26.1, 26.6, and 24.9 °C for low, normal, and high BMI categories, respectively). In all of the BMI groups, females had lower comfort temperatures, as did older subjects. A similar trend was observed in the ADB (Fig. 7). A review by Wang et al. [25] identified fitness (obesity and self-perceived health) as an influential factor for individual differences in thermal comfort.

5.3. Environmental satisfaction

Using proxy IEQ satisfaction scales, we found that females expressed significantly higher dissatisfaction than males in all IEQ scales considered in our surveys and in the ADB, with the exception of IAQ satisfaction, where the difference was not significant (Fig. 8). Using binary logistic regression, we demonstrated that females are more likely to feel dissatisfied with IEQ factors than males, confirming earlier findings: homes and offices and a university study [21], North American Post-occupancy Evaluation (POE) database analysis [22], climate chamber experiments [17], open-plan offices surveys in Turkey [63] and POE studies of university students in USA [64].

Building ownership, clothing type, BMI, and age group were strong co-predictors of occupant satisfaction alongside gender. Satisfaction with thermal sensation (temperature) was found to be the most critical parameter in all surveys and the ADB. Satisfaction with other IEQ factors such as indoor air movement, noise level, and lighting level were also significant response variables for females in Doha ($p < 0.05$). For example, female dissatisfaction with noise level is 64% more likely than male dissatisfaction when BMI and age group are also considered.

In the ADB, in addition to temperature, air movement is a strong response variable with significant sex differences. We found that women were 74% more likely to feel dissatisfied with air movement than men across all the data in ADB.

Many socio-cultural constructs and psychological factors may affect women's thermal comfort experiences. Researchers have pointed out that females often feel that they have less control over room temperature [21]. However, females are also more likely to "*give in*" when men are negotiating their thermal comfort needs, as Sintov et al. point out [26]. The literature provides evidence for this gender bias in exercising the use of controls such as thermostats and common fans, in part attributed to gender roles [26], cultural norms [42], and lack of knowledge [21]. In such a scenario, in unisex workplaces with a large number of male subjects, it may be that women's perceived control is lower; for example, in Doha private offices, the likelihood of subjects feeling dissatisfied is higher than in public offices, all else being equal (Table 9).

A lack of control (both perceived and actual) adversely affects productivity [37]. We noted that females felt non-neutral, and particularly colder sensations. A literature review by Sintov et al. suggests that women suffer reduced cognitive performance at colder temperatures, whereas men perform better in such conditions [26]. The highest self-reported productivity was noted in thermal neutrality settings, and it increased as thermal satisfaction increased [33]. Notably, 64.4% of female subjects in Doha voted non-neutral. This partly explains their proclivity to feel more dissatisfied with IEQ and, therefore, to be more likely to report under-productivity than men in the same environments. Therefore, it may be necessary to offer improved personal control to females, zones with wider thermal excursions, and air speed regimes to accommodate their thermal comfort variations with hormonal cycles. In

Table 9
Crude and adjusted odds ratios (OR) for various environmental dissatisfaction variables (with females and dissatisfaction coded as 1).

Database	Environmental quality parameter	N	Odds ratio (OR)	Predictive accuracy (%)	N	Adjusted odds ratio (AOR)	Predictive accuracy (%)	Sex adjusted OR of covariates	Covariates
Doha	Thermal sensation satisfaction	3742	2.04** [1.75; 2.39]	75.9	3358	2.11** [1.71; 2.52]	76.2	1.19^{+} [1.01; 1.41]	BMI group
					3742	1.73** [1.46; 2.04]	75.9	1.6** [1.33; 1.91]	Ownership
					3742	1.67** [1.38; 2]	75.9	1.6** [1.28; 2]	Clothing type
					3324	2** [1.67; 2.39]	76.3	1.24^{+} [1.05; 1.47]; 1.21^{+} [1.01; 1.43];	BMI group; Age group
	Thermal acceptability	3742	1.57** [1.32; 1.87]	82.7	3595	1.43** [1.19; 1.72]	83	1.65** [1.37; 1.99]	Age group
	Air movement acceptability	3742	1.35** [1.13; 1.62]	84.1	3324	1.4* [1.13; 1.72]	84.4	1.26^{+} [1.04; 1.53]	BMI group
	Noise level satisfaction	3742	1.5** [1.29; 1.74]	73.3	3324	1.64** [1.38; 1.95]	73.6	1.2^{+} [1.02; 1.41]; 1.71** [1.41; 2.07]	BMI group; Age group
					3358	1.39** [1.51; 1.67]	73.6	1.18^{+} [1.0; 1.439]; 1.2+ [1.02; 1.41]	BMI group; Ownership
	Lighting level satisfaction	3742	1.53** [1.3; 1.79]	76.9	3358	1.59** [1.33; 1.91]	76.9	1.3* [1.1; 1.54]	BMI group
	Thermal effect on productivity	3742	1.97** [1.59; 2.43]	89.7	3595	1.77** [1.42; 2.21]	89.7	2.3** [1.79; 3]	Age group
C, D, H, T Surveys	Thermal sensation satisfaction	10031	1.41** [1.28; 1.55]	76.4	9962	1.43** [1.3; 1.58]	76.7	1.17^{+} [1.06; 1.3]	Age group
Asia	Thermal sensation satisfaction	9627	1.3** [1.17; 1.44]	78.6	4220	1.29* [1.07; 1.57]	87.6	0.41** [0.34; 0.5]	Age group
Asia	Air movement preference satisfaction	7985	0.83** [0.76; 0.92]	56.7					
Rest of the world	Thermal sensation satisfaction	9974	1.44** [1.29; 1.6]	83.1	7418	1.44** [1.25; 1.61]	83.6	1.33** [1.17; 1.52]	Age group
Rest of the world	Air movement preference satisfaction	3514	1.63** [1.41; 1.88]	64.4					
Rest of the world	Thermal acceptability	3498	2.14** [1.69; 2.69]	88.5					
Rest of the world	Air movement acceptability	3577	1.80** [1.5; 2.17]	82.9					
ASHRAE databases: All	Thermal sensation satisfaction	19601	1.25** [1.17; 1.35]	80.9	19601	1.27** [1.27; 1.47]	80.9	1.44** [1.34; 1.55]	Continental group
ASHRAE databases: All	Air movement acceptability	3852	1.74** [1.45; 2.09]	83.7					

**: $p < 0.001$; *: $p < 0.01$; +: $p < 0.05$; Values in the square brackets are the lower and upper bounds of 95% CI.

addition, better complaint redressal mechanisms also help to improve overall satisfaction in both genders.

Some controlled studies have found little evidence for gender differences in thermal comfort perceptions and female dissatisfaction [16, 60]. Wang et al. did not find a strong effect of sex as a factor on neutral temperature and thermal sensitivity when analyzing the ASHRAE database [23]. However, the evident dissatisfaction of female subjects observed in our database of over 10,000 thermal comfort field survey responses from offices running in AC mode in Asia is worth noting. While significant, these small gender differences of 0.3–1.5 K found in comfort temperature may not be of immediate engineering value. However, this tiny but daily dissatisfaction can trigger (a) a constant search for adaptive control and (b) increased system grievances. If these are left unattended, it may lead to reduced self-reported productivity. Rather, women's stringent thermal comfort preferences can be considered and may be used to benchmark occupant control provisions/-standards and indoor environmental satisfaction.

5.4. Limitations and the direction forward

The Doha, Chennai, and Hyderabad surveys were yearlong, while the Tokyo survey was conducted for three summer months. Therefore, they are treated independently. A comparison enables us to understand the trends in the results. The female sample was approximately half of the male sample size. Therefore, we treated the two samples separately in our analysis to avoid sampling bias.

Our surveys used an equal-interval TSV scale and Nicol's five-point TP scale, as opposed the continuous TSV and three-category McIntyre scale of the ADB. These factors affect the granularity of the databases. We examined IEQ satisfaction using proxy scales and other subjective thermal responses. While inferior to direct measurement, it provides initial knowledge, which can be further investigated. Detailed exploration of women's access/perceived access, the operation of adaptive controls, issues in clothing adaptation, and the level of complaint response [37] are all necessary to understand and address women's environmental dissatisfaction.

6. Conclusions

This paper presents gender differences in thermal comfort and satisfaction in Doha. For analysis and comparison, it relies on our field surveys in offices running in AC mode in Doha, Chennai, Hyderabad, and Tokyo (Qatar, India, and Japan) (N = 10031) as well as the ASHRAE databases (n = 19846) [40].

In Doha, about 34% females voted uncomfortable, often feeling colder sensations, despite having higher clothing insulation (0.95 (0.31) clo). Overall, women adapted through clothing (0.05 clo/K) more than men (0.02 clo/K).

We noted significant sex differences in comfort temperature in the Doha and other surveys. Comfort temperature in Doha (24 °C) is approximately 3 K lower than that of Chennai and Tokyo, where mean air speeds were much higher (0.2–0.5 m/s), compared to the still air conditions in Doha (0.04 m/s). Younger females in Doha had the lowest comfort temperature (22.6 °C), compared to all other groups as well as younger males. An increase in BMI significantly lowered comfort temperature overall (26.1, 26.6, and 24.9 °C for low, normal, and high BMI categories, respectively).

Using the proxy IEQ satisfaction scales, we found that females expressed significantly higher dissatisfaction than males in all IEQ scales considered in our surveys and in the ADB, excepting IAQ satisfaction, where the difference was not significant. Using binary logistic regression, we demonstrated that females are more likely to feel dissatisfied with IEQ factors than males. In Doha, females are 2.04 times more likely to feel dissatisfied with thermal feeling than males. The likelihood of female dissatisfaction with air movement, noise, and light level varied between 35% and 57%, compared to males in Doha. Females in Doha are 97% more likely than males to state that their self-reported productivity is affected by the thermal environment. Older-age subjects report this 2.3 times more frequently than younger subjects. Age, BMI, building ownership, and clothing type were significant co-predictors to gender.

This paper highlighted the differences in thermal comfort and higher female IEQ dissatisfaction seen in offices in Doha and other locations. Some of these differences, although not of great significance for engineering, call for an attitudinal change in the design of, provision of, and access to personal environmental controls aimed at females to improve environmental satisfaction.

We note that women are much more prone to discomfort and dissatisfaction than men in Asian AC offices, and it may well be that this is because the men often have more power to control the environment than do the women; additionally, we note that in these countries, equal regard for the sexes is not well advanced. This suggests that individual control would go a long way toward restoring balance.

Women's stringent thermal comfort requirements can be used to benchmark occupant control provisions and indoor environmental satisfaction evaluations. A robust complaint redressal system may also be required. Additionally, this study highlights the need to design more female-centric environments that are conducive to their environmental needs in addition to the privacy concerns being considered at present. Only then will the office environment be occupant centric.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The authors acknowledge the support of the Japan Society for the Promotion of Science (Grant number: JSPS/ FF1/ 246/ ID No. P 11372), Prof. Ryozo Ooka of the University of Tokyo, Japan, Prof. Hom Rijal of Tokyo City University, Japan and Qatar University, and all of the subjects for their respective contributions and online research databases. They also thank the anonymous reviewers for their valuable suggestions. The authors also acknowledge the support of Qatar National Library for providing the open access funding for this article.

Appendix 1(a) Clothing ensembles noted in the (a) Qatar, (b) India, and (c) Japan surveys

References

[1] A. Meier, M. Darwish, S. Sabeeh, "Complexities of saving energy in Qatar, in: ECEEE 2013 Summer Study Proceedings– Rethink, Renew, Restart, 2013, pp. 41–46.

[2] The World Bank, "The World Bank," [Online]. Available, https://data.worldbank.org/country/qatar?view=chart, 2019. (Accessed 24 May 2021).

[3] S. Rodriguez, M. Pant, J.C. Flores, Energy Price Reforms in the GCC: what Can Be Learned from International Experiences? International Monetary Fund, Washington, 2015.

[4] B. Fattouha, L. El-Katiria, "Energy subsidies in the Middle East and North Africa, Energy Strategy Reviews 2 (1) (2013) 108–115.

[5] I.M. Budaiwi, A.A. Abdou, M.S. Al-Homoud, "Envelope retrofit and air-conditioning operational strategies for reduced energy consumption in mosques in hot climates, Building Simulation 6 (2013) 33–50.

[6] International Energy Agency (IEA), 23 5 [Online]. Available, http://energyatlas.iea.org/#!/profile/WORLD/QAT, 2018.

[7] Ministry of Development Planning and Statistics, Qatar, "Qatar national vision 2030 [Online]. Available, https://www.gco.gov.qa/wp-content/uploads/2016/09/GCO-QNV-English.pdf, 2016. (Accessed 24 May 2021).

[8] M. Indraganti, D. Boussaa, A method to estimate the heating and cooling degree-days for different climatic zones of Saudi Arabia, Journal of Building Services Engineering Research & Technology 38 (3) (2017) 327–350.

[9] R. Elnaklah, A. Alnuaimi, B.S. Alotaibi, E. Topriska, I. Walker, S. Natarajan, Thermal Comfort Standards in the Middle East: Current and Future Challenges, May 2021, p. 107899.

[10] M. Indraganti, D. Boussaa, An adaptive relationship of thermal comfort for the Gulf Cooperation Council (GCC) Countries: the case of offices in Qatar, Energy Build. 159 (2018) 201–212, 2018.

[11] A. Alshaikh, S. Roaf, R. Smith, What is the relationship betwen humidity and comfort at high temperatures? In search of new ways of looking at the issue, in: 8th Windsor Conference: Counting the Cost of Comfort in a Changing World, Network for Comfort and Energy Use in Buildings, 2008. http://nceub.org.uk. Windsor, UK, 27–29 July 2008. London.

[12] S. Heidari, S. Sharples, A comparative analysis of short-term and long-term thermal comfort surveys in Iran, Energy Build. 34 (2002) 607–614.

[13] CIBSE, CIBSE Guide A: environmental design, The Chartered Institution of Building Services Engineers, London, 2006, pp. 16–33.

[14] Global Sustainability Assessment System (GSAS), GSAS Building Typologies: Design Guidelines 2015-v2.1, Gulf ORganization for Research and Development, Doha, 2015.

[15] ISO, ISO 7730:2005(E) Ergonomics of the Thermal Environment — Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria, ISO, Switzerland, 2005.

[16] P.O. Fanger, Assessment of man's thermal comfort in practice, Br. J. Ind. Med. 30 (1973) 313–324.

[17] M.Y. Beshir, J.D. Ramsey, Comparison between male and female subjective estimates of thermal effects and sensations, Appl. Ergon. 12 (1) (1981) 29–33.

[18] Y. Zhai, Y. Zhang, Q. Meng, H. Chen and J. Wang, "Gender differences in thermal comfort in a hot-humid climate," in Proceedings of the 13th International Conference Indoor Air, Hong Kong, July 2014.

[19] T.H. Karyono, Report on thermal comfort and building energy studies in Jakarta, Indonesia, Build. Environ. 35 (2000) 77–90.

[20] M. Indraganti, R. Ooka, H.B. Rijal, Thermal comfort in offices in India: Behavioral adaptation and the effect of age and gender, Energy Build. 103 (2015) 284–295.

[21] S. Karjalainen, Gender differences in thermal comfort and use of thermostats in everyday thermal environments, Build. Environ. 42 (2007) 1594–1603.

[22] J. Kim, R. de Dear, C. Cândido, H. Zhang, E. Arens, Gender differences in office occupant perception of indoor environmental quality (IEQ), Build. Environ. 70 (2013) 245–256.

[23] Z. Wang, H. Zhang, Y. He, M. Luo, Z. Lic, T. Hong, B. Lin, Revisiting individual and group differences in thermal comfort based on ASHRAE database, Energy Build. 219 (2020) 110017.

[24] S. Karjalainen, Thermal comfort and gender: a literature review, Indoor Air 22 (2012) 96–109.
[25] Z. Wang, R. de Dear, M. Luo, B. Lin, Y. Hea, A. Ghahramani, Y. Zhu, Individual difference in thermal comfort: a literature review, Build. Environ. 138 (2018) 181–193.
[26] N.D. Sintov, L.V. White, H. Walpole, Thermostat wars? The roles of gender and thermal comfort negotiations in household energy use behavior, PloS One 14 (no. 11) (2019) p. e0224198.
[27] D.S. Molliet, C.E.K. Mady, Exergy analysis of the human body to assess thermal comfort conditions: comparison of the thermal responses of males and females, Case Studies in Thermal Engineering, 25 (2021) 100972.
[28] W. Fisk, H.A. Rosenfeld, Estimates of improved productivitv and health from better indoor environments, Indoor Air 7 (1997) 158–172.
[29] T. Akimoto, S.-i. Tanabe, T. Yanai, M. Sasaki, Thermal comfort and productivity-Evaluation of workplace environment in a task conditioned office, Build. Environ. 45 (2010) 45–50.
[30] A. Leaman, B. Bordass, Productivity in Buildings: the "killer" variables, Build. Res. Inf. 27 (1) (1999) 4–19.
[31] A. Chen, V.W.-C. Chang, Human health and thermal comfort of office workers in Singapore, Build. Environ. 58 (2012) 172–178.
[32] I. Mujan, A.S. Anđelković, V. Munćan, M. Kljajić, D. Ružić, Influence of indoor environmental quality on human health and productivity - a review, J. Clean. Prod. 217 (2017) 646–657.
[33] A. Lipczynska, S. Schiavon, L.T. Graham, Thermal comfort and self-reported productivity in an office with ceiling fans in the tropics, Build. Environ. 135 (no. 1) (2018) 202–212. May.
[34] R. Kosonen, F. Tan, Assessment of productivity loss in air-conditioned buildings using PMV index, Energy Build. 36 (2004), 987–993.
[35] W. Fisk, P. Wargowcki, X. Zhang, Do indoor CO2 levels directly affect health or work performance? CIBSE Journal (September) (2019), 70–18.
[36] A. Kaushik, M. Arif, P. Tumula, O.J. Ebohon, Effect of thermal comfort on occupant productivity in office buildings: response surface analysis, Build. Environ. 180 (2020) 107021.
[37] A. Leaman, B. Bordass, Productivity in Buildings: Part Two the "Killer" Variables - Part 2, EcoLibrium, 2005, p. 22. May.
[38] The World Economic Forum, The Global Gender Gap Index Rankings 2021, WEF, Geneva, 2021. http://www3.weforum.org/docs/WEF_GGGR_2021.pdf.
[39] M. Belarmino, M.R. Roberts, Japanese gender role expectations and Attitudes: a qualitative analysis of gender inequality, J. Int. Wom. Stud. 20 (7) (2019) 272–288.
[40] V.F. Ličina, T. Cheung, H. Zhang, R. de Dear, et al., Development of the ASHRAE global thermal comfort database II, Build. Environ. 142 (9) (2018) 502–512.
[41] M. Indraganti, R. Ooka, H.B. Rijal, G.S. Brager, "Adaptive model of thermal comfort for offices in hot and humid climates of India, Build. Environ. 74 (4) (April 2014) 39–53.
[42] M. Indraganti, R. Ooka, H.B. Rijal, Thermal comfort in offices in summer: findings from a field study under the 'setsuden' conditions in Tokyo, Japan, Build. Environ. 61 (2013) 114–132.
[43] ASHRAE, "ANSI/ASHRAE Standard 55-2020 Thermal Environmental Conditions for Human Occupancy,", ASHRAE, Atlanta, 2020.
[44] European Committee for Standardization, "EN 16798-1, 2019 Energy Performance of Buildings - Ventilation for Buildings - Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acous, European Committee for Standardization, Brussels, 2019.
[45] M. Indraganti, J. Lee, H.A.E.A. Zhang, Thermal adaptation and insulation opportunities provided by different drapes of Indian saris, Architect. Sci. Rev. 58 (1) (2015) 87–92.
[46] Japan Meteorological Agency [Online]. Available, http://www.data.jma.go.jp/obd/stats/etrn/view/daily_s1.php?prec_no=44&block_no=47662&year=2012&month=7&day=&view=p. (Accessed 27 May 2021).
[47] "Weather Underground [Online]. Available, https://www.wunderground.com/weather/qa/doha.
[48] R. de Dear, "A global database of thermal comfort field experiments, Build. Eng. 104 (1998) 1141–1152.
[49] J. Pallant, in: SPSS Survival Manual: A Step by Step Guide to Data Analysis Using the SPSS Program, fourth ed., Open University Press McGraw-Hill Education, Berkshire, England, 2011.
[50] J.R. de Dear, S.G. Brager, D. Cooper, Developing an Adaptive Model of Thermal Comfort and Preference (ASHRAE RP- 884), Macquarie Research Ltd., Macquarie University, Sydney, NSW 2109 AUSTRALIA and Center for Environmental Desi, Sydney, NSW 2109 AUSTRALIA, 1997.
[51] A.G. Rosen, Why a Quiet Office Is Bad News vol. 26, April 2011 [Online]. Available, https://money.usnews.com/money/blogs/outside-voices-careers/2011/04/26/why-a-quiet-office-is-bad-news. (Accessed 11 May 2021).
[52] I.D. Griffiths, Thermal Comfort in Buildings with Passive Solar Features: Field Stud, Report to the Commission of the European Communities, University of Surrey, Guildford, UK, 1990, 1990 EN3S-090., 1990.
[53] M. Humphreys, F. Nicol, S. Roaf, Adaptive Thermal Comfort, Foundations and Analysis, Routledge, , Oxon, 2016, p. 377.
[54] R.F. Rupp, J. Kim, E. Ghisi, R. de Dear, Thermal sensitivity of occupants in different building typologies: the Griffiths Constant is a Variable, Energy Build. 200 (2019) 11–20.
[55] F. Tartarini, S. Schiavon, T. Cheung, T. Hoyt, CBE Thermal Comfort Tool : Online Tool for Thermal Comfort Calculations and Visualizations, The Center for Built Environment, UC, Berkeley, USA, 2020.
[56] United Nations, Department of economic and social Affairs youth [Online]. Available, https://www.un.org/development/desa/youth/what-we-do/faq.html. (Accessed 8 May 2021).
[57] WHO, "BMI classification," [Online]. Available, http://apps.who.int/bmi/index.jsp?introPage=intro_3.html, 2004. (Accessed 26 May 2014).
[58] M. Indraganti, K.D. Rao, Effect of age, gender, economic group and tenure on thermal comfort: a field study in residential buildings in hot and dry climate with seasonal variations, Energy Build. 42 (2010) 273–281.
[59] F. Zhang, R. de Dear, Impacts of demographic, contextual and interaction effects on thermal sensation—evidence from a global database, Build. Environ. 162 (2019) 106286.
[60] C.K. Parsons, The effects of gender, acclimation state, the opportunity to adjust clothing and physical disability on requirements for thermal comfort, Energy Build. 34 (2002) 593–599.
[61] F. Nicol, M. Humphreys, S. Roaf, Adaptive Thermal Comfort, Principles and Practice, Routledge, , London, 2012.
[62] S. Thapa, Insights into the thermal comfort of different naturally ventilated buildings of Darjeeling, India – effect of gender, age and BMI, Energy Build. 193 (2019) 267–288.
[63] K. Yildirim, A. Akalin-Baskaya, M. Celebi, The effects of window proximity, partition height, and gender on perceptions of open-plan offices, J. Environ. Psychol. 27 (2007) 154–165.
[64] S. Bae, C.S. Martin, A.O. Asojo, Higher education students' indoor environmental quality satisfaction benchmark, Building Research & Information, vol (2020), https://doi.org/10.1080/09613218.2020.1813012.