Investigation of Indoor Thermal Perceptions and Comfort Temperature in Educational Spaces in Qatar

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Abstract

We conducted thermal comfort field surveys in female educational spaces in Qatar in the autumn and winter of 2018 and 2020 – 21 and collected 324 datasets. They contained all the four environmental measurements and simultaneous thermal responses of female university students dressed in traditional Islamic clothing consisting of headgears and full-body cloaks (abayas) (mean clothing: 1.21 clo). Exacerbating the occupant discomfort, classrooms are overcooled/overheated in autumn/winter, respectively. About 89.9% respondents had no access to indoor temperature control and 43.5% had no access to any environmental controls. We evaluated the mean indoor comfort temperature as 22.9 (3.1) ˚C. In 64.2% cases, it did not conform to the comfort zone in international standards. We noted significant seasonal differences in indoor environments. Air speed was zero most of the time. Only 53.8% felt comfortable thermal sensations, and 66% accepted the environments, as against 80% in the international standards. The predicted mean vote (PMV) was significantly inaccurate up to three scale points and in 86.4% cases PMV mis-predicted by half a scale point or more. Therefore, framing the narrative around user-controlled air movement and indoor controls is necessary, so that indoor temperature can be effectively increased in autumn and lowered in winter.

Keywords: Adaptive comfort; Comfort temperature; Field study; Hot climates; Buildings

1 Introduction

Qatar is a gas rich country in the Arabian Gulf with highest per capita income and CO_2 emissions in the world (International Energy Agency (IEA), 2018); (The World Bank, 2019). Most public buildings are air-conditioned yearlong, often in disharmony with the outdoor conditions. Energy is heavily subsidized often served free to the government establishments. This often leads to energy wastage and excessive use of air-conditioning (AC). Recent studies in the Middle East have pointed out that the buildings are being over-cooled and heated much to the discomfort of the occupants (Elnaklah, et al., 2021) (Indraganti & Boussaa, 2018) (Alshaikh, et al., 2008). Qatar and the Gulf region are yet to have custom designed adaptive comfort standards (Global Sustainability Assessment System (GSAS), 2015). As a result, environmental engineers in the region propose prescriptions based on the predicted mean vote approach (PMV) (ISO, 2005). Internationally, many researchers demonstrated from field study results that the PMV greatly mis-predicted the actual sensation by as much as 60%, irrespective of the building type and mode of environmental control (Cheung, et al., 2019) (Humphreys & Nicol, 2002). Researchers pointed out that increasing the indoor set point in the Gulf region from 18˚C to 24 ˚C would potentially accrue 16 – 68% savings in Energy (Indraganti & Boussaa, 2018).There are no thermal comfort studies that reported the thermal comfort of occupants in the Middle Eastern classrooms. There are many studies on thermal comfort in naturally ventilated classrooms and laboratories (Singh, et al., 2018), (Mishra & Ramgopal, 2015). Some reports also presented thermal comfort in air-conditioned university classrooms in Malaysia and Japan (Zaki, et al., 2017), Indonesia (Karyono, et al., 2015) and Ecuador (Guevara, et al., 2021). However, the climate, clothing, and cultural practices of people in the Middle East is quite different from these reports, which need to be studied for appropriate indoor environmental design. Therefore, this study has the following objectives: (a) to evaluate the thermal comfort temperature of the students in university learning spaces in autumn and winter seasons, (b) to compare the data with the related adaptive standards, and (c) to study the adaptative use of controls and limitations in using them.

2 Methodology

2.1 Survey Location and Buildings Surveyed

Qatar has hot humid desert climate (Bwh in Köppen climate classification). Doha (N25° 17', E51° 32') is its capital city and is 10 m above the mean sea level. The survey was conducted in autumn and winter seasons in Qatar University (QU), Doha, which is 2 km from the Gulf Shore. The surveys were conducted in three Women's college buildings named B1, B2 and B3 in two phases: November 8 – 30, 2018 (N= 165) and October 3, 2020 – February 15, 2021 (N = 159), avoiding the periods of examinations and vacations. The SARS-COV-19 pandemic after March 2020 affected the data collection. Overall, we invested 33 days in the surveys. The learning areas (Fig. 1) in these buildings are randomly selected for field survey (Table 1).

Table 1: Details of the buildings surveyed

Building, N, age	Nature of Learning Space Surveyed	Survey Periods	Glazing/ Operable Windows/ Thermostats
B1, 276, 15 years	Lecture hall, computer classroom, architecture design studio, study hall	Nov 8, 2018 - Nov 30, 2018 (9 days), Oct 3, 2020 - Nov 10, 2020 (8 days), Jan 31, 2021- Feb 15, 2021 (7 days)	Fixed glazing; Operable windows in two ground floor studios; Wall mounted, but dysfunctional
B2, 18, 35 years	Lecture hall, computer classroom	Oct 6, 2020 - Oct 21, 2020 (6 days)	Fixed glazing: Wall mounted, but dysfunctional
B3, 30, 15 years	Lecture hall	Oct 24, 2020 - Oct 26, 2020 (3 days)	Fixed glazing: Wall mounted

2.2 Data Collection

This was a *right-now-right here* transverse survey. We collected occupant responses through a thermal and indoor environmental quality (IEQ) questionnaire survey through Google Forms and measured the indoor environment simultaneously as the subjects responded. The instrument tripod and the set-up used in the surveys are shown in Fig. 1 and Table 2. After setting up the instrument tripod close to a group of 5-10 subjects. We measured indoor air temperature (T_a), indoor globe temperature (T_g), and relative humidity (RH) in all the surveys. In addition, in 2020-21 we measured air velocity (V_a), CO_2 concentration also in all the surveys at a 5-minute interval. All the measurements are done with sensors at 1.1 m from the finished floor level. We obtained the outdoor daily mean temperature (T_o) from a meteorological website (Anon., 2021).

Table 2: Details of the dataloggers and sensors used in the surveys

Survey Period (sample size)	Description	Trade Name/ Manufacturer	Parameter Measured	Range	Accuracy
Nov 8, 2018 - 30 Nov 2018 (165)	Thermo-hygro data logger with probe thermometer with black painted table tennis ball	U12-013 (Temp/RH/2 Ext) with TMC1-HD/ Onset, Hobo, USA	Air temperature	0 to 50 °C	±0.35 °C (0° to 50°C)
			Humidity	5 to 90% RH	±2.5% (10 to 90%)
			Globe temperature	0 to 50 °C	±0.35 °C (0° to 50°C)
Oct 3, 2020 - Nov 10, 2020 (113)	Testo 400 IAQ and comfort kit with tripod Testo, Germany	IAQ probe with Bluetooth (0632 1551)	Air temperature	(- 60 to 155 °C)	±0.5 °C (0° to 50°C)
			Humidity	5 to 95% RH	±3% (10 to 35%) ±2% (35 to 65%) ±3% (65 to 90%)
Jan 31, 2021 - Feb 15, 2021 (46)			CO_2 Concentration	0-10,000 ppm	± 50 ppm (0 to 5,000 ppm)
		Globe thermometer Ø 150 mm (0602 0743)	Globe temperature	0 to +120 °C	Class 1. ±0.5 °C
		Omni directional turbulence probe, (0628 0152)	Air velocity	0 to +5 m/s	± 0.03 m/s (0 to 5 m/s)

Fig. 1: Instrument set-up and the surveys in progress in lecture halls, studios and computer classrooms

2.3 Thermal Questionnaire and Respondents

The participants in the survey are acclimatized students and teaching staff engaged with the surveyed space for over 15 minutes prior to the survey. Being a public university, the undergraduate campuses are gender-segregated and this research is conducted primarily in the women’s campus. Therefore, we collected 96% data from females. The questionnaire survey included three age group options, viz., 18-30, 30-50 and above 50 years. The questionnaire was prepared in English and translated to Arabic, broadly following thermal satisfaction surveys of ASHRAE Standard-55 and other researchers (ASHRAE, 2020); (Huizenga, et al., 2006). We used ASHRAE 7-point scale for evaluating the thermal sensation (TSV). Satisfaction for various indoor environmental quality parameters were measured on 7-point scales based on the research of de Dear et al. (1997); Huizenga et al. (2006) and (Indraganti & Boussaa, 2018). The Internal Review Board (IRB) at QU approved them for ethical compliance (Permission number: QU IRB 1226-E/20). The questionnaire had three segments: (1) personal identifiers such as age group, building number, type of the surveyed space, and the period of engagement with the space prior to the survey, (2) questions on thermal comfort and environmental satisfaction and access to the environmental controls and (3) checklists for various pieces of garments, and list of activities. The surveyors made field notes about the indoor environmental controls in use within the surveyed space, while the survey/measurement was going on. We collected a total of 324 valid responses overall.

3 Results and Discussion

3.1 Clothing Insulation, Metabolic Rates, Outdoor and Indoor Conditions

We estimated the clothing insulation (I_{cl}) values for Western and non-Western ensembles using standard checklists and earlier reports (ASHRAE, 2020); (ISO, 2005); (Indraganti, et al., 2015); (Havenith, et al., 2015) and (Al-ajmi, et al., 2008). Subjects in non-Western ensembles had significantly higher clothing insulation with a large effect size (mean of Western ensembles = 0.67 (0.11) clo, mean of non-Western ensembles = 1.21 (0.13) clo, t(322) = -24.41; p <0.001, eta squared = 0.65). It was noted that student subjects in the 18-30 years age group had higher I_{cl} values. In response to a direct question on satisfaction with their dress choice, 92% said they are satisfied with their choice of dress and 32.7% cited convenience was the reason behind their choice. Results show that 84.9% subjects were in non-Western clothing, which consisted of *abaya*, *hijab*, full length skirts, Punjabi scarves, *salwar-kameez* etc. This is much higher than 16% subjects in non-Western clothing as noted in an office building study in Qatar (Indraganti & Boussaa, 2018). We estimated the metabolic rates using the values in (ISO, 2005).

During the survey period the outdoor daily mean temperature varied from 19.3 – 34.3 °C while relative humidity also varied widely between 34 – 76% with 26.3 (3.5) °C and 63.3 (9.7)% as the mean values, respectively. High temperature coupled with moderate to high humidity causes perspiration and discomfort in September and October. Outdoor discomfort eases as the temperatures plummet in November to February while the humidity remains high, for Doha is a coastal place in the Arabian desert. Humphreys et al. (2016) suggested exponentially weighted running mean temperature as a superior predictor for indoor conditions. Therefore, we estimated the running mean temperature (T_{rm}) taking 0.8 for α indicating a half-life of 3.5 days. In this survey the range in running mean temperature was 19.6 – 34.4 °C while the mean was 27.4 (3.4) °C.

Table 3: Descriptive statistics of outdoor and indoor environmental variables

Season	N	Outdoor Daily Mean Temperature (°C)	Air Temperature (°C)	Globe Temperature (°C)	Mean Radiant Temperature (°C)	Operative Temperature (°C)	Air Velocity (m/s)	Relative Humidity (%)
Winter	48	19.6 (0.2)	24.3 (1.3)	24.3 (1.2)	24.3 (1.2)	24.3 (1.3)	0.01 (0.01)	48.5 (2)
Autumn	278	27.4 (2.3)	22.1 (1.1)	21.9 (1.5)	21.8 (1.5)	22 (1.3)	0 (0)	58 (6.6)
All	324	26.3 (3.5)	22.4 (1.4)	22.2 (1.7)	22.2 (1.7)	22.3 (1.5)	0 (0)	56.7 (7)

Comparatively, the indoor thermal conditions were less variable as the buildings were centrally air-conditioned throughout. We noted about 8 K variation in indoor air temperature through the survey period. However, independent t-test revealed significant seasonal differences in the means of all the indoor environmental parameters ($p < 0.05$). For example, there was a significant difference in To recorded in autumn (mean (standard deviation (s.d.)) = 21.9 (1.3) °C) and winter (mean (s.d.) = 24.3 (1.2) °C; t (322) = -11.771, p < 0.001 (two-tailed)). The magnitude of the differences (effect size) in the means (mean difference = 2.4 K 95% CI: -2.775 to -1.962) was very large (eta squared = 0.301) (Pallant, 2011). There were negligible inter-building differences in the thermal indices. All the four thermal indices viz. air, globe, mean radiant and operative temperatures correlated strongly with each other (p < 0.001), and their mean values were also very similar (i.e., < 0.2 K difference). It means that any of these indices can be used in the analysis. Therefore, to compare the results with the literature and triangulation with the international standards we propose to use operative temperature (Zaki, et al., 2017), (ASHRAE, 2020), (European Committee for Standardization, 2019). Near still air conditions prevailed throughout the survey, with air velocity averaging at 0.0 m/s on all data. Of the 159 samples with V_a records, only in 27% cases, we had V_a >= 0.01 m/s. It indicates that there is much scope for increasing the air speeds.

3.2 Subjective Thermal Responses

Overall, the mean thermal sensation is found to be -0.29 (1.73), indicating subjects voting on the cooler side of the 7-point sensation scale (Fig. 2). Importantly, only 23.5% and 48.8% subjects voted neutral and within the central three categories of the sensation scale, respectively.

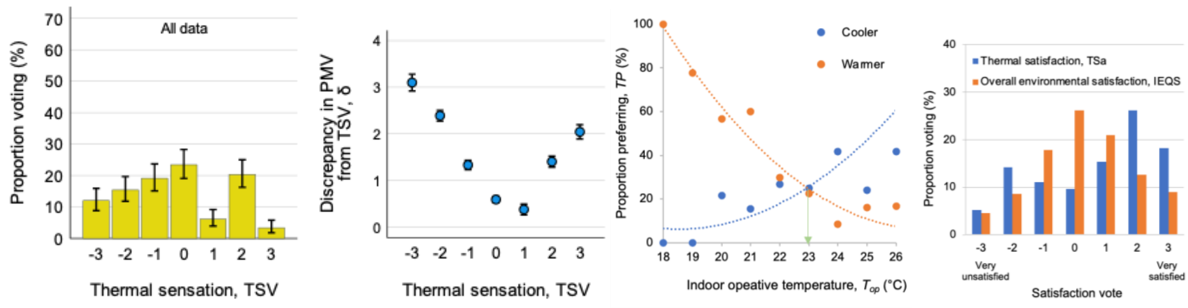

Fig. 2: Histogram of TSV; mean discrepancy in PMV from TSV (δ) varying with TSV; Proportion of subjects wanting cooler and warmer environments at various Top bins; Proportion voting on thermal satisfaction (TSa) and overall environmental satisfaction scales (IEQS); Error bars indicate 95% CI

Moreover, 46.6% and 27.5% subjects voted on the cooler side of sensation and on the cooler side of discomfort (TSV < -1), respectively, while 23.8% voted on the warmer side of discomfort (TSV > 1). This result clearly indicates that most subjects were feeling uncomfortable (mostly cold) sensations. Zaki et al. (2017) made a similar observation about air-conditioned classrooms in Malaysia and Japan. Mean thermal sensation vote varied significantly with season (autumn (mean (s.d.) = -0.55 (1.64)) and winter (mean (s.d.) = 1.26 (1.42); t (322) = -7.806, p < 0.001 (two-tailed)). The magnitude of differences in the mean was large (1.81) with large effect size (eta squared = 0.16). That most subjects felt uncomfortably warmer sensations in winter, colder sensations in autumn suggests that there was overheating in winter and overcooling in autumn. Thermal preference (TP) correlated very strongly with thermal sensation (r = -0.729, p < 0.001) and TP averaged at 0.11(0.76), indicating a preference for warmer environments on the whole (Table 4). Only 41% subjects preferred no change in their thermal conditions while as much as 34.2% subjects preferred warmer/cooler than the ambient conditions, even while voting neutral on TSV. We also noted similar significant seasonal variations in TP (mean difference = 0.56, t(322) = 6.6, p < 0.001, eta squared = 0.12), as was noted in TSV, implying overcooling/overheating in autumn/winter.

3.3 Evaluation of Predicted Mean Vote (PMV) and Predicted Percent Dissatisfied (PPD)

The mean PMV was 0.45 and PPD was 13.9%. In response to a direct question on thermal acceptability (TA), 33.6% subjects voted the environments unacceptable. It can be observed that PMV failed to accurately capture the actual thermal sensation in 86.4% cases, where |PMV – TSV| > 0.5. It can be noted in Fig. 2 that the discrepancy (δ) in PMV from TSV is significantly higher at all scale points of TSV, by as much as 3 scale points towards the cold sensation. This finding is very important in the context of the Middle East where, PMV is used to evaluate the indoor environmental design. Hence, misprediction of such high proportions jeopardizes the accuracy of thermal comfort design, leading to intense discomfort to occupants. In response to a direct question on thermal satisfaction, 59.8% subjects considered the thermal environment satisfactory, while 42.7% subjects felt the same for the overall indoor environmental quality, even though the subjects felt the environments overcooled autumn and overheated in winter. The descriptive statistics of subjective thermal variables is presented in Table 4.

Table 4: Descriptive statistics (mean and standard deviation) of subjective thermal variables (Values in bold indicate significant seasonal difference at $p < 0.001$ with a large effect size)

Data (N)	TSV	PMV	TP	TA (%)	PPD (%)	TSa	IEQS
All (324)	-0.29 (1.73)	0.45 (0.46)	0.11 (0.76)	33.64 (47.3)	13.92 (9.52)	0.67 (1.88)	0.24 (1.55)
Autumn (278)	**-0.55 (1.64)**	**0.39 (0.45)**	**0.19 (0.76)**	34.5 (47.6)	**12.7 (8.65)**	0.62 (1.88)	0.23 (1.55)
Winter (46)	**1.26 (1.42)**	**0.8 (0.36)**	**-0.37 (0.48)**	28.3 (45.5)	**21.3 (11.17)**	1.02 (1.88)	0.33 (1.56)

3.4 Evaluation of Neutral Temperature by Linear Regression

Linear regression of indoor temperature with thermal sensation is regarded a simple method to estimate the neutral temperature. In this study we linearly regressed indoor operative temperature with measured TSV and PMV estimated from the indoor environmental and personal variables to evaluate the neutral temperature (Figure 3). We obtained 0.513 /K ($p < 0.001$) as the sensitivity of TSV which is the same as 0.51 /K reported from AC buildings of two large ASHRAE and European databases (Humphreys, et al., 2016). Our result is also comparable to 0.424 /K, the slope obtained in AC classrooms in Japan, but higher than 0.216 /K, the slope obtained in AC offices Qatar (Zaki, et al., 2017); (Indraganti & Boussaa, 2018). This returned a rate of change in sensation vote of 1.9 °C and neutral temperature of 22.9 °C, which matched closely with the preferred temperature of 23 °C obtained from thermal preference vote as shown in Fig. 2. This is about 1.9 K lower than the neutral temperature obtained in an office study in Doha (Indraganti & Boussaa, 2018). Further, we obtained 0.170 /K ($p < 0.001$) as the slope with PMV and corresponding a neutral temperature of 19.1 °C. It appears that the subjects in learning spaces in Qatar were more sensitive to ambient temperature changes, which the PMV index failed to capture.

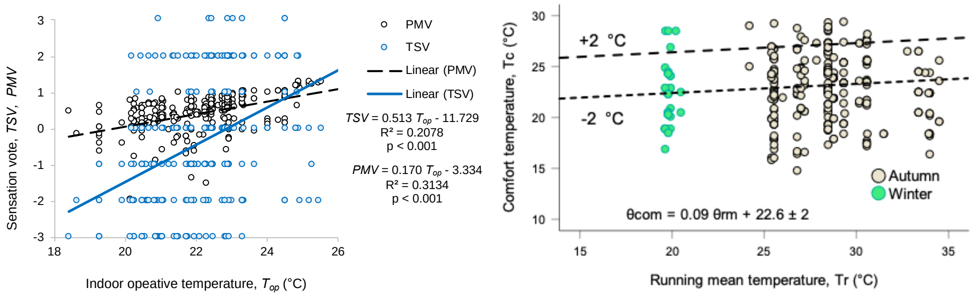

Fig. 3: (Left) Linear regression of indoor operative temperature with TSV and PMV, (right) Comfort data from the current study superimposed over the adaptive model suggested in the Chartered Institute of Building Services Engineers (CIBSE) Guide. Comfort temperature (Θ_{com}), daily outdoor running mean temperature (Θ_{rm})

3.5 Griffiths Method to Estimate the Comfort Temperature (T_c)

We used Griffith's method to estimate the comfort temperature (Griffiths, 1990). We tested the data with three Griffiths coefficients (α) 0.25, 0.33 and 0.5 as suggested in the literature (Rijal, et al., 2013); (Rijal, et al., 2017); (Humphreys, 2013). We noted that α at 0.5 returned the most reliable and consistent estimate of comfort temperature overall, when the data were split in two seasons. With smaller values of α, the variability in comfort temperature is much wider, often resulting in unreliable values of T_c. Therefore, we use 0.5 for α as Humphreys et al. (2016) suggested, similar to others (Zaki, et al., 2017); (Singh, et al., 2018).

The comfort temperature in winter is about 1.3 K lower than in autumn (23 °C) (95% CI). The mean comfort temperature overall was found to be 22.9 ± 3.1 °C. This value is identical with the (a) regression neutral temperature (22.9 °C), (b) comfort temperature of 23 °C, with the highest probability of expressing comfort (b) and comfort temperature 23 °C, obtained by intersecting the regression lines of thermal preference for warmer and cooler environments (Fig. **2**). Further, our result is slightly lower than the comfort temperature (24.0 ± 2.6 °C) reported through a yearlong study in offices in Qatar, where 64.1% of the respondents were men (Indraganti & Boussaa, 2018).

It is important to note that the current comfort temperature in classrooms in Qatar is 3-4 K less than the comfort temperatures in AC classrooms in Ecuador (25.4 – 26.4 °C) (Guevara, et al., 2021), Malaysia (25.2 °C) and Japan (26.2 °C) (Zaki, et al., 2017), where air speeds were effectively higher than Qatar. Increasing air movement in autumn allows higher indoor temperatures and reduces cold discomfort votes. Significantly, Taiwan (25.6 °C) (Hwang, et al., 2006), Indonesia (24.9 °C) (Karyono, et al., 2015) achieved higher comfort temperature by increasing air speed. Notably, cross-tabulation revealed that cold discomfort (TSV < = -2) increased thermal and IEQ dissatisfaction by 20%. Similarly overheating in winter when the subjects were dressed in warmer clothes also caused higher dissatisfaction. Overheating and overcooling were perhaps the two main reasons why thermal sensation satisfaction (TSa) was not even 50%, as against the 80% in standards (ASHRAE, 2020).

3.6 Evidence of Adaption and Lack of Adaptive Opportunities

Humphreys et al. (2016) define adaptive thermal comfort as "If a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort." If adaptation is restrained, people express dissatisfaction. Fig. **4** (a) Fig. **4** (b) show the proportion of subjects voting dissatisfied on the 7-point equal interval thermal satisfaction scale (TSa) and the corresponding proportion of sensation of thermal drift felt in the environment. Results show that thermally dissatisfied subjects (30.6%) were most often feeling the environment cold (65%). While most of the spaces investigated had no operable windows (< 8%), only 11.1% occupants said that they have the ability to change the temperature in their room. Fig. **4** (c) shows the controls voted to have been adjusted around the time of the survey. It is important to note that most of the subjects were feeling handicapped with their ability to have access to temperature control (89.9%) and 43.5% subjects have not accessed any of the suggested controls. The following open-ended response on the thermal satisfaction and the feeling of thermal drift aptly summarizes the current overcooling situation and the ensuing discomfort to students in autumn: "la astadee'a tahamol alboruda ashar bala'eya wa alsabab shidat alboruda, لا أستطيع تحمل البرودة، أشعر بالإعياء والسبب شدة البرودة (I can't handle the cold. I feel tired/unconscious and the reason is the extreme cold)."

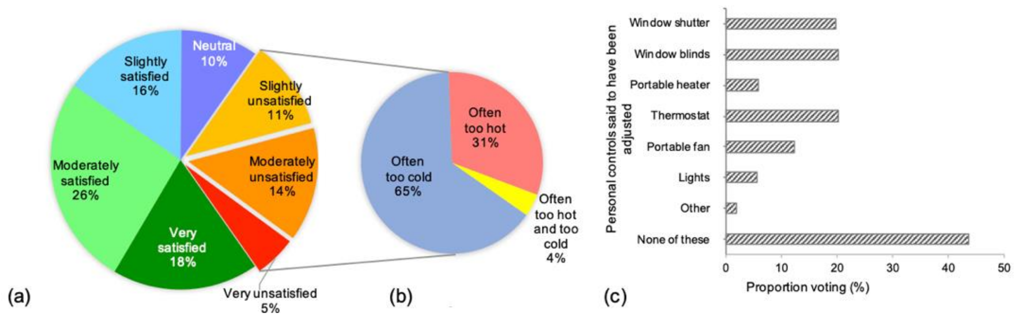

Fig. 4: (a) Proportion of voting thermal dissatisfaction (N: 324); **(b)** Proportion of sensation of thermal drift (N: 99); **(c)** Proportion of various controls said to have been adjusted

4 Conclusions

A thermal comfort and environmental quality evaluation (IEQ) survey was conducted in autumn and winter seasons in higher education learning environments in Qatar. Indoor temperatures were low compared to international surveys (mean T_{op} was 22.4 ˚C). Significant seasonal differences were noted in indoor and outdoor temperatures and we found overcooling in autumn and overheating in winter seasons with near still air conditions overall. This resulted in cooling/heating discomfort in these two seasons, respectively. As a result, maximum proportion voting comfortable was found to be only 53.8% as against the 80% suggested value in international standards. Thermal acceptability was only 66%. Fanger's PMV was inaccurate up to three sensation points. Moreover, in as much as 86.4% cases it mispredicted by half a scale point or more. Mean indoor comfort temperature was found to be 22.9 ˚C, which is about 3- 4 K lower than classrooms in Japan, Malaysia and Asia. The comfort data were juxtaposed with the international standards and 64.2% cases are outside the ± 2 K limits for the comfort zone suggested in the CIBSE Guide, the majority of which fell below the lower limit of the international standard. Most subjects (89.9%) said they have no access to control the indoor temperature. Overall, 30% felt thermal dissatisfaction and 65% of the dissatisfied felt the environments were often cold and 31% felt them too hot often. Less than 8% data were recorded with spaces with operable windows. Overall, 43.5% felt they have no access to any of the indoor environmental controls such as thermostats, windows and blinds.

These findings call for greater opportunities for personal control, increased air movement and corresponding elevation in indoor temperatures in autumn. It would not only improve user satisfaction but would also save energy. Further, it is necessary to frame the narrative around the use of operable controls in learning environments in Qatar, rather than simply overcooling/overheating them full throttle, exacerbating the occupant dissatisfaction.

Acknowledgments

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