E3S Web of Conferences **396**, 01070 (2023)
IAQVEC2023
https://doi.org/10.1051/e3sconf/202339601070

Investigation of thermal comfort in bedrooms in Qatar

Madhavi Indraganti[*1]

[1]Department of Architecture and Urban Planning, College of Engineering, Qatar University, Doha, Qatar

Abstract. Good quality sleep is essential for overall health and productivity of human beings. In a field survey in bedrooms in Qatar, 833 sets of occupant responses on thermal comfort and sleep quality before going to bed and after getting up were made together with the corresponding environmental measurements and occupant's clothing and bedding information. Subject's thermal sensation was on the cooler side with a preference for warmer environments mostly. People generally felt comfortable, with Griffiths comfort temperature (Tc) being 24.3 ℃. and 20.2 ℃ in free-running (FR) and air-conditioned (AC) modes respectively. Adaptive use of air-conditioners was noted. In 82.7% cases in (AC) mode, the comfort temperature was below the lower limit of the international standard. The quality of sleep was good and overall self-declared sleep quality increased with thermal acceptability. Higher depth of sleep was noted when ACs were on. Qatar bedrooms recorded high mean global Pittsburgh Sleep Quality Index (PSQI) score in general (mean = 10.7), indicating good quality sleep. It was higher in free-running mode (mean = 11) than in AC mode (mean 10.4). It increased as subjects liked their HVAC systems, indicating the occupants perception of performance of AC systems affecting the sleep quality. This study highlights the need reduce overcooling in spring and to increase air-movement to enable free-running mode, without reducing the sleep quality.

1 Introduction

Sleep is a basic human need and quality sleep is vital for human health and wellbeing. It is known for long that sleep quality and bedroom temperature are negatively correlated [1]. Recent studies have found that room freshness (lower CO_2 levels) significantly enhanced the occupant's sleep quality, performance in a test of logical thinking and reduced the symptoms of next day reported sleepiness [2]. That elevated air movement enhances sleep quality is now well established through bio-physical modelling and field experiments and that fans could be used to great advantage in heat wave situations [3], [4].

Literature also pointed to subjects sleeping well in Japanese homes with the help of adaptive measures such as cooling and fans [5]. In this context it is important to note that buildings in Qatar are maintained at near zero indoor air speeds [6]. Cheap energy prices coupled with long hot and humid seasons increase the air-conditioner usage. And overcooling in buildings is rampant in the Gulf Cooperation Countries (GCC) [7], [6].

Further, in Qatar, the final electricity consumption in residential sector is very high (45%) and has increased by 33% between 2015-18, while the country ranked highest in per capita CO_2 emissions in the world [8]. Moreover, building energy for space cooling and heating contributes substantially to the greenhouse gas emissions. Gulf nations like Qatar have already seen average temperature increases above 2˚C [9].

As there is no custom-developed adaptive thermal comfort standard for the GCC [10], engineers usually follow the predicted mean vote (PMV) heat balance approach to for indoor environmental design following international standards [11] [12]. Researchers claimed this approach was inaccurate in predicting actual thermal comfort and suggested transition the air-conditioning practice to the adaptive framework [13] [14] [15]. Thermal comfort in residential spaces and especially sleep environments is under reported in the Middle East. Therefore, we conducted a field study to investigate the thermal comfort, quality of sleep and occupant adaptive behavior in sleep environments of six residences Qatar in winter and spring seasons.

2 Methodology

2.1 Survey location and buildings surveyed

Qatar is a peninsular nation in the Arabian desert with hot desert climate (Bwh in Köppen climate classification). Its capital is Doha (N25° 17', E51° 32', 10 m above the mean sea level). It has five months of harsh summer (May – September) and mild winter (December – February) with very low precipitation. Autumn (October, November) and spring (March, April) are short mild seasons of two months each. This is an ongoing longitudinal survey in six randomly selected residences (B1-B6) involving nine healthy

---

* Corresponding author: madhavi.indraganti@fulbrightmail.org; madhavi@qu.edu.qa

https://doi.org/10.1051/e3sconf/202339601070

participants in Doha metropolitan area. This report includes data from December 28, 2020 – March 29, 2021, consisting of 833 sets of subjective thermal responses and simultaneous objective environmental measurements. The SARS-COV-19 pandemic after March 2020 affected the data collection. Table 1 shows the details of the buildings surveyed (Fig. 1.) The buildings are multi-storied low-rise apartment blocks and independent villas. They have concrete structural frame and concrete block masonry infill walls with sliding and sash windows, a typical style used locally. Only B1 had portable fans. Buildings B1-5 have cloth curtains while B6 had roller blinds.

Table 1. Details of the buildings studied.

House (Sample size) respondents	**Window Glazing**	**Location**	**Room area (m^2)**	**Ceiling height (m)**	**AC System**
B1 (110) 1	Single	Najma	14.5	3.2	Window
B2 (69) 1	Single	Madinat Khalifa South	17.4	2.8	Split
B3 (79) 1	Single	Al-Mamoura	20	3	Split
B4 (283) 3	Double	Bin-Mahmoud South	21	3.5	Ducted Central
B5 (87) 1	Double	Al-Nasr	20	3	Split
B6 (205) 2	Double	Al-Tarfa	80	4.5	Ducted Central

2.2 Data collection

Set to a 10-minute interval, calibrated sensors of the data loggers were fixed to a hanger or a board at 1.1 m height from the floor in all the bedrooms. They recorded indoor air temperature (T_a), globe temperature (T_g), relative humidity (RH) and air velocity (V_a) in all the bedrooms. Excepting in B2, B4, CO_2 concentration was also measured in all the other houses.

We obtained the outdoor daily mean temperature (T_o) from the meteorological website [16]. The mean radiant temperature (T_{mrt}) is calculated following the procedure in American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Handbook [17] and operative temperature (T_{op}) was taken as the average value of T_{mrt} and T_a [11]. The instrument details and the set-up used in the surveys are shown in Fig. 2 and Table 2.

Fig. 1. Typical buildings surveyed

Table 2. Details of the buildings studied.

House	**Trade name**	**Variable**	**Range**	**Accuracy**
B2, B4	Hobo U12-013 (Temp/RH/2 Ext)	T_a	0 to 50 °C	±0.35 °C (0° to 50°C)
		RH	5 to 90% RH	±2.5% (10 to 90%)
	Onset TMC1-HD probe	T_g	0 to 50 °C	±0.35 °C (0° to 50°C)
	Accusense F900-O-10-0 hot wire anemometer	V_a	0.15 - 5 m/s	± 0.05 m/s (0 to 5 m/s)
B1, B3, B5, B6	Onset MX 1102A	T_a	0° to 50°C (32° to 122°F)	±0.21°C from 0° to 50°C
		RH	1% to 70% RH	±2% from 20% to 80%
		CO_2	0 to 5,000 ppm	±50 ppm ±5% of reading at 25°C
	T-DCI-F300-1A3 hot wire anemometer	V_a	0.15 - 5 m/s	± 0.05 m/s (0 to 5 m/s)
	TMC1-HD probe with 080340-275 Cu globe	T_g	0 to 50 °C	±0.35 °C (0° to 50°C)

Fig. 2. Instrument setup and the interiors surveyed*

*(A: MX1102A; B: UX120-006M; C: hot-wire anemometer; D: Cu globe with thermal probe)

2.3 Thermal questionnaire and the respondents

Table 3 lists all the scales used in this survey. A total of nine respondents participated in the survey of which one was a male participant in B4 (Age: 60 years, Sample size (n): 141). It was learned that men in Arab families usually spend winters in tent structures “kashta” (كشته) in the desert away from home, and therefore our survey recruited fewer men. Consequently, we collected 83.1 % data from females (mean age: 30.2 (standard deviation (SD) (11.1) years). The bedrooms in B4 and B6 had two subjects each, while the rest had one each.

Aged 21-60 years (mean: 35.3 ±15.1 years), the respondents are all healthy residents of Qatar living in the surveyed areas for longer than one year and are assumed to be acclimatized to the local climate. The respondents were requested to respond to the online Google survey twice a day: (1) before going to bed after spending 15 minutes in the bedroom and (2) soon after waking up reflecting on the thermal comfort during sleep. The questionnaire was modelled after Imagawa & Rijal [5] in English and translated to Arabic. Following Tsang, et al. [18], we prepared the detailed sleep quality questions to estimate the Pittsburgh Sleep Quality Index (PSQI) [19]. PSQI is a self-scoring subjective measure of sleep quality in all seven dimensions of sleep such as quality, latency, efficiency, disturbances, medications, and daytime disfunction. A higher PSQI index refers to better sleep quality. To the PSQI, we added overall sleep quality score and obtained Global PSQI.

The Internal Review Board (IRB) at QU approved the questionnaire for ethical compliance. We used ASHRAE 7-point scale for evaluating the thermal sensation (TSV). The questionnaire had three segments: time and personal identifier/variables followed by branching questions of thermal comfort and the use of controls. A separate one-time background survey collected the building and personal details such as age. The thermal questionnaire included elaborate pictorial checklists for various pieces of garments, three types of bedding, and a list of activities to choose from. It also included a list of environmental controls (AC/fan/heater/window/curtain/lights) which are coded as 0: not in use, 1: in use and 2: Unavailable. The occupants gave 433 and 400 datasets before going to bed and after getting up respectively.

Table 3. Scales used in the survey.

Scale	TSV	TP	Preference on cooling/ heating	TA
3	Hot			
2	Warm	Much Cooler		
1	Slightly warm	A Bit Cooler	Like	Unacceptable
0	Neutral	No Change	Neither like nor dislike	Acceptable
-1	Slightly cool	A Bit Warmer	Dislike	
-2	Cool	Much Warmer		
-3	Cold			

Scale value	Overall comfort (OC)	Depth of sleep	Sensitivity to warmth (SW)	Overall sleep quality
6	Very comfortable	Very deep		
5	Comfortable	Deep		
4	Slightly comfortable	Slightly deep	Sensitive to heat and cold	
3	Slightly uncomfortable	Slightly light	Sensitive to cold	Very good
2	Uncomfortable	Light	Not sensitive to heat/cold	Good
1	Very uncomfortable	Very light	Sensitive to heat	Bad
0				Very bad

3 Results and discussion

3.1 Outdoor and indoor conditions

The following sections present the results of the data considered in two groups: FR (free running – no cooling or heating) and AC (cooling/heating by air-conditioning). We used SPSS Ver.27. In FR mode, the mean outdoor temperature was 20.8 and 20.9 ˚C, before going to bed and after getting up respectively, and similarly in AC mode it was 21.1 and 20.9˚C respectively. Likewise, in FR mode, the mean outdoor relative humidity was 60.1 and 59.4 % before going to bed and after getting up respectively, and similarly in AC mode it was 59.4 and 61.8 %, respectively. As indoor operative temperature (Top) correlated very strongly ($r = 0.999\text{-}0.996$, $p < 0.001$) with other indoor thermal indices T_g, T_{mrt} and T_a, we decided to use Top in the analysis to enable easy comparison with literature and standards. The indoor thermal conditions in FR mode were significantly warmer than AC mode (mean difference = ~ 4.6 K, $p < 0.05$), while the difference in T_{op} “before going to bed” and “after getting up” was very small. Comparatively, RH was less variable among the four conditions examined (Fig. 3) This result suggests that people in Doha sleep in humid-cooler conditions in AC mode and humid-warmer conditions in FR mode. The descriptive statistics of outdoor and indoor variables is presented in Table 4. For it is winter and spring season study, we noted very low air movement indoors (mean air speed = 0.03 m/s).

Table 4. Descriptive statistics (mean and standard deviation) of outdoor and indoor environmental variables.

Mode (n)	FR (433)	AC (400)	All (833)
Outdoor daily mean temperature (°C)	20.9 (2.4)	21 (2.3)	20.9 (2.3)
Outdoor relative humidity (%)	59.7 (12.1)	60.4 (11.6)	60.1 (11.8)

Operative temperature (°C)	23.9 (1.5)	19.8 (2.2)	21.9 (2.8)
Air temperature (°C)	24.1 (1.5)	20.1 (2.2)	22.2 (2.7)
Relative humidity (%)	61.4 (5.8)	61.3 (6.1)	61.4 (5.9)
Air Velocity (m/s)	0.02 (0.04)	0.04 (0.07)	0.03 (0.06)

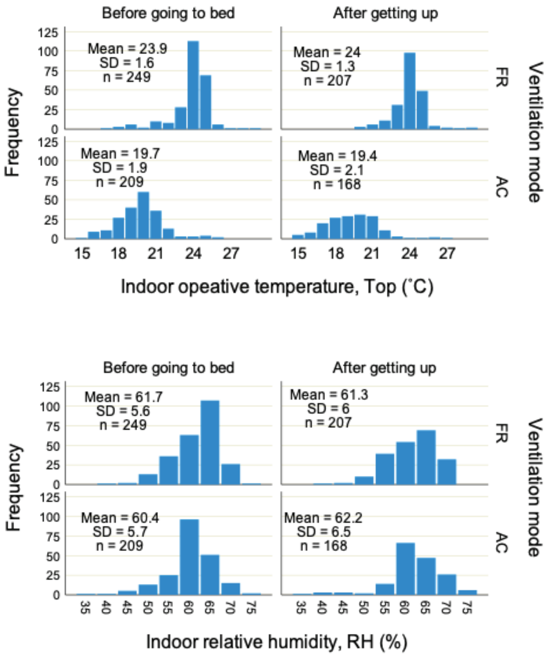


Fig. 3. Instrument setup and the interiors surveyed*

We estimated the clothing insulation (I_{cl}) for all subjects before and after the sleep. The I_{cl} values of Western and non-Western ensembles were estimated using the standard checklists and reports [11], [12], [20], [21], [22] and [23]. The bedding and mattress insulations were estimated following Lin & Deng [24], assuming the subjects to be using similar mattress and heavy/light duvets and blankets. We estimated the metabolic rates as per [12].

3.2 Subjective thermal responses

Overall, the mean thermal sensation was found to be -0.19 (1.1), indicating the subjects voting on the cooler side of the 7-point sensation scale. In FR and AC modes it was -0.20 and -0.17 respectively, implying that the subjects were often feeling cooler sensations. In both FR and AC modes, subjects were feeling significantly warmer sensations after getting up (by about ½ sensation vote) ($p < 0.05$). Interestingly, literature indicates that warmer thermal sensations ($TSV > 0.8$) are counterproductive to sleep quality improvement [25]. Much as expected, the preference (TP) was for warmer environments with mean TP vote being -0.14 overall (Fig. 4).

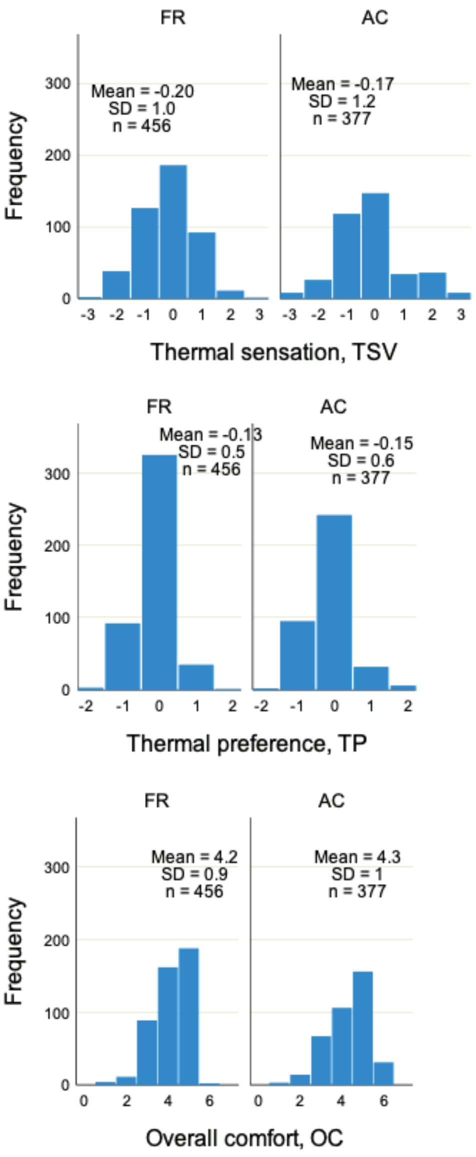


Fig. 4. Distribution of thermal sensation, thermal preference and overall comfort votes in FR and AC modes.

In FR mode, TP was significantly different before going to bed and after getting up ($p < 0.05$), but not in AC mode. While the overall comfort (OC) of subjects was the highest in AC mode after getting up, no significant modal or before sleep and after sleep differences were noted in OC vote. The results also indicated that subjects were comfortable with their sleep environments most of the time, with the proportion of subjects voting on comfortable side of the OC scale being 63.2% - 83.3% and the proportion comfortable ($-1 \leq TSV \leq 1$) also being high (79 - 93%) in all the four cases considered as above (Fig. 4). This result is comparable to the 80% satisfaction rate proposed in ASHRAE Std-55 [11].

3.3 Estimation of comfort temperature

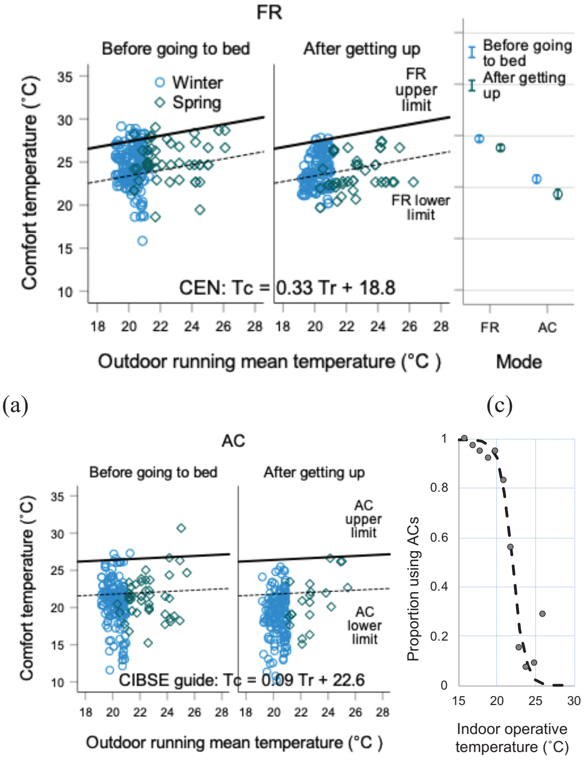
Comfort temperature refers to the temperature needed indoors for people to feel comfortable. Linear regression is one of the methods used to estimate it. In this study we regressed T_{op} with TSV and obtained the following relationship for FR mode:

$$TSV = 0.167\, T_{op} - 4.185 \; (r = 0.253,\ p < 0.001,\ n = 433,\ \text{standard error (SE)} = 0.031) \qquad (1)$$

The equation in AC mode was not significant at 95% confidence interval (CI) and the slopes for "before going to bed" and "after getting up" cases were found to be homogenous at 95% CI. This relationship retuned a comfort neutral temperature of 25.1 ˚C in FR mode and a comfort band ($-1 \leq TSV \leq 1$) of 19.1 - 31.5 ˚C. The mean T_{op} when subjects voted neutral in FR mode was 24 (1.2) ˚C which was slightly lower than the regression natural temperature. In AC mode it was 20.2 (2.2) ˚C. Often it is noted in field experiments that both subjective sensation and or the thermal stimuli do not fluctuate much, and consequently the regression equation may not be significant, as in the case of AC mode in this study [26] (p. 287). Therefore, literature points to the use of Griffiths method to evaluate the comfort temperature [27]. Further, in field experiments most subjects express near neutral sensations even when the temperature varies in FR mode and vice versa in AC mode. This results in low coefficient of determination between the temperature and thermal sensation. Literature points to errors in neutral temperature attributed to the scatter of the thermal sensation and the lack thereof. Therefore, Griffiths method is suggested to as a more suitable method for small batches of data. We used Griffiths method to estimate the comfort temperature (T_c) testing initially with three different Griffiths coefficient (α)s: 0.25, 0.33 and 0.50. Significantly, 0.5 as α resulted in the most reliable prediction of T_c (with lowest SD value). Therefore, we used 0.5 for α as Humphreys et al. [26] (p. 251) also suggested. We obtained the following mean comfort temperatures: in FR mode 24.7 (2.3) ˚C and 23.8 (1.9) ˚C before going to bed and after getting up respectively; and in AC mode 20.8 (3) ˚C and 19.3 (3.2) ˚C before going to bed and after getting up respectively. This result is comparable to Hong Kong AC bedrooms in high-rise residences, where Lin and Deng [28] found the preferred temperature to be below 24 ˚C.

3.4 Comparison with international standards

In order to compare, we super-imposed our comfort data on the Comité Européen de Normalisation (CEN) and The Chartered Institution of Building Services Engineers (CIBSE) Guide standards as shown in Fig. 5 a, b. [29], [30]. Observable, in FR mode, most of the data (60%) was lying within the ± 2 K comfort band of the adaptive relationship, while in AC mode only 18% was within the respective comfort band. Importantly, 34.9 %, and 81% data fell below the lower limit of the CEN/CIBSE Guide standards in FR and AC modes respectively. In AC mode, 82.7% (n = 277), and 72.3% (n = 47) cases recorded T_c below the CIBSE guide value in these two seasons (Figure 5b). It could mean that subjects were achieving lower winter temperatures by using less heating in winter in AC mode. Having habituated to lower temperatures, the subjects continued maintaining lower temperature in spring season also as is evident in Fig. 5b. Observable, comfort temperatures were significantly lower in AC mode ($p < 0.001$) with large effect size ($\eta^2 > 0.14$, $p < 0.05$) (Fig. 5 c). A review by Lan et al. [31] suggested that maintaining lower comfort temperature in winter does not compromise sleep quality, much similar to the result obtained in this study.



(a) (c)

(b) (d)

Fig. 5. Comfort data of this research with markers shown for winter and spring seasons for "before going to bed" and "after getting up" cases super-imposed over the European standard for (a) FR and (b) AC modes; (c) significant differences in mean comfort temperature in FR and AC modes in "before going to bed" and "after getting up" cases ($p < 0.05$); (d) probability of AC use varying with indoor operative temperature, with markers shown for actual proportion or AC use in 1K bins. Bins with fewer than ten samples are omitted.

3.5 Evidence of adaptation

Qatar has salubrious weather in winter and spring seasons and as a result, subjects used air-conditioning systems adaptively in residences (mean usage = 48%, n = 833). We noted the proportion using ACs varying significantly with the indoor operative temperature. As this was majorly a winter study, the ACs were used in heating mode and their usage plummeted as the temperature increased as shown in Fig. 5 d. To estimate the probability of AC use at various indoor temperatures, we conducted logistic regression of proportion of AC use (pac)with indoor operative temperature, and obtained the following relationship:

$$Logit(p_{ac}) = -1.248\, T_{op} + 27.488 \; (n = 833,\ R^2 = 0.574;\ p < 0.001) \qquad (2)$$

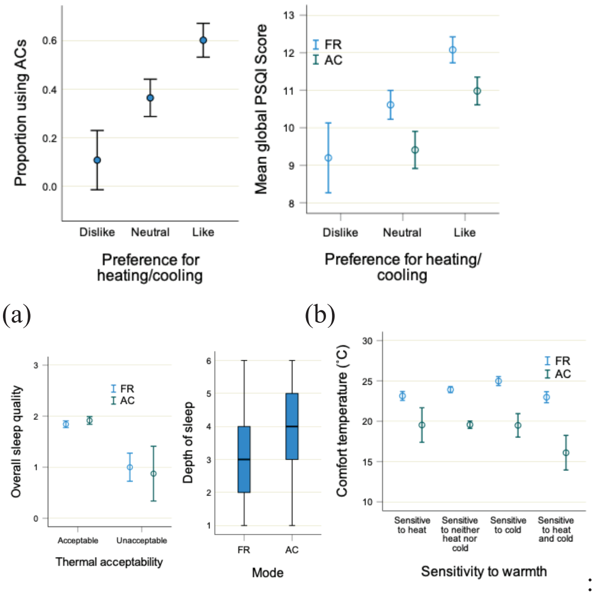
where T_{op} is the indoor operative temperature (˚C), n is the sample size, p is the level of significance of the regression coefficient and R^2 is the Cox and Snell R^2. It can be noted from this relationship that AC usage was

80% at 20.9 ˚C. Imagawa and Rijal [5] noted similar adaptation in cooling device use in Japanese bedrooms.

3.6 Sleep quality

Fig. 6 (a) shows that significantly higher proportion of people liked the AC systems when about 60% of the AC systems were in use. This clearly indicated higher proclivity for using ACs at bedtime. Imagawa and Rijal [5] found slightly lesser (55%) AC usage when subjects liked the cooling systems. Results also indicated that subjects liking the AC systems had significantly higher global PSQI score. Importantly, subjects in FR mode had significantly higher global PSQI score than in AC mode, as shown in Fig. 6 b at all levels of preference for ACs. This figure also shows that residents in Qatar generally ranked high in PSQI score, indicating good sleep.

We noticed subjects who accepted the thermal environments had significantly higher self-reported overall sleep quality in both modes as shown in Fig. 6 c. Tsang, et al. [18] reported similar association between overall sleep quality neutral TSV. Our results also indicated that subjects in AC mode had deeper sleep than in FR mode (Fig. 6 d). On the other hand, subjects in FR mode had significantly higher comfort temperature than AC mode. However, their comfort temperature at various levels of sensitivity to warmth (SW) did not vary significantly in both modes. It means that was not fully explaining the variation in comfort temperature in both the modes. On the other hand, results also showed that people sensitive to cold had significantly higher comfort temperature ($p < 0.05$) than those expressing other sensitivities to warmth as shown in Fig. 6 e. Similar association was noted between Top and SW, indicating that other dimensions of the thermal environment such as air movement could have influenced SW.



(a) (b)

(c) (d) (e)

Fig. 6. Association with the three preferences for heating/cooling and (a) mean proportion using ACs, (b) mean global Pittsburgh Sleep Quality Index score; (c) Overall sleep quality varying with thermal acceptability; (d) depth of sleep varying with mode; (f) comfort temperature varying with various levels of sensitivity to warmth. ($p < 0.05$); ($n = 372$).

4 Conclusion

A thermal comfort field survey was done in sleep environments in homes in Qatar during the winter and spring seasons of 2020-21. A total of 833 datasets provided thermal comfort data before going to bed and after getting up in six bedrooms. The conclusions are as follows:

1. The subjects expressed cooler sensations and preferred warmer indoors in both FR and AC modes.
2. People are generally comfortable with their sleep environments and the Griffiths comfort temperature (T_c) was 24.3 ˚C and 20.2 ˚C in FR and AC modes respectively. In both modes, T_c before going to bed was slightly higher ($p < 0.05$).
3. Subjects used ACs adaptively in heating mode in winter and tolerated low bedroom temperatures and as a result, in AC mode 82.7% data fell below the lower limit in the CIBSE Guide.
4. The occupants enjoyed quality sleep in Qatar. Overall self-declared sleep quality significantly improved with thermal acceptability.
5. The depth of sleep was higher in AC mode (mean = 3.86). On the other hand, mean global Pittsburgh Sleep Quality Index score was high in general, indicating good quality sleep, and significantly so in FR mode (mean = 11) compared to the AC mode (mean = 10.4). It increased as subjects liked their AC systems.
6. This study suggests that overcooling in spring can be avoided by increasing the air movement without compromising sleep quality.

Acknowledgements

The author thanks all the surveyors and respondents. Qatar National Research Fund through the Undergraduate Research Experience Program (UREP26-033-2-010) funded this research. Some instruments used in the survey were funded by the Japan Society for Promotion of Science through a Post-doctoral Fellowship (JSPS/FF1/246/P 11372). She thanks both the funding agencies. The views expressed in this paper are solely of the author.

References

[1] M. A. Humphreys, “A Simple Theoretical Derivation of Thermal Comfort Conditions,” The Journal of the Institute of Heating and Ventilating Engineers, vol. 38, no. 8, p. 95–98, 1970.

[2] P. Strøm-Tejsen, D. Zukowska, P. Wargocki and D. P. Wyon, “ The effects of bedroom air quality

on sleep and next-day performance," Indoor Air, vol. 26, pp. 679-686, 2016.

[3] N. B. Morris, G. K. Chaseling, T. English, F. Gruss, M. F. B. Maideen, A. Capon and O. Jay, "Electric fan use for cooling during hot weather: a biophysical modelling study," Lancet Planet Health, vol. 5, p. e368–77, 2021.

[4] L. Lan, L. Xia, J. Tang and Z. Wang, "Elevated airflow can maintain sleep quality and thermal comfort of the elderly in a hot environment," Indoor Air, vol. 29, p. 1040–1049, 2019.

[5] H. Imagawa and H. B. Rijal, "Field survey of the thermal comfort, quality of sleep and typical occupant behaviour in the bedrooms of Japanese houses during the hot and humid season," Architectural Science Review, vol. 58, no. 11, pp. 11-23, 2015.

[6] M. Indraganti and D. Boussaa, "An adaptive relationship of thermal comfort for the Gulf Cooperation Council (GCC) Countries: The case of offices in Qatar," Energy and Buildings , vol. 159 (2018) , p. 201–212, 2018.

[7] R. Elnaklah, A. Alnuaimi, B. S. Alotaibi, E. Topriska, I. Walker and S. Natarajan, "Thermal comfort standards in the Middle East: Current and future challenges," p. 107899, May 2021.

[8] IEA, "Key energy statistics 2018," 2018. [Online]. Available: https://www.iea.org/countries/qatar. [Accessed 2 07 2021].

[9] A. Al-Saffar and M. V. d. Beeuren, "The case for energy transitions in major oil- and gas-producing countries," 18 11 2020. [Online]. Available: https://www.iea.org/commentaries/the-case-for-energy-transitions-in-major-oil-and-gas-producing-countries.

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

[11] ASHRAE, "ANSI/ ASHRAE Standard 55-2020 Thermal environmental conditions for human occupancy," ASHRAE, Atlanta, 2020.

[12] 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.

[13] M. A. Humphreys and J. F. Nicol, "The validity of ISO-PMV for predicting comfort votes in every-day thermal environments," Energy and Buildings , vol. 34, pp. 667-684, 2002.

[14] T. Cheung, S. Schiavon, T. Parkinson, P. Lib and G. Brager, "Analysis of the accuracy on PMV – PPD model using the ASHRAE Global Thermal Comfort Database II," Building and Environment, vol. 153, pp. 205-217, 2019.

[15] T. Parkinson, R. de Dear and G. Brager, "Nudging the adaptive thermal comfort model," Energy and Buildings, vol. 206, p. 109559, 2020.

[16] "Weather Underground," 2021. [Online]. Available: https://www.wunderground.com/weather/qa/doha. [Accessed 23 6 2021].

[17] ASHRAE, "ASHRAE Handbook: Fundamentals, SI," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA, USA, 2005.

[18] T. Tsang, K. Mui and L. Wong, "Investigation of thermal comfort in sleeping environment and its association with sleep quality," Building and Environment, vol. 187, p. 107406, 2021.

[19] D. Buysse, C. R. III, T. Monk, S. Berman and D. Kupfer, "The Pittsburgh Sleep Quality Index: a new instrument for psychiatric practice and research," J. Psychiatr. Res., vol. 28, no. 2, p. 193–213, 1989.

[20] M. Indraganti, J. Lee and H. A. E. A. Zhang, "Thermal adaptation and insulation opportunities provided by different drapes of Indian saris," Architectural Science Review, vol. 58, no. 1, p. 87–92, 2015.

[21] G. Havenith, K. Kulklane, J. Fan, S. Hodder, Y. Ouzzhra, K. Lundgren, Y. Au and D. Loveday, "A Database of Static Clothing Thermal Insulation and Vapor Permeability Values of Non-Western Ensembles for Use in ASHRAE Standard 55, ISO 7730, and ISO 9920," ASHRAE Transactions, vol. 121, no. 1, pp. 197-215, 2015.

[22] S. Mitsuzawa and S.-i. Tanabe, "Effect of air movement on thermal comfort under hot and humid conditions while wearing traditional clothing," London, UK, 2001.

[23] F. F. Al-ajmi, D. L. Loveday, K. H. Bedwell and G. Havenith, "Thermal insulation and clothing area factors of typical Arabian Gulf clothing ensembles for males and females: Measurements using thermal manikins," Applied Ergonomics, p. 39 (2008) 407–414, 2008.

[24] Z. Lin and S. Deng, "A study on the thermal comfort in sleeping environments in the subtropics—Measuring the total insulation values for the bedding systems commonly used in the subtropics," Building and Environment, vol. 43, p. 905–916, 2008.

[25] C. Song, T. Zhao, Z. Song and Y. Liu, "Effects of phased sleeping thermal environment regulation on human thermal comfort and sleep quality," Building and Environment, vol. 181, p. 107108, 2020.

[26] M. Humphreys, F. Nicol and S. Roaf, Adaptive thermal comfort, Foundations and Analysis, Oxon: Routledge, 2016, p. 377.

[27] I. D. Griffiths, “Thermal Comfort in Buildings with Passive Solar Features: Field Studies,” 1990.

[28] Z. Lin and S. Deng, “A questionnaire survey on sleeping thermal environment and bedroom air conditioning in high-rise residences in Hong Kong,” Energy and Buildings, vol. 38, pp. 1302-1307, 2006.

[29] 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.

[30] CIBSE, “CIBSE Guide A: Environmental Design,” The Chartered Institution of Building Services Engineers , London, 2015.

[31] L. Lan, K. Tsuzuki, Y. Liu and Z. Lian, “Thermal environment and sleep quality: A review,” Energy and Buildings, vol. 149, pp. 101-113, 2017.