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Publication Date
2021-08-21

DOI
10.1111/ina.12926

A sex/age anomaly in thermal comfort observed in an office worker field study: a menopausal effect?

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Keywords: women; menopause; hot flush; thermal comfort; office; field study

https://doi.org/10.1111/ina.12926
https://escholarship.org/uc/item/1dk4z7th

Abstract

In a field study conducted in office settings in Sydney, Australia, background survey and *right-here-right-now* thermal comfort questionnaires were collected from a sample of office workers. Indoor environmental observations including air temperature, mean radiant temperature, air velocity and relative humidity, were also recorded and matched with each questionnaire according to time and location. During exploratory data analyses we observed that female subjects aged over 40 and 50 or younger registered significantly warmer sensations than other subjects, male and female, from other age ranges. To further explore this phenomenon, the sample of building occupants were classified into two groups – women of perimenopausal age (over 40 and 50 or younger) while the remaining respondents served as a reference group for comparison. Women in the perimenopausal age range demonstrated an increased perception of warmth (p<0.01) and expressed thermal dissatisfaction more frequently (p<0.01) than the reference group respondents who were exposed to the same indoor environmental conditions. Further, women of perimenopausal age also expressed preference for cooler thermal environments i.e. lower air temperature (p<0.01) and greater air movement (p<0.01) than the reference group, and their thermal neutrality (i.e. the room temperature corresponding to a neutral thermal sensation), was approximately 2°C cooler than that of the reference group (20.7°C vs 22.4°C). A potential physiological explanation for the distinct thermal perception of women aged over 40 and 50 or younger observed in this study could stem from menopausal symptoms – the presence of hot flushes and dysregulation of the thermoregulatory system.

Practical implications

If the hypothesis emerging from the current study is validated in more focused follow-up research, then facility management of open-plan workplaces should include deliberate indoor climatic “zoning” to accommodate the special thermal requirements and preferences of perimenopausal and postmenopausal women. In addition, Personal Comfort Systems (PCS) including desk fans and flexible dress codes in the workplace would be useful in mitigating thermal discomfort across this important demographic group in the workforce.

1. Introduction

Heating, ventilation and air conditioning (HVAC) energy use is remarkably high, accounting for up to 50% of building energy consumption [1]. Much of the energy goes into the effort of creating a tightly controlled range of indoor temperatures that are supposedly comfortable for a representative occupant. This approach has been shown to work poorly; current office buildings do not satisfy large fractions of their occupants overall, nor at any specific time [2–4]. It has also been demonstrated that narrower ranges of indoor temperature control fail to satisfy a larger number of occupants compared to looser temperature ranges, notwithstanding presumptions embedded in contemporary HVAC guidelines and standards [5,6]. A likely explanation for this observation is the large inter-individual variability in how people perceive the same built environment resulting in diverse thermal comfort preferences, which is about 3K[7]. As a consequence, there is no "one-size-fits-all" centralized HVAC system that can satisfy *all* building occupants.

Sex and age differences in human thermal perception have received attention in the recent thermal comfort literature. It is widely believed that women experience more thermal discomfort, particularly on the cool side of the comfort zone [2,8–11], preferring warmer thermal environments than male counterparts [3,12–14]. Federspiel [11] consolidated unsolicited complaints from 23,500 occupants in 690 commercial buildings and related them to temperatures from a complaint log, concluding that on average, females complained of being cold at warmer air temperatures (19.1°C) compared to their male counterparts (18.6°C). Similarly, in a study with 3,094 respondents in Finland, females reported preference for warmer air temperatures than males [3]. Further analysis of data from both climate chamber studies and field studies concluded that females express more dissatisfaction than males in the same thermal environments (meta-analysis of Odds Ratio: 1.74, 95% confidence interval: 1.61–1.89) [12].

Metabolic and clothing insulation are the two common explanations for sex difference in response to the indoor thermal environment [14–17]. Kingma and Van Marken Lichtenbelt [14] measured a group average metabolic rate for young adult females that was significantly lower than the value assumed by the HVAC industry [18] which is based on an "average man." This discrepancy in metabolic rate per unit body surface area between sexes leads to the assumption of a warmer neutral temperature for women because less dry heat loss is required to maintain thermal equilibrium. However, others have reported no sex differences in metabolic rate. A recent study of oxygen consumption rate, carbon dioxide output, respiratory quotient, and DuBois body surface area of 60 college students performing a range of typical office activities, including sitting, standing and walking, found no significant differences [17]. In terms of clothing, detailed clothing garment checklists in office buildings in diverse climate zones have reported females' average clothing insulation values to be about 0.1 clo (1.0 clo = 0.155 m^2 K/W) lower than that of males, which empirically equates to almost a full degree (K) of operative temperature difference [10,15].

In addition to potential sex differences in thermal comfort, age has also been investigated in recent years. Most studies simply compare thermal comfort between older adults (> 60 years) and young adults [19–22], however, they have not considered explicitly the potential combined effects age and gender, for example, the menopause transition

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representing a crucial demographic within a specific middle-age bracket of women, on thermal perception.

While it is evident that different people require consideration of their personal thermal requirements to ensure a comfortable working environment, there is a paucity of literature addressing the combined effects of age and sex on thermal perception. A previous thermal comfort field study performed in Sydney offices in 2009-10 [23] offered a large source of data suitable for analysis in the present paper.

2. Method

The original thermal comfort study [23,24] took place in Sydney (34°S, 151°E), Australia, with a humid subtropical climate (Köppen-Geiger climate class Cfa) [25], characterised by warm-to-hot summers and cool winters. The study building site was located in a university campus, 16 km north-west of Sydney's central business district. Variations in the site's outdoor climate are summarized in Fig.1 [26]. The warmest month is January, with an average air temperature of 22°C. Winters are mild, with the coldest month of July having an average air temperature of 13°C. Given this moderate seasonality, Sydney's mild climate is well suited to the mixed-mode ventilation design strategy.

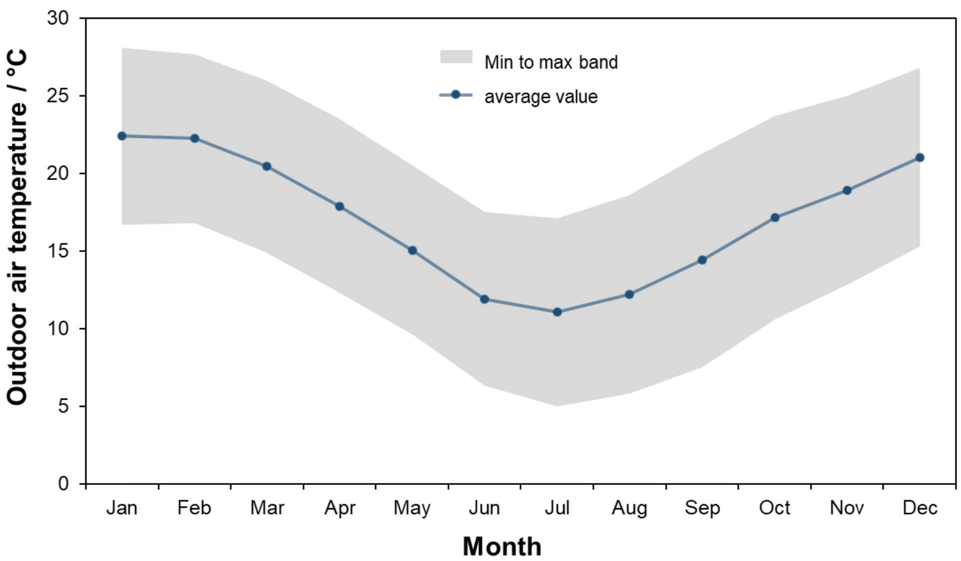

Fig.1 Climatology of the building site. Data was sourced from the nearest weather station located 1 km from the study site [26].

The data used in the present study came from a seven-storey mixed-mode (MM) office building [23]. The building has a usable floor area of 6,541 m^2 consisting mostly of private offices interspersed with some open plan sections. It operates as a change-over MM or 'hybrid' ventilation system that switches between natural ventilation and air-conditioned

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modes whenever outdoor and indoor conditions are amenable. Automated high and low external louvres embedded in the façade provide natural ventilation to each floor, with adjustable internal grilles to control airflow, supplemented by user-operable windows [23].

In the longitudinal thermal comfort field study, a total of 1,359 responses were collected from 60 subjects across 1 year, starting in March 2009 and finishing in April 2010, so as to include a full cycle of Sydney's seasons. Subjects answered on average 23 times while some respond more often than the others. The building accommodated approximately 190 occupants at the time of the study. The sex distribution for the building's population was approximately 45% female, 55% male. Table 1 summarises the structure of the questionnaires used for this research. Subjects were asked to specify their sex and age bracket. To minimize the disturbance to subjects, the questionnaire was designed to be completed within one minute. In the "*right-here-right-now*" questionnaire, subjects were asked about their thermal sensation, thermal acceptability, thermal preference, and air movement preference. Throughout the field study a standardised clothing garment checklist was used to estimate subjects' clothing insulation at the time of answering the questionnaire.

Table 1
Summary of the questionnaire structure, scales and coding.

Questionnaire item	Measuring scale
Sex	☐ Male ☐ Female
Age	☐ [20.1, 30] ☐ [30.1, 40] ☐ [40.1, 50] ☐ [50.1, 60] ☐ [60.1, 70]
Thermal sensation: *How do you feel right now? You can tick between two categories, if you wish.*	cold (-3) — cool (-2) — Slightly cool (-1) — neutral (0) — slightly warm (+1) — warm (+2) — hot (+3)
Thermal acceptability: *Is the thermal environment acceptable to you?*	☐ Acceptable ☐ Unacceptable
Thermal preference: *Right now I would prefer to be:*	☐ Warmer ☐ No change ☐ Cooler
Air movement preference: *Right now I would prefer:*	☐ More air movement ☐ No change ☐ Less air movement

When subjects were filling out the paper-based questionnaires, simultaneous instrumental measurements were made of their immediate thermal environment. Temperature-humidity loggers were installed throughout the building to record air temperature and relative humidity at 5-min intervals. A 40-mm ping pong ball painted matte black was attached to an external temperature sensor to record black globe temperature, and these observations, along with air temperature and air speed, were used to estimate mean radiant temperature. Loggers were placed at a height of 0.6 m within 1 m of the occupants' workstation to characterise the immediate thermal environment experienced by the occupant. While subjects were completing questionnaires, air velocity was also measured at the same height and distance from the subject using a handheld hot-wire anemometer. Indoor operative temperatures were calculated from the workstation dataloggers to reveal the range of temperatures occupants experienced within the building. Table 2 lists the specifications for the sensors used for thermal environment measurement. More detailed technical information on this survey have been reported previously [23,24].

Table 2

Specifications of indoor thermal environment sensors.

Parameter	Instrument	Range	Accuracy	Resolution
Air temperature	HOBO U12-013	- 20 °C ~ 70 °C	± 0.35 °C	0.03 °C
Relative humidity	HOBO U12-013	5% ~ 95%	± 2.5%	0.03%
Black globe temperature	HOBO TMCI-HD temperature probe attached to a 40 mm black ball	- 40 °C ~ 50 °C	± 0.25 °C	0.03 °C
Air speed	TSI VelociCalc	0 ~ 30 m/s	± 0.015 m/s or 3% of reading	0.01 m/s

The individual survey responses recorded throughout the monitoring period were matched *post-hoc* with real-time indoor thermal environment measurement for subsequent analyses. In terms of age, all subjects in this study responded in the age brackets which were presented in the survey in 10-year ranges, e.g. 20.1-30 y, 30.1-40 y, etc (see Table 1).

Statistical analysis was performed using SPSS 25.0 at a significance level of $p<0.05$. Each response was regarded as independent in the analysis because surveys were completed randomly – randomly across the 12-month study, randomly throughout the day, and randomly throughout the working week. To explore the effects of age and sex on thermal perception, one-way analysis of variance (ANOVA) was used to compare thermal sensations of male and female subjects from different age brackets. Female participants aged between 40.1-50 y showed a significant warmer sensation than females from other age ranges; no similar trend was observed in male subjects (see Fig. 2). Generally, women aged 40-60 will experience the natural menopause (last menstrual period). In Australia the average age of the menopause is 51y [27], with the years directly prior being known as perimenopause, and characterised by fluctuating sex hormones. As women account for 40% or more of the total workforce in many countries [28], the menopause transition represents a crucial demographic within a

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specific middle-age bracket which, to date, has been under-researched. Since women falling in the 40.1 to 50 y age bracket in the present study registered different thermal sensation votes compared to other groups (Fig. 2), the sample was divided into two categories for more detailed analyses – G1: women of perimenopausal age group (women aged 40.1 - 50 y), and G2: the reference group comprising the rest of the sample (see Table 3).

Table 3
Definition of demographic groups used in this study.

Groups	G1	G2
Group name	women of perimenopausal age group	reference group
Definition	female subjects aged 40.1-50	male subjects aged 20.1-70 + female subjects aged 20.1-70 but excluding 40.1-50

Student's t tests were used to determine if the mean clothing insulation and mean thermal sensation vote of the two groups (the women of perimenopausal age group and the reference group) were significantly different from each other. Fisher's Exact Tests were used to assess the significance of differences on categorical variables like thermal acceptability, thermal preference, and air movement preference. Linear regression was performed to model the relationship between thermal sensation vote and indoor operative temperature.

3. Results

A total of 1,359 valid sets of data were collected during normal occupied office hours (Monday to Friday, 9 am to 5 pm), with representative coverage of responses from both sexes (643 responses from 31 males and 716 responses from 29 females) as shown in Table 4. There are 204 responses from women of perimenopausal age.

Table 4
Number of questionnaire responses by age and sex.

Sex	**Age bracket**				
	[20.1, 30]	***[30.1, 40]***	***[40.1, 50]***	***[50.1, 60]***	***[60.1, 70]***
Female	95 (2)	122 (7)	204 (8)	221 (8)	74 (4)
Male	18 (2)	223 (9)	275 (13)	110 (5)	17 (2)

*numbers in parentheses represents the count of individual subjects

Ninety-two percent of questionnaires, 1,257 out of the total 1,359 responses, were completed when the indoor operative temperatures fell between 21°C and 25°C. These temperature limits were embedded in the building management system's control logic - the building switches into mechanical conditioning mode whenever the internal temperatures in any given zone went above 25°C or below 19°C. It should be noted that, for the purpose of easier comparison, indoor operative temperature data was binned at 1 degree Celsius resolution (Figs. 2 – 8).

The bar charts in Fig. 2 present the mean thermal sensation votes for each of the indoor operative temperature bins, for both males and females in each age bracket. Female subjects aged between 40.1-50 (i.e. of perimenopausal age) showed a warmer sensation than females from other age ranges. A one-way ANOVA was conducted to compare the effect of age on thermal sensations under various indoor operative temperature conditions. For female subjects experiencing 23°C at the time they completed the questionnaire, there was a significant effect of age on thermal sensation at the $p<0.05$ level for the five age groups ($F(4,123) = 11.539$, $p<0.001$). *Post hoc* comparisons using the Tukey test indicated that the mean thermal sensation for the 40.1-50 y female group (M = 1.19, SD = 1.28) was significantly warmer than the 30.1-40 y age group (M = -0.06, SD = 0.77), 50.1-60 y age group (M = -0.24, SD = 1.10) and 60.1-70 y age group (M = -0.24, SD = 0.66). Similar trends were observed for females under various operative temperature bins. The male subjects aged 40.1-50 y did not significantly differ from other age groups. It should be noted that we only showed the comparisons between 40.1-50 y age group and other age groups in Fig. 2. Taken together, these results suggest that age seems to have a prominent influence on female thermal sensation. Specifically, Fig. 2 suggests that females aged 40.1-50 y felt significantly warmer than others in the same environment; no similar trend was observed in male subjects.

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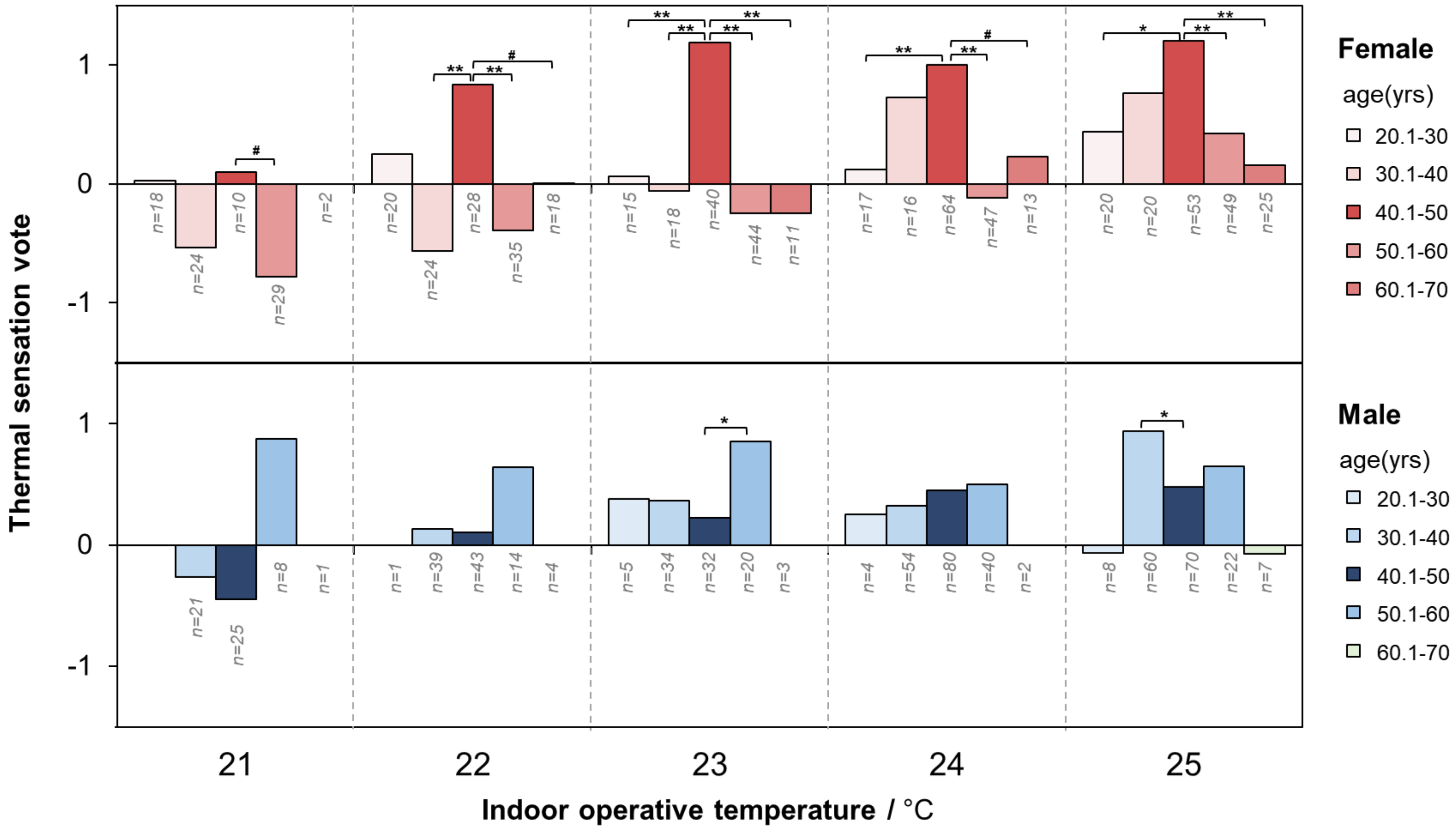

Fig.2. Comparison of thermal sensation between occupants aged 40.1-50 y and other age brackets in different indoor temperature bins. Women aged 40.1-50 felt significantly warmer than others; no similar trend observed in male occupants (ANOVA with Tukey HSD *post hoc*, # $p<0.1$, * $p<0.05$, ** $p<0.01$).

Fig.3 shows the comparison of clothing insulation between G1 and G2. Given that all participants answered the questionnaires while sitting in a standard office chair (estimated to be 0.09 clo), these were included in the final estimation of each subject's clo value. In the 21°C - 23°C operative temperature bins, G1 dressed more lightly than the reference group; however, the difference was not statistically significant.

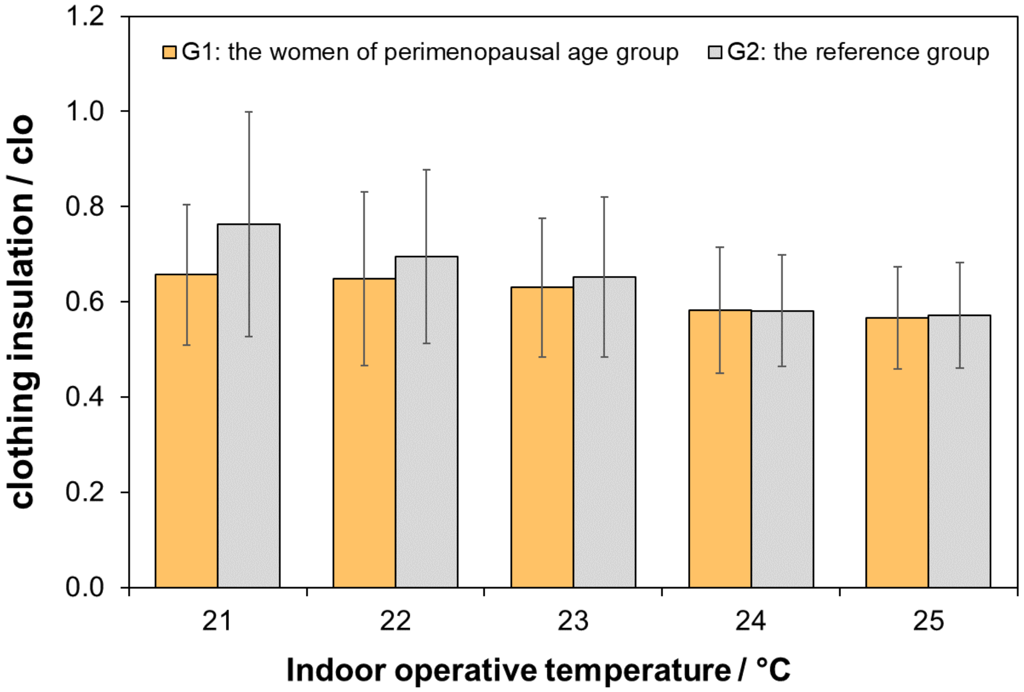

Fig.3. Comparison of clothing insulation between the women of perimenopausal age (G1) and the reference group (G2) in different operative temperature bins. No significant difference in clothing was observed between two groups (T tests).

Fig.4 below compares thermal sensation votes between the women of perimenopausal age (G1) and reference (G2) groups. T-tests were performed to find any significant differences between the two groups. G1 felt significantly warmer than G2 under different indoor operative temperature bins. In 22°C and 23°C operative temperature bins, the mean thermal sensations of G1 were about +1 (*slightly warm* thermal sensation) while the corresponding values of G2 were close to 0 (*neutral* thermal sensation), demonstrating that the thermal sensation difference between the two groups was up to one unit on the seven-point ASHRAE thermal sensation scale at 22°C and 23°C. Based on the online ASHRAE *Thermal Comfort Tool* (https://comfort.cbe.berkeley.edu/), one scale unit corresponds to approximately 3°C ambient temperature difference. That means the women of perimenopausal age at 22°C and 23°C felt the same as the rest of the sample at 25°C and 26°C. Fig.4 also shows that the variability (S.D.) of thermal sensation responses of the women at menopausal age, G1, under 21°C - 24°C was about 1.1-1.4, larger than the values of G2 (with

S.D. around 0.9).

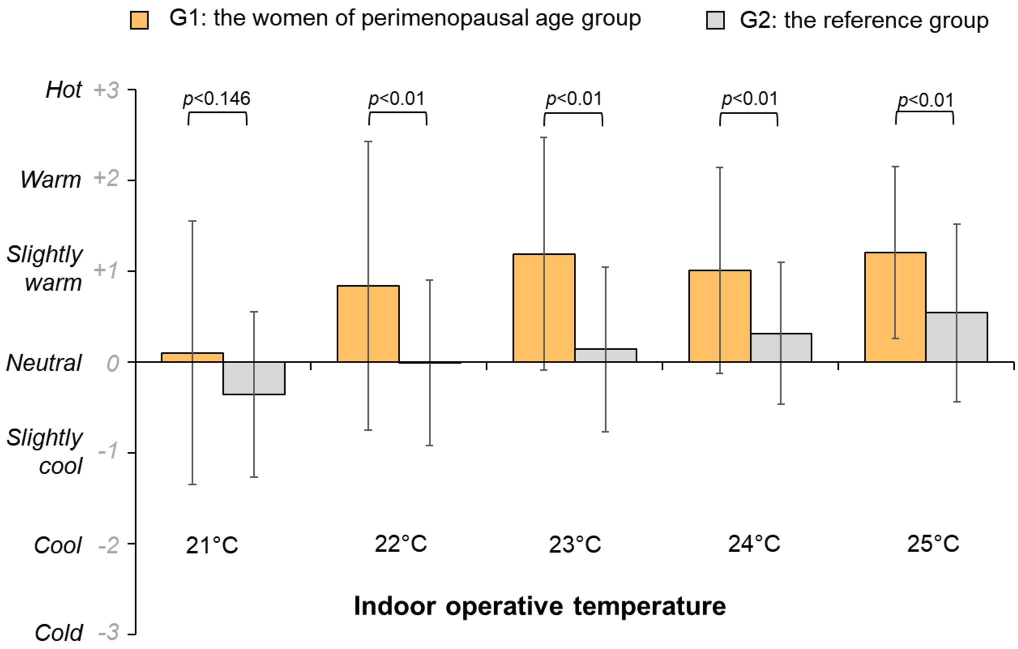

Fig.4. Comparison of thermal sensation between the women of perimenopausal age (G1) and the reference group (G2) in different operative temperature bins. Perimenopause-age women felt significantly warmer than the reference group (T tests).

Fig. 5 and Fig.6 illustrate thermal acceptability ratings and thermal preferences of the two groups of subjects. In the 22^{o}C operative temperature bin, 54% of G1 (15 out of 28 responses) reported conditions as thermally unacceptable, which was significantly higher than the corresponding percentage 16% (31 out of 138 responses) in the reference group G2. Moreover, 50% of the women of perimenopausal age G1 group wanted a cooler environment, even in 22^{o}C operative temperature. Again, this result was higher than the corresponding percentage (11%) wanting a cooler environment in the G2 reference group in the same temperature bin. In summary, the percentages of thermally unacceptable votes and preferences for cooler environments coming from the G1 subjects were twice as high as the G2 reference group across 22^{o}C – 25^{o}C range of operative temperatures.

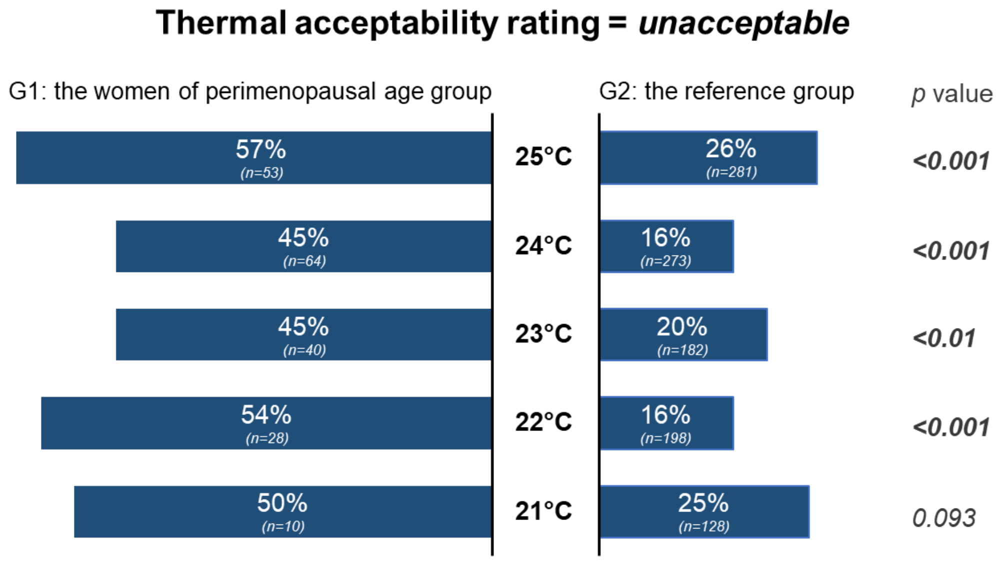

Fig.5. Comparison of thermal unacceptability between the women of perimenopausal age group (G1) and the reference group (G2) in different operative temperature bins. Significantly higher percentages of the G1 reported thermal unacceptability than their counterparts in the G2 group (Fisher's Exact Tests) in all temperature bins except 21°C.

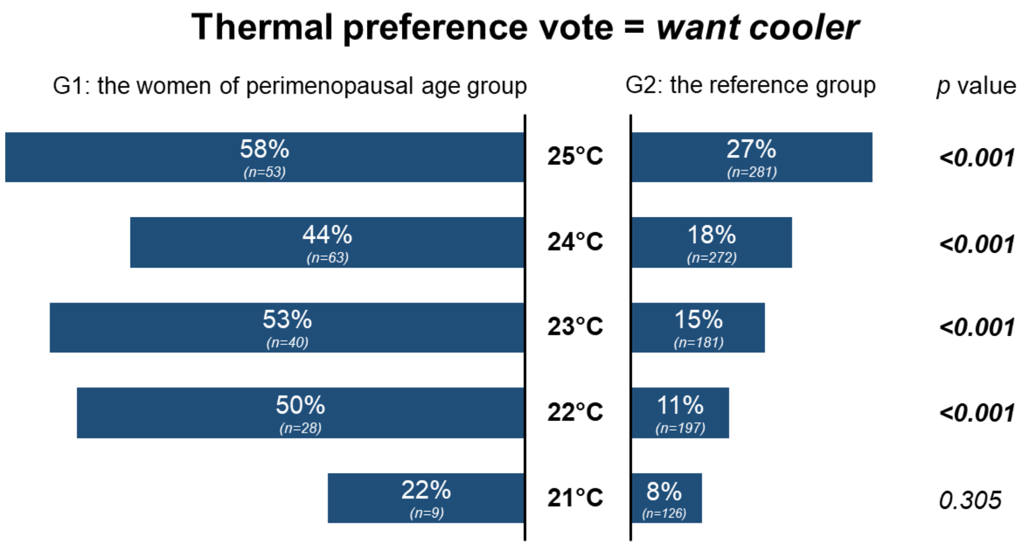

Fig.6. Comparison of thermal preferences between perimenopausal women (G1) and others (G2) in different indoor temperature bins. Significantly higher percentages of the G1 group preferred to be cooler than their counterparts in the G2 group (Fisher's Exact Tests) in all temperature bins except 21°C.

To further compare the thermal comfort perceptions of women of perimenopausal age with those of the reference group, we analysed combinations of thermal acceptability and preferences. *Warm unacceptability* was defined as perceiving the indoor environment to be *unacceptable* as well as preferring to be *cooler* while *cold unacceptability* was defined as perceiving the indoor environment to be *unacceptable* and preferring to be *warmer*. As shown

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in Fig. 7 when the indoor operative temperature decreased from 25°C to 21°C, the incidence of cold unacceptability increased from 11% to 84% in the G2 reference group. In contrast, the percentages of cold unacceptability were much lower for G1, ranging from 0% at 25°C to 60% under 21°C. The percentages of warm unacceptability for G2 decreased from 83% in the 25°C operative temperature bin to 9% in the 21°C operative temperature bin, however, G1 had consistently high percentages (> 70%) of warm unacceptability complaints across the 22°C - 25°C operative temperature range.

Comparisons of air movement preference between two groups are displayed the Fig. 8. Fifty five percent of G1 wanted more air movement compared to only 23% of G2 in the operative temperature bin of 25°C. Even at the relatively low operative temperature of 22°C, 46% of G1 wanted more air movement compared to 13% from G2. Significantly higher percentages of the G1 group preferred more air movement than their counterparts in the G2 group (Fisher's Exact Tests) in all of the temperature bins except 21°C (Fig. 8).

Neutral temperature is the indoor operative temperature at which people feel a *neutral* thermal sensation on a 7-point rating scale. As indicated in Fig. 4, the neutral temperature of G1 should be marginally cooler than 21°C while the neutral temperature of G2 is likely to sit between 21°C and 23°C. To estimate neutral temperature more accurately, thermal sensation votes were plotted against indoor operative temperatures for both groups as shown in Fig. 9 and simple regression models were fitted. Using this method, the neutral temperatures were estimated to be 18.8°C and 22.4°C for G1 and G2 respectively, a 3.6 K difference. The 95% confidence bands above and below the fitted regression models represent confidence interval estimates for the mean thermal sensation at a specific operative temperature. So, as seen in Fig. 9, the indoor operative temperature of 20.7 °C is the upper limit of neutral temperature for the women of perimenopausal age group, indicating that the neutral temperature of G1 is approximately 2 K cooler than the G2 reference group.

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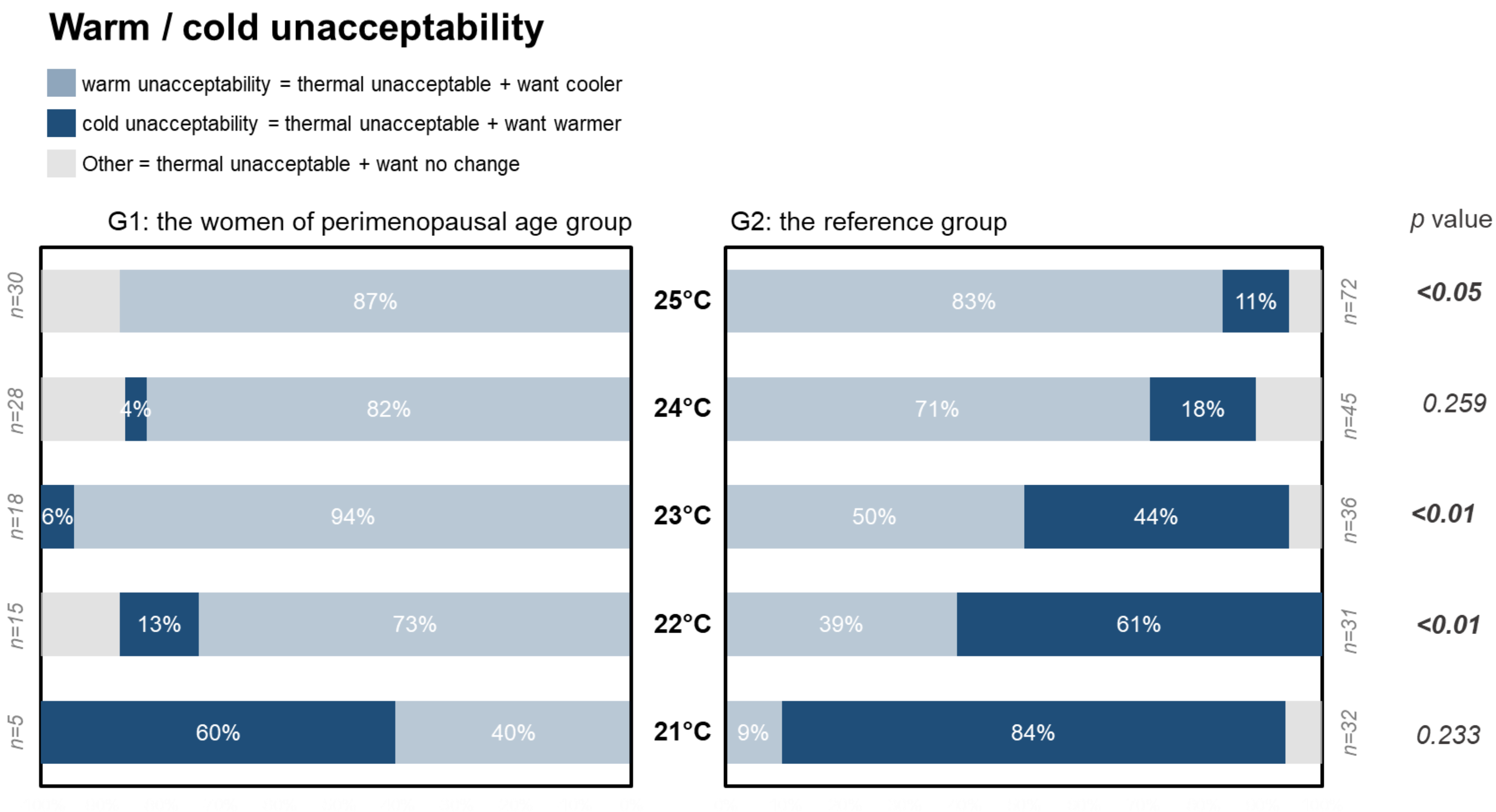

Fig.7 Comparison of warm and cold unacceptability complaints between women of perimenopausal age (G1) and others (G2) at different indoor temperatures. Higher percentages of perimenopausal women voted *warm unacceptability* compared to the other occupants (Fisher's Exact Tests).

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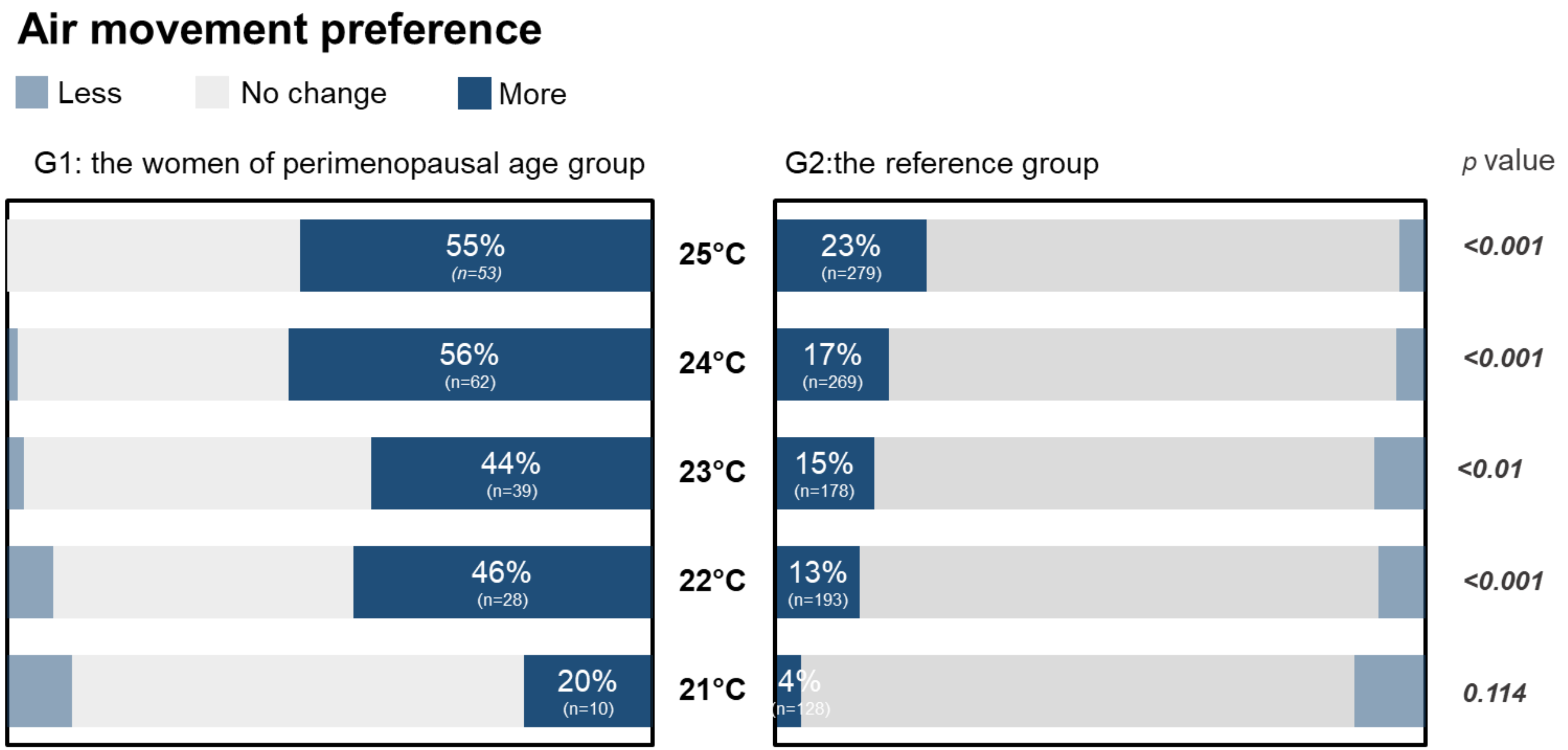

Fig.8. Comparison of air movement preferences of women of perimenopausal age (G1) and the reference group (G2) at different indoor temperatures. Higher percentages of perimenopausal women wanted more air movement compared to the other building occupants (Fisher's Exact Tests).

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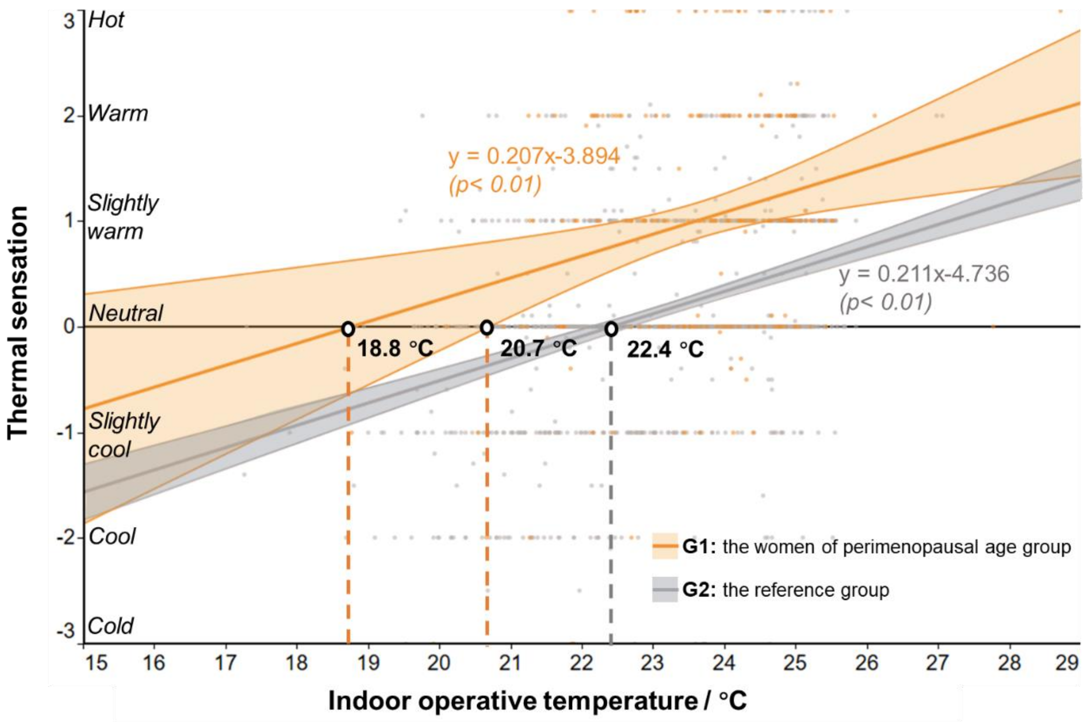

Fig.9. Relationship between indoor operative temperatures and observed thermal sensation votes. The linear regression lines are plotted including the 95% CIs (shaded bands). Women of perimenopausal age have a cooler neutral temperature than the reference group.

4. Discussion

The women of perimenopausal age (G1) sampled in this academic office building comfort survey felt warmer (Fig.4), more frequently expressed preference for cooler temperatures (Fig.6), and made more frequent requests for increased air movement (Fig.8) in their workplaces compared to members of the reference group (G2). Our findings from the perimenopausal age segment of the female office workforce contradict the consensus prevailing in the research literature on sex differences in thermal comfort [3,13,14], that women generally feel *cooler* than male in the same environment, and are more likely than males to request office building facility managers to *increase* thermostat setpoints. Not only did the perimenopausal age women in this study perceive their office environment to be warmer than their male co-workers, but their thermal sensations also differed from their younger and older female colleagues (Fig.2). These results support anecdotal reports from women undergoing the menopausal transition that their tolerance of warm environments is diminished. Globally, the mean age of the menopause is 48.8 y, while Australia's mean age of the menopause is 51y [27]. Perimenopausal women experience pronounced fluctuations in endogenous sex hormones, usually resulting in intense symptom onset in the years leading up to the menopause [29]. Whilst the cessation of menstrual activity has no direct effect on the workforce, the vast spectrum of symptoms associated with the menopause transition, particularly the hot flush, can impact

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work performance, sleep quality, and quality of life [30–33]. The hot flush represents a physiological phenomenon in which peripheral vasodilation and sweating occur alongside an increased sensation of heat [27,34]. Normally lasting only a few minutes, the hot flush can undoubtedly cause dramatic fluctuations in one's perceived thermal state. To date the physiological mechanism behind the hot flush has remained elusive, but environmental temperature has been implicated as a contributing factor, in that warmer temperatures may increase hot flush frequency [35,36].

While it is evident that symptomatic menopausal women require special consideration of their personal thermal requirements to ensure a comfortable working environment, research literature remains sparse. A theme emerging from recent research highlights the impact of hot flushes in the workplace, with thermal discomfort and increased frequency of hot flushes being attributed to hot and/or poorly ventilated workplaces [37–39]. For example, a survey of Australian menopausal women found that those who perceived themselves as having some degree of control over the air temperature within their immediate work environment reported a reduced incidence of menopausal symptoms [40]. Therefore, the air temperature of the work environment is perceived by menopausal (peri- or post-) women to be intrinsically linked to the frequency of their flushes.

There are thermal remediation strategies that can support the productivity of women during menopausal transition. In contemporary Activity-Based Workplaces where workers are free to choose their workstation, diversification of indoor climate zones can more readily accommodate the thermal preferences of this important demographic in offices than the current "one-size-fits-all" approach. More energy is required to constrain indoor temperature within a narrow band - roughly 7% more energy for each degree (K) of reduced temperature control deadband [5,41,42]. However, given the diversity of comfort preferences in the population of office building occupants due to myriad causes, including menopause, relaxing indoor temperature control deadbands may create more inclusive environments for all while simultaneously reducing HVAC energy demand. For example, women experiencing severe, prolonged, or frequent hot flushes could move themselves into and out of the "cool climate zones" of the building, as required, while others gravitate towards warmer climes in the perimeter HVAC zones against the building facades facing the sun. Indeed, abandoning the goal of indoor thermal homogeneity could dispense with the need for separate perimeter HVAC control zones altogether, bringing substantial savings on the capital costs of mechanical services.

Personal Comfort Systems (PCS) represent another strategy to manage thermal discomfort for perimenopausal women in office buildings. As seen in Fig.8, women of perimenopausal age preferred more air movement within their work environment than their co-workers. A device as simple as a ceiling or task fan can increase air flow for individuals.

ASHRAE Standard 55-2017 [18] quantifies how much warmer the comfort zone is stretched when air speeds increase: up to 3.5 K at 0.8 m/s without occupant control, and to 4K above 1.2 m/s when the occupants are granted control over the air movement. Moreover, cooling from frontal air jets provides a cooling power of up to 3 K at relatively low air movements [43]. Greater variability of thermal sensation observed in women of perimenopausal age group (Fig. 4 and Fig. 9) suggests that this demographic would derive even greater benefit from Personal Comfort Systems (PCS) than the general population at large. By comparing paired test conditions (with and without PCS), the satisfaction rate with PCS was observed to be higher than without personal control [43]. Provision of PCS under neutral temperatures has repeatedly been observed to increase satisfaction rates compared to no PCS [44,45].

Implementation of a flexible dress code within working environments could also benefit perimenopausal women to select fabrics that are ideal for heat dissipation and designs with multiple layers of insulation that can be removed and replaced, if and when required. Where the option to directly modify the workstation's environment is not possible, the introduction of cooling aids may be beneficial for women who are amidst the menopause transition. Cooling or working aids may include access to a well ventilated area, possibly outdoors or semi-outdoors, and access to cold products which could be applied to the skin or drunk, providing positive alliesthesia and helping in the management of lingering negative associations [46,47].

5. Limitation of this study

This study is exploratory, based on the re-analysis of pre-existing field study data that were collected for another research purpose. In this analysis, women aged 40.1 to 50 years were categorized as the perimenopausal age group. Whilst there is no certainty that every subject in this group was in fact experiencing hot flushes, the results of our analysis clearly differentiate the thermal perceptions of this group from the rest of the sample, and this difference can plausibly be attributed to the presence of symptoms in the perimenopause. Future research by members of this team will be focused specifically on symptomatic and asymptomatic perimenopausal or menopausal women using a rigorous, controlled climate chamber research design.

All subjects in this study identified their age by selecting from the decadal age brackets (not specific value). In future field studies, it would be better if occupants' specific age (i.e. years since birth) could be recorded or even their menopausal status could be defined, which will allow for a more detailed analysis on age and sex effect on thermal comfort.

6. Conclusion

A thermal comfort field study involving middle-aged women subjects in an office building in Sydney, Australia, potentially identified the effects of the menopause transition. Subjects were asked to fill out a "*right-here-right-now*" questionnaire while their immediate thermal environmental conditions were measured. The observed thermal perception, thermal preferences, and neutral temperatures for women of perimenopausal age group (age 40.1-50 y) were compared to those of all other subjects in the same building, who served as the reference group. The following conclusions can be drawn.

1) Women in the perimenopausal age bracket felt significantly **warmer** and reported reduced levels of thermal environmental acceptability compared to the rest of the sample of occupants in this survey.
2) Women falling in the perimenopausal age bracket expressed a preference for **cooler** thermal environments (**cooler** air temperature and **more** air movement) and their neutral temperature was approximately **2 K lower** than other occupants in this survey.

Acknowledgement

We express our appreciation to all the building occupants who responded to the questionnaires.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of Interest statement

No conflict of interest declared.

Author contribution statement

Jing Xiong was involved in formal analysis, methodology, visualization, writing the original draft, writing - review & editing. **Sarah Carter** was involved in writing the original draft, writing - review and editing. **Ollie Jay** was involved in writing - review & editing. Edward Arens was involved in conceptualization, writing - review & editing. **Hui Zhang** was involved in conceptualization, writing - review & editing. **Max Deuble** was involved in investigation, data curation, writing - review & editing. **Richard de Dear** was involved in conceptualization, investigation, methodology, writing the original draft, writing - review & editing.

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