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Initial study on the impact of thermal history on building occupants' thermal assessments in actual air-conditioned office buildings

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Abstract

This preliminary study examines the influence of longer thermal history on building occupants' thermal sensation, perceived air temperature and thermal acceptability during the initial period of occupancy and after an extended period of occupancy in actual air-conditioned office buildings. Each of the subjects' forty-eight-hour thermal history was assessed using measured air temperatures with a wireless chip, "iButton," placed close to their skins. Subjects did thermal assessments of their offices through a web-based survey link while they had their "iButton" on them. In addition, the subjects were required to fill the survey 4 times in their offices: during initial occupancy, before lunch break, after lunch break and before they left their offices for the day. Subjects' thermal assessments followed typical transient perceptions during initial occupancy of their offices. However, subjects' thermal assessments followed typical steady-state perceptions after extended period of occupancy because of diminished influence of thermal history. Maximum thermal acceptability occurred around neutral point of rating scales of thermal sensation and perceived air temperature throughout occupancy periods. Additionally, gender and body mass index influenced building occupants' thermal assessments. These results provide understanding on how thermal history influences occupants' thermal sensation, perceived air temperature, and thermal acceptability should be accounted for in the design and operation of air-conditioned buildings where occupants spend considerable amount of time.

1. Introduction

It is well known that unfavourable thermal environment can compromise building occupants' thermal comfort [1-4]. The discomfort can progressively lead to health problems and decrease in performance and productivity [4-8]. To improve building occupants' indoor environment experience, building control systems should be designed appropriately. Design of building control systems for optimum thermal performance is subject to understanding environmental and personal related factors which affect occupants' thermal assessments - thermal sensation, perceived air temperature, and thermal acceptability. This present study focuses on how building occupants' thermal history, an example of personal related factors, could influence building occupants' thermal assessments.

Over two decades ago, Jones and Ogawa [9] and de Dear et al. [10] demonstrated that human thermal history could influence building occupants' thermal assessments during initial occupancy of indoor environment. Several studies have also been conducted to confirm this understanding [11-17]. The concern is, most of these studies focused on transient thermal history, i.e. short thermal experience. Very little is known about longer thermal experience, such as a whole day, days, weekly, monthly, yearly thermal histories. However, there are emerging evidences bridging this knowledge gap. In experiments conducted in Seoul and Japan, Chun et al. [18] examined the influence of longer thermal history on subjects' thermal assessments. In their study, subjects wore data logger for 24-hr and periodically completed thermal diary survey prior to their thermal assessments in a controlled test chamber. In the controlled chamber, subjects wore uniforms and completed thermal survey at 10-min intervals for 1-hr. A key finding from their study is that subjects' longer thermal history influenced their thermal assessments in the controlled chamber.

Candido et al. [19] and Yu et al. [20] examined the effect of much longer thermal histories on building occupants' thermal preference and perception. One of the research questions in Candido et al. [19] study was "Does the frequency of prior exposure to air-conditioned (AC) bias building occupants' thermal expectations". To answer this question, they examined how building occupants' previous exposures to workplaces with and without air-conditioning systems affect their thermal preference inside naturally ventilated buildings. All subjects ($n=975$) that participated in this study were exposed to same operative air temperature in the natural ventilated building.

Reported findings in their paper was based on summer period when cooling was prevalent air-conditioning mode. A key finding from their study is that "Thermal preferences for 'cooler' were significantly higher for occupants who had been exposed to AC systems at their workplace compared with occupants without AC exposure during summer season". Cooler thermal expectation of subjects who had been exposed to AC systems caused them to rate their natural ventilated building to be warmer. Warmer thermal expectation of subjects who had not been exposed to AC systems caused them to rate their natural ventilated building to be cooler. Furthermore, they observed that 65.7% and 34.3% of occupants exposed to AC systems at their workplaces preferred AC systems and natural ventilation, respectively. They also observed that 34.5% and 65.5% of occupants without exposure to AC systems at their workplaces preferred AC systems and natural ventilation, respectively.

Yu et al. [20] study probed whether there are differences in thermal adaptation to cold indoor environments between people who are used to living in heating and non-heating air-conditioned buildings. They examined thermal perception and physiological responses of subjects with exposure thermal history in indoor space with or without heating facilities during winter season. The two groups of subjects were exposed to five different air temperatures (12°C, 14°C, 16°C, 18°C, and 20°C) in two different experimental controlled

chambers with same environmental conditions. Thermal expectations of young men with long-term experience in indoor space with and without heating facilities were warmer and cooler, respectively. Warmer thermal expectation caused greater complaints of cold discomfort and poorer physiological acclimatization during exposures to the low five air temperature in the chamber.

Chun et al. [18] did not study impact of longer thermal history on thermal assessments after occupants have spent considerable amount of time in the same air-conditioned indoor environment. Understanding of this knowledge gap has practical implication because occupants usually spend extended period of time indoors. Furthermore, they and Yu et al. [20] conducted their indoor thermal assessments study in a controlled air-conditioned chamber. This is to reduce confounders that could compromise relating thermal history to indoor thermal assessments. However, actual buildings are usually not well controlled. Thus, many factors may influence occupants' thermal assessments. This means the findings from controlled chamber experiments may not necessarily be applicable to actual buildings. For practical purpose, it is important to know if current understanding of the relationship between longer thermal history and thermal assessments is applicable to actual buildings. Candido et al. [19] study was done in actual buildings to bridge this knowledge gap. However, thermal assessments were done in a natural ventilated building and not air –conditioned buildings.

The objective of the current study is to improve our understanding of the impact of thermal history on thermal assessments in actual air-conditioned buildings. More specifically, this present study was conducted to have preliminary understanding on how forty-eight-hour thermal history could influence occupants' thermal sensation, perceived air temperature, and thermal acceptability during initial occupancy and after extended period of occupancy in actual air-conditioned office buildings. To the best knowledge of the author, prior to this study no other study has examined this objective in actual air-conditioned buildings.

Secondary objective of this study has been to examine influence of gender and body mass index on indoor thermal assessments. A better understanding of these objectives in actual buildings is relevant to development of healthy and energy efficient air-conditioned buildings.

2. Methods

This section provides information on recruitment of subjects and ethical approval, statistical analysis of measured data and subjects' responses, and study protocol.

2.1 Subjects recruitment and ethical approval

The institutional review board (IRB) at Pennsylvania State University, United States, approved the use of human subjects for this study (IRB number- 40630). Participants were healthy graduate research students and staff members with individual offices or workstations. These were requirements for participation in the study. Several emails were sent to graduate students and staffs from the population of Pennsylvania State University. Subjects were provided necessary information needed to make informed decision before deciding to participate in the study. A total of 28 participants from different offices volunteered to participate in the study. Out of the 28 participants, data for 18 subjects were analyzed. Subjects that did not use 'iButton' prior to their office assessments and/or did not complete surveys in their offices were excluded from data analysis. Table 1 shows personal characteristics of the 18 subjects that participated and completed the entire required tasks in this study.

2.2 Statistical analysis

Sampling distribution was assumed to be of "T-distribution for better estimation of confidence intervals. These methods were also used for gender and body mass index data analysis. Wilcoxon Signed-Ranks test was used to compare body temperatures and thermal

assessments between periods. Wilcoxon Sum-of-Ranks (Mann-Whitney) test was used to compare male and female, and over and normal weight subjects' data. This is because sample sizes of these two compared groups were not the same. ANOVA analysis was used to calculate statistical difference (p-value) for comparisons between subjects' thermal assessment ratings during their extended periods of occupancy - P2, P3, and P4. A single data value for extended periods of occupancy is the average of data values of P2, P3, and P4.

2.3 Study protocol

The study was conducted during spring season, when the prevailing mode of air-conditioning was heating because of human preference for warmer indoor environment. Subjects' thermal history was assessed using measured air temperatures with wireless chip, "iButton". "iButton" was tucked in a small perforated plastic pocket. The perforated plastic pocket placed under subjects' clothes extends down from their necks to top stomach level, like office name tag with the aid of string, to measure their body temperature. Measured temperature is regarded as body temperature before occupancy. Subjects received their data loggers, with their research study 'ID' written on it, on Friday. Subjects were advised to use their data logger from early Saturday morning immediately after waking up. The actual thermal history data logging started from 8am on Saturday. "iButton" was used to log subjects' body temperature, at every 15 minutes interval, for more than 48-hr before resuming work on Monday. Additionally, "iButton" was used to measure subjects' body temperature while they worked in their offices on Monday. This method provides indication of subjects' thermal exposures in their offices.

In addition to physical measurement data obtained using "iButton", subjects were asked to access web-based survey link. They were required to fill the same survey 4 times in their offices at the following specific times: during initial occupancy of their offices in the morning

(~8-10am) - P1, before they went for lunch break (~10am-12 pm) - P2, after they came back from lunch (~1pm-3pm) - P3, and before they left their offices for the day (~3pm-5pm) - P4. They were instructed to fill the survey only in their offices at the specified times. Reminder text messages were sent to all subjects at specified time for filling survey. This was done to ensure subjects fill the survey at required time. They were also encouraged to spend most of their times in their offices, except for the lunch break period. The survey took approximately 5-7 minutes to complete at each specified time. The purpose of the survey exercise is for subjects to provide thermal sensation, perceived air temperature, and acceptability of their offices' thermal environments. Subjects were asked to provide the following information that are central to the objective of this study: (i) gender, (ii) height, (iii) weight, (iv) specific time of filling the survey (v) survey 'ID', (vi) type of activities performed in the offices or at workstations, (vii) type of clothing, (viii) thermal sensation, (ix) thermal acceptability, (x) air quality acceptability, and (xi) perceived air temperature and humidity conditions.

Male and female subjects were used in this study because ideal office environment consists of both genders. Furthermore, evidences suggest that gender does influence human thermal assessments [21-24]. We requested for gender information to understand role of gender, within the influence posed by thermal history, on thermal assessments during initial occupancy and after extended period of occupancy. We requested for information on weight and height that was used to calculate body mass index. Evidences suggest that body mass index does influence human thermal assessments [23-24]. Information on specific time of filling the survey helped to establish when each survey response was made. Subjects were required to use the same "ID" on their "iButton" for the survey response. Survey 'ID' information was required in order to be able to link each subject survey responses to their measured body temperatures. Information on activity in the office is required because human

activity can influence thermal sensation, perceived air temperature, and acceptability [25, 26]. Subjects' reported that they performed sedentary activities in their offices.

Clothing level is also important determinant of building occupant's thermal perception and comfort in indoor environment [26, 27]. In this study, subjects wore typical office wear in their offices. The cloth type generally consists of a) for male subjects: cotton/wool fabric shirt with or without t-shirt, cotton/wool/jeans trouser, men's briefs, calf-length socks and shoes and b) for female subjects: cotton/wool dress or blouse with skirt or cotton/wool trouser, women's briefs, ankle-length socks and ladies shoes. Similarities in subjects' clothes suggest limited effects of clothes on their thermal perception and preferences.

Subjects assessed their thermal condition and indoor air quality acceptability in their offices using acceptability scale. There is a mid-point (coded as "0") in the scale to clearly distinguish between "clearly acceptable" (coded as "+1") and "clearly unacceptable" (coded as "-1") [28]. A 7-point scale associated with predictive mean vote (PMV) was used for thermal sensation assessments [29]. The 7 point thermal sensation scale ranges from 'Cold' (-3) to 'Hot' (3). Other points marked on the scale are 'Cool' (-2), 'Slightly cool' (-1), 'Neutral' (0), 'Slightly warm' (1) and 'Warm' (2). Perceived (inhale) air temperature and humidity were evaluated using visual analogue scale with labelled endpoints (left end-point = 0, right end-point = 100) [28]. In the case of temperature, "left end point" corresponds to "too cold" while "right end point" corresponds to "too warm". Perceived inhaled air temperature should not be confused with thermal (neutral) sensation. In this study, perceived inhaled air temperature and humidity are merely a measure of sensitivity of the nasal sensation to air temperature and humidity respectively, while body temperature can better be used to predict thermal sensation [30]. In the case of humidity, "left end point" corresponds to "too dry" while "right end point" corresponds to "too humid".

3. Results and discussion

This section provides information on (i) impacts of thermal history on thermal assessments, (ii) subjects' thermal sensation and perceived air temperature correlation with their thermal acceptability, (iii) effect of gender on thermal assessment, (iv) effect of body mass index on thermal assessment, and (v) uncertainties in the study.

3.1 Impacts of thermal history on thermal assessment in indoor environment.

Figures 1 shows subjects' average body temperature before occupancy, during initial occupancy, and after extended period of occupancy. Subjects' body temperature during initial occupancy (31.9°C, 95%CI: ± 0.73) was significantly higher ($p=0.00024$) than subjects' body temperature (28.5°C, 95%CI: ± 1.11) before occupancy. Subjects' body temperature after extended period of occupancy (32.7°C, 95%CI: ± 0.61) was also significantly higher ($p=0.0002$) than subjects' body temperature (28.5°C, 95%CI: ± 1.11) before occupancy. The significant increase is due to subjects' exposure to air-conditioned (heating mode) offices. Continuous exposure to the air-conditioned offices caused subjects' body temperature during initial occupancy to be significantly lesser ($p=0.00854$) than subjects' body temperature after extended period of occupancy.

When subjects were asked to assess their offices' thermal conditions, their relatively cooler thermal history, as suggested by their body temperature, influenced their thermal assessment during initial occupancy. The influence is due to subjects' ability to keep memory of their thermal history [14-15, 26]. However, the influence of thermal history on subjects' thermal assessment diminished after their extended period of occupancy. Subjects' perceived air temperature during initial occupancy (53.9, 95%CI: ± 11.1) was warmer ($p=0.17702$), than subjects' perceived air temperature (51.9, 95%CI: ± 5.78) after extended period of occupancy

(see Figure 2). Subjects' cooler thermal history caused them to lower their perceived air temperature expectation during initial occupancy. Subjects' perceived air temperature expectation increased after they have spent more time in their offices. Thermal history also influenced subjects' thermal sensation during initial occupancy. Despite subjects' body temperature during initial occupancy being highly significantly lower ($p=0.00854$) than after extended period of occupancy, subjects' thermal sensation during initial occupancy was significantly warmer ($p=0.03752$) than after extended period of occupancy. Subjects' thermal sensation at initial occupancy was $0.35(95\%CI: \pm 0.33)$, while their thermal sensation after extended period of occupancy was $-0.13(95\%CI: \pm 0.31)$ as shown in Figure 3.

The preferred warmer thermal sensation and perceived air temperature, during spring season, influenced subjects' thermal acceptability during initial occupancy to be higher ($p=0.1902$) than after extended period of occupancy. Subjects thermal acceptability during initial occupancy was $0.33(95\%CI: \pm 0.21)$, while their thermal acceptability was $0.24(95\%CI: \pm 0.15)$ after extended period of occupancy as shown in Figure 4. Subjects' thermal sensation and perceived air temperature during initial occupancy followed what would be expected for typical transient period assessments. Subjects' thermal sensation and perceived air temperature followed what would be expected for typical steady state period after extended period of occupancy.

This observation was tested using correlation analysis. The hypothesis is that due to thermal history influence, correlations during initial occupancy should be lower than after extended period of occupancy due to diminished thermal history influence. Weak correlation ($r=0.27$) was observed between subjects' body temperatures and their thermal sensations during initial occupancy, while moderate correlation ($r=0.47$) was observed after extended period of occupancy (see Figure 5). No correlation ($r=0.08$) was observed between subjects' perceived air temperatures and their thermal sensations during initial occupancy. However,

after subjects have spent more time in their offices, their perceived air temperatures was strongly correlated ($r=0.84$) with their thermal sensations (see Figure 6).

At steady state period- after extended period of occupancy, body temperature was found to be a better predictor of thermal sensation after extended period of occupancy, while body temperature is a relatively poorer predictor of perceived air temperature after extended period of occupancy (see Figure 7). This finding supports observation from Rintamäki et al. [30] that body temperature can better be used to predict thermal sensation. Correlation results were generally not strong because in actual air-conditioned buildings, other indoor environmental quality (IEQ) conditions (indoor air, acoustics, and light) which were not controlled in this study could have influenced subjects' thermal assessments [31-32]. The other IEQ conditions were not controlled in order to retain the realistic scenario of actual air-conditioned office buildings.

Table 2 shows details of subjects' body temperature, thermal sensation, perceived air temperature and humidity, and thermal acceptability during extended period of occupancy- P2, P3, and P4. Of particular concern is how long it takes the subjects to adapt to the office environment. Subjects' body temperature during initial occupancy of their offices in the morning (~8-10am) "P1" was significantly ($p<0.05$) lower than their body temperature before they went for lunch break (~10am-12 pm) - P2, after they came back from lunch (~1pm-3pm) - P3, and before they left their offices for the day (~3pm-5pm) - P4. However, there was no significant ($p>0.05$) difference between P2, P3, and P4 as evident from the ANOVA statistical analysis results shown in Table 2. Furthermore, the difference between subjects' thermal assessments during initial occupancy (P1) and during extended period of occupancy- (average of P2, P3, and P4) were less close than the difference between values at P2, P3, and P4 (extended period of occupancy). These observations apply to whether subjects were considered altogether or based on gender and body mass index. These findings suggest that,

with no 'drastic' change in factors that influence thermal condition and comfort, 2 hours after initial occupancy of an indoor environment may be enough for subjects to adapt to their occupied indoor environment. Could the stabilization of subjects' body temperature and adaptation of their thermal perception and preference to the office have been achieved before the 2 hours? It is difficult to tell as thermal assessments at P2 were done 2 hours after initial occupancy. Further investigation is needed for better understanding of these preliminary findings.

Anyway, findings from this study support earlier observation reported by Chun et al. [18] that thermal history does influence thermal assessments during initial occupancy. This preliminary study extended understanding that thermal history influence on thermal assessments will diminish after extended period of occupancy in air-conditioned buildings.

3.2 Correlation of subjects' thermal sensation and perceived air temperature with their thermal acceptability.

As shown in Figure 8, polynomial correlation was observed between subjects' thermal sensation and their thermal acceptability. The same applies to subjects' perceived air temperature (see Figure 9). Optimum thermal acceptability peaked close to neutral thermal sensation. Optimum thermal acceptability peaked exactly at neutral point of perceived air temperature scale. Correlations were higher during initial occupancy than after extended period of occupancy. Subjects' thermal sensation was moderately correlated with thermal acceptability both at initial ($r=0.55$) occupancy and after extended period of occupancy ($r=0.46$). Moderate correlation was observed between subjects' perceived air temperature and their thermal acceptability both during initial ($r=0.58$) occupancy and after extended period of occupancy ($r=0.46$).

Reductions in correlation after extended period of occupancy suggest the influence of other plausible confounders. Example of such confounders is perceived indoor air quality. Figure 10 shows correlations between thermal acceptability and indoor air acceptability. Correlation increases as subjects spend more time in their offices. Correlation ranges from weak correlation ($r=0.19$) when subjects just entered their offices in the morning to strong correlation ($r=0.71$) just before they left their offices at the end of working hours in the evening. This means that if building occupants are asked to judge their thermal acceptability after extended period of occupancy - steady state period, they may actually be reporting their indoor air acceptability.

3.3 Effect of gender on thermal assessments

Figure 11 shows effects of gender on subjects' body temperature, thermal sensation, perceived air temperature, and thermal acceptability. Exposure to air-conditioned (heating mode) offices significantly increased female and male subjects' body temperatures when they occupied their offices. Female subjects' body temperature (29.3°C , 95%CI: ± 2.2) before occupancy was significantly lesser ($p < 0.05$) than their body temperature (32.6°C , 95%CI: ± 1.2) during initial occupancy and their body temperature ($\sim 33^{\circ}\text{C}$, 95%CI: ± 1.34) after extended period of occupancy. No significant difference ($p > 0.05$) was observed between female subjects' body temperatures during initial occupancy and after extended period of occupancy. Male subjects' body temperature ($\sim 28^{\circ}\text{C}$, 95%CI: ± 1.39) before occupancy was significantly lesser than their body temperature (31.5°C , 95%CI: ± 0.96) during initial occupancy ($p = 0.0034$) and their temperature (32.5°C , 95%CI: ± 0.73) after extended period of occupancy ($p = 0.0034$). Significant difference ($p = 0.0164$) was observed between male subjects' body temperature during initial occupancy and after extended period of occupancy.

Female subjects' body temperature was observed to be higher than that of male subjects before occupancy, during initial occupancy, and after extended period of occupancy. Perhaps, this is due to physiological and biological rhythms associated with females [33, 34]. Female subjects' body temperature (29.3°C, 95%CI: ± 2.2) was higher ($p=0.4122$) than male subjects' body temperature ($\sim 28^\circ\text{C}$, 95%CI: ± 1.39) before occupancy. Female subjects' body temperature (32.6°C, 95%CI: ± 1.2) was also higher ($p=0.1236$) than male subjects' body temperature (31.5°C, 95%CI: ± 0.96) during initial period of occupancy. After extended period of occupancy, Female subjects' body temperature ($\sim 33^\circ\text{C}$, 95%CI: ± 1.34) was only slightly higher ($p=0.5892$) than male subjects' body temperature (32.5°C, 95%CI: ± 0.73) after extended period of occupancy.

Female subjects' perceived air temperature became warmer and their thermal acceptability increased with more time they spent in their offices. However, male subjects' perceived air temperature became cooler and their thermal acceptability decreased with more time they spent in their offices. This observation suggests subjects' preference for warmer office environment. Female subjects' perceived air temperature was cooler than that of male subjects at initial occupancy and after extended period of occupancy [35]. It is not very clear why female perceived air temperature was lesser than that of male subjects, especially during initial exposure. Further investigations regarding impact of physiological and psychological differences in male and female human subjects' perceived air temperature in actual air-conditioned buildings may provide better understanding.

Female subjects' perceived air temperature (42.4, 95%CI: ± 24.08) was cooler ($p=0.34212$) than that of male subjects (61.3, 95%CI: ± 11.3) during initial occupancy. Female perceived air temperature (46.3, 95%CI: ± 12.65) was still lesser ($p=0.20408$) than that of male subjects (55.4, 95%CI: ± 6.09) after extended period of occupancy. The same trend as perceived air temperature was observed for thermal air acceptability. Female subjects' thermal

acceptability (0.17, 95%CI: ± 0.42) was lesser ($p=0.20408$) than male subjects' thermal acceptability (0.44, 95%CI: ± 0.25) during initial occupancy. After extended period of occupancy, female subjects' thermal acceptability (0.19, 95%CI: ± 0.30) was still lesser ($p=0.5287$) than male subjects' thermal acceptability (0.28, 95%CI: ± 0.19). However, the difference was much closer at this stage. This observation suggests that female and male subjects' perceived air temperature and thermal acceptability are closer during steady state period than during transient period.

Comparing periods, female subjects perceived air temperature during initial occupancy (42.4, 95%CI: ± 24.08) was cooler ($p>0.05$) than after extended period of occupancy (46.3, 95%CI: ± 12.65). Female subjects' thermal acceptability (0.17, 95%CI: ± 0.42) during initial occupancy was almost the same ($p>0.05$) as their thermal acceptability (0.18, 95%CI: ± 0.30) after extended period of occupancy. Male subjects' perceived air temperature (61.3, 95%CI: ± 11.3) during initial occupancy was warmer ($p=0.06876$) than that after extended period of occupancy (55.4, 95%CI: ± 6.09). Male subjects' thermal acceptability (0.44, 95%CI: ± 0.25) during initial occupancy was more ($p=0.54186$) than their thermal acceptability (0.28, 95%CI: ± 0.19) after extended period of occupancy.

The effect of "cooler" thermal history on thermal sensation during transient period- initial occupancy is more evident in female subjects than male subjects. Female subjects' thermal sensation was almost significantly warmer ($p=0.05$) than that of male subjects during initial occupancy period. After extended period of occupancy, expectation for thermal sensation assessment became warmer due to exposure to air-conditioned (heating mode) office. This caused both male and female subjects' thermal sensation ratings to decrease. However, female subjects' thermal sensation rating was cooler ($p=0.36282$) than that of male subjects, as female subjects seem to be more sensitive to thermal history- warmer in this case. Female subjects' thermal sensation was significantly warmer ($p<0.05$) during initial occupancy (0.80,

95%CI: ± 0.5) than after extended period of occupancy (-0.36 , 95%CI: ± 0.68). Male subjects' thermal sensation (0.11 , 95%CI: ± 0.41) during initial occupancy was also warmer ($p=0.54186$) than that after extended period of occupancy (0.02 , 95%CI: ± 0.34).

3.4 Effect of body mass index on thermal assessments

Figure 12 shows effects of body mass index on subjects' body temperature, thermal sensation, perceived air temperature, and thermal acceptability. Exposure to air-conditioned (heating mode) offices increased overweight and normal subjects' body temperatures during occupancy. Overweight subjects' body temperature (29.4°C , 95%CI: ± 3.0) before occupancy was lesser ($p>0.05$) than their body temperature (32.1°C , 95%CI: ± 1.48) during initial occupancy. However, overweight subjects' body temperature before occupancy was significantly lesser ($p<0.05$) than after extended period of occupancy (32.9°C , 95%CI: ± 1.39). Their body temperature after extended period of occupancy was significantly higher ($p<0.05$) than their body temperature during initial occupancy. Normal-weight subjects' body temperature (28.0°C , 95%CI: ± 1.15) before occupancy was significantly lesser ($p=0.0034$) than their temperature during initial occupancy (31.8°C , 95%CI: ± 0.98). Their body temperature before occupancy was also significantly lesser ($p=0.0034$) than after extended period of occupancy (32.6°C , 95%CI: ± 0.77). There was no significant difference ($p=0.07508$) between normal subjects' body temperature during initial occupancy and after extended period of occupancy.

Overweight subjects' body temperature (29.4°C , 95%CI: ± 3.0) was higher ($p=0.3953$) than normal-weight subjects' body temperature (28.0°C , 95%CI: ± 1.15) before occupancy. This is due to subjects' relatively higher activities, especially just before subjects entered their offices. However, when subjects' activities during office occupancy were sedentary in

nature, the differences between overweight and normal weight subjects were much closer than that of before occupancy. Overweight subjects' body temperature (32.1°C, 95%CI: ± 1.48) was slightly higher ($p=0.2113$) than normal-weight subjects' body temperature (31.8°C, 95%CI: ± 0.98) during initial occupancy period. The same applied to after extended period of occupancy, overweight subjects' body temperature (32.9°C, 95%CI: ± 1.39) was slightly higher ($p=0.45326$) than normal-weight subjects' body temperature (32.6°C, 95%CI: ± 0.77). Overweight subjects' perceived air temperature was warmer than that of normal subjects during initial ($p=0.6171$) and extended ($p=0.4533$) period of occupancy. Comparing periods, overweight subjects' perceived air temperature at initial occupancy (54.3, 95%CI: ± 24.82) was almost the same ($p>0.05$) with their perceived air temperature (54.9, 95%CI: ± 8.3) after extended period of occupancy. Normal-weight subjects' perceived air temperature during initial occupancy (54.1, 95%CI: ± 15.0) was warmer ($p=0.4237$) than after extended period of occupancy (50.4, 95%CI: ± 8.73).

Overweight subjects' thermal sensation (0.63, 95%CI: ± 0.70) was warmer ($p=0.2113$) than normal-weight subjects' thermal sensation (0.20, 95%CI: ± 0.40) during initial occupancy. After extended period of occupancy, overweight subjects' thermal sensation (0.04, 95%CI: ± 0.56) was still warmer ($p=0.5157$) than normal-weight subjects' thermal sensation (-0.21, 95%CI: ± 0.41). Overweight subjects' thermal sensation (0.63, 95%CI: ± 0.70) during initial occupancy was warmer ($P>0.05$) than their thermal sensation (0.04, 95%CI: ± 0.56) after extended period of occupancy. Normal weight subjects' thermal sensation (0.20, 95%CI: ± 0.40) at initial occupancy was warmer ($p>0.05$) than their thermal sensation (-0.21, 95%CI: ± 0.41) after extended period of occupancy.

Normal weight subjects' accepted their offices' thermal conditions more than overweight subjects both during initial occupancy and after extended period of occupancy. Overweight subjects' thermal acceptability (0.04, 95%CI: ± 0.41) was lesser ($p=0.0703$) than normal-

weight subjects' thermal acceptability (0.48, 95%CI: ± 0.23) during initial occupancy. After extended period of occupancy, overweight subjects' thermal acceptability (0.17, 95%CI: ± 0.24) was lesser ($p=0.58232$) than normal-weight subjects' thermal acceptability (0.28, 95%CI: ± 0.21).

Overweight subjects' thermal acceptability (0.04, 95%CI: ± 0.41) during initial occupancy was lesser ($p>0.05$) than their thermal acceptability (0.17, 95%CI: ± 0.24) after extended period of occupancy. Normal-weight subjects' thermal acceptability (0.48, 95%CI: ± 0.23) during initial occupancy was significantly higher ($p=0.0232$) than their thermal acceptability (0.28, 95%CI: ± 0.21) after extended period of occupancy. Perhaps, overweight subjects felt some form of physiological discomfort before occupancy due to their higher body fats. This apparently caused overweight subjects' thermal acceptability to be lesser than that of normal weight subjects during initial occupancy. However, after extended period of occupancy when subjects have settled down in their offices with sedentary activity, the discomfort both group of subjects experienced reduced. This apparently made both group of subjects' acceptability to be closer. This presumption should be further investigated.

3.5 Uncertainties in the study.

Subjects' thermal assessments in a well-controlled chamber will reduce confounders posed by actual buildings-uncontrolled environment. In Chun et al. [18] study, subjects wore uniform while assessing thermal condition in a controlled chamber. However, in our study, subjects filled thermal survey in real buildings. Their clothing was not controlled either. "Uncontrolled" nature of our study may affect accuracy of reported results. To have idea of thermal condition in each of the subjects' offices, body temperature of each of the subjects was measured. A more accurate, albeit expensive, is to measure thermal condition parameters in each of the subjects' offices in addition to measuring their body temperature. "iButton"

was tucked in a small perforated plastic pocket placed under cloth of the subjects, close to their skins but not directly on their skins. There may be variations between “body temperatures” measured close to the skins and directly on the skins of the subjects. Body temperature will also vary depending on which part of the body is measured. Furthermore, subjects’ strict adherence to placing “iButton” close to their body at all time, except when in contact with water, e.g. bathing or swimming, cannot be ascertained.

Subjects were required to fill survey at specified time. We cannot ascertain subjects’ strict adherence to filling survey at specified times. To reduce the effect of this potential source of error, 2 hour time band was given for each period. In addition to this, reminder text messages were sent to subjects twice during the period they were required to fill survey. Subjects were advised to spend most of their times in their offices. Subjects’ strict adherence to the instruction cannot be ascertained. However, body temperature measurements suggest subjects spent most of their time in their offices. Although subjects’ clothing levels are almost similar, the variations would have influenced presented data. Despite all these identified potential sources of errors, this study shows that longer thermal history does influence building occupants’ thermal sensation, perceived air temperature, and thermal acceptance during initial occupancy of indoor environment [18].

4. Closing thoughts

Building occupant’s thermal comfort can be affected by environmental and personal related factors. This is largely due to the influence of these factors on body temperature. It is very reasonable to believe that air-conditioning, heating in this case, will govern the indoor environmental related factors. Metabolic rates and clothing levels are major personal related factors that can affects human body temperature. Subjects’ activities, body mass index, and

gender (e.g. menstrual cycle phase and female reproductive hormones) can influence metabolic rates [34]. Subjects activities during occupancy was generally sedentary- activities generally expected (and reported by the subjects) in the kind of office environment used for this study. Effect of body mass index and gender were examined in this present study. Irrespective of the subjects' BMI and gender, subjects' body temperature increase from before occupancy to occupancy period (initial and extended), and from during initial occupancy to extended period of occupancy. Thus, it is reasonable to attribute this observation to environmental factors governed by air-conditioned (heating mode) offices in this study.

According to the literature, influences of above mentioned environmental and personal related factors on body temperature determine human thermal perception and preferences. If that is the case, without the influence of human psychology-thermal history in this case, increase in body temperature should result into increase in thermal sensation [36]. However, as evident in this study, increase in body temperature does not necessarily mean higher thermal sensation. Despite subjects' body temperature during initial occupancy being highly significantly lower than after extended period of occupancy, thermal sensation during initial occupancy was significantly warmer than after extended period of occupancy. Subjects' psychological condition (thermal history in this case) can reasonably be used to explain the observation. This understanding is based on knowledge gained from the literature (e.g. Chun et al. [18]) on thermal history. The effect of thermal history on subjects' thermal perception affected their thermal preferences.

Subjects' perceived air temperature, perceived thermal comfort, and thermal acceptability followed typical transient period perceptions during initial occupancy of their offices. This is because their benchmark for thermal assessment during initial occupancy was largely due to their thermal history and not thermal condition of the environment they were assessing.

However, subjects' perceived thermal assessments followed typical steady-state perceptions after extended period of occupancy because of diminished influence of thermal history. At this stage, benchmark for their thermal assessment was more of their current than previous environments. Optimum thermal acceptance for perceived air temperature, humidity, and perceived thermal sensation occurred around mid-point of rating scales.

Subjects' gender and body mass index also influenced subjects' sensitivity to thermal history. Female subjects' rated their thermal sensation to be warmer than that of male subjects during initial occupancy periods. However, after extended period of occupancy, expectation for thermal sensation assessment became warmer due to exposure to heated office environment. This caused female subjects' thermal sensation to be significantly cooler than that of male subjects, as female subjects were more sensitive to the changes in thermal exposure. Female subjects' thermal acceptability was lesser than male subjects' thermal acceptability during initial occupancy and after extended period of occupancy. Overweight subjects' thermal sensation was warmer than normal-weight subjects' thermal sensation during initial occupancy. After extended period of occupancy, overweight subjects' thermal sensation was still warmer than that of normal-weight subjects' thermal sensation. Overweight subjects' thermal acceptability was lesser than normal weight subjects' thermal acceptability during initial occupancy and after extended period of occupancy.

Considering limitation of this study-small sample size, further research efforts with larger sample sizes are needed to confirm findings from this study and identified knowledge gaps that warrant further investigation. Additional research effort with regards to summer period-when outdoor environment is very hot, and winter period-when outdoor environment is very cold, is needed. Nevertheless, this preliminary study provides initial understanding on how building occupants' longer thermal history could influence their thermal assessment during initial occupancy and after extended period of occupancy. It also provides initial knowledge

on how building occupants' gender and body mass index, within the thermal history confounder, could influence their thermal assessments.

In conclusion, findings from this study should be considered as a preliminary understanding that is useful for developing hypothesis for studies addressing the impact of thermal history on building occupants' thermal assessments in actual air-conditioned office buildings. This preliminary understanding is important because, prior to this paper, no other study has examined the impact of longer thermal history on subjects' thermal perception and preferences in actual air-conditioned buildings.

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TABLE CAPTIONS

Table 1: Personal characteristics of the subjects that participated and completed the entire required tasks in this study

Table 2: Subjects' body temperature, thermal sensation, perceived air temperature and humidity, and thermal acceptability before and during occupancy

Table 1: Personal characteristics of the subjects that participated and completed the entire required tasks in this study

Sample size*		18
Age (years)- (range/ mean $\pm$ 95%CI)		23 to 35/ 29.9 $\pm$ 1.8
Height (m)- (range/ mean $\pm$ 95%CI)		1.58 to 1.98/ 1.69 $\pm$ 0.04
Weight (kg)- (range/ mean $\pm$ 95%CI)		44.5 to 90.7/ 66.3 $\pm$ 5.8
Occupation		Graduate research students and staff
Gender	Number of Male	11
	Number of Female	7
BMI index (kg/m ²)	Number of under-weight subjects (from 16 to 18.5)	1**
	Number of normal-weight subjects (from 18.5 to 25)	6
	Number of overweight subjects (from 25 to 30)	11
Activity type		Sedentary

*Actual number of participants in this study is 28. We excluded subjects with incomplete data

**Not included in data analysis for effect of BMI on thermal assessment

Table 2: Subjects' body temperature, thermal sensation, perceived air temperature and humidity, and thermal acceptability before and during occupancy

Assessment	Group	Before occupancy	Initial occupancy	Extended period of occupancy			ANOVA (for P2 to P4)
		Before	P1	P2	P3	P4	(p-value)
Body temperature (°C) - Mean ($\pm 95\%CI$)	All subjects	28.5 (± 1.1)	31.9 (± 0.73)	32.5 (± 0.85)	33.0 (± 0.56)	32.6 (± 0.70)	0.59
	Male	28.0 (± 1.39) $\downarrow p=0.4122$	31.5 (± 0.96) $\downarrow p=0.1235$	32.1 (± 1.01) $\downarrow p=0.4122$	32.8 (± 0.81) $\downarrow p=0.4715$	32.7 (± 0.88) $\downarrow p=0.9282$	0.46
	Female	29.3 (± 2.20) $\downarrow$	32.6 (± 1.17) $\downarrow$	33.1 (± 1.82) $\downarrow$	33.2 (± 0.92) $\downarrow$	32.5 (± 1.51) $\downarrow$	0.68
	Normal weight	28.0 (± 1.20) $\downarrow p=0.3953$	31.7 (± 0.97) $\downarrow p=0.2113$	32.2 (± 1.02) $\downarrow p=0.4533$	32.8 (± 0.86) $\downarrow p=0.8415$	32.5 (± 0.87) $\downarrow p=0.6527$	0.61
	Overweight	29.4 (± 3.02) $\downarrow$	32.1 (± 1.48) $\downarrow$	33.0 (± 2.19) $\downarrow$	33.1 (± 0.66) $\downarrow$	32.7 (± 1.78) $\downarrow$	0.89
Thermal sensation - Mean ($\pm 95\%CI$)	All subject	NA	0.35 (± 0.32)	-0.01 (± 0.48)	-0.09 (± 0.33)	-0.13 (± 0.60)	0.9
	Male	NA	0.11 (± 0.41) $\downarrow p=0.05$	0.09 (± 0.37) $\downarrow p=0.81034$	0.13 (± 0.43) $\downarrow p=0.1310$	-0.06 (± 0.44) $\downarrow p=0.53526$	0.77
	Female	NA	0.8 (± 0.50) $\downarrow$	-0.16 (± 1.30) $\downarrow$	-0.4 (± 0.53) $\downarrow$	-0.3 (± 0.46) $\downarrow$	0.89
	Normal weight	NA	0.12 (± 0.39) $\downarrow p=0.2113$	-0.02 (± 0.77) $\downarrow p=0.96012$	-0.14 (± 0.40) $\downarrow p=0.3576$	-0.18 (± 0.32) $\downarrow p=0.5418$	0.91
	Overweight	NA	0.63 (± 0.70) $\downarrow$	0.03 (± 0.61) $\downarrow$	0.12 (± 0.74) $\downarrow$	0.08 (± 0.85) $\downarrow$	0.98
Perceived air temperature - Mean ($\pm 95\%CI$)	All subject	NA	53.9 (± 11.1)	53.6 (± 9.0)	52.3 (± 4.4)	49.7 (± 8.0)	0.73
	Male	NA	61.3 (± 11.3) $\downarrow p=0.3421$	59.7 (± 9.2) $\downarrow p=0.1471$	55.7 (± 5.2) $\downarrow p=0.0414$	50.6 (± 7.6) $\downarrow p=0.8572$	0.18
	Female	NA	42.4 (± 24.1) $\downarrow$	43.9 (± 19.1) $\downarrow$	46.9 (± 7.1) $\downarrow$	48.2 (± 20.8) $\downarrow$	0.9
	Normal weight	NA	54.1 $\downarrow p=0.6170$	53.2 $\downarrow p=0.9601$	52.6 $\downarrow p=0.9601$	45.4 $\downarrow p=0.118$	0.46

			(±15.0)	(±14.2)	(±5.5)	(±9.4)	
	Overweight	NA	54.3 (±24.8)	55.3 (±9.8)	52.0 (±10.9)	57.5 (±18.5)	0.76
Perceived air humidity - mean (±95%CI)	All subject	NA	42.7 (±8.7)	50.8 (±8.5)	47.7 (±9.3)	43.0 (±7.8)	0.4
	Male	NA	46.1 (±11.0) $\updownarrow p=0.5287$	55.6 (±5.7) $\updownarrow p=0.2983$	50.6 (±11.9) $\updownarrow p=0.4715$	45.7 (±9.5) $\updownarrow p=0.38978$	0.41
	Female	NA	37.3 (±17.6) $\updownarrow$	43.4 (±17.6) $\updownarrow$	43 (±19.0) $\updownarrow$	38.7 (±17.0) $\updownarrow$	0.85
	Normal weight	NA	44.0 (±8.5) $\updownarrow p=0.6171$	53.3 (±12.5) $\updownarrow p=0.5485$	49.5 (±11.3) $\updownarrow p=0.4237$	44.9 (±11.3) $\updownarrow p=0.9203$	0.52
	Overweight	NA	40.3 (±27.2) $\updownarrow$	47.0 (±14.5) $\updownarrow$	39.7 (±18.7) $\updownarrow$	41.7 (±22.7) $\updownarrow$	0.77
Thermal acceptability - Mean (±95%CI)	All subject	NA	0.33 (±0.21)	0.25 (±0.20)	0.22 (±0.15)	0.24 (±0.21)	0.96
	Male	NA	0.44 (±0.25) $\updownarrow p=0.2041$	0.28 (±0.24) $\updownarrow p=0.5892$	0.25 (±0.21) $\updownarrow p=0.6527$	0.27 (±0.26) $\updownarrow p=0.6527$	0.99
	Female	NA	0.17 (±0.42) $\updownarrow$	0.21 (±0.45) $\updownarrow$	0.16 (±0.26) $\updownarrow$	0.20 (±0.26) $\updownarrow$	0.98
	Normal weight	NA	0.44 (±0.23) $\updownarrow p=0.0703$	0.21 (±0.27) $\updownarrow p=0.0703$	0.24 (±0.19) $\updownarrow p=0.5157$	0.25 (±0.26) $\updownarrow p=0.4839$	0.96
	Overweight	NA	0.04 (±0.41) $\updownarrow$	0.20 (±0.30) $\updownarrow$	0.17 (±0.39) $\updownarrow$	0.13 (±0.24) $\updownarrow$	0.94

Note: Subjects' body temperature during initial occupancy of their offices in the morning (~8-10am) - P1, before they went for lunch break (~10am-12 pm) - P2, after they came back from lunch (~1pm-3pm) - P3, and before they left their offices for the day (~3pm-5pm) - P4.

FIGURE CAPTIONS

Figure 1. Subjects' average body temperature before occupancy, at initial occupancy, and after extended period of occupancy.

Figure 2. Subjects' perceived air temperature at initial occupancy and after extended period of occupancy.

Figure 3. Subjects' thermal sensation at initial occupancy and after extended period of occupancy (P value is a 2-tailed test)

Figure 4. Subjects' thermal acceptability at initial occupancy and after extended period of occupancy (P value is a 2-tailed test)

Figure 5. Correlation between subjects' thermal sensations and their body temperatures (a) at initial occupancy and (b) and after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 6. Correlation between subjects' thermal sensations and perceived air temperature (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 7. Correlation between subjects' perceived air temperature and body temperature (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 8. Correlation between subjects' thermal acceptability and thermal sensation (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 9. Correlation between subjects' thermal acceptability and perceived air temperature (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 10. Correlation between subjects' indoor air acceptability and thermal acceptability at P1, P2, P3, P4 (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 11. Effects of gender on subjects' (a) body temperature, (b) thermal sensation, (c) perceived air temperature, and (d) thermal acceptability (P value is a 2-tailed test)

Figure 12. Effects of body mass index on subjects' (a) body temperature, (b) thermal sensation, (c) perceived air temperature, and (d) thermal acceptability (P value is a 2-tailed test)

Figure 1. Subjects' average body temperature before occupancy, at initial occupancy, and after extended period of occupancy.

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Figure 4. Subjects' thermal acceptability at initial occupancy and after extended period of occupancy (P value is a 2-tailed test)

Figure 5. Correlation between subjects' thermal sensations and their body temperatures (a) at initial occupancy and (b) and after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 6. Correlation between subjects' thermal sensations and perceived air temperature (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 7. Correlation between subjects' perceived air temperature and body temperature (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 8. Correlation between subjects' thermal acceptability and thermal sensation (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

Figure 9. Correlation between subjects' thermal acceptability and perceived air temperature (a) at initial occupancy and (b) after extended period of occupancy (~ 0 : no correlation; $\leq \pm 0.1 < r < \pm 0.3$: weak correlation; $\geq \pm 0.3 < r < \pm 0.7$: moderate correlation; $\geq \pm 0.7 < r < \pm 1$: strong correlation; ± 1 : perfect correlation)

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Figure 11. Effects of gender on subjects' (a) body temperature, (b) thermal sensation, (c) perceived air temperature, and (d) thermal acceptability (P value is a 2-tailed test)

*Statistical difference was determined from *W*-value. Sample size of is not large enough for the distribution of the Wilcoxon *W* statistic to form a normal distribution. Therefore, it is not possible to calculate an accurate *p*-value from *z*-value

Figure 12. Effects of body mass index on subjects' (a) body temperature, (b) thermal sensation, (c) perceived air temperature, and (d) thermal acceptability (P value is a 2-tailed test)

*Statistical difference was determined from *W*-value. Sample size of is not large enough for the distribution of the Wilcoxon *W* statistic to form a normal distribution. Therefore, it is not possible to calculate an accurate *p*-value from *z*-value