Effects of Air Temperature Step Changes on Thermal Perception and Perceived Arousal in an Actual Environment under Hot-Humid Climate Conditions

Etika Vidyarini1) and Takafumi Maeda2)

1) Human Science International Course, Graduate School of Design, Kyushu University
4-9-1, Shiobaru, Minami-ku, Fukuoka, 815-8540, Japan.
E-mail:etika.vidyarini@gmail.com

2) Department of Human Science, Faculty of Design, Kyushu University
4-9-1, Shiobaru, Minami-ku, Fukuoka, 815-8540, Japan.
Tel: +81-92-553-4522
E-mail:maeda@design.kyushu-u.ac.jp

(received on 4th December, 2018, accepted on 5th April, 2019)

Abstract

The use of air-conditioning in offices located in hot-humid regions creates differences between indoor and outdoor air temperatures. Previous studies, which focused on artificial environments, found that air temperature step changes affect human thermal sensations and comfort. However, their effect on workers’ perceived arousal has been rarely discussed. The purpose of the present study is to evaluate the effects of air temperature step changes (both up-step and down-step) on thermal perception and perceived arousal.

Thirty-seven workers from two offices in Jakarta responded to a rating scale questionnaire about thermal perception that covered the following sub-topics: overall and local thermal sensations, thermal comfort, satisfaction, adjustment, and perceived arousal (i.e., alertness, freshness, and concentration) during working time. Air temperature and relative humidity around the subjects were recorded every 5 minutes by a data logger, from 10:00 to 17:00. During lunch time, the subjects walked to a nearby restaurant, exposing themselves to non-shaded outdoor temperature before returning to the office.

Office A workers experienced larger temperature changes than Office B workers. Indoor and outdoor temperatures of Office A were 22.9 °C and 32.1 °C, respectively, whereas, for Office B they were 24.2 °C and 29.5 °C, respectively. Perceived arousal decreased significantly in Office A after the workers experienced the change in air temperature. However, no significant difference in perceived arousal was registered in Office B, likely due to a larger gap between indoor and outdoor air temperatures in the case of Office A. The data of just before and after the temperature step changes were analyzed: no negative correlations were found between changes in the overall thermal sensation and alertness ($p < 0.05$), freshness ($p < 0.05$), or concentration ($p < 0.01$). Therefore, warm sensations after the air temperature changes, associated with a hysteresis effect, should have lowered the perceived arousal. Our findings suggest that thermal perception and perceived arousal are altered by relatively large changes in air temperature. These changes are determined not only by the range of air temperature steps, but also by the air temperature experienced previously. In addition, mild air temperature changes in the actual environment, combined with exercise, food intake, and direct radiation exposure, induced warmer thermal sensations than those simulated through laboratory experiments.

Keywords: air temperature step changes, actual environment, thermal perceptions, perceived arousal

1. Introduction

The use of heating, ventilating, and air-conditioning systems allows offices to maintain tolerable thermal conditions and be minimally influenced by outdoor temperatures. Although air-conditioning systems maintain thermally comfortable temperatures in offices,
sudden temperature step changes are inevitable for workers that move in and out of the office building during summer, or generally in countries characterized by hot and humid climates. A tropical country with a hot-humid climate experiences air temperatures between 27 °C–35 °C and an average relative humidity (RH) of 50% (Haymes and Wells, 1986). For instance, during a previous study in Indonesia, Karyono (2015) recorded an average outdoor temperature of 28 °C and an average RH of 78%. Indonesian local guidelines (Badan Standardisasi Nasional, 2011) suggest to maintain office temperatures between 24 °C–27 °C and at a RH of 60% ± 5. However, many workers in Jakarta (Indonesia) informally reported a cold sensation, since many offices are set at lower temperatures (22 °C–25.5 °C). Moreover, they frequently experienced temperature up-step and down-step changes when moving out of and into a relatively cold building.

Initial thermal sensations, after an air temperature step change, depend on skin thermoreceptors, which fire impulses based on the previously experienced temperature (De Dear et al., 1993; Lv and Liu, 2007). Human physiology is not adapted to abrupt air temperature changes and requires some time to adjust. Thus, variations in ambient temperature cause discomfort (Kuno 2007). Additionally, people seem to be more susceptible to up-step temperature changes (Dahlan and Gital, 2016; Zhou et al., 2017).

Temperature step changes can be either unidirectional (e.g., neutral-hot, hot-neutral) or bidirectional (e.g., neutral-hot-neutral). In the case of unidirectional changes, the thermal sensation drops following a sudden cooling, before gradually increasing and stabilizing (De Dear et al., 1993; Zhou et al., 2017). Bidirectional changes seem to have an additional effect. Gagge et al. (1967) studied transient temperatures, consisting of both down-step and up-step temperature changes (neutral-cold-neutral) in climatic chambers. He found that the subjects had different thermal sensations between the down-step and after the up-step temperature, although they had entered the chamber with the similar temperature that they previously experienced. A similar observation has been reported in Du et al. (2014).

The effects of air temperature step changes have been mostly studied in climatic chambers. In previous studies on actual environments, temperatures were recorded at a specific point (Dahlan and Gital, 2016; Zhou et al., 2017). However, the distribution of air temperature, velocity, RH, and radiation around subjects is usually unequal in actual environments. In this study, the varied distribution of air temperature and RH around each subject was considered.

Under steady-state conditions, air temperature affects thermal comfort and perceived performance, consequently affecting the actual working performance (Maula et al., 2016). Warm discomfort seems to lower mental performance more than cold discomfort (Cui et al., 2013; Maula et al., 2016). Task performance was reduced by 2% for each 1 °C increase in air temperature between 25 °C–32 °C, while no changes in task performance were observed for temperatures between 21 °C–25 °C (Seppänen et al., 2003). Cognitive impairment occurs when neural coupling does not increase enough during synaptic activity. This could be determined by alterations in the brain blood flow under thermal stress (Ogoh, 2017).

None of the above studies discussed the effects of air temperature step changes on the subjects’ cognitive state. Tsutsumi et al. (2007) studied the effects of RH step changes on subjects’ text-typing performance, from 30 °C at 70% RH (in chamber 1) to 25.2 °C at 30%, 40%, 50%, and 70% RHs (in chamber 2). Thermal sensations and task performances did not change significantly with RH. A lowered task performance could be related to changes in body temperature. In this regard, Wright et al. (2002) found that task performance is associated with physiological arousal, which increased at slightly higher core body temperature. In this study, outdoor humidity levels were not significantly different for the two offices (47.98 ± 3.94% RH and 47.02 ± 4.47 % RH for Office A and Office B, respectively). Thus, we focused on the effect of air temperature step changes. We hypothesized that air temperature step changes would alter both thermal perception and perceived arousal. Our purpose was to investigate, in particular, the effects of air temperature step changes (up-step and down-step) on the thermal perception and perceived arousal of office workers in Indonesia.

2. Methods

This study was conducted in December during different days in two offices (Office A and Office B) located in Jakarta (Indonesia). A total of 37 workers, consisting of 17 males and 20 females, were paid to participate as subjects in the experiment. A written informed consent was obtained from all subjects. Information about the subjects is indicated in Table 1.

| Table 1. Subject’s characteristics |
|-----------------------------------|
| Office A | Office B |
| N | 6 males, 9 females | 11 males, 11 females |
| Age (years) | 28.47 ± 4.96 | 27.59 ± 3.25 |
| Height (cm) | 163.53 ± 7.05 | 163.55 ± 8.54 |
| Weight (kg) | 60.27 ± 11.79 | 64.36 ± 14.07 |
| BMI (kg/m²) | 22.50 ± 4.96 | 23.92 ± 3.97 |
| BSA (m²) | 1.65 ± 0.18 | 1.70 ± 0.21 |

*BMI: body mass index; BSA: body surface area.
The BSA was calculated using the Mosteller formula.
All subjects had enough sleep and refrained from caffeinated drinks (e.g., coffee, green tea) 12 hours prior to and during the experiment. Subjects of both offices were additionally told to wear similar working clothes (i.e., a long sleeve shirt, trousers/skirt, socks, and shoes). As indicated in Table 1, 30.7% and 45.5% of the female subjects in Office A and Office B wore headscarfs, respectively. Based on these conditions, we assumed that the clo-values of Office A and Office B would be comparable, but that they would not be comparable between male and female subjects. Therefore, the effects of sex differences are not discussed in the current study. Subjects were requested to not change their clothes during the measurements, which took place from 10:00 to 17:00. At lunch time (LT = 12:00), the subjects left the office building and walked to a restaurant located approximately 500 m from the office, avoiding shaded areas and hence under direct solar radiation. The subjects spent 35 ± 9 min (Office A) and 32 ± 14 min (Office B) in the restaurant and had the same lunch menu, which contained few spices. Afterwards, at 13:00, they returned to the office building. Before entering the office, the subjects spent time in a transition area of the office building for 9.4 ± 1.2 min (Office A) and 9.1 ± 1.3 min (Office B). The outdoor exposure lasted for a total of 28 min for the workers of Office A, and 31 min for those of Office B. After returning to the office room, the subjects continued working until 17:00. During the indoor measurements, the subjects of both offices performed their ordinary daily work, which consisted in data reading and typing using a computer.

Thermal perception and perceived arousal were measured by using a rating scale questionnaire (Figure 1). Perceived arousal included alertness, freshness, and concentration. On the other hand, thermal perception included thermal sensation, comfort, satisfaction, and adjustment. Thermal sensations were recorded considering overall body sensations and local sensations in different body parts (i.e., head, trunk, arms, hands, legs, and feet), to evaluate their specific sensitiveness to air temperature step changes. A commonly used thermal scale is the ASHRAE, which includes “comfort” and “discomfort” sensations. However, in this study we used the Bedford’s scale (Parsons, 2014), which allows a comparison between subjects’ feelings and preferences. All variables were obtained from all subjects at four voting times: at the beginning of the experiment (VT1), right before the outdoor exposure (VT2), right after the outdoor exposure (VT3), and at the end of the experiment (VT4). VT3 reflected the subjects’ response after 9 min of outdoor exposure, because subjects remained in the transition area for that interval of time before entering the office room: VT3 was measured immediately after their entrance in the office room and not at a steady state, to collect their first impressions once arrived in the cold indoor ambient. We mainly focused on subjective differences in vote before the up-step (VT2) and after the down-step (VT3).

![Figure 1. Subjective responses to the questionnaires about: a) thermal perception and b) perceived arousal.](image-url)
Both offices and restaurants used air conditioning systems. Air temperature and RH were measured continuously every 5 min using a data logger (HOBO Onset series 877-275-9606). The data logger, that was hung on each subject’s neck, obtained thermal data from the surroundings of eight subjects in each office. Besides indoor and outdoor temperatures, the subjects were also exposed to air temperatures in the transition area and in the restaurant. The air temperature in the transition area was not significantly different for Office A (25.88 ± 0.30 °C) and Office B (26.17 ± 0.33 °C). Air temperature in the restaurant was also not significantly different between Office A (28.38 ± 0.62 °C) and Office B (28.00 ± 0.76 °C). Because no significant temperature differences were identified, the air temperatures in the transition area and in the restaurant were neglected. Instead, we compared the air temperatures at VT1, VT2, VT3, VT4, and during the outdoor exposure (LT). The air temperature values at LT were calculated as the average of those experienced during the walk toward the restaurant and that back to the office.

The thermal conditions were analyzed through a two-way ANOVA, which included subject groups and time, using the statistical software SPSS. The subjective responses were analyzed through Friedman’s test and Wilcoxon signed rank (post hoc) test. The correlations between variables were verified through Pearson correlation tests. For all statistical tests, a significance level of \( p < 0.05 \) was considered.

### 3. Results

We measured air temperature and RH at VT1, VT2, LT, VT3, and VT4 in Office A and Office B (Table 2). Generally, Office A experienced lower indoor temperatures and warmer outdoor temperatures compared to Office B. VT2 and LT (up-step temperature change) and LT and VT3 (down-step temperature change) were compared to each other. Air temperatures significantly increased \( (p < 0.01) \) during the up-step temperature change and significantly decreased during the down-step temperature for both offices. The air temperature differences during the up-step were 9.12 ± 0.77 °C and 5.37 ± 1.08 °C for Office A and Office B, respectively. Thus, subjects from Office A experienced a larger change in air temperature. Significant interactions \( (p < 0.05) \) were identified between time and air temperature, or RH.

Figure 2 shows the overall change in body thermal sensations as well as in local body parts at different VTs. The overall body thermal sensation in Office A was colder \( (p < 0.1) \) at VT2 and significantly warmer at VT3 compared to Office B. In Office A, the subjects experienced significantly warmer leg sensations at VT1 and significantly warmer head and trunk sensations at VT3, compared to Office B. Thermal sensations at VT2 and VT3 were compared for both offices. In Office A, the subjects experienced significantly warmer thermal sensations in their overall body and in all body parts. On the other hand, warm sensations increased only in hands and feet in Office B subjects.

Changes in thermal comfort, satisfaction, and adjustment are presented in Figure 3. Although in both offices the subjects experienced relatively comfortable conditions at all times, the comfort of Office A subjects significantly shifted from “comfortably cool” to “comfortably warm” following the temperature step changes, indicating a tendency toward the discomfort state in Office A. Subjects of Office A preferred a warmer temperature at VT2 and a colder temperature at VT3, while subjects in Office B remained neutral. Interestingly, subjects of Office B tended to demonstrate a higher thermal satisfaction \( (p < 0.1) \) than those of Office A at VT1, VT2, and VT4.

Here, we considered perceived arousal as a self-reported feeling of alertness or sleepiness (alertness), freshness or tiredness (freshness), and ease of concentration (concentration). Figure 4 shows the changes in alertness, freshness, and concentration at different voting times. Although there were no significant differences between Office A and Office B in these three variables, the subjects of Office A reported a slightly higher alertness at VT2 \( (p < 0.1) \). Alertness, freshness, and concentration in Office A after the temperature step changes significantly decreased, almost to the same level of Office B. On the other hand, the situation in Office B remained steady over time. Concentration in Office A at VT3 significantly decreased compared to VT2: the subjects of Office A found it difficult to

| Voting Time | Office A | Office B | Office A | Office B |
|-------------|----------|----------|----------|----------|
| VT1         | 23.10 ± 0.39 | 24.06 ± 0.60** | 43.15 ± 2.43 | 40.50 ± 2.29* |
| VT2         | 22.99 ± 0.43 | 24.21 ± 0.92** | 43.75 ± 3.47 | 39.03 ± 1.39** |
| LT          | 32.11 ± 0.58 | 29.57 ± 0.71 | 47.98 ± 3.94 | 47.02 ± 4.47 |
| VT3         | 23.41 ± 1.07 | 24.08 ± 0.85** | 41.68 ± 1.77 | 35.94 ± 3.20** |
| VT4         | 22.80 ± 0.53 | 24.36 ± 0.78** | 43.98 ± 3.37 | 38.90 ± 2.43** |

*significantly different from Office A \( (p < 0.05) \), **significantly different from Office A \( (p < 0.01) \).

Values are presented as Mean ± SD.
concentrate after having experienced the temperature step changes, even though they re-entered in the same cold office. Between VT3 and VT4, the air temperature remained at a steady state inside the office. Interestingly, a significant decrease in freshness was reported in Office B at VT4.

Figure 5 shows the relation between changes in thermal sensation and perceived arousal after outdoor exposure (the response at VT3 subtracted by the response at VT2). The outdoor exposure resulted in an increase in the thermal sensation value in Office A: from -0.6 (slightly cool) to 1.2 (slightly warm). The thermal sensation in Office B increased only slightly, from -0.09 into +0.14 (in the range of neutral sensations). The perceived arousal in Office A decreased as much as -0.73 ± 0.88, -0.87 ± 1.41, and -0.93 ± 1.49 in relation to perceived alertness, freshness, and concentration, respectively. At the same time, changes in perceived arousal in Office B decreased as much as -0.09 ± 0.97, -0.09 ± 1.02, and -0.14 ± 0.83 in relation to

Figure 2. Changes in thermal sensation in the overall body and in local body parts. The bars represent standard deviations. N=37, ♦ p < 0.1, *p < 0.05, **p < 0.01.
Figure 3. Changes in thermal comfort, satisfaction, and adjustment. The bars represent standard deviations. N=37, †p < 0.1, *p < 0.05, **p < 0.01.

Figure 4. Changes in perceived arousal, alertness, freshness, and concentration. The bars represent standard deviations. N=37, †p < 0.1, *p < 0.05, **p < 0.01.

Figure 5. Correlation between changes in perceived arousal and changes of overall thermal sensation. Changes value derived by subtracting VT3 and VT2 value. Changes in alertness, freshness, and concentration are negatively correlated to changes in the overall thermal sensation. N=37.
perceived alertness, freshness, and concentration, respectively. The data collected from all subjects were tested for correlation between changes in thermal sensation and perceived arousal. The Pearson correlation tests indicated negative correlations between changes in thermal sensation and perceived alertness \((p < 0.05)\), freshness \((p < 0.05)\), or concentration \((p < 0.01)\).

4. Discussion

Up-step and down-step air temperature changes in this study altered thermal perception and perceived arousal in Office A. Although the difference between air temperature step changes in Office A and Office B was not significant, subjective votes before and after the temperature step changes shifted in almost all measured variables, except for thermal satisfaction.

The air temperature difference experienced by the subjects of Office A was larger. Additionally, thermal sensation became warmer after the up-step and down-step air temperature change. Previous studies have evaluated thermal sensations following air temperature differences of 10–11 °C (Du et al., 2014; Xiong et al., 2016). In Du et al. (2014) the thermal sensation values decreased after up-step and down-step air temperature changes of 12–22–12 °C. Xiong et al. (2016) noticed instead that thermal sensations did not change much after air temperature step changes of 26–37–26 °C. Gagge et al. (1967) investigated larger air temperature step changes, such as, 28–48–28 °C and 17–43–17 °C. They found that thermal sensations decreased slightly following air temperature step changes of 28–48–28 °C, but increased after air temperature step changes of 17–43–17 °C. The increase in thermal sensation following the 17–43–17 °C air temperature step changes reported in the study of Gagge et al. (1967) agrees with the results of our study, although we registered a higher increase. None of the previous studies have presented an increase in thermal sensation equal to the ones we observed. The difference between these results can be explained by the additional exposure of subjects to hot conditions. In fact, previous experiments have been conducted in thermal chambers, in which the subjects remained seated and were not exposed to solar radiation. On the other hand, the subjects of our study walked under direct solar radiation and ingested food. Factors of daily energy expenditure include activity-induced thermogenesis, diet-induced thermogenesis, and basal metabolic rate (Westerterp, 2004). During our experiment, the metabolic heat production probably increased in the subjects due to physical activity and diet-induced thermogenesis. Direct solar radiation also increases body temperature (Parsons, 2014). Katavoutas (2015) found that subjects who walked under direct solar radiation showed higher skin wetness, which is associated with discomfort, compared to subjects that remained seated under a tree or walked under non-direct radiation. Thus, the mild temperature step changes in our study should have induced different thermal sensations compared to other laboratory studies due to the inclusion of physical activity, direct radiation exposure, and food intake.

In our study, the subjects of Office A experienced higher thermal stress, which induced a higher hysteresis effect in thermal sensations compared to Office B. Although no votes could be obtained during the exposure to high temperatures, due to the limited time spent by the subjects under those conditions, the thermal sensations during outdoor exposure should have been higher for subjects of Office A, due to the higher corresponding outdoor air temperature. Our results are different from those of Dahlan and Gital (2016). In fact, these authors studied warm-neutral-warm transient conditions in an actual office environment in a hot, humid country, but without direct exposure of the subjects to solar radiation and including only a short walk in the experiment. Hysteresis did not affect thermal sensations, perhaps due to a reduced heat stress. The short walking distance and the passage of the subjects in shaded areas during warm exposure probably avoided heat stress. Thus, the short walking distance and the indirect radiation explained the different results to our finding. This suggests that, in our study, the absence of hysteresis effect on the thermal sensations of subjects from Office B was a symptom of reduced heat stress.

Lagged thermal sensations were observed in the case of larger differences in air temperature for the overall body \((p < 0.01)\) and all body parts. Interestingly, in the case of a smaller differences in air temperature, lagged thermal sensations were reported for hands \((p < 0.05)\) and feet \((p < 0.05)\). These findings suggest that peripheral body parts are more susceptible to air temperature step changes. As a matter of fact, the hands, face, and neck are body parts that are extremely sensitive to sudden temperature changes, due to the abundance of thermoreceptors in the skin of these regions (De Dear et al., 1993).

Thermal satisfaction in Office A tended to be lower at VT1, VT2, and VT4 \((p < 0.1)\). Notably, between VT1 and VT2, and between VT3 and VT4, the temperature remained steady. Perhaps, the lower thermal satisfaction in Office A was induced by a steady state of cold discomfort. Perceived alertness tended to be higher at VT2 \((p < 0.01)\) in Office A, where the indoor temperature was equal to 22.3 °C. It is known that the optimum arousal level can be raised by thermal stimulation (Ramsey and Kwon, 1988). As low temperatures induce vasconstriction, the blood flow in the peripheral skin gets reduced, lowering the skin temperature. Nozawa and Tacano (2009) found that a decrease
in nasal skin temperature, due to displaced blood flow, was correlated to an increase in arousal. The relatively high perceived alertness in Office A resulted from the colder indoor temperature.

The heat stress during the outdoor exposure of subjects from Office A increased considerably because a difference of 9.12 °C in the up-step temperature change. A series of physiological adaptations occur under heat stress to cope with thermal stress, such as sweating, elevated heart rate and altered brain blood flow (Gagge et al., 1967; Ogoh, 2017). However, in our study we did not identify any significant difference in perceived arousal between the subjects of Office A and Office B. Subjects of both offices were exposed to similar average temperatures throughout the measurements. In the case of Office A, subjects experienced colder indoor and warmer outdoor temperatures than Office B subjects. The average temperatures were equal to 24.22 ± 0.50 °C and 24.71 ± 0.49 °C (p > 0.05) in Office A and Office B, respectively. Therefore, we were not surprised to observe no significant differences in the perceived arousal.

The thermal state in a first environment affects the response of a subject in a second environment (Stolwijk and Hardy, 1966; Dahlan and Gital, 2016). In our study, a sudden change in thermal conditions from 22.99 ± 0.43 °C to 32.11 ± 0.58 °C induced a stronger warm sensation than the passage from 24.21 ± 0.92 °C to 29.57 ± 0.71 °C. This results may be explained by the action of skin thermoreceptors, which fire impulses based on the magnitude of the air temperature change (Lv and Liu, 2007). In addition, a significant decrease in the perceived arousal variables followed the larger air temperature step change. Hence, we conclude that the air temperature in the first room influenced both thermal perception and perceived arousal. Moreover, a larger difference in air temperature resulted in more disruptive effects on thermal perception and perceived arousal.

Negative correlations were observed between changes in thermal sensation and perceived alertness (p < 0.05), freshness (p < 0.05), or concentration (p < 0.01) (Figure 5). Larger changes in thermal sensations of subjects, after their return in the relatively cold office, were associated with lower perceived alertness, freshness, and concentration. The correlation results were also affected by the subject's treatment during outdoor exposure. In fact, all subjects ate food, which can induce thermogenesis and sleepiness. This effect should have affected all subjects in the same way, since they had the same lunch menu. Additionally, the subjects were likely physically tired from the walk and due to the length of time. Generally, the perceived arousal decreased for all subjects following the temperature step changes. The observed negative correlations should have been strongly influenced by changes in thermal sensations. Consequently, an increase in thermal sensation following air temperature step changes corresponded to a decrease in perceived arousal. Notably, Maula et al. (2016) found a decrement in the subjects' concentration under slightly warm conditions. We can conclude that the hysteresis effect, which is associated with heat stress, was probably responsible for the decrease in perceived arousal.

The limitations of our study derive from difficulties in controlling the subjects' treatment as well as in the measurement of thermal factors and sweat rate in an actual office environment. Subjects treatment included break and smoking times. Among all subjects, 21% and 25% of Office A and Office B, respectively, were smokers. It was hard to control the break and smoking times during working hours, due to the activity in the actual office. Note that radiation and air velocity, which could be used to clarify the subjects' responses during outdoor exposure, were not measured in this study.

Future studies on air temperature step changes in actual environments are needed to monitor break and smoking times during working hours, as well as the clo-value. Moreover, we recommend recording solar radiation and air velocity, and evaluating gender differences. The problem of air temperature step changes-induced differences in subjects' responses is closely related to physiological responses. Experimental studies investigating physiological responses (including sweating rates and administering task performances) are needed to clarify the physiological mechanisms and the state of arousal.

5. Conclusion

Subjective responses to thermal perceptions and perceived arousal were evaluated in two offices experiencing different air temperature step changes (up-step and down-step). Our main finding was that larger differences in air temperature elicited a hysteresis effect on all measured variables, except for thermal satisfaction, increasing heat stress and decreasing perceived arousal after the air temperature step changes. Moreover, a smaller air temperature difference in the actual environment, combined with walking activity, direct radiation exposure, and food intake, induced warmer thermal sensations than those registered during laboratory studies. Hence, we conclude that initial thermal conditions determine thermal perception and arousal after the air temperature step changes.

Acknowledgments

This paper presents a detailed analysis of data presented at the International Conference of Occupational Health and Safety 2017. The first author is grateful for the economic support provided by a scholarship from...
the Indonesia Endowment Fund for Education (LPDP).

References
Badan Standardisasi Nasional. (2011). SNI 6390:2011 Konservasi energi sistem tata udara bangunan gedung. BSN, Jakarta, Indonesia.
Cui, W., Cao, G., Park, J.H., Ouyang, Q., Zhu, Y. (2013). Influence of indoor air temperature on human thermal comfort, motivation and performance. Building and Environment 68: 114-122.
Dahlan, N.D., Gital, Y.Y. (2016). Thermal sensations and comfort investigations in transient conditions in tropical office. Applied Ergonomics 54: 169-176.
De Dear, R., Ring, J., Fanger, P. (1993). Thermal sensations resulting from sudden ambient temperature changes. Indoor Air 3(3): 181-192.
Du, X., Li, B., Liu, H., Yang, D., Yu, W., Liao, J., Huang, Z., Xia, K. (2014). The response of human thermal sensation and its prediction to temperature step-change (cool-neutral-cool). PLoS One 9, e104320.
Gagge, A.P., Stolwijk, J., Hardy, J. (1967). Comfort and thermal sensations and associated physiological responses at various ambient temperatures. Research Environmental 1(1): 1-20.
Haymes, E.M., Wells, C.L. (1986). Environment and human performance. Human Kinetics, Champaign, Illinois.
Karyono, T.H. (2015). Predicting Comfort Temperature in Indonesia, an Initial Step to Reduce Cooling Energy Consumption. Buildings 5(3): 802-813.
Katavoutas, G., Flocas, H.A., Matzarakis, A. (2015). Dynamic modeling of human thermal comfort after the transition from an indoor to an outdoor hot environment. International Journal of Biometeorology 59(2): 205-216.
Kuno, S. (2007). A new concept of air-conditioning systems based on the theory of thermal comfort in transitional conditions, in: Proceedings of International Symposium on EcoToopia Science 2007, ISET07. Nagoya, Japan: 1171-1174.
Lv, Y.-G., Liu, J. (2007). Effect of transient temperature on thermoreceptor response and thermal sensation. Building and Environment. 42(2), 656-664.
Maula, H., Hongisto, V., Östman, L., Haapakangas, A., Koskela, H., Hyönä, J. (2016). The effect of slightly warm temperature on work performance and comfort in open-plan offices - a laboratory study. Indoor Air 26(2): 286-297.
Nozawa, A., Tacano, M. (2009). Correlation analysis on alpha attenuation and nasal skin temperature. Journal of Statistical Mechanics 1.
Ogoh, S. (2017). Relationship between cognitive function and regulation of cerebral blood flow. Journal of Physiological Sciences 67(3): 345-351.
Parsons, K. (2014). Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance, Third Edition, CRC Press.
Seppänen, O., Fisk, W.J., Faulkner, D. (2003). Cost benefit analysis of the night-time ventilative cooling in office building, in: Proceedings of the Healthy Buildings 2003 Conference. Singapore (3): 394-399.
Stolwijk, J. a, Hardy, J.D. (1966). Partitional calorimetric studies of responses of man to thermal transients. Journal of Applied Physiology 21(3): 967-977.
Tsutsumi, H., Tanabe, S., Harigaya, J., Iguchi, Y., Nakamura, G. (2007). Effect of humidity on human comfort and productivity after step changes from warm and humid environment. Building and Environment 42(12): 4034-4042.
Westerterp, K.R. (2004). Diet induced thermogenesis. Nutrition & Metabolism 1(1): 5.
Wright JR, K.P., Hull, J.T., Czeisler, C.A. (2002). Relationship between alertness, performance, and body temperature in humans. American Journal of Physiology-Regulatory, Integrative and Comparative Physiology 283(6): R1370-R1377.
Xiong, J., Zhou, X., Lian, Z., You, J., Lin, Y. (2016). Thermal perception and skin temperature in different transient thermal environments in summer. Energy Build. 128, 155-163.
Zhou, H., Jia, M., Liu, B., Chen, Z. (2017). Thermal sensation in transient conditions at subway stations during the winter. International Journal of Heat and Technology 35(2): 371-377.