Conference Paper

Effect of Transient Changes of Air Temperature on Subjective Response of Office Worker in Tropical Country (Case Study: Jakarta, Indonesia)

Etika Vidyarini[1,2] and Takafumi Maeda[3]

[1]Department of Human Science, Graduate School of Design, Kyushu University, Fukuoka, Fukuoka Prefecture, Japan
[2]Faculty of Visual Art and Design, Institut Teknologi Bandung, Jl. Ganesha No.10, Lb. Siliwangi, Coblong, Kota Bandung, Jawa Barat 40132, Indonesia
[3]Faculty of Design, Kyushu University, Fukuoka, Fukuoka Prefecture, Japan

Abstract

Moderately cold indoor air temperature among offices in hot–humid country caused a sudden change of experienced air temperature when worker went out for a short time and returned to a moderately cold office. Thought that extreme changes of air temperature induced disruption for body thermoregulation and reduced thermal comfort. Current study aimed to investigate thermal comfort and perceived arousal toward mild transient change of air temperature in two actual offices with air-conditioning system in Jakarta, Indonesia. Participants in each office were grouped into workers who experienced transient state of temperature (TS) and workers who stayed indoor and experienced only steady state condition (SS). Thermal conditions surrounding 16 transient state participants were recorded at 5-minutes intervals using data logger from 10:00 to 17:00. Transient state participants went out and were exposed to outdoor temperature for approximately 1 hour at lunch time. The difference of mean air temperature between indoor and outdoor reached 8.49°C and 4.50°C for office A and B, respectively. Subjective votes indicating thermal sensation, thermal comfort, thermal satisfaction, alertness, freshness, and concentration were obtained from the total of 43 participants. Significant negative correlation found between changes of temperature and thermal sensation, thermal comfort, but not on thermal satisfaction. A tendency of decreased alertness, freshness, and concentration were observed among transient state participants of Office A, but was not observed in steady state participant of Office A and in both subject groups in Office B. These findings suggest that transient change of air temperature would lower arousal level in a more extreme temperature change.

Keywords: transient change temperature, arousal, workplace, subjective vote

Corresponding Author:
Etika Vidyarini
etika.vidyarini@gmail.com

Received: 15 May 2018
Accepted: 3 June 2018
Published: 19 June 2018

Publishing services provided by Knowledge E

Selection and Peer-review under the responsibility of the ICOHS 2017 Conference Committee.

How to cite this article: Etika Vidyarini and Takafumi Maeda, (2018), "Effect of Transient Changes of Air Temperature on Subjective Response of Office Worker in Tropical Country (Case Study: Jakarta, Indonesia)" in *International Conference of Occupational Health and Safety (ICOHS-2017)*, KnE Life Sciences, pages 435–444. DOI 10.18502/kls.v4i5.2574

1. Introduction

Body thermoregulation is important consideration in workplace since thermal condition can manipulate physiology and subjective thermal comfort. Human makes physiological adjustment to protect core body parts toward discomfort temperature. However, physiological adjustment seems not ascertain the subjective acceptability if encountered to un-adaptive thermal environment. Operative temperature did not directly affect working performance, although many previous studies confirmed that discomfort temperature causing thermal comfort. Thus, induced negative effects on working performance [1, 2]. As explained by Sellaro et al. [3], decrements in working performance were related to Ego Depletion, a concept of reduced self-control after performing a difficult task. This condition was significantly shown on the less-preferred temperature condition. These studies implied that exposure of discomfort temperature would be a drawback for working performance, due to a compensation of thermal stress.

Tropical countries with hot–wet climate have a quite high air temperature of 27°C to 35°C with average humidity of 50 percent [4]. Due to humid condition, sweating evaporation from skin decreased and less of body heat can be lost, which lead to discomfort feeling. Air-conditioning systems were used in most office buildings in Jakarta, Indonesia. Local guidelines proposed by Badan Standardisasi Nasional suggested workplace temperature to be 24–27°C with relative humidity 60% ± 5% [5]. Although many workers in Jakarta, Indonesia informally reported cold sensation because many offices were set on lower temperature of 22–25.5°C. Previous research by Damiati et al. [6] also reported average operative air temperature of Indonesian offices with cooling system was 25.5°C while outdoor temperature in Bandung was 25°C to 30°C, which is located in higher altitude with cooler temperature than Jakarta. As many other lowland cities in Indonesia, Jakarta has warmer air temperature than the highland cities. Average outdoor temperature reached 28°C with mean relative humidity of 78 percent [7]. The moderately cold office caused mild changes of air temperature between indoor and outdoor.

Transient change of air temperature and thermoregulation has been studied in artificial setting. Xiong et al. [8] found that after sudden heating of 5°C or higher, rapid increase was observed on thermal sensation, skin temperature, heart rate, self-report of increased sweating rate and eye strain. Thus, it lowered thermal comfort and thermal acceptability. Stress also observed by the sudden increased of IL-6, a biological stress indicator in both male and female after exposure of 11°C temperature difference or higher. Previous study highlights the disruptive effects of extreme temperature difference on body thermoregulation. There is still considerable uncertainty concerning how transient temperature affects arousal. Stimuli of mild temperature difference which human frequently encountered to and actual environment were less studied as well. Here, we investigate the effects of mild temperature change on thermal comfort and perceived arousal in actual offices in Jakarta, Indonesia.

2. Methods

Forty-three workers from two different offices in Jakarta, Indonesia, participated in this measurement. They were grouped into participant who experienced transient change of temperature and participant who experienced only steady state temperature. Transient state participant were 6 males and 9 females for office A (A-TS), and 11 males and 11 females from Office B (B-TS). While the steady state participants were 4 females for Office A (A-SS) and 2 Males for Office B (B-SS). Participants wore working clothes and were requested not to adjust their clothes during measurement.

Measurements conducted from 10:00 to 17:00 on different day for each office. During lunch time from around 12:00 to 13:00 (LT), transient state participants were asked to walk in outdoor to have lunch at a restaurant located in the range of 500–800 meter distance and returned to office. Time of leaving and returning were reported by participants to the experimenter. Mean and standard deviation for time spent at outdoor were 64.38 ± 9.80 minutes for A-TS participants, and 75.00 ± 21.55 minutes for B-TS participants. While steady state participants had lunch inside their office. Thermal condition including air temperature and relative humidity were measured using data logger (*HOBO H8 Loggers*) at 5-minutes intervals. Participants carried a data logger that hung on their neck. Thereby, the intervention of body temperature was limited.

All participants voted the questionnaire at the beginning of measurement time (Vt1), right before went out from office (Vt2), right after returned to office (Vt3), and at the end of measurement time (Vt4). Modified thermal sensation vote of ASHRAE [9] was used to indicate overall thermal sensation, that is, hot (7), warm (6), slightly warm (5), neutral (4), slightly cool (3), cool (2), and cold (1). Thermal comfort were measured using thermal comfort vote of Bedford scale [10], that is, much too warm (7), too warm (6), comfortably warm (5), comfortable (4), comfortably cool (3), too cool (2), much too cool (1). To see the relation with cognitive state, a seven-scale questionnaire of arousal, freshness, and concentration were used. Arousal scale was presented as follows; very alert (7), moderately alert (6), slightly alert (5), neutral (4), slightly sleepy (3), moderately sleepy (2), and very sleepy (1). Freshness scale was presented as follows; very fresh (7), moderately fresh (6), slightly fresh (5), neutral (4), slightly sleepy (3), moderately sleepy (2), and very sleepy (1). Concentration scale was presented as follows; very easy to concentrate (7), moderately easy to concentrate (6), slightly easy to concentrate (5), neutral (4), slightly hard to concentrate (3), moderately hard to concentrate (2), and very hard to concentrate (1).

This study underlined the effect of transient change of air temperature. Changes of thermal conditions on step up condition (Vt2–LT) and step down condition (LT–Vt3) and changes of subjective vote on before and after transient change (Vt2–Vt3) were mainly discussed. Repeated measures ANOVA were carried out with Vt2 and Vt3 as within-subject factor on all measured variables, unless on steady state participants due to not enough number of participants. Pearson correlation test was conducted between temperature difference and thermal perceptions. A significance level of $p < 0.05$ was applied for all statistical test.

3. Results

3.1. Thermal condition

Air temperature experienced by transient state participant and steady state participant from both offices were averaged separately for each office. Indoor air temperatures experienced by transient state participant were quite similar for all measurement time. In office A, mean air temperatures and standard deviations in indoor were 23.10°C ± 0.68°C (Vt2) and 23.44°C ± 0.29°C (Vt3), while in outdoor during lunch time was 31.59°C ± 0.32°C (LT). In office B, mean air temperatures and standard deviations in indoor were 24.50°C ± 0.40°C (Vt2) and 24.40°C ± 0.29°C while outdoor temperature was 28.90°C ± 0.98°C (LT). Air temperature difference experienced by A–TS participant were 8.49°C on step up and 8.16°C on step down condition. B–TS participant experienced smaller difference of air temperature, 4.40°C for step up and 4.50°C for step down. Steady state participant from both offices experienced relatively constant air temperatures for all measurement time, including measurement during lunch time. Air temperature experienced by steady state participant were ranging from 22.14–23.24°C and 23.96–24.79°C for office A and B, respectively. Compared to office B, participants of office A were exposed to lower indoor temperature and higher outdoor temperature. Thus, A–TS participant experience a wider temperature difference.

Absolute humidity on step up and step down condition in both offices were significantly different. A–TS participant experienced significant increase of absolute humidity as much as 6.74 gr/m^3 on step up condition ($p < 0.05$) and 7.32 gr/m^3 on step down condition ($p < 0.05$). Absolute humidity of B–TS participant was increased as much as 3.75 gr/m^3 on step up and decreased 4.60 gr/m^3 on step down condition ($p < 0.05$). Relative humidity in office A were higher than office B. In office A, indoor relative humidity was 43.93% ± 3.38% (Vt2) and 40.28% ± 3.54% (Vt3), while the outdoor relative humidity was 47.68% ± 3.31% (LT). Significant difference was obtained only on step down condition with 7.40 percent difference of relative humidity. Meanwhile, office B has lower indoor relative humidity of 39.19% ± 1.60% (Vt2) and 35.61% ± 1.33% (Vt3), while the outdoor relative humidity was 43.37% ± 2.60% (LT). Significant differences found on step up and step down condition ($p < 0.05$). These results of thermal condition indicate that A–TS participant experienced intense warmer and humid environment during step up and intense cooler and dry environment during step down.

3.2. Thermal perception

Changes of subjective response at Vt2 and Vt3 were compared to evaluate the effect of temperature step changes on thermal sensation, thermal comfort, and thermal satisfaction. In Office A, thermal sensation of A–TS participant were significantly increased ($p < 0.05$) from 3.40 ± 0.74 (slightly cool–neutral) to 5.20 ± 1.42 (slightly warm – warm), respectively for Vt2 and Vt3. In contrary, A–SS participant experienced relatively similar neutral sensation from 3.93 ± 0.88 to 4.07 ± 0.26, respectively for Vt2 and Vt3. In Office B, thermal sensation of B–TS participant were 3.91 ± 0.97 and 4.14 ± 1.13, respectively for Vt2 and Vt3 which is still in the range of 'slightly cool–neutral'. Thermal sensations of B–TS participant were not changed due to smaller difference of air temperature. The B–SS participant experienced slightly decreased sensation from 4.00 ± 1.41 (neutral) to 3.50 ± 0.71 (slightly cool–neutral), respectively for Vt2 and Vt3. Significant difference of thermal sensation only found in A–TS participant.

All participants were in the range of comfortable on before and after temperature step changes. However, A–TS participant experienced less discomfort than B–TS participant due to warmer sensation. Thermal comfort of A–TS participant were significantly difference ($p < 0.05$) from 33.33 ± 0.62 (comfortably cool – comfortable) to 4.93 ± 1.10 (comfortably warm). While the thermal comfort votes of A–SS participant were stay in the range of 'comfortably cool – comfortable'; 3.00 ± 0.82 (Vt2) and 3.50 ± 0.58 (Vt3).

Moreover, thermal comforts of B–TS participant were in the range of 'comfortable'; 3.95 ± 1.05 (Vt2) and 4.18 ± 0.96 (Vt3). Steady state participant of both offices were in the same thermal comfort range of 'neutral and slightly cool'. Significant difference of thermal comfort between Vt2 and Vt3 was only obtained in A–TS participant.

Thermal satisfaction of participant from both offices were slightly decrease after temperature step changes, but no significant difference found. All vote still in the same range of 'neutral to satisfied'. However, B–TS participant show a slightly better satisfaction than A–TS participant. This result indicates that smaller thermal difference between indoor and outdoor might be a better preference for workers who encountered transient change of temperature.

3.3. Arousal response

Subjective response of three variables; alertness, freshness, and concentration were obtained to indicate air temperature step changes on arousal response. A–TS participant encountered significant decrease on alertness ($p < 0.05$) from 4.47 ± 1.06 (neutral–slightly alert) to 3.73 ± 0.96 (slightly sleepy–neutral). While the alertness votes of A–SS participant were stay in the range of 'slightly sleepy to neutral'; 3.75 ± 0.50 (Vt2) to 3.50 ± 1.29 (Vt3). Meanwhile, either B–TS and B–SS participant were not experienced different alertness. Both were stay in the same range of 'slightly sleepy to neutral'. Alertness level of B–TS participant were; 3.79 ± 1.50 (Vt2) to 3.69 ± 1.40 (Vt3) and B–SS participant were; 4.00 ± 2.83 (Vt2) to 3.50 ± 0.71 (Vt3). Among all participant groups, significant decrease of alertness only observed on A–TS participant.

Freshness level indicating how fresh or tired the subject is after temperature step changes. It shows similar trend as alertness level. A–TS participant experienced significant decrease on freshness ($p < 0.05$) from 4.60 ± 1.12 (neutral–slightly fresh) to 3.73 ± 0.96 (slightly tired – neutral). The freshness votes of A–SS participant were stay in the range of 'neutral'; 3.25 ± 0.150 to 4.25 ± 2.22, respectively for Vt2 and Vt3. Unlike steady state participant, A–TS participant prone to feel more tired after step changes of temperature. Meanwhile, B–TS participant did not show any different in freshness level. Freshness level of B–TS participant were stay in the range of 'neutral'; 3.92 ± 1.55 (Vt2) to 3.82 ± 1.50 (Vt3) and B–SS participant were decreased from 4.50 ± 0.71 (neutral–slightly fresh) to 3.50 ± 0.71 (slightly tired–neutral). Among all participant groups, significant decrease of freshness level only observed on A–TS participant.

A–TS participant also become the only participant group that show significant decrease on concentration level ($p < 0.05$). Their concentration level was decreased from 4.67 ± 1.18 (neutral–slightly easy to concentrate) to 3.71 ± 1.28 (slightly hard to concentrate – neutral). The freshness levels of A–SS participant were stay in the range of 'slightly easy to concentrate – moderately easy to concentrate'; 5.00 ± 1.15 to 5.25 ± 1.50, respectively for Vt2 and Vt3. Meanwhile, concentration level of B–TS participant did not show any different, both were in the range of 'neutral'; 4.05 ± 1.28 (Vt2) to 3.93 ± 1.21 (Vt3) and B–SS participant were decreased from 4.00 ± 1.41 (slightly hard to concentrate–neutral) to 3.00 ± 0.00 (slightly hard to concentrate). It shows that concentration level was prone to decreased on A–TS participant who experienced wider temperature change. These results of arousal condition consisting alertness, freshness and concentration level yield the same trends where significant difference only obtained on A–TS participant who exposed to air temperature step up as much as 8.49°C. It indicates that wider temperature change was prone to lower arousal level.

4. Discussion

The aforementioned findings highlight the negative effect of wider difference of air temperature on subjective response in thermal perception and arousal level. Pearson correlation test was conducted. Significant negative correlation found between changes of temperature and thermal sensation, thermal comfort, but not on thermal satisfaction. Basically, thermal condition of Vt2 and Vt3 were relatively similar, but overshoot response on Vt3 were observed, especially on transient state participant of Office A. This non-uniform sensation is also observed in [11], explained that subjects who returned to the same cool room after exposed to comfortable temperature voted the more extreme response. As found in current study, thermal comfort would be lower than the response on before temperature step changes. Significant decrease on thermal comfort is consistent with the study of Damiati et al. [6] who observed thermal comfort range of office workers in several countries with hot–humid thermal conditions; Indonesia, Malaysia, Singapore, and Japan during summer season. They found that thermal sensation should be kept at slightly cool to neutral in order to provide thermal comfort for offices in Indonesia. It explains the significant decrease on thermal comfort only observed in A–TS participants who reported slightly warm thermal sensation after exposure of outdoor warm temperature.

Thermal satisfaction on Vt2 and Vt3 did not show any difference. Significant negative correlation also did not find between changes of temperature and thermal satisfaction. Previous study [12] measured air temperature step changes of warm–cool–warm in actual office. When participant returned from cool room to the previous warm room, thermal tolerance was decreased in the first 5 minutes. This response was related to the skin temperature at hand due to sudden increase of experienced air temperature. The thermal acceptance vote was just slightly different than the response on the warm room at the first time. In our study, both Vt2 and Vt3 were obtained in the mildly cold office. Thermal satisfaction might show difference if Vt2 or Vt3 were compared to the thermal satisfaction on warm temperature (LT).

Generally known that in transient change condition, skin temperature is gradually increased on step up temperature and decreased on step down temperature due to blood vessel vasodilation and vasoconstriction. Xiong et al. [6] mentioned that the changes of skin temperature after sudden heating is gradually increased and takes 30 minutes or more to stable, depends on the difference of air temperature. Physiological response requires time to adapt [13]. In our finding, a tendency of lowered arousal after wider difference of air temperature might be a compensation of unstable skin temperature after sudden heating and cooling that require more time to stable.

Considering ego depletion theory where cognitive decrements observed on the less preferred temperature and after performing difficult task [3], a tendency of lowered arousal after transient temperature change might be stronger if participants perform a certain task that require cognitive performance. It is important to note that Vote3 was obtained right after participants entering cold environment. Participants might not aware of their cognitive state since they did not perform any cognitive task. Subjective vote or task that is not cognitive-demanding may not sensitive in indicating arousal level [2, 12]. A decrement of arousal level after transient change of temperature change in current study is likely to be clearer if participants perform a certain task since subjective vote might not sensitive enough to represent arousal level.

Du et al. [11] suggested to control the air temperature difference between two environments not to exceed 5°C during winter. Our finding shows significant decrease on thermal perception and arousal level after exposure of 8.49°C difference of air temperature, but not significant on 4.50°C. However, we could not suggest the range of acceptable air temperature difference for thermal perception and arousal level since this study only examined two thermal conditions.

5. Conclucions

To study how transient change of air temperature affects thermal perception and arousal level, workers from two offices in Jakarta participated in a measurements involving exposure of natural air temperature step changes. Thermal data were obtained by each participant through a data logger carried by themselves. Thus, we examined subjective response to the exact thermal condition they experienced. Statistical analysis were done to identify the differences between before and after transient changes. It was shown that air temperature step changes of 8.49°C tends to shift thermal sensation, lower thermal comfort. it also tends to lower arousal level. While smaller air temperature difference of 4.50°C did not shows any difference.

There are some limitations in this study. Globe temperature, air velocity, and physiological indexes of participants were not measured and asessment of arousal level was only depend on subjective vote. Although, our finding emphasize the importance of considering thermal difference between indoor and outdoor temperature related to working productivity. These findings also provide new consideration in creating a supportive working environment. Further research work involving physiological measurement and cognitive-demanding task is needed for a comprehensive study of transient temperature change.

Conflict of Interest

None declared.

Funding

The authors would like to express a gratitude to the Ministry of Finance, Indonesia Endowment Fund for Education (LPDP) for the support of scholarship.

References

[1] Cui, W., Cao, G., Park, J. H., ey al. (2013). Influence of indoor air temperature on human thermal comfort, motivation and performance. Building and Environment, vol. 68, pp. 114–122.

[2] Maula, V., Hongisto, L., Östman, A., et al. (2016). The effect of slightly warm temperature on work performance and comfort in open-plan offices - A laboratory study. Indoor Air, vol. 26, no. 2, pp. 286–297.

[3] Sellaro, R., Hommel, B., Manaï, M., et al. (2015). Preferred, but not objective temperature predicts working memory depletion. Psychological Research, vol. 79, no. 2, pp. 282–288.

[4] Haymes, E M. and Well, C. L. (1986). Environment and Human Performance. Illionis: Human Kinetics Publishers.

[5] Badan Standardisasi Nasional (BSN). (2011). SNI 6390:2011 Konservasi Energi Sistem Tata Udara Bangunan Gedung. BSN, Jakarta, Indonesia.

[6] Damiati, S. A., Zaki, S. A., Rijal, H. B., et al. (2016). Field study on adaptive thermal comfort in office buildings in Malaysia, Indonesia, Singapore, and Japan during hot and humid season. Building Environment, vol. 109, pp. 208–223.

[7] Karyono, T. (2015).Predicting comfort temperature in Indonesia, an initial step to reduce cooling energy consumption. Buildings, vol. 5, no. 3, pp. 802–813.

[8] Xiong, J., Lian, Z., Zhou, X., et al. (2015). Investigation of gender difference in human response to temperature step changes. Physiology & Behavior, vol. 151, pp. 426–440.

[9] ASHRAE. 2010. ANSI/ASHRAE Standard 55-2010: Thermal environmental conditions for human occupancy, in American Society of Heating, Refrigerating and Air-Conditioning, Inc. Atlanta.

[10] Parsons, K. (2014). Human Thermal Environments: The Effects of Hot, Moderate, and Cold Environments on Human Health, Comfort, and Performance (third edition).

[11] Du, X., Li, B., Liu, H., et al. (2014). The Response of human thermal sensation and its prediction to temperature step-change (cool-neutral- cool). PLoS One, vol. 9, no. 8, pp. 1–10.

[12] Hancock, P. A. and Vasmatzidis, I. (2003). Effects of heat stress on cognitive performance: The current state of knowledge. International Journal of Hyperthermia, vol. 19, no. 3, pp. 355–372.

[13] Zhou, H., Jia, M., Liu, B., et al. (2017). Thermal sensation in transient conditions at subway stations during the winter. International Journal of Heat and Technology, vol. 35, no. 2, pp. 371–377.