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Room air temperature affects occupants' physiology, perceptions and mental alertness

Kwok Wai Tham*, Henry Cahyadi Willem

Department of Building, School of Design and Environment, National University of Singapore, 4 Architecture Drive, Singapore 117566, Singapore

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ABSTRACT

Thermal environment that causes thermal discomfort may affect office work performance. However, the mechanisms through which occupants are affected are not well understood. This study explores the plausible mechanism linking room air temperature and mental alertness through perceptual and physiological responses in the tropics. Ninety-six young adults participated as voluntary subjects in a series of experiment conducted in the simulated office settings. Three room air temperatures, i.e. 20.0, 23.0 and 26.0 °C were selected as the experimental conditions. Both thermal comfort and thermal sensation changed significantly with time under all exposures ($P < 0.0001$). Longer exposure at 20.0 °C led to cooling sensations due to lower skin temperatures ($P < 0.0001$) and was perceived as the least comfortable. Nevertheless, this moderate cold exposure induced nervous system activation as demonstrated by the increase of α-Amylase level ($P < 0.0001$) and the Tsai–partington test ($P < 0.0001$). A mechanism linking thermal environment, occupants' responses and performance is proposed.

1. Introduction

Thermal environment that causes thermal discomfort may affect office work performance. Seppanen and Fisk meta-analyzed various studies and reported that increasing room air temperature within 20.0–23.0 °C may improve work performance while any increase beyond this range may lead to negative productivity [1]. To some extent, this is consistent with a study in the Tropics, which revealed that office workers preferred a slightly cooler work environment within the range of 20.0–24.0 °C [2]. Wyon and Wargocki postulated in another review that room air temperature seems to affect office work by lowering arousal, elevating Sick Building Syndrome (SBS) symptoms and reducing manual dexterity [3]. Nevertheless, the mechanisms through which occupants are affected are not well understood. It seems that optimization of work performance under moderate thermal exposure depends on various factors within a person in dealing with both the thermal stressors and the tasks at hand. Little information is currently available on this, including that for tropically-acclimatized office occupants. The main objective of this study is to identify a plausible mechanism linking a target thermal parameter, i.e. room air temperature, and the mental alertness through perceptual and physiological responses. It encompasses the effects of room air temperature on work performance through several interrelated factors: 1) occupants' perceptions as the subjective indicator, 2) cutaneous measure such as skin temperature to indicate direct thermoregulatory responses, and 3) a target salivary biomarker, α-Amylase, to measure the nervous system's activation level. It is envisaged that this information would allow for a better and more effective control of thermal exposure; and thus the improvement of overall health, well-being and productivity of the occupants.

2. Research methods

Ninety-six young adults, aged between 20 and 23 years old, participated as paid voluntary subjects. The selection process was made based on health background (no chronic illnesses and allergies), smoking habits (non-smoker), initial performance test results obtained from the training session, interviews, and availability throughout the experimental period. The subjects were divided equally into 6 groups of 16 subjects with each group having an equivalent number of male and female participants. Before commencing the actual experiment, subjects were given three training sessions to familiarize the subjects to the test procedure as well as the performance tests to be taken. The subjects wore typical clothing attires for office workers in the tropics, which generally consist of a) for male subjects: light cotton shirt with or without t-shirt, light trousers, men's briefs, light calf-length socks and shoes, and b) for female subjects: light dress or blouse with skirt or light trousers, women's briefs, ankle-length socks and ladies shoes. Throughout the experiments, subjects were encouraged to adjust

* Corresponding author. Tel.: +65 65163413; fax: +65 67755502.
E-mail address: bdgtkw@nus.edu.sg (K.W. Tham).

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their clothing attires as and when necessary for achieving and maintaining thermal neutrality. They were required to bring additional light sweater and jacket during each session since the experimental condition was kept blind to them. Subsequently, the clothing insulation values were found to be higher with lower air temperature which suggests that subjects were attempting to achieve thermal neutrality in the colder conditions.

The research was conducted in a simulated office environment. Conditioned-air was delivered to the chamber via six concentric air terminal devices with perforated panel at the outlet to ensure uniform air distribution or mixing and minimize the risk of non-uniform turbulence intensity. In controlling the room thermal parameters, room air temperature and relative humidity feedbacks were obtained from five pairs of thermo-humidistats located at each of the four clusters of workstations and at the center of the room.

Three room air temperatures were selected as the experimental conditions. These conditions, ranging from moderate cool to moderate warm, were within the acceptable range of room air temperature, not uncommon to the actual office environment in the Tropics. The first condition was 20.0 °C, representing the moderate cool exposure commonly encountered in many offices in the tropics. The next condition was 26.0 °C, selected to represent situations of inadequate cooling in some offices that may cause moderate warm discomfort. The third condition, at the mid-point of the selected range, 23.0 °C, was selected to represent a condition that is considered to be comfortable. These conditions were introduced to the subjects using the blind intervention approach. During interventions to room air temperature, the level of relative humidity was kept at 60% Rh and outdoor air supply rate at c.a. 9.0 L/s/p. All other indoor environmental parameters were kept constant according to the existing design conditions. It should be noted that the Tropical maritime climate, where this study had been carried out, is characterized by year round uniform high air temperature, high humidity and abundant rainfall. The annual mean of outdoor air temperature ranges from minimum of 24.8 °C to maximum of 31.1 °C and the mean relative humidity is usually between 61% and 65% but frequently exceeds 90% in the morning hours (data from 1997, 2002–2007) [4].

Each experimental session lasted for 4 h with a ten-minute break after approximately two hours. The experimental schedule is shown in Table 1. Subjects were asked to arrive at least 15 min before the start of the experiment. Prior to entering, subjects were asked to seat outside the simulated office. This waiting area was a common area with air-conditioning and was maintained at air temperature approximately between 24.0 and 25.0 °C. During each session, subjects stayed in the simulated office and performed the performance test batteries. Subjects also completed a total of five surveys. The survey consisted of questions pertaining to perceptual aspects such as thermal comfort, whole-body thermal sensation, and local thermal sensations at various sections of the body, i.e. the forehead, upper arm, lower arm, hand, chest, back, thigh, calf, and foot. These subjective responses were obtained using continuous scale. Dichotomous comfort scale was used to determine thermal comfort level. The scale comprises of two regions of a vertical line contrasting the "comfortable" range to the "uncomfortable". The seven-point AHSRAE rating scale was used for whole-body thermal sensation, while local thermal sensations were obtained using the visual-analog (VA) scale. For VA scale, each scale was marked with two endpoints that represent the extreme points of the subjective response, e.g. "hot" – "cold". The subjects were asked to tick within the scale according to their immediate perception. It should be informed here that this paper only focuses on the results of the whole-body thermal sensation and the corresponding thermal comfort rating.

Table 1
Experimental schedule during each session.

Task	Time elapsed (minutes)
Survey & saliva collection	0–10
Reasoning test	10–18
Typing	18–66
Concentration test	66–72
Survey	72–76
Addition	76–84
Activity involving walking	84–88
Creativity test	88–100
Arousal test	100–104
Proofreading	104–118
Survey	118–122
Mid session break	122–132
Concentration test	132–138
Creativity test	138–150
Proofreading	150–164
Arousal test	164–168
Survey	168–172
Activity involving walking	172–176
Typing	176–224
Reasoning test	224–230
Survey	230–234
Addition	234–242
Saliva collection	242–247

Skin temperatures were measured by calibrated thermistors with accuracy level of ±0.5%. The thermistor is also commonly used as sensor in digital thermometer and other medical appliances. Thermistors were affixed on the skin surface at five sections of the body using thin dermiform tape. These locations are forehead, upper arm, back, hand and foot. A passive drool salivary sampling procedure was applied for saliva collection before and after exposures. Subjects expelled saliva into a labeled sampling tube. Afterwards, the tube was tightly sealed, stored in a thermally insulated box with ice packs, and then transported to the laboratory for processing. Kinetic immunoassay measurement was employed to determine salivary α-amylase concentration in the saliva.

Measures of mental performance of the subjects were obtained from various tests, i.e. arousal/alertness, concentration, creativity, and reasoning. However, in accordance to the scope of this paper, only the arousal/alertness test result would be reported and discussed. A modified Tsai–partington test was used to determine arousal/alertness level of the subjects. Originally known as Trial Making Test, it was devised for purposes including sequencing ability, mental flexibility, visual search and test of motor function. In this study, subjects were asked to link 55 numbers in descending order within 2 min. The total number of links per minute and the number of incorrect links were used as speed and accuracy measures, respectively. Under high arousal/alertness, subjects were expected to perform worse on Tsai–partington test due to narrow attention span. Here, it should be reiterated that the Tsai–partington test should not be interpreted as a direct measure of work performance. This test is used to measure the subliminal condition of arousal/alertness that would eventually affect work performance. The relationship between arousal/alertness and work performance is commonly described following the classic Yerkes–Dodson law which dictates that work performance improves with arousal/alertness up to an optimal point beyond which the work performance decreases (an inverted-U curvilinear relationship). The later is commonly described as the over-arousal state. Association between arousal/alertness and work performance is also governed by the type of tasks under consideration. Tasks/works that emphasize on attention, endurance and stamina usually require a higher arousal while those demanding thinking abilities are better performed under lower arousal state. Analysis of salivary biomarker focused on α-Amylase, a correlate of catecholamines