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The Effect of Indoor Temperature and CO₂ Levels on Cognitive Performance of Adult Females in a University Building in Saudi Arabia

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Abstract

Temperatures and indoor CO₂ levels within buildings play a crucial role, not only for energy consumption, but also for occupant performance and particularly cognitive performance regarding all mental activities such as thinking, reasoning, and remembering. Using a multi-variable multilevel approach, the effects of classroom temperature and CO₂ levels were estimated on vigilance and memory tasks. The analysis is based on two classrooms' physical environmental measurements data in a university located in Saudi Arabia. Participant votes on standard subjective thermal rating scales were collected from 499 adult female students, which were correlated with relevant environmental parameters such as humidity, radiant temperature, air velocity and self-reported clothing levels. Performance against two neurobehavioral cognitive tests was evaluated. The effects of three temperature levels were investigated. Statistically significant associations were observed between the cognitive test outcomes and the investigated exposure conditions of classrooms' temperature and CO₂ concentration levels. The associations remained significant after adjusting for confounding variables.

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Keywords: Indoor temperature; CO₂ concentration levels; Cognitive performance; Education and tasks conducive to learning.

1. Introduction

Students' ability to sustain attention and concentration are key requirements for achieving high performance. According to a number of studies, classrooms' environmental factors such as temperature and ventilation rates are

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known to disrupt concentration and attention in educational buildings, and are likely to undermine academic performance [1]. In educational buildings, classroom ventilation has been already recognized as an important determinant of indoor air quality since the beginning of the 20th century; however, studies worldwide up to date showed that classrooms ventilation requirements in educational buildings are not met yet in most buildings. With specific regards to Saudi Arabia, recent evidence was provided based on data collected from 36 schools indicating that classroom ventilation rates in Saudi Arabia do not meet building standards [2]. Consequently, this has led to higher indoor Carbon dioxide (CO₂) concentrations in buildings. High CO₂ levels suggest that there is poor ventilation and movement of air in a space, which could lead to increased concentrations of a variety of irritants.

Moreover, providing sufficient classrooms' ventilation rates alone is not sufficient to provide a good learning environment. Room temperature has been found to influence productivity directly and also indirectly through its impact on prevalence of SBS symptoms or satisfaction with air quality [3]. In addition, according to a number of studies, thermal environment that causes thermal discomfort may affect performance. However, scarce data and very little empirical evidence is currently available from the mechanically ventilated and cooled educational buildings located in the hot climates regions and particularly from the Arabian Gulf Peninsula where energy has become cheap and affordable. It is of a particular importance to investigate the effects in air-conditioned buildings since most air conditioners re-circulate a significant portion of the indoor air to maintain comfort and reduce energy costs associated with heating or cooling outside air. Inhaling the circulated air can cause adverse health problems and respiratory diseases attributed to the airborne pollutants [4]. The central nervous system has also been proposed to be a target organ for the detrimental effects of airborne pollutants [5]. In addition, females' educational buildings are presumed to be relatively in a poorer condition and left behind in Saudi Arabia relative to males' educational buildings because of cultural issues, and less attention is paid to them [6]. Furthermore, the effects of room temperatures and indoor air quality are mostly provided from studies conducted in educational buildings which are mostly based on schoolwork by children. On-going research is focusing on children performances as they are more vulnerable to effects from environmental hazards. Nonetheless, the science of developmental neuropsychology recognized that more complex thinking executive functions (such as perception of time, abstract understanding of language and selective attention) occur approximately from the age of 9 to 23 years [7].

Therefore, the main objective of this study is to further underpin the science of IAQ and cognitive performance whilst helping to understand the implications for educational buildings' design on the ability of students to learn in the mechanically ventilated and cooled buildings located in hot climates whilst considering the air-conditioners' acclimation effect in this context of study. Continuous performance test (CPT) was selected as a representative of an attention task and match to sample (MTS) was selected as a representative of a working memory task. Attention and working memory are two key requirements for the tasks conducive to learning. In this study, a multi-variable multilevel statistical modelling approach was adopted which took into account of the nested structure of the data whilst adjusting for the confounding variables including thermal comfort sensations, age, physical activity, clothing levels, stress, caffeine intake, sleeping hours, noise levels, air-conditioners' set temperature at home, as well as ethnic background. Only one recent study has adopted multi-variable multilevel statistical modelling approach; nevertheless, none of these confounding variables were included in their model and the sample size was much smaller whereby no statistically significant associations have been obtained.

2. Research Methods

2.1. Protocol of the study

A female university building located in Jeddah, Saudi Arabia, was selected for the study. Four hundred and ninety nine female subjects were tested under nine different exposure conditions combining temperatures (20°C, 23°C and 25°C) and CO₂ levels (600 ppm, 1000 ppm and 1800 ppm). Participants performed eight different cognitive tests (only two of which are discussed in this paper, namely: continuous performance test (CPT) and match to sample (MTS)). In parallel, the participants evaluated their thermal comfort sensations during the exposures. Within-subjects design was adopted where the same participants were exposed to the same exposure conditions, where exposures took place on the same weekday to avoid any influence of weekday on the within-

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