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RESEARCH ARTICLE

Evaluation of indoor environmental quality conditions in elementary schools' classrooms in the United Arab Emirates

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Abstract
This study presents findings of indoor environmental quality (IEQ) investigations conducted in elementary schools' classrooms in the United Arab Emirates (UAE). Average TVOC, CO_2, O_3, CO, and particle concentrations measured in the classrooms were 815 $\mu g/m^3$, 1605 ppm, 0.05 ppm, 1.16 ppm, and 1730 $\mu g/m^3$, respectively. Whereas, local authority known as Dubai Municipality recommended 300 $\mu g/m^3$, 800 ppm, 0.06 ppm, 9 ppm, and 150–300 $\mu g/m^3$ for TVOC, CO_2, O_3, CO, and particle, respectively. Dubai Municipality recommended temperature and relative humidity (RH) levels of 22.5 °C to 25.5 °C and 30%–60%, respectively. Average temperature and RH levels measured in the classrooms were 24.5 °C and 40.4%, respectively. Average sound level in the classrooms was 24 dB greater than recommended sound level limit of 35 dB. Six (6) classrooms had average lux levels in the range of 400–800 lux. Two (2) classrooms had average lux levels in the range of 100–200 lux. The remaining classrooms had lux levels around the recommended 300 lux. High occupancy density was observed in majority of the studied classrooms. Observations during walkthrough investigations could

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be used to explain measured IEQ data. Poor IEQ conditions in the studied classrooms highlight the need for further research investigation to understand how poor classrooms' IEQ condition could influence students' health, comfort, attendance rate, and academic performance.

1. Introduction

A typical child spends about 1300 h in classroom each year (Juster et al. 2004; U.S. Department of Education, 1992). Time spent in classroom is mainly for learning and academic purposes. Thus, classroom indoor environmental quality (IEQ) conditions should be conducive for such purposes. IEQ include indoor air, thermal, acoustics, visual (light), and spatial conditions (Frontczak and Wargocki, 2011). If classroom IEQ conditions are compromised, learning and academic activities may be compromised (Schneider, 2002; Mendell and Heath, 2004; Daisey et al., 2003; Bako-Biro et al., 2012; Bareett et al., 2012). Poor classroom IEQ conditions can also affect students' health and comforts (Sousa et al., 2012). Poor classroom IEQ conditions with young children are of particular concern. This is because young children immune systems are not yet fully developed like that of adults. Children are therefore at higher risk than adults. To minimize children risk, conscious effort is needed to understand and address poor IEQ conditions in elementary schools' classrooms with young children. Such effort has health and comforts, learning, academic and economic benefits (Wargocki and Wyon, 2013). A search of science-direct, PubMed, and other related research databases will reveal growing lists of research studies on IEQ conditions in elementary schools. However, very little is known about IEQ conditions in United Arab Emirates (UAE) elementary schools' classrooms. This is surprising because there are indoor and outdoor sources that could potentially lead to poor IEQ conditions in the UAE elementary schools' classrooms.

This present study is a continuous effort to bridge the gap in knowledge. This present study builds on earlier study, indoor air quality (IAQ) and thermal conditions in Dubai public elementary schools, conducted by Behzadi and Fadeyi (2012), by investigating previously unexamined but important IEQ conditions. They include particle size distributions and concentration, and acoustics, light and spatial conditions. To address objectives of this study, physical measurements and walkthrough investigations were adopted. Such methods had been used in classrooms' IEQ studies reported in the literature (De Giuli et al., 2013; Corgnati et al., 2007, 2009). Data for this study were collected from sixteen (16) air-conditioned elementary schools (public and private) in two Emirates (States) in the UAE. The study was conducted between the months of April 2012 to February 2013. The Emirates of Dubai and Fujairah were the focus of this study. Dubai schools were chosen to represent typical schools in the urban areas of the country. Chosen schools in the village part of Fujairah represent typical schools in the rural areas of the country. It is important to note that the primary aim of this study is to provide knowledge about typical IEQ conditions in UAE elementary schools' classrooms in relation to recommended IEQ standards. This paper should be read in this context.

2. Methods

2.1. Measurement protocols

This present study was conducted in four (4) phases. The phases include: (i) selection of schools; (ii) initial visit to eligible schools; (iii) detailed walkthrough investigation; and (iv) data collection with instruments (physical measurements). In phase 1, technical calls were made to verify the suitability of chosen schools and seek permission from authorities of chosen schools. After getting approval from the schools, follow up calls were made to confirm date for initial visits to the schools. The purpose of the 2nd phase, initial visits to eligible schools, was to familiarize with the chosen schools. During this 2nd phase, we made preliminary discussions with the schools' operators/heads as to the reasons for intended investigations. We later made detailed walkthrough investigations for each of the chosen classrooms, i.e., phase 3. Building systems, which include envelope; mechanical, electrical and plumbing (MEP); interior; and structure, were assessed during walkthrough investigations of entire studied 16 classrooms. The impact of each of the building systems and integrations between them were analysed in the context of their potential impact on IEQ conditions. Impact of outdoor conditions on classrooms' IEQ conditions were also considered during the walkthrough investigations.

In phase 4, instruments were used to collect physical data. Due to limited available instruments, manpower and limited access given by the schools, collection of physical data were done in one classroom for each of the chosen schools. Due to limited instruments, we were not able to simultaneously take outdoor measurement while we were doing indoor measurement. We were also not able to do outdoor measurement another day due to limited access we were given. With regards to IAQ conditions, total volatile organic compounds (TVOCs), carbon dioxide (CO_2), carbon monoxide (CO), ozone (O_3), formaldehyde (HCHO), and particle mass concentrations data were collected. Biological contaminants were not measured due to lack of resources to conduct such analysis. With regards to thermal conditions, temperature and relative humidity (RH) data were collected. Sound levels were measured to assess acoustic conditions. Light levels were measured to assess light conditions. To address spatial conditions, the distances between the students' desks and their teaching board were measured.

TSI Optical Particle Sizer 3330 was used to measure particle concentrations every 30 s interval for 8 h. A total of 16 channels of the optical particle sizer, ranging between 0.3 nm to 10 nm diameters were analysed. GrayWolf Direct Sense IAQ monitor was used to measure IAQ and thermal