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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

Table 1 Instruments used and the uncertainty of the instruments.

Name of instruments	Name of instruments	Uses	Range and accuracy according to ISO guidelines	Source of information	Measurement type	Placement position
IAQ	Direct Sense IAQ-IQ probe 610	Carbon dioxide	Range:0–10,000 ppm; accuracy: ±3% rdg ±50 ppm	Manufacturer's specifications	Continuous measurement	One location -middle of classroom at about 0.8 m height from the floor
		Carbon monoxide	Range:0–500 ppm; accuracy: ±2 ppm <50 ppm, ±3% rdg ±50 ppm			
		TVOC	Range: 20–20,000 ppb			
		Relative humidity	Range: 0–100% RH; accuracy: ±2% RH<80% RH (±3% RH>80% RH)			
		Temperature	Range: −10–+70 °C; accuracy: ±0.38C			
		Ozone	Detection limit 10 ppb			
	Formaldehyde gas monitor (model RK-FP30)	Formaldehyde	Range: 0–0.4 ppm for detection time of 30 min		Spot measurement	
	TSI Optical Particle Sizer 3330	Particle	Size resolution<5% at 0.5 μm; Size range: 0.3–10 μm in up to 16 channels; Wide concentration range from 0 to 3000 particles/cm^3		Continuous measurement	
Acoustic	SL130G EXTECH Sound Level Alert with Alarm	Acoustic	Ranges: 30 to 80 dB, 60 to 110 dB, 80 to 130 dB; Accuracy: ±1.5 dB (under reference conditions)/0.1 dB; Frequency bandwidth: 31.5 Hz to 8 kHz		Spot measurement	Nine locations in classroom-hand held at about 0.8 m height from the floor
Light	HD450 EXTECH Data logging Light Meter	Light	Range: 400, 4000, 40 k, 400 k lux; Accuracy: ±5% rdg; max resolution: 0.01 fc/0.1 lux		Spot measurement	
Spatial	Measurement tape	Spatial	Not applicable	Not applicable	Spot measurement	One location- distance between classroom teaching board and students' front row desks

conditions at 15 min intervals for 8 h during school hours. SL130G EXTECH sound level meter and data logging light meter were used to measure acoustic and HD 450 450 EXTECH light conditions, respectively. Unlike the continuous measurement adopted for IAQ and thermal conditions, acoustic (sound levels) and visual (light levels) conditions were assessed using spot measurement method. Sound levels were measured three times in front, middle, and back of each of the studied classrooms, in the morning- at the beginning of class session, during class session-few minutes before lunch break, and just before closing hour. Light levels were also measured three times, like sound level measurements, at nine different spots in each of the studied classrooms. Measuring tapes were used to measure the distance between classroom's teaching board and students' front row desks. Table 1 shows instruments used and the uncertainty of each of the instruments. Phases 3 and 4 were done the same day for each of the studied classrooms. Measurements of IEQ parameters were done at students' seating level. Our intention was not to influence typical operations of studied classrooms. This protocol helps to have good understanding of what expect on a typical day. Measurements started 1 h before students resumed for their classes in the morning and ceased 1 h after closing time.

2.2. Data analysis method

In addition to average 8 h for the studied classrooms, standard deviation (SD), 95% confidence interval (CI), minimum and maximum, and 25%, 50% and 75% percentile of measured data were calculated for entire studied IEQ parameters studied (see Table 2). These data were compared with recommended limits provided by Dubai Municipality (2010) and recommended limits reported in the literature. Dubai Municipality IEQ standard metric are based on international metrics like ASHRAE Standard 62.1-2007; Building Bulletin 101; ASHRAE Standard 55—2010, USEPA air quality standards, IESNA lighting handbook, and Building Bulletin 93. Where otherwise specified, recommended limits set by Dubai Municipality (2010) are based on average 8-h.

Ventilation rate in each of the studied classrooms was calculated using online ventilation rate and air quality calculator (www.veetech.org.uk/PHP%20Programs/phpco2.php). The ventilation rate calculator is based on CEN European Committee for Standardization 13779 (2007). Volume of classroom, number of occupants (students and teacher) in classroom, outside CO_2 concentration, and steady state CO_2 concentration when occupants were present in the classroom were used to calculate ventilation rate. Outside CO_2 concentration was assumed to be 380 ppm (Satish et al., 2012). We did not measure outdoor CO_2 concentration because of limitations mentioned above. The calculation assumed office type of work (since desk works were performed) was performed by the students and teachers. Another limitation of adopted calculation method is that it assumed human as the only source of classrooms' CO_2. These limitations will affect accuracy of calculated ventilation rates. Thus, calculated ventilation rates should only be considered as estimates. Estimated ventilation rate data for each of the studied 16 schools was correlated with each of the classroom's TVOCs, and particle mass

Table 2 IEQ conditions for entire studied 16 classrooms.

Analysis	Indoor air quality					Thermal		Acoustics	Light	Spatial
	TVOC ($\mu g/m^3$)	Carbon Dioxide (ppm)	Ozone (ppm)	Carbon Monoxide (ppm)	Particle ($\mu g/m^3$)	Temp. (°C)	RH (%)	Sound level (dB)	Light level (lux)	Distance between board and front row (cm)
Average	**815**	**1605**	**0.05**	**1.16**	**1730**	**24.5**	**40.4**	**59**	**385***	**146**
Standard deviation	420	972	0.01	0.57	2270	2.1	6.5	7.1	190	57
95%CI	206	476	0.01	0.28	1112	1.0	3.2	3.5	93	28
Minimum	252	786	0.04	0.48	316	20.5	31	48	138	46
Maximum	1615	4050	0.08	2.68	9828	27.8	52	80	742	287
25% Percentile	518	950	0.04	0.76	572	22.9	36	56	287	116
50% Percentile	712	1317	0.05	1.11	1254	24.2	39	58	317	130
75% Percentile	1141	1740	0.06	1.38	1703	26.3	46	61	446	171
Recommended threshold limit	**300**	**800**	**0.06**	**9**	**150-300**	**22.5 to 25.5**	**30 to 60**	**35**	**300**	**300**

Note: Formaldehyde concentrations were measured in all the studied 16 classrooms. However, concentrations were below instrument detection limit of 0.01 ppm for all the classrooms.

*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.

concentrations. The same was done for steady state CO_2 in each of the studied classrooms. This was done to examine influence of ventilation on IAQ.

3. Results and discussion

Figure 1 shows representative pictures of observed issues, during walkthrough investigations that would influence measured IEQ conditions-indoor air quality, thermal, acoustics, light and spatial, reported in the following sections.

3.1. Indoor air quality

Table 2 shows TVOCs, CO_2, Ozone, CO, particles mass concentrations, including measured values for temperature, relative humidity, sound, light, and spatial conditions for entire studied classrooms. Average TVOCs concentration of 815 $\mu g/m^3$ (with SD of ± 420 and 95% CI of 206) was recorded for entire studied classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured TVOC concentration can be found in Table 2. According to Dubai municipality, TVOCs concentration should not be more than 300 $\mu g/m^3$ (Dubai Municipality, 2010). Indoor sources, such as pen inks, air refreshers, painting works done by the students, and furniture, that could have contributed to measured TVOC concentrations in the classrooms were observed. However, they cannot be used to explain high TVOC concentrations measured in the studied classrooms.

The "marginal" moderate correlation ($r = -0.32$) between calculated ventilation rate in the studied classrooms and measured indoor TVOC concentration support our presumption that outdoor to indoor transport of TVOCs is the major source of TVOCs in the classrooms (see Figure 2). This is because, if outdoor air is clean and did not transport high TVOC concentration into the classrooms, there should be very strong negative correlation between ventilation rates and measured TVOC concentrations (Hodgson et al., 2003). That is, the higher the ventilation rate, the lower indoor TVOC concentration should be. However, as evident in this study, higher ventilation rate does not necessarily mean lower TVOC concentration. This is because depending on outdoor TVOC concentration of a particular studied classroom, dilution benefit inherent in the use of ventilation may be compromised. Ventilation in these classrooms were mainly due to infiltration.

It is important to note that TVOCs is a mixture of several VOCs. While some VOCs can have significant health and discomfort implications, others do not, depending on their nature and concentrations. The consensus among indoor air researchers, based on current understanding, is that TVOCs are better used as indicator for testing materials, insufficient or poor ventilation design, and identification of high polluting activities (ECA-IAQ Report 19-EUR 17675). It is recommended that TVOCs should only be used as indicator for skin and sensory irritation symptoms—irritation of the eyes, nose, and throat (ECA-IAQ Report 19-EUR 17675). Evidences suggesting effect of TVOCs on sensory irritation symptoms are doubtful though. Some studies found association while others did not (Andersson et al., 1997). TVOCs values greater than 666 $\mu g/m^3$ could cause considerable increase in eye, skin, nose, throat, and mouth irritations (Brasche et al., 2004). Average TVOCs concentration (815 $\mu g/m^3$) for entire studied classrooms was higher than the 666 $\mu g/m^3$ benchmark. Measured TVOCs concentrations in each of the studied classrooms were within 200–3000 $\mu g/m^3$, a range where some sort of sensory irritations and discomfort may be experienced (Molhave and Nielsen, 1992). Molhave and Nielsen (1992) suggested that other types of health effects and discomfort will be expected for TVOCs concentration above 3000 $\mu g/m^3$. Values greater than 3000 $\mu g/m^3$ were not measured in this study. The only exception was an episode when some students broke their teacher's small bottle of perfume during the measuring period in a classroom. During this episode, TVOCs concentration peaked at 3130 $\mu g/m^3$.

Another concern with having considerable high TVOCs in classroom is TVOC potential in participating in ozone initiated chemistry process. Such chemistry process could generate more VOCs that might not be present indoors initially (Fan et al., 2003). Newly formed VOCs may be more toxic, have more sensory irritations, and other health and discomfort effects (Wolkoff et al., 2006). Most of the studies addressing association between TVOCs and health and comfort effects were conducted for adult subjects. Young children may be

Figure 1 Representative pictures of observed issues that would influence IEQ conditions in the studied classrooms. (a) Accumulated dry dust at the windows. The poor envelope systems condition would compromise studied classrooms' IAQ conditions. (b) Gaps at the wall A/C through units and classroom facades. The poor integration between MEP and envelope systems would compromise studied classrooms' IAQ, thermal, and acoustic conditions. (c) (i) Window covered with curtains/papers prevented sunlight penetration. The poor integration between envelope and interior systems would compromise studied classrooms' light conditions; (ii) beams obstruct light provided by luminaires. The poor integration between structural and MEP systems would compromise studied classrooms' light conditions. (d) Gaps between facade wall and door frame. The poor integration within envelope system would compromise studied classrooms' IAQ, thermal, and acoustic conditions. (e) High occupancy density, too many furniture, close proximity of front desks to white board, no dedicated space for school bags. The poor interior systems condition would compromise classrooms' spatial conditions. (f) Dusty and exposed wires on the floor would compromise studied classrooms' integrity. (g) (i) Dusty artworks hanged across classrooms. The poorly maintained interior systems would potentially compromise IAQ (ii) papers hanged between columns, protruding from wall facade, served as obstruction for teacher. The poor integration between interior and structural systems would compromise studied classrooms' spatial conditions. (h) (i) Cupboards placed directly in front of window blocked sunlight. The poor integration between interior and envelope systems would compromise classrooms' light conditions; (ii) Cupboards/students' chairs and desks placed directly in front of windows. This restricted access to curtain/blinds. The poor integration between interior and envelope systems would compromise studied classrooms' spatial conditions. (i) Schools surrounded by sandy hills - potential sources of high outdoor particle concentration. The sandy outdoor condition, especially during windy or sandstorm event, would compromise classrooms' IAQ. (j) Classrooms surrounded by school buses. This would increase outdoor particle and CO concentrations, and potentially compromise classrooms' IAQ conditions. Engine sound from school buses would also increase classrooms' sound levels.

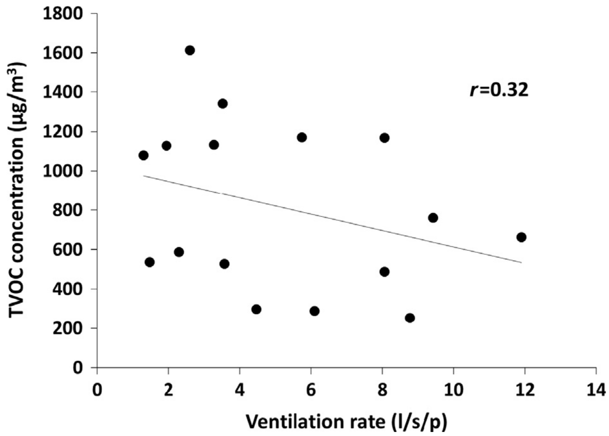

Figure 2 Correlation analysis between calculated ventilation rate and average TVOC concentration in each of the studied 16 classrooms.

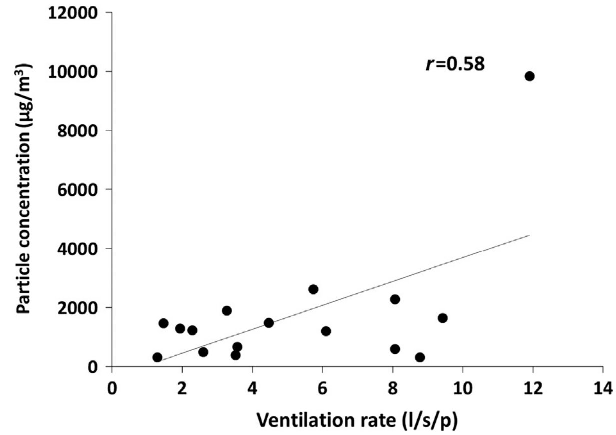

Figure 4 Correlation analysis between calculated ventilation rate and average particle concentration in each of the studied 16 classrooms.

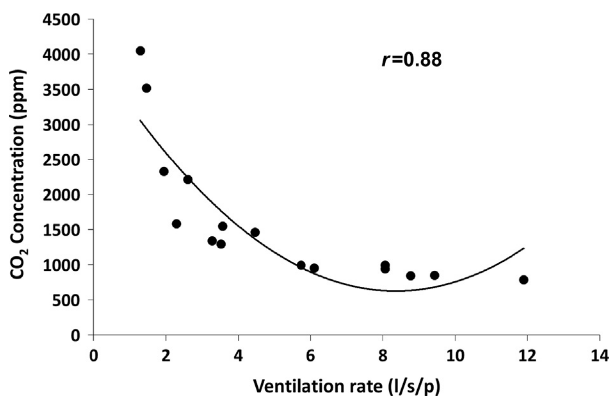

Figure 3 Correlation analysis between calculated ventilation rate and steady state CO_2 concentration in each of the studied classrooms.

more susceptible due to their immune system that is not yet fully developed. It is important to reduce students' exposure, especially those in elementary schools, to high TVOCs concentration in indoor environment.

Average CO_2 concentration of 1605 ppm (with 'SD' of $\pm$972 and 95% CI of 476) was recorded for entire studied classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured CO_2 concentration for each of the studied classroom can be found in Table 2. Average CO_2 concentrations for entire studied classrooms ranged between 786 and 4050 ppm. Majority of the studied classrooms had concentrations around or above 1500 ppm. Considering these measured values, students' learning ability and performance in addition to their health and comfort may be compromised (Mendell and Heath, 2004; Daisey et al., 2003; Satish et al., 2012). Dubai municipality recommended that indoor CO_2 concentration should not be more than 800 (ASHRAE Standard 62.1-2007).

According to Seppanen et al. (1999), if CO_2 concentration is above 800 ppm, complaints such as headache, fatigue, eye throat irritation may increase. CO_2 concentrations greater than 1500 ppm may lead to headache, dizziness, tiredness, difficulties in concentrating, and unpleasant odour in classrooms (Myhrvold et al., 1996). Students and teachers were the main sources of measured CO_2 in the classrooms. We observed that CO_2 concentrations varied depending on occupancy density. Occupancy density and poor ventilation rates contributed to measured high CO_2 concentrations (Clements-Croome et al., 2008). A strong correlation ($r=0.88$) was observed between calculated ventilation rate and steady state CO_2 concentration in each of the studied classrooms (see Figure 3). The correlation analysis showed that if appropriate ventilation rates are provided in the studied classrooms, CO_2 concentration will be reduced. However, out of the sixteen (16) classrooms studied, eleven (11) classrooms had ventilation rates below ventilation standards of 8 l/s/p provided by ASHRAE Standard 62.1-2007. In fact, eight (8) classrooms had ventilation rates below minimum 3 l/s/p recommended for schools by Building Bulletin 101. Effect of high CO_2 concentrations, due to poor ventilation, on students' health and comforts, and performance in schools is well documented in the literature (Bako-Biro et al., 2012; Mendell et al., 2013). It is important to note that calculated ventilation rates in these classrooms are largely due to infiltration. The consequence of this is that as ventilation dilutes pollutants generated indoors, untreated ventilation (infiltration) will increase outdoor to indoor transport of pollutants.

Closeness of school buses and vehicular traffic to classrooms could contribute to classrooms' CO concentrations. We did not observe major sources of CO in the studied classrooms. As evident from measure data, CO was not an issue. Average CO concentration of 1.16 ppm (with 'SD' of $\pm$0.57 and 95% CI of 0.28) recorded in the studied classrooms was far below Dubai municipality recommended 9 ppm (Dubai Municipality, 2010). Minimum and maximum, and 25%, 50% and 75% percentile of measured CO concentration for each of the studied classroom can be found in Table 2. Formaldehyde concentration of <0.01 ppm was measured in each of the studied classrooms. Measured formaldehyde concentration was below 0.08 ppm limit set by Dubai Municipality (Dubai Municipality, 2010).

Average ozone concentration of 0.05 ppm (with 'SD' of $\pm$0.01 and 95% CI of 0.01) was recorded in all the studied classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured ozone concentration for each of the studied classroom can be found in Table 2. According to Dubai municipality, ozone concentration should not be more than 0.06 ppm (Dubai Municipality, 2010). Ozone concentrations for entire studied schools ranged from 0.04 ppm to 0.08 ppm. Out of the sixteen (16) classrooms studied, five classrooms had ozone concentrations above 0.06 ppm. Ozone levels could be higher than reported values if occupants (students and their teachers) were not in the classrooms at all or for longer period of time. Human are sink for ozone (Fadeyi et al., 2013). Sensory and respiratory problems are associated with ozone exposure (Becker et al., 1998).

Children exposure to high particle concentration in classrooms is a concern (Mullen et al., 2011). Average particle mass concentration of 1730 μg/m^3 (with 'SD' of ±2270 and 95% CI of 1112) was recorded for all the studied classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured particle concentration for each of the studied classroom can be found in Table 2. Particle mass concentrations recorded for entire studied classrooms ranged between 316 μg/m^3 and 9828 μg/m^3. All the classrooms' particle mass concentrations exceeded World Health Organisation (WHO) recommended 24 h limit of 150–230 μg/m^3 (World Bank Group, 1998). High particle mass concentrations measured in the classrooms are of great concern, considering the nature of exposed occupants- young children. Potential particles health implications include coughing, runny nose, sore throat, respiratory, asthmatic, chronic obstructive pulmonary disease, and various cardiovascular problems (Institute for Environment and Health, 2000).

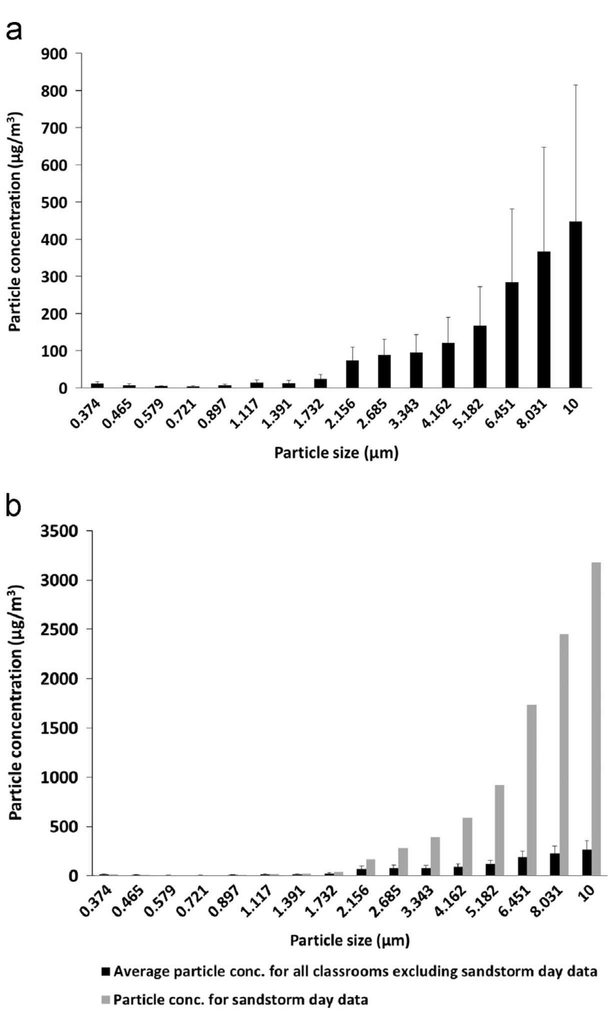

Figure 5 Particle mass concentrations for various particle sizes (a) for the entire studied classroom, and (b) during storm and non-storm events.

The University of North Carolina Gillings School of Global Public Health examined the health effects of particles exposure as part of their comprehensive study that addressed state of environmental health in the UAE (University of North Carolina Gillings School of Global Public Health, 2010). They estimated 250 (with a plausible range of 100–410) excess deaths each year to particles exposure indoors. Exposure to particles of outdoor sources was reported to be responsible for respiratory diseases and cardiovascular diseases. They estimated that 8330 (with a plausible range of 2170–17,100) and 5,370 (with a plausible range of 2170–17,100) hospital visits, respectively. The moderate correlation (r = 0.58)—see Figure 4, between ventilation rates and measured particle mass concentrations in the classrooms suggests that outdoor to indoor transport of particles is not the only major source of particles measured in the classrooms. A strong correlation was not observed because settled dusts in the classrooms would contribute to measured gas phase particle concentrations when students' activities and wind disturbance cause dust particles to be re-suspended into the gas phase.

US EPA recommended 24 h limit of 35 μg/m^3. Average $PM_{2.5}$ concentration for entire studied classrooms was around 100 μg/m^3-judging from $PM_{2.2}$ (74 μg/m^3 ±72) and $PM_{2.7}$ (96 μg/m^3 ±98) concentration shown in Figure 5. This poses health concern for the children. Pope et al. (2002) attributed high deposition of $PM_{2.5}$ on human arteries-gas exchange region of the lungs to vascular inflammation and atherosclerosis-hardening of the arteries that reduces elasticity. Atherosclerosis can cause heart attacks and other cardiovascular problems. Dubai Municipality (2010) and US EPA recommended 24 h limit value of 150 μg/m^3 for PM_{10}. PM_{10} for entire studied classrooms ranged between 65 μg/m^3 and 3178 μg/m^3 (average of 448 μg/m^3 ±748) as shown in Figure 5. Out of the 16 classrooms studied, ten classrooms had average PM_{10} values greater than150 μg/m^3. High outdoor PM_{10} concentration is prevalent in the UAE (Fadeyi, 2012). Concentration of outdoor to indoor transport of PM_{10} will increase indoor PM_{10} concentration. Out of the 16 classrooms studied, 'moderate' sandstorm occurred during measurement of one classroom. On this particular day, larger particle sizes (especially PM_{10}) during this 'moderate' sandstorm day were significantly higher than days with no sandstorm event—see Figure 5b. There was no much difference in the case of smaller particle sizes. The effect of the sandstorm event on indoor PM_{10} concentration was more pronounced due to obvious leakages at the classrooms' envelopes. Opened windows and doors also contributed to outdoor to indoor transport of particles. High PM_{10} concentrations the children were exposed to pose major health concern. Exposure to high levels of PM_{10} on continuous basis would have adverse health implication on brain, lungs, heart, and blood (Aphekom, 2011).

Walkthrough investigations were conducted to have in-depth understanding of issues that would contribute to measured IAQ data. Many dry dusts were found at the windows of almost all the studied classrooms. Untreated ventilation air through obvious leakages at the windows and doors joints of studied classrooms and intermittent opening of doors during measurements would enhance outdoor to indoor transport of measured pollutants. Gaps were also observed at the window and wall air-conditioned through units of some of the studied classrooms. All the studied classrooms had poor filtration systems. These filters were ineffective in reducing indoor air pollutants of indoor and outdoor sources. 14 of the studied 16 classrooms used split units and/or windows and through wall air-conditioned units with very ineffective filters to cater for high pollutants concentrations in the classrooms.

Visible dirt on air diffusers, fans, split units, windows and through wall air-conditioned units in the studied classrooms would contribute to pollutants measured in the classrooms. Observed dirty and dusty classrooms' surfaces and indoor materials, like window blinds, curtains, and education materials were potential sources that would contribute to measured pollutants in the classrooms. Students' presence and activities would contribute to particulates and CO_2 concentrations measured in the studied classrooms. Too many furniture were found in almost all the studied classrooms. Airflow obstruction caused by too many furniture would cause air pollutants stagnations. Observed high occupancy density in almost all the studied classrooms contributed to high CO_2 concentrations measured in the classrooms. Polluted outdoor conditions of the studied classrooms would compromise the use of ventilation to reduce pollutants concentrations in the classrooms.

3.2. Thermal

Measured temperature and RH levels were used to address thermal conditions of studied classrooms. Average temperature of 24.5 °C (with 'SD' of $\pm$2.1 and 95% CI of 1.0) was recorded for entire studied classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured temperature and RH levels for each of the studied classroom can be found in Table 2. According to Dubai municipality, temperature level should be within 22.5 °C to 25.5 °C (Dubai Municipality, 2010). Average temperature in each of the studied classrooms ranged between 20.5 °C and 27.7 °C. Out of the sixteen (16) classrooms studied, one classroom had temperature value lower than the recommended limit of 22.5 °C to 25.5 °C. Five classrooms had temperature values higher than the recommended limit. Occupants, solar radiation, outdoor to indoor transport of hot outdoor air and poor control of temperature settings would contribute to measured temperature levels in the studied classrooms. Average RH of 40.4% (with 'SD' of $\pm$6.5 and 95% CI of 3.2) was recorded for all the studied classrooms. This value is within Dubai Municipality recommended limit of 30% to 60% (Dubai Municipality, 2010). Average RH level in each of the studied classrooms ranged between 31% and 52%. Occupant density and outdoor to indoor transport of humid outdoor air would contribute to measured RH levels in the classrooms.

Walkthrough investigations were conducted to have in-depth understanding of issues that would contribute to measured thermal condition data. Most of the studied classrooms did not have external window shading devices that could be used to prevent direct solar radiation into the classrooms. Observed poor solar radiation prevention glass windows in all the studied classrooms would also enhance solar radiation into the classrooms. Obvious leakages at the windows and doors joints would enhance outdoor to indoor transport of latent and sensible heat into the classrooms. Window blinds, curtains, papers pasted on the windows, used as a form of solar radiation prevention were not effective in preventing solar radiation into the classrooms. All these inadequacies would increase the classrooms' sensible cooling loads. Heat and moisture generated due to occupants' presence and activities would influence classrooms' thermal conditions. Airflow obstruction caused by too many furniture in the studied classrooms would also compromise classrooms' thermal conditions. Effort should be made to ensure classroom's thermal conditions are favourable to students and teachers. Poor classroom thermal condition would reduce students' learning ability and performance, and increase absenteeism (Mendell and Heath, 2004; Smith and Graham, 1994).

3.3. Acoustics

Dubai municipality recommended 35 dB sound level for effective teaching and learning environment (Dubai Municipality, 2010). However, average sound level of 59 dB (with 'SD' of $\pm$7.1 and 95% CI of 3.5) was recorded for all the studied classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured acoustic condition for each of the studied classroom can be found in Table 2. Sound levels in all the studied classrooms ranged between 48 and 80 dB.

Walkthrough investigations were conducted to have in-depth understanding of issues that would contribute to measured acoustic condition data. Obvious leakages at the windows and doors joints, gaps between through wall air-conditioned units, and intermittent openings and closings of doors during measurements would enhance outdoor to indoor transport of sound. Additionally, observed poor acoustic façade materials would not be effective in mitigating outdoor to indoor transmission of sound. Major indoor sources that would contribute to sound level include sound generated by air-conditioned systems, mechanical fans, and unavoidable teachers' and students' activities. Unfortunately, studied classrooms' had poor indoor acoustic materials to mask indoor generated sound. Although, Dubai municipality recommended standard is meant for unoccupied classrooms, effort should still be made to improve the classrooms' acoustic conditions. This is because high classroom sound level would increase students' fatigue during mental memory tasks and would also reduce their tolerance levels, performances, and learning abilities (Shield and Dockrell, 2003; Klatte et al., 2010). High sound level would also affect teachers' performances (Skarlatos and Manatakis, 2003). If teachers' performances are compromised, knowledge transfer to students will be compromised.

3.4. Light

Light level and quality would influence students' learning and performance (Hathaway, 1992). Illuminating Engineering Society of North America (2000) (IESNA) recommended maintained average illuminance level of 300 lux at 0.8 m working level for elementary school classrooms. Minimum and maximum, and 25%, 50% and 75% percentile of measured light condition for each of the studied classroom can be found in Table 2. Average light level in each of the studied classrooms ranged between 138 lux and 742 lux. Six (6) classrooms had average lux levels in the range of 400–800 lux. Ten (10) classrooms had average lux levels greater than the recommended 300 lux. Six (6) classrooms had lux levels lesser than the recommended 300 lux. Two (2) classrooms had average lux levels in the range of 100–200.

Walkthrough investigations were conducted to have in-depth understanding of issues that would contribute to measured light condition data. All studied classrooms did not have external window shading device that could prevent glare in the classrooms. Poor integration between interior and envelope systems would reduce the potential of maximizing daylight in the classrooms. For example, in some of the studied classrooms, cupboards were placed directly in front of windows. Additionally, windows were covered with blinds, curtains, and papers in some of the classrooms. Such indoor arrangements blocked daylight penetration into the classrooms. Most of the classrooms relied on luminaires as source of light even though there was abundant daylight. Such practice will cause higher energy usage. We also observed that majority of the luminaires used in the classrooms were not energy efficient lighting systems. Effort should be made to eradicate or reduce these lapses. Use of intelligent devices on classrooms' façades can be used to achieve desirable indoor light levels in the classrooms with least amount of energy consumption.

3.5. Spatial

With regards to spatial requirement, distance between 1st row and chalkboard should be about 300 cm (Wong and Jan, 2003). However, students' desks in all studied classrooms were closer to the chalkboard than recommended distance. Measured distance ranged between 46 and 287 cm. Minimum and maximum, and 25%, 50% and 75% percentile of measured acoustic condition for each of the studied classroom can be found in Table 2. Such closeness increases students' risk of being exposed to particles generated from the teaching board. As evident from walkthrough investigations, high occupancy density and too many furniture in most of the studied classrooms limited available usable spaces. Classrooms' seats were also placed very close to one another.

3.6. Other issues—Classroom integrity

Other issues observed in some of the studied classrooms that could affect classroom integrity are; dusty and exposed wiring system on the floor; warn out building materials; stained classroom surfaces; patched flooring and walls; potentials for causing fire outbreaks—many papers, furniture and wirings; and crack walls that could harm, e.g., cut or scratch, the children legs/arms while playing in the classrooms. Furthermore, energy efficient classrooms provisions were lacking in almost all the studied classrooms.

4. Conclusions and future works

This study has shown that children in the studied classrooms were exposed to poor IEQ conditions, especially with regards to issues relating to IAQ. Examined IAQ conditions include TVOC, CO_2, O_3, CO, and particulates levels. 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, Dubai Municipality recommended limits for TVOC, CO_2, O_3, CO, and particle are 300 $\mu g/m^3$, 800 ppm, 0.06 ppm, 9 ppm, and 150–300 $\mu g/m^3$.

Thermal conditions in most of the studied classrooms were within temperature and RH recommended limits of 22.5 °C to 25.5 °C and 30% to 60%, respectively. Average sound level measured in the classrooms was 59 dB, while recommended sound level is 35 dB. Out of the 16 classrooms studied, six (6) classrooms had average lux levels in the range of 400–800 lux. Ten (10) classrooms had average lux levels greater than the recommended limit of 300 lux. Two (2) classrooms had average lux levels in the range of 100–200. Six (6) classrooms had lux levels less than the recommended limit of 300 lux. Majority of the studied classrooms had high occupancy density. Front desk rows were very close to the chalkboard. Our walkthrough investigations revealed sources that compromised studied classrooms' IEQ conditions. Poor systems integrations affected IEQ conditions in the studied classrooms.

There are very limited studies in the literature addressing IEQ conditions in UAE elementary schools. This present study provides knowledge about typical IEQ conditions in UAE elementary schools in relation to recommended IEQ standards. Knowledge provided in this paper will be useful for future studies. Studies addressing effects of classrooms' IEQ conditions on students' health and comforts, learning abilities, performance, and attendance rates should be conducted. Effects of outdoor conditions on UAE classrooms' IEQ conditions should be investigated. Importance of students' physiology, psychology and sociology should also be considered when assessing the effects of IEQ on students' perceptual responses. More studies examining baseline biological conditions in UAE elementary schools should also be conducted. Identified knowledge gaps should be bridged to create environmental friendly and conducive learning environment for elementary school children.

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