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Building and Indoor Environmental Quality Assessment of Nigerian Primary Schools: A Pilot Study

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Abstract

A total of 15 classrooms went through on-site assessments/inspections, including measurements of temperature (T), and concentrations of carbon monoxide (CO) and carbon dioxide (CO_2). In addition, the level of surface bio-contamination/cleaning effectiveness was assessed by measuring adenosine

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triphosphate (ATP) levels on students' desks. Based on the data, the quality of facilities in the buildings was low. Classroom occupancy exceeded ASHRAE 50 person/100m^2 standard in all cases indicating overcrowding. However, concentrations of CO_2 remained below 1000 ppm in most classrooms. On the other hand, indoor T was above the recommended levels for thermal comfort in all classrooms. Maximum indoor CO was 6 ppm. Median ATP concentrations on the desk tops were moderately high in all schools. The use of open incinerators and power generator sets near classrooms, which was suspected to be the main source of CO, should be discouraged. Improved hygiene could be achieved by providing the students access to functioning bathroom facilities and cafeteria, and by effective cleaning of high contact surfaces such as desks. Although ventilation seems adequate based on CO_2 concentrations, thermal comfort was not attained especially in the afternoon during extreme sunlight. Therefore, installing passive and/or mechanical cooling systems should be considered in this regard.

Keywords: Indoor Environmental Quality; Thermal Acceptability; Natural ventilation; Cleaning; School Classrooms; Educational Buildings.

Practical Implications:

The results are concerning in terms of the poor quality of facilities, lack of functional toilets and use of hazardous materials in and around Nigerian elementary school buildings. The study protocol and the results can be utilized in developing further studies and in terms of improving the existing schools so that standards will always be adhered to.

1 Introduction

Research has shown children to be more vulnerable to indoor environmental quality (IEQ) issues [1], which makes the research on school IEQ an important topic. Although studies have shown the effects of the indoor environment on humans (e.g. [2]), there are only a few studies on IEQ from developing nations including Nigeria [3,4].

Occupants' wellbeing can be simultaneously affected by several IEQ factors in a complex way [5–7]. Studies have shown that schools can be contaminated by various chemical and biological pollutants [3,8]. Exposure to these pollutants may have varied impacts on the health of the pupils, potentially causing illness, absence, and decreased performance [9], depending on the type and quantity of the pollutants exposed to, duration and frequency of exposure, and associated toxicity of the specific pollutant [10]. Indoor pollution levels may be higher in developing nations when compared to the developed world [4].

Building condition which is characterized by the type of construction and materials used, as well as the location and age of the building, may affect IEQ in schools. For example, studies by Furuya and Takahashi [11] and Boulanger et al. [12] suggested that buildings with certain materials, such as aluminum composite material (AMC), may contribute to building occupants' exposure to asbestos. In addition, especially older school buildings may have flaking asbestos ceiling tiles and other materials containing asbestos [13]. Buildings may also have leaky parts enabling mold and bacterial growth [14]. Building facilities such as basements have higher risk of dampness and mold presence [15–17], while school buildings located near sources of pollution such as mines, factories and incinerators are exposed to perennial air pollution [18].

Building construction as well as heating, ventilation and air conditioning (HVAC) systems are important factors influencing thermal conditions and indoor air quality. Thermal comfort refers to the feeling of people in their thermal environment, and is most directly related to air temperature and humidity conditions [19,20]. Thermal comfort is also affected by several other environmental and personal factors such as radiant temperature, air speed, clothing material/insulation and metabolic rate [21,22]. A study by Andersen and Gyntelberg [23] found that temperature in classrooms should be 23°C or lower to achieve the level of thermal comfort recommended by ASHRAE Standard 55. A study by Salthammer and colleagues [24] recommended a range of acceptable classroom temperature of 20-22°C. On the other hand, Lu et al. [20] described indoor temperatures up to 31°C as acceptable in a naturally ventilated building. This may be due to adaptive thermal comfort: occupants can adapt to a wider temperature range especially in naturally ventilated rooms in tropical climates [25,26]. In addition to discomfort, higher temperatures have been associated with impaired performance and learning outcomes, but only in temperate or mixed climates [27,28]. Due to a lack of studies in tropical climates, it is not clear if the adaptation to a higher temperature also applies to learning outcomes. Nevertheless, indoor temperature should not be lower than 18°C [29].

Studies have also associated thermal comfort with ventilation adequacy (e.g. [30,31]). Especially in crowded indoor environments, such as schools; adequate ventilation is needed to replace stale indoor air with cleaner air [32]. Ventilation is expected to help replenish indoor oxygen while simultaneously reducing concentrations of CO_2 and other bio-effluents and pollutants [33–35]. The air exchange can be done naturally through the opening of doors, windows and sometimes through other building openings, or by mechanical equipment [36].

Natural ventilation usually has a low investment and operational costs, while mechanical ventilation systems are more expensive and consume energy [37].Although there are several guidelines and standards by reputable organizations such as WHO (World Health Organization) and ASHRAE (American Society of Heating, Refrigerating and Air-Condition Engineers), as well as national building codes, these standards are not always met: many studies from different countries have shown ventilation to be inadequate in a large proportion of classrooms [31,38–41]. The reasons could be related to overcrowding in classrooms, as well as the type and condition of the school building and the ventilation system [42–44].

Traditionally, natural ventilation has been utilized to dilute and remove the build-up of indoor pollutants [45]. In a naturally ventilated building, the ventilation rate depends on natural driving forces such as winds and thermal buoyancy. This may result in either inadequate ventilation when wind speed is low, or overventilation when wind speed is high [46]. The air is not filtered or conditioned, resulting in outdoor pollutants entering indoors, which may be significant especially in highly polluted areas, near to high volume traffic, or uncontrolled incinerators [47]. According to Chen et al. [48], the concentration of outdoor pollutants diffusing indoors is much higher when natural ventilation such as opening of windows and doors are used, as compared to using mechanical ventilation.

In addition to exposure via polluted indoor air, students' exposure to various pollutants may also occur via contact. Whereas personal hygiene practices are important to control infectious diseases, research has indicated that the rapid spread of infectious diseases in crowded classrooms is associated with the cleanliness of high contact inanimate objects [49]. The challenge in setting practitioner-based cleaning protocols is more related to how we define the term clean as it applies to health. The routine cleaning protocol based on visual assessment appears inadequate for the removal of the unseen fraction. A study by Shaughnessy et al. [50] described a quantitative approach to measure cleanliness in schools using adenosine triphosphate (ATP) as a marker for surface contamination. Another study associated cleanliness of high contact surfaces (such as desks and cafeteria tables) with students' health outcomes [51].

As a whole, thermal conditions, ventilation, and cleanliness are considered important factors affecting IEQ as well as students' health and academic performance [17,31,51,52]. Therefore, this study was designed to evaluate IEQ and related factors in a sample of five elementary school buildings in Nigeria. The results will inform development of recommendations for improving school environments locally, nationally, and internationally.

2 Materials and Methods

Nigeria is a tropical country in West Africa with two distinct weather conditions (rainy and dry seasons), the period of which varies according to location. The schools included in the study are in South-Western Nigeria. There are six states in this region: Oyo, Osun, Ondo, Ogun, Lagos and Ekiti. The rainy season period is from March to October while the dry season is from November to February. The rainy season is associated with wetness due to rainfall, while dry season is associated with heat due to dryness and enormous amount of sunlight. According to Akinbode et al. [53], the mean annual temperature in South-Western Nigeria is between 22 and 30^{o}C while the minimum and maximum annual temperature range is between 13 and 26^{o}C and 22 and 40^{o}C, respectively.

Five Nigerian schools from two states in southwestern Nigeria were randomly selected for the study. Three schools are in Ibadan city in Oyo State while the other two schools are in Osun State (one in Ipetumodu and another in Ile-Ife). Three schools are privately owned while the other two are owned by the State government. The schools were investigated following the same protocol within a normal school week during the dry season (between December 2016 and January 2017). Part of the protocol was adapted from the WHO Schools Survey [54].

Three classrooms from each school were randomly selected for on-site investigation, which included measuring of classroom dimensions, visually inspecting the mode of ventilation and condition of the surfaces and materials (e.g. presence of moisture damage), interviewing maintenance personnel/head teachers, and assessing cleaning procedures. Other IEQ indicators were also assessed. This included proximity of the classroom to potential sources of pollutants such as traffic or incinerators and assessing waste and sewage disposal methods.

Measurements were done from outdoors and three representative classrooms per school for at least one day. Indoor and outdoor temperature (T) and relative humidity (RH) were monitored with CEM DT-172 data loggers, which were new, and factory calibrated. Carbon dioxide (CO_2) and carbon monoxide (CO) were measured with Delta OHM HD21AB data loggers that had been used in a previous study[55]. As a part of the regular maintenance, these data loggers were tested with side-by-side simultaneous tests before starting the field measurement campaign and the loggers that were showing larger than ±50ppm difference in CO_2 concentrations were sent to manufacturer's calibration. The data loggers were set to log at 1-minute interval. Logging started at least 30 minutes before the students arrived at the class in the morning and ended at least 30 minutes after the school hours. Data loggers were set in schools between 6.00 and 7.00am. Students and staff typically resume some minutes past 7.00am for a school assembly, which ends some minutes before 8.00am. Normal classroom activities start by 8.00am and end by 2.00pm, except for Fridays when schools close by 1.00pm. Some schools may choose to close around 12.00pm during examination periods. Corresponding outdoor measurements were also taken at the outdoor corridor of the buildings (≈ 1 meters) away from direct sunlight.

Pre- and post-cleaning data from the same classrooms were collected from desk tops after school hours by swabs. A minimum of ten pre-and five post-cleaning samples were collected per school and analyzed to detect and quantify adenosine triphosphate (ATP) with NovaLUM system (Charm Sciences, Inc., Lawrence, Kans.). Desk surfaces were swabbed with a standard 25cm^2 template. The template was disinfected with 95% isopropyl alcohol before each use. After pre-cleaning sampling, the desks were cleaned according to the protocol described by Shaughnessy et al. [50] as follows: 1) test surfaces were first wiped with a clean microfiber towel and wiped with disinfectant, 2) the surface was then wiped with another clean microfiber cloth until dry. Finally, post-cleaning ATP samples were collected directly adjacent to locations where the corresponding pre-cleaning samples were taken.

The data were analyzed with IBM SPSS statistic 23 (International Business Machines Corporation, New York City, NY, USA) and Microsoft Excel 2016 V16.0 (Microsoft Headquarters One Microsoft Way Redmond, WA 98052, Washington, USA).

3 Results

In the following, the investigated schools are coded with letters A to E, and classrooms with numbers 1 to 3.

3.1 Observations

Table 1 summarizes the school level characteristics from all schools, and Table 2 presents classroom level characteristics/observations. The schools were built between 1958 and 2006. The total number of students in each school varied from 106 to 371 and the number of personnel (including teachers) from 13 to 30. All school buildings had shallow foundations with concrete floors (school B had partial hard wood flooring), and none of them had a basement. All buildings were predominantly masonry structures with ridge roof. Roofing material was sheet metal except in one school (D), where it was asbestos. One school (E) had a portable classroom. None of them had a kitchen, cafeteria, nor sports or assembly hall. Assembly and sports was done outside in open space and only two schools (A and D) had those spaces paved. There were no door mats at the buildings and classrooms entrances of any school.

Only one school (D) had functioning toilets, whereas the other four schools were missing appropriate toilet and handwashing facilities. All five schools employed natural ventilation by leaving windows and doors open. In schools A and B, the windows were permanently opened (the classrooms had only window openings) while the windows in other schools were opened when students arrived in the morning and closed after school period ended in the afternoon.

School A

School A is a privately-owned primary school located in Ile-Ife town in Osun State Nigeria. The school consists of two pairs of buildings with primary and secondary school sections. According to the head teacher, there has been no air quality complaints in the past five years.

The school had a gasoline-operated generator near by the building housing secondary school students. The generator served only the administrative section of the building, and it was set on standby in case of power outage. Moisture damage and mold presence was located at the base of the building depicting an upward capillary movement of water from the foundation.

In the classrooms it was noticed that the desks were shared by two to three students. Unfinished concrete floors were broken with visible fine sand/concrete dust residue. While the older pupils cleaned their classrooms, the classrooms housing 1st and 2nd grade students were cleaned by janitors as needed during the school hours. During the walkthrough, ventilation was perceived insufficient (stuffy air noted) especially in the afternoon.

School B

School B is a private school situated in Ipetumodu in Osun State. Information from the administrative staff indicated that there has been no damage, renovation or structural addition to the building in the past five years. They complained of periodical waste burning by neighbours, which sometimes affects the air quality. Almost half of the building was decked with wood and the other half with concrete. There were signs of visible mold growth in the building especially at the region decked with wood.

School C

This is a state government owned school situated in Ibadan City. Since the original construction in 1958, there had been several renovations and additions to the building. The school had a large surrounding environment with sand cover, where students play football and other sports activities. The ceilings were made of asbestos.

School D

The school, which was situated in Ibadan city, was privately owned and built in 2000. It had two 2-floor buildings: one building accommodated elementary school students, while the other was for secondary school students. According to the school principal, there was no water, fire or any other damage to the school, neither there had been any air quality complaints in the past five years.

Most furniture was made of plastic. Each classroom had a bathroom equipped with toilet system that was well managed. School-hired cleaners cleaned the classrooms and bathrooms at least once a day. Classroom ventilation was perceived insufficient, and only one of the three classrooms investigated was cross-ventilated.

School E

School E was also situated in Ibadan city. It is owned by the state government and consisted of two permanent buildings built in 2006 and 2014. All buildings were used for classes by elementary pupils. The school personnel had not noticed any air quality problems in the past five years. Water damage and mold growth was observed in one of the building's ceiling suggesting roof leakage.

3.2 Measurements

Table 3 shows the descriptive statistics for T, RH, CO_2, CO and ATP in the classrooms during school time. In schools where measurements were taken for two days, the outcome was similar and highly correlated. One-day measurement was therefore used in the analysis. Mean indoor T ranged from 29 to 32 ^{o}C and the maximum indoor T reached over 34 ^{o}C. Mean indoor RH was usually above 60% (range 57% - 72%). Maximum indoor CO level was 6 ppm in School A, which also had the highest observed outdoor CO level (23 ppm). Maximum CO_2 stayed within 700 ppm above outdoor levels in all but two classrooms in one school (D). As shown in Table 3, median pre-cleaning ATP values ranged from 77,800 RLUs (relative light units) in School C to 391,400 RLUs in School E. Some pictures of the physical condition of the classrooms are shown in Figure 1.

4 Discussion

According to the needs assessment report of the Nigerian educational sector [56], there are about sixty thousand elementary schools in Nigeria with over twenty million students. Most Nigerian public schools are free (no tuition paid) while private schools charge fees.

There are only a few studies on classroom IEQ in underdeveloped and developing countries when compared to the developed world. This may be associated with the minimal funding for environmental research, lack of adequate researchers and some belief that the environment plays a limited or no role in the health and academic achievements of children. Although there has been school related studies in Nigeria such as: 1) a 2009 research on air pollution and another on noise pollution in and around secondary schools in Ibadan Nigeria and their negative effect on students' health [57,58]; 2) a 2011 study on waste management challenges in secondary schools in Ibadan, Nigeria

[59]; 3) a 2011 investigation on the effect of traffic air pollution on school children's respiratory health [4], and 4) a 2014 study that assess primary school environment[60], none of them measured classroom/school IEQ parameters such as indoor and outdoor temperature, ventilation rates (with CO_2 measurement), CO measurement and cleaning effectiveness. To the best of our knowledge, this is the first study that critically assess with measurements, building condition and IEQ in Nigerian elementary schools.

Although all the school administrators reported their building structure to be in good condition, on-site investigations showed some parts to be in poor condition. These findings point out the usefulness of the application of standardized monitoring methods; identifying existing problems and raising awareness of indoor environmental issues among school administrators and policymakers both on local and regional scales [54].

Looking at the general building condition of the schools investigated, it can be deduced that maintenance and adherence to standards was not usually done. About six of the sampled classes were without ceilings, while those that had ceilings were made of asbestos. According to WHO [61], all types of asbestos exposure are dangerous to health causing asbestosis and different types of cancer (e.g. lung and ovarian). This material was banned from being used in construction several years ago in developed countries but is still being used in Nigeria.

It was alarming to see that only one of the schools studied had functional and effective toilet systems. This is a major problem in developing countries where a lot of sanitation studies have been done [62]. According to WHO [63], only four out of ten Africans have access to a good toilet system. The National building code of Nigeria [64] recommends elementary schools to have one toilet per 35 girls, and one toilet per 100 boys as well as one urinal per 30 boys. In a study by Olatunya et al. [60], about

6% of schools studied had the recommended toilet to pupils' ratio. As observed in this study, the lack of functional toilet systems results in open urination, and it also causes missed school time when students need to defecate. This unhygienic practice may inadvertently lead to the spread of communicable diseases such as noroviruses; as proper sanitation is very important for students' health [65].

In general, none of the buildings investigated had a basement, which is an advantage against moisture damage and mold growth as reported in schools with basements (e.g. [17]). Shallow foundation on the other hand, if not well damp proofed, can cause an upward capillary movement of ground water [66] leading to issues with moisture and mold as seen in one of the schools studied.

It was noted that wall finishing did not exist in some classrooms while those painted had paint peeling. None of the schools had floor covering, the floors were bare concrete and broken, exposing students to re-suspended particulate matter (PM) especially during and after cleaning with brooms. We did not measure the PM concentration in the classrooms. However, students activities as well as cleaning of floors by sweeping with brooms can resuspend PM polluting indoor air and depositing contaminants on students' desks, chairs and possibly food[67]. Children's exposure to all fractions of PM has been associated with respiratory problems[68,69].

Furthermore, most of the classrooms had high levels of clutter which can affect the ability to maintain a clean environment for the occupants of the room. In addition, the clutter items themselves can be a reservoir or amplification site for various contaminants. While privately owned schools sometimes hire professional cleaners for the upkeep of their schools, public school students clean their classroom and school surroundings themselves. This may be partly due to inadequate funding to hire cleaners and the aim to teach children basic cleaning practices at a young age.

Mean indoor RH was usually above 60%, which is often recommended as a maximum due to risks related to dampness and microbial growth [70]. All classrooms had indoor temperatures above the maximum 23°C thermal comfort set point suggested by Andersen and Gyntelberg [23] and between 20°C and 22°C suggested by Salthammer et al. [24] for classrooms. This is against the set point of between 26°C and 29°C suggested by Schiavon et al. [71] for improved performance, whereas according to Lu et al. [20], an indoor temperature of about 31°C is still acceptable for a naturally ventilated room. While the study by Schiavon et al. was done in an academic setting that of Lu et al. was not. The highest overall comfort for students was still achieved at 23°C without fans and 26°C–29°C with fans [71]. Nevertheless, the studied classroom temperatures increased along with an increase in outdoor temperature, with only marginal lower temperatures measured indoors. Some of the classrooms did not have ceilings and those with ceilings may not have enough insulation against the radiating heat from the roof. Another issue is the introduction of warm unconditioned outdoor air through open windows and doors.

Classroom occupancy exceeded ASHRAE standard 62 [72] classroom occupancy of 50 person/100m^2 in all investigated classrooms depicting overcrowding [73]. Overcrowding affects ventilation adequacy, thermal comfort and associates with spread of diseases [73–75].

Use of gasoline-operated generators was likely the cause of the elevated maximum outdoor CO concentration of 23ppm. According to the United States Environmental Protection Agency [76] the maximum concentration for outdoor CO levels should not exceed 35 ppm for 1-hour average and 9 ppm for 8-hour average; this should not be exceeded more than once a year. CO is a colorless, odorless and tasteless gas. The health effect of exposure to CO include decrease in ventilatory/pulmonary function, cardiovascular problems and hematological effects [77]. Long term exposure to CO may also impair the neurological development of children even at low concentration levels [78,79]. It should be noted that the source of the CO emission was closer to the secondary school building block and farther away (about 30 meters) from our point of measurement. It is possible for the concentration to exceed the maximum value closer to the source of emission. Some schools also had an open incinerator for refuse burning.

Investigated classrooms appeared to be adequately ventilated based on CO_2 concentrations, which was in majority of cases lower than 700 ppm above outdoor level (<1000ppm), the adjudged threshold for inadequate ventilation [80]. Maximum indoor CO_2 exceeded this limit in two classrooms from one school (D). The two classes with higher CO_2 concentrations did not have a cross-ventilated window system as described in National building code of Nigeria [64]. In cross-ventilated systems, windows are located approximately on opposite sides of the room, which helps to move air through the building. In addition, CO_2 concentration exceeded 1000 ppm in one classroom of School A, which was on the ground floor and there was a gasoline-operated generator on that floor that possibly impacted CO_2 concentration (about 35 meters). This generator was regularly operated due to frequent power outage.

It was noticed that the minimum CO_2 levels measured were somewhat lower than expected both indoors and outdoors, which could point to a potential calibration issue. The data loggers were tested simultaneously and showed consisted results before starting the data collection, but was not possible to perform testing or calibration in the field conditions. Whereas we do not have reference data for atmospheric CO_2 levels in Nigeria, it could be assumed to be around 400 ppm. Therefore, the possible drifting of the CO_2 levels would be around 50-100 ppm, which would not significantly change our conclusions.

Although ventilation seemed adequate based on CO_2 levels, this was not the case with respect to indoor temperature. While ventilation adequacy has been associated with thermal comfort in previous studies (e.g. [30]), our results are in line with Yang and Zhang [81] and Prajongsan and Sharples [82], who found most of naturally ventilated rooms to have thermal discomfort.

As reported by Olatunya et al. [60], it is likely that most Nigerian elementary schools are naturally ventilated by opening windows and doors. The use of natural ventilation saves energy and subsequently money [83] but there may be some attendant negative effects that may outweigh the benefits. For example, a comparative study of mechanically and naturally ventilated buildings by Wallner et al. [84] found mechanically ventilated buildings to have an all-round better IEQ than those naturally ventilated.

Since the natural ventilation in the studied classrooms provide adequate ventilation but not the required educational thermal comfort, a hybrid ventilation system that is primarily based on natural ventilation but switches to mechanical ventilation during thermal discomfort could improve the conditions[85]. This type of system is energy efficient and helps in achieving an acceptable IEQ[86]. In addition, passive and/or mechanical cooling systems could be considered in this regard. Although mechanical systems are more expensive (both initial and operating costs), they are already used in some offices in Nigeria. Whereas utilizing passive cooling methods could be more realistic and sustainable in a large scale, more studies are needed to find the most optimal approach that could be applied in schools in hot climates.

The pre-cleaning ATP values were comparable to data from elementary schools in southwestern US [50], reporting the trimmed mean log-transformed value of 5.01 (i.e. 102, 300 RLUs) and suggesting reasonable range ≤ 5.37 (i.e. 234, 400 RLUs). Based on our results, three out of five schools were above 234, 400 RLUs. The post-cleaning values ranged from 20, 500 to 206, 000 RLUs. They could be compared to the ISSA Clean Standard for K-12 Schools for classroom desks, which indicates ineffective cleaning when ATP (Charm Sciences system) reading is ≥ 17301 RLUs. Hence, the concentration of ATP was moderately high on all desks tested, including those visually inspected as clean. These results may be affected by the common usage of wooden furniture and the cleaning method used by the schools which likely cause floor dirt to be suspended and settle on desks. The fact that students did not have a cafeteria but ate at their desks, could influence the microbial contamination of the desks by bacteria that feeds on crumbs [87].

The sample size of five schools studied in this work may be the main limiting factor affecting the assessment of IEQ in Nigerian elementary schools. Another factor may be the period of sampling during the dry season which did not cover the entire season range in Nigeria, the rainy season being associated with cooler temperature as compared to the dry season. In addition, sampling was done only in the southwestern part of the country, while temperature range differs as wetness reduces from the south to the northern part of the country. With our findings, an elaborate research that is representative of all Nigerian elementary schools is needed for more robust conclusions.

5 Conclusion

The main issues affecting IEQ in the studied elementary schools include the use of hazardous materials (e.g. asbestos), gasoline-burning generators close to classrooms, inadequate sanitation and maintenance of school facilities, overcrowding, and thermal discomfort. Use of hazardous materials and open incineration should be discontinued, and functional toilets and hand washing facilities provided. Processes that can increase exposure to pollutants (such as sweeping of floors with brooms) should be discouraged and replaced with effective exposure removal techniques (such as vacuuming and wiping of surfaces). Classroom occupancy should conform to standard to avoid overcrowding. Adding hybrid ventilation systems along with passive and/or mechanical cooling should be considered for achieving educational thermal comfort in schools.

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Competing interests

Authors declare no conflict of interest.

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Table 1. Summary of school level characteristics.

Building characteristics	**School ID**				
	A	B	C	D	E
Year of construction	1996	1970s	1958	2000	2006
Number of portable classrooms	0	0	0	0	1
Area of building (m^2)	169	117	276	262	358
No. of students	156	147	263	106	371
No of teachers	8	10	15	10	24
No. of other personnel	6	3	8	8	6
Number of floors	2	2	1	2	1
Repair/structural addition in 5 years	Library (2014)	None	Roof, façade, windows, ceiling, furniture (2011)	Plumbing, furniture (2016)	Portable classroom (2012)
Roof condition	Good	Good	Good	Good	Leaking
Roof material	Sheet metal	Sheet metal	Sheet aluminum	Sheet metal	Asbestos
Ceiling in classrooms/material	None	None	All classes/asbestos	All classes/asbestos	All classes/asbestos
Wall material(s)	Painted concrete	Painted concrete	Painted concrete	Bare concrete	Painted concrete
Wall condition	Deteriorated	Deteriorate	Good	No finishing	Deteriorated
Floor condition	Deteriorated	Deteriorated	Deteriorated	Deteriorated	Deteriorated
Floor cleaning method	Broom (dry floor)	Broom (dry floor)	Broom (dry floor)	Broom (dry floor), mop once a week	Broom (dry floor)
Plumbing and toilet system	None	None	None	Good	None
Moisture damage areas > $1m^2$	Yes	Yes	No	No	Yes
Current signs of visible mold	Yes	Yes	No	No	Yes
Current perception of mold odor	Yes	Yes	No	No	No
Current perception of other odors(s)	Urine, dust	No	No	No	No
Potential sources of pollutant within 10m of fresh air intake	PM from cleaning/ unpaved road, pathogens from unkempt toilet, mold, open urination near classrooms.	PM from cleaning/vehicular emission and unpaved road, pathogens from unkempt toilet, mold, open urination near classrooms.	PM from cleaning activities, emissions from open incinerator, pathogens from unkempt toilet.	PM from cleaning activities.	PM from cleaning activities, emissions from open incinerator, pathogens from unkempt toilet.
Perceived ventilation	Insufficient	Insufficient	Insufficient	Insufficient	Insufficient

Table 2. Classroom level characteristics/observations.

Classroom #	Grade level	Students (N)	Teachers (N)	Floor area [m^2]	Room volume [m^3]	Degree of clutter	Other observations
A1	1	22	1	9.2	27.4	Excessive	Moisture damage and visible mold, odors (mold, urine)
A2	2	18	1	8.8	41.1	Excessive	Odor (dust)
A3	4	20	1	11.5	43.8	Moderate	
B1	2	24	1	11.9	37.2	Moderate	
B2	5	14	1	9.8	30.8	Moderate	Moisture damage and visible mold
B3	3	21	1	8.7	27.9	Excessive	
C1	4	26	1	25.5	150.3	Small	Odor (soot)
C2	4	26	1	25.5	150.8	Small	
C3	3	46	2	25.5	150.8	Small	
D1	5	15	1	10.9	42.6	Excessive	
D2	3	18	1	11	42.7	Excessive	
D3	4	13	1	11	32.2	Excessive	
E1	6	72	3	20.2	123.9	Excessive	
E2	4	81	4	20.2	123.9	Excessive	
E3	3	66	4	20.2	123.9	Excessive	

Table 3. School level descriptive statistics of T, CO_2, CO, RH and ATP measurements in the classrooms and outdoors during school hours.

School	T, °C Mean(Min-Max)	RH, % Mean(Min-Max)	CO_2, ppm Mean(Min-Max)	CO, ppm Mean(Min-Max)	$ATP_{pre,}$ RLU Median	$ATP_{post,}$ RLU Median
A Indoor	29.3(24.9-34.3)	64.1(32.1-88.5)	454(318-1032)	1.1(0.0-6.0)	280666	94769
A Outdoor	31.6(26.1-36.5)	57.1(27.0-84.1)	396(270-1035)	3.6(1.0-23.0)		
B Indoor	29.8(26.1-33.9)	71.9(48.4-85.9)	446(300-851)	0.7(0.0-3.0)	198603	50180
B Outdoor	32.4(27.3-35.2)	62.5(45.1-81.4)	461(362-921)	1.1(1.0-2.0)		
C Indoor	29.8(27.9-32.5)	69.3(57.8-79.0)	377(309-560)	1.0(0.0-2.0)	77797	77730
C Outdoor	31.4(27.3-34.0)	66.3(46.5-81.4)	369(306-404)	3.0(3.0-3.0)		
D Indoor	28.8(25.2-32.6)	60.9(32.0-79.7)	498(333-4229)	0.9(0.0-4.0)	160546	20529
D Outdoor	30.0(26.2-33.0)	57.3(25.5-79.1)	428(398-640)	2.5(2.0-5.0)		
E Indoor	30.4(27.4-33.8)	65.4(50.7-78.6)	489(344-815)	0.9(0.0-3.0)	391411	206010
E Outdoor	31.3(26.8-36.3)	62.3(44.1-81.2)	429(380-571)	2.4(2.0-3.0)		

Figure 1. Some pictures of the physical condition of the classrooms