SCHOOL BUILDINGS AND INDOOR ENVIRONMENTAL QUALITY IN NIGERIAN ELEMENTARY SCHOOLS AND THEIR POTENTIAL HEALTH EFFECTS ON STUDENTS

Oluyemi Olagoke Toyinbo

Master's thesis

Public Health

School of Medicine

Faculty of Health Sciences

University of Eastern Finland

June, 2018

UNIVERSITY OF EASTERN FINLAND, Faculty of Health Sciences

Public health

Toyinbo, Oluyemi O.: School buildings and indoor environmental quality in Nigerian elementary schools and their potential health effects on students

Master's thesis, 74 pages.

Instructors: Ulla Haverinen-Shaughnessy (D.Sc) and Sohaib Khan (PhD)

June 2018

Keywords: IEQ, schools, cleanliness, building characteristics

SCHOOL BUILDINGS AND INDOOR ENVIRONMENTAL QUALITY IN NIGERIA ELEMENTARY SCHOOLS AND THEIR POTENTIAL HEALTH EFFECTS ON STUDENTS

This thesis evaluates the condition of elementary school buildings in Nigeria as well as indoor environmental conditions of the classrooms and their potential health effects on students.

A total of 15 classrooms from five elementary schools were assessed. The conditions prevalent in the classrooms were evaluated on site and indoor/outdoor environmental indicators such as temperature (T), carbon dioxide (CO_2) and carbon monoxide (CO) were measured. Cleaning effectiveness was also assessed on site by measuring adenosine triphosphate (ATP) concentration on students' desk after school hours.

All schools used natural ventilation by opening windows and doors. Classroom occupancy exceeded 50 person/100m^2 in all cases indicating overcrowding. Concentration of CO_2 remained below 1000 ppm in most classrooms: only three classrooms exceeded this limit with two of these classrooms from the same school. Maximum indoor CO was 6 ppm. Indoor T raised during the day mimicking outdoor T. ATP concentrations on desk tops were

moderately high in all schools. The general quality of facilities in the buildings was low (e.g. only one school had functioning toilets).

The use of asbestos as a building material, and the use of open incinerators and power generator sets near classroom, which was the main source of CO, should be discouraged. Students should have access to functioning bathroom facilities and cafeteria. Improving hygiene, for example by cleaning desks and other high contact surfaces, should also be encouraged. Although ventilation seems adequate based on CO_2 concentrations, thermal comfort was not achieved especially in the afternoon during extreme sunlight. Installing passive and/or mechanical cooling systems should therefore be considered in this regard. Based on the literature, exposures to the previously mentioned IEQ issues are associated with increased risk for adverse health effects, including respiratory illnesses, communicable diseases, and general symptoms such as headache and fatigue. These may also cause absence from school and decreased learning.

ABBREVIATIONS

% - Percentage

ASHRAE – American Society of Heating, Refrigeration, and Air Conditioning

ATP – Adenosine Triphosphate

CDC – Centers for Disease Control and Prevention

CO – Carbon Monoxide

CO_2 – Carbon Dioxide

GDP – Gross Domestic Product

HVAC – Heating, Ventilation, and Air Conditioning

IAQ – Indoor Air Quality

IEQ – Indoor Environmental Quality

ISSA – International Sanitary Supply Association

NO_3 – Nitrate

NOx – Nitrogen Oxide

O_3 – Ozone

^oC – Degree Celsius

P – Pressure

PAH – Polycyclic Aromatic Hydrocarbon

PM – Particulate Matter

ppm – Parts Per Million

RH – Relative Humidity

RLU – Relative Light Units

SO_2 – Sulfur Dioxide

T – Temperature

U.S – United States of America

VOCs – Volatile Organic Compounds

WHO – World Health Organization

ACKNOWLEDGEMENTS

I wish to thank the school administrators for their responses, the National Institute for Health and Welfare (THL), Kuopio Finland for providing data loggers for measurement (T, RH, CO_2 and CO), the Indoor Air Program, the University of Tulsa, USA and Charm Sciences for providing ATP measuring device, Wellstate limited for helping with the field work and Mari Turunen for her technical assistance.

I am very grateful to my supervisor Ulla Haverinen-Shaughnessy (D.Sc) for her guidance and making sure that I get all required equipment for the field work. I am also thankful to the co-supervisor Sohaib Khan (PhD) for his kind supervision.

I will forever be grateful to my parents, brothers and friends for always being there for me.

Contents

1 INTRODUCTION

Children usually spend about six hours in school, which expose them to pollutants in their school indoor environment. Although studies have shown the effect of the indoor environment on humans (e.g. Frontczak et al. 2012), there are only a few studies on indoor environmental quality (IEQ) from developing nations including Nigeria (Ayanbimpe et al. 2010, Mustapha et al. 2011). Indoor pollution levels can be higher in developing nations when compared to the developed world (Mustapha et al. 2011).

Exposure to indoor environmental pollutants in schools may have varied impact on the health of the pupils, illness absence, and decreased performance (Mendell & Heath 2005), depending on the type of pollutant, quantity of the pollutants exposed to, duration and frequency of exposure, and associated toxicity of the specific pollutant (Nandasena et al. 2010). Ventilation, thermal conditions (including temperature and humidity), and cleanliness are considered important factors affecting IEQ in school buildings (Haverinen-Shaughnessy et al. 2015). Studies have shown that schools can be contaminated by various indoor pollutants, such as molds, bacteria, allergens, particles, and volatile organic compounds (Zhao et al. 2008, Ayanbimpe et al. 2010).

According to Chen et al. (2011), the concentration of outdoor pollutants diffusing indoors is much higher when direct ventilation such as opening of windows and doors are used, compared to using mechanical ventilation. Most Nigerian elementary schools use direct ventilation by opening windows and doors. There are only a few studies on the effects of ventilation type and thermal comfort on student’s health and academic performance (Mendell et al. 2013, Toyinbo et al. 2016b).

In addition, insufficient cleaning and maintenance of schools and accessories, compounded by the effects of emerging infectious disease agents, can severely change the biodiversity of microorganisms in school buildings thereby affecting students' health. Research has indicated that the rapid spread of infectious diseases in crowded classrooms is associated with the cleanliness of high contact inanimate objects (Jara-Perez & Berber 2000). 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 unseen fraction, substances we term pollutants (i.e. biological, chemical, particulate residues), thereby failing to reduce the burden of exposure and health risk to the building's occupants. A study by Shaughnessy et al. (2013) described a quantitative approach to measure cleanliness in schools using adenosine triphosphate (ATP) as a marker for surface contamination. Another study demonstrated the importance of indoor temperature, ventilation and cleanliness of high contact surfaces such as desks and cafeteria tables on IEQ parameters as well as students' health and learning outcomes (Haverinen-Shaughnessy et al. 2015).

This study will evaluate the current condition of selected elementary school buildings in Nigeria by assessing school facilities, classroom IEQ, and cleaning effectiveness. It will also discuss the potential effects of the school environment on school children's health. The results will inform development of recommendations for improving school environments both locally, nationally, and internationally.

2 LITERATURE REVIEW

2.1 An introduction to Nigeria

Nigeria is a developing country situated in the western part of Africa with a population of about 190 million people, 44% of which are children below the age of 15 (WENR 2017). The country was colonized by Britain and independence was given in the year 1960 (October 1). Currently, there are thirty six states in the country along with a federal capital territory. The country can be divided into different sections based on 1) Three major tribes as Hausa, Ibo and Yoruba 2) Six geo-political zones as South West, South-East, South-South, North-East, North-West and North-Central and 3) two zones of North and South to mention but a few (Ekong et al. 2012). Nigeria has a diverse ethnic groups speaking different languages, but English language is chosen as the national language (Ukiwo 2005; Onwuzuruigbo 2010). Figure 1 shows the map of Nigeria with some major ethnic groups while figure 2 shows the six geo-political zones.

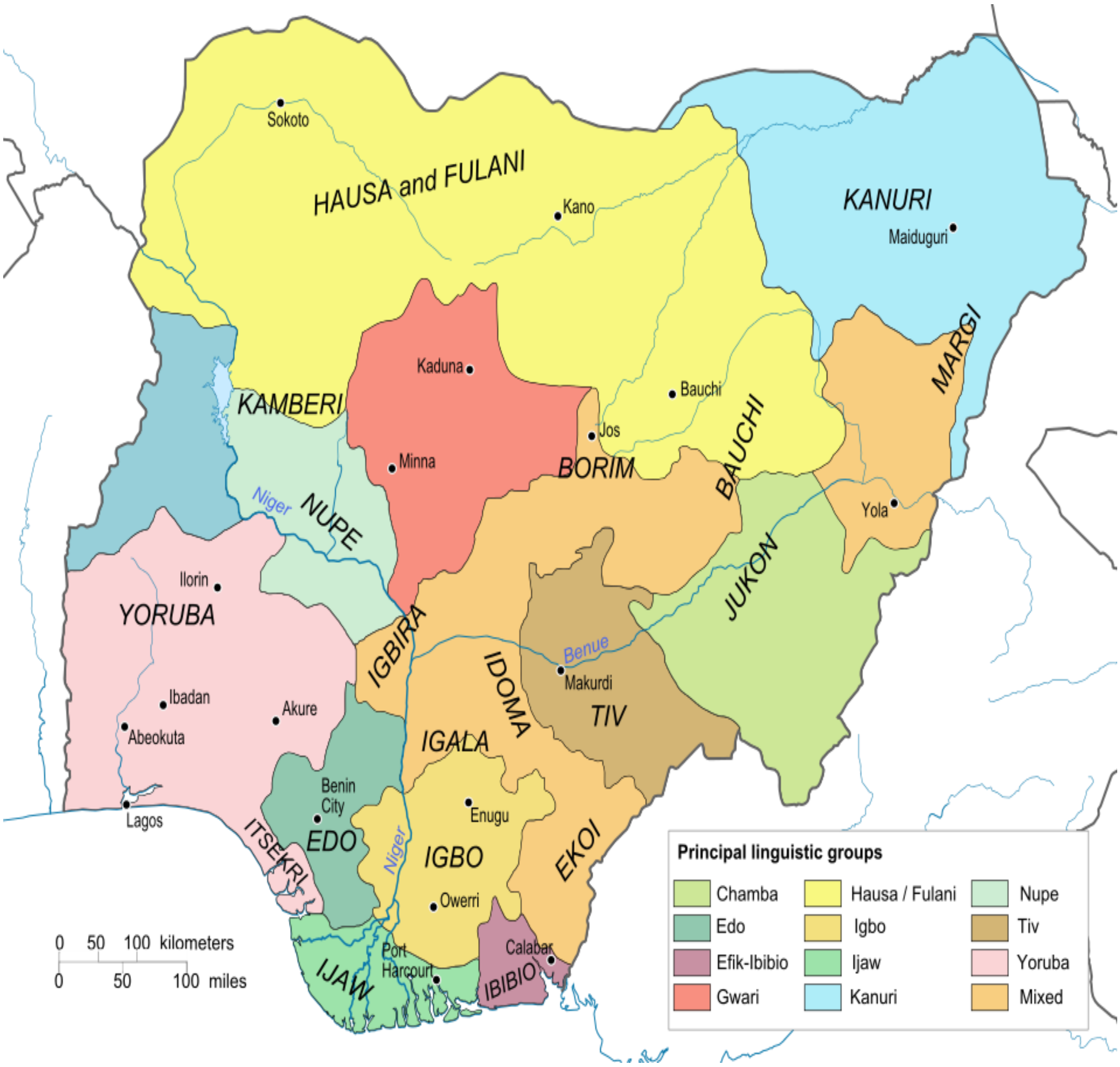

Figure 1. Map of Nigeria showing some major ethnic groups (Wikipedia).

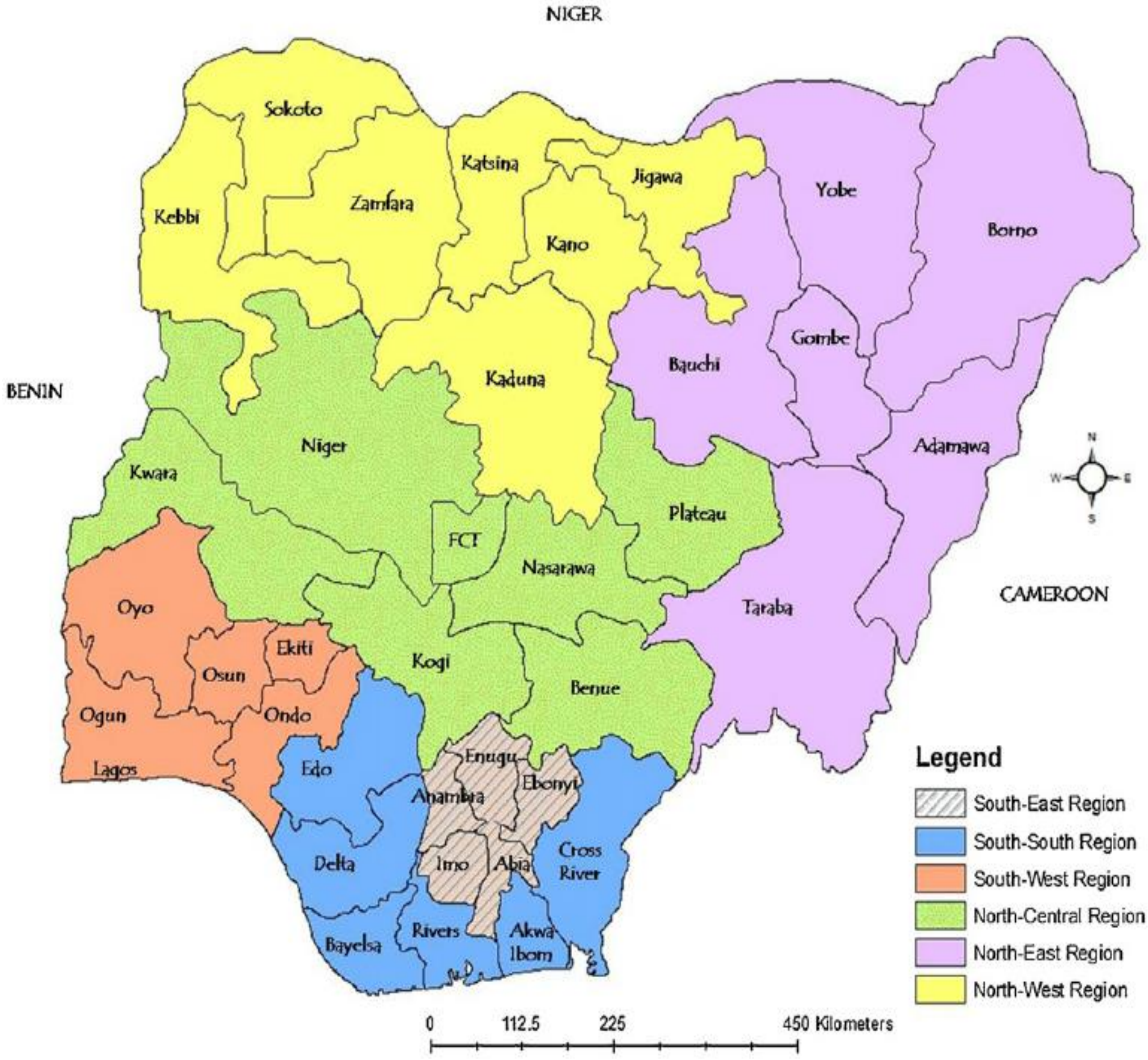

Figure 2. Map of Nigeria showing the six geo-political zones (Ekong et al. 2012).

Nigeria has three tiers of government namely Federal government, 36 states government and 774 local governments (WENR 2017). Almost half of the population live in the urban areas and the majority (60%) of the population work in the agricultural industry (EFA 2015). Nigeria has the largest economy in Africa with gross domestic product (GDP) of about 500 billion U.S dollars. Elementary school education is the responsibility of the local government (WENR 2017).

According to the NEEDs assessment report of the Nigerian educational sector (2014), there are over sixty thousand elementary schools in Nigeria with over twenty million students (EFA 2015). Student to teacher ratio is about 1:60 (UBEC 2012). Nigerian public elementary schools are free (no tuition paid) while private schools charge fees. Inadequate government funding and parents poverty affects early enrollment of children in school (EFA 2015; WENR 2017). This makes Nigeria to have about 9 million children out of school which is the highest in the world (WENR 2017). This can be seen in the disparity in the enrollment rate of students. For example, Nigeria has an enrollment rate into elementary school of 64% which is lower that the world average of 89% (WENR 2017). This have a direct effect on youth and adult literacy that stands at 73% and 60% respectively. This is far below the global average of 91% and 85% respectively (WENR 2017). The educational system in Nigeria follow a 6-3-3-4 system in which students will spend 6 years in elementary/primary school and 3 years in junior secondary school both of which are compulsory (Federal Ministry of Education 2015). The next 3 years will be in senior secondary school while the remaining 4 years will be used for tertiary education. Both senior secondary education and tertiary education are optional (Nuffic 2017).

2.2 Concept of Indoor Environmental Quality in schools

The indoor environment relates to the environment in a building and how it affects the wellbeing of occupants (Sakellaris et al. 2016; Al-Awadi 2018). The indoor environment is complex as several factors acts individually and together to affect it. This include physical factors such as temperature and lighting; chemical factors such as radon and formaldehyde and; biological factors such as mold and bacterial (Cartieaux et al. 2011). Table 1 and figure 3 extracted from Toyinbo (2012) illustrates the different IEQ factors and components respectively.

Table 1. Different physical, chemical, biological and particle factors that affect IEQ (Toyinbo 2012).

Indoor Environmental Quality			
Physical factors	Chemical factors	Biological factors	Particulate matter
Temperature	(Organic) VOCs,	Moulds (fungi)	Dust
	PAH e.g.		
Humidity	Benzo[a]pyrene,	Bacteria	Tobacco smoke
	Formaldehyde		
Air pressure, Air		Plant pollen	Fibres (e.g. asbestos)
movement (draught)	(Inorganic) CO_2,		
	CO, SO_2,NO_x, O_3,	Dust mites	Combustion by-
Lighting	NH_3, Radon		products
		Animal dander	
Noise	(Odours)		
Cleanliness			

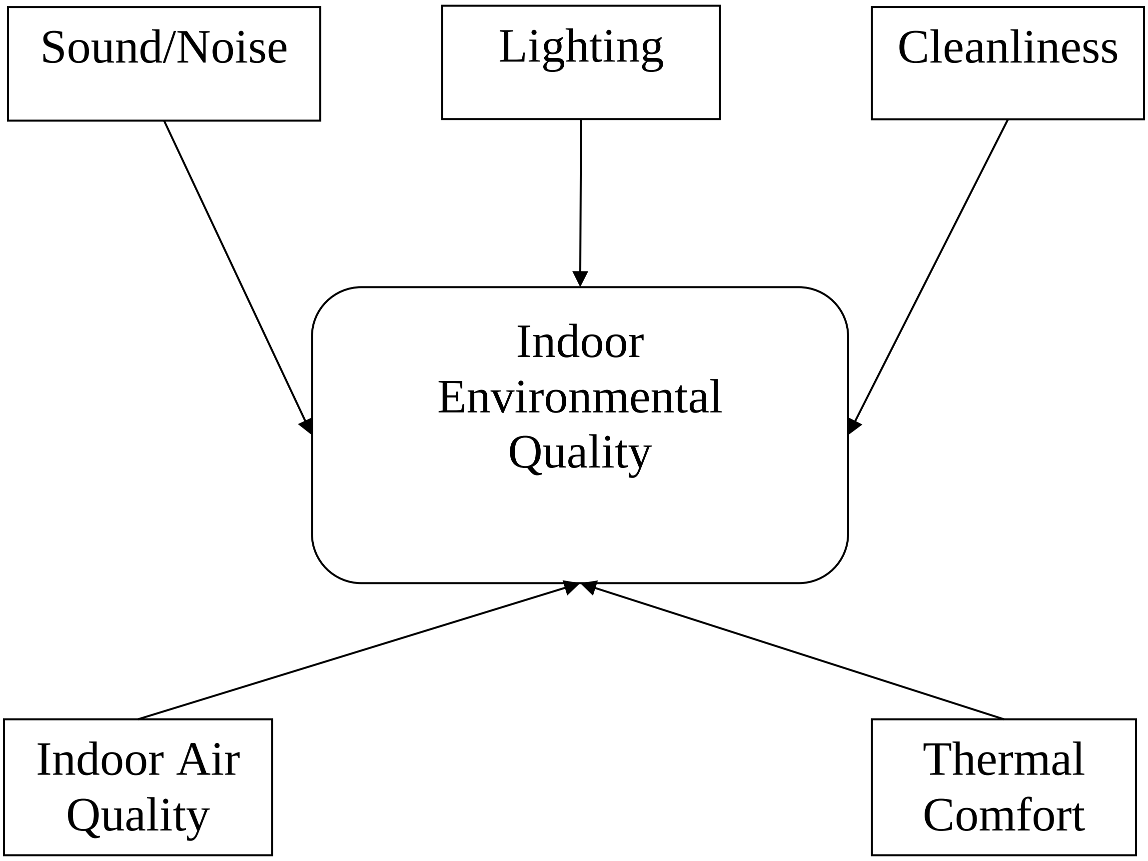

Figure 2. Different components affecting IEQ (Toyinbo 2012).

Research has shown children to be more vulnerable to IEQ issues (Aas et al. 1995). Several studies have shown the impact of the school/classroom environment on students (Turunen et al. 2014; Haverinen-Shaughnessy et al. 2015; Haverinen-Shaughnessy & Shaughnessy 2015; Toyinbo et al. 2016 a & b). The above, along with the amount of time children spend in school studying makes the research on school IEQ an important topic.

Although there are several standards and recommendations by reputable international organizations such as WHO (World Health Organization) and ASHRAE (American Society of Heating, Refrigerating and Air-Condition Engineers) and different countries building codes, this recommendations are sometimes not met. For example, only 44 out of 108 classrooms (41%) met the Finnish building code ventilation rate per student of 6 *l/s per* *student* in a Finnish study (Toyinbo et al. 2016b). In another study by Ferreira and Cardoso (2013), the concentration of CO_2 in studied Portuguese classrooms exceeded the minimum recommendation of 984 ppm.

2.3 Building and Environmental quality studies in Nigerian elementary schools

A literature search was conducted on the above topic on Google Scholar and PUBMED using different search iteration such as 1) indoor air in Nigeria schools; 2) indoor environmental quality in Nigeria schools; 3) environmental quality in Nigeria schools; 4) ventilation in Nigeria schools; 5) temperature in Nigeria schools; 6) thermal comfort in Nigeria schools; and 7) building in Nigeria schools. A few published articles that relate to environmental qualities in Nigerian primary schools were retrieved through the search. This include a 2008 study by Ekpo et al. (2008) on hygiene conditions and helminth infection of primary school students in Ogun state Nigeria; a study by Mustapha et al. (2011) on the effect of risk factors such as traffic air pollution on respiratory illness in school children in the Niger-Delta area of Nigeria; a study by Adedoja et al. (2015) on intestinal helminths infection of primary school students in Kwara state Nigeria; a study by Ayanlowo et al. (2014) on the prevalence of *Tinea Capitis* among primary school pupils in Ogun state Nigeria; and a study by Olatunya et al. (2014) that assess primary school environment in a local government area of south western Nigeria.

With the above, it can be said that there are very limited scientific studies on indoor environmental quality in Nigeria elementary schools even though over 20 million children are in Nigerian primary schools (EFA 2015). The lack of adequate research may be related to lack of interest in the topic by researchers. It may also be due to inadequate funding for research as well as the lack of environmental health researchers in this field.

2.4 Ventilation and thermal comfort

Ventilation is the process of replacing stale air in any space with cleaner air (Patton et al. 2016). This exchange of air usually occur between the outdoor and the indoor environment. This can be done naturally through the opening of doors, windows and sometimes through cracks and other building openings, or mechanically through the installation of mechanical equipment (Aflaki et al. 2015). While mechanical ventilation is expensive to run because of its use of energy, natural ventilation usually has a low operational costs (Tong et al. 2017).

Ventilation rate in naturally ventilated building depends on the airflow rate of outdoor air. This may result to inadequate ventilation when wind speed is low or overventilation when wind speed is high (Chu et al. 2015). The air is not filtered or conditioned; this may encourage the introduction of outdoor pollutants into the indoor environment especially in highly polluted areas such as those near to high volume traffic or uncontrolled incinerators (Amram et al. 2011). But in an environment with limited pollution, natural ventilation can be utilized to provide a constant exchange of air that dilutes and remove the build-up of indoor pollutants such as bacterial, mold and CO_2 (Joshi 2008).

Mechanical ventilation on the other hand uses a force technique in providing air exchange. Energy dependent mechanical plant(s) are used to drive air with air flow rate being dependent on the strength/force rate of the plant (WHO 2009). Mechanical ventilation system can either be a mechanical supply and exhaust ventilation system in which fresh air is mechanically introduced indoor and stale air is mechanically removed, or a mechanical exhaust ventilation system in which only stale air is mechanically removed from the indoor environment (Niachou et al. 2005). The speed/airflow rate are sometimes adjustable to give a specific or desired ventilation rate. In commercial buildings such as schools, air is sometimes recirculated and/or outdoor air intakes blocked to reduce energy cost and also to quickly achieve desired thermal condition (Martin 2014). Air recirculation may encourage the build-up of pollutants indoor. Air recirculation can also make indoor CO_2 to increase when oxygen used for metabolic activities become depleted and not replaced (Jurado et al. 2014). This can encourage sick building syndrome (Joshi 2008). Some HVAC (Heating Ventilation and Air condition) systems may have filters for pollutants (e.g. dust) removal, although filters may not be able to remove biological pollutants such as bacterial (Schmidt et al. 2012).

Adequate ventilation of a building is expected to help replenish indoor oxygen while simultaneously reducing indoor CO_2 and other bioeffluents due especially to metabolic activities (Rosbach et al. 2013; Gaihre et al. 2014). It is also expected to reduce the concentration of indoor pollutants such as bacterial, mold and odor and regulate indoor temperature to comfort level (Smedje et al. 2017).

Studies have also shown ventilation to affect indoor temperature with rooms adequately ventilated having thermal comfort and vice versa (e.g. Sekhar 2016). Thermal comfort refers to the feeling of people in their thermal environment (ASHRAE Standard 55 2004; Lu et al. 2015). Thermal comfort is affected by some environmental and personal factors such as radiant temperature, air speed, humidity, air temperature, clothing material/insulation and metabolic rate (Daghigh 2015). For example, the material and the number of clothes worn can affect the body heat stress. So can also the radiant heat from the environment such as those from the sun and electrical equipment (e.g. printers).

2.5 Ventilation and thermal comfort in schools

There are standards set for ventilation adequacy as well as for thermal comfort in schools. The standards are set for ventilation rate per person/per area by international organizations such as ASHRAE, and building codes of different countries. Ventilation adequacy can also be estimated with indoor CO_2 level. For example, ventilation rate per student should not be lower than 7.1 *l/s-person* in U.S schools (Batterman 2017) while ventilation per student and per area of classroom should not be lower than 6 *l/s-person* and 3 $l/s/m^2$ in Finnish schools respectively (National Building Code of Finland 2005). For schools in Portugal, the maximum acceptable in CO_2 concentration is 984 ppm (Ferreira & Cardoso 2013).

ASHRAE standard 55 recommended 80% of building occupants to agree with their thermal environment for thermal comfort to be achieved. This comfort level was reviewed to 85% (at a temperature below 24^oC) in a study by Andersen and Gyntelberg (2011). In that study (Andersen and Gyntelberg 2011), classroom indoor temperature was suggested to be 23^oC or lower in classrooms for thermal comfort to be achieved by students. This agreed with a 2016 study by Salthammer and colleagues (2016) that gave a range of acceptable classroom temperature of 20-22^oC. Nevertheless, indoor temperature should not be lower than 18^oC (WHO 2007).

Studies like Haverinen-Shaughnessy et al. (2011), Ferreira & Cardoso (2014), Toyinbo et al. (2016b), Madureira et al. (2016) and Batterman (2017) have shown ventilation to be insufficient in many school classrooms. A low ventilation in classroom is associated with the type of HVAC, school building model and condition, weather condition especially in naturally ventilated school building and sometimes overcrowding in classrooms (Smedje & Norbäck 2000; Al-Rashidi et al. 2012; Fadeyi et al. 2014). Some of these studies also show a concurrent thermal discomfort associated with inadequate ventilation (e.g. Toyinbo et al. 2016b).

The influence of ventilation and temperature on students have been documented in literature. Inadequate ventilation which is related to a high classroom CO_2 levels was found to increase student absenteeism (Shendell et al. 2004; Annesi-Maesano et al. 2013; Mendell et al. 2013). It can also affect students' concentration in classroom as well as their cognitive performance (Hutter et al. 2013; Ferreira & Cardoso 2014). A low ventilation rate in classroom is related to asthmatic symptoms caused by a lower respiratory function (Smedje & Norbäck 2000; Sundell et al. 2011).

Thermal discomfort in classroom on the other hand may result to heat stress which can cause inconvenience and can make students to miss school (Annesi-Maesano et al. 2013). It can result to students getting easily tired and losing concentration during classes (Bidassey-Manilal et al. 2016), being drowsy and having headaches and other health outcomes such as eye symptoms and respiratory problems (Mi et al. 2006; Andersen & Gyntelberg 2011; Annesi-Maesano et al. 2013).

2.6 Cleanliness and hygiene in schools

Children come in contact with one another more than adults and the space they occupy for study is usually crowded. This along with the fact that pollutants as well as microbes related to unhygienic conditions affect children more than adult makes cleanliness and hygiene in school an important issue. According to the Centers for Disease Control and Prevention (CDC 2016), contact surfaces such as desk, doors and toilets systems can be contaminated with microbes and needs regular cleaning and/or disinfecting. In addition to the above, schools should have an efficient waste disposal system with hand washing points to encourage hand washing by students (Priest et al. 2014; Johansen et al. 2015; Jordanova et al. 2015).

In view of the above, effective cleaning practices is lacking is some schools. This may be related to the lack of understanding the need for personal hygiene by students (Sarkar 2013) as well as inadequate supervision and maintenance of school facilities (Chatterley et al. 2014). In a study by Marja & Gur (2010), about 50% of schools studied in India had effective toilet systems while 40% of the schools had waste disposal system problems. Overcrowding of classroom was another problem affecting about 90% of the schools studied (Marja & Gur 2010). A similar problem was realized in a study by Chatterley et al. (2014) where up to 95 students use a toilet in Bangladesh schools. Some of these schools also lack hand washing places (Chatterley et al. 2014). Inadequate toilet systems coupled with lack of water may encourage open defecation as reported by Xuan et al. (2012).

2.7 Indoor environmental quality, students' health and wellbeing

The different indoor environmental factors/components in school can influence students' health by either causing or exacerbating a health outcome since higher concentration of indoor pollutants are sometimes observed in schools than in homes (Permaul et al. 2012). Students' wellbeing in term of comfort as well as their learning performance can also be affected (Bakó-Biró et al. 2012; Turunen et al. 2014). Examples of health outcomes related to the school environment includes asthmatic symptoms among pupils (Zhao et al. 2008), influenza virus (Koep et al. 2013), wheezing (Ferreira & Cardoso 2014), rhino-conjunctivitis (Annesi-Maesano et al. 2012) and breathlessness (Kim et al. 2007).

A low humidity in classroom was related to an increase influenza virus transmission during the winter months as shown by Koep et al. (2013). Humidification of the indoor environment is therefore essential in this regard to curtail viral spread (Myatt et al. 2010; Koep et al. 2013; Metz & Finn 2015). A 2012 study by Annesi-Maesano and colleagues found associations between the prevalence of asthma in school children and high concentration of particulate matters ($PM_{2.5}$), Nitrogen dioxide (NO_2) and aldehyde with odd ratios (OR) 1.21; 95% CI 1.05-1.39, 1.16; 95% CI 0.95-1.41 and 1.22; 95% CI 1.09-1.38 respectively. The study also associated the occurrence of formaldehyde in the schools studied with rhino-conjunctivitis in pupils (OR 1.19; 95% CI 1.04-1.36). In another study by Mi et al. 2006, thermal comfort was found to affect daytime breathlessness in students (OR 1.26: $P < 0.001$), asthma attack was related with mold (OR 2.40: $P < 0.05$) while current asthma associated with both CO_2 and NO_2 (OR 1.18 for 100 ppm: $P < 0.01$ and OR 1.51 for 10 μg/m^3: $P < 0.01$ respectively). A school study of 2000 pupils in China found 30% of the students to have daytime breathlessness while 8 and 2% had wheezing and asthma respectively (Zhao et al. 2008). Breathlessness as well as wheezing by students were found to be related to Sulfur dioxide (SO_2), NO_2 or formaldehyde in schools.

Students comfort can also be affected by unfavorable indoor environmental quality. For example, thermal discomfort in school may result to loss of concentration of students due to tiredness and sleepiness (Bidassey-Manilal et al. 2016). Absenteeism may increase due to inadequate ventilation (Mendell et al. 2013; Gaihre et al. 2014), exposure to PM (Macnaughton 2017) and thermal discomfort (Mendell & Heath 2005).

In addition to the above, IEQ can affect students learning outcomes as shown in the following studies. An increase in classroom ventilation by 1 *l/s per person* increased mathematics and reading achievements of students by 2.9% (95%CI 0.9-4.8%) and 2.7% (95% CI 0.5-4.9%) respectively (Haverinen-Shaughnessy et al. 2011). In another study by Haverinen-

Shaughnessy & Shaughnessy (2015), 1 *l/s per student* increase in ventilation and 1^{o}C reduction in temperature increased students test score in mathematics by 0.5%. A similar result was presented by Toftum et al. (2015) where students in classrooms with higher ventilation rates had better academic performance with 1.45% relative difference $P < 0.05$.

3 OBJECTIVES OF THE STUDY

Aims of the project are to

1. Assess the effects of different school building characteristics, maintenance and cleaning practices on school indoor environmental quality in Nigeria.

2. Determine if the ventilation rates and temperatures in schools are in agreement with that stipulated by different international standards such as WHO, ASHRAE, and Nigeria building code regulations.

3. Study the potential health effects related to the school environment based on the existing literature.

4 MATERIALS AND METHODS

Nigeria is a tropical country in West Africa with two distinct weather conditions (rainy and dry seasons) but the period varies according to location. The schools included in the study are located in South-Western Nigeria. There are six states in this region which include; Oyo, Osun, Ondo, Ogun, Lagos and Ekiti state. The rainy season period is from March to October while that for dry season is from November to February. Rainy season is associated with wetness due to rainfall. Dry season is a period associated with heat due to dryness and enormous amount of sunlight.

A total of five Nigerian schools were investigated during the dry season. Three schools are located in Ibadan city in Oyo State while the other two schools are located in Osun State (one in Ipetumodu and another in Ile-Ife). Three of the schools are privately owned while the other two are owned by the State government. The investigations were done using the same protocol in all schools during a normal school week between December 2016 and January 2017.

Three classrooms from each school were randomly selected for on-site investigation, which included measuring classroom dimension, 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, and assessing waste and sewage disposal methods.

Indoor and outdoor temperature (T) and relative humidity (RH) were measured with CEM DT-172 data loggers, while carbon dioxide (CO_2), carbon monoxide (CO) and atmospheric pressure (P) were measured with Delta OHM HD21AB data loggers from three representative classrooms per school for at least one day. The data loggers were set to log at 1-minute interval. Logging started at least 30 minutes before students arrived to the class in the morning, and ended at least 30 minutes after the school hours. Corresponding outdoor measurements were also taken. Data loggers were set in schools between 6.00 and 7.00am. Students and staff typically resume some minutes past 7.00am for school assembly, which ends some minutes before 8.00am. Normal classroom activities start by 8.00am and ends by 2.00pm except for Fridays when schools close by 1.00pm. Some schools may close around 12.00pm during examination period.

Pre- and post-cleaning data from the same classrooms were collected from student desks after school hours by swab. A minimum of 10 pre-and 5 post-cleaning samples were collected per school and analyzed to detect and quantify ATP with NovaLUM system (Charm Sciences, Inc., Lawrence, Kans.). Desk surfaces were swabbed with $25cm^2$ designed 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 in Shaughnessy et al. (2013) 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 initial project plan included the collection of students' health outcomes with validated health questionnaire. This was shelved due to some bureaucracy in granting ethical approval, coupled with the limited time available for data collection. Health related outcomes pertaining to the results are therefore reviewed in the discussion section of the thesis.

The data was 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).

5 RESULTS

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

5.1 School A

School A is a privately owned primary school located in Ile-Ife town in Osun State Nigeria. The school was constructed in 1996. It consists of two pairs of buildings, one with two floors and one with a single pair. The school has primary and secondary school sections. The primary school classrooms under investigation were located in one of the buildings with two floors.

According to the head teacher of school A, there has been no air quality complaints in the past five years. There was also no water, structural or other damage incidents reported, and the only replacement/repair done during this time was a structural addition of a library and replacement of some furniture in 2014. During walkthrough, ventilation was perceived insufficient especially in the afternoon with air feeling stuffy. In general, the floors and walls appeared to be in poor condition, with signs of flaking and moisture damage observed. None of the classrooms in the school have ceilings. Furniture in the classrooms are made of wood and appeared to be in good condition. Two to three students share a desk. There was no effective plumbing system and hand washing facilities in the building. Students engage in open urination while latrines are unkempt. Some classrooms in the first floor have urine odor. Moisture damage and mold presence was located at the base of the building depicting an upward capillary movement of water from the foundation. The school had a gasoline-operated generator set on standby in case of power outage. The generator set served only the administrative section of the building. The generator set was nearer to the building housing secondary school students.

The three classrooms sampled in the school were occupied by primary school students in grades 1, 2 and 4. Classroom #1 was situated on the ground floor and the other two classrooms studied were on the second floor. All classroom floors were made of concrete with no floor covering. The floors were broken and showing some sand/fine broken concrete. The floors were cleaned daily with locally made brooms. While the pupils cleaned classroom #3 once a day, classrooms #1 and #2 were cleaned as needed during the school hours by cleaners. This method was employed to keep younger children's classrooms always clean.

5.2 School B

School B is a private school situated in Ipetumodu in Osun State. The school had one building with two floors. The building design suggests the year of construction to be in the 1970s. Information from the administrative staff shows that there has been no damage, renovation and/or structural addition to the building in 5 years. They complained of periodical waste burning by neighbors, which sometimes affects the air quality. The investigator felt the air in most of the classrooms was stuffy, and there were many students per class. The stuffiness increased in the afternoon. Almost half of the building was decked with wood and the other half with concrete. There was no ceiling in most of the classrooms and classroom floors and walls were broken. There was no plumbing system in the school as the students and staff used pit toilet. Students also openly urinate in open space. There were signs of visible mold growth in the building especially at the region decked with wood. Cleaners with brooms exclusively perform cleaning of classrooms two to three times a day. The whole building looked dilapidated and in need of urgent renovation.

Primary school students in grade 2, 5 and 3 occupied the sampled classrooms. Classroom # 1 and 3 was situated on the second floor while # 2 was on the first floor. Less than half of classroom #1 had ceiling, #2 and 3 had no ceiling. The floor of class #1 was made of wood which showed some mold growth, the other classroom floors were made with concrete which was broken, discharging sand and concrete residues.

5.3 School C

This is a state government owned school situated in Ibadan City. The school was originally constructed in 1958 and there had been several renovations and additions to the building. The most recent large-scale renovation in 2011, included structural additions of more classrooms, repair/replacement of roof, building façade, windows, ceiling, painting, furniture and building foundation. The school had a large environment with sand cover, where students play football and perform other sports activities. Burning of waste was done periodically in the school compound. Air quality complaints were regular during incineration and sport activities. In addition to the above, ventilation as a whole was perceived insufficient with the inherent thermal discomfort resulting from sunshine. None of the classrooms had floor covering and classroom floors were broken but the ceilings and walls were in good condition. The ceilings were made of asbestos.

Classroom furniture were made of wood. Chairs are shared between pupils. There was no working sewage, plumbing and handwashing system in the school. The toilets were in bad shape and unusable. This encouraged open urination and missed periods in school (pupils had to take time to defecate). Exclusively, students performed cleaning of the classrooms and the surrounding environment with brooms. This was usually done once a day.

5.4 School D

This school was situated in Ibadan city, privately owned and built in 2000. The school had two buildings with two floors. One of the buildings accommodated elementary school students while the other was for secondary school students. The three investigated classrooms were on the second floor. There had not been any major renovations since the school building was constructed except for the repair of the plumbing system and replacement of some furniture in 2016. According to the school principal, there had not been any air quality complaints in the school for 5 years. There was also no water, fire or any other damage to the school in 5 years. During the walkthrough, classroom ventilation was perceived insufficient. Some classrooms were not cross-ventilated. For example, while classroom # 1 had windows directly opposite one another for cross ventilation, classroom # 2 had a set of windows facing the door that led to a common building corridor. Classroom # 3 on the other hand had two sets of windows adjacent to each other. The school building/classroom walls/floors had no external finishing. For example, classroom floors were bare concrete and walls were not painted. All classrooms had ceiling made of asbestos. The roof of the building was also made of asbestos.

The level of clutter (the level of clutter relates to the amount of space present in the classroom for regular movement) in all elementary classrooms seemed excessive with very little space between students' desks. In most classrooms, students sat alone and most furniture were made of plastic. School building facilities such as furniture, ceiling, walls, plumbing and sewage system were in good condition but floors were broken. Each classroom had a bathroom equipped with toilet system that was well managed. School-hired cleaners cleaned the bathrooms as well as the classrooms at least once a day. Sweeping of classrooms was performed once a day, while mopping with water was performed once a week.

5.5 School E

School E was also situated in Ibadan city. It is owned by the state government and constructed in 2006. The school had three buildings with one of the buildings being a portable classroom. All buildings were used for classes by elementary pupils. The school personnel had not noticed any air quality problem in years. The building with a portable classroom was added in 2012 while another building was constructed in 2014, adding to the lone building being formally used by pupils.

Some parts of the building such as the walls, roof and classroom ceilings appeared to be in good condition. There seemed to be water damage and mold growth in one of the building's outdoor ceiling suggesting roof leakage. There was peeled paint on the walls of the oldest building and all classrooms floor had some cracks. All ceilings were made with asbestos. There was a lack of appropriate plumbing and toilet system in the school. Pupils therefore had to urinate outside and had to go home to defecate. The students performed the cleaning of classrooms and surrounding environment once a day in the morning with brooms. The school also had an open incinerator for burning of waste.

5.6 Summary of results from observations and measurements

Table 2 summarizes the school level characteristics from all schools, and Table 3 presents classroom level characteristics/observations.

Table 2. School level characteristics from all schools.

Building characteristics	Response				
	School A	School B	School C	School D	School E
Year of construction	1996	1970s	1958	2000	2006
Number of portable classrooms	0	0	0	0	1
Area of building (m^2)	169.05	117.11	275.52	261.62	357.74
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
Predominant mainframe structure	Masonry	Masonry	Masonry	Masonry	Masonry
Predominant flooring material in hallway	Concrete	Concrete/hardwood	Concrete	Concrete	Concrete
Predominant flooring material in classrooms	Concrete	Concrete/hardwood	Concrete	Concrete	Concrete
Type of roof	Ridge	Ridge	Ridge	Ridge	Ridge
Good roof condition	Yes	Yes	Yes	Yes	No (leaking)
Roof material	Iron sheet	Iron sheet	Aluminum sheet	Asbestos	Iron sheet
Wall covering	Concrete	Concrete	Concrete	Concrete	Concrete
Wall finishing	Paint	Paint	Paint	None	Paint
Wall condition	Paint peeling & moisture damage.	Broken wall, moisture damage & mold.	Good	No wall finishing.	Paint peeling.
Track off mat at primary entrance	No	No	No	No	No
Track off mat at secondary entrance (from the playground)	No	No	No	No	No
Cafeteria	No	No	No	No	No
HVAC system type	Natural ventilation	Natural ventilation	Natural ventilation	Natural ventilation	Natural ventilation
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.
Can ventilation be altered?	No	No	No	No	No
Is a Humidifier/dehumidifier present?	No	No	No	No	No
Type of heating source	None	None	None	None	None
Moisture damage/wet building materials >1m^2	Yes	Yes	No	No	Yes
Current sign of visible mold	Yes	Yes	No	No	Yes
Current perception of mold odor	Yes	Yes	No	No	No
Current perception of other odors	Yes (Urine, dust)	No	No	No	No

Table 3. Classroom level characteristics/observations.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
SCHOOL A														
1	1	22	1	9.2	27.4	Concrete	None	None	Yes	Yes	Yes	Yes (Urine)	Excessive	No
2	2	18	1	8.8	41.1	Concrete	None	None	No	No	No	Yes (Dust)	Excessive	No
3	4	20	1	11.5	43.8	Concrete	None	None	No	No	No	No	Moderate	No
SCHOOL B														
1	2	24	1	11.9	37.2	Hardwood	Hardboard	Paint	No	No	No	No	Moderate	No
2	5	14	1	9.8	30.8	Concrete	None	Paint	Yes	Yes	No	No	Moderate	No
3	3	21	1	8.7	27.9	Concrete	None	None	No	No	No	No	Excessive	No
SCHOOL C														
1	4a	26	1	25.5	150.3	Concrete	Asbestos	Paint	No	No	No	Yes (Soot)	Little	No
2	4b	26	1	25.5	150.8	Concrete	Asbestos	Paint	No	No	No	No	Little	Yes
3	3	46	2	25.5	150.8	Concrete	Asbestos	Paint	No	No	No	No	Little	No
SCHOOL D														
1	5	15	1	10.9	42.6	Concrete	Asbestos	None	No	No	No	No	Excessive	No
2	3	18	1	11.0	42.7	Concrete	Asbestos	None	No	No	No	No	Excessive	No
3	4	13	1	11.0	32.2	Concrete	Asbestos	None	No	No	No	No	Excessive	Yes
SCHOOL E														
1	6	72	3	20.2	123.9	Concrete	Asbestos	Paint	No	No	No	No	Excessive	No
2	4	81	4	20.2	123.9	Concrete	Asbestos	Paint	No	No	No	No	Excessive	No
3	3	66	4	20.2	123.9	Concrete	Asbestos	Paint	No	No	No	No	Excessive	No

I = Grade level; II = Number of students; III = Number of teachers; IV = Area of classroom (m^2); V = volume of classroom (m^3); VI = Flooring material; VII = Ceiling material; VIII = Wall finishing IX = Current moisture/water damage; X = Current sign of visible mold
XI = Current perception of mold odor; XII = Current perception of other odors; XIII = Degree of clutter (1 = little, 2 = moderate, 3 = excessive); XIV = Is ventilation perceived sufficient?

All schools investigated employed natural ventilation by leaving windows and doors open. None of them had a basement in their school building and they all had shallow foundations. None of them had a kitchen, cafeteria, sports or assembly hall. Assembly and sports was done outside in open space and only two schools (A and D) had those spaces paved. All sampled classrooms were free of cleaning supplies and other chemicals. They were also free from plants, toys and animals. In schools A and B, classroom 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 in the afternoon.

Table 4 shows the descriptive statistics of T, CO_2, CO, RH and P in the classroom during school time. The minimum mean indoor T was 28^{o}C. This was measured in school D classroom 1 while the maximum mean indoor T was 31^{o}C in school E classroom 2. The corresponding minimum and maximum mean indoor CO_2 were recorded in school C classroom 1 (363 ppm) and school D classroom 2 (553 ppm) respectively. The maximum recorded indoor T, RH and CO_2 are 34.3 (school A classroom 3), 88.5% RH (school A classroom3) and 4229 ppm (school D classroom 2) respectively.

In schools where measurements were taken for two days, the outcome was similar and correlated as shown in Figure 4. One-day measurement was therefore used for T and RH and also time and CO_2 graph in figures 5 to 14 in the appendix. Some images showing the physical condition of the classrooms are shown in figure 15 in the appendix.

Table 4. Descriptive statistics of T, CO_2, CO, RH and P in the classroom during school time.

	Mean(Min.-Max) T °C	Mean(Min.-Max) RH %	Mean(Min.-Max) CO_2 ppm	Mean(Min.-Max) CO ppm	Mean(Min.-Max) Patm (hPa)
SCHOOL A					
1	29.0(26.8-30.9)	64.9(42.2-77.8)	514(363-1032)	1.9(1.0-4.0)	979(976-980)
2	29.4(24.9-33.1)	63.8(34.7-84.5)	458(363-881)	1.4(1.0-6.0)	978(976-980)
3	29.6(25.0-34.3)	63.6(32.1-88.5)	389(318-583)	0.1(0.0-2.0)	980(977-981)
Outdoor	31.6(26.1-36.5)	57.1(27.0-84.1)	396(270-1035)	3.6(1.0-23.0)	980(977-981)
SCHOOL B					
1	28.8(27.2-30.9)	75.4(59.9-83.7)	479(346-851)	1.0(1.0-3.0)	981(979-982)
2	30.2(26.8-33.9)	70.0(48.5-85.7)	443(327-654)	1.0(0.0-2.0)	980(977-982)
3	30.3(26.1-33.8)	70.4(48.4-85.9)	416(300-716)	0.0(0.0-0.0)	982(979-983)
Outdoor	32.4(27.3-35.2)	62.7(45.1-81.4)	461(362-921)	1.1(1.0-2.0)	982(979-983)
SCHOOL C					
1	29.7(28.0-32.4)	69.2(58.4-77.7)	363(332-490)	2.0(2.0-2.0)	983(982-983)
2	30.1(28.2-32.5)	68.7(57.8-78.0)	403(309-560)	1.0(1.0-1.0)	983(983-984)
3	29.7(27.9-32.1)	70.1(58.9-79.0)	365(326-443)	0.0(0.0.0.0)	985(984-985)
Outdoor	31.4(27.3-34.0)	66.3(46.5-81.4)	369(306-404)	3.0(3.0-3.0)	984(984-984)
SCHOOL D					
1	28.0(26.0-32.6)	61.1(32.0-79.7)	422(333-884)	1.6(0.0-4.0)	982(979-983)
2	29.6(27.7-31.9)	59.2(34.6-71.2)	553(336-4229)	1.2(1.0-2.0)	982(979-983)
3	28.7(25.2-31.5)	62.5(36.8-79.5)	519(356-1770)	0.0(0.0-1.0)	983(981-984)
Outdoor	30.0(26.2-33.0)	57.3(25.5-79.1)	428(398-640)	2.5(2.0-5.0)	983(981-984)
SCHOOL E					
1	30.5(27.4-33.2)	64.6(51.8-78.5)	488(364-815)	1.5(1.0-3.0)	986(984-988)
2	30.7(27.6-33.8)	64.8(50.7-78.6)	481(344-658)	1.3(1.0-2.0)	987(985-988)
3	30.0(27.5-32.2)	66.9(52.2-78.2)	499(357-612)	0.0(0.0-0.0)	988(986-989)
Outdoor	31.3(26.8-36.3)	62.3(44.1-81.2)	429(380-571)	2.4(2.0-3.0)	988(986-989)

Table 5 shows the median results of ATP sampling and desk cleaning effectiveness. Table 6 in the appendix shows the full result of ATP sampling.

Table 5. Median ATP levels on desk tops.

School	Pre-cleaning ATP [RLU]	Post-cleaning ATP [RLU]
A	280666	94769
B	198603	50180
C	77797	77730
D	160546	20529
E	391411	206010

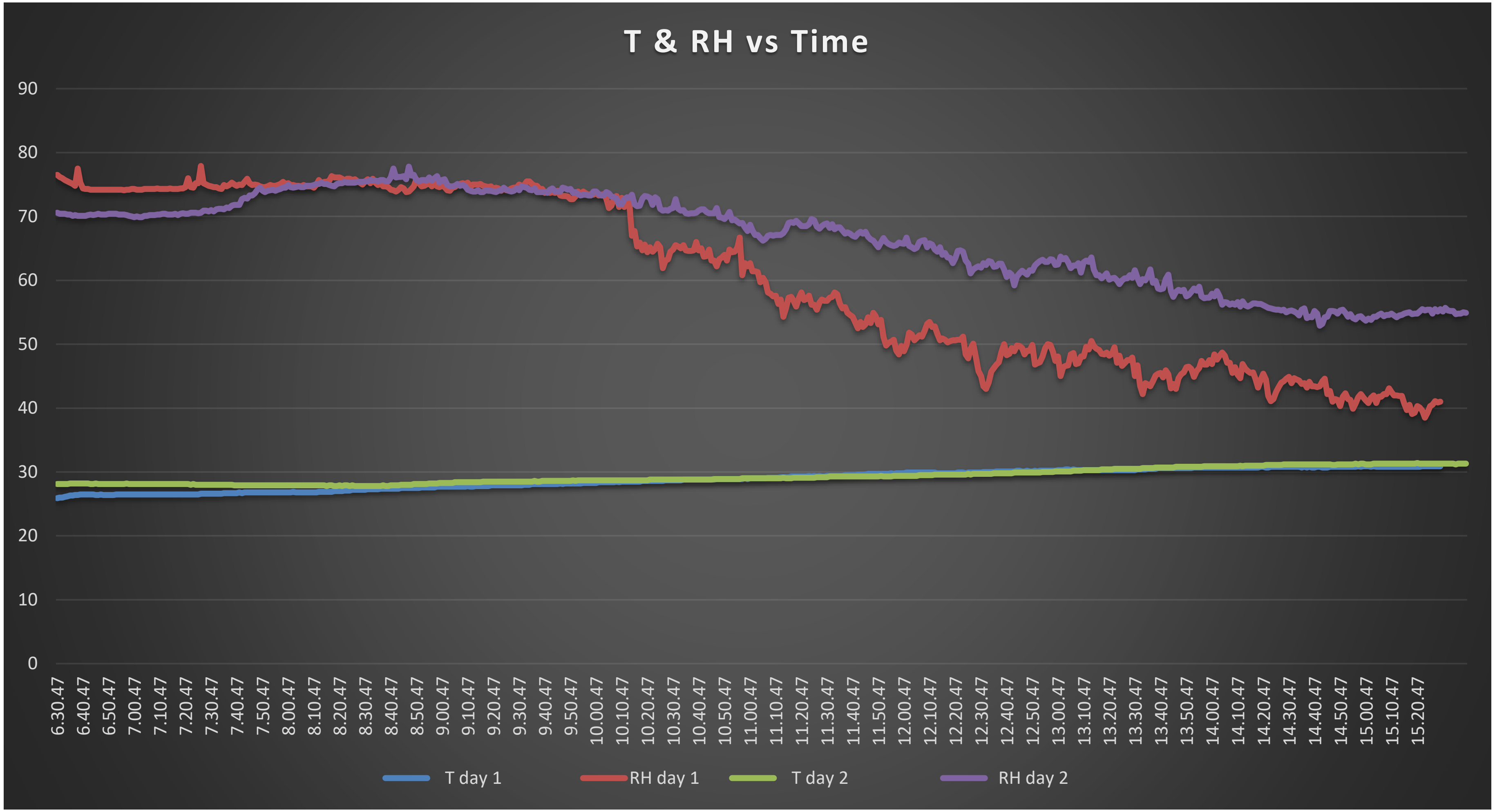

Figure 4. T and RH vs time in school A class 1 for day 1 and 2.

6 DISCUSSION

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 (Ana et al. 2009a, Ana et al. 2009b); 2) a 2011 study on waste management challenges in secondary schools in Ibadan, Nigeria (Ana et al. 2011); 3) a 2011 investigation on the effect of traffic air pollution on school children's respiratory health (Mustapha et al. 2011), and a 2014 study that assess primary school environment (Olatunya et al. 2014), 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 building condition and IEQ in Nigerian elementary schools.

All investigated classrooms appeared to be adequately ventilated judging by the CO_2 concentrations predominantly staying below 1000ppm, the adjudged threshold for inadequate ventilation (ASHRAE standard 62 1992; ASHRAE standard 62.1 2016). Maximum indoor CO_2 exceeded this limit in three classrooms from two schools (school A and D). The classroom affected in school A was on the ground floor and there was a gasoline-operated generator on that floor that possibly impacted its CO_2 concentration. This generator was regularly operated due to regular power outage. The two classes that had a higher CO_2 concentrations in school D did not have a cross-ventilated window system as described in

National building code of Nigeria (2006). In cross-ventilated systems, windows are located approximately on opposite sides of the room, which helps to move air from one opening or openings to the other through the building (Aldawoud 2017; Walker 2016). It helps in the introduction of fresh air and the removal of stale air; while a lack of cross ventilation encourages the buildup of spent air in the building (Aldawoud 2017).

Use of gasoline-operated generators was also likely the cause of the elevated maximum outdoor CO concentration of 23 ppm. Some schools also had an open incinerator for refuse burning. CO is a colorless, odorless and tasteless gas that is hard to detect. According to ASHRAE standard 62.1 (2016), the maximum concentration for outdoor CO levels is 35 ppm for 1-hour averaging and 9 ppm for 8-hour average. It should be noted that the source of the CO emission was closer to the secondary school building block and a little farther away from our point of measurement. It is possible for the concentration to exceed the maximum value if our equipment is closer to the source of emission; students move closer to the source of emission during break time. The health effect of exposure to CO include decrease in ventilatory/pulmonary function, cardiovascular problems and hematological effects (Wilbur et al. 2012). Long term exposure to CO may also impair the neurological development of children even at low concentration levels (Townsend and Maynard 2002, Levy 2015). Other health effects according to the Center for Disease Control and Prevention (CDC 2017) include dizziness, nausea, headache and vomiting, along with a moderate to high levels of exposure for a long period associated with an increased incidence of heart related problems.

Although ventilation seems adequate in all classrooms where measurements were done, adequate ventilation did not affect indoor temperature as required. An increase in ventilation adequacy has been associated with thermal comfort in previous studies e.g. Sekhar (2016) but

Yang and Zhang (2008) and Prajongsan and Sharples (2012) found the majority of naturally ventilated rooms to have thermal discomfort. Mean, minimum and maximum indoor temperatures were above the 23^{o}C suggested by Andersen and Gyntelberg (2011) as the minimum required for classroom thermal comfort. This is against the set point of between 26^{o}C and 29^{o}C suggested by Schiavon et al. (2017) for improved performance. According to Lu et al. (2015), an indoor temperature of about 31^{o}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. Nevertheless, the highest overall comfort for students was still achieved at 23^{o}C without fans and 26^{o}C–29^{o}C with fans in the study by Schiavon et al. (2017).

As shown in the results, classroom temperatures in the studied schools increase with an increase in outdoor temperature with a marginal reduction seen between outdoor and indoor temperature value. Some of the classrooms did not have ceiling and those with ceiling may not have enough insulation against the radiating heat from the roof. Another problem is the introduction of warm unconditioned outdoor air through open windows and doors.

The use of natural ventilation saves energy and subsequently money (Ng and Payne 2016) but there may be some attendant negative effect that may outweigh the amount saved. For example, a comparative study of mechanically and naturally ventilated buildings by Wallner et al. (2015) found mechanically ventilated buildings to have an all-round better IEQ than those naturally ventilated. Since the natural ventilation in these classrooms provide adequate ventilation but not the required educational thermal comfort, a hybrid ventilation system that primarily uses natural ventilation but switches to mechanical ventilation during thermal discomfort should be employed in these schools (Ji et al. 2009, Brittle et al. 2016).

According to a review by Andersen & Gyntelberg (2011), lack of thermal comfort in classroom can make students drowsy while studying. The review also associated it with headaches as well as eye and respiratory complains among students. In another study by Bidassey-Manilal et al. (2016), heat stress made 97% of students tired while about 94% slept due to it. In a study by Annesi-Maesano et al. (2013), student absenteeism from school raised by 1.28 fold due to thermal discomfort; thermal discomfort also affected respiratory symptoms leading to daytime breathlessness in the study. This result is similar to the result of Mi et al. (2006) where the odd ratio (OR) for daytime breathlessness was up to 1.26 ($P < 0.001$) due to thermal discomfort in classroom.

When cleaning effectiveness was assessed with ATP sampling, the concentration of ATP was moderately high on all desks tested, including those visually inspected as cleaned. The value reduced after cleaning. Median pre-cleaning values ranged from 77 800 RLUs (relative light units) in School C to 391 400 RLUs (School E). The values were comparable to data from elementary schools in southwestern US (Shaughnessy et al. 2013), 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). Median post-cleaning values ranged from 20 500 to 206 000 RLUs. They could be compared to the ISSA (International Sanitary Supply Association) Clean Standard for K-12 Schools for classroom desks, which indicates effective cleaning when ATP (Charm Sciences system) reading is ≤ 5399 RLUs, needs improvement when 5400 to 17300 RLUs, and ineffective cleaning when ≥17301 RLUs. The high ATP values may be due to the cleaning method used by the schools which made floor dirt to be re-suspended and settle on desks. The fact that students did not have a cafeteria but ate at their desks, could have also affected the microbial contamination of the desk by bacteria that feeds on crumbs (Dingsdag & Coleman 2013).

Inadequate sanitation and hygiene contributes to around 10% global burden of disease (Mara et al. 2010). This can encourage the transfer and spread of communicable diseases in schools. For example, a systematic review of forty-one literatures by Jasper et al. (2012) found sanitation inadequacies in schools to increase the incidence of gastrointestinal diseases in students. This lack of sanitation also increases absenteeism. Another systematic review of fifteen sanitation and health outcomes scientific studies by Joshi and Amadi (2013) found unhygienic practices in school to be related to students having respiratory infections as well as gastrointestinal symptoms such as diarrhea. In a study by Freeman et al. (2015), a good water supply in schools which encourage hand washing practices among students and clean toilets initiatives strongly associated with a reduction in parasitic infection of students.

Looking at the general building condition of the schools investigated, it can be deduced that maintenance and adherence to standards is not usually done. About six of the sampled classes were without ceiling, while those that had were made of asbestos. According to WHO (2017a), 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.

As said earlier, none of the schools had floor covering, the floors were broken, exposing students to PM especially during and after cleaning with brooms. Wall finishing did not exist in some classrooms while those painted had paint peeling. Only one school (school C) had classrooms with little level of clutter (the level of clutter relates to the amount of space present in the classroom for regular movement). This result agrees with that by Olatunya et al. (2014) where 42% of Nigerian primary schools studied were dilapidated with 22% having no ceiling, 62% partially ceiled and only 16% properly ceiled, but the study did not assess the material used for the ceilings.

Research have shown children exposure to PM to be related to the onset of acute lower respiratory infection (Gurley et al. 2013; Gurley et al. 2014). It reduces the pulmonary function of school children (Watanabe et al. 2015; Watanabe et al. 2016). Other health effects as explained by USEPA (2017) includes respiratory symptoms such as cough and breathing difficulty, irregular heartbeat, aggravated asthma and premature death.

Classroom occupancy for all schools exceeded ASHRAE standard 62 (1989) classroom occupancy of 50 person/100m^2 in all classrooms depicting overcrowding (Rovelli et al. 2014). Overcrowding affects ventilation adequacy, thermal comfort and encourages the spread of diseases (Rovelli et al. 2014, Jongcherdchootrakul et al. 2014, Taylor et al. 2016). According to WHO (2017b) overcrowding can result to epidemic of diseases such as meningitis, cholera and typhus.

It was alarming to see that only one of the schools studied (school D) had functional and effective toilet systems. In a study by Olatunya et al. (2014), about 6% of schools studied had the recommended toilet to pupils’ ratio. The recommended ratio for elementary schools by the National building code of Nigeria (2006) is 1 toilet to 100 boys and 35 girls respectively and 1 urinals to 30 boys. This is a huge problem in developing countries where a lot of sanitation studies have been done (Joshi & Amadi 2013). According to WHO (2008), only four out of ten Africans have access to good toilet system.

The lack of functional toilet systems results in open urination and missed school time when students need to defecate. This unhygienic practice may inadvertently lead to the spread of communicable diseases; as proper sanitation is very important for students' health (Caruso et al. 2014). The use of proper toilet system coupled with hand washing with soap reduces the spread of microorganism such as bacterial, viruses and other parasites such as protozoans found in human feces that causes communicable diseases (WHO 2008).

In general, none of the buildings investigated had a basement but they all had a shallow foundation. The lack of a basement is an advantage against moisture damage and mold growth as reported in schools with basements (e.g. Toyinbo et al. 2016a). Shallow foundation on the other hand if not well damp proofed can cause an upward capillary movement of ground water leading to moisture problem and mold formation as seen in school A. 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.

Classrooms floors were not covered and were already flaking. The condition of floors greatly impacted on classroom IEQ. There were no track off mats at the building and classroom entrances of any school. We did not measure the particulate matter (PM) concentration in the classrooms. For example, when classroom floors were cleaned by sweeping with brooms, a great amount of PM were suspended that polluted the indoor air and deposited contaminants on students' desks, chairs and possibly food. 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 is partly due to inadequate funding to hire cleaners and the need to teach children basic cleaning practices at a young age. The exposure of children to all fractions of PM has been associated with respiratory problems (Tecer et al. 2008, Orellano et al. 2017) as discussed earlier.

A limited number of schools were studied in this work, this may be the main limiting factor affecting our assessment of IEQ in Nigerian elementary schools. Another limiting factor may be the period of sampling which did not cover the entire season in Nigeria; and the fact that sampling was done only in the southwestern part of the country. With our findings, an elaborate research that encompasses all Nigerian elementary schools or that is representative of all Nigerian elementary schools is needed for a more robust conclusion.

7 CONCLUSIONS

The main issues affecting IEQ and students' health and effective learning in the studied elementary schools in Nigeria include the use of hazardous materials (e.g. asbestos), gasoline-burning generators, inadequate sanitation and maintenance of school facilities, overcrowding, and thermal discomfort. Use of hazardous materials and open incineration should be discontinued, and functional toilet and plumbing systems provided. Student occupancy in classrooms should conform to standard to avoid overcrowding, and a hybrid ventilation system recommended in schools to achieve the desired educational thermal comfort. Processes that can affect classroom IEQ such as sweeping of dry floors that suspends PM should be discouraged. Students should be taught the danger of open urination and encouraged to improve on their personal hygiene, which includes regular cleaning of their chairs and desks. The culture by which student eat their lunch on their classroom desk could be discouraged and cafeterias provided.

REFERENCES

1. Aas K, Andersen T, Becher R, Berner M, Holmen TL. Children's indoor environment. A study of Norwegian dwellings. Tidsskr Nor Laegeforen 1995;115(17):2048-51.
2. Adedoja A, Tijani BD, Akanbi AA, Ojurongbe TA, Adeyeba OA, Ojurongbe O. Co-endemicity of *Plasmodium falciparum* and Intestinal Helminths Infection in School Age Children in Rural Communities of Kwara State Nigeria. PLoS Neglected Tropical Diseases 2015;9(7):e0003940. doi:10.1371/journal.pntd.0003940.
3. Aflaki A, Mahyuddin N, Mahmoud ZA, Baharum MR. A review of natural ventilation applications through building façade components and ventilation openings in tropical climates. Energy and Building 2015;101:153-162.
4. Al-Awadi L. Assessment of indoor levels of volatile organic compounds and carbon dioxide in schools in Kuwait. J Air Waste Manag Assoc 2018;68(1):54-72.
5. Aldawoud A. Windows design for maximum cross-ventilation in buildings. Advances in Building Energy Research 2017;11(1):67-86.
6. Al-Rashidi K, Loveday D, Al-Mutawa N. Impact of ventilation modes on carbon dioxide concentration levels in Kuwait classrooms. Energy and Buildings 2012;47:540-549.
7. Amram O, Abernethy R, Brauer M, Davies H, Allen RW. Proximity of public elementary schools to major roads in Canadian urban areas. International Journal of Health Geographics 2011;10:68. doi:10.1186/1476-072X-10-68.
8. Ana GR, Oloruntoba EO, Shendell D, Elemile OO, Benjamin OR, Sridhar MK. Solid waste management problems in secondary schools in Ibadan, Nigeria. J Environ Health 2011;74(2):24-8.
9. Ana GR, Shendell DG, Odeshi TA, Sridhar MK (a). Identification and initial characterization of prominent air pollution sources and respiratory health at secondary

schools in Ibadan, Nigeria. J Asthma 2009;46(7):670-6. doi: 10.1080/02770900902972152.

10. Ana GREE, Shendell DG, Brown GE, Sridhar MKC (b). Assessment of Noise and Associated Health Impacts at Selected Secondary Schools in Ibadan, Nigeria. J Environ Public Health. 2009;2009:739502. doi:10.1155/2009/739502.
11. Andersen I, Gyntelberg, F. Modern indoor climate research in Denmark from 1962 to the early 1990s: An eye witness report. Indoor Air 2011;21:182-190.
12. Annesi-Maesano I, Baiz N, Banerjee S, Rudnai P, Rive S, SINPHONIE Group. Indoor air quality and sources in schools and related health effects. J Toxicol Environ Health B Crit Rev 2013;16(8):491-550. doi: 10.1080/10937404.2013.853609.
13. Annesi-Maesano I, Hulin M, Lavaud F, Raherison C, Kopferschmitt C, de Blay F, Charpin DA, Denis C. Poor air quality in classrooms related to asthma and rhinitis in primary schoolchildren of the French 6 Cities Study. Thorax 2012;67(8):682-688. doi:10.1136/thoraxjnl-2011-200391.
14. Approved American National Standard (ANSI)/American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE). ANSI/ASHRAE Standard 62.1-2016: Ventilation for Acceptable Indoor Air Quality. Atlanta, GA 2016.
15. ASHRAE Standard 55-2004. American Society of Heating Refrigerating, and Air Conditioning Engineers (ASHRAE). 2004. Thermal environmental Conditions for Human Occupancy. Atlanta, GA.
16. ASHRAE Standard 62-1989. Ventilation for Acceptable Indoor Air Quality, Atlanta 1989.
17. Ayanbimpe GM, Wapwera SD, Kuchin D. Indoor air mycloflora of residential dwellings in Jos metropolis. Afr Health Sci 2010;10(2):172-6.

18. Ayanlowo O, Akinkugbe A, Oladele R, Balogun M. Prevalence of *Tinea Capitis* Infection Among Primary School Children in a Rural Setting in South-West Nigeria. Journal of Public Health in Africa 2014;5(1):349. doi:10.4081/jphia.2014.349.
19. Bakó-Biró Z, Clements-Croome DJ, Kochhar N, Awbi HB, Williams MJ. 2012. Ventilation rates in schools and pupils' performance. Build Environ 2012;48:215-223.
20. Batterman S. Review and Extension of CO_2-Based Methods to Determine Ventilation Rates with Application to School Classrooms. Int J Environ Res Public Health 2017;14(2):145. doi:10.3390/ijerph14020145.
21. Bidassey-Manilal S, Wright CY, Engelbrecht JC, Albers PN, Garland RM, Matooane M. Students' Perceived Heat-Health Symptoms Increased with Warmer Classroom Temperatures. International Journal of Environmental Research and Public Health 2016;13(6):566.
22. Bidassey-Manilal S, Wright CY, Engelbrecht JC, Albers PN, Garland RM, Matooane M. Students' Perceived Heat-Health Symptoms Increased with Warmer Classroom Temperatures. Int J Environ Res and Public Health 2016 13(6): 566. http://doi.org/10.3390/ijerph13060566.
23. Brittle JP, Eftekhari M, Firth SK. Mechanical ventilation & cooling energy versus thermal comfort: A study of mixed mode office building performance in Abu Dhabi. Proceedings of 9th Windsor Conference: Making comfort relevant. Cumberland Lodge, Windsor, UK, 7-10 April 2016. Network for comfort and energy use in buildings.
24. Cartieaux E, Rzepka MA, Cuny D. Indoor air quality in schools. *Arch Pediatr* 2011;18(7):789-96.
25. Caruso BA, Freeman MC, Garn JV, Dreibelbis R, Saboori S, Muga R, Rheingans R. Assessing the impact of a school-based latrine cleaning and handwashing program on pupil absence in Nyanza Province, Kenya: A cluster-randomized trial. TM & IH 2014;19(10):1185-1197. doi:10.1111/tmi.12360.

26. CDC (Centers for Disease Control and Prevention). Carbon Monoxide Poisoning 2017. (Assessed 21.10.2017) https://ephtracking.cdc.gov/showCoRisk.action.

27. Chen C, Zhao B, Yang X. Impact of two-way air flow due to temperature difference on preventing the entry of outdoor particles using indoor positive pressure control method. J Hazard Mater 2011;186(2-3):1290-9.

28. Chu CR, Chiu YH, Tsai YT, Wu SL. Wind-driven natural ventilation for buildings with two openings on the same external wall. Energy and Buildings 2015;108:365-372.

29. Daghigh R. Assessing the thermal comfort and ventilation in Malaysia and the surrounding regions. *Renew Sustain Energy Rev* 2015;48:681-691.

30. Dingsdag S, Coleman NV. Bacterial communities on food court tables and cleaning equipment in a shopping mall. Epidemiol Infect 2013;141(8):1647-51. doi: 10.1017/S0950268812002142.

31. EFA (Education for All) 2015 National Review. 2015. (Assessed 25.8.2017) http://unesdoc.unesco.org/images/0023/002310/231081e.pdf.

32. Ekong PS, Ducheyne E, Carpenter TE, Owolodun OA, Oladokun AT, Lombin LH, Berkvens D. Spatio-temporal epidemiology of highly pathogenic avian influenza (H5N1) outbreaks in Nigeria, 2006-2008. Prev Vet Med 2012;103(2-3):170-7. doi: 10.1016/j.prevetmed.2011.

33. Ekpo UF, Odoemene SN, Mafiana CF, Sam-Wobo SO. Helminthiasis and Hygiene Conditions of Schools in Ikenne, Ogun State, Nigeria. PLoS Neglected Tropical Diseases 2008;2(1):e146. doi:10.1371/journal.pntd.0000146.

34. Fadeyi MO, Alkhaja K, Sulayem MB, Abu-Hijleh B. Evaluation of indoor environmental quality conditions in elementary schools' classrooms in the United Arab Emirates. Frontiers of Architectural Research 2014;3(2):166-177.

35. Federal Ministry of Education. Education for all 2015 National review 2015. (Assessed 20.8.2017) http://unesdoc.unesco.org/images/0023/002310/231081e.pdf.

36. Ferreira AM, Cardoso M. Indoor air quality and health in schools. *J Bras Pneumol* 2014;40(3):259-268.
37. Ferreira AMC, Cardoso SM. Exploratory study of air quality in elementary schools, Coimbra, Portugal. Revista de Saúde Pública 2013;47(6):1059-1068.
38. Freeman MC, Chard AN, Nikolay B, Garn JV, Okoyo C, Kihara J, Njenga SM, Pullan RL, Brooker SJ, Mwandawiro CS. Associations between school- and household-level water, sanitation and hygiene conditions and soil-transmitted helminth infection among Kenyan school children. Parasit Vectors 2015;8:412.
39. Frontczak, M, Andersen, RV, Wargocki, P. Questionnaire survey on factors influencing comfort with indoor environmental quality in Danish housing. Build Environ 2012;50:56-64.
40. Gaihre S, Semple S, Miller J, Fielding S, Turner S. 2014. Classroom carbon dioxide concentration, school attendance, and educational attainment. J Sch Health 2014;84(9):569-74. doi: 10.1111/josh.12183.
41. Gaihre S, Semple S, Miller J, Fielding S, Turner S. Classroom carbon dioxide concentration, school attendance, and educational attainment. J Sch Health 2014;84(9):569-74. doi: 10.1111/josh.12183.
42. Gurley ES, Homaira N, Salje H, Ram PK, Haque R, Petri W, Bresee J, Moss WJ, Breysse P, Luby SP, Azziz-Baumgartner E. . Indoor exposure to particulate matter and the incidence of acute lower respiratory infections among children: A birth cohort study in urban Bangladesh. Indoor air 2013;23(5):379-386. doi:10.1111/ina.12038.
43. Gurley ES, Homaira N, Salje H, Ram PK, Haque R, Petri W, Bresee J, Moss WJ, Luby SP, Breysse P, Azziz-Baumgartner E. Indoor Exposure to Particulate Matter and Age at First Acute Lower Respiratory Infection in a Low-Income Urban Community in Bangladesh. Am J Epidemiol 2014;179(8):967-73. doi: 10.1093/aje/kwu002.

44. Haverinen-Shaughnessy U, Moschandreas DJ, Shaughnessy RJ. Association between substandard classroom ventilation rates and students' academic achievement. Indoor Air 2011;21:121-131.
45. Haverinen-Shaughnessy U, Moschandreas DJ, Shaughnessy RJ. Association between substandard classroom ventilation rates and students' academic achievement. Indoor Air 2011;21:121-131.
46. Haverinen-Shaughnessy U, Shaughnessy R, Cole G, Toyinbo O, Moschandreas D. An assessment of indoor environmental quality in schools and its association with health and performance. Build Environ 2015;93(1):35-40. doi:10.1016/j.buildenv.2015.03.006.
47. Haverinen-Shaughnessy U, Shaughnessy RJ. Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores. PLoS ONE 2015;10(8):e0136165. doi:10.1371/journal.pone.0136165.
48. Jara-Perez JV, Berber A. Primary prevention of acute respiratory tract infections in children using a bacterial immunostimulant: A double-masked, placebo-controlled clinical trial. Clin Ther 2000;22(6):748-59.
49. Jasper C, Le T-T, Bartram J. Water and Sanitation in Schools: A Systematic Review of the Health and Educational Outcomes. Int J Environ Res Public Health 2012;9(8):2772-2787.
50. Ji Y, Lomas KJ, Cook MJ. Hybrid ventilation for low energy building design in south China. Build Environ 2009;44:2245-2255.
51. Jongcherdchootrakul K, Henderson AK, Iamsirithaworn S, Modchang C, Siriarayapon P. First pandemic A (H1N1) pdm09 outbreak in a private school, Bangkok, Thailand, June 2009. J Med Assoc Thai 2014;97(2):S145-52.

52. Joshi A, Amadi C. Impact of Water, Sanitation, and Hygiene Interventions on Improving Health Outcomes among School Children. J Environ Public Health 2013;2013:984626.
53. Joshi A, Amadi C. Impact of Water, Sanitation, and Hygiene Interventions on Improving Health Outcomes among School Children. Journal of Environmental and Public Health 2013;2013:984626. doi:10.1155/2013/984626.
54. Joshi SM. The sick building syndrome. Indian Journal of Occupational and Environmental Medicine 2008;12(2):61-64. doi:10.4103/0019-5278.43262.
55. Kim JL, Elfman L, Mi Y, Wieslander G, Smedje G, Norbäck D. Indoor molds, bacteria, microbial volatile organic compounds and plasticizers in schools – associations with asthma and respiratory symptoms in pupils. Indoor Air 2007;17:153-163.
56. Koep TH, Enders FT, Pierret C, Ekker SC, Krageschmidt D, Neff KL, Lipsitch M, Shaman J, Huskins WC. Predictors of indoor absolute humidity and estimated effects on influenza virus survival in grade schools. BMC Infect Dis 2013;13:71. doi:10.1186/1471-2334-13-71.
57. Levy RJ. Carbon Monoxide Pollution and Neurodevelopment: A Public Health Concern. Neurotoxicology and teratology 2015;49:31-40. doi:10.1016/j.ntt.2015.03.001.
58. Lu S, Fang K, Qi Y, Wei S. Influence of Natural Ventilation on Thermal Comfort in Semi-open Building under Early Summer Climate in the Area of Tropical Island. Procedia Engineering 2015;121:944-951.
59. MacNaughton P, Pegues J, Satish U, Santanam S, Spengler J, Allen J. Economic, Environmental and Health Implications of Enhanced Ventilation in Office Buildings. International Journal of Environmental Research and Public Health 2015;12(11):14709-14722. doi:10.3390/ijerph121114709.

60. Madureira J, Paciência I, Pereira C, Teixeira JP Fernandes EO. Indoor air quality in Portuguese schools: levels and sources of pollutants. Indoor Air 2016;26(4):526-37. doi: 10.1111/ina.12237.
61. Mara D, Lane J, Scott B, Trouba D. Sanitation and Health. PLoS Med 2010;7(11):e1000363.
62. Mendell MJ, Eliseeva EA, Davies MM, Spears M, Lobscheid A, Fisk WJ, Apte MG. Association of classroom ventilation with reduced illness absence: A prospective study in California elementary schools. Indoor Air 2013;23:515-528.
63. Mendell MJ, Eliseeva EA, Davies MM, Spears M, Lobscheid A, Fisk WJ, Apte MG. Association of classroom ventilation with reduced illness absence: A prospective study in California elementary schools. Indoor Air 2013;23:515-528.
64. Mendell MJ, Heath GA. Do Indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air 2005;15: 27-32.
65. Mendell MJ, Heath GA. Do Indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. Indoor Air 2005;15:27-32.
66. Metz JA, Finn A. Influenza and humidity--Why a bit more damp may be good for you! J Infect 2015;71(1):S54-8.
67. Mi YH, Norback D, Tao J, Mi YL, Ferm M. Current asthma and respiratory symptoms among pupils in Shanghai, China: Influence of building ventilation, nitrogen dioxide, ozone, and formaldehyde in classrooms. Indoor Air 2006;16:454-464.
68. Mi YH, Norback D, Tao J, Mi YL, Ferm M. Current asthma and respiratory symptoms among pupils in Shanghai, China: Influence of building ventilation,

nitrogen dioxide, ozone, and formaldehyde in classrooms. Indoor Air 2006;16:454-464.

69. Mustapha BA, Blangiardo M, Briggs DJ, Hansell AL. Traffic Air Pollution and Other Risk Factors for Respiratory Illness in Schoolchildren in the Niger-Delta Region of Nigeria. Environ Health Perspect 2011;119(10):1478-82.
70. Myatt TA, Kaufman MH, Allen JG, MacIntosh DL, Fabian MP, McDevitt JJ. Modeling the airborne survival of influenza virus in a residential setting: the impacts of home humidification. Environ Health 2010;9:55-069X-9-55.
71. Nandasena YLS, Wickremasinghe AR, Sathiakumar N. Air pollution and health in Sri Lanka: a review of epidemiologic studies. BMC Public Health 2010 (2);10:300.
72. National Building Code of Nigeria. 2006. Assessed 25.9.2017) http://sdngnet.com/Files/Lectures/FUTA-ARC-807-Professional_Practice_and_Procedure/CD%202013-2014/National%20Building%20Code%20of%20Nigeria%202006.pdf.
73. NEEDs assessment of Nigerian educational sector by international organization for migration, Abuja, Nigeria. 2014. (Assessed 21.9.2017) https://nigeria.iom.int/sites/default/files/newsletter/ANNEX%20XXIV%20REPORT%20OF%20NEEDS%20ASSESSMENT%20IN%20EDUCATION%20SECTOR%202014.pdf.
74. Ng LC, Payne WV. Energy Use Consequences of Ventilating a Net-Zero Energy House. Applied thermal engineering 2016;96:151-160. doi:10.1016/j.applthermaleng.2015.10.100.
75. Niachou K, Hassid S, Santamouris M. Comparative monitoring of natural, hybrid and mechanical ventilation systems in urban canyons. Journal of Energy and Buildings 2005;37:503-513.

76. Nuffic. Education system in Nigeria; The Nigerian education system described and compared with the Dutch system 2017. (Assessed 26.9.2017) https://www.nuffic.nl/en/publications/find-a-publication/education-system-nigeria.pdf.

77. Olatunya OS, Oseni SB, Ogundele O, Oyelami OA. A study of the primary school environment in a local government area, South West Nigeria. J Community Med Health Educ 2014;4:321. doi:10.4172/2161-0711.1000321

78. Onwuzuruigbo I. Researching ethnic conflicts in Nigeria: the missing link. Ethnic and Racial Studies 2010;33(10):1797-1813.

79. Orellano P, Quaranta N, Reynoso J, Balbi B, Vasquez J. Effect of outdoor air pollution on asthma exacerbations in children and adults: Systematic review and multilevel meta-analysis. PLoS ONE 2017;12(3):e0174050. doi:10.1371/journal.pone.0174050.

80. Patton AP, Calderon L, Xiong Y, Wang Z, Senick J, Allacci MS, Plotnik D, Wener R, Andrews CJ, Krogmann U, Mainelis G. Airborne Particulate Matter in Two Multi-Family Green Buildings: Concentrations and Effect of Ventilation and Occupant Behavior. Int J Environ Res Public Health 2016:144. doi:10.3390/ijerph13010144.

81. Permaul P, Hoffman E, Fu C, Sheehan W, Baxi S, Gaffin J, et al. Allergens in urban schools and homes of children with asthma. Pediatr Allergy Immunol 2012;23(6):543-549.

82. Prajongsan P, Sharples S. Enhancing natural ventilation, thermal comfort and energy savings in high-rise residential buildings in Bangkok through the use of ventilation shafts. Build Environ 2012;50:104–113.

83. Rosbach JTM, Vonk M, Duijm F, van Ginkel JT, Gehring U, Brunekreef B. A ventilation intervention study in classrooms to improve indoor air quality: the FRESH study. Environmental Health 2013;12:110. doi:10.1186/1476-069X-12-110.

84. Rovelli S, Cattaneo A, Nuzzi CP, Spinazzè A, Piazza S, Carrer P, Cavallo DM. Airborne Particulate Matter in School Classrooms of Northern Italy. Int J Environ Res Public Health. 2014;11(2):1398-1421. doi:10.3390/ijerph110201398.
85. Sakellaris IA, Saraga DE, Mandin C, Roda C, Fossati S, de Kluizenaar Y, Carrer P, Dimitroulopoulou S, Mihucz VG, Szigeti T, Hänninen O, de Oliveira Fernandes E, Bartzis JG. Bluyssen PM. Perceived Indoor Environment and Occupants' Comfort in European "Modern" Office Buildings: The OFFICAIR Study. Int J Environ Res Public Health 2016;13(5).
86. Sarkar M. Personal hygiene among primary school children living in a slum of Kolkata, India. Journal of Preventive Medicine and Hygiene 2013;54(3):153-158.
87. Schiavon S, Yang B, Donner Y, Chang VW, Nazaroff WW. Thermal comfort, perceived air quality, and cognitive performance when personally controlled air movement is used by tropically acclimatized persons. Indoor Air 2017;27(3):690-702. doi: 10.1111/ina.12352.
88. Sekhar SC. Thermal comfort in air-conditioned buildings in hot and humid climates – why are we not getting it right? Indoor Air 2016;26:138-152.
89. Shaughnessy RJ, Cole EC, Moschandreas D, Haverinen-Shaughnessy U. ATP as a marker for surface contaminant of biological origin in schools and as a potential approach to the measurement of cleaning effectiveness. J Occup Environ Hyg 2013;10:336-346. doi: 10.1080/15459624.2013.784633
90. Shendell DG, Prill R, Fisk WJ, Apte MG, Blake D, Faulkner D. Associations between classroom CO_2 concentrations and student attendance in Washington and Idaho. Indoor Air 2004;14(5):333-41.
91. Smedje G, Norbäck D. New ventilation systems at select schools in Sweden – effects on asthma and exposure, Arch. Environ. Health 2000;55:18-25.
92. Smedje G, Wang J, Norbäck D, Nilsson H, Engvall K. SBS symptoms in relation to dampness and ventilation in inspected single-family houses in Sweden. International

Archives of Occupational and Environmental Health 2017;90(7):703-711. doi:10.1007/s00420-017-1233-z.

93. Taylor JG, Yates TA, Mthethwa M, Tanser F, Abubakar I, Altamirano H. Measuring ventilation and modelling M. tuberculosis transmission in indoor congregate settings, rural KwaZulu-Natal. Int J Tuberc Lung Dis 2016;20(9):1155-1161. doi:10.5588/ijtld.16.0085.

94. Tecer LH, Alagha O, Karaca F, Tuncel G, Eldes N. Particulate matter (PM(2.5), PM(10-2.5), and PM(10)) and children's hospital admissions for asthma and respiratory diseases: a bidirectional case-crossover study. J Toxicol Environ Health A 2008;71(8):512-20. doi: 10.1080/15287390801907459.

95. Toftum J, Kjeldsen BU, Wargocki P, Menå H.R, Hansen EMN, Clausen G. Association between classroom ventilation mode and learning outcome in Danish schools. Build Environ 2015;92:494-503.

96. Tong Z, Chen Y, Malkawi A. Estimating natural ventilation potential for high-rise buildings considering boundary layer meteorology. Applied Energy 2017;193:276-286.

97. Townsend C, Maynard R. Effects on health of prolonged exposure to low concentrations of carbon monoxide. Occup Environ Med 2002;59(10):708-711. doi:10.1136/oem.59.10.708.

98. Toyinbo O, Matilainen M, Turunen M, Putus T, Shaughnessy R, Haverinen-Shaughnessy U (a). Modeling association between principals' reported indoor environmental quality and students' self-reported respiratory health outcomes using GLMM and ZIP models. Int J Environ Res Public Health 2016; 13(4):385; doi: 10.3390/ijerph13040385.

99. Toyinbo O, Shaughnessy R, Turunen M, Putus T, Metsämuuronen J, Kurnitski J, Haverinen-Shaughnessy U (b). Building characteristics, indoor environmental quality,

and mathematics achievement in Finnish elementary schools. Build Environ 2016;104:114-121. doi: 10.1016/j.buildenv.2016.04.030.

100. Turunen M, Toyinbo O, Putus T, Nevalainen A, Shaughnessy R, Haverinen-Shaughnessy U. Indoor environmental quality in school buildings, and health and wellbeing of students. Int J Hyg Environ Health 2014;217(7):733-9. doi: 10.1016/j.ijheh.2014.03.002. Epub 2014 Mar 19.

101. Ukiwo U. On the study of ethnicity in Nigeria. Centre for research on inequality, human security and ethnicity (CRISE). CRISE working paper No. 12.

102. Universal Basic Education Commission. National Personnel Audit Report 2012. Abuja.

103. USEPA (United States Environmental Protection Agency). Health and Environmental Effects of Particulate Matter (PM). (Assessed 8.11.2017) https://www.epa.gov/pm-pollution/health-and-environmental-effects-particulate-matter-pm.

104. Walker A. Natural ventilation. Whole building design guide (WBDG), a program of the National Institute of Building Sciences. National Renewable Energy Laboratory 2016.

105. Wallner P, Munoz U, Tappler P, Wanka A, Kundi M, Shelton JF, Hutter HP. Indoor Environmental Quality in Mechanically Ventilated, Energy-Efficient Buildings *vs.* Conventional Buildings. Int J Environ Res Public Health 2015;12(11):14132-14147. doi:10.3390/ijerph121114132.

106. Watanabe M, Noma H, Kurai J, Kato K, Sano H, Tatsukawa T, Nakazaki H, Yamasaki A, Shimizu E. Association between pulmonary function and daily levels of sand dust particles assessed by light detection and ranging in schoolchildren in

western Japan: A panel study. Allergol Int. 2016;65(1):56-61. doi: 10.1016/j.alit.2015.07.005.

107. Watanabe M, Noma H, Kurai J, Sano H, Kitano H, Saito R, Kimura Y, Aiba S, Oshimura M, Shimizu E. Variation in the Effect of Particulate Matter on Pulmonary Function in Schoolchildren in Western Japan and Its Relation with Interleukin-8. Int J Environ Res Public Health 2015;12(11):14229-14243. doi:10.3390/ijerph121114229.

108. WENR (World Education News & Reviews). Education in Nigeria. 2017. (Assessed 30.8.2017) http://wenr.wes.org/2017/03/education-in-nigeria.

109. WHO (World Health Organization). Housing, energy and thermal comfort: A review of 10 countries within the WHO European region. WHO Regional Office for Europe: Copenhagen 2007. (Assessed 8.05.2018) http://www.euro.who.int/__data/assets/pdf_file/0008/97091/E89887.pdf.

110. WHO (World Health Organization). Guidelines for Indoor Air Quality: Dampness and Mold. WHO Regional Office for Europe: Copenhagen 2009. (Assessed 8.01.2018) http://www.euro.who.int/__data./pdf_file/0017/43325/E92645.pdf?ua=1.

111. WHO (World Health Organization). International programme on chemical safety (asbestos) 2017a. (Assessed 21.8.2017) http://www.who.int/ipcs/assessment/public_health/asbestos/en/.

112. WHO (World Health Organization). Poor sanitation threatens public health 2008. (Assessed 8.11.2017) http://www.who.int/mediacentre/news/releases/2008/pr08/en/.

113. WHO (World Health Organization). What are the risks related to overcrowding? 2017b. (Assessed 8.11.2017) http://www.who.int/water_sanitation_health/emergencies/qa/emergencies_qa9/en/.

114. Wilbur S, Williams M, Williams R, Scinicariello F, Klotzbach JM, Diamond GL, Citra M. Toxicological Profile for Carbon Monoxide. U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES, Public Health Service. Agency for Toxic Substances and Disease Registry (US); RELEVANCE TO PUBLIC HEALTH 2012.

115. Yang W, Zhang G. Thermal comfort in naturally ventilated and air-conditioned buildings in humid subtropical climate zone in China. Int J Biometeorol 2008;52:385-398.

116. Zhao Z, Zhang Z, Wang Z, Ferm M, Liang Y, Norbäck D. Asthmatic Symptoms among Pupils in Relation to Winter Indoor and Outdoor Air Pollution in Schools in Taiyuan, China. Environ Health Perspect 2008;116(1):90-97.

8 APPENDIX

Table 6. Results from ATP sampling; assessment of cleaning effectiveness.

	No. of student desks	Appearance of desk	Desktop material	Pre-cleaning ATP [RLU]	Post-cleaning ATP [RLU]
A class 1					
Desk 1	7	Clean	Wood	110126	54799
Desk 2		Clean	Wood	176440	27416
Desk 3		Clean	Wood	377604	
Desk 4		Clean	Wood	208721	49160
A class 2					
Desk 1	6	Clean	Wood	287788	161982
Desk 2		Clean	Wood	273543	94769
Desk 3		Clean	Wood	251683	
A class 3					
Desk 1	7	Clean	Wood	435973	368223
Desk 2		Clean	Wood	297915	255413
Desk 3		Clean	Wood	307041	
B class 1					
Desk 1	6	Clean	Wood	139824	93553
Desk 2		Clean	Wood	36794	5044
Desk 3		Clean	Wood	199364	
Desk 4		Clean	Wood	197841	
B class 2					
Desk 1	8	Clean	Wood	379549	48565
Desk 2		Clean	Wood	160949	50180
Desk 3		Clean	Wood	200118	
B class 3					
Desk 1	7	Dirty	Wood	477904	313820
Desk 2		Clean	Wood	95539	
Desk 3		Clean	Wood	354403	
C class 1					
Desk 1	10	Dirty	Wood	29984	4186
Desk 2		Clean	Wood	158676	132314
Desk 3		Clean	Wood	273375	
Desk 4		Dirty	Wood	291341	
C class 2					
Desk 1	7	Dirty	Wood	55766	25001
Desk 2		Dirty	Wood	46326	81604
Desk 3		Clean	Wood	53306	
C class 3					
Desk 1	18	Dirty	Wood	119416	77730
Desk 2		Clean	Wood	99828	
Desk 3		Clean	Wood	48242	
D class 1					
Desk 1	13	Clean	Plastic	111040	8830
Desk 2		Clean	Plastic	298043	22178
Desk 3		Clean	Plastic	434828	24565
Desk 4		Clean	Plastic	155964	
D class 2					
Desk 1	9	Clean	Wood	297892	147546
Desk 2		Clean	Wood	43557	20529
Desk 3		Clean	Wood	125389	
D class 3					
Desk 1	12	Clean	Plastic	136540	15694
Desk 2		Clean	Plastic	177851	19719
Desk 3		Clean	Plastic	165128	
E class 1					
Desk 1	28	Clean	Wood	821264	177991
Desk 2		Clean	Wood	258423	141506
Desk 3		Clean	Wood	824210	
Desk 4		Clean	Wood	407381	
E class 2					
Desk 1	26	Clean	Wood	830681	504471
Desk 2		Clean	Wood	371950	252291
Desk 3		Clean	Wood	375440	
E class 3					
Desk 1	26	Clean	Wood	749642	206010
Desk 2		Clean	Wood	194963	
Desk 3		Clean	Wood	359377	

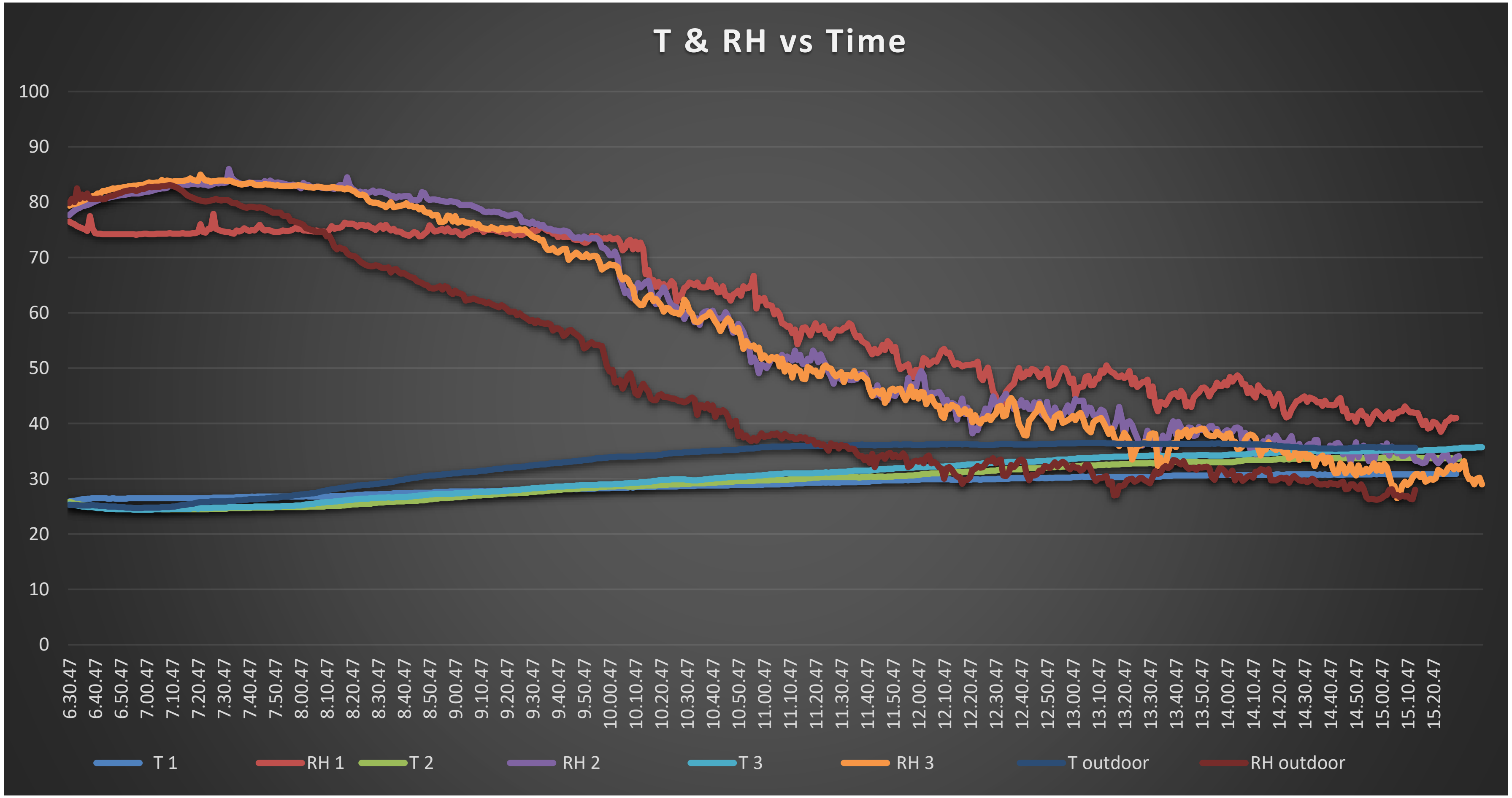

Figure 5. T and RH vs time in school A class 1 to 3 and outdoor.
T = Temperature; RH = Relative Humidity; 1, 2, 3 = Classroom #1, 2 and 3 respectively.

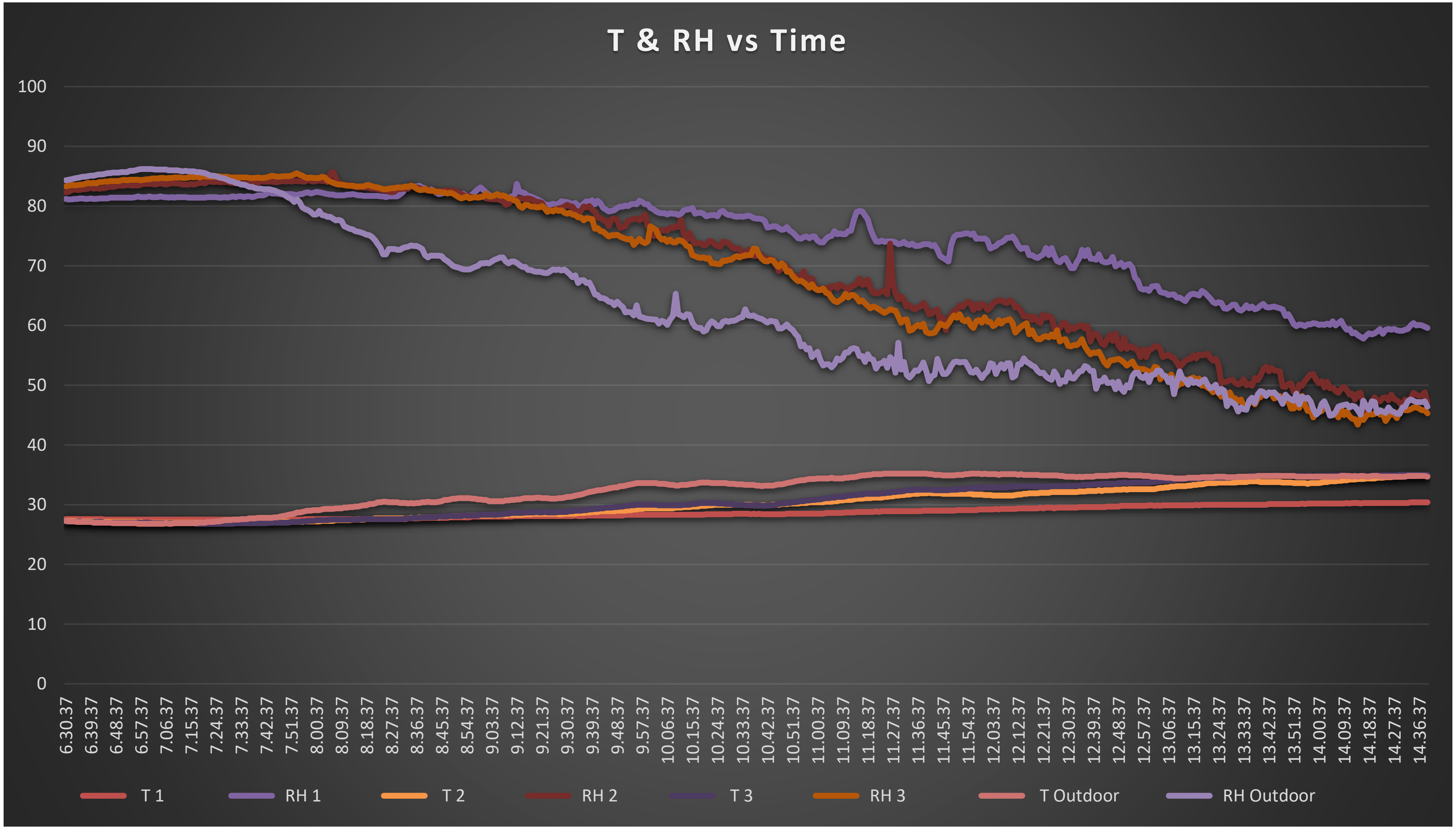

Figure 6. T and RH vs time in school B class 1 to 3 and outdoor.
T = Temperature; RH = Relative Humidity; 1, 2, 3 = Classroom #1, 2 and 3 respectively.

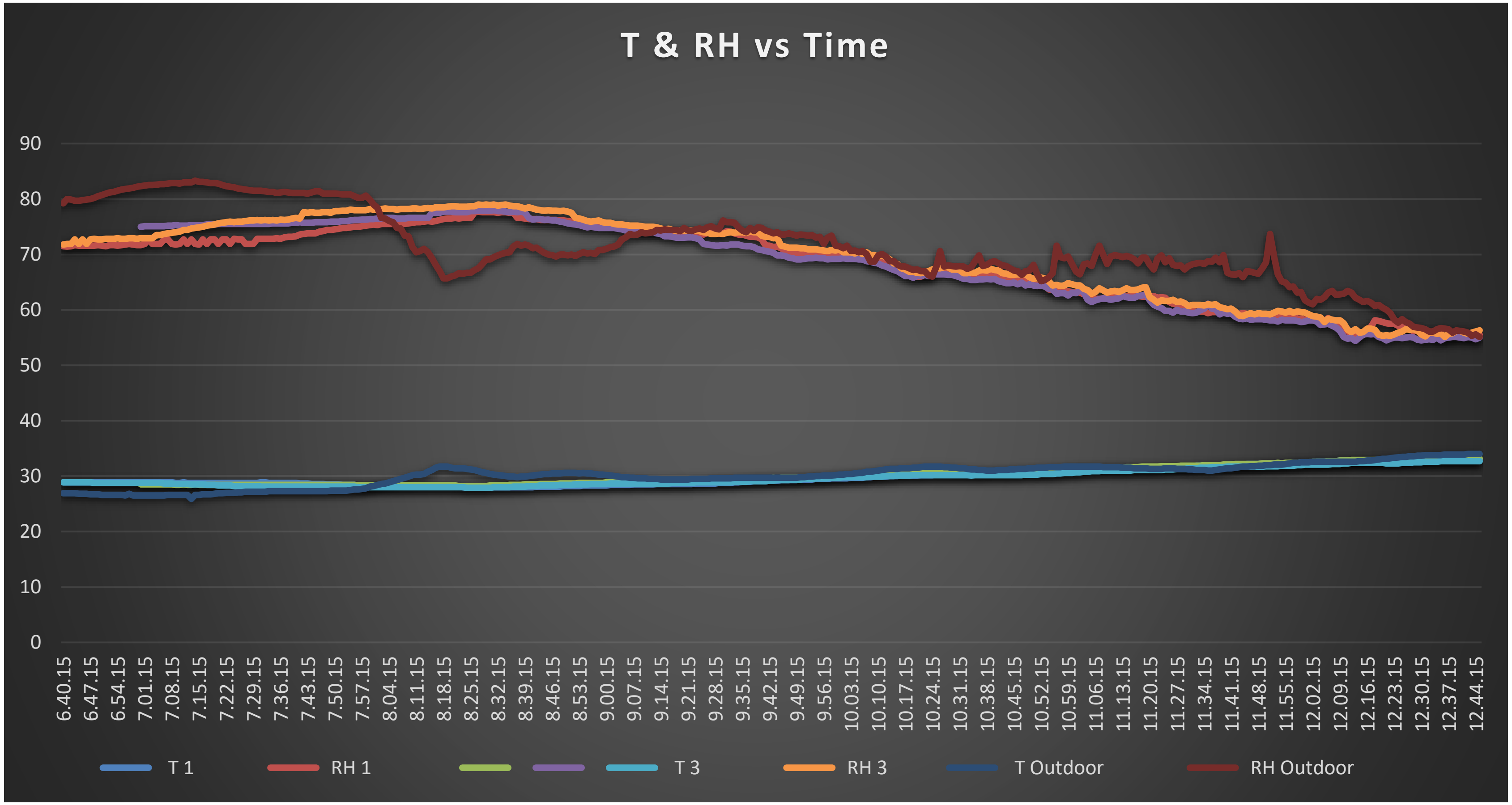

Figure 7. T and RH vs time in school C class 1 to 3 and outdoor.
T = Temperature; RH = Relative Humidity; 1, 2, 3 = Classroom #1, 2 and 3 respectively

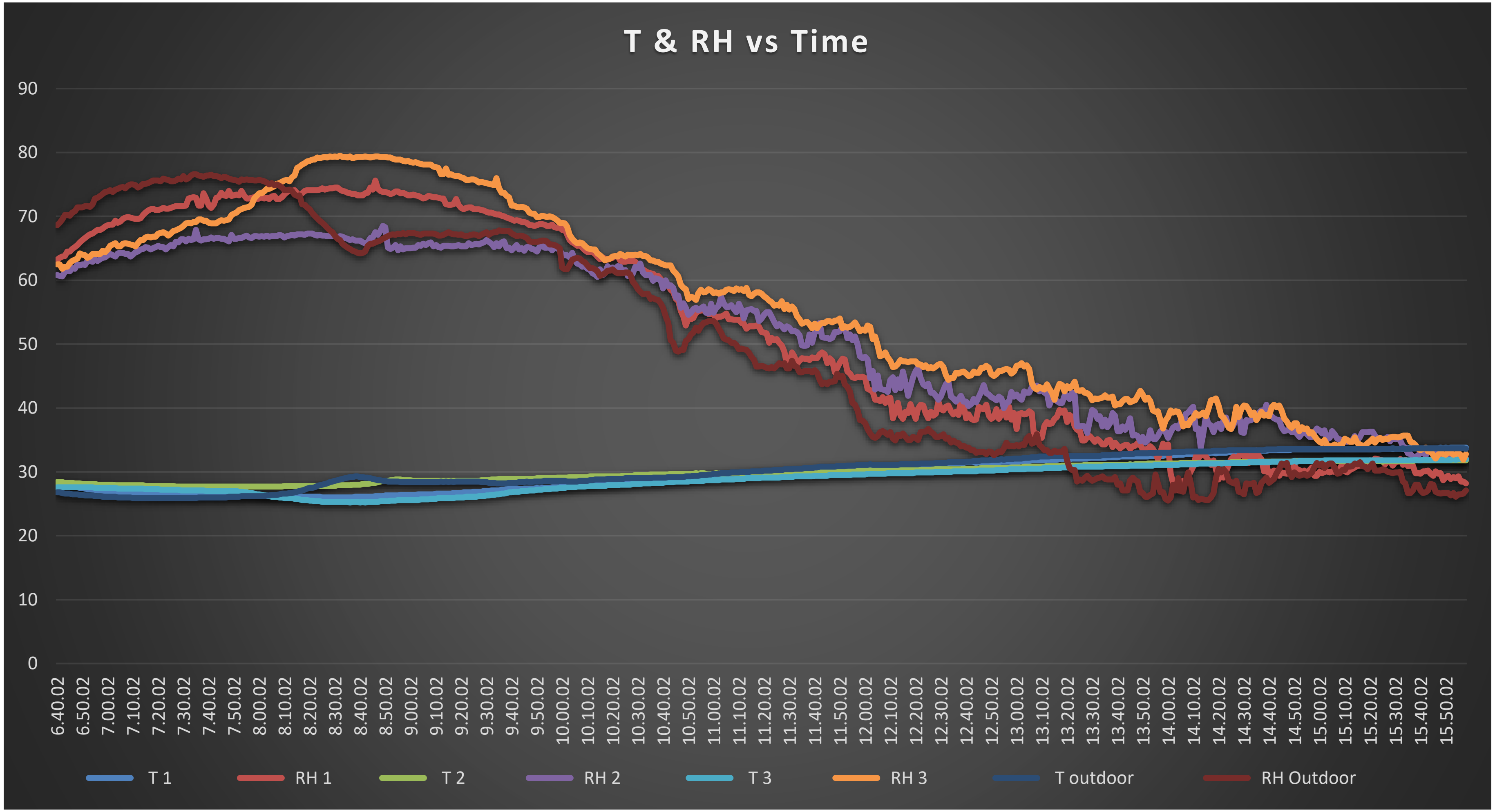

Figure 8. T and RH vs time in school D class 1 to 3 and outdoor.
T = Temperature; RH = Relative Humidity; 1, 2, 3 = Classroom #1, 2 and 3 respectively.

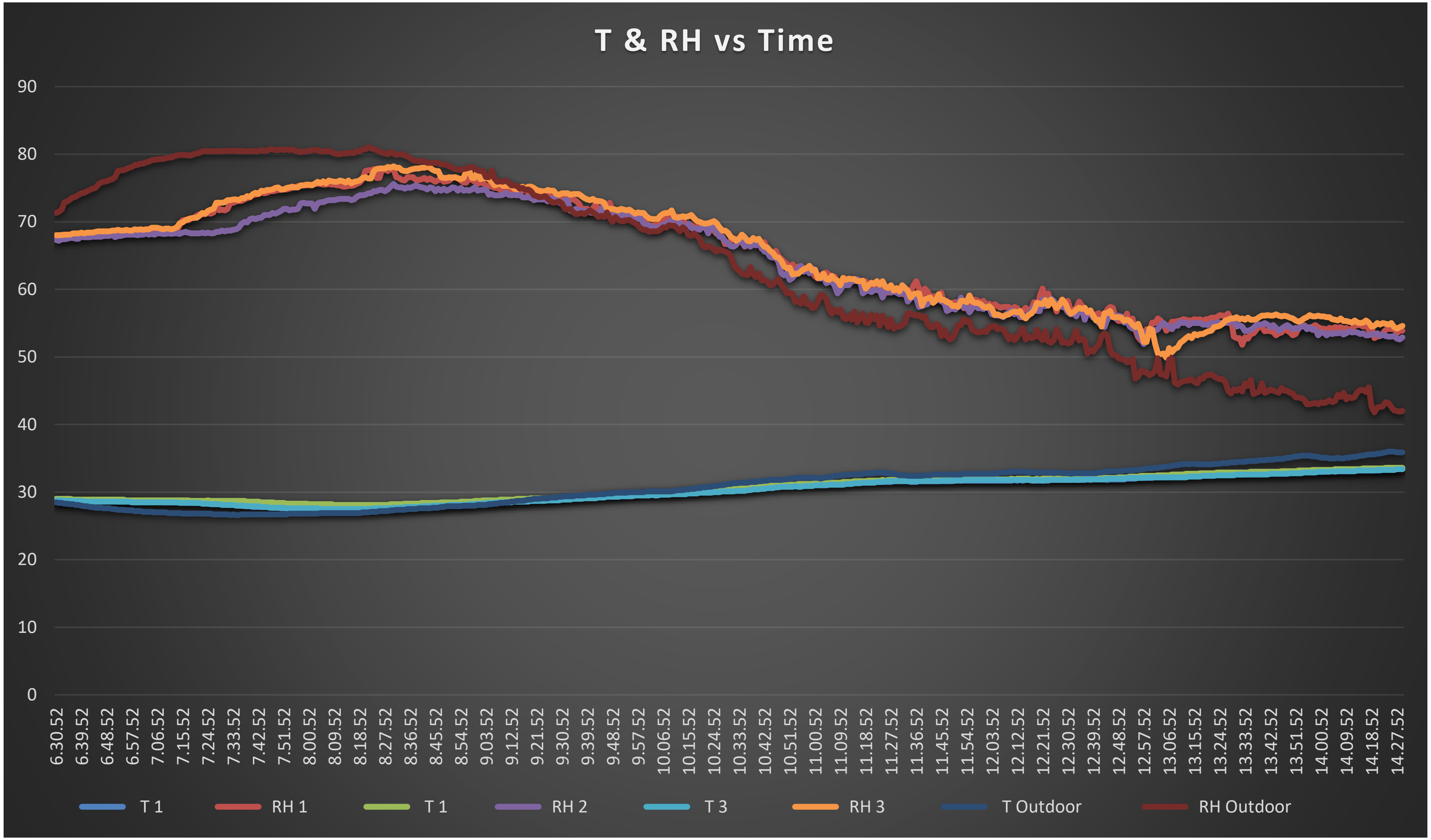

Figure 9. Time vs T and RH in school E class 1 to 3 and outdoor.
T = Temperature; RH = Relative Humidity; 1, 2, 3 = Classroom #1, 2 and 3 respectively.

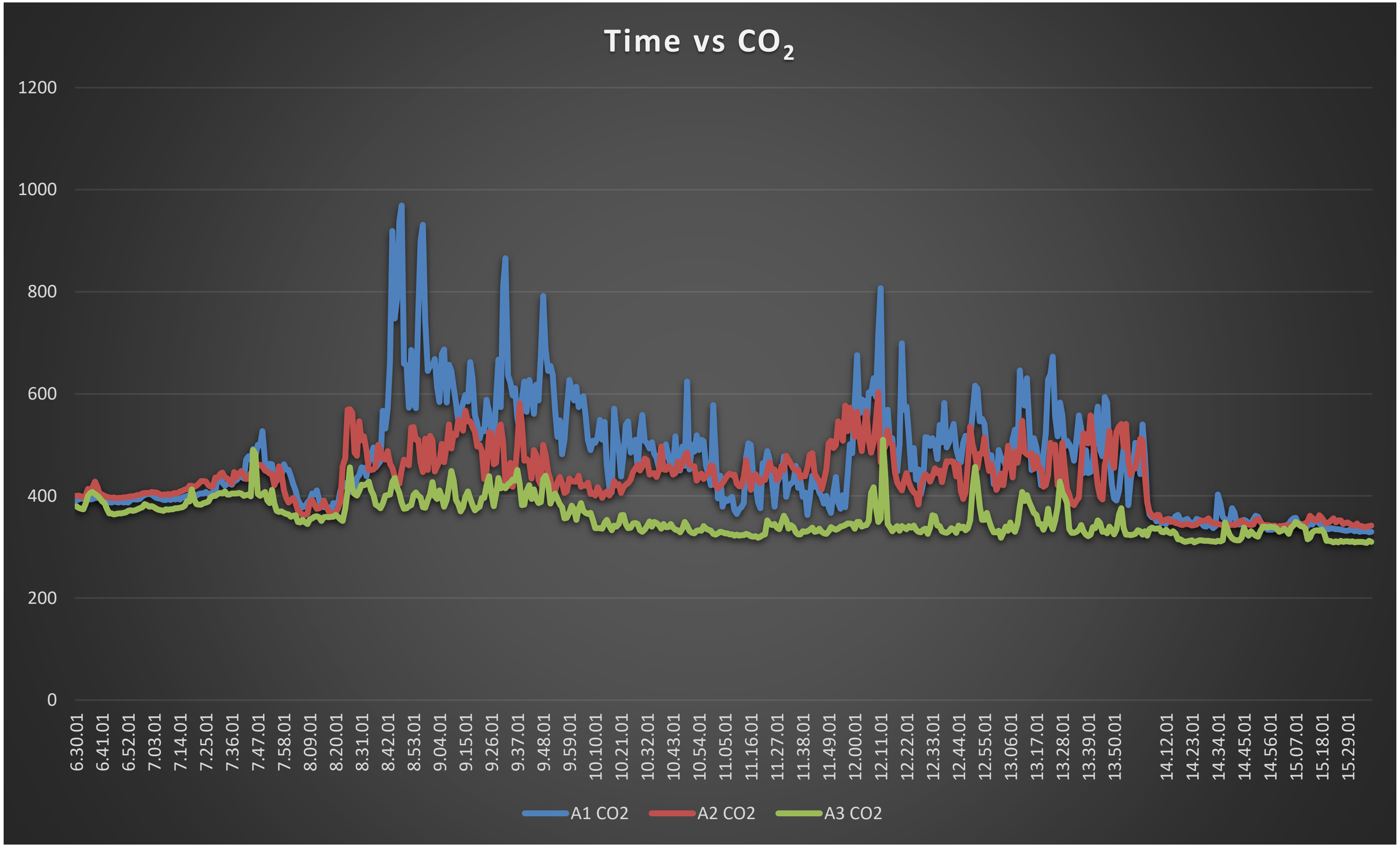

Figure 10. Time vs CO_2 in school A class 1 to 3.

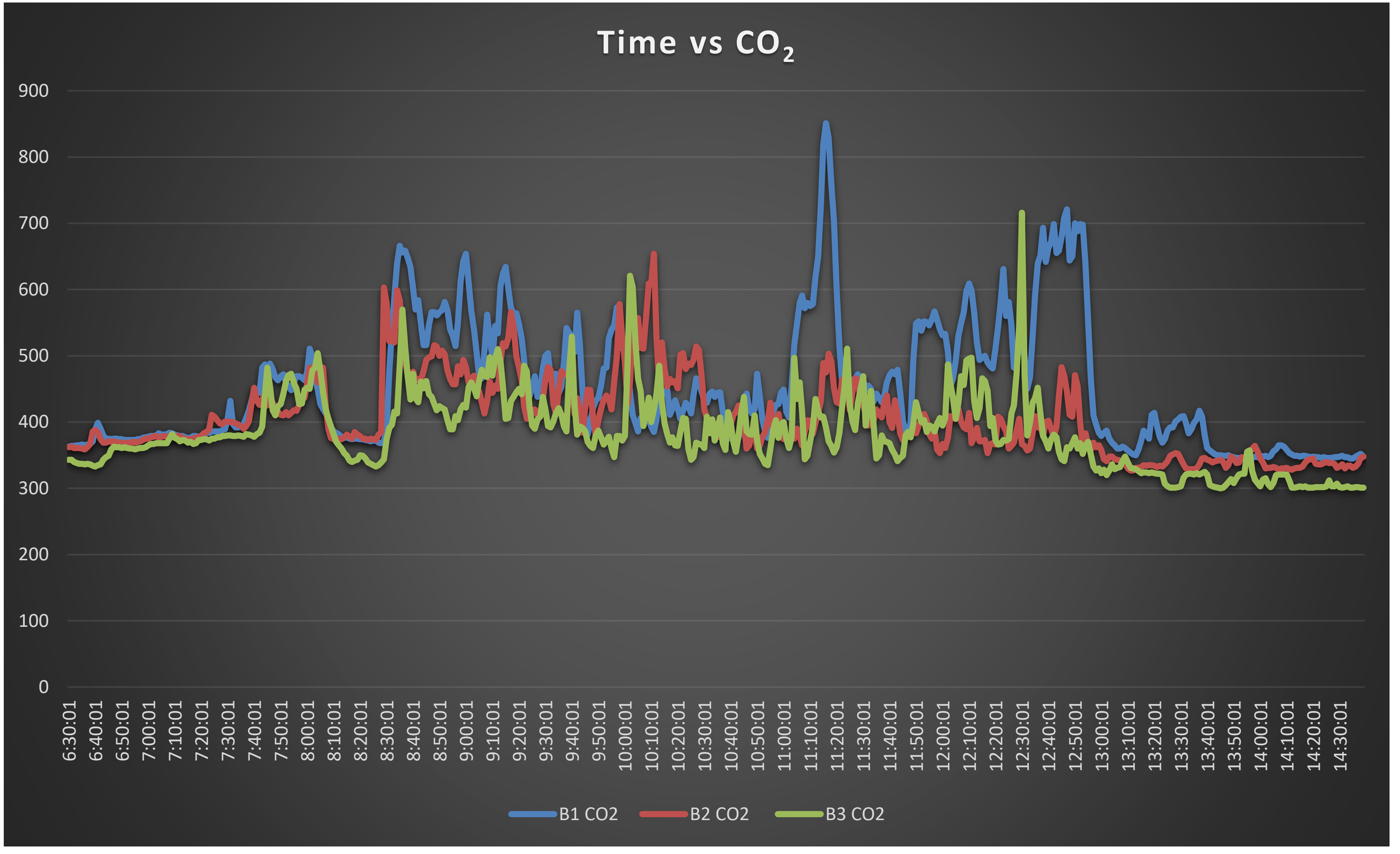

Figure 11. Time vs CO_2 in school B class 1 to 3.

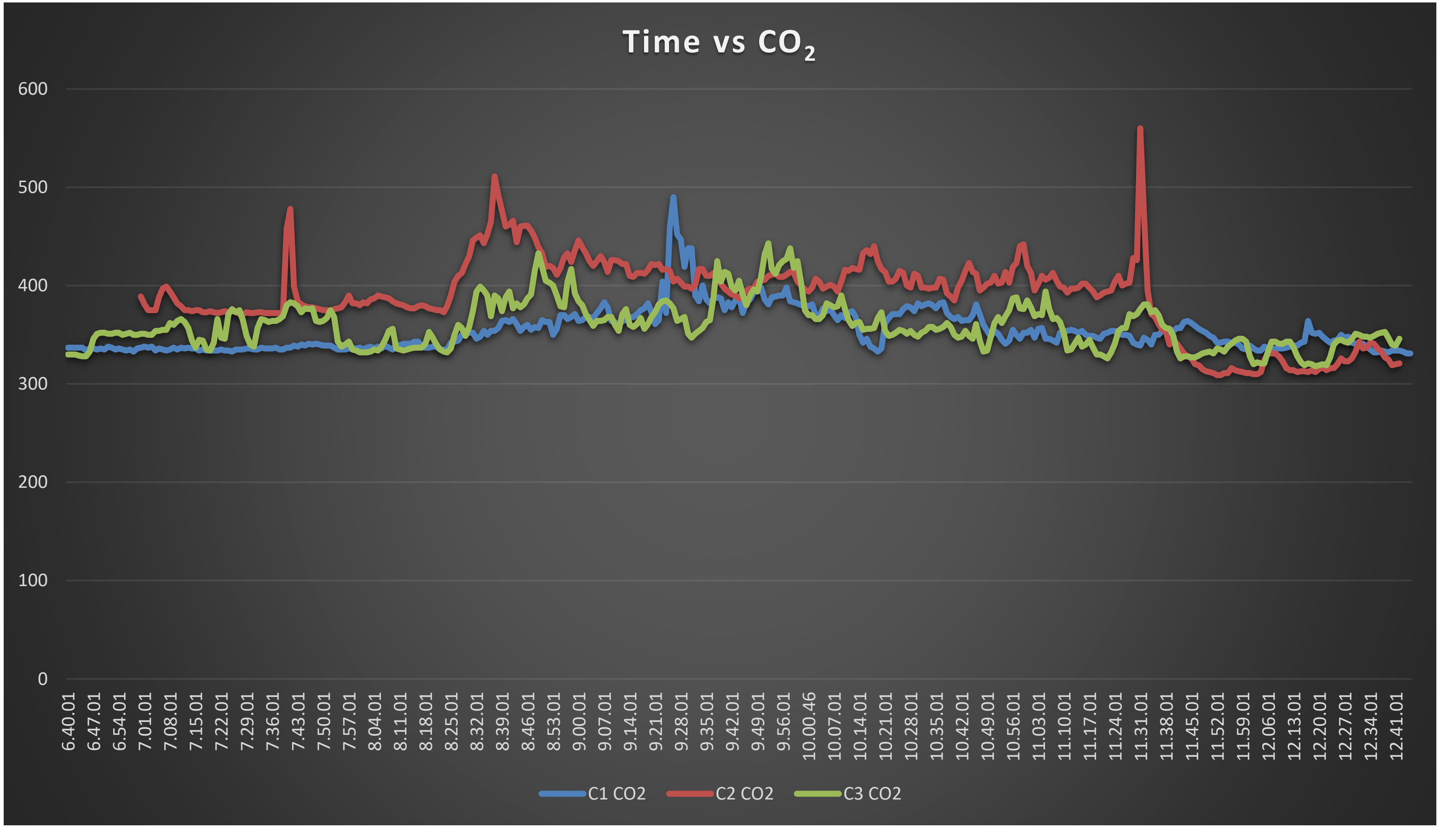

Figure 12. Time vs CO_2 in school C class 1 to 3.

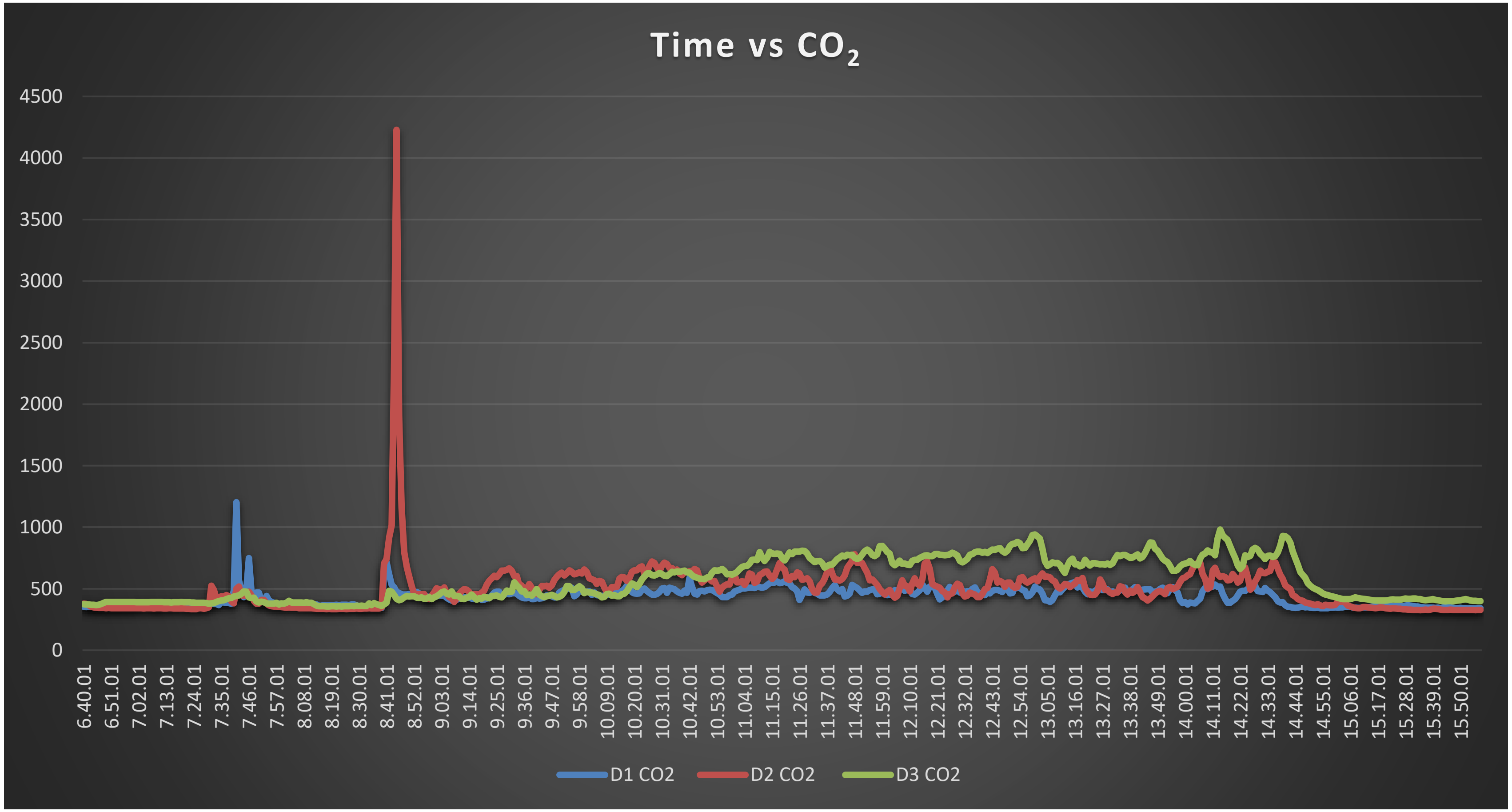

Figure 13. Time vs CO_2 in school D class 1 to 3.

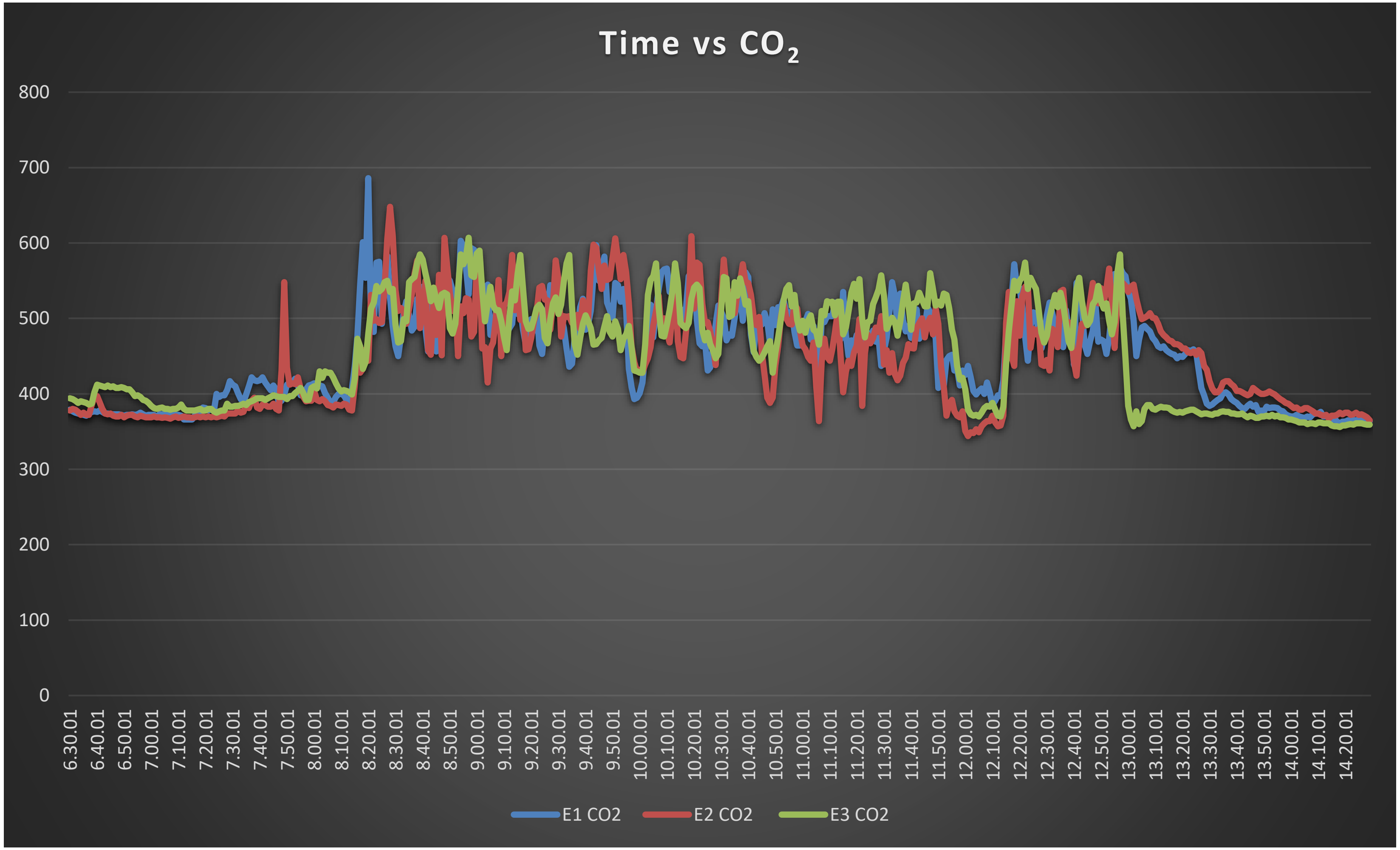

Figure 14. Time vs CO_2 in school E class 1 to 3.

Figure 15. Some images of the physical condition of the classrooms