



EVALUATING INDOOR AIR QUALITY IAQ IN PRIMARY SCHOOLS IN DOWNTOWN CAIRO, EGYPT

Nourhan A. Sary Eldin^{1*}, Ahmed A. Faggal² and Tamir El-Khouly³

+ 1,2,3 Department of Architecture, Faculty of Engineering, Ain Shams University, Egypt

1,3 Department of Architecture, School of Sciences and Engineering, The American University in Cairo, Egypt

2, Department of Architecture, Faculty of Engineering, Canadian International College, Egypt

*Corresponding Author E-mail: nourhansaryeldin@aucegypt.edu

Received :5 Sept. 2021 Accepted:14 Oct. 2021

ABSTRACT

There has been a growing interest in investigating indoor air quality levels in complex buildings such as primary schools to assess the impact of students' performance and well-being. Concerns are raised towards identifying the parameters that negatively affect indoor air quality in classrooms. Poor indoor air quality is expected to play a vital role in the prevalence of allergic and respiratory diseases.

Indoor air quality in schools plays an important role in assessing student exposure to air pollution as children are more sensitive when exposed to unhealthy air because they breathe more air than their body weight and at a faster rate.

This study shows measurements of carbon dioxide (CO₂), particulate matter (PM_{2.5}) and volatile organic compounds (VOCs) on indoor air quality for classrooms in a primary school in Cairo, Egypt, and discusses the concentration levels of these parameters on indoor air quality. Readings of the measurements were applied on an air quality monitoring system that is developed by the authors. This study raises awareness towards considering indoor air quality in schools designs with the purpose to minimize health risks and improve students' Learning performance.

KEYWORDS: Indoor air quality, primary school, natural ventilation, carbon dioxide (CO₂), particulate matters (PM_{2.5}), volatile organic compounds (VOCs).

تقييم جودة الهواء الداخلي بالمدارس الإبتدائية بوسط القاهرة، مصر

نورهان سري الدين^{1*}، أحمد عاطف فجال²، تامر عبد العظيم الخولي³

1,2,3 قسم الهندسة المعمارية، كلية الهندسة، جامعة عين شمس، القاهرة، مصر

1,3 قسم الهندسة المعمارية، كلية العلوم والهندسة، الجامعة الامريكية، القاهرة، مصر

2 قسم الهندسة المعمارية، كلية الهندسة، الكلية الكندية الدولية، القاهرة، مصر

E-mail nourhansaryeldin@aucegypt.edu

الملخص:

أصبحت جودة الهواء الداخلي (IAQ) موضوعًا للعديد من الدراسات بسبب القلق المتزايد داخل المجتمع العلمي حول تأثيرات جودة الهواء الداخلي على الصحة، خاصة وأن الناس يقضون وقت أطول داخل البيئة المبنية مقارنةً بالهواء الطلق. لذلك فمن المتوقع أن يكون تقييم جودة الهواء في المباني المدرسية دورًا رئيسيًا في تقييم آثار تعرض الأطفال لتلوث الهواء، حيث يقضي الأطفال ثلث وقتهم على الأقل داخل المباني المدرسية، أي ما يقرب من سبع ساعات أو أكثر من اليوم في المدرسة. وبذلك يؤثر تقييم جودة الهواء الداخلي IAQ الرديء على الأداء العلمي والحضور للتلاميذ.

يكون الأطفال أكثر حساسية عندما يتعرضون للهواء غير الصحي، لأنهم يتنفسون عمومًا كمية أكبر من الهواء بالنسبة لوزن الجسم بمعدل أسرع. فيكون لسوء نوعية الهواء الداخلي الناتج عن تركيزات ثاني أكسيد الكربون (2CO) والمركبات العضوية (VOC) الزائدة تأثير سلبي على حضور التلاميذ وقدراتهم على التعلم، ويؤدي إلى ضعف الأداء الأكاديمي. لذلك، تعد جودة الهواء الداخلي في المباني المدرسية مهمة للغاية، وقد يكون لها تأثير كبير على نظام الرعاية الصحية في الدولة. أشارت الدراسات أيضًا إلى أن تركيزات ملوثات الهواء الداخلية في الفصول الدراسية، مثل تركيزات ثاني أكسيد الكربون 2CO والجسيمات العالقة PM والمركبات العضوية VOCs تتأثر بشكل كبير بمصادر تلوث الهواء خارج المدرسة، وخصوصًا حركة المرور والانبعاثات الصناعية). بقدر ما تحدد حركة الهواء والرطوبة النسبية ودرجة حرارة الهواء حالة الهواء الداخلي، يمكن فحص نوعية الهواء الجيدة من خلال عدد الملوثات التي يمكن أن تؤدي إلى مشاكل صحية.

يركز هذا البحث على قياس وتقييم جودة الهواء في الفصول الدراسية بالمدارس المصرية استكشاف ما إذا كان هناك أي تأثير لتصميم الفراغات التعليمية (الفصول الدراسية) على جودة الهواء الداخلي وسيتم إجراء القياسات بواسطة نظام جهاز تم تطويره من قبل الباحثين لقياس ملوثات الهواء .

الكلمات المفتاحية:

جودة الهواء الداخلي، المدرسة الابتدائية، التهوية الطبيعية، ثاني أكسيد الكربون، الاتربة، المركبات العضوية المتطايرة

1. INTRODUCTION

In recent years, the world has been suffering from serious air pollution problems with the growing industrial and urbanization and increasing energy consumption in industrialized cities. Studies have shown that most cities all over the world do not meet the World Health Organization (WHO) air quality guidelines for acceptable air quality [1]. The map highlights areas within countries that exceed WHO air quality limits is shown in Figure 1. Air pollution can lead to health damage to public health, including the health of 'sensitive' populations such as children, pregnant, asthmatics, and the elderly. WHO statistics show in 2016, 91% of the world population was living in places where the WHO air quality guidelines levels were not met. Ambient (outdoor air pollution) in both cities and rural areas were estimated to cause 4.2 million premature deaths worldwide in 2016 [2]. Health symptoms like stroke, heart disease, lung cancer, and respiratory diseases including asthma are known to be associated with air quality.

In recent years, the concern about the effect of air pollution on children has been raised. Children are more sensitive when they are exposed to unhealthy air because they generally breathe a higher volume of air relative to body weight at a faster rate. Therefore, indoor air quality in school buildings is highly important, and may have a significant impact on a nation's healthcare system. Children spend at least a third of their time inside school buildings, that is, approximately seven or more hours a day in school. Poor IAQ can affect scholarly performance and attendance. The authors in [3] investigated that there is a statistically significant association between IAQ, and health associated with the prevalence of allergic and respiratory diseases among school children with poor IAQ in classrooms. A study carried out in Greece showed that poor indoor air quality has a negative impact on students' achieved scores and caused lowest attendance rates [4].

Over the past decades, Egypt has been experiencing serious air pollution problems due to rapid industrialization, urbanization, and increasing energy consumption [5]. A study from WHO shows that air pollution in Egypt, especially in Cairo and Alexandria, has been of concern for several years. Particulate matter is the most common air pollutant in urban and industrial areas [6]. The few epidemiological studies of air pollution in Egypt have indicated a significant increase in chest problems for those exposed to high levels of particulate in the residential industrial areas. Furthermore, particulate matter and lead pollution have been recognized as the most deleterious agents to health in Cairo's environment [7].

According to IQAir (IQAir is a Swiss air quality technology company, specializing in protection against airborne pollutants, developing air quality monitoring and air cleaning products. IQAir also operates AirVisual, a real-time air quality information platform.) Most polluted cities (PM2.5) 2019 annual report Cairo came at 1026 place according to data aggregated over 60.000 data points and Egypt came at 56 according to data aggregated over 89 data points [8]. IQAir ranking is shown in Figure 2.

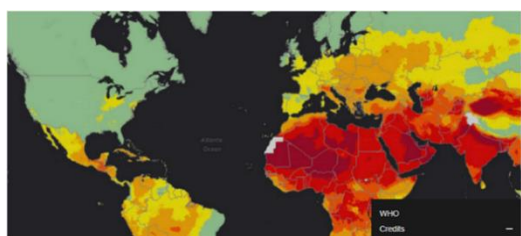


Fig. 1: interactive maps highlight areas within countries that exceed WHO air quality limits [1].

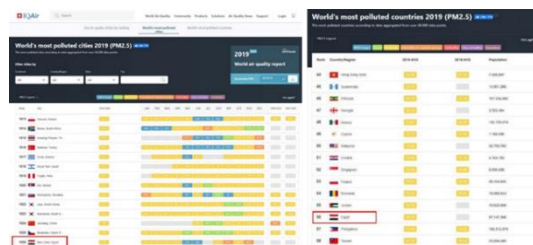


Fig. 2: (left) World most polluted cities 2019 (PM2.5), (right) World most polluted countries 2019 (PM2.5) [7].

2. AIR POLLUTANTS

The most common pollutants that will be measured are particulate matter (PM), carbon dioxide (CO₂), volatile organic compounds (VOCs) and meteorological data such as relative humidity (RH) and temperature will also be measured.

Carbon dioxide CO₂ is a colorless gas having a faint sharp odor and a sour taste. It is one of the most important greenhouse gases linked to global warming [9]. CO₂ is primarily a by-product of human metabolism and is constantly being emitted into the indoor environment by building occupants. CO₂ may come from combustion sources as well. The major sources of indoor carbon dioxide are as follows: People, kerosene and gas space heaters, tobacco smoke, and outside air [10].

Particulate matters PM, known as dust, is a mixture of organic and inorganic substances found in the air. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small they can only be detected using an electron microscope. Respiratory health problems can be caused by both PM₁₀ (PM with a size 10 micrometers and smaller) and PM_{2.5} (PM with a size 2.5 micrometers and smaller). PM_{2.5} are finer particles that travel deeper into the lungs and settle there. Elderly and young children and the elderly are more susceptible to the health effects of PM_{2.5}. PM_{2.5} Negatively affects the lung and aggravates asthma and heart disease [11].

Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids. VOCs include a variety of chemicals, some of which may have short- and long-term adverse health effects.

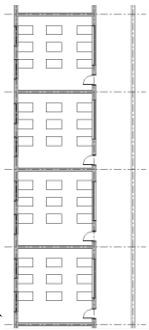
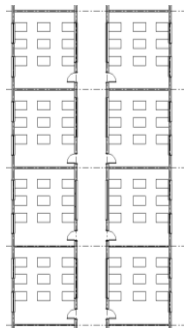
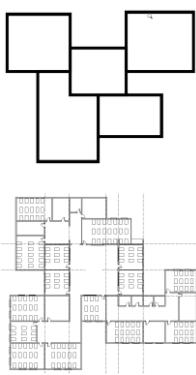
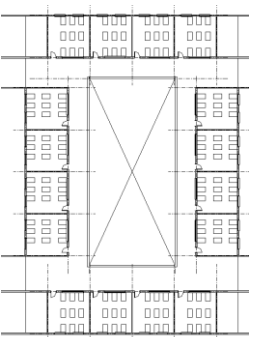

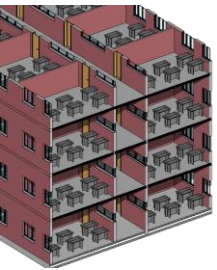
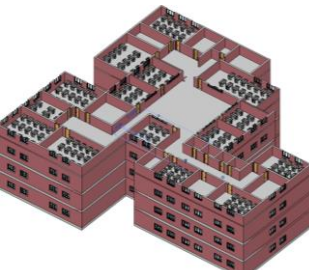
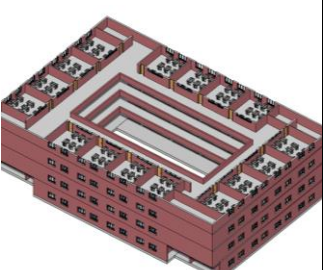
Concentrations of many VOCs are consistently higher indoors (up to ten times higher) than outdoors. VOCs are emitted by a wide array of products numbering in the thousands. Examples include paints and lacquers, paint strippers, cleaning supplies, pesticides, building materials and furnishings, office equipment such as copiers and printers, correction fluids and carbonless copy paper, graphics and craft materials including glues and adhesives, permanent markers, and photographic solutions [12].

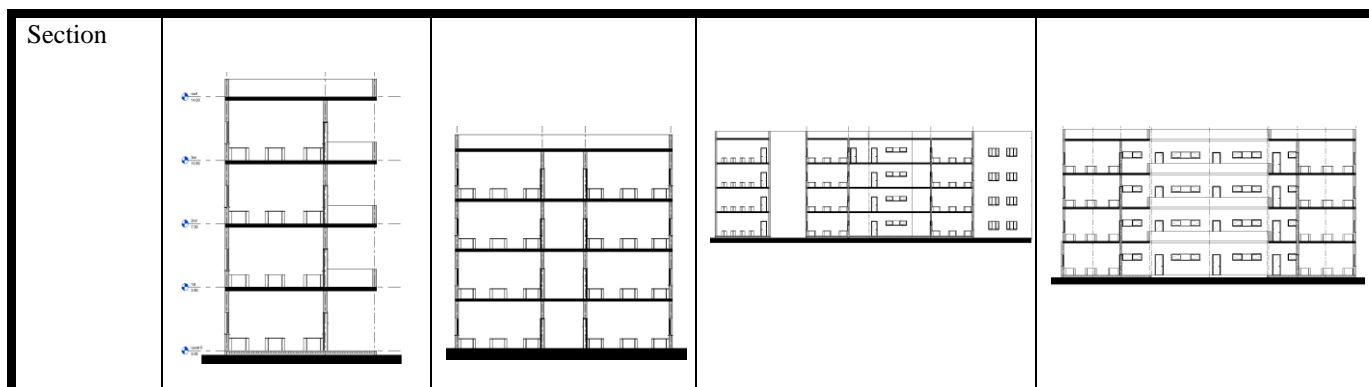
3. TYPOLOGIES of SCHOOLS

Schools in Egypt have various architectural configurations which have an impact on the indoor environmental quality. The configurations divide into three typologies: Linear type single or double loaded, clustered, and central around court. Table 1 shows the three typologies.

This research studies the linear type single and double loaded and the clustered type

Table 1: schools design configurations– Source: Authors

School typology	Linear		Clustered	Central around court
	Single loaded	Double loaded		
Plan				
3D				



4. RESEARCH METHOD

4.1. A new Indoor Air Quality Monitoring Device

The devices available in the Egyptian Environmental Affairs Agency (EEAA) monitor air pollutants in external spaces only and do not measure indoor spaces, and each device measures only one factor; one device measures PM_{2.5}, another measures CO₂, Temperature and Humidity, and a third measures CO₂ and VOC.

As there is no available device that can monitor all the parameters that are required for this study and because of the difficulty of placing three devices in the classroom to monitor air quality parameters, the researchers prepared and developed a new device using the Arduino platform and recorded the readings on the computer for comparison.

Based on this, the new device achieves the following purposes: firstly, it measures air quality in the classroom, and secondly, it contains multiple sensors to simultaneously read and record factors responsible for air quality. The Arduino platform uses three sensors that monitor five types of air quality parameters: PM_{2.5}, CO₂, VOCs, temperature and humidity.

4.1.1. The Calibration Process

In order to validate the use of this new device, it has been calibrated contrasting its readings against three authorised and validated devices by the EEAA; Aeroqual portable (series 500) measuring CO₂ and VOC, AQ9600 measuring Particulate matters PM_{2.5}, and CO2390 measuring CO₂, Temperature and Humidity.

The calibration process extended to eight as a reasonable time frame to monitor, detect and record the results under different conditions. After completion, it was found that the error factor in reading CO₂ and VOC is 0.05, while in reading PM_{2.5} is 0.01. The error factors are minimal but all the reading values that are used in this study have been corrected according to these error factors. Hence, the device became validated for use. Figure.3 shows the framework and illustration of the developed monitoring device.

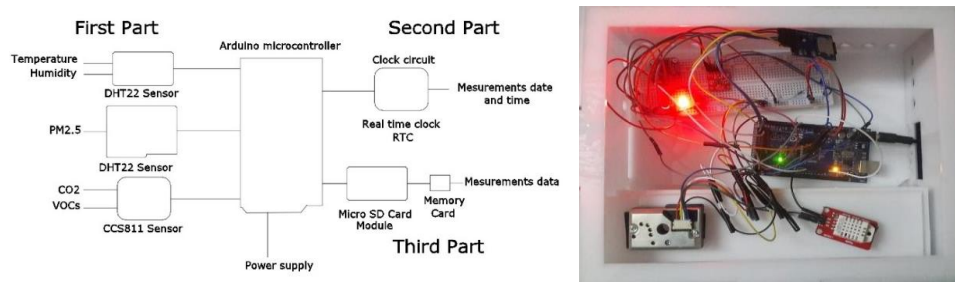


Fig. 3: The air quality monitoring framework Source: Authors

The framework of this device supports user-friendly objectives for monitoring the parameters and understanding the conditions under which air quality levels in classrooms can be affected. Since it includes multiple types of sensors, the device can be customised to detect some other various conditions, e.g., rain detection by using rain sensor module [13].

4.1.2. Advantages and Disadvantages

The advantages of this device are:

1. It is a mobile device that can be remotely located anywhere.
2. It is an integration of multiple parameters into one digital platform.

The disadvantage:

1. The results come in the form of numeric values that requires the researcher to transform data into a graph to be easily read.

This framework collects of environmental parameters, e.g., CO₂ concentrations and the amount of dust PM_{2.5} present in the air which is an important indicator of air quality.

The monitoring device is located 150 cm above the floor.

The measurements were made between October 18, 2020, and December 10, 2020.

4.2. Sampling Selection Criteria and Data Collection

A field study was conducted on five classrooms in four primary schools located in different residential areas, where the students' ages range from six to ten years. The sampled classrooms are representative of many cases that can be found in other schools across Egypt. The measurements were taken in hot and cold seasons. The selected schools are in Misr El Qadima district, in the southern urban area of Greater Cairo within the boundaries of Cairo Governorate Figure. 3. Field visits were conducted to the selected schools to obtain their consent to participate in the study.



Schools were chosen carefully to be different in the architectural design configuration of school buildings but share the same climate conditions, so these schools to some extents are in the same geographical zone. To make the climate a fixed factor to measure the varies school designs.

The sample of schools selected to participate in this study provided the researchers with the actual drawings of the school building after its construction (as-built set of drawings). In fact, after the COVID-19 pandemic, it was difficult to obtain permission from school principals to run the experiments and many schools refused to participate and withdrew from the study. But the schools that allowed the study to take place were assured that the data would only be used for scientific purposes. The observed results show the need to take indoor air quality monitoring seriously in primary schools in Egypt in general. As a result of the measurement time limitations provided by the schools due to COVID-19 precautionary measures, the results are a close representation of the general conditions in the classroom studied but further measurements are recommended. Measurements over a long period were conducted to assure more reliability. All schools' teaching duration operated in a naturally ventilated environment and all buildings are in a good condition. Classroom cleaning work took place after students left school or

EVALUATING INDOOR AIR QUALITY IAQ IN PRIMARY SCHOOLS IN DOWNTOWN CAIRO, EGYPT

before they arrived around 7:00 AM. The measurements were taken between October and December 2020 in the presence of students.

Table 4: cold area measurements – Source: Authors

School	A	B	C	D
School Name	Salah Eldin primary school	Field Marshal Ahmed Ismail Official Language School	Future language school	Ahmed Lotfy El Sayed Primary School
Location	Elzaharaa -Misr el Qadima	Elzaharaa -Misr el Qadima	Al Fostat - Misr el Qadima	AlManial -Misr el Qadima
Year of construction	1990	2000	2010	1995
Design configuration	Cluster 	L-shape building 	3 linear buildings parallel to each other 	Two buildings are opposite to each other. 
	 	 	 	 

EVALUATING INDOOR AIR QUALITY IAQ IN PRIMARY SCHOOLS IN DOWNTOWN CAIRO, EGYPT

Number of stories	four-story (ground and 3 typical floors).	four-story (ground and 3 typical floors).	four-story (ground and 3 typical floors).	four-story (ground and 3 typical floors).
No. of students	520	1650	1400	430
Type and Age	public primary school students' age six to twelve years	public primary school students' age five to eighteen years	a private school for students' age five to eighteen years	public primary school students' age between six and twelve years

to take place were assured that the data would only be used for scientific purposes. The observed results show the need to take indoor air quality monitoring seriously in primary schools in Egypt in general. As a result of the measurement time limitations provided by the schools due to COVID-19 precautionary measures, the results are a close representation of the general conditions in the classroom studied but further measurements are recommended. Measurements over a long period were conducted to assure more reliability. All schools' teaching duration operated in a naturally ventilated environment and all buildings are in a good condition. Classroom cleaning work took place after students left school or before they arrived around 7:00 AM. The measurements were taken between October and December 2020 in the presence of students.

School A

This is a public primary school for students' age six to twelve years (Grades 1-6). Around 520 students are registered in this school. The school is a four-floor building (a ground floor and three typical floors). Classes start at 8:00 am and end at 12:30 pm. Two classrooms were chosen in this school located on the second floor; one is oriented towards South while the other is oriented towards the North. There are two schools, one club and one mosque in the same school district. Break time is from 10:25 am to 10:50 am.

School B

This is a public primary school for students' ages five to eighteen years (Grades 1:12). Around 1650 students are registered in this school. The school is a four-story (ground and 3 typical floors). Classes start at 8:00 am and end at 1:15 pm. The selected classroom is on the second floor and oriented towards the South. The school is in a highly polluted area due to a chemical factory. There are three schools attached to the selected school.

School C

This is a private school for students' ages five to eighteen years (Grades 1:12). Around 1400 students are registered in this school. The school building is of four-story (ground and 3 typical floors). The

classes start by 8:00 am and end by 2:00 pm. The selected classroom is located on the ground floor and oriented towards the North. There are four schools and one big mosque in the same school district.

School D

It is a public primary school which provides education for students' ages between six and twelve years (Grades 1-6). Around 430 students were studying in this school. The school is a four-story (ground and 3 typical floors). The selected classroom is located on the ground floor and oriented towards the North. There are three schools and a club in the same school district. The Nile River is located on the eastern side of the school.

4.3. Characteristics of the selected classrooms

Classroom School A (SA-C1)

The classroom volume is around 100 m³ (height 3m, width 6m, length 5.5 m). The classroom has two wall mounted fans as shown in Figure. 5. The windows are in two walls that face South and East directions. Class capacity is 19 occupants: 18 students and one teacher. The classroom is located on the last floor and is oriented towards the South.

Classroom School A (SA-C2)

The classroom volume is around 100 m³ (height 3m, width 6m, length 5.5 m). The classroom has two wall mounted fans as shown in Figure. 6. The windows are on two sides facing West and North. The classroom is on the first floor. There are 21 students in the classroom.

Classroom School B (SB-C3)

The classroom volume is around 93.75 m³ (height = 3m, width = 6.25m, length = 5 m). The classroom has two ceiling fans as shown in Figure 7. The windows are on two opposite sides, at the southern-east direction and the other window is located at the corridor but is closed during the measurements time. The classroom is located on the second floor. There are 20 students in the classroom. There is no handmade works mounted in the classroom during the measuring time. The classroom is usually cleaned at 7:15 am before the arrival of the students. Dust was observed on indoor surfaces of the classroom. A chemical factory located close to the studied classroom is supposed to be a source of pollutants.

Classroom School C (SC-C4)

The building and other facilities were in a very good condition. The classroom is on the ground floor. The classrooms were cleaned after the students' departure at 2:00 pm. The classroom volume is around 120.5m³ (height = 3m, width = 6 m, length = 6.7 m). The classroom has one ceiling fan as shown in Figure. 8. The classroom is in the north direction of the building. The windows are on two opposite sides as shown in figure 8, at the north direction and the other window located at the corridor but it was closed during the measurements time.

Classroom School D (SD-C5)

The building and other facilities were in a good condition. The classroom is on the first floor. The classroom was cleaned at 7:30am. The classroom volume is around 120 m³ (height = 3 m, width = 5 m, length = 8 m). The classroom has two ceiling fans as shown in Fig. 12. The classroom is in the north direction of the building. The windows are on two opposite sides, at the north direction and the other window located at the corridor. Walls were covered by students' handmade works during the measuring time as shown in Figure 9.

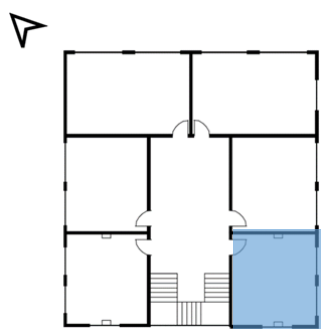


Fig. 5: School A (SA-C1)

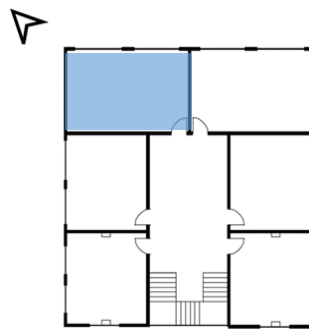


Fig. 6: School A (SA-C2)

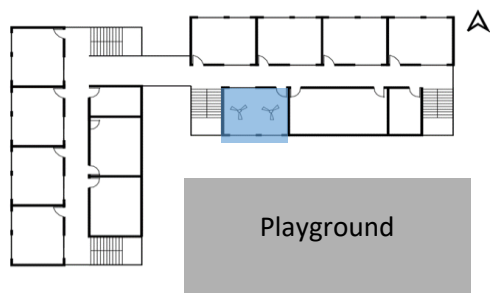


Fig. 7: School B (SB-C3)

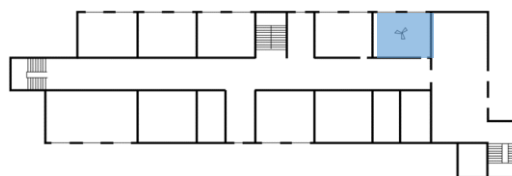


Fig. 8: School C (SC-C4)

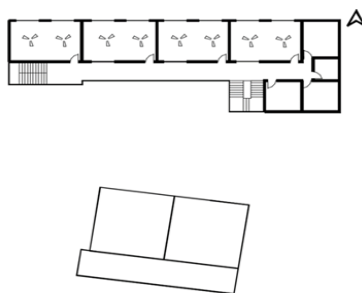


Fig. 5: School A (SA-C1)

5. AIR POLLUTANTS

Tables 2 and 3 show the average values of the three parameters that were measured for the five classrooms during a school day from 8:00 AM to 14:00 PM, where the sample was measured for classrooms located in qualitatively cold and mild areas.

5.1. Carbon Dioxide (CO₂) levels inside classrooms

Figure 9,10. shows a comparison of CO₂ concentration levels for the five natural ventilated classrooms in both mild and cold areas during full student occupancy. By comparing these results with the values recommended by the World Health Organization; WHO standard, regarding CO₂ concentration levels

(1300 ppm) and ASHRAE guidelines and ventilation rates (7.5 L/sec/person) in classrooms, CO2 concentration levels within these classrooms are not consistent with WHO and ASHRAE Standard 62 recommendations.

It is also noted that when the classroom is empty during break time, CO2 levels decrease; the classroom was open at the time of the measurement, but it still exceeded the universally accepted limits.

After the break time, the reading shows a marked increase in CO2 concentrations; the maximum levels of carbon dioxide in the autumn temperate season were about 8000 parts per million, while it did not exceed 6000 parts per million during the cold winter season.

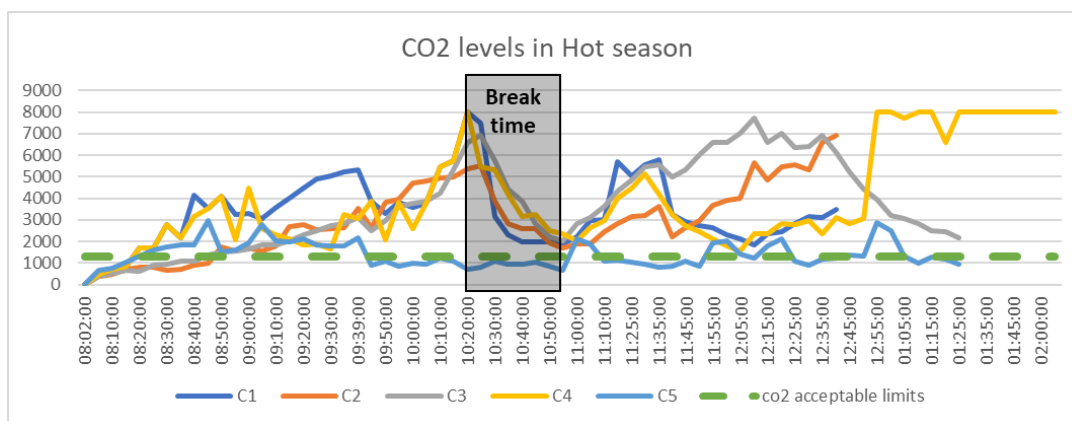


Fig. 9: CO2 concentrations in classrooms (mild areas) – Source: Author

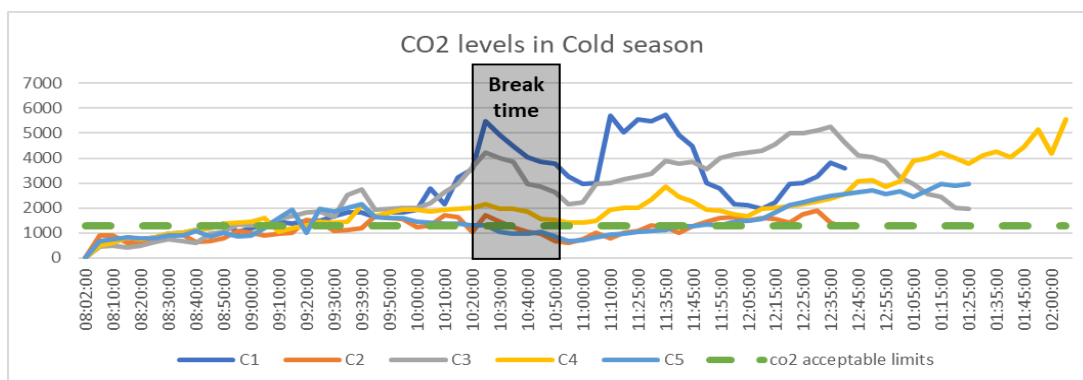


Fig. 10: CO2 concentrations in classrooms (cold areas) – Source: Authors

5.2. Volatile Organic Compounds (VOC) levels inside classrooms

Concentration levels of VOCs exceed accepted global standards during the measurement time in both temperate (autumn) and (winter) seasons as shown in the attached graph of Figure 11,12.

Break time levels decrease in concentrations, but they gradually rise again after students return from their break. These levels are higher than the levels recommended by the World Health Organization and ASHRAE guidelines. It is noted that the concentration levels in the mild season (autumn) are higher than the levels of the cold season measurements (winter); where the maximum levels of VOCs in the temperate season are approximately 1200 ppm while they do not exceed 1,000 ppm during the cold

season as shown in the Figure 11,12. Classrooms with students' handiwork that are hung on walls record higher readings in concentration levels than others that do not have any educational materials mounted on the walls. Student personal possessions, bags, etc. may contribute to the effect on the measured levels of VOCs.

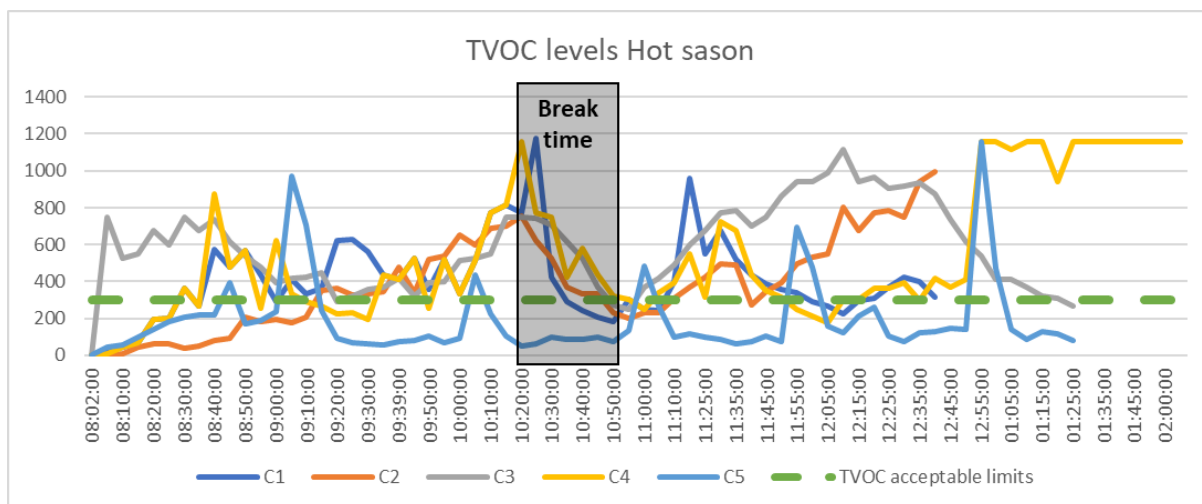


Fig. 11: TVOC concentrations in classrooms (mild areas) – Source: Authors

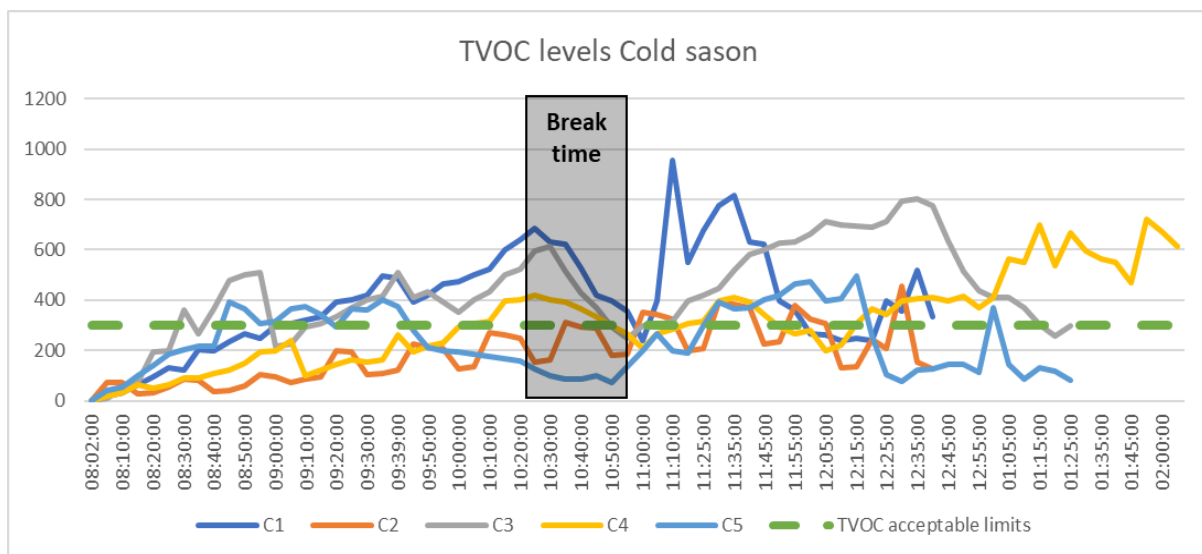


Fig. 12: TVOC concentrations in classrooms (cold areas) – Source: Authors

5.3. Particulate matters (PM2.5) levels inside classrooms

The comparison between the PM2.5 concentration level for the 5 classrooms during the natural ventilation mode in both hot and cold seasons is shown in Figure 13,14. It is observed that the dust PM2.5 levels have fluctuated, and it is above the acceptable limits. Morning activities (both outdoor and indoor) influenced indoor TPM concentration. The outdoor air may also have contributed to this value

as the windows were fully opened during this period. The classrooms that had been cleaned with detergent before 7:30 am have high concentration levels during the early hours.

In general, the elevated indoor concentration of TPM is due to polluted outdoor air. Desert climate of this country also needs to be taken into consideration.

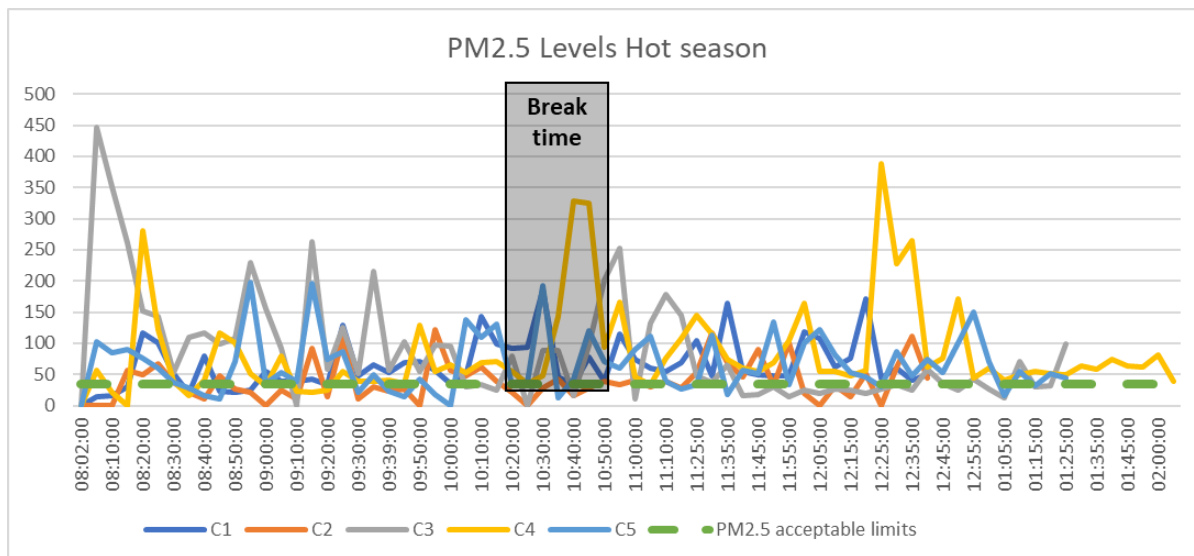


Fig. 13: PM2.5 concentrations in classrooms (mild areas) – Source: Authors

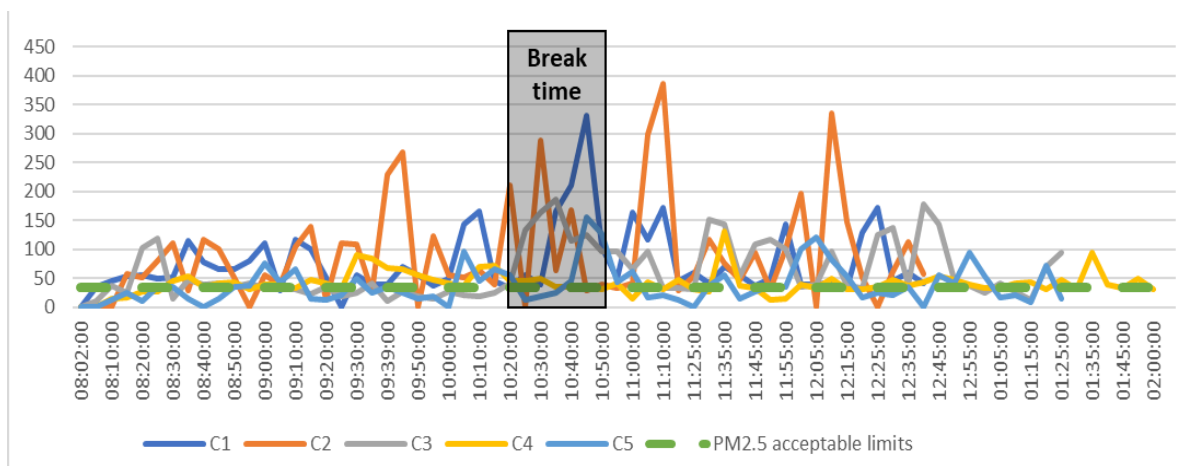


Fig. 14: PM2.5 concentrations in classrooms (cold areas) – Source: Authors

5.4. Temperature and Humidity levels inside classrooms

It is noted that the levels of temperature and humidity readings are higher than the universally accepted standards in the measurement times (autumn and winter); see Figure 15,16

EVALUATING INDOOR AIR QUALITY IAQ IN PRIMARY SCHOOLS IN DOWNTOWN CAIRO, EGYPT

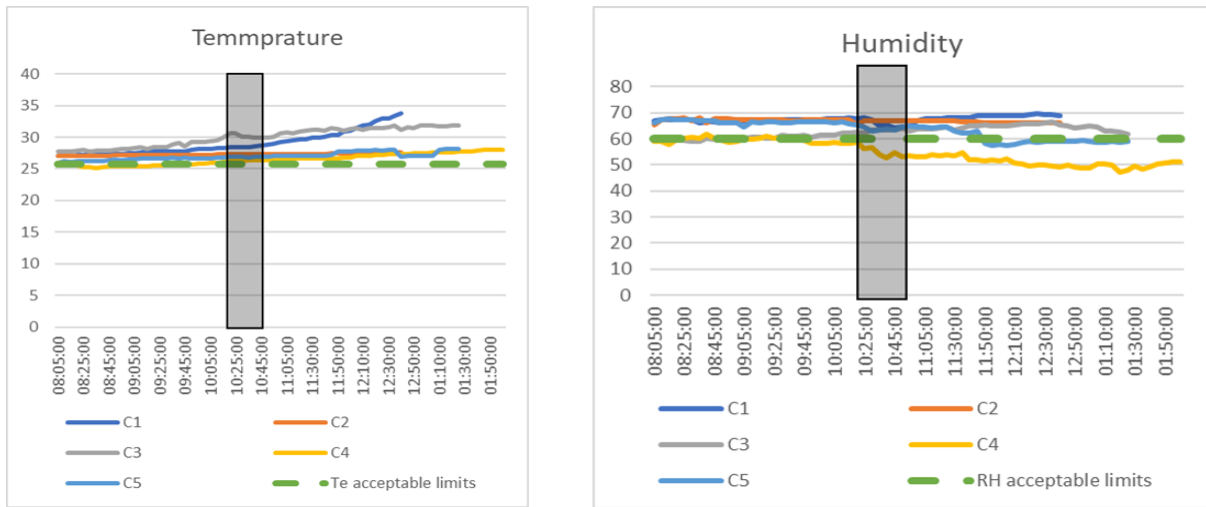


Fig. 15: Temperature and humidity levels (mild areas) – Source: Authors

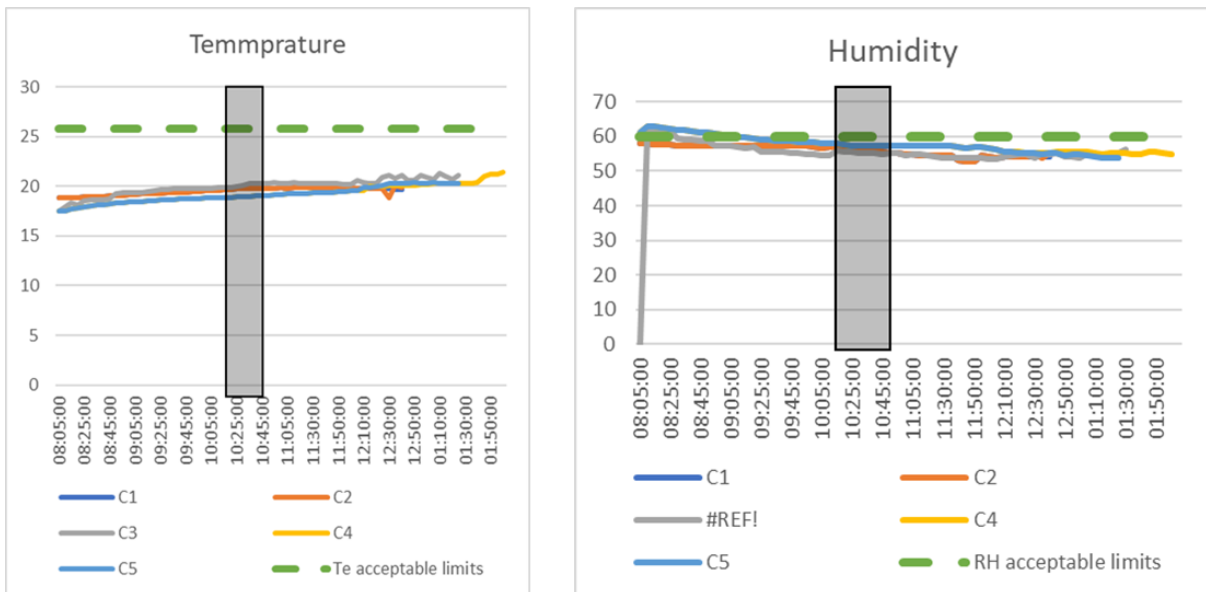


Fig. 16: Temperature and humidity levels (cold areas) – Source: Authors

Table 2: mild area measurements – Source: Authors

Characteristics		October			
		CO2	TVOCs	TP _{2.5}	Temperature
Classroom	Classroom Location at school building	Concentrations ranged between 460 ppm and 7,987 ppm	Concentrations ranged between 25 ppb and 1,175 ppb	Concentrations ranged between 15 µg/m ³ and 185 µg/m ³	Starts from 27 °C and increased during the measuring time and the maximum level was 33.8 °C, the average was 30 °C
	Classroom orientation	South	North and northwest	South	Starts from 26.1 °C and increased during the measuring time and the maximum level was 28.6 °C, the average was 27.3 °C
	Volume	100 m ³ (height 3m, width 6m, length 5.5 m)	100 m ³ (height 3m, width 6m, length 5.5 m)	93.75 m ³ (height ~ 3m, width ~ 6.25m, length ~ 5 m).	Starts from 59.5 % and increased during the measuring time and the maximum level was 66.7% the average was 64%.
Number of occupants		19	21	21	
Classroom		C1	C2	C3	
Schools		A			B
		Concentrations ranged between 405 ppm and 7481 ppm	Concentrations ranged between 9 ppb and 756 ppb	Concentrations ranged between 5 µg/m ³ and 450 µg/m ³	Starts from 27.8 °C and increased during the measuring time and the maximum level was 32 °C, the average was 30 °C
		Concentrations ranged between 409 ppm and 7,793 ppm	Concentrations ranged between 9 ppb and 756 ppb	Concentrations ranged between 5 µg/m ³ and 450 µg/m ³	Starts from 27.8 °C and increased during the measuring time and the maximum level was 32 °C, the average was 30 °C

		October	
Characteristics	CO2	Concentrations ranged between 405 ppm and 7,992 ppm	Concentrations ranged between 460 ppm and 2,985 ppm
	TVOCs	Concentrations ranged between 16 ppb and 388 ppb	Concentrations ranged between 61 ppb and 973 ppb
	TP 2.5	Concentrations ranged between 16 µg/m ³ and 388 µg/m ³	Concentrations ranged between 15 µg/m ³ and 198 µg/m ³
	Temperature	Starts from 25°C and increased during the measuring time and the maximum level was 28.2°C. the average was 26.5 °C	Starts from 22°C and increased during the measuring time and the maximum level was 29°C. the average was 27 °C
	Humidity	Starts from 48.% and decreased during the measuring time and reached 60% at the end of measuring time. the average was 52%.	Starts from 57.% and decreased during the measuring time and the maximum level was 69%. the average was 65%.
Classroom	Classroom Location at school building	Ground floor	First floor
	Classroom orientation	West	North
	Volume	120.5m ³ (height ~ 3m, width ~ 6 m, length ~ 6.7 m).	120 m ³ (height ~ 3 m, width ~ 5 m, length ~ 8 m).
Schools	Number of occupants	21	19
		C4	C5
		C	D

Table 3: cold area measurements – Source: Authors

Characteristics		October		
		CO2	TVOCs	TP 2.5
Classroom	Classroom Location at school building	Third floor (Last floor)	second floor	second floor
	Classroom orientation	South	North and north west	South
	Volume	100 m ³ (height 3m, width 6m, length 5.5 m)	100 m ³ (height 3m, width 6m, length 5.5 m)	93.75 m ³ (height ~ 3m, width ~ 6.25m, length ~ 5 m).
Number of occupants		19	21	21
Classroom		C1	C2	C3
Schools		A B		

EVALUATING INDOOR AIR QUALITY IAQ IN PRIMARY SCHOOLS IN DOWNTOWN CAIRO, EGYPT

		October	
Characteristics	CO2	Concentrations ranged between 514 ppm and 5,789 ppm	Concentrations ranged between 683 ppm and 2,985 ppm
	TVOCs	Concentrations ranged between 17 ppb and 701 ppb	Concentrations ranged between 43ppb and 498 ppb
	TP 2.5	Concentrations ranged between 5 µg/m ³ and 130 µg/m ³	Concentrations ranged between 5 µg/m ³ and 155 µg/m ³
	Temperature	Starts from 16.5°C and increased during the measuring time and the maximum level was 20°C, the average was 18.5 °C	Starts from 16°C and increased during the measuring time and the maximum level was 20.5°C, the average was 18.5 °C
	Humidity	Starts from 52.% and decreased during the measuring time and reached 62%.at the end of measuring time, the average was 58%.	Starts from 55.% and decreased during the measuring time and the maximum level was 61%. the average was 58%.
	Classroom Location at school building	Ground floor	First floor
Classroom orientation	West	North	
Volume	120.5m ³ (height ~ 3m, width ~ 6 m, length ~ 6.7 m).	120 m ³ (height ~ 3 m, width ~ 5 m, length ~ 8 m).	
Number of occupants	21	19	
Classroom	C4	C5	
Schools	C	D	

6. CONCLUSION

This research study provided a means of measuring quantitative information for some of the main factors affecting the quality of natural ventilation in classrooms in primary schools in Egypt. Carbon Dioxide, Volatile organic compounds, Particulate matters.

The used device was developed locally by the researcher and some of his assistants, and it was calibrated by comparing with the readings of other devices. What distinguishes this device is the ease of reading several transactions at the same time; They are recognized as major influences on indoor air quality, and they are coefficients Carbon Dioxide, Volatile organic compounds, Particulate matters, Temperature and Humidity.

The measurements were made on four schools in downtown Cairo, where the areas of overcrowding, the degree of pollution is somewhat high. Table 4.

Configuring the design of buildings and classroom locations in the school building plays a vital role in reducing pollution limits and reducing indoor CO₂ and VOC levels.

Levels of carbon dioxide and volatile organic compounds in all the schools studied were high enough to cause health or comfort problems.

It is observed that classrooms which oriented towards north and northwest direction (C2, C5) have the lowest concentration levels of CO₂ and VOCs. Also, the 5 minutes break between the classes to change the teachers helps in reducing the concentration levels. Ventilation rates in all studied schools were insufficient to dilute indoor air contaminants. Polluted outdoor air also compromised the benefits of ventilation usage. C2 has openings at 3 walls of the classroom at the north and west direction (towards the prevailing wind direction) therefore, the CO₂ concentration levels have fluctuated but at the acceptable ranges most of the measuring time, and the highest level was 1903 ppm. comparing this with C1 and C4, as C1 has openings at 3 walls but it is located at the southern part of the building therefore, it has poor air quality. C4 windows openings towards the west direction and has window and the door at the corridor which are closed during the teaching time that negatively affected the air flow and it caused the inadequate indoor air quality. Classrooms which were cleaned before start of the first-class session in morning with detergent had high indoor level of TVOCs. The CO₂ concentration levels recorded inside the classrooms during operation time in the mild areas exceed values recommended in standards and are higher than those measured during cold areas.

During the break time the classroom's door was open, and no one was in the classroom, hence CO₂ and TVOCs had a descending trend as it is expected. So, the break time helps in reducing the CO₂ and TVOC levels. The students' belongings and students themselves may have contributed to the measured levels of TVOCs. It is observed that the dust PM_{2.5} levels have fluctuated, and the outdoor air pollution has an impact on the indoor concentration levels as the classrooms are naturally ventilated spaces.

7. LIMITATION

The major limitation of the study was that no Impact measurements include student's educational performance, students', and teachers' satisfaction survey. Not all types of school's designs configuration have been studied.

8. RECOMMENDATION

Suitable recommendations are categorized for Ministry of education, schools' directors and the design consultants which play significant roles in enhancing the educational school buildings.

8.1. Recommendations for Ministry of education and schools' directors

1. It is essential for ministry of education to design schools which improve the educational and teaching needs of students and teachers, rather than continue implementing the same building prototypes regardless of the current functional needs of the educational environment.

2. It is necessary to understand the importance of air quality and its impact on health and educational performance of the students.

8.2. Recommendations for Design Consultants

Collaborating between the responsible stakeholders include the architects, teachers, students, and community members is important and necessary to improve the indoor air quality.

Some points observed by the authors

- Schools' building should be located away from the road, as it is observed that C5 which located at school D has a good air quality compared with the others.
- The orientation of the classrooms has a major effect in the adequacy of the indoor air quality, north and northwest direction are the best orientations.
- Rooms that are located at southern direction should be replaced with laboratories instead of being classrooms.
- Cleaning works should be done at least one hour before the start of the first class, or after the departure of students.
- Students number should be reasonable with the area of the classroom.

ACKNOWLEDGMENT

The authors would like to express their gratitude to Ismail S. Hasaballa, and Omar El Rawy for their help in developing the air quality monitoring device. Director of Misr El Qadima Educational Administration for his help in getting access to the schools used for this study. Assistance provided by schools' principals, and teachers are also gratefully acknowledged.

REFERENCES

1. UNEP Yearbook 2014 emerging issues update Air Pollution: World's Worst Environmental Health Risk Available online at: <https://www.who.int/news/item/27-09-2016-who-releases-country-estimates-on-air-pollution-exposure-and-health-impact> Last accessed at 01/07/2021. EN 1338: Concrete Paving Blocks–Requirements and test methods. In British Standards (Vol. 3, Issue 1, pp. 1–33).
2. Ambient (outdoor) air quality and health: Available online at: [https://www.who.int/en/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-health](https://www.who.int/en/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health) Last accessed at 01/07/2021.
3. Cartieaux, E., Rzepka, M.A. and Cuny, D., (2011), Indoor Air Quality in Schools. Archives de Pediatrie (Page: 791-792).
4. Dorizas, P.V., Assimakopoulos, M. N. and Santamouris, M., (2015), A holistic approach for the assessment of the indoor environmental quality, student productivity, and energy consumption in primary schools. Environmental monitoring and assessment (Page: 5-6).
5. Egyptian Environment Affairs Agency, the Environmental Information and Monitoring Program (EEAA-EIMP), 2013, Population report for 2012-2013, Available online at: www.capmas.gov.eg and www.eeaa.gov.eg - Last accessed at 20/4/2019.
6. Almeida, R., De Freitas, V. P. and Delgado, J. M. (2015) Indoor Environmental Quality; School Buildings Rehabilitation.
7. Country cooperation strategy for WHO and Egypt 2014 Air Pollution: World's Worst Environmental Health Risk (Available online at: <http://www.unep.org/yearbook/2014/PDF/chapt7.pdf>) Last accessed at 01/07/2021.
8. IQAir most polluted cities 2019 (PM2.5) (Available online at: <https://www.iqair.com/world-most-polluted-cities?continent=&country=&state=&page=45&perPage=50&cities=>) Last accessed at 01/07/2021.
9. United States Environmental Protection Agency EPA (Available online at: <https://www.epa.gov/ghgemissions/overview-greenhouse-gases>) Last accessed at 01/07/2021.
10. Canha, N.; Mandin, C.; Ramalho, O.; Wyart, G.; Ribéron, J.; Dassonville, C.; Hänninen, O.; Almeida, S.M.; Derbez, M., (2015), Assessment of ventilation and indoor air pollutants in nursery and elementary schools in France. Indoor Air, pp. 361-362.
11. United States Environmental Protection Agency EPA (Available online at: <https://www.epa.gov/pm-pollution/particulate-matter-pm-basics>) Last accessed at 01/07/2021.
12. United States Environmental Protection Agency EPA (Available online at: <https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality>).
13. Zhou Li. (2017) Arduino environmental air monitoring system