MAKING UAE SCHOOLS HEALTHY

In-depth Measurement of Indoor Air Quality

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Disclaimer

The Making UAE Schools Healthy: In-depth Measurement of Indoor Air Quality results, findings and conclusions are based on literature reviews, research, and measurement analysis. EmiratesGBC and Saint-Gobain do not assume any liability or responsibility to the user for accuracy, completeness, or reliance of information contained in these reports.

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About Emirates Green Building Council

Emirates Green Building Council (EmiratesGBC) is a business forum based in the United Arab Emirates formed in 2006 with the goal of advancing green building principles. The Council gathers member companies and partners representing a diverse range of stakeholders from within the building industry, government, and academia. EmiratesGBC functions as a common platform for all stakeholders to meet, discuss, interact, and exchange ground-breaking ideas which helps to promote a sustainable built environment in the UAE and the surrounding region.

Since its formation, EmiratesGBC has initiated several programs and events related to improving the operational efficiency of existing buildings. Membership is open to all stakeholders willing to influence a positive change in the country's-built environment.

About Saint-Gobain

Saint-Gobain designs, manufactures and distributes materials and solutions for the construction, mobility, healthcare and other industrial application markets. Developed through a continuous innovation process, they can be found everywhere in our living places and daily life, providing wellbeing, performance and safety, while addressing the challenges of sustainable construction, resource efficiency and the fight against climate change.

This strategy of responsible growth is guided by the Saint-Gobain purpose, "MAKING THE WORLD A BETTER HOME", which responds to the shared ambition of all the women and men in the Group to act every day to make the world a more beautiful and sustainable place to live in.

€42.6 billion in sales in 2019

More than 170, 000 employees, located in 70 countries

Committed to achieving Carbon Neutrality by 2050

For more details on Saint-Gobain,

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FOREWORD

Promoting a cleaner and greener living environment is a national priority of the UAE, underlined by its commitment to the Paris Agreement and Net Zero Buildings by 2050. As the region's leader in driving sustainable development through visionary initiatives, the nation is also focused on promoting healthy lifestyles, which assumes even more importance in the new reality.

This report outlines how we look at the quality of indoor environments at schools. It offers us excellent insights on how we can inspire our youth to be environmental champions, and in turn achieve the goal of a sustainable, healthy living environment.

In fact, we established the Emirates Coalition for Green Schools with the goal of promoting healthier, greener schools so that every child in the UAE can be educated in a 'green school'. This complements the Centennial 2071 vision announced by His Highness Sheikh Mohammed bin Rashid Al Maktoum, UAE Vice President and Prime Minister and Ruler of Dubai. The strategic roadmap to establish our nation among the best in the world places high importance on world-class education to achieve a diversified knowledge economy within a happy and cohesive society.

One of the key initiatives by the Emirates Coalition for Green Schools is a joint study on indoor environmental quality with Saint-Gobain, a corporate and board member of EmiratesGBC. Apart from a detailed report with findings, recommendations, and a case study of a representative UAE school, the Making UAE School Healthy report highlights that we must all come together and strive for more robust evaluation of the indoor environmental quality of our schools.

It also recommends several actions such as updating local green building regulations to use air sampling devices instead of continuous monitoring, mandatory IEQ levels with regular inspection and incorporation of IEQ as part of school's rating.

Just as we nurture our children in our homes, we must make sure that the school environment is safe and healthy for them to learn and grow, especially in the new reality. With this in mind, we have outlined several actions for all key stakeholders responsible for a healthier school environment. Building on our commitment and continued efforts to promote sustainable built environments, we realise that only concerted efforts and alignment with global best practices will enable our nation to stand out as a 'green nation.'

All the key stakeholders such as school facility management, designers & green building consultants, manufacturers and suppliers, NGOs & research institutes, students as well as the staff play an important role to elevate the IEQ of schools in the UAE. And we must join hands and work together to achieving the positive change.

I thank Saint-Gobain for its efforts in partnering with us and providing us their knowledge and expertise. We recognise the importance of the private sector in leading the way for a sustainable future and urge the rest all private and the public sector to partner in this journey to securing the best indoor environmental quality – at homes, businesses, hotels, and schools – to ensure the well-being of occupants and to build a greener future.

Paul Button
CEO, Saint-Gobain UAE

FOREWORD

For the past decade, Saint-Gobain core strategy has been to design homes and living places that promote comfort, well-being and quality of life of those who occupy them. Today, in the aftermath of the pandemic, we understand even more the importance of a healthy indoor environment.

The topic of healthy schools resonates particularly strongly for Saint-Gobain because we know that by improving the design, performance and indoor environmental quality of our schools we can achieve the perfect environment for learning and improve health, comfort & well-being for the students and teachers.

This is why we decided to partner with EmiratesGBC on this particular topic, to evaluate the Indoor Environmental Quality of a UAE school, supporting the Emirates Coalition for Green School's vision and objectives of ensuring that every child in the UAE learns in a green school within this generation.

The focus at Saint-Gobain, with the recent carbon neutrality goals, has been on the development of sustainable retrofitting solutions for the existing building stocks, including schools. In fact, creating the perfect educational environment involves careful design of acoustic solutions to reduce noise and improve clarity of speech and audibility for a better concentration, short-term memory and the reduction of mental stress. It is also important to achieve a good level of thermal comfort through the enhancement of the building envelop with an optimize airtightness and external insulation solution. Moreover, visual comfort is a key parameter related to our biological need for natural light and Saint-Gobain has developed glass & solar film solutions to maximize natural daylight, thus enhancing the productivity and motivation to learn and process information. More importantly, Saint-Gobain has developed low emitting VOC materials and finishes to improve indoor air quality as well as innovative construction materials with the active technology to remove polluting and harmful VOCs from indoor air.

I would like to thank Saint-Gobain and EmiratesGBC participants who worked extensively on finalizing this study during the pandemic. The expertise and knowledge sharing within the team is going to be beneficial for all UAE stakeholders. I am confident that the findings of this study will provide breakthrough insights on the importance of retrofitting and will build awareness around the risks related to a bad indoor environment.

Executive Summary

Emirates Green Building Council (EmiratesGBC) and Saint-Gobain partnered to evaluate the Indoor Environmental Quality (IEQ) of a UAE school, supporting the Emirates Coalition for Green School's (ECGS) vision and objectives of ensuring that every child in the UAE learns in a green school within this generation. It is important to note that the study is crucial for UAE given that a limited number of schools, if any, fulfil all aspects of the definition of a green school.

The Study focused on measuring the Indoor Air Quality (IAQ) parameters of a representative school in the UAE and included investigation of other IEQ factors such as lighting, acoustics and thermal comfort. The aim in publishing the findings and recommendations is to increase the IEQ local data availability, identify areas for further research and improvements, raise awareness with stakeholders and provide a call to action for improving IEQ in UAE schools.

The first section of the report highlights a detailed literature review of the importance of IEQ, which includes the impact of the visual, acoustic, thermal comfort and IAQ factors on students' health, productivity, performance, physical and mental development.

In the proceeding section, a case study of a representative UAE school is presented along with the study's methodology. For the IAQ, the measurements focus on continuous monitoring combined with standardised air sampling. A simplified approach was considered to evaluate the thermal comfort, lighting and acoustics which relied on comparing the temperature, relative humidity, luminance and noise levels with local regulation's requirements. One of the main findings conclude that the limit values set by Dubai Municipality for temperature, humidity, and carbon dioxide (CO_2) are far from being met in the two classrooms in the selected school, impacting the children's learning abilities. In addition, the identification of individual Volatile Organic Compounds (VOC), carried out through the air sampling, brings additional and valuable inputs. The main pollutants are identified; acetone, benzene, toluene, ethylbenzene and xylene (BTEX) and terpenes, the latter being usually generated from cleaning products. In one of the rooms, an additional and an unexpected compound (1,4 dichlorobenzene) was identified. It is recommended to further investigate this pollutant, which is suspected to be carcinogenic. In terms of IEQ, the measurements of illuminance and acoustics have shown that important improvements are needed to ameliorate these comfort parameters and improve the well-being and comfort of all occupants and learning abilities of students.

The study also concludes that continuous monitoring should not be considered a standardised method for Total Volatile Organic Compounds (TVOC) concentration measurement, as different values can be obtained, which are dependent on several factors, and therefore should only be used for comparative analysis. It is recommended to amend local regulations to align with other international green building certifications that consider air sampling and not continuous monitoring devices to determine TVOC concentration.

In order to improve the IEQ of the classrooms, a set of recommendations have been proposed for the specific school. However, further research and monitoring projects should be conducted to represent the overall condition of UAE schools. The proposed recommendations also take the current coronavirus-19 (COVID-19) pandemic situation into account and follow on the recommended guidance published by leading global organisations such as American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA).

"One of the main findings conclude that the limit values set by Dubai Municipality for temperature, humidity, and carbon dioxide (CO_2) are far from being met in the two classrooms in the selected school, impacting the children's learning abilities. In addition, the identification of individual Volatile Organic Compounds (VOC), carried out through the air sampling, brings additional and valuable inputs. The main pollutants are identified; acetone, benzene, toluene, ethylbenzene and xylene (BTEX) and terpenes, the latter being usually generated from cleaning products. In one of the rooms, an additional and an unexpected compound (1,4 dichlorobenzene) was identified."

The main recommendations are to:

- Increase the outdoor air rate of the building as per ASHRAE/REHVA standards, and reduce the percentage of indoor air recirculation; this will avoid CO_2 and pollutant accumulation and cross contamination.
- Maintain the humidity level within an acceptable range, both for thermal comfort as well as to prevent any mould issue.
- Change the cleaning products by selecting fragrance-free products and/or with eco-label to reduce terpenes concentration.
- Inclusion of acoustic ceilings and acoustic heating, ventilation, and air conditioning (HVAC) ducts to improve the classroom's acoustics.
- VOC — Use low emitting VOC products and depolluting products to reduce the concentration of pollutants.
- Use window solar films to concurrently address visual comfort, glaring, daylight autonomy and energy efficiency.
- Insulate the external walls to reduce thermal losses. The insulation should be properly arranged to minimise thermal bridging. This will provide energy savings and thermal comfort of the building envelop. This will also improve the maintenance and life expectancy of the ventilation system.

Call to Action

It is vital to involve all school related stakeholders as their involvement and support is required for the evolution towards healthy green schools. This section is divided according to the different stakeholder groups and lists the required actions from these groups. It is expected that these call to actions will drive clear transformative steps towards healthier school environments.

Government Authorities/Policy Makers

The role of the educational government authorities and policy makers should showcase the leadership values of the UAE to be the one of the most sustainable countries in the world. Given that that IEQ plays a pivotal role in education and learning, it is expected that improving and maintaining good IEQ will also help the UAE in achieving its goal of building a knowledgeable and globally competitive society.

Key Actions:

Updating the local green building regulations to use air sampling and not continuous monitoring devices to determine TVOC concentration (as continuous monitoring is not considered a standardized method for TVOC concentration measurement).

Updating the local regulations to include identification of individual VOC along with stipulated targets.

Set and mandate IEQ (lighting, acoustics, IAQ and thermal comfort) standards and codes in new and existing schools, prioritising minimum IEQ levels in line with global best practices.

Regular inspection of IEQ levels within schools.

Incorporation of IEQ as part of schools' rating/performance.

Provide incentives and/or enact policy enablers to the IEQ industry. For examples, this can be through providing incentives for low emitting building materials/products, facilitating IEQ measurements within in schools, providing guidance for maintaining adequate IEQ within the school or through awards/recognition of healthy schools in the country.

Schools and School Facility Management

There are over 1000 schools (public and private) in the UAE and as the primary stakeholders, the school and its facility management have the biggest share of responsibility in safeguarding the health and wellbeing of their students and staff. While their primary role is education, numerous scientific evidence show that IEQ plays a measurable role in students' performance. Thus, schools should equally prioritise actions that improve IEQ.

Key Actions:

Lead by example by monitoring/measuring IEQ in their schools and implement corrective measures to improve and advance these factors. For example, this can include installing sensors to detect levels of lighting, noise, CO_2, etc; the use of automated control systems and/or dashboards to enable the facility management to robustly respond as required; the chemicals used during cleaning should have low VOC/eco-labelled.

Set appropriate IEQ targets (for lighting, acoustics, IAQ and thermal comfort) in line with global best practices.

Thorough and regular inspection and maintenance of HVAC systems, lighting, sensors, and controls used in the maintaining the school's IEQ.

Publicly disclose IEQ information. Not only will this allow most data to be obtained from schools directly, but it can also serve to educate parents and students about the role of the indoor environment.

Advocate towards the role of schools in improving health and wellbeing to parents, students, and parent committees. This not only helps raise awareness, but also builds confidence with existing parents and students and can potentially attract more parents and their children.

Parents, Students and School staff

As the main group whose health, wellbeing and performance is affected by IEQ factors within the school, this group of stakeholders have a great level of influence for advocating for improvements and enabling change. They have a central position within the dynamics of the school operations and as a result can elicit higher and faster response from the school.

Key Actions:

- Act as a pressure and advocacy group on school management to improve IEQ.
- Continually question and check IEQ performance within the school.
- Inform authorities on inadequate IEQ environment for learning in schools.
- Collaborate within their parent-teacher-school or professional/social communities/networks to inform, educate, investigate, advocate and/or address IEQ issues within the school.
- Showcase and highlight the findings of this report to their respective schools for further investigation and remedial actions.

Designers & Green Building Consultants

Several IEQ-related factors are related to the building itself and therefore it is the role of the building designers, consultants, and contractors to design and construct the school according to green building practices. As a result, maintaining adequate IEQ levels for the school facility management can be streamlined.

Key Actions:

- Specify low VOC building materials/products that are specific for schools.
- Specify adequate IEQ factors (for lighting, acoustics, IAQ and thermal comfort) when designing schools as per global best practices.
- Ensure that any deviation from the design and specifications during the construction phase does not compromise IEQ in the completed school.
- Actively engage clients to consider improvements to IEQ throughout the lifecycle of the school.

Manufacturers and Suppliers

The materials and products that are used within the school plays a crucial role in the IEQ levels, whether it is in relation to the IAQ, lighting, or thermal comfort. It should be noted that the stakeholders identified for this group not only includes the manufacturers/suppliers for construction but also includes suppliers for all products that are used within the school products such as carpets, curtains, desks, chairs, cleaning products, etc.

Key Actions:

- Understand and disclose the health implications/impacts of their products through material safety data sheets (MSDS), Health Product Declarations (HPD), Declare Label or any other acceptable health-related material/product declaration.
- Ensure their products do not use any dangerous/toxic chemicals, or are biodegradable, or have obtained a respective eco-label as per their specific product/industry.
- Showcase local case studies for IEQ using their safe/healthy products/materials.
- Develop product/material catalogue/range/line that promote health and wellbeing using their Research and Development (R&D) or manufacturing/product development teams.
- Advocate for the betterment of health and wellbeing through superior IEQ products/materials to schools, supply chains, and the governmental authorities.

NGOs & Research Institutes

These stakeholders are uniquely positioned to connect and collaborate with all the stakeholders as well as reach out to a wider network for expertise, guidance and/or funding. They can play an integral role in accelerating the movement towards green schools through identification and evaluations of the barriers and challenges and develop solutions towards them.

Key Actions:

- Provide further research, proof of concepts, and case studies to support better IEQ in schools.
- Increase the number of studies linking student performance in UAE schools to IEQ.
- Actively engage and collaborate with the government to influence policy towards healthier schools.
- Engage and collaborate with schools to develop solutions towards better IEQ performance.
- Advocate and build awareness of better IEQ across their entire network groups

Background

Emirates Coalition for Green Schools

The Emirates Coalition for Green Schools was launched in November 2017 by the Emirates Green Building Council, which aims to bring together the UAE's strongest advocates of green schools to create a national vision of healthy, high performance schools that are conducive to learning, while saving energy, resources, and money. The vision of the coalition is to ensure that every child in the UAE learns in a green school within this generation. Its focus ranges from K-12 up to tertiary level institutes and is part of the Global Coalition for Green Schools, founded by the Centre for Green Schools at the U.S. Green Building Council in partnership with the World Green Building Council.

The Emirates Coalition's objectives are to provide a platform for different stakeholders to discuss and exchange information about the state of the existing schools in the UAE; raise awareness amongst stakeholders about solutions and best practices on making new and existing schools greener and disseminate this information to school administration and parents; engage schools to encourage energy efficient operations and retrofits of existing school facilities; support policy and regulations toward improved sustainability performance in UAE schools; foster partnerships and collaboration between private sector, government bodies, academia, and school stakeholders to improve school infrastructure; offer tools, research, and resources to support the growth of the green schools in the UAE.

Study Objectives

In 2019, EmiratesGBC and Saint-Gobain, corporate and board member of EmiratesGBC, partnered to evaluate the Indoor Environmental Quality (IEQ) of a UAE school and publish the results, findings, and recommendations. This Study aims to investigate the IEQ of a representative school in the UAE by taking continuous and standardized active and passive air sampling measurements of Indoor Air Quality (IAQ) parameters, as well as acoustic, thermal and illuminance comfort measurements. Additionally, the Study aims to increase the IEQ data availability of UAE schools, identify areas for further research and improvements, provide data/case studies to raise awareness with stakeholders and support the case for improving IEQ in schools in the UAE by providing a call to action for improvement. Overall, this publication is intended to support the Emirates Coalition's vision and objectives.

This study and publication directly follow the recommendations of the roundtable hosted by EmiratesGBC in November 2018, which discussed the lack of adequate IAQ in UAE schools. In particular, the stakeholders agreed that IAQ in schools should be given greater importance as there is limited data and more focus should be directed towards IEQ, more importantly majority of the schools were built before green building regulations. The main consensus of the roundtable concluded that further research should be done to investigate the current indoor air quality and environment of UAE schools.

Furthermore, the findings reported in this report align with the findings of the Emirates Coalition's 2018 State of our Schools white paper, where it was noted that a limited number of schools in the UAE fulfil all the aspects of the definition of a green school. The white paper defines green schools as one that 'provides a healthy environment for occupants conducive to learning while optimising environmental performance and encouraging environmental literacy.' With 1,316 schools in the UAE and over a million students enrolled, the recommendations from 2018 State of our Schools white paper help reiterate that school buildings have significant potential for decarbonisation of the building sector and can support meeting local targets as well as COP 21 commitments of limiting global warming to 1.5°C.

Literature Review

It is understood that indoor environmental quality (IEQ), including indoor air quality (IAQ), impacts building occupants' comfort and performance. Collecting quantitative scientific evidence, however, requires careful and controlled experimental procedures as several building features may interact.

Indoor Air Quality in Schools & Learning Abilities

In the context of schools, there is comprehensive research to support that **indoor environmental quality (IEQ), which includes visual, acoustical, thermal comfort and indoor air quality, has a significant impact on students' health, productivity, performance, physical and mental development** [1], [2], [3], [4], [5], [6], [7]. In terms of school building occupants, impacts are not limited to students; inadequate IEQ in schools have also shown to negatively impact staff health, absenteeism, and teaching quality [2], [3], [6].

IAQ in schools is critical as not only is it linked to students' performance, but also because children are more susceptible to some environment pollutants than adults. Physiologically, they breathe higher volumes of air relative to their body weights and their organs are actively growing. Additionally, children spend more time in school than in any other indoor environment and providing them a safe and healthy environment to learn will support their learning potential.

One of the earliest review paper, published in 2005, by Heath and al. [8] helped bring attention to American authorities for the need to improve the school buildings in the US, as 14 million students were considered to attend school in buildings considered below US standards. The number of studies related to children at school was low at that time, so they extended their initial research to other indoor spaces with adult occupants. Even though over 500 studies were examined for the review paper, only 30 were considered well designed to provide primary evidence on the impact of both chemical pollutants and thermal conditions on occupants. Although the authors identified gaps and concluded on the need to collect more data in school environments, this first review provided quantitative scientific evidence that paved the way for future research.

In 2012, a study carried out in 8 primary schools in England showed unacceptable and poor indoor air quality conditions in schools, with CO_2 levels up to 5000 parts per million (ppm). This significantly reduced pupils' attention and vigilance, and negatively affected their memory and concentration, indicating that the physical environment can affect teaching and learning. After enhancing the ventilation rate, the results of computerized performance tasks, performed by more than 200 pupils, showed significantly faster and more accurate responses for Choice Reaction by 2.2%, Colour Word Vigilance by 2.7%, Picture Memory by 8% and Word Recognition by 15% [9].

More recent review papers bring additional support to those early reported findings. One such review is done by Wargocki and al. [10], which compiles twenty studies run between 1996 and 2015, carried out in more than 760 schools with more than 2000 classrooms and over 15,000 children younger than 18 years old. The compiled results were analysed to derive a systematic quantitative relationship between learning outcomes and air quality in classrooms. CO_2 concentration was taken as the proxy of the indoor air quality in those studies. The analysis predicts that **reducing CO_2 concentration from 2100 ppm to 900 ppm would improve the performance of psychological tests and school task by 12%**. They conclude that the effects of air quality on learning outcome are about five times higher than its effects on the performance reported in office work related studies. The same authors also published a similar study focusing

on classroom temperature and the performance of schoolwork [11], and found that while **most research evaluates them independently, several IEQ factors have an impact on learning abilities**. While they point out that there is need for research that evaluates multiple IEQ factors at the same time, it will be complex to study as it is not a simple additive impact of these factors.

Hviid et al. [12], however, reports on the impact of individual and combined effect of ventilation rate and lighting on 92 children between the age of 10 and 12 in the Nordics. Performance was assessed by processing speed, concentration, logical reasoning and math skills while submitting them to ventilation rate between 3.9 l/s per person (low) and 10.6 l/s per person (high) and to illuminance from constant warm light to dynamic cool light. The different scenarios showed that **processing speed, concentration and math skills were positively correlated to higher diffuse ventilation rate and dynamic lighting**.

According to a study done by Klatte in 2013 [13], noise was also found to adversely impact reading and writing. Moreover, the research suggests that chronic exposure to noise may impact children's cognitive development.

Additionally, a paper by Vakalis and al. [14] presents a review of studies linking one or several criteria of the LEED rating system for schools (new construction or existing ones) with their impact on student performance. The most often studied building feature is school acoustics and the **results show strong correlation between low reverberation and low noise level in green schools and performance for cognitive tests**. The second most studied building features all relate to air quality, mostly ventilation rate, outdoor ambient particulate matter (PM) and ozone concentration. Ventilation rate is the most studied, and it shows statistically **significant relationship between improved ventilation rate in green building with tests results and absenteeism**. This review also highlights existing gaps: in none of the studies the indoor air levels of pollutants are measured; considering only outdoor PM may not be enough; indoor pollutants having generally a larger contribution; furthermore, only the short-term cognitive effects are studied; for pollutants, long term effects should be considered as well.

It is also important to point out that the cleaning operations also heavily impact the IAQ within the building. In a paper published by the French Scientific and Technical Center for Building (CSTB) and French Observatory on Indoor Air Quality (OQAI), the top 10% most frequent chemical components of reported cleaning products used in age care and social facilities were identified and their potential risks presented [15]. Out of 1109 commercial cleaning products, they analysed 299 safety data sheet and identified 216 chemical substances. The most frequent VOCs reported are solvents (Isopropanol, Ethanol) and scenting agents (D-Limonene, Linalool…); Ethanol, Limonene and Linalool are the most common (occurrence is respectively 19%, 18% and 12% in all the cleaning products analysed). Some semi-volatile organic compounds (SVOC) are also reported, used as disinfectants. The risks associated are multiple: some promote skin irritation and others are suspected to be endocrine disruptors. In the presence of ozone, they also can react and be decomposed to produce secondary volatile compounds such as formaldehyde.

In the UAE, there is limited research available on IAQ in schools, with only two studies dated back to 2012 and 2014 by Behzadi et al. [16,17]. They present the results of IAQ measurements in UAE schools, highlighting the high levels of CO_2 and TVOC. However, the results do not provide information regarding individual chemical pollutants and their potential source. Therefore, it was key to conduct this study and collect the complete set of quantitative and qualitative data.

Local and International IAQ Requirements

There are several international building standards used today for green school building requirements, with the difference between the requirements of green buildings and green schools addressed in detail in the Emirates Coalition for Green Schools' white paper [18]. Comparing the requirements of the two international rating systems, LEED and WELL, and two local building regulations, Dubai Green Building Regulations and Specifications (DGBRS) in Dubai and Estidama in Abu Dhabi, green schools have additional requirements to the standard green building requirements; namely, emphasis on IEQ in schools to ensure increased safety and health.

In UAE, the key outcome from the State of Our Schools roundtable was the collective agreement that **a very limited number of schools, if any, fulfil the aspects of the definition of a green school**. Even though there are local regulations which apply to educational buildings, 70% of the schools were built before the regulations.

Indeed, DGBRS include IAQ criteria with quantitative values regarding CO_2, TVOC, formaldehyde and PM levels "Table 1". This regulation also imposes that the IAQ measurements should be performed by a locally accredited laboratory.

The Dubai and Abu Dhabi green building codes also have minimum ventilation rate requirements for new buildings "Table 2". Thermal comfort is another important criterion to mention since it has an impact on pollutants' emission. The regulations state that the HVAC system must be capable of providing a dry bulb temperature between 22.5 and 25.5 °C and a relative humidity between 30 and 60% during 95% of the year. For occupant comfort, occupied spaces should have an average air velocity between (0.2 – 0.3) m/s.

Table 1: IAQ criteria in Dubai Green Building Regulations and Specifications

Dubai Green Building Regulations and Specifications		Max Acceptable	Sampling Duration
New (preoccupancy) & existing constructions	Formaldehyde	< 0.08 ppm (= 100 μg/m³)	8-hour continuous monitoring
	TVOC	< 300 μg/m³	
	CO_2	800 ppm	
Existing constructions	Respirable Dust (<10μm)	< 150 μg/m³	
	Ozone	0.06 ppm	
	CO_2	800 ppm	
	CO	9 ppm	
	Bacteria	500 CFU/m³ (Algar Plate)	
	Fungi	500 CFU/m³ (Algar Plate)	

Table 2: Ventilation requirements in DGBRS & Estidama

Requirements	DGBRS [19]	Estidama [20]
Minimum Ventilation Rates comply with the minimum requirements of ASHRAE Standard 62	**401.01** - Minimum Ventilation Requirements for Adequate Indoor Air Quality	**LBi-R1** - Healthy Ventilation Delivery
Permanent filters having Minimum Efficiency Reporting Value (MERV)	**401.02** – Indoor Air Quality during Construction, Renovation or Decoration	**LBi-3** - Construction Indoor Air Quality Management
Separation Distances between outdoor air intakes and any exhausts or discharge	401.03 - Air Inlets and Exhausts	**LBi-R1** - Healthy Ventilation Delivery
Indoor air quality testing must be below **threshold limits**	**401.06 & 401.07** - Indoor Air Quality Compliance - New & Existing Buildings	**LBi-1** - Ventilation Quality, **LBi-2.1** – Material Emissions: Adhesives & Sealants, **LBi-2.2** – Material Emissions: Paints and Coatings, **LBi-2.5** - Material Emissions: Formaldehyde Reduction
Air Leakage Compliance	**501.05** - Air Leakage	**RE-R1** - Minimum Energy Performance

In the UAE, the most well-known and adopted international label for green building is LEED (Leadership in Energy and Environmental Design). Referring to LEED v4 [20] from April 5, 2016 for building design and construction and its corresponding guideline document, that applies to many types of buildings including schools, credits are granted for Indoor Air Quality, with prerequisites required to get minimal credit. For LEED v4, prerequisites for IAQ concern the design of the ventilation system, where the minimum requirements are based on ASHRAE Standard 62.1–2010 for US projects and CEN Standards EN 15251–2007 and EN 13779–2007 for non-US projects. Credit is not awarded based on a CO_2 limit value. Additional credits are being awarded for enhanced indoor air quality strategies that includes indoor air quality assessment before occupancy and under typical occupancy ventilation conditions. The corresponding limit values are summarized in "Table 3". Compared to DGBRS, for new constructions, LEED is more stringent on formaldehyde and PM limit values. It is also more stringent for TVOC as it sets limit values both for TVOC and individual VOC components (the chemicals listed in CDPH standard) whereas the Dubai regulation only sets a limit for TVOC. Another difference is that LEED recommends ISO methods to measure those pollutants whereas the DGBRS recommend continuous monitoring.

For LEED V4 existing building operation and maintenance [22], credits are also granted for enhanced IAQ strategy and covers CO_2 monitoring on a regular basis. The monitoring system should be configured to generate a visual alarm to the system operator if the differential CO_2 concentration in any zone rises above 15% of the minimum outdoor air rate required from the ventilation system design.

Table 3: IAQ Criteria for LEED

Contaminant	Maximum concentration	Maximum concentration (healthcare only)	ASTM and U.S. EPA methods	ISO methods
Formaldehyde	27 ppb	16.3 ppb	ASTM D5197; EPA TO-11 or EPA Compendium Method IP-6	ISO 16000-3
Particulates (PM10 for all buildings; PM2.5 for buildings in EPA nonattainment areas, or local equivalent)	PM10: 50 micrograms per cubic meter PM2.5: 15 micrograms per cubic meter	20 micrograms per cubic meter	EPA Compendium Method IP-10	ISO 7708
Ozone (for buildings in EPA nonattainment areas)	0.075 ppm	0.075 ppm	ASTM D5149 - 02	ISO 13964
TVOCs	500 micrograms per cubic meter	200 micrograms per cubic meter	EPA TO-1, TO-15, TO-17, or EPA Compendium Method IP-1	ISO 16000-6
Target chemicals listed in CDPH Standard Method v1.1, Table 4-1, except formaldehyde	CDPH Standard Method v1.1-2010, Allowable Concentrations, Table 4-1	CDPH Standard Method v1.1-2010, Allowable Concentrations, Table 4-1	ASTM D5197; EPA TO-1, TO-15, TO-17	ISO 16000-3, ISO 16000-6
Carbon monoxide	9 ppm; no more than 2 ppm above outdoor levels	9 ppm; no more than 2 ppm above outdoor levels	EPA Compendium Method IP-3	ISO 4224

The health and wellbeing of building occupants has become a focal point within the green buildings industry, and the COVID-19 pandemic has brought even more attention to how the indoor environmental quality (IEQ) is a major factor influencing health. The WELL standard, developed by International WELL Building Institute, is one of building certifications available in industry for certifying buildings based on their impact on human health and well-being. A revised version WELL_v2 was released in 2020. WELL-V2 emphasises more on occupant's comfort, well-being and health as compared to LEED with criteria focusing on Nourishment, Mind (cognitive and emotional well-being), and Movement (physical activity). Examination of the Air quality criteria shows that the WELL-v2 standard has a total of 14 criteria, out of which 4 are mandatory and 10 are optional. While the ventilation requirements are the same as LEED, WELL-v2has more stringent limits on indoor pollutants related criteria, summarized in "Table 4". It is also more stringent than UAE green buildings regulations. WELL-v2 also grants credit for air quality monitoring and requires installation of indoor air monitors for PM2.5, PM10, CO, CO_2, formaldehyde, NO2 and TVOC, with specific criteria on using the most appropriate monitors. Credit is also given to air quality awareness, which requires informing occupants of the monitored values through dashboards on display screens or websites. All measurements related to IAQ are to be referenced and the report is to be sent to WELL for approval. More information can be found on the WELL website [23].

Table 4: IAQ criteria for WELL-v2

	Prerequisite (Minimal requirements) Limit Value	Optional (additional requirement) Limit Value	Methodology
Formaldehyde	50 µg/m³	30 µg/m³	Verified by performance test according to standard, test results to be sent to WELL board for approval
Acetaldehyde		140 µg/m³	
TVOC (if Benzene and Toluene are not measured, this is option 2 for VOC)	< 500 µg/m³ for 95% of the time after one-month monitoring with a TVOC sensor with accuracy +/- 20µg/m³		
Benzene	10 µg/m³	3 µg/m³	
Toluene	300 µg/m³	300 µg/m³	
Acrylonitrile		5 µg/m³	
Caprolactame		2.2 µg/m³	
Naphtalene		9 µg/m³	
PM2.5	15 µg/m³ (25 µg/m³ in outdoor polluted area)	10 µg/m³	
PM10	50 µg/m³	20 µg/m³	
Ozone	0,051 ppm		
CO_2	no limit value, refer to ventilation design requirements		
CO	9 ppm	6ppm	
NO2		40 µg/m³	
Bacteria			
Fungi			

Case Study

School Description

The measurement study was carried out in a K12 Dubai school located in Al Qusais and built in 1999. The school is a G+1 building for girls and G+2 building for boys with a total built up area of around 160 k sq.ft. It has a total of 120 classrooms for around 2000 students. The building has a non-insulated façade and green tinted glass from the U.S.

It should be noted that at the time of measurement, there was a lot of ongoing road work in the near surroundings as well as some large construction work.

Building HVAC System

The building is equipped with a HVAC central system. From the information collected on site from the building manager, the HVAC system partially recirculates the indoor air and partially injects fresh air coming from outdoor (inlet is on the rooftop of the building). HVAC system is switched on every morning at 6:00 am before the arrival of the children and is switched off after class between 3 and 4 pm. In each classroom, the air inlet and air outlet are both localized on the same wall, close to the ceiling.

Cleaning Procedure

The corridors had a characteristic odour which persisted throughout the morning due to the cleaning product used for the polishing machine. The classrooms were cleaned by housekeepers with a simple broom and mop and did not have any distinctive odour. When the classes finish in the afternoon, it was a lighter cleaning process with only a broom to mostly remove dust. There was no noticeable odour after this cleaning process. Even though the cleaning products composition was not identified, they are considered as sources of VOCs and could contribute to indoor air pollution.

Classrooms Identified for Measurements

Three different classrooms were selected for the study:

» A kindergarten class

» An elementary class

» An empty class, furnished but unoccupied

The selection has been made to include an unoccupied room used as a "reference" room, and two occupied classrooms where children age and activities differ. The kindergarten and elementary class are on the same side of the building but on a different floor (ground floor and first floor respectively).

Class Hours

The class schedule depends on the weekday, from Sunday to Thursday. Class usually starts at 8:00 am in the morning and finishes at 2:30 pm, except for Thursdays where classes finish earlier. Children start arriving to the classroom at around 7:15 am and may stay until the school buses leave at 3:00 pm. It is important to note that elementary classes have lunch outside of the classroom whereas kindergarten classes use the classroom.

IEQ Measurements Methodology

The IEQ measurements was conducted on four consecutive days on 9 - 13 Feb and was designed to combine air sampling on cartridges and continuous monitoring measurements to provide valuable information about IEQ in the selected classrooms.

» Continuous monitoring of IAQ provided qualitative information and enabled the measurement team to follow trends during a representative day in the classrooms and compare the IAQ between the classrooms. However, when it comes to TVOC, the continuous monitoring cannot provide the type and quantity of the main chemical compounds.

» Air Sampling was also performed to identify the individual chemical components. This method consists in sampling air on a sorbent and further elution, separation, identification, and quantification of the adsorbed molecules in a dedicated laboratory. Individual components (Aldehydes, Ketones and VOCs) can be quantified at the parts per billion (ppb) level. Compared to continuous monitoring, this method requires expertise, and is costly. It is important to note that it only provides the average concentrations during the time of sampling.

Continuous Monitoring

Three different devices were used for continuous monitoring

» Two TVOC devices from two different suppliers (Device 1 and Device 2).

» One Formaldehyde device (Device 3)

The reason why two TVOC devices were used is because TVOC sensors integrated in those systems can be of different technology; as a result, they will have different selectivity and sensitivity. This impacts the reliability of the TVOC concentrations. The third equipment (Device 3) used to monitor formaldehyde was chosen based on the high selectivity towards this particular pollutant. However, this device has a sensitivity issue for very low concentration, typically below 20 ppb.

In addition to that, all 3 devices measure Temperature and Relative Humidity. Device 1 and Device 2 measure CO_2 with Device 2 also measuring illuminance and noise levels.

Air Sampling

Both active and passive air sampling were conducted. Active sampling and passive sampling are complementary air sampling systems: Active sampling requires the use of a pumping device to actively pass air through the cartridge whereas passive sampling relies on only diffusion of the gases onto the cartridge without any pumps.

Active sampling allows to evaluate concentration of chemicals on short period (1 hour to several hours) and passive sampling is more dedicated to long term evaluation (several hours till several days).

Thus, passive sampling gives the mean concentration value of chemicals in indoor air and active sampling could be used to discriminate the impact of some activities and compare with the background (period with and without children for instance).

The measurements were performed according to ISO16000 standards.

Figure 1: Air sampling equipment

Measurement Procedure

The study was designed to collect as much data as possible during a representative school week, for different conditions of occupancy (with and without the children) and ventilation (HVAC system ON/OFF).

» Continuous Monitoring: a pair of Device 1 + Device 3 was installed in each classroom, starting from Monday around 3pm until Thursday around 7am. In parallel, Device 2 was moved from one room to another each day as only one equipment was used.

» Air sampling: each day was dedicated to one classroom and with the same measurement sequence done for each respective classroom, thus dividing each day in four consecutive periods:

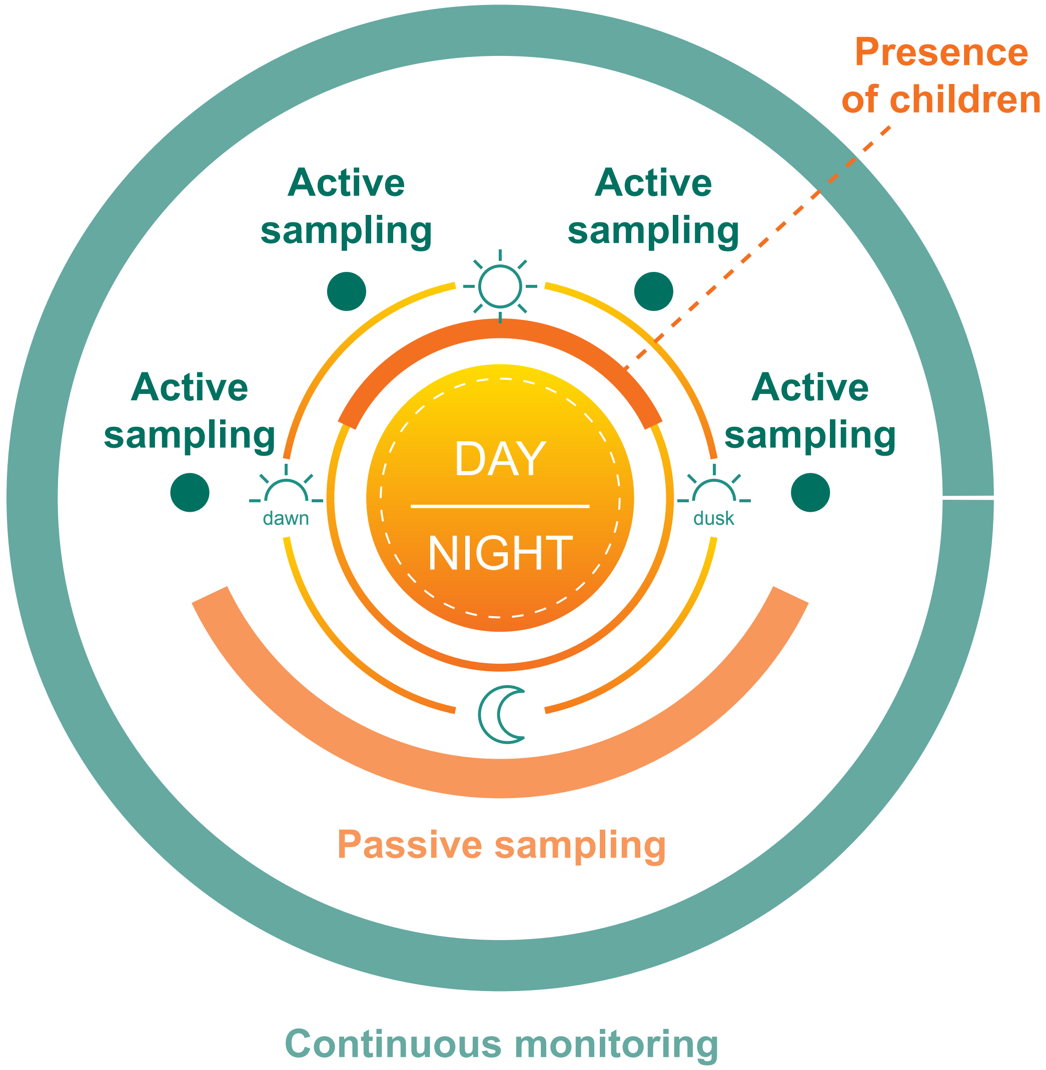
- Morning: Unoccupied and HVAC ON
- Morning: Occupied and HVAC ON
- Afternoon: Occupied and HVAC ON
- Afternoon: Unoccupied and HVAC ON & OFF

For each of the sampling period, two sampling locations were chosen: one in the middle of the room and one at the inlet. All samplings were duplicated to check reproducibility.

Overnight passive sampling was also performed in the three classrooms, during the same night. Finally, Outdoor sampling was also performed to rule out any specific outdoor pollutant source.

A schematic of the campaign is summarized in “Figure 2”. Samplings were done on Monday in the empty room, Tuesday in the kindergarten classroom and Wednesday in the elementary room.

Figure 2: Schematic representation of the IAQ measurements



Results and Analysis

Temperature, Relative Humidity and CO_2

A simplified approach was considered to evaluate the thermal comfort which relied on comparing the temperature and relative humidity with local regulation's requirements. The temperature, relative humidity (RH) and CO_2 concentration (ppm) were monitored during the complete duration of the continuous monitoring and results are represented with average hour values in "Figure 3" and "Figure 4". Mean values of temperature and relative humidity measured during the occupied periods are summarized in "Table 5".

Figure 3: T°, RH and CO_2 continuous monitoring in the elementary Classroom; Occupied period dark green area on the graph, Black arrow indicates HVAC system switch ON/OFF; three colors highlight different levels of comfort zone for CO_2: green-Comfortable; Orange-Uncomfortable; Red: Critical

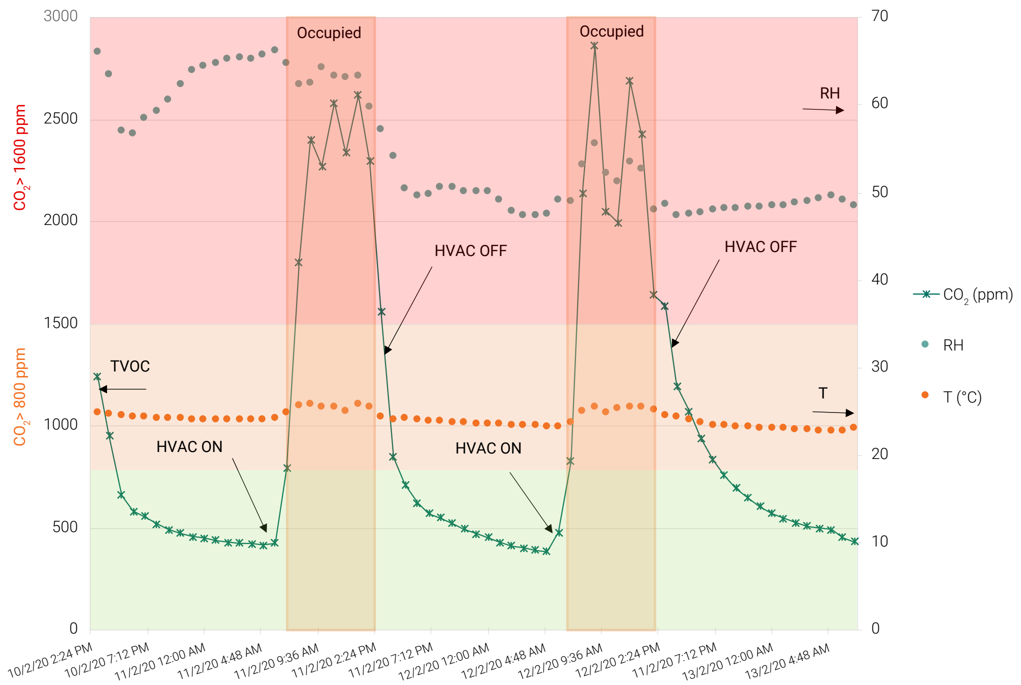


Figure 4: T°, RH and CO_2 continuous monitoring in the kindergarten classroom; Occupied period dark green area on the graph, Black arrow indicates HVAC system switch ON/OFF; three colors highlight different levels of comfort zone for CO_2: green-Comfortable; Orange-Uncomfortable; Red: Critical

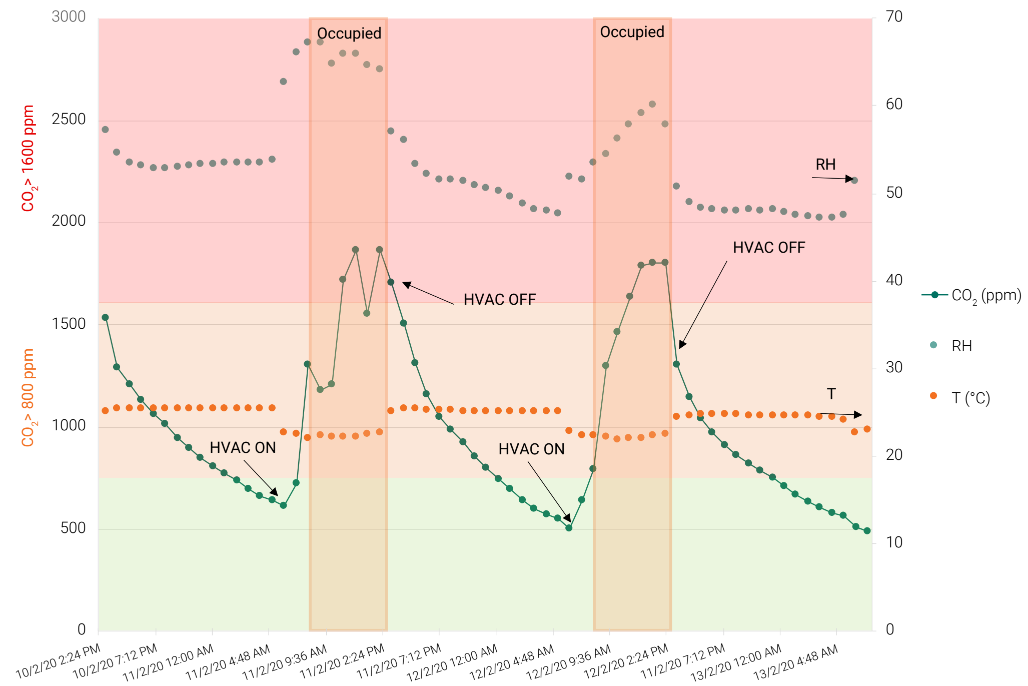


Table 5: Mean Temperature and relative Humidity Values in the kindergarten and elementary Classes for the two consecutive days; color code: Green=compliant with Dubai Regulation; Red= not compliant with Dubai Regulation; Orange=slightly below/above Dubai Regulation

Parameter	Kindergarten Day 1	Kindergarten Day 2	Elementary Day 1	Elementary Day 2
	Feb 11	Feb 12	Feb 11	Feb 12
T (°C)	22.4	22.3	25.6	25.3
RH (%)	65.6	57.1	62.7	52.4

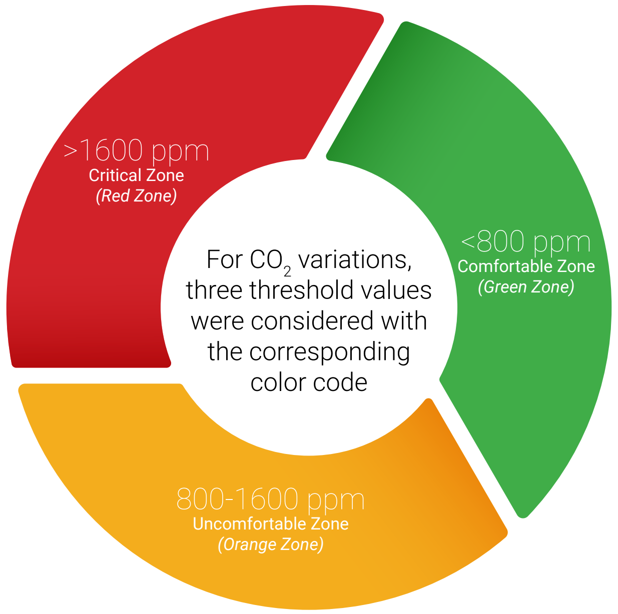
During two consecutive days, mean temperature is kept constant in kindergarten room, slightly below the lower limit of thermal temperature set-point recommended by Dubai Municipality (22.5°C); it is also quite constant in the elementary room, but at an average temperature 3°C higher than in the kindergarten room. On February 11th, the mean temperature is slightly above the higher limit of thermal temperature set-point recommended by Dubai Municipality (25.5°C). February is not the hottest period of the year so it might be interesting to note the temperature in the classes during the summer.

At the same time, in both rooms, humidity level is higher on the first day recorded, and above the upper limit of the local regulation (60%). Each day, the humidity level is higher in the kindergarten room compared to the elementary classroom.

Both rooms are located on a different floor in the school but have the same orientation, one on the ground floor, one on the first floor. The HVAC system settings may be different from one floor to the other, which could explain the difference in indoor measured temperature and relative humidity.

When comparing with the local weather data during the measurement period, it was observed that relative humidity level at night reached very high values during the week, over 80% RH, except for Tuesday night, which was dryer with RH level closer to 60%. At 6 am when the HVAC system is switched on, outdoor humidity is still very high.

The decrease in RH observed in the classrooms between Tuesday and Wednesday is consistent with outdoor decrease of RH during the same period.



The comfortable zone on the graph corresponds to the CO_2 threshold value of DGBRS, where a limit value of 800 ppm is considered stringent.

A summary table of CO_2 main concentrations is presented in "Table 6". It is important to note that it is not only the maximum level reached that matters, but also how often the CO_2 level exceeds the limit value, which provides insight on the exposure period. The percentage of time during which the children are exposed to the orange and red zones is calculated and compared with the local regulations.

As an example, for the orange zone (uncomfortable zone), this time percentage is calculated as the ratio of the total duration of exposure to values of CO_2 concentration above 800 ppm in minutes divided by the total duration of the class in minutes (considered to be 8 h from 8:00 am to 3:00 pm).

Table 6: Mean, Min, Max CO_2 concentration and % of time occupancy in orange and red zone for the two classrooms for the two days of monitoring

CO_2 (ppm)	Kindergarten Day 1	Kindergarten Day 2	Elementary Day 1	Elementary Day 2
	Feb 11th	Feb 12th	Feb 11th	Feb 12th
CO_2 mean	1530	1512	2330	2259
CO_2 min	1043	720	1284	1221
CO_2 max	1954	2071	3053	3233
% of occupancy time >800 ppm (uncomfortable)	100	83	100	100
% of occupancy time > 1600 ppm (critical)	44	40	>95	93

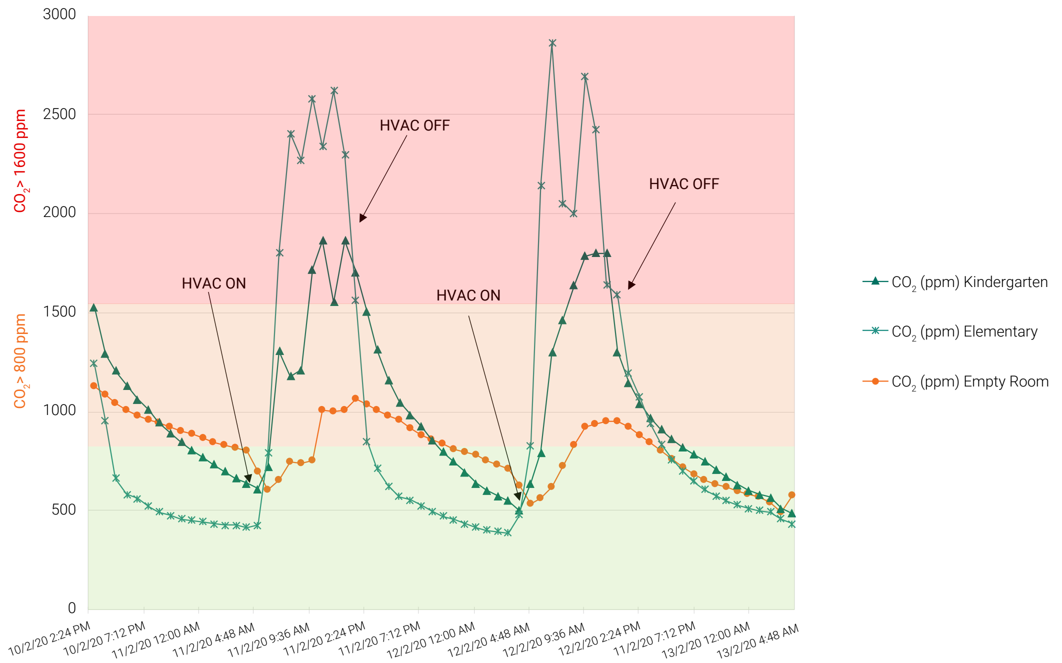
CO_2 variations during a typical day in class are correlated with the room occupancy. As soon as the class starts at 8:00 am, the CO_2 starts to accumulate in the classroom and does not decrease. Even during the breaks, as the children stay in class, the CO_2 concentration does not decrease. The short decrease observed in the kindergarten on February 11th may be due to a door opening during the short break by the teacher. In the elementary classroom, the decrease observed on February 12th was due to a window opening during the break. Indeed, the CO_2 levels only start to significantly decrease after 2:30-3:00 pm, when the children leave the class.

During the occupancy period, extremely high levels of CO_2 are observed, up to close 3000 ppm in the elementary class. As a result, the children spent most of their learning in uncomfortable or critical CO_2 conditions.

After class, there is a decrease in CO_2 concentration, which can be partially attributed to the doors remaining opened during the cleaning process. The HVAC system, however, is switched off at the end of the school day, which slows down the CO_2 reduction. As a result, only the natural ventilation through the doors or other infiltration points of the building help contribute to the CO_2 reduction. However, for the elementary class, it takes almost 12 hours (from 3:00 pm to 3:00 am) for the CO_2 level to go down to the expected value of 400 ppm with no occupancy. In the case of the kindergarten class, it does not reach this value until 6 am the next morning, where it is closer to 500 ppm.

As soon as the HVAC system is started again the next morning at 6 am, and until 8 am before the class begins, it was observed that the CO_2 starts to build up in the class. This was not expected as the ventilation should help decrease the CO_2 further down to 400ppm. A likely cause for this could have been an unknown CO_2 source within in the building that would be distributed partly in the other rooms through the HVAC system. This seems plausible as it is consistent with the indoor air recirculation in the whole building based on the central HVAC system operations.

Figure 5: CO_2 concentration comparison in between the three monitored classrooms: empty room (ground floor), kindergarten room (ground floor), elementary room (first floor)



The CO_2 levels in the three monitored classrooms were compared, including the non-occupied reference room "Figure 5". The gradual increase CO_2 is from occupants' breathing. For non-occupied room, it is expected that the CO_2 would remain at a stable value close of 400ppm, the outdoor CO_2 concentration. Instead, it was observed that the CO_2 concentrations follow the same pattern as that of the occupied classes, which supports the hypothesis that the ventilation system is partially recirculating the internal air to the other rooms and there is insufficient fresh air intake. As a result, there can be cross-contamination of pollutants throughout the building.

From these results, it can be concluded that the limit values set by Dubai regulations for Temperature, Humidity and CO_2 "Table 1" for "Green schools" are not being met in the two measured classrooms during this period. As highlighted in the literature review, these conditions are counter-productive to the children's learning capabilities.

It is recommended to adjust the HVAC system operations by:

- » **Increasing the air exchange rate of the building**
- » **Reducing indoor air recirculation and bring more outdoor air to avoid CO_2 and pollutants accumulation and cross contamination**
- » **Decreasing the humidity level in the room, both for thermal comfort as well as to prevent any mould issues**

All these measures will benefit the children learning abilities as well as teachers and school staff comfort.

Chemical Pollutants

TVOC

Continuous Monitoring

"Figure 6" presents the TVOC concentration variations (in ppb) in the elementary classroom for two consecutive days. "Occupied" areas represent the periods when the children are in class. T°, RH and CO_2 variations are presented as well.

From the recorded data, we determined the average, minimum and maximum values of TVOC during class hours "Table 7".

Table 7: Daily Mean, Minimum and Maximum TVOC concentration recordings in ppb for the kindergarten and elementary classrooms

TVOC (ppb)	Kindergarten Day 1	Kindergarten Day 2	Elementary Day 1	Elementary Day 2
	Feb 11th	Feb 12th	Feb 11th	Feb 12th
TVOC mean	817	492	823	309
TVOC min	657	290	421	201
TVOC max	1169	603	1110	441

It was noticed that TVOC concentrations follow the same trend as CO_2 variations throughout the day, with higher TVOC levels occurring when the children are in class. There can be multiple TVOC sources. For instance, they can be emitted by the building itself, in particular if there was a recent retrofit; in the school the PVC floor was replaced one year ago. Other contributions to TVOC include the furniture and the cleaning products. Finally, activities such as painting and drawing can also contribute to TVOC levels, especially for kindergarten classes which may explain the increase in TVOCs when the classrooms are occupied.

Comparing two consecutive days in the same classroom, it was observed that on February 12th, the TVOC levels recorded during occupancy are much lower than the day before. The number of children did not change during the two days (17 children) and their activities were also similar. It could be likely that TVOC reduction was caused by 10% decrease in average humidity level in between the two days, as temperature and humidity are known to have an impact on TVOC emissions.

Figure 6: TVOC variations (in ppb) in the elementary classroom; "Occupied" area represent the class hours; HVAC system switch ON/OFF are indicated by a black arrow;

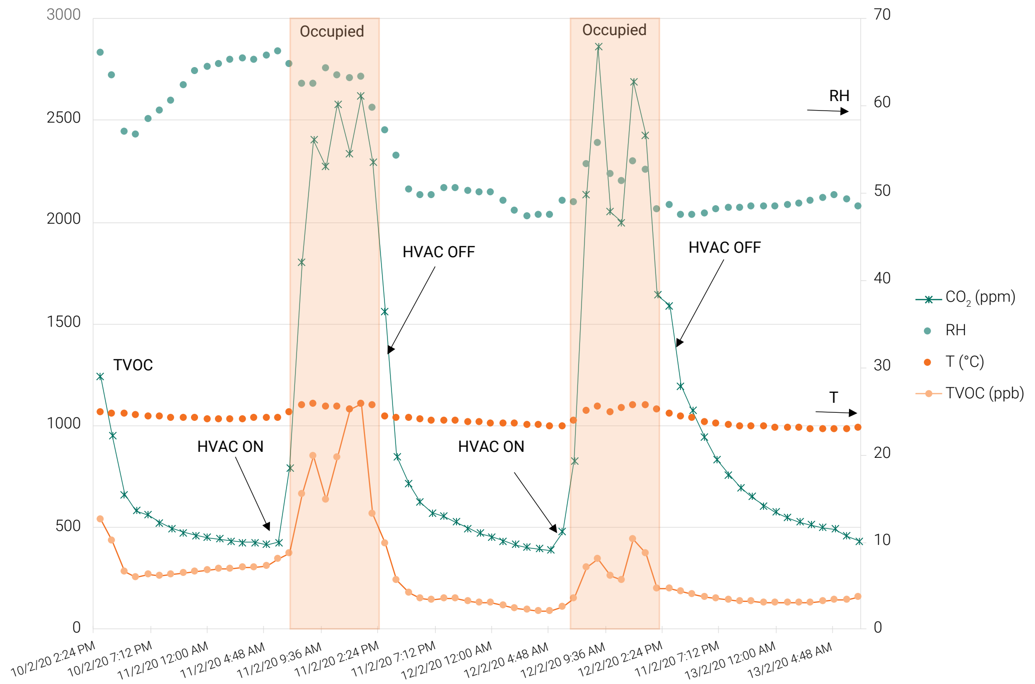
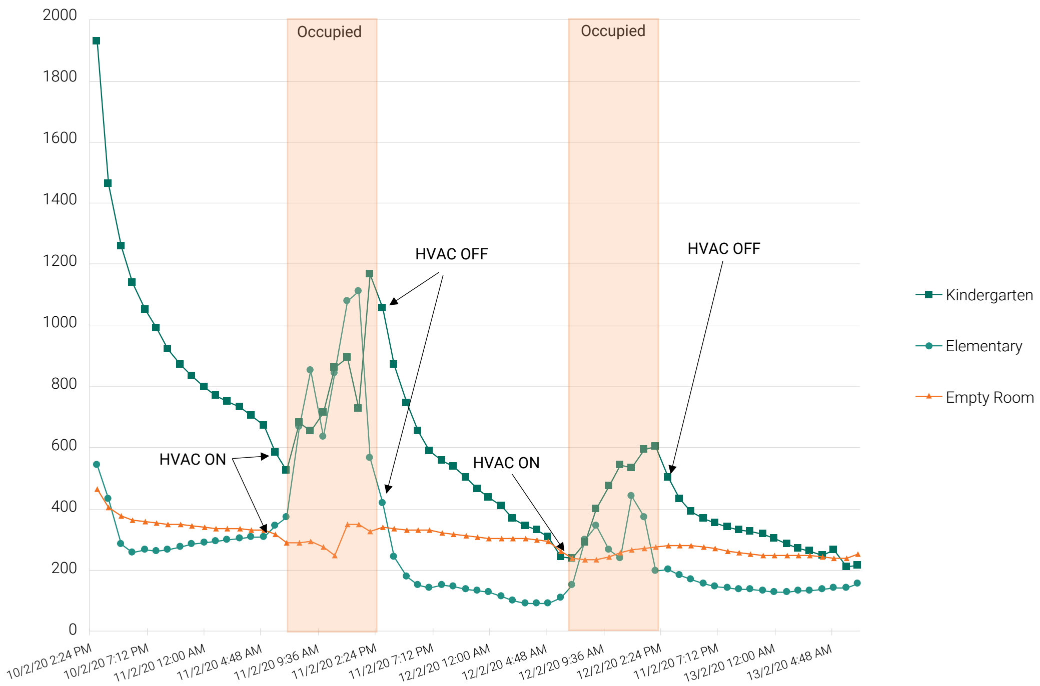


Figure 7: TVOC variations (in ppb) comparison in between the three monitored room: empty room (ground floor), kindergarten room (ground floor), elementary room (first floor); "Occupied" area represent the class hours; HVAC system switch ON/OFF are indicated by a black arrow;



In the kindergarten room "Figure 7", the TVOC variations follow the same trend, with TVOC increasing when the room is occupied. A lower level of TVOC was observed on the second day, which could be linked to a decrease in the humidity level in the room (average decrease of 8%).

When classes are finished, TVOC concentration decreases in both rooms. However, the reduction is delayed when the ventilation is switched off (the slope of the TVOC curve is lowered when the HVAC system is switched off). When comparing the reduction of TVOC between the two classrooms, it was observed that the reduction rate in the kindergarten class is lower than in the elementary class. It was also the same for CO_2 reduction rate "Figure 5".

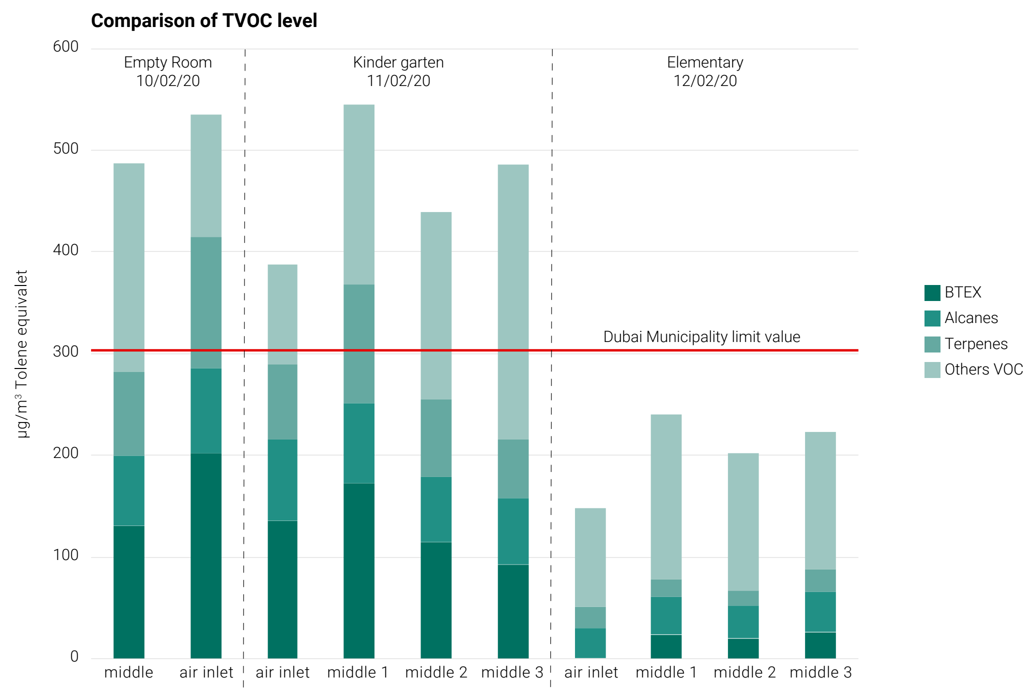
Because of a lower reduction rate during the period when the HVAC system is off, and even if natural ventilation occurs through opened door and air infiltration through the building envelope, the air in the room is not renewed fast enough, and some of the TVOCs accumulated during the day are not totally off-gassed overnight. As the consequence, the next morning, before the HVAC system is switched ON again, the TVOC concentration in the kindergarten class is still high, and as the settings may be different between the ground floor and the first floor, there is a higher TVOC level in the kindergarten as compared to the elementary class.

The TVOC remains fairly stable in the empty room during the measuring period. This is not consistent with the CO_2 variations that were observed in the empty room, which had showed a peak coming from other rooms, indicating cross-contamination "Figure 5". We would expect the TVOC curve to follow the same trend with some pollutants coming from the other rooms to be recirculated in the empty room as well. This might indicate that the TVOC sensor (device 1) installed in the empty room was not working.

Air Sampling

According to standard definition, TVOC (Total Volatile Organic Compounds) is the sum of all VOCs eluted within hexane and hexadecane (C6-C16). TVOC results obtained by air sampling are shown on "Figure 8", with concentrations reported in "Table 8". The graph shows both the total VOC concentration as well as representative contributions of main identified chemical families: alkanes, terpenes and BTEX. The main risk is associated with aromatic compounds, in particular Benzene. However, in the presence of ozone, all these chemicals can be decomposed and transformed into secondary volatile compounds, such as formaldehyde, making it vital to limit their concentrations.

Figure 8: TVOC results on active samplings in µg/m³ toluene equivalent



As a reminder, samplings were done on different days for each room. The empty room and kindergarten classroom show the same level of TVOC unlike in elementary room, where the TVOC concentration is around half. A similar ratio is also observed on continuous monitoring "Figure 7", where it was noted that the humidity level had decreased in between the two days. Humidity is known to have an impact of VOC emission and thus partially explains the decrease observed.

Table 8: TVOC, BTEX, Alkanes, Terpene and Other VOC concentrations in µg/m³ toluene equivalent from air samplings in the different classrooms; color code: green= below Dubai limit value; red= above Dubai limit value

	Empty Room		Kindergarten				Elementary			
Component	middle	air inlet	air inlet	middle	middle 2	middle 3	air inlet	middle	middle 2	middle 3
TVOC	487	535	387	545	439	486	148	240	201	223
BTEX	131	203	136	172	115	92	0	24	20	26
Alcanes	69	83	80	79	64	65	30	36	32	40
Other VOC	205	120	98	177	185	270	96	161	134	135
Terpenes	82	129	74	116	75	59	21	18	15	22

Compared to the limit value of 300µg/m³ set by the DGBRS, it can be concluded that during the entire day on February 11th, the children in the kindergarten class are exposed to values above the regulation. In the elementary class on February 12th, the situation is better and below the limit value. But as the continuous monitoring shows that elementary class and kindergarten class have similar concentrations on February 11th and February 12th, it is anticipated that on the most humid day, on February 11th, both classes are above the limit and on the driest day, on February 12th, both classes are below the limit.

At this stage, it is important to go into the detailed identification of the main constituents, especially for the day above the limit value, to make sure none of the chemical components, especially the level of individual BTEX components, are exposed to the children.

In addition to the comparison of results on cartridges, the results are compared to those of the continuous monitoring "Figure 9" and "Figure 10". Device 2 was used for a different room each day, whereas Device 1 was used for 2.5 days in each classroom. Cartridges results are indicated by a short bar on the graph, at the period of the sampling; the bar length represents the sampling duration. Qualitatively, for each room, the two devices follow the same trend: peaks are detected by both devices at the same time, decreases are detected at the same time as well. The absolute values are on the contrary quite different between the two devices. For example, in the elementary Classroom, Device 2 detects a peak above 2000 ppb on February 12th, but for the same event, Device 1 reads a TVOC concentration around 500 ppb.

The difference in readings is linked to the miniaturized TVOC sensor incorporated in the devices. There are many commercially available TVOC sensors that have different sensitivity and selectivity. Device 1 and Device 2 integrate a different TVOC sensor, so they do not detect the same mix of VOC molecules. It could also be likely that for a molecule detected by both sensors, the sensitivity threshold might be different, thus eliciting a different response coefficient. Comparing the continuous monitoring with air sampling results, cartridges results (in green) are consistent between passive and active sampling and in accordance with the trends observed on continuous recording, i.e. when a peak of TVOC is observed, the cartridges values are higher.

But the TVOC concentrations are also different when comparing Device 1 and 2 readings:

» In the elementary class, values are between 148-240 µg/m³, where Device 1 indicates values between 110-440 µg/m³ and Device 2 shows values between 953-2184 µg/m³ for the same period. As a result, Device 1 results would be compliant to Dubai Municipality requirements, but Device 2 results would not be compliant.

» In the kindergarten class, values are between 385-547 µg/m³, where Device 1 indicates values between 524-1169 µg/m³ and Device 2 shows values between 1777-2987 µg/m³ for the same period. This time results from both devices would not be compliant to Dubai regulation limits.

Therefore, it is also important to note that, depending on the type and sensitivity of continuous monitoring devices, the results can be totally different.

Figure 9: Comparison between continuous monitoring and samplings on cartridges over the study in the elementary class.

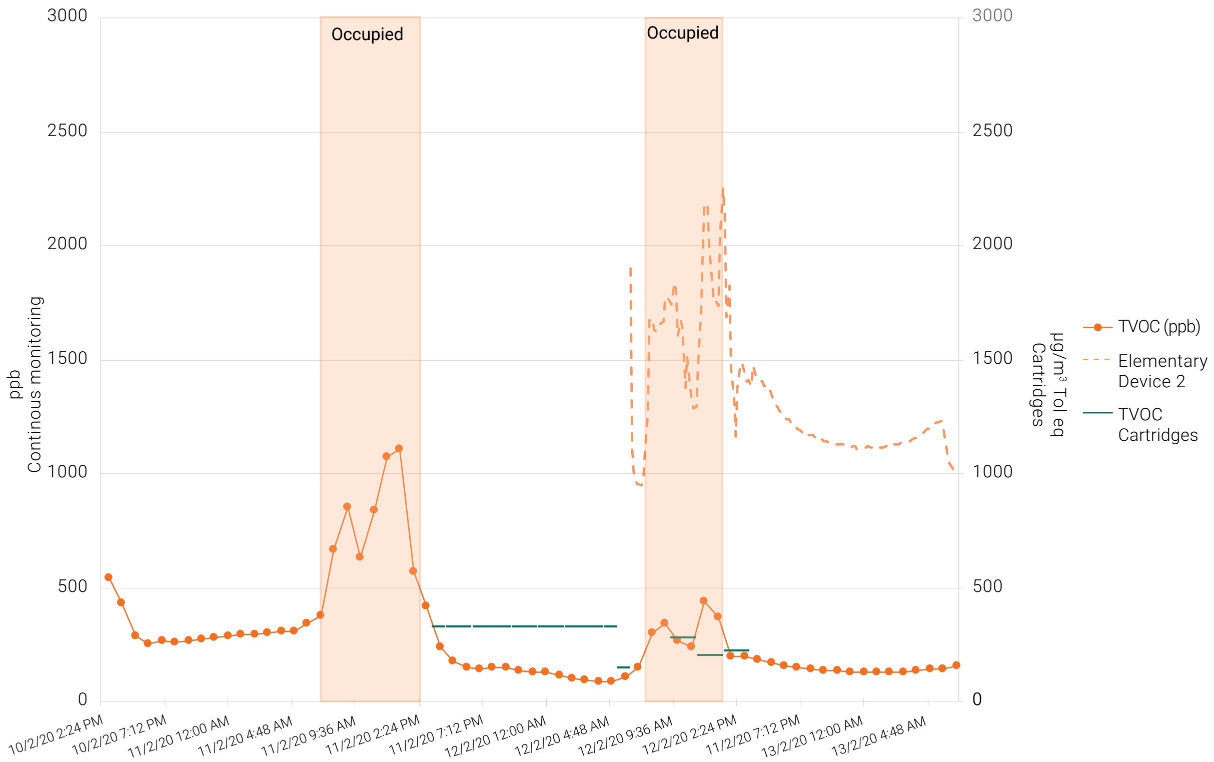
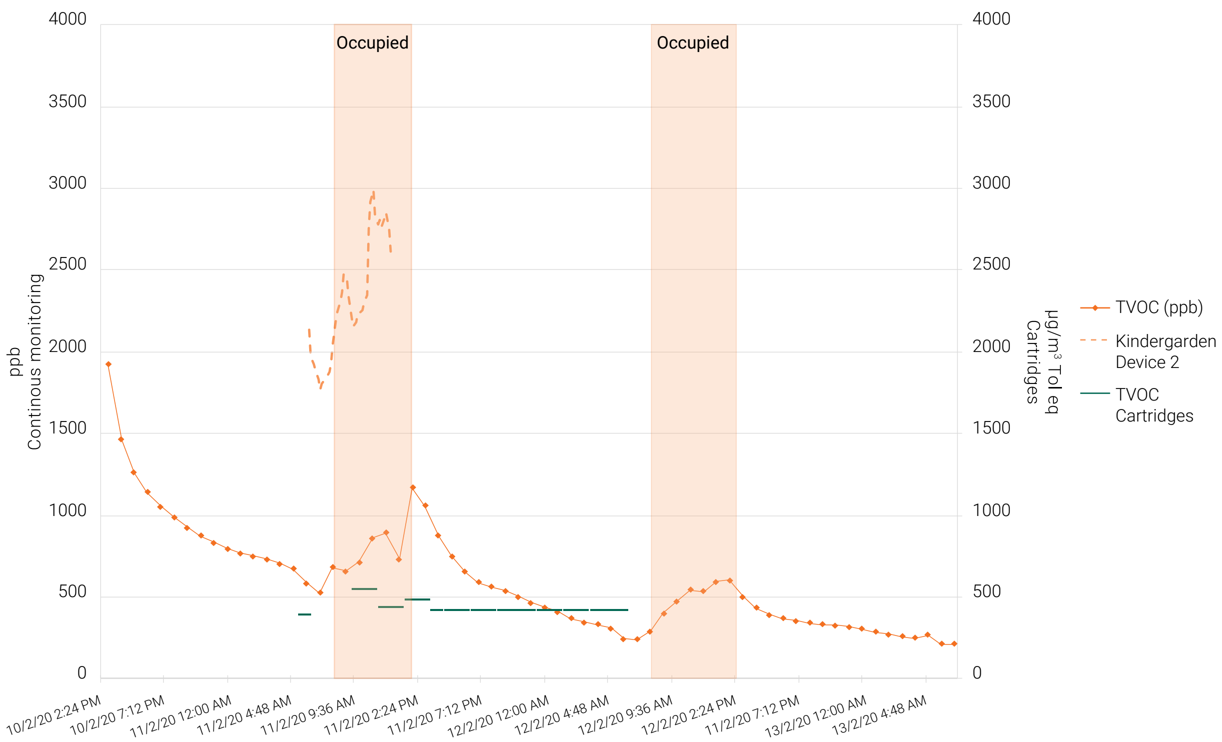


Figure 10: Comparison between continuous monitoring and samplings on cartridges over the study in the kindergarten class.



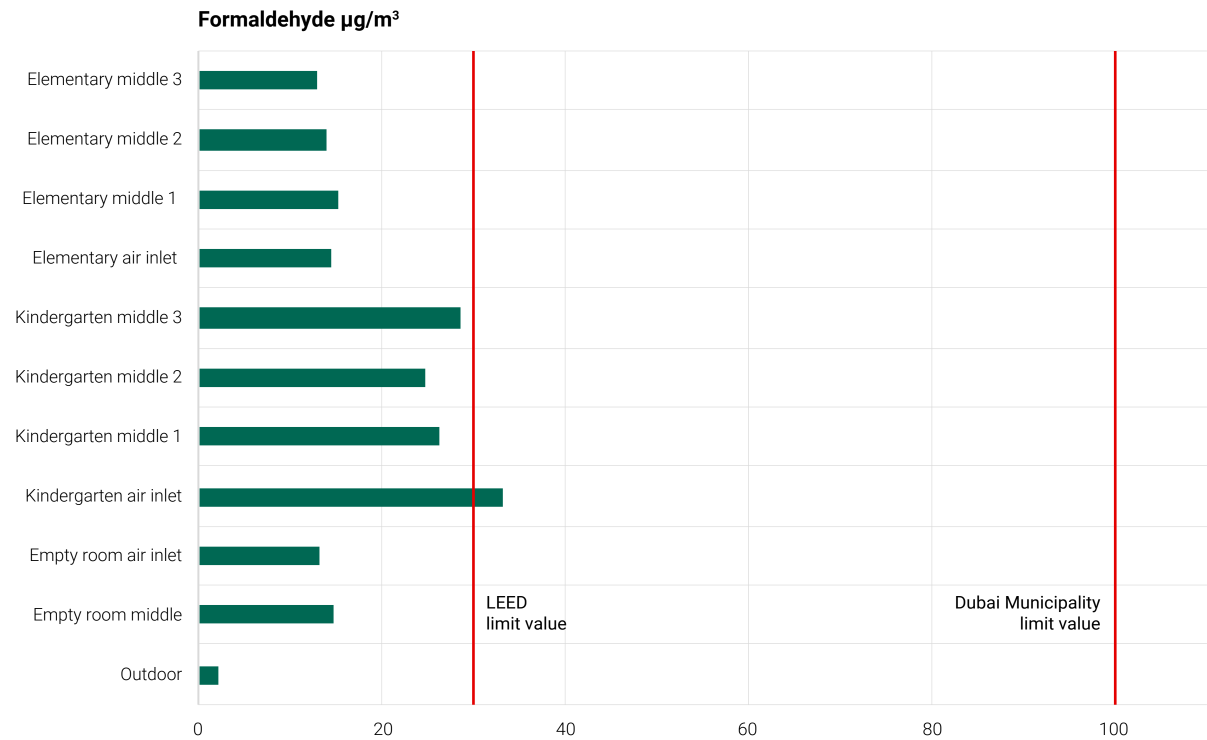
The Dubai Green Building Regulations and Specifications set a threshold value for TVOC of 300 µg/m³ based on 8h continuous monitoring. As seen from the results, the TVOC readings can vary based on continuous monitoring devices used and thus the compliance with regulations can be tailored. It is worthwhile mentioning that continuous monitoring is not considered a standardized method for TVOC concentration measurement and is mostly used for comparative analysis, as is this case here where it is used to compare the three classrooms. Indeed, international green building certifications such as LEED, refer to the ISO standard method, which considers air sampling for TVOC measurement.

It is recommended to align the local regulation requirements with international green building certifications that consider air sampling and not continuous monitoring devices to determine TVOC concentration.

Formaldehyde

DNPH (2,4-Dinitrophenylhydrazine) sampling is used to determine the main aldehydes & ketones concentration, especially formaldehyde. "Figure 11" presents the comparative results of formaldehyde concentrations:

Figure 11: Formaldehyde results on active samplings



Formaldehyde concentration is always below the 100 µg/m³ limit value of the Dubai Green Building Regulations & Specifications. As mentioned earlier, other certifications such as LEED have more stringent criterion for formaldehyde limit value, which is 27 ppb, which is equivalent to 30 µg/m³. The 100 µg/m³ formaldehyde limit value should not be exceeded for more than 30 minutes and requires immediate action to identify the source and remove it. Formaldehyde is carcinogenic so there is a high health risk if children are exposed to high concentration for a long time. **Thus, it is recommended to review Dubai's requirement for more stringent threshold for formaldehyde.**

In the school, the obtained results are compliant with the Dubai Municipality regulation. Even considering the LEED threshold, this limit value was only exceeded once in the kindergarten class.

As expected, outdoor air has a low concentration of formaldehyde as compared to the indoor concentration, which varies depending on the room. The slightly higher level for kindergarten on 11th February is consistent with higher TVOC observed with continuous monitoring. The higher humidity level is one factor that could explain the higher concentration, as well as the different activities in the classroom, which can also be linked to the different concentration levels.

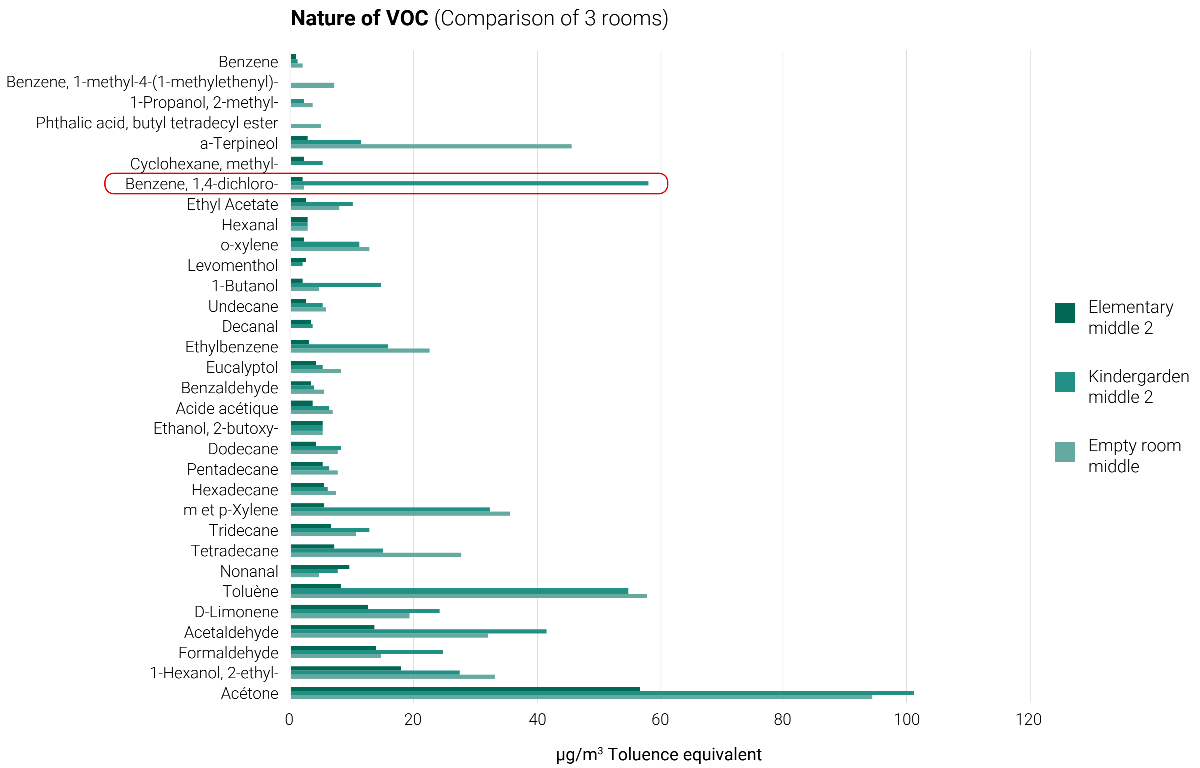
A similar concentration level was noted at the air inlet and in the middle of the room, which is consistent with the CO_2 monitoring. This again indicates an issue of air renewal and cross contamination between rooms.

Individual VOCs

"Figure 12" shows the ranking and the type of individual VOC for the three classrooms.

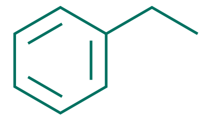
In the 3 rooms, the main component is acetone followed by BTEX molecules (Benzene, Toluene, Ethylbenzene, Xylene) and Terpenes. These molecules could be from various sources such as the outdoor traffic exhaust, indoor activities within the classrooms and/or from household/cleaning products. Some detected components from terpene family are emitted from perfumes in cleaning products. For example, Terpineol is typical for hyacinth odour, limonene for citrus odour and eucalyptol for fresh mint odour. The selection of cleaning products with low VOC level could positively impact the level of TVOC. In particular, cleaning products without any fragrance should be preferred. We can see on "Figure 12" that Terpineol concentration could vary a lot between rooms, which could have resulted from the difference between cleaning and air sampling times.

Figure 12: Comparison of VOC & aldehydes between the 3 rooms: chemicals ranking per concentration

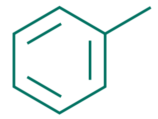


In addition to TVOC and formaldehyde limit values, WELL certification defines a list of 35 individual VOC of interest with their own limit values as seen below:

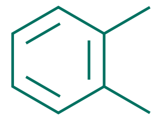
Benzene
30µg/m³



Ethylbenzene
1000µg/m³



Toluene
150µg/m³



Xylenes mixture
350µg/m³

1.4 Dichlorobenzene
400µg/m³

For all these compounds, the concentration measured during the study was below these threshold values.

In the kindergarten room, a singular VOC is significantly detected, which is not detected in the other rooms: 1,4 dichlorobenzene. This molecule is a chlorinated VOC that is widely used as repellent against snakes, rats, mice, and insects (ex in mothballs) or as deodorant in fresheners.

This compound is suspected to be carcinogenic and the WELL certification has a limit value for this compound at 400µg/m³.

As mentioned above, concentration was below the limit value, but it is still recommended to identify the source of this compound to eliminate this pollutant as its presence is most likely linked to the activity within the room by the children and/or teacher; as no significant amount was detected in the other rooms.

The analysis of individual VOC from the Air inlet confirms the cross contamination between rooms and an issue of air renewal as identified with CO_2 measurements. The same VOC at similar concentrations was observed between air inlet, the middle of classrooms and in the empty room (where there was no activity).

In conclusion, identifying the individual VOC levels brings additional and valuable information as compared to continuous monitoring. During the measurement period, the results show that all three rooms have almost the exact same mix of chemical pollutants with Acetone and BTEX as the main components followed by terpenes. Terpenes may be emitted by cleaning products and their concentrations can be easily reduced by selecting fragrance free products and/or products with ecolabels. In one of the rooms, an additional and an unexpected compound, 1,4 dichlorobenzene, was also identified. It is recommended to identify the pollutant source and limit the impact on occupants as this product is suspected to be carcinogenic.

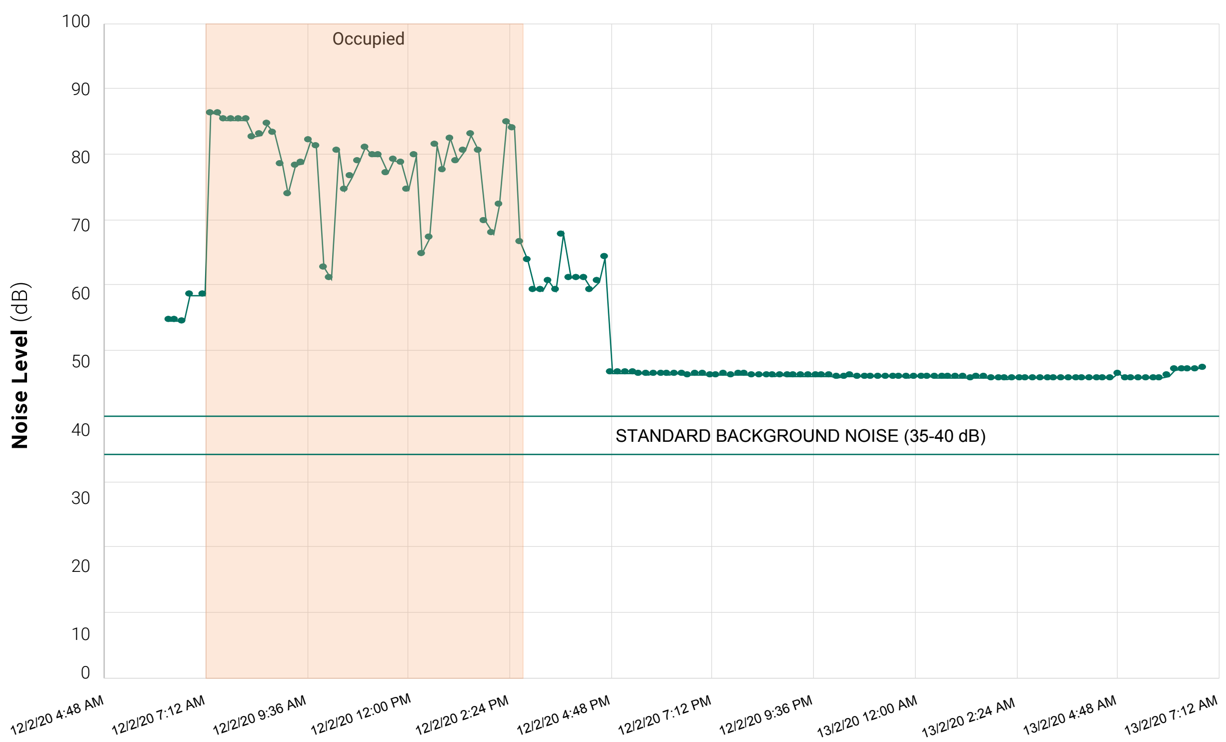
Other IEQ Measurements

While the objective of this study was focused on IAQ, data related to the room acoustic and the room illuminance were also collected and analysed. The measurements were done with Device 2 that records noise level in dB and with the Saint-Gobain MC350 device that collects noise level (dB), reverberation time (s) and illuminance (Lux). Several minute-long recordings in each of the classroom was done with the MC350. The mean values are summarised in "Table 9". A longer recording of the noise level was obtained from Device 2 that shows the variation trend during a representative day "Figure 13". The results observed show high levels of noise, up to 80 dB in the class, a level that corresponds to a road with traffic. This level is outside the comfort zone, which considered to be below 40 db. The level of natural light is low compared to the comfortable zone at 1000 lux. It was also noticed that in each class, the windows were covered with papers or translucent films, presumably to limit direct sunlight and heat. These preliminary results suggest there is room for improvement in the classroom for both acoustics and natural lighting.

Table 9: Mean value of Noise level, Reverberation Time and Illuminance recorded in the three rooms with the MC350

Classroom	Noise level (dB)	Reverberation time (s)	Illuminance (Lux)
Empty room	58	0.71	62
Kindergarten	68	0.59	239
Elementary	52	0.59	65

Figure 13: Noise level variation during class in the elementary classroom. The occupied period represents the class hours. The region between 35 and 40 dB represents the comfortable zone



Conclusions and Recommendations

Study Conclusions

Following the results and detailed analysis conducted on IAQ and other data collected on IEQ in general, a set of recommendations proposed for the selected school to enhance IAQ, visual, acoustical and thermal comfort and achieve a positive impact on the kids and teachers' comfort, health, productivity and performance. It is recommended to conduct further research and monitoring analysis to include more sample schools of different sizes and at different locations in the UAE, in order to provide an overview of the levels of IAQ and IEQ in existing schools.

Indoor Air Quality Comfort

The high CO_2 levels measured in the classrooms in the selected school have concluded that the ventilation system is not optimised: the air renewal is too low, with insufficient rate of fresh air in the recirculation. This causes an accumulation of CO_2 and pollutants in the classrooms, which cannot be diluted fast enough during the night. There was also an issue of cross-contamination due to recirculation of indoor air. In addition, high levels of humidity and TVOCs have been recorded, the main components being acetone, toluene, and terpenes. By using innovative products and solutions, the CO_2 and VOC levels can be minimised creating a healthier place for kids and students to work in. Healthier buildings have a big impact on wellbeing and productivity.

Good design, proper ventilation (mechanical and natural ventilation) and specification of the right building materials are essential to increase the supply of fresh air in a building and to remove or minimize emissions of all pollutants at source:

» Outdoor sources (traffic and industry)

» Occupant-related activities and products (tobacco smoke, cleaning products, personal care, printers)

» Building finishes and furnishings (plywood, paint, furniture, floor/wall coverings)

» Ventilation system components (filters, ducts, humidifiers)

Ventilation

It is important to optimize the flow of outdoor air depending on room size, occupancy level and type of activity to keep low levels of CO_2 (below 800 ppm) and pollutants. It is important as well to limit as much as possible recycled air in recirculation to avoid spreading the pollutants in other classrooms. The ideal scenario would be to keep sufficient level of fresh air with minimum recirculation, if any. Mechanical ventilation systems are more effective in environments like UAE, where natural ventilation is not recommended during the hot and humid seasons and during sandstorms. The best strategy is to use hybrid ventilation: natural ventilation in mid-seasons and mechanical in more extreme weather conditions. It is important as well to check the airtightness of the building's envelope to make sure there is limited infiltration of non-recycled outdoor air, keeping outdoor pollutions from penetrating.

Air Filters

It is important to filter incoming and outgoing air to help remove harmful particulates. However, air filters need to be maintained to prevent the ventilation system itself from becoming a source of pollution, rather than the solution. A wet filter, for instance, provides a nutrient-rich site for microbial growth and therefore should be kept dry. Filter efficiency also changes over the loading cycle, generally increasing as the filter loads with an accumulated layer of particulate matter, although some types of media can lose efficiency during loading. Therefore, it is important to ensure that the filters are regularly maintained and replaced as required.

Low Emitting and Active Scavenging Materials

It is important to remove or limit internal sources of pollution as much as possible, including high VOC emitting materials, finishes and cleaning products. The local regulations, product certifications and labelling schemes are mandatory to help choose the right solutions to avoid blacklisted chemicals and components. Eco-labelled cleaning products are also useful to limit pollutant concentrations. The Green Key eco-label, for instance, requires that either eco-labelled products are only used for daily cleaning or avoid products that contain specific types of surfactants, acids, bases among several others. The full list of avoided compounds for cleaning required by Green Key is available publicly [24].

Moreover, solutions can be added in the space to actively break-down impurities in the indoor air. Indeed, some modern construction materials have been specifically developed to actively remove polluting and harmful VOCs from indoor air.

Acoustic Comfort

The measurements in the classrooms have shown extremely high level of noise (80 db) coming mainly from the children and the ventilation system. It is important to achieve good speech clarity in the within the classroom to ensure an optimal learning environment. A sound-regulated environment, where some sound waves are reflected while others are absorbed, ensures good speech clarity. Students sitting at the back will hear the teacher just as clearly as those sitting at the front.

Acoustic comfort in the classrooms can be easily improved by installing acoustic materials on reflective surfaces. Usually, the surface of the ceiling is the most available as not used in a school environment. 80% can be covered with acoustic products, such as perforated gypsum boards or glass wool tiles for better performance as explained in BB93 (Building Bulletin 93: acoustic design of schools). The bigger the perforation percentage, the better will be the absorption especially with an additional acoustic glass wool insulation in the plenum cavity. If this option is not sufficient, or not possible for some reason, acoustic wall panels can be installed.

Visual & Thermal Comfort

The results of the room illuminance have shown excessive glare due to high lux levels inside the rooms. The key to visual comfort in buildings is based on access to outdoor views, daylight provision in good combination with artificial light and absence of glare. Visual comfort can be achieved without compromising on the thermal comfort or glare by using the right glazing solutions or solar films.

It is important to remove the current existing posters fixed on the windows and to install transparent films/ high performing glass which allow access to natural daylight and views, at the same time maintaining thermal comfort:

- Glass with a light transmission between 30-40% is recommended to achieve optimum lux levels inside the room and minimize glare. The internal reflection of the glass is recommended to be under 12% to maintain the access to outdoor views. The shading coefficient of the glass should be less than 0.30 to cut on all the incoming heat from sun. The U-value of glass should be under 1.5 W/m2.K to avoid the indirect flow of heat inside the classrooms due to temperature difference between outside and inside.
- Solar films to improve the performance of the existing glass and reduce the heat transmission. This will generate a moderate temperature in different locations of the room and reduce the cooling loads. It will also provide glare reduction and ensure the transmission of the essential light's quantity and quality for visual comfort. It also absorbs 99% of the UV says harmful for the skin and furniture.

The insulation of the building plays an integral role in not only reducing the heat gain and cooling demand of the building, but it also acts as a heat flow barrier, and helps maintain the thermal comfort of the occupants. Heat reflective paints and coatings on the walls and roof of the building can also help limit heat gain and heat flow into the building.

External Thermal Insulation Composite Systems (ETICS) or Exterior Insulation Finishing System (EIFS) can also be used as an external façade renovation solution for façade retrofitting to reduce thermal bridging, provide energy savings, thermal comfort and enhance the airtightness of the building's envelop. It can be used around the windows and door to limit air, heat and pollutants infiltration, which positively impacts the maintenance and life expectancy of the ventilation system.

COVID 19 & Indoor Air Quality

Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) and Corona-virus 2019 (COVID-19)

The SARS-CoV-19, the virus that causes the COVID-19, triggered a pandemic in 2020, which has been a major concern for several countries across multiple sectors in terms of the impact to the livelihood and health of people and the economy.

At the time of this publication, there is still much debate internationally among government, researchers, and health authorities on the specific mode of transmission of SARS-CoV-19. This mainly relates to whether the virus can spread through airborne and/or aerosol transmission, droplet sizing, the distance the virus can spread, as well as the period in which the virus can remain infectious. It is clear, however, from the World Health Organisation (WHO) [25], the European Centre for Disease Prevention and Control (ECDC)[26], and the U.S. Centers for Disease Control and Prevention (CDC)[27], the virus spreads mainly from person-to-person contact through respiratory droplets produced when an infected person coughs, sneezes, or talks. Additionally, they also state that the virus can spread through direct contact with an infected subject or indirect contact, through hand-mediated transfer of the virus from contaminated surface/object (fomites) to the mouth, nose, or eyes.

The current pandemic, however, has placed greater importance on the Indoor Environmental Quality (IEQ) and, in particular, the Indoor Air Quality (IAQ) of buildings. For instance, there have been several studies [28, 29, 30], that have investigated the transmission of the virus in closed environments with minimal ventilation, which have concluded that it is important to consider ventilation to protect against transmission. This is also highlighted in American Society of Heating, Refrigerating and Air-Conditioning Engineers' (ASHRAE) position statement regarding transmission of SARS-CoV-2 and the operation of HVAC systems during the COVID-19 pandemic, where they state: "Ventilation and filtration provided by heating, ventilating, and air-conditioning systems can reduce the airborne concentration of SARS-CoV-2 and thus the risk of transmission through the air. Unconditioned spaces can cause thermal stress to people that may be directly life threatening and that may also lower resistance to infection. In general, disabling of heating, ventilating, and air-conditioning systems is not a recommended measure to reduce the transmission of the virus."

According to the European Centre for Disease Prevention and Control (ECDC) and the CDC, a small percentage of overall reported COVID-19 cases were among children (aged 18 years or younger). They are most likely to have a mild or asymptomatic infection, meaning that the infection may go undetected or undiagnosed, whereas those who are symptomatic can transmit to adults. Both the ECDC and CDC have reported that more specialised studies are needed to understand transmission and infection rates in children. However, it should also be noted that school staff and parents are primarily adults, who would be in close proximity for a prolonged period with students which increases the rate of transmission.

To support schools in their re-opening/continuing operations, the ASHRAE Epidemic Task Force developed guidance on the operation of HVAC systems to help mitigate the airborne transmission of SARS-CoV-2. Similarly, the Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) also has developed guidance on proper operation of HVAC systems to prevent the spread of SARS-CoV-2. These guidelines [31, 32], are meant to provide practical information directly to school and university administrators and operators.

In accordance with the guidelines, it is recommended to:

» undergo proper inspection and maintenance according to ASHRAE Standard 180-2018

» ensuring good supply of outside air according to ASHRAE Standard 62.1-2019

» not turning off ventilation and switching ventilation on at nominal speed at least 2 hours before the building opening time and set it to lower speed 2 hours after the building usage time

» use of at least MERV-13 rated filters or portable HEPA air cleaners in case of no mechanical ventilation.

» Air cleaners such as germicidal ultraviolet air disinfection devices may also be considered to supplement ventilation and filtration, but care should be taken to avoid generating additional lean space air without generating additional contaminants or negatively impacting space air distribution.

List of Abbreviations

ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers

BTEX: Benzene, Toluene, Ethylbenzene, and Xylene

CO_2: Carbon Dioxide

COVID-19: Coronavirus-19

DGBRS: Dubai Green Building Regulations and Specifications

HVAC: Heating, Ventilation, and Air Conditioning

IAQ: Indoor Air Quality

IEQ: Indoor Environmental Quality

L/S: Litres per Second

LEED: Leadership in Energy and Environmental Design

PM: Particulate Matter

PPM: Parts per Million

REHVA: Federation of European Heating, Ventilation and Air Conditioning

RH: Relative Humidity

TVOC: Total Volatile Organic Compounds

VOC: Volatile Organic Compounds

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MAKING UAE SCHOOLS HEALTHY

In-depth Measurement of Indoor Air Quality

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