frontiers | Frontiers in Built Environment

TYPE Original Research
PUBLISHED 13 November 2023
DOI 10.3389/fbuil.2023.1286053

Check for updates

OPEN ACCESS

EDITED BY
Hasim Altan,
Prince Mohammad bin Fahd University, Saudi Arabia

REVIEWED BY
Nishant Raj Kapoor,
Academy of Scientific and Innovative Research (AcSIR), India
Chanjuan Sun,
University of Shanghai for Science and Technology, China

*CORRESPONDENCE
Gamal El Samanoudy,
g.elsamanoudy@ajman.ac.ae

RECEIVED 30 August 2023
ACCEPTED 23 October 2023
PUBLISHED 13 November 2023

CITATION
Jung C, El Samanoudy G, Alqassimi N and Sherzad M (2023), Assessing the impact of ventilation systems on indoor air quality: a mock-up experiment in Dubai.
Front. Built Environ. 9:1286053.
doi: 10.3389/fbuil.2023.1286053

Assessing the impact of ventilation systems on indoor air quality: a mock-up experiment in Dubai

Chuloh Jung[1], Gamal El Samanoudy[2]*, Nahla Alqassimi[3] and Mohammed Sherzad[3]

[1]Department of Architectural Engineering, College of Engineering, University of Sharjah, Sharjah, United Arab Emirates, [2]Department of Interior Design, College of Architecture, Art, and Design, Ajman University, Ajman, United Arab Emirates, [3]Department of Architecture, College of Architecture, Art, and Design, Ajman University, Ajman, United Arab Emirates

Indoor Air Quality (IAQ) has become an important concern in Dubai, driven by public health awareness, environmental regulations, and government initiatives. The Dubai Municipality has introduced guidelines and standards for IAQ in residential and non-residential buildings, emphasizing ventilation, material selection, and testing protocols. IAQ monitoring and testing are encouraged, and public awareness campaigns educate individuals about IAQ and its impact on health. Green building regulations in Dubai also address IAQ considerations. The Dubai Municipality has comprehensively assessed IAQ in public buildings, leading to stringent regulations. However, research on IAQ improvement and challenges associated with apartment ventilation systems is limited. This study aims to evaluate the IAQ improvement and potential issues of a ventilation system in an apartment through a mock-up experiment. Factors such as air volume, ventilation system type, and supply/exhaust duct configuration are analyzed. The results show that installing a ventilation device with a ventilation rate of 0.3–0.8 times/h reduces Formaldehyde (HCHO) and Volatile Organic Compounds (VOCs) concentrations by 30%–50%. The IAQ improvement is not significantly influenced by air volume. Each room supply/exhaust method shows a 10% higher reduction in VOC concentrations than the supply/kitchen exhaust unit method. Preventing backflow and addressing cold drafts are recommended during ventilation system installation. Noise measurements comply with standards in most cases. These findings contribute to developing guidelines for ventilation system design and installation in apartments, promoting healthier indoor environments. Further research with a broader range of ventilation devices and real-world conditions is recommended to validate these findings.

KEYWORDS

indoor air quality (IAQ), formaldehyde (HCHO), volatile organic compounds (VOCs), ventilation systems, mock-up experiment

1 Introduction

The recognition and emphasis on Indoor Air Quality (IAQ) in Dubai have markedly increased in recent years (Jung and Awad, 2021a; Awad and Jung, 2021; Awad and Jung, 2022). This uptick can be linked to various elements, such as growing public health awareness, stringent environmental standards, and forward-thinking governmental actions (Jung et al., 2021a; Awada et al., 2021; Jung and Al Qassimi, 2022). Heeding these concerns, Dubai's authorities have rolled out diverse strategies to mitigate air contamination and bolster IAQ in indoor environments like homes, workplaces, educational institutions, and shopping centers (Mannan and Al-Ghamdi, 2021; Kakoulli et al., 2022). A pivotal move in this endeavor has been the Dubai Municipality's launch of regulations and directives, specifically the "Indoor Air Quality Standard DM 04 (2013)" for residential infrastructures and the "Indoor Air Quality Standard DM 04 (2017)" for commercial properties (Jung and Awad, 2021b; Mahmoud et al., 2023a). These all-encompassing IAQ regulations address vital concerns such as ventilation, material selection, and indoor testing methodologies (Arar and Jung, 2021). Adherence to these standards is obligatory for enterprises and property owners to guarantee a salubrious setting for inhabitants (Jung et al., 2022a; Jung and El Samanoudy, 2023).

Beyond regulations, there's a strong push for IAQ monitoring and testing among organizations (Steinemann et al., 2017). Consistent monitoring allows for early detection of IAQ problems, leading to swift rectifications (Rickenbacker et al., 2020; Monge-Barrio et al., 2022). The Environmental Department of Dubai Municipality performs IAQ audits to confirm buildings meet the established standards (Dubai Municipality, 2023b). Public awareness drives are crucial in informing individuals about IAQ's importance and its ramifications on health (Marques et al., 2020; Sadrizadeh et al., 2022). These drives include workshops, seminars, and conferences on IAQ themes to enlighten the public (Jung et al., 2022b; Jung et al., 2022c). Dubai has also adopted green building standards like the "Al Safat Green Building Rating System" and the "Dubai Green Building Regulations and Specifications." These prioritize sustainable construction and energy efficiency (Dubai Municipality, 2023a), specifically focusing on IAQ factors such as proper ventilation, utilization of low-emission materials, and the correct setup of air filtration systems (Arar et al., 2021; Jung et al., 2022d).

The Public Health and Safety Department of the Dubai Municipality has taken the initiative to comprehensively assess IAQ in public buildings, encompassing educational institutions, universities, schools, nurseries, kindergartens, and healthcare centers (Jung et al., 2021b; Arar et al., 2022). This extensive evaluation has led to the establishment of stringent regulations governing IAQ standards (Jung and Awad, 2023). As per these guidelines, the presence of formaldehyde (HCHO) should not exceed 0.08 ppm, while the levels of Total Volatile Organic Compounds (TVOC) must not exceed 300 μg/m^3 (Bani Mfarrej et al., 2020). Furthermore, suspended particulate matter measuring less than 10 microns in size (PM_{10}) should not exceed 150 μg/m^3 during continuous monitoring over 8 h before occupancy (Mahmoud et al., 2023b; Gilbey et al., 2023). These stipulations have been implemented to ensure optimal IAQ conditions and promote a healthy and safe environment for occupants in public buildings (Jung et al., 2021c). Continuous efforts to improve building standards and enhance public education will further contribute to the advancement of IAQ and the creation of a healthier living environment for the people of Dubai (Jung et al., 2021d; Abdelaziz Mahmoud and Jung, 2023).

As part of its efforts to enhance IAQ, the Dubai Municipality has implemented regulations requiring the installation of either natural ventilation facilities or mechanical ventilation systems capable of providing continuous ventilation for 24 h, with a minimum ventilation rate of 0.7 times the room volume (Jung et al., 2022e; Sherzad and Jung, 2022). However, there is a lack of research examining the effectiveness of IAQ improvement and the various challenges associated with installing ventilation systems in apartments (Jung and Arar, 2023). Moreover, reference materials are scarce that guide constructing an efficient ventilation system (Al Qassimi and Jung, 2022). While some luxury high-rise residential buildings have adopted waste heat recovery ventilation systems, complaints regarding cold drafts during winter have been reported (Jung et al., 2021e; Kharrufa et al., 2022).

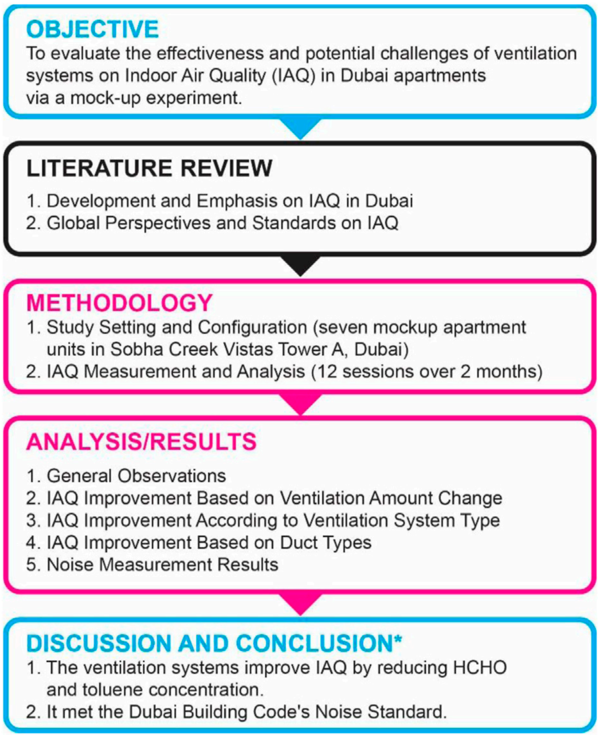


FIGURE 1
Research Process to evaluate the Effectiveness of Ventilation System on IAQ.

The World Health Organization (WHO) advises an indoor air concentration limit of 0.1 mg/m^3 for formaldehyde (HCHO) over 30 min to prevent sensory irritation in the majority of individuals. For Toluene, they recommend a weekly average of 260 μg/m^3 to counteract annoyance and potential neurotoxic effects (World Health Organization, 2010). Abdul-Wahab et al. (2015) thoroughly review standards and guidelines established by international entities, stressing the need for stringent ventilation and air purification measures to diminish pollutant levels and their subsequent health implications. Basner et al. (2014) further underscore the importance of regulating indoor noise, especially during nighttime, for restorative sleep and overall wellbeing. These collective studies highlight the significance of effective ventilation in achieving and upholding optimal indoor air quality.

This research study aims to address these gaps by conducting a comprehensive mock-up test on a ventilation system installed in an apartment, focusing on identifying the impact on IAQ improvement and evaluating potential issues. The mock-up experiment will assess the effectiveness of the ventilation system in improving indoor air

TABLE 1 Overview of target units setting.

Category	Compositions			
Site	Sobha creek vistas tower a in mohamed bin rashid city, Dubai			
Unit type	2 bedroom apartment unit			
Ventilator Type	Unit Number	Type	ACH	Ducttype
	202 (NE_01)	No heat exchanger	N/A	N/A
	203 (TE_02)	Total heat exchanger	0.3	Standard
	302 (TE_03)	Total heat exchanger	0.5	Standard
	303 (TE_04)	Total heat exchanger	0.8	Standard
	502 (SE_05)	Sensible heat exchanger	0.5	Standard
	503 (TE_06)	Total heat exchanger	0.5	Individual room
	602 (AE_07)	Alternating current type	0.5	Individual room
Temperature	24°C			
Humidity	Humidifier (No adjustment))			

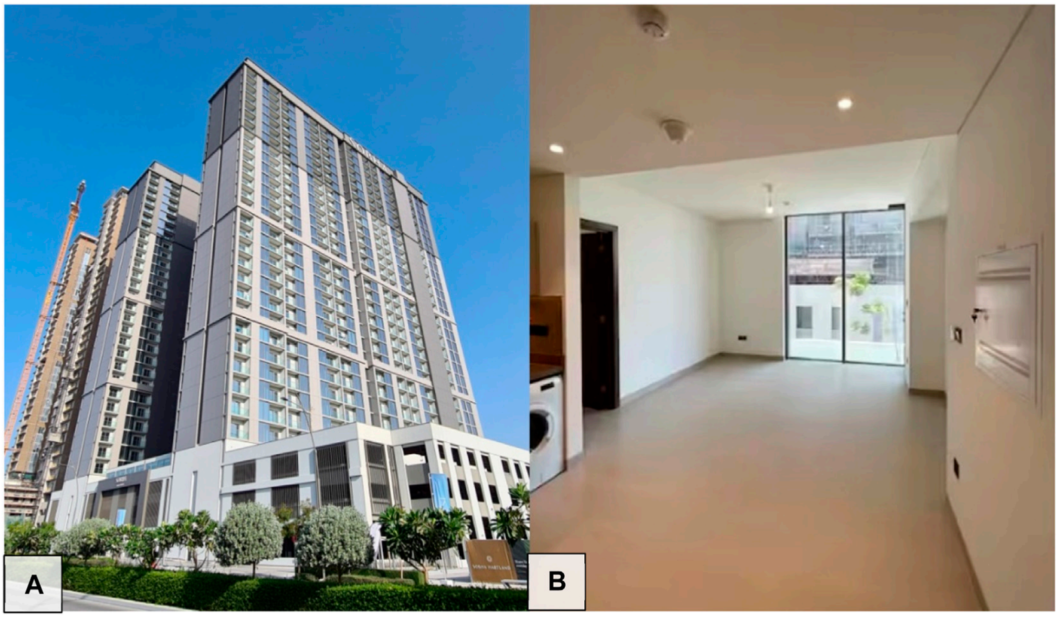


FIGURE 2
Sobha Creek Vistas Tower A in Mohamed Bin Rashid City. **(A)** façade/side view, and **(B)** interior of the unit (602 (AE_07).

quality, considering factors such as air volume, ventilation system type, and supply/exhaust duct configuration (Shin et al., 2018). Additionally, parameters such as supply/exhaust temperatures and noise levels will be examined (Han, 2021). By analyzing the results of this study, valuable insights can be gained into the IAQ enhancement potential and potential challenges associated with ventilation system implementation in apartments (Awad et al., 2022) (Figure 1). These findings will contribute to developing guidelines and best practices for designing and installing effective ventilation systems promoting healthier indoor environments in residential settings (Jung and Abdelaziz Mahmoud, 2023).

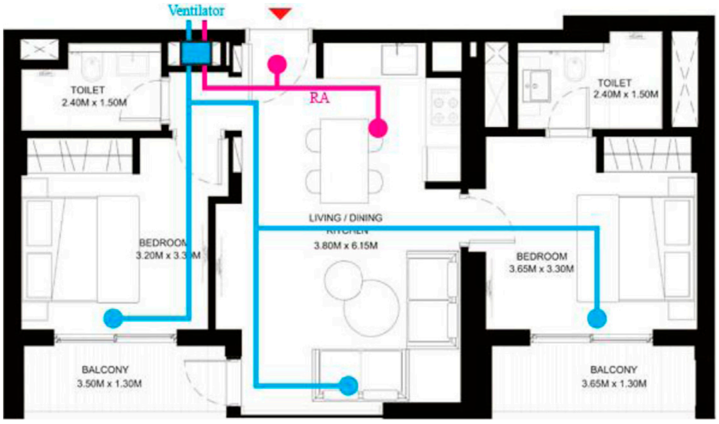
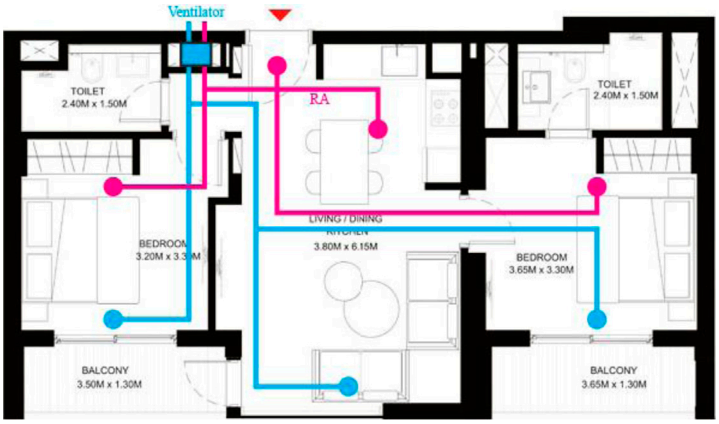
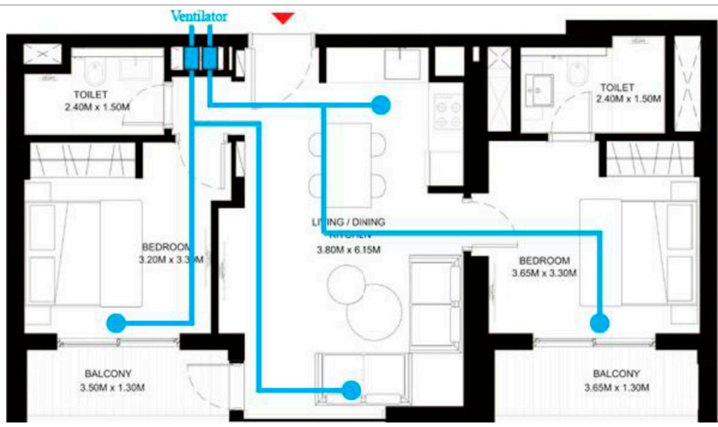
2 Materials and methods

2.1 Composition of target units

Table 1 provides an overview of the mockup units used in this study. The mockup units consist of seven adjacent apartment units on the second to sixth floors of Sobha Creek Vistas Tower A in Mohamed Bin Rashid City, Dubai (Figure 2) (Sobha Residence, 2023). These units were finished with identical specifications simultaneously (Jung et al., 2022f). One of the seven units serves as a blank household without a ventilation system installed (Zhang

10.3389/fbuil.2023.1286053

TABLE 2 Ventilator (in Blue) and Ductwork Setting showing Return Air RA (in Red).

<table>
<tr><th>Category</th><th>Ventilator and Ductwork setting</th></tr>
<tr><td>Total heat exchanger and sensible heat exchanger (standard)</td><td>
</td></tr>
<tr><td>Total heat exchanger (Individual room)</td><td>
</td></tr>
<tr><td>Alternating current type</td><td>
</td></tr>
</table>

et al., 2020). This household serves as a benchmark for future comparative analysis.

To investigate the impact of ventilation on improving indoor air quality, the total heat exchange type ventilation system was set to three stages: 0.3, 0.5, and 0.8 times/h (Zhao et al., 2020; Lee et al., 2022). Additionally, three types of ventilation devices were used: total heat exchange type, sensible heat exchange type, and AC type (Choi et al., 2018; Jung and Mahmoud, 2022). These devices were installed based on a ventilation frequency of 0.5 times/h.

Furthermore, to explore the differences based on duct methods, ducts were installed in the basic type and each room supply/exhaust type of the total heat exchange type ventilation device (ventilation frequency of 0.5 times/h) (Biler et al., 2018; Elsaid and Ahmed, 2021). After the mockup units were constructed, two units on the third floor were chosen. The aim was to measure the infiltration rate and assess its impact on IAQ. Specifically, we looked at concentrations of pollutants (HCHO and Toluene) and thermal conditions that could adversely influence the health, comfort, and performance of the building's occupants (Palanisamy and Ayalur, 2019).

The infiltration rate was measured using the constant concentration method with SE_05 (Liang et al., 2022). The measurement results indicated an infiltration rate of 0.75 times/h for the NE_01 unit and 0.65 times/h for the TE_02 unit, representing a difference of 0.1 times/h. Although a 0.1 times/h difference in infiltration rate is not negligible, it was considered an error factor for subsequent IAQ measurements, and no specific measures were taken to address it (Ben-David and Waring, 2018; Alonso et al., 2022).

Following the infiltration measurement, the supply/exhaust volume of the ventilation system was adjusted through TAB (Testing, Adjusting, and Balancing), ensuring that the opening rate of the exhaust diffuser matched the set value for each household and room (Degois et al., 2021). The apartment interiors were maintained at a room temperature of 24°C using air conditioning, and a household humidifier was installed in the living room for humidification (Zhao et al., 2018). During the operation of the ventilation system, the indoor relative humidity did not reach 50% with a single household humidifier (Okada et al., 2022). However, considering using one humidifier per unit is common, only one humidifier was installed, and the humidification amount was set to the maximum.

Table 2 provides an overview of the ventilation system - the blue lines show the ventilators and the red lines show the return air ducts - duct installation, and the state of duct insulation. For the total heat exchange type (ventilation frequency of 0., 0., and 0.8 times/h) and sensible heat exchange type duct systems, air supply diffusers were installed near the windows of each room. In contrast, exhaust diffusers were positioned near the dining room and entrance in the upper part of the corridor (Zhong et al., 2020; Al-Rawi et al., 2022). This configuration, named the basic type, was adopted in this study (Ghani et al., 2018). In contrast, each room supply/exhaust duct system involved the installation of an air supply diffuser and an exhaust diffuser in each room (Soares et al., 2021). The air supply diffuser was located similarly to the basic type, while the exhaust diffuser was positioned near the door of each room (Bai et al., 2022). In the AC-type system, exhaust and supply air alternated through a single duct, with a diffuser installed near the window of each room (Kwok et al., 2022; Tan et al., 2023). The AC ventilation system was designed to perform one cycle every 6 min, with exhaust for 3 min followed by air supply for 3 min (Xue et al., 2020). While the ducts inside the units were not insulated, the outdoor duct sections were insulated (Ismail et al., 2023).

2.2 Measurement method

The research study measured indoor air quality (IAQ), specifically Formaldehyde and Toluene, supply/exhaust temperature, and noise levels of the ventilation system operation (Szabados et al., 2021). The IAQ concentration measurement followed the IAQ Process Test Method outlined by the World Health Organization (WHO) for sampling and analysis (World Health Organization, 2010). The measurement period spanned 2 months, from 10 December 2022, to 23 February 2023, with 12 indoor air sampling and analysis sessions. Sampling within the unit took place in the center of the living room, while outside air sampling was conducted on the balcony of the fifth-floor living room side (Settimo et al., 2020).

TABLE 3 Measurement schedule.

Year	Date	On	Off
2022	December 10		○
	December 14		○
	December 17		○
	December 21	○	
	December 24		○
2023	January 2	○	
	January 7		○
	January 15	○	
	February 2		○
	February 5	○	
	February 10		○
	February 18	○	
	February 23	○	

Table 3 outlines the sampling schedule based on the operating conditions of the ventilation system. Under the "ventilator OFF" condition, IAQ measurements were taken to assess the effectiveness of the ventilation system in reducing indoor air pollutant concentrations (Földváry et al., 2017). This involved following the IAQ Management Act recommended by the WHO, where the ventilation system is continuously operated at the construction site but stopped during indoor air sampling (World Health Organization, 2010).

In contrast, under the "Ventilation device ON" condition, the ventilation system was operational during indoor air sampling to assess the IAQ improvement effect achieved by operating the ventilation device (Yin et al., 2019; Kozielska et al., 2020). Additionally, temperature/humidity data logger sensors were installed in the supply air (SA) and return air (RA) ducts near the ventilation system (Ismaeel and Mohamed, 2022). These sensors recorded the temperature/humidity of the supply/exhaust air at 10-min intervals (Da Silva et al., 2017). The measurement of noise levels by the Dubai Municipality Noise Vibration Process Test Method was conducted while considering the operation of the ventilation system (Lei et al., 2019). The living room and main room, which featured supply/exhaust diffusers, were selected as representative rooms for measurement (Cho et al., 2019). Five points, including the center of each room, were measured to determine the noise levels (Sarkhosh et al., 2021). To account for background noise, the measured noise level values in each room were adjusted using the background noise value from the household without a ventilation system.

2.3 Measurement tools and scenario

The measured indoor air pollutants were formaldehyde (HCHO) and Toluene. The measurement method is based on the

TABLE 4 Measuring IAQ factors and scenario.

Measuring factors		Measurement	Measuring time	Measuring location
Background Factors	Indoor Temperature	Digital Thermo-Hygrometer (TR-72U)	10:00 a.m.–6:00 p.m. (Autosave every 10 min for 8 h)	1.5 m from the floor in the center of the living room
	Relative Humidity			
IAQ Factors	Formaldehyde	DNPH Cartridge Σ300 Pump	10:00 a.m.–6:00 p.m. (Measured every 20 min)	
	Toluene	Tenax Tube Σ300 Pump	10:00 a.m.–6:00 p.m. (Measured every 20 min)	

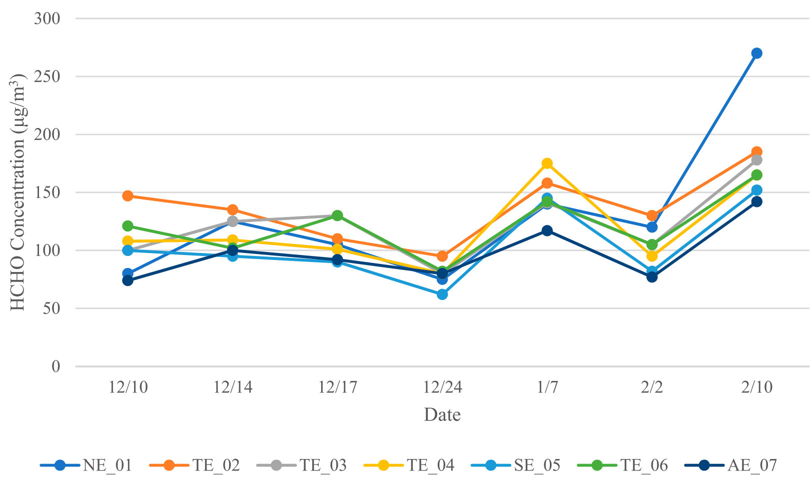


FIGURE 3
HCHO concentration change (ventilator off).

WHO standards, measured 1.5 m from the living room center from 10 a.m. to 6 p.m. (Table 4) (World Health Organization, 2010). For the first step to measure formaldehyde (HCHO) concentration, all windows and interior furniture doors are opened for 30 min to perform natural ventilation before sampling. As the second step, close all the windows for more than 5 h to prevent airflow (Yin et al., 2019). The furniture, doors, and built-in cabinet are opened to allow air movement for indoor air pollutant collection. In the third step, a sample is collected with a DNPH (2,4-Dinitrophenylhydrazine) cartridge after 5 h, rolled up with tinfoil to block any possible light effects (Kozielska et al., 2020). At this time, the natural and forced ventilation is sealed, and samples are collected. An ozone scrubber is used to collect air samples, and 15 L is collected for 20 min using a precise mini suction pump (0.5 mL/min). The air samples in the last step are precisely analyzed by HPLC (High-Performance Liquid Chromatography). In the TVOC concentration measurement method, the two stages of the formaldehyde (HCHO) sampling method are the same, and a Tenax tube is used in the third step (Ismaeel and Mohamed, 2022). The last step analyzes the air sample by GC/MS (Gas Chromatography/Mass Spectroscopy). However, since the device used in this study is a direct-reading method for instantaneous values, it measures instantaneous concentrations multiple times, unlike the collection method of process test methods (Da Silva et al., 2017).

3 Results

The room temperature was kept constant throughout the measurement at the set temperature of 24°C. However, the humidity varied among households due to the differences in ventilation rates. Figure 3 and Figure 4 depict the changes in HCHO concentration during the measurement period for the 'ventilator OFF' and "ventilator ON" conditions, respectively. In both cases, the HCHO concentration generally satisfies the IAQ recommendation standard of 210 μg/m³. However, the concentration does not decrease over time and shows a slight upward trend. This can be attributed to the gradual emission of HCHO from the complex composition of finishing materials, which gradually increases over time.

Regarding VOCs, toluene exhibits the highest concentration, and the trend of other VOC substances in terms of reduction over time is similar to that of toluene. Therefore, this paper focuses on analyzing the changes in toluene concentration. Figure 5 and Figure 6 illustrate the variations in toluene concentration for the "ventilator OFF" and "ventilator ON" conditions, respectively. Under the "ventilator ON" condition, the toluene concentration experienced a significant increase on December 21st, followed by a rapid decrease on January 7th, approximately 1 month into the measurement period, ultimately falling below the standard value. Subsequently, the rate of decline slowed down. On the other hand, for the "ventilator ON" condition, the concentration of toluene reached its

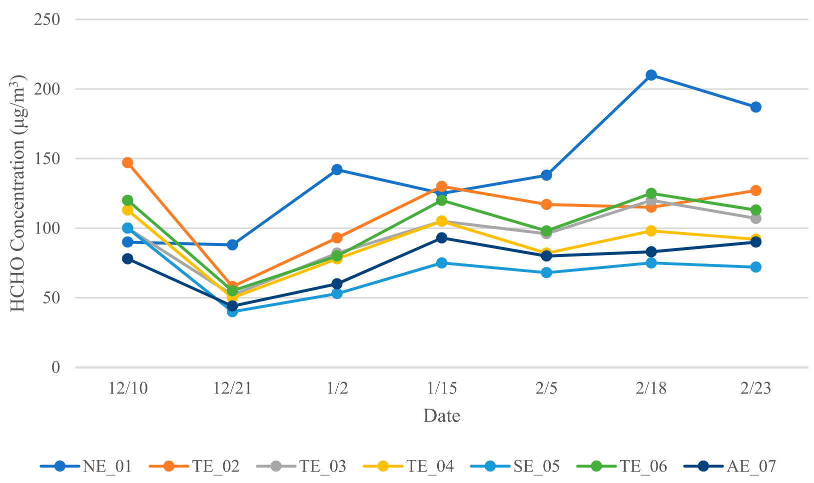


FIGURE 4
HCHO concentration change (ventilator on).

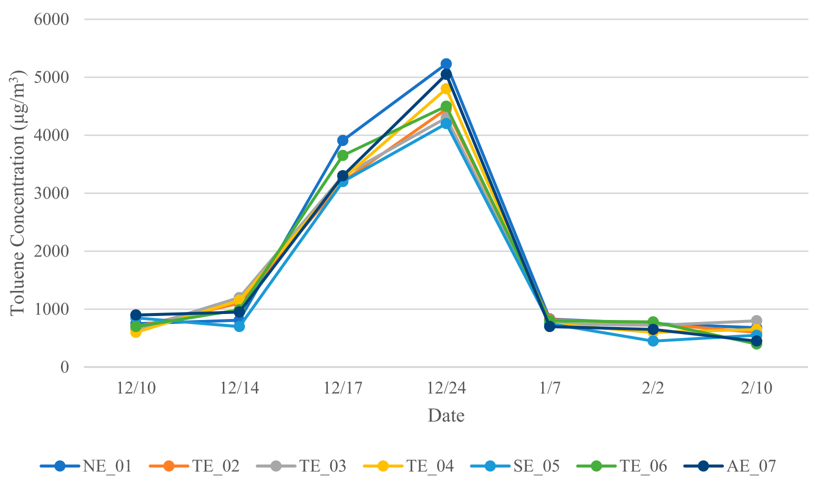


FIGURE 5
Toluene concentration change (ventilator off).

highest value on December 21st and gradually decreased over time. By January 15th, around 1 month after the start of measurement, the concentration consistently satisfied the standard value.

3.1 IAQ improvement according to ventilation amount change

To compare and analyze the temporal change in pollutant concentration, it is crucial to account for different temperature/humidity conditions during measurement. Therefore, in this study, the temperature and humidity conditions were standardized to 24°C and 50% using the Inoue equation. Moreover, since the initial concentration varies among generations, it is challenging to directly compare the formaldehyde and toluene improvement effect between generations or the reduction effect in concentration over time.

To address this issue, the concentration values for each measurement day were dimensionless concerning the concentration on December 10, the first day of measurement. These values were then presented as a percentage multiplied by 100 for comparison and review. Figure 7 and Figure 8 illustrate the dimensionless concentration of HCHO at different air volumes of the ventilator, corresponding to ventilation frequencies of 0.3, 0.5, and 0.8 times/h. Figure 7 depicts the case of "ventilator OFF," it shows no significant difference in HCHO concentration over time between households with and without a ventilation system initially. However, after 1.5 months into the measurement period, specifically on February 2, the formaldehyde and toluene improved by approximately 20%. By the end of the 2-month measurement period on February 10, the improvement reached around 30%. This indicates the formaldehyde and toluene improvement effect resulting from the regular operation of the ventilation system.

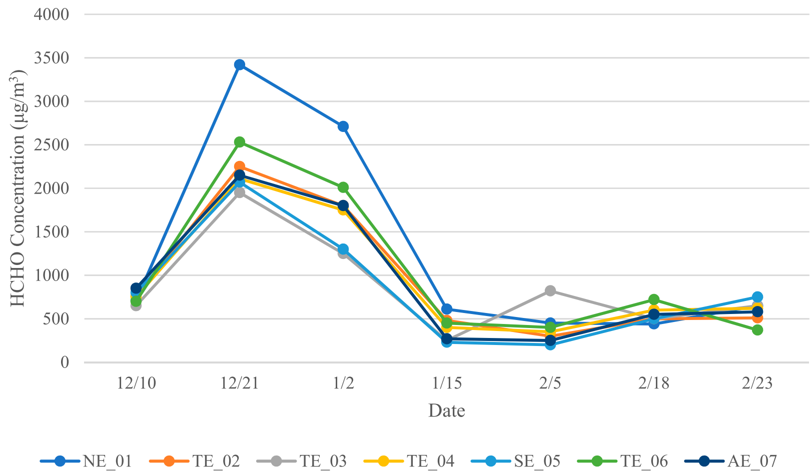


FIGURE 6
Toluene concentration change (ventilator on).

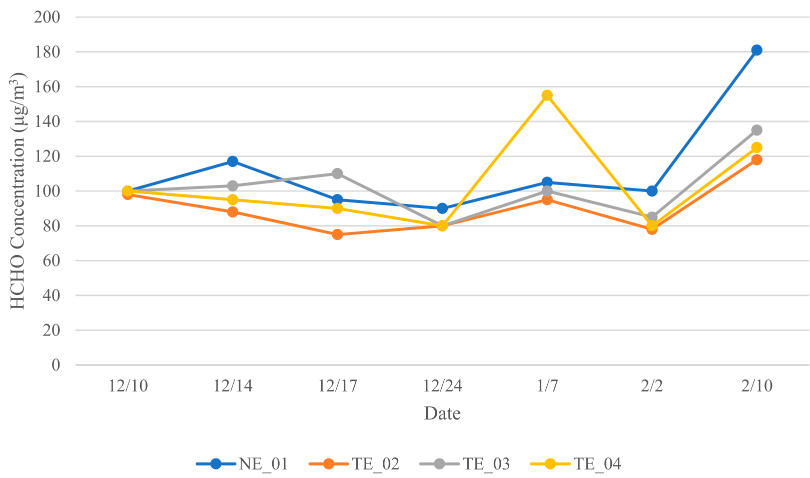


FIGURE 7
HCHO concentration change by ventilation rate (ventilator off).

Regarding the formaldehyde and toluene improvement effect based on ventilation rate variations, the concentration of HCHO was lower at a ventilation rate of 0.3 times/h compared to 0.5 or 0.8 times/h. However, the difference was around 5%, within the measurement error range. Consequently, the effect of improving indoor air quality based on ventilation variations did not demonstrate a significant difference. In the case of "ventilator ON," the average improvement effect was approximately 40%, except for January 15. However, the difference associated with changes in air volume was approximately 5%, which was considered within the measurement error range. These findings suggest that during the winter season in Dubai, which coincided with the measurement period, the infiltration rate was relatively high at approximately 0.7 times/h. As a result, the difference in ventilation rate between 0.3 and 0.8 times/h was relatively small, compounded by construction errors.

The toluene concentration was dimensionless concerning the concentration on the first measurement day without temperature/humidity correction. Figure 9 and Figure 10 present the relatively dimensionless concentration of toluene for the "ventilator OFF" and "ventilator ON" conditions, respectively. The toluene concentration remained relatively high until December 24, 0.5 months into the measurement period. During this period, with the ventilation system turned OFF, there was an approximate 15% IAQ improvement effect compared to households without a ventilation system. This improvement can be attributed to the constant operation of the ventilation system. However, starting from January 7, approximately 1 month into the measurement period, the declining trend slowed down, and the formaldehyde and toluene improvement effect due to regular ventilation system operation became less apparent.

When comparing the differences based on air volume, the case of 0.3 times/h showed a lower value by approximately 5%. However, considering the measurement error, this difference is considered insignificant. In the case of "ventilator ON," the analysis focused only on the measured values from December 21, January 15, and February 23,

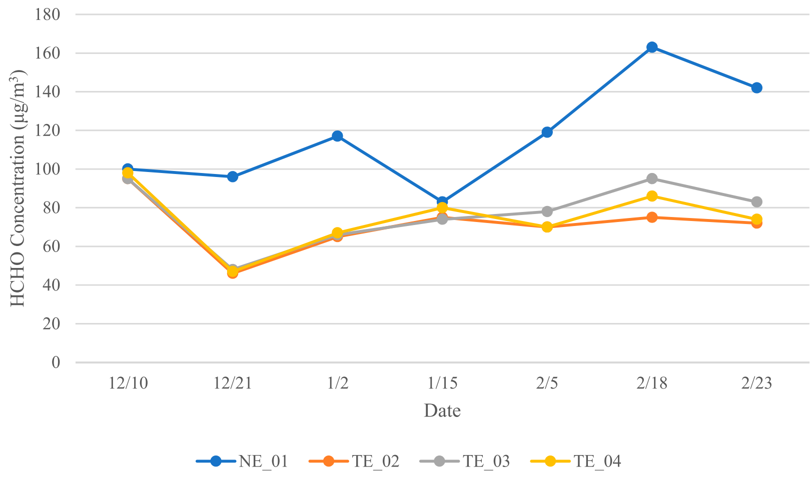


FIGURE 8
HCHO concentration change by ventilation rate (ventilator on).

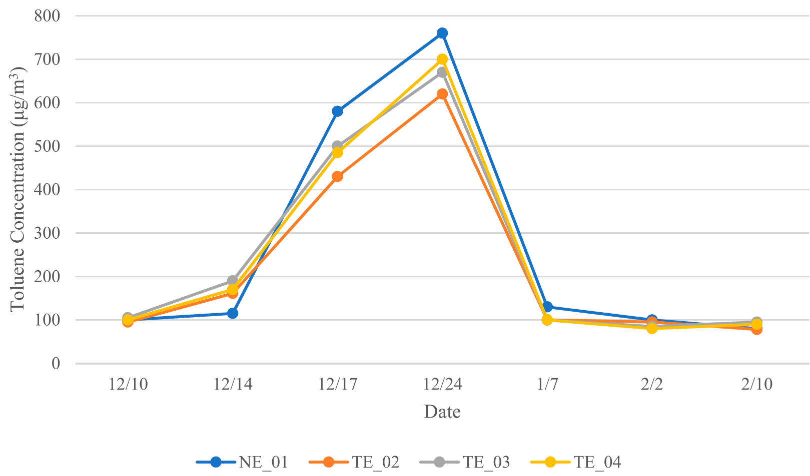


FIGURE 9
Toluene concentration change by ventilation rate (ventilator off).

excluding instances where the outdoor air concentration was affected by road pavement work near the site during the measurement period. On December 21, when the concentration was at its highest, toluene concentration in households without ventilation increased to about 500% of the initial concentration. In households with ventilation, it rose to approximately 300% regardless of air volume, resulting in a 40% IAQ improvement effect. However, starting from January 15, approximately 1 month into the measurement period, the formaldehyde and toluene improvement effect due to the operation of the ventilation system gradually diminished.

3.2 IAQ improvement according to the type of ventilation system

The IAQ (formaldehyde and toluene) improvement effect of waste heat recovery ventilation systems with different heat exchanger types, namely, total heat exchange, sensible heat exchange, and alternating current types, was examined. All three ventilation systems operated at the same frequency of 0.5 times/h. Figure 11 and Figure 12 present the relatively dimensionless concentration of HCHO according to the ventilation system type. In the case of "ventilator OFF," the reduction effect in concentration is only apparent on January 7, approximately 1 month after the initial measurement. However, a reduction effect of around 15% becomes evident from February 2, about 1.5 months into the measurement period. By the end of the 2 months on February 10, the alternating current type demonstrated a 40% IAQ improvement effect, while the sensible heat exchange type and total heat exchange type showed an improvement of approximately 25%. When the ventilation system is "ON," the sensible heat exchange type exhibits a 50% improvement, while the total heat exchange type and AC type show a 40% improvement compared to units without ventilation, except for January 15.

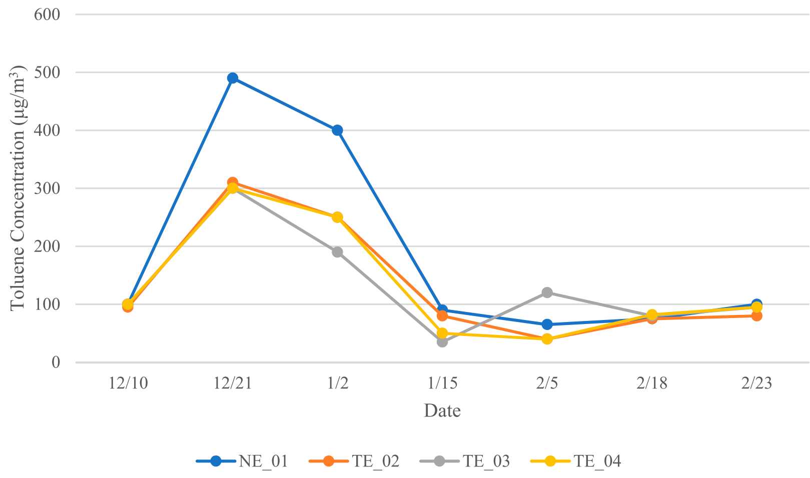


FIGURE 10
Toluene concentration change by ventilation rate (ventilator on).

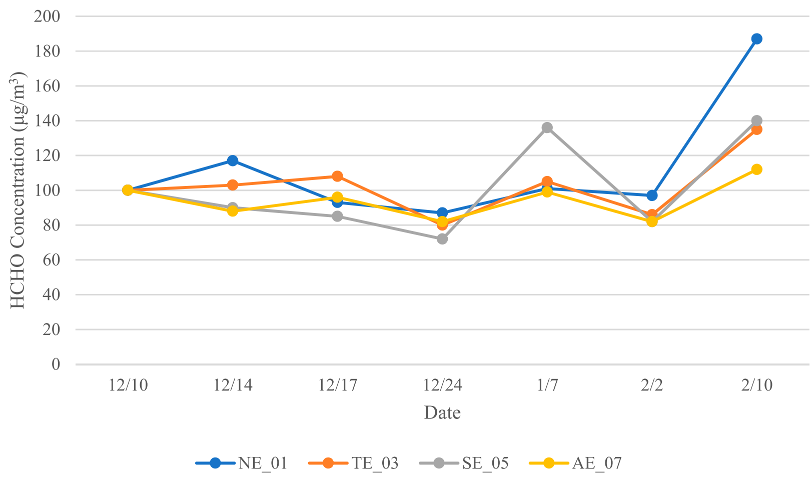


FIGURE 11
HCHO concentration change by heat exchanger type (ventilator off).

Figure 13 and Figure 14 illustrate the relatively dimensionless concentration of toluene for different waste heat recovery ventilators. In the case of "ventilator OFF," the total heat exchange type and AC type show about a 10% improvement on December 17 and December 24, when the toluene concentration is relatively high compared to units without ventilation. On the other hand, the sensible heat exchange type demonstrates a relatively higher formaldehyde and toluene improvement effect compared to other ventilation device types. However, starting from January 7, when the concentration began to decrease, the differences gradually diminished, and the formaldehyde and toluene improvement effect became less evident. In the case of "ventilator ON," excluding instances where the outdoor air concentration of toluene was high, the measured values on December 21, January 15, and February 23 were reviewed. The concentration in units without ventilation was higher than the initial concentration. At the same time, the sensible heat exchange type reached 250%, and the total heat exchange type and AC type reached 300% and 350%, respectively. This resulted in a formaldehyde and toluene improvement effect of approximately 50% for the sensible heat exchange type and around 40% for both the total and AC types.

3.3 IAQ improvement according to the supply/exhaust duct types

The ventilation system's duct method is analyzed, comparing the IAQ (formaldehyde and toluene) improvement effect between each room supply/kitchen exhaust unit and each room supply/exhaust unit. In the "ventilator OFF" scenario, formaldehyde concentration measurements were conducted until February 2nd, 1.5 months into

10.3389/fbuil.2023.1286053

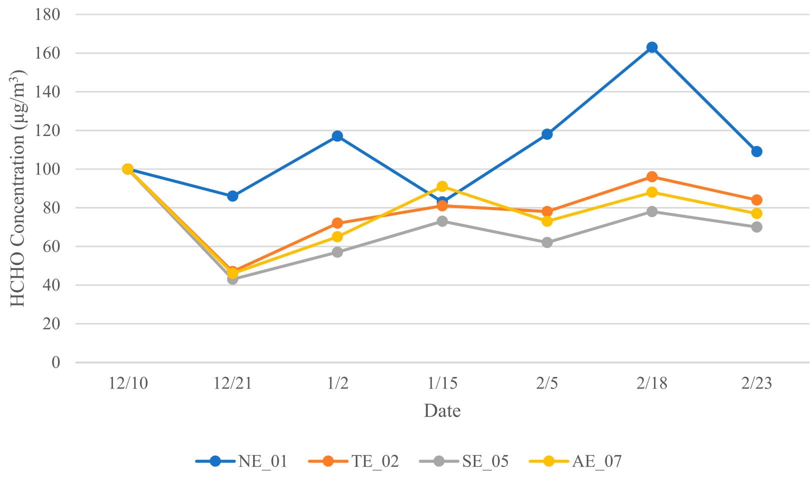


FIGURE 12
HCHO concentration change by heat exchanger type (ventilator on).

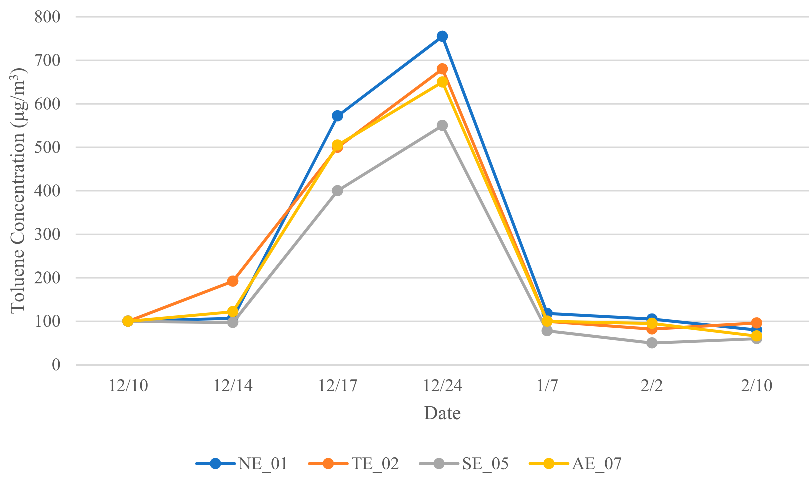


FIGURE 13
Toluene concentration change by heat exchanger type (ventilator off).

the measurement period. Although the concentration reduction effect was not initially apparent, a slight reduction effect became noticeable on February 2nd. After 2 months, on February 10th, each room supply/kitchen exhaust unit and each room supply/exhaust unit exhibited an improvement effect of 25% compared to units without ventilation. The difference between the supply/exhaust duct methods was insignificant, within 5%. In the "Ventilation ON" case, except for January 15th, each room supply/kitchen exhaust unit showed a 40% improvement effect, while each room supply/exhaust unit demonstrated a 30% improvement effect compared to units without ventilation. The difference between the two methods was within 10%. However, considering the margin of error, there needs to be a clear distinction in the reduction effect of formaldehyde concentration based on the supply/exhaust duct method.

The dimensionless concentration change of toluene is as follows. In the "ventilator OFF" scenario, each room supply/exhaust unit showed an improvement effect of approximately 25% compared to units without ventilation until December 24th, 0.5 months after the start of the measurement. Meanwhile, each room supply/kitchen exhaust unit exhibited an improvement effect of about 10%. In the 'Ventilation ON' case, when examining the data for December 26th, where the outdoor air concentration was relatively low, each room supply/exhaust unit displayed a 50% improvement effect, while each room supply/kitchen exhaust unit showed a 40% improvement effect. However, the 10% difference in the IAQ (formaldehyde and toluene) improvement effect based on the supply/exhaust duct method is considered insignificant when considering measurement errors.

3.4 Noise measurement result

Table 5 presents the results of the noise measurements. When considering the Dubai Municipality Building Code's standard of 40 dB(A), the noise levels in the living room range from 32.5 to 41.8 dB(A), depending on the type of ventilation system. However,

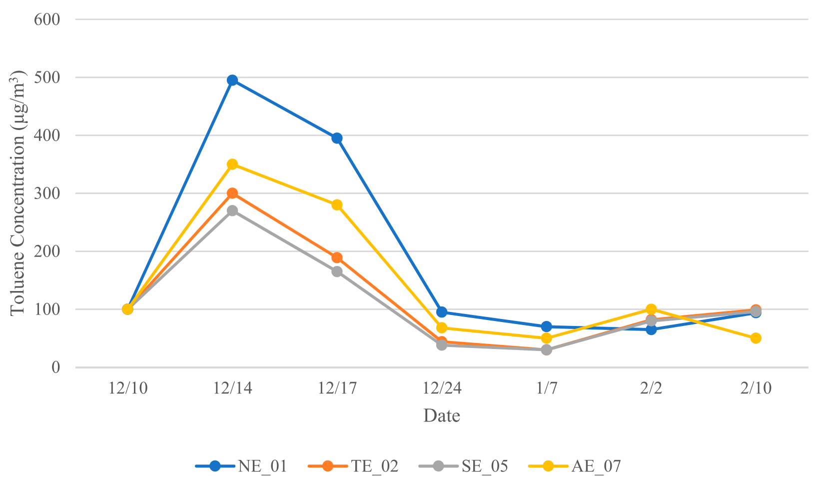


FIGURE 14
Toluene concentration change by heat exchanger type (ventilator on).

TABLE 5 Noise level.

Unit number	Type	ACH	Living room (dB(A))	Bedroom (dB(A))
203 (TE_02)	Total heat exchanger	0.3	35.2	31.8
302 (TE_03)	Total heat exchanger	0.5	35.1	31.2
303 (TE_04)	Total heat exchanger	0.8	32.5	28.2
502 (SE_05)	Sensible heat exchanger	0.5	41.8	38.8
503 (TE_06)	Total heat exchanger	0.5	38.2	30.7
602 (AE_07)	Alternating current type	0.5	34.4	34.2
Background Noise			18.6	20.1

one unit registered a noise level of 41.8 dB(A), exceeding the standard. On the other hand, all other units met the prescribed criterion. Regarding the master bedroom, the distribution of noise levels varies from 28.2 to 38.8 dB(A), depending on the type of ventilation system. Notably, all measurements in this area adhered to the standard value.

4 Discussion

The present study investigated the impact of different ventilation systems on IAQ and pollutant concentrations in an apartment setting. Specifically, the focus was on HCHO and toluene concentrations. Measurements were conducted under varying ventilation conditions, including ventilator OFF and ventilator ON scenarios. The study also examined the influence of ventilation rate, heat exchanger type, and supply/exhaust duct method on IAQ improvement. Additionally, noise levels in the living room and master bedroom were assessed.

Interpretations of the findings indicate that the implemented ventilation systems significantly improved formaldehyde and toluene by reducing formaldehyde and toluene concentrations. The formaldehyde and toluene improvement effects were more pronounced when the ventilation systems were turned ON. Intriguingly, on December 21st, there was a sudden surge in the concentration of toluene despite the ventilator being ON. This unexpected spike necessitates further exploration to understand its cause. However, some concentration reduction was observed even with the ventilation systems turned OFF. Changes in the ventilation rate did not substantially impact IAQ improvement. Similarly, the type of heat exchanger employed did not show significant differences in IAQ improvement. Likewise, the supply/exhaust duct method choice did not yield significant variations in IAQ improvement. However, it is worth noting that noise levels in some units exceeded the noise level standard specified by the Dubai Municipality Building Code.

The implications of the study findings underscore the importance of proper ventilation systems in enhancing formaldehyde and toluene by reducing formaldehyde and toluene concentrations. Adequate operation of ventilation systems is vital for maintaining a healthy indoor environment. While the specific variables examined in this study did not significantly impact formaldehyde and toluene improvement, further investigations can explore other factors that may influence formaldehyde and toluene. Moreover, adherence to noise level standards is crucial to ensure a comfortable living environment for occupants.

4.1 Study limitations

Our study, centered within an apartment milieu, endeavored to discern the effects of diverse ventilation systems on IAQ, predominantly focusing on the concentrations of HCHO (formaldehyde) and toluene. We incorporated many ventilation conditions into our experimental design, encompassing scenarios where ventilators were activated and deactivated (Al-Rawi et al., 2022). Beyond these primary conditions, our research also delved into the subtleties of ventilation rate, the intricacies of heat exchanger types, and variations in the supply/exhaust duct methods, seeking correlations with improvements in IAQ (Ghani et al., 2018).

Our analysis shows that the ventilation systems employed had a tangible, positive influence on the IAQ by significantly reducing the concentrations of formaldehyde and toluene. Interestingly, this enhancement in air quality was not solely contingent on the active ventilators. Even in their deactivated state, a reduction in pollutant concentration was discernible, albeit less pronounced than in the active state. Despite our thorough exploration of various parameters, changes in ventilation rates, the type of heat exchanger, or the chosen supply/exhaust method did not appear to be critical differentiators in the level of IAQ improvement achieved (Bai et al., 2022). Nonetheless, one area of potential concern emerged from our findings: certain units manifested noise levels that surpassed the prescribed thresholds set forth by the Dubai Municipality Building Code.

Drawing from these insights, the overarching message is unequivocal: proficient ventilation systems' integration and optimal operation are paramount for curtailing formaldehyde and toluene concentrations, fostering a salubrious indoor ambiance. Although the variables examined in this iteration of our research did not dramatically alter the levels of formaldehyde and toluene, we acknowledge the vastness of the IAQ domain and anticipate that supplementary studies might unearth additional influential factors. Ensuring adherence to noise regulations, as evidenced by our findings, remains pivotal to providing residents with a serene and healthful living environment.

5 Conclusion

The mock-up experiment conducted in Sobha Creek Vistas Tower A provided valuable insights into the IAQ improvement effect of mechanical ventilation systems. It is important to note that the findings are specific to the ventilation devices used in this experiment and may not be universally applicable to all ventilation systems. The results demonstrated that installing and operating a ventilation device with a ventilation rate ranging from 0.3 to 0.8 times/h in the target units significantly reduced HCHO and VOC concentrations. The IAQ improvement effect ranged from 30% to 50% compared to units without ventilation. This emphasizes the importance of implementing proper ventilation systems to mitigate indoor air pollutants effectively.

Interestingly, the study revealed that the IAQ improvement effect was not directly influenced by the air volume of the ventilation system within the tested range of ventilation frequencies. Further investigation is required to explore other factors that may contribute to IAQ improvements and determine optimal ventilation parameters.

Regarding the supply/exhaust duct method, it was observed that each room supply/exhaust method demonstrated approximately a 10% higher reduction in VOC concentrations compared to each room supply/kitchen exhaust unit method. This finding suggests the importance of considering the specific duct configuration in achieving effective pollutant reduction.

Based on the study findings, it is recommended to include a duct mechanism to prevent backflow during strong winds when implementing ventilation systems. Additionally, measures should be taken to address potential issues of cold drafts to ensure occupant comfort and satisfaction.

The noise measurements conducted during the study indicated that most of the recorded values complied with the standard of 40 dB(A) or below. This reinforces the significance of considering noise control measures in ventilation system design and installation to create a comfortable indoor environment.

While the results provide valuable insights, it is crucial to interpret them within the context of the specific mock-up experiment conducted. Further research and field studies involving a broader range of ventilation devices and real-world conditions are recommended to validate and generalize these findings. This will enhance our understanding of IAQ improvement strategies and their applicability in various settings.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

CJ: Conceptualization, Data curation, Formal Analysis, Methodology, Resources, Validation, Visualization, Writing–original draft. GE: Data curation, Investigation, Methodology, Project administration, Software, Supervision, Writing–review and editing. NA: Investigation, Project administration, Supervision, Validation, Visualization, Writing–review and editing. MS: Methodology, Resources, Software, Validation, Visualization, Writing–review and editing.

Funding

The authors would like to thank Ajman University for financial support.

Acknowledgments

The authors would like to thank the University of Sharjah, and the Sustainable Architecture and Resilient Design Research Group (SARD-RG) for providing a great research environment, and Ajman University for financial support.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abdelaziz Mahmoud, N. S., and Jung, C. (2023). Analyzing the bake-out effect in winter for the enhancement of indoor air quality at new apartments in UAE. *Buildings* 13 (4), 846. doi:10.3390/buildings13040846

Abdul-Wahab, S. A., Chin Fah En, S., Elkamel, A., Ahmadi, L., and Yetilmezsoy, K. (2015). A review of standards and guidelines set by international bodies for the parameters of indoor air quality. *Atmos. Pollut. Res.* 6 (5), 751–767. doi:10.5094/apr.2015.084

Alonso, M. J., Wolf, S., Jørgensen, R. B., Madsen, H., and Mathisen, H. M. (2022). A methodology for the selection of pollutants for ensuring good indoor air quality using the de-trended cross-correlation function. *Build. Environ.* 209, 108668. doi:10.1016/j.buildenv.2021.108668

Al Qassimi, N., and Jung, C. (2022). Impact of air-purifying plants on the reduction of volatile organic Compounds in the indoor hot desert climate. *Front. Built Environ.* 7, 188. doi:10.3389/fbuil.2021.803516

Al-Rawi, M., Farid, M. M., Jones, R. J., and Louie, K. (2022). Evaluation of a polyester filter and UV light (PFUV) dehumidifier to improve indoor environmental quality: preliminary results. *Sustainability* 14 (8), 4504. doi:10.3390/su14084504

Arar, M., and Jung, C. (2021). Improving the indoor air quality in nursery buildings in United Arab Emirates. *Int. J. Environ. Res. Public Health* 18 (22), 12091. doi:10.3390/ijerph182212091

Arar, M., Jung, C., Awad, J., and Chohan, A. H. (2021). Analysis of smart home technology acceptance and preference for elderly in dubai, UAE. *Designs* 5 (4), 70. doi:10.3390/designs5040070

Arar, M., Jung, C., and Qassimi, N. A. (2022). Investigating the influence of the building material on the indoor air quality in apartment in Dubai. *Front. Built Environ.* 7, 804216. doi:10.3389/fbuil.2021.804216

Awad, J., Arar, M., Jung, C., and Boudiaf, B. (2022). The comparative analysis for the new approach to three tourism-oriented heritage districts in the United Arab Emirates. *Heritage* 5 (3), 2464–2487. doi:10.3390/heritage5030128

Awad, J., and Jung, C. (2021). Evaluating the indoor air quality after renovation at the Greens in Dubai, United Arab Emirates. *Buildings* 11 (8), 353. doi:10.3390/buildings11080353

Awad, J., and Jung, C. (2022). Extracting the planning elements for sustainable urban regeneration in Dubai with AHP (analytic hierarchy process). *Sustain. Cities Soc.* 76, 103496. doi:10.1016/j.scs.2021.103496

Awada, M., Becerik-Gerber, B., Hoque, S., O'Neill, Z., Pedrielli, G., Wen, J., et al. (2021). Ten questions concerning occupant health in buildings during normal operations and extreme events including the COVID-19 pandemic. *Build. Environ.* 188, 107480. doi:10.1016/j.buildenv.2020.107480

Bai, H. Y., Liu, P., Alonso, M. J., and Mathisen, H. M. (2022). A review of heat recovery technologies and their frost control for residential building ventilation in cold climate regions. *Renew. Sustain. Energy Rev.* 162, 112417. doi:10.1016/j.rser.2022.112417

Bani Mfarrej, M. F., Qafisheh, N. A., and Bahloul, M. M. (2020). Investigation of indoor air quality inside houses from UAE. *Air, Soil Water Res.* 13, 117862212092891. doi:10.1177/1178622120928912

Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S., et al. (2014). Auditory and non-auditory effects of noise on health. *Lancet* 383 (9925), 1325–1332. doi:10.1016/s0140-6736(13)61613-x

Ben-David, T., and Waring, M. S. (2018). Interplay of ventilation and filtration: differential analysis of cost function combining energy use and indoor exposure to PM2.5 and ozone. *Build. Environ.* 128, 320–335. doi:10.1016/j.buildenv.2017.10.025

Biler, A., Unlu Tavil, A., Su, Y., and Khan, N. (2018). A review of performance specifications and studies of trickle vents. *Buildings* 8 (11), 152. doi:10.3390/buildings8110152

Cho, H. M., Lee, J., Wi, S., and Kim, S. (2019). Field study on indoor air quality of wood remodeled welfare facilities for physical and psychological benefits. *J. Clean. Prod.* 233, 197–208. doi:10.1016/j.jclepro.2019.05.293

Choi, Y. H., Song, D., Seo, D., and Kim, J. (2018). Analysis of the variable heat exchange efficiency of heat recovery ventilators and the associated heating energy demand. *Energy Build.* 172, 152–158. doi:10.1016/j.enbuild.2018.04.066

Da Silva, C. F., Stefanowski, B., Maskell, D., Ormondroyd, G. A., Ansell, M. P., Dengel, A. C., et al. (2017). Improvement of indoor air quality by MDF panels containing walnut shells. *Build. Environ.* 123, 427–436. doi:10.1016/j.buildenv.2017.07.015

Degois, J., Veillette, M., Poulin, P., Lévesque, B., Aubin, D., Ouazia, B., et al. (2021). Indoor air quality assessment in dwellings with different ventilation strategies in Nunavik and impacts on bacterial and fungal microbiota. *Indoor air* 31 (6), 2213–2225. doi:10.1111/ina.12857

Dubai Municipality (2023a). *Al sa'fat – Dubai green building system*. Available from https://www.dm.gov.ae/municipality-business/al-safat-dubai-green-building-system/.

Dubai Municipality (2023b). *Practice guide Al Safat regulations rev 01*. Available from https://www.dm.gov.ae/wp-content/uploads/2021/01/Practice-Guide-Al-Safat-Regulations-Rev-01.pdf.

Elsaid, A. M., and Ahmed, M. S. (2021). Indoor air quality strategies for air-conditioning and ventilation systems with the spread of the global coronavirus (COVID-19) epidemic: improvements and recommendations. *Environ. Res.* 199, 111314. doi:10.1016/j.envres.2021.111314

Földváry, V., Bekö, G., Langer, S., Arrhenius, K., and Petráš, D. (2017). Effect of energy renovation on indoor air quality in multifamily residential buildings in Slovakia. *Build. Environ.* 122, 363–372. doi:10.1016/j.buildenv.2017.06.009

Ghani, S., Gamaledin, S. M. A., Rashwan, M. M., and Atieh, M. A. (2018). Experimental investigation of double-pipe heat exchangers in air conditioning applications. *Energy Build.* 158, 801–811. doi:10.1016/j.enbuild.2017.10.051

Gilbey, S. E., Reid, C. M., Zhao, Y., Soares, M. J., and Rumchev, K. B. (2023). Factors affecting indoor environmental air quality of non-smoking residences in Perth, Western Australia. *Indoor Built Environ.* 32, 961–976. doi:10.1177/1420326X221149288

Han, K. T. (2021). Effects of visible greenness, quantity and distance of indoor plants on human perceptions and physical parameters. *Indoor Built Environ.* 30 (9), 1353–1372. doi:10.1177/1420326x20939595

Ismaeel, W. S., and Mohamed, A. G. (2022). Indoor air quality for sustainable building renovation: a decision-support assessment system using structural equation modelling. *Build. Environ.* 214, 108933. doi:10.1016/j.buildenv.2022.108933

Ismail, Y. A., Eldosoky, M. A., Rashed, M. R., and Soliman, A. M. (2023). Numerical investigation of indoor air quality in health care facilities: a case study of an intensive care unit. *J. Build. Eng.* 68, 106143. doi:10.1016/j.jobe.2023.106143

Jung, C., and Abdelaziz Mahmoud, N. S. (2023). Exploring customer behavior in shopping malls: a study of rest areas in dubai, United Arab Emirates. *Sustainability* 15 (12), 9169. doi:10.3390/su15129169

Jung, C., and Al Qassimi, N. (2022). Investigating the emission of hazardous chemical substances from mashrabiya used for indoor air quality in hot desert climate. *Sustainability* 14 (5), 2842. doi:10.3390/su14052842

Jung, C., Al Qassimi, N., Abdelaziz Mahmoud, N. S., and Lee, S. Y. (2022f). Analyzing the housing consumer preferences via analytic hierarchy process (AHP) in dubai, United Arab Emirates. *Behav. Sci.* 12 (9), 327. doi:10.3390/bs12090327

Jung, C., Al Qassimi, N., Arar, M., and Awad, J. (2021b). The analysis of indoor air pollutants from finishing material of new apartments at business bay, dubai. *Front. Built Environ.* 7, 765689. doi:10.3389/fbuil.2021.765689

Jung, C., Al Qassimi, N., Arar, M., and Awad, J. (2022b). The improvement of user satisfaction for two urban parks in dubai, UAE: bay avenue park and Al ittihad park. *Sustainability* 14 (6), 3460. doi:10.3390/su14063460

Jung, C., Alqassimi, N., and El Samanoudy, G. (2022d). The comparative analysis of the indoor air pollutants in occupied apartments at residential area and industrial area in dubai, United Arab Emirates. *Front. Built Environ.* 8, 998858. doi:10.3389/fbuil.2022.998858

Jung, C., and Arar, M. (2023). Natural vs. Artificial light: a study on the influence of light source on chlorophyll content and photosynthetic rates on indoor plants. *Buildings* 13 (6), 1482. doi:10.3390/buildings13061482

Jung, C., and Awad, J. (2021a). The improvement of indoor air quality in residential buildings in Dubai, UAE. *Buildings* 11 (6), 250. doi:10.3390/buildings11060250

Jung, C., and Awad, J. (2021b). Improving the IAQ for learning efficiency with indoor plants in university classrooms in Ajman, United Arab Emirates. *Buildings* 11 (7), 289. doi:10.3390/buildings11070289

Jung, C., and Awad, J. (2023). Sharjah sustainable city: an analytic hierarchy process approach to urban planning priorities. *Sustainability* 15 (10), 8217. doi:10.3390/su15108217

Jung, C., Awad, J., and Al Qassimi, N. (2021d). Analyzing the users' satisfaction levels and perceptions of the dubai water canal for future waterfront development in UAE. *Future Cities Environ.* 7 (1). doi:10.5334/fce.134

Jung, C., Awad, J., and Al Qassimi, N. (2021e). Evaluation of residents' comfort in high-rise residential buildings in Dubai, United Arab Emirates. *Front. Built Environ.* 145. doi:10.3389/fbuil.2021.766057

Jung, C., Awad, J., and Chohan, A. (2021c). The planning of smart elderly housing in Dubai with IoT technologies. *Open House Int.* 46, 668–681. doi:10.1108/OHI-08-2020-0121

Jung, C., Awad, J., Sami Abdelaziz Mahmoud, N., and Salameh, M. (2021a). An analysis of indoor environment evaluation for the Springs development in Dubai, UAE. *Open House Int.* 46 (4), 651–667. doi:10.1108/ohi-11-2020-0165

Jung, C., Awad, R., and Awad, J. (2022c). A study of optimal design process for complex-shaped skyscrapers' structural systems in United Arab Emirates. *Ain Shams Eng. J.* 13 (5), 101683. doi:10.1016/j.asej.2021.101683

Jung, C., and El Samanoudy, G. (2023). Mitigating indoor air pollution in university dormitory: the need for better ventilation and resident awareness. *Buildings* 13 (5), 1144. doi:10.3390/buildings13051144

Jung, C., and Mahmoud, N. S. A. (2022). Extracting the critical points of formaldehyde (HCHO) emission model in hot desert climate. *Air, Soil Water Res.* 15, 117862212211050. doi:10.1177/11786221221105082

Jung, C., Mahmoud, N. S. A., and Alqassimi, N. (2022e). Identifying the relationship between VOCs emission and temperature/humidity changes in new apartments in the hot desert climate. *Front. Built Environ.* 8, 1018395. doi:10.3389/fbuil.2022.1018395

Jung, C., Mahmoud, N. S. A., El Samanoudy, G., and Al Qassimi, N. (2022a). Evaluating the color preferences for elderly depression in the United Arab Emirates. *Buildings* 12 (2), 234. doi:10.3390/buildings12020234

Kakoulli, C., Kyriacou, A., and Michaelides, M. P. (2022). A review of field measurement studies on thermal comfort, indoor air quality and virus risk. *Atmosphere* 13 (2), 191. doi:10.3390/atmos13020191

Kharrufa, S. N., Awad, J., Jung, C., and Sherzad, M. (2022). Evaluating an active low-energy cooling upgrade to the building envelope in the hot climates of the Middle East. *Int. J. Low-Carbon Technol.* 17, 118–129. doi:10.1093/ijlct/ctab091

Kozielska, B., Mainka, A., Żak, M., Kaleta, D., and Mucha, W. (2020). Indoor air quality in residential buildings in Upper Silesia, Poland. *Build. Environ.* 177, 106914. doi:10.1016/j.buildenv.2020.106914

Kwok, H. H., Cheng, J. C., Li, A. T., Tong, J. C., and Lau, A. K. (2022). Impact of shaft design to thermal comfort and indoor air quality of floors using BIM technology. *J. Build. Eng.* 51, 104326. doi:10.1016/j.jobe.2022.104326

Lee, J., Woo, D. O., Jang, J., Junghans, L., and Leigh, S. B. (2022). Collection and utilization of indoor environmental quality information using affordable image sensing technology. *Energies* 15 (3), 921. doi:10.3390/en15030921

Lei, L., Chen, W., Xue, Y., and Liu, W. (2019). A comprehensive evaluation method for indoor air quality of buildings based on rough sets and a wavelet neural network. *Build. Environ.* 162, 106296. doi:10.1016/j.buildenv.2019.106296

Liang, W., Chen, F., Lv, M., and Yang, X. (2022). A pre-assessment and pollution prevention tool for indoor volatile organic compound simulations during the interior design stage. *Build. Environ.* 226, 109584. doi:10.1016/j.buildenv.2022.109584

Mahmoud, N. S. A., El Samanoudy, G., and Jung, C. (2023a). Simulating the natural lighting for a physical and mental Well-being in residential building in Dubai, UAE. *Ain Shams Eng. J.* 14 (1), 101810. doi:10.1016/j.asej.2022.101810

Mahmoud, N. S. A., Jung, C., and Al Qassimi, N. (2023b). Evaluating the aircraft noise level and acoustic performance of the buildings in the vicinity of Dubai International Airport. *Ain Shams Eng. J.* 14 (8), 102032. doi:10.1016/j.asej.2022.102032

Mannan, M., and Al-Ghamdi, S. G. (2021). Indoor air quality in buildings: a comprehensive review on the factors influencing air pollution in residential and commercial structure. *Int. J. Environ. Res. Public Health* 18 (6), 3276. doi:10.3390/ijerph18063276

Marques, G., Saini, J., Dutta, M., Singh, P. K., and Hong, W. C. (2020). Indoor air quality monitoring systems for enhanced living environments: a review toward sustainable smart cities. *Sustainability* 12 (10), 4024. doi:10.3390/su12104024

Monge-Barrio, A., Bes-Rastrollo, M., Dorregaray-Oyaregui, S., González-Martínez, P., Martin-Calvo, N., López-Hernández, D., et al. (2022). Encouraging natural ventilation to improve indoor environmental conditions at schools. Case studies in the north of Spain before and during COVID. *Energy Build.* 254, 111567. doi:10.1016/j.enbuild.2021.111567

Okada, N., Shiraishi, Y., Tomomatsu, K., Oguma, T., and Asano, K. (2022). Moldy odor from air conditioners in the residences of Japanese participants with and without asthma. *Indoor air* 32 (11), e13156. doi:10.1111/ina.13156

Palanisamy, D., and Ayalur, B. K. (2019). Development and testing of condensate assisted pre-cooling unit for improved indoor air quality in a computer laboratory. *Build. Environ.* 163, 106321. doi:10.1016/j.buildenv.2019.106321

Rickenbacker, H. J., Collinge, W. O., Hasik, V., Ciranni, A., Smith, I., Colao, P., et al. (2020). Development of a framework for indoor air quality assessments in energy conservation districts. *Sustain. Cities Soc.* 52, 101831. doi:10.1016/j.scs.2019.101831

Sadrizadeh, S., Yao, R., Yuan, F., Awbi, H., Bahnfleth, W., Bi, Y., et al. (2022). Indoor air quality and health in schools: a critical review for developing the roadmap for the future school environment. *J. Build. Eng.* 57, 104908. doi:10.1016/j.jobe.2022.104908

Sarkhosh, M., Najafpoor, A. A., Alidadi, H., Shamsara, J., Amiri, H., Andrea, T., et al. (2021). Indoor Air Quality associations with sick building syndrome: an application of decision tree technology. *Build. Environ.* 188, 107446. doi:10.1016/j.buildenv.2020.107446

Settimo, G., Manigrasso, M., and Avino, P. (2020). Indoor air quality: a focus on the European legislation and state-of-the-art research in Italy. *Atmosphere* 11 (4), 370. doi:10.3390/atmos11040370

Sherzad, M., and Jung, C. (2022). Evaluating the emission of VOCs and HCHO from furniture based on the surface finish methods and retention periods. *Front. Built Environ.* 8, 1062255. doi:10.3389/fbuil.2022.1062255

Shin, M. S., Rhee, K. N., Lee, E. T., and Jung, G. J. (2018). Performance evaluation of CO2-based ventilation control to reduce CO2 concentration and condensation risk in residential buildings. *Build. Environ.* 142, 451–463. doi:10.1016/j.buildenv.2018.06.042

Soares, N., Rosa, N., Monteiro, H., and Costa, J. J. (2021). Advances in standalone and hybrid earth-air heat exchanger (EAHE) systems for buildings: a review. *Energy Build.* 253, 111532. doi:10.1016/j.enbuild.2021.111532

Sobha Residence (2023). *Creek Vistas by Sobha at MBR city, Dubai*. Available from https://sobha-residences.ae/creek-vistas.php.

Steinemann, A., Wargocki, P., and Rismanchi, B. (2017). Ten questions concerning green buildings and indoor air quality. *Build. Environ.* 112, 351–358. doi:10.1016/j.buildenv.2016.11.010

Szabados, M., Csákó, Z., Kotlík, B., Kazmarová, H., Kozajda, A., Jutraz, A., et al. (2021). Indoor air quality and the associated health risk in primary school buildings in Central Europe–The InAirQ study. *Indoor air* 31 (4), 989–1003. doi:10.1111/ina.12802

Tan, H., Wong, K. Y., Othman, M. H. D., Kek, H. Y., Nyakuma, B. B., Ho, W. S., et al. (2023). Why do ventilation strategies matter in controlling infectious airborne particles? A comprehensive numerical analysis in isolation ward. *Build. Environ.* 231, 110048. doi:10.1016/j.buildenv.2023.110048

World Health Organization (2010). *Guidelines for indoor air quality: selected pollutants*. Denmark: WHO Regional Office for Europe.

Xue, K., Cao, G., Liu, M., Zhang, Y., Pedersen, C., Mathisen, H. M., et al. (2020). Experimental study on the effect of exhaust airflows on the surgical environment in an operating room with mixing ventilation. *J. Build. Eng.* 32, 101837. doi:10.1016/j.jobe.2020.101837

Yin, H., Liu, C., Zhang, L., Li, A., and Ma, Z. (2019). Measurement and evaluation of indoor air quality in naturally ventilated residential buildings. *Indoor Built Environ.* 28 (10), 1307–1323. doi:10.1177/1420326x19833118

Zhang, Y., Li, J., Liu, M., Liu, J., and Wang, C. (2020). Experimental investigation of large-scale flow structures in an aircraft cabin mock-up. *Build. Environ.* 184, 107224. doi:10.1016/j.buildenv.2020.107224

Zhao, Y., Sun, H., and Tu, D. (2018). Effect of mechanical ventilation and natural ventilation on indoor climates in Urumqi residential buildings. *Build. Environ.* 144, 108–118. doi:10.1016/j.buildenv.2018.08.021

Zhao, Y., Tao, P., Zhang, B., and Huan, C. (2020). Contribution of Chinese hot pot and barbecue restaurants on indoor environmental parameters. *Aerosol Air Qual. Res.* 20 (12), 2920–2940. doi:10.4209/aaqr.2020.04.0141

Zhong, X., Wu, W., and Ridley, I. A. (2020). Assessing the energy and indoor-PM2. 5-exposure impacts of control strategies for residential energy recovery ventilators. *J. Build. Eng.* 29, 101137. doi:10.1016/j.jobe.2019.101137