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Evaluating the adsorption performance of functional building material with HCHO remover

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Dubai Municipality is making significant efforts to reduce the concentration of chemical substances in major buildings *via* Green Building Regulations & Specifications. However, it has limitations to the problem because it simply regulates the indoor air concentration of some harmful substances from building materials. The functional building materials capable of adsorbing and decomposing indoor pollutants such as Formaldehyde (HCHO) and Volatile Organic Compounds (VOCs) are gradually spreading. This paper aims to evaluate the performance of functional building materials and analyze the effect of improving the indoor air environment. As a methodology, the investigation was done to research trends and standards for functional building standards. 20 L small chamber experiment was performed for wallpaper with 0%, 5%, 7%, 10%, and 15% of the ethylene urea ($C_5H_{10}N_2O_3$), HCHO remover. The result showed standard wallpaper's adsorption rate on the seventh day was 6.21%. The formaldehyde remover adsorption rate for 7 days was 50.43% when formaldehyde remover was added at a 5 wt% (weight percentage); 60.21% when it was added at 7 wt%; 63.45% when it was added at 10 wt%; and 73.58% when it was added at 15 wt%. The adsorption rate on the seventh day with 7 wt%, 10 wt%, and 15 wt% HCHO remover showed a 60% or more (IS O 16000-24 standard). However, wallpaper with 15 wt%, displayed the highest value, was 5.736 μg/m^2, which did not satisfy the IS O 16000-24 standard (6.000 μg/m^2). It was statistically proven when the amount of the HCHO remover is increased; the adsorption performance is improved in proportion to the amount added. This study will serve as primary data to prepare UAE standards for the functional building materials with adsorption and decomposition performance of harmful chemicals, moisture absorption and moisture-proof performance, and antibacterial/anti-fungal performance.

KEYWORDS

indoor air quality, formaldehyde (HCHO), HCHO remover, eco-friendly functional building material, HCHO adsorption

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1 Introduction

Dubai residents in the United Arab Emirates spend more than 90% of their time indoors due to hot arid desert weather (Jung and Awad, 2021a). Interest in Indoor Air Quality (IAQ) is significantly increasing in residential buildings since Sick Building Syndrome (SBS) has been highlighted in UAE (Awad and Jung, 2021a; Jung and Awad, 2021b). According to the analysis of the survey results released by Dubai Municipality in 2013, 29.8% of the respondents had experienced SBS (Jung and Al Qassimi, 2022). It was surveyed that about 7.5% of all residents had ever been to the hospital due to SBS (Arar and Jung, 2021). According to the 2019 UAE National Air Emissions Inventory Project by the Ministry of Climate Change and Environment, 93.5% of residents consider indoor air quality in their housing very important, and 42.9% of respondents were willing to invest up to 100–2,000 AED to improve indoor air quality (The Khaleej Times, 2013). It has been shown that the expert group and the public are very interested in IAQ (Nationals, 2013). Improving the indoor air environment in residential spaces is one of the most critical problems in Dubai (Al Qassimi and Jung, 2021). Factors affecting these indoor air environment problems include harmful chemicals such as formaldehyde (HCHO) and Volatile Organic Compounds (VOCs) such as Benzene (C_6H_6), Toluene (C_7H_8), Ethylbenzene (C_8H_{10}), Xylene (C_8H_{10}), and Styrene (C_8H_8), emitted from building materials, furniture, home appliances, and indoor household items, airborne bacteria, fungus, and viruses (Arar et al., 2021; Jung and Awad, 2021c). In addition, the causes are very diverse, such as problems with buildings and mechanical facilities, such as a decrease in the opening area due to the high-rise of a residential building, and a lack of ventilation due to high insulation and high airtightness for energy saving of buildings (Ai et al., 2015; Awad and Jung, 2021b).

The use of indoor building materials that emit harmful substances is one of the most influential factors among the various causes that affect indoor air quality deterioration and indoor air environment problems (Tham, 2016). In new buildings, the release of harmful chemicals to the human body such as HCHO and VOCs emitted from adhesives, paints, flooring, and wooden boards used as interior and finishing materials threaten human health. Research to solve and identify these hazards is actively conducted (Jiang et al., 2017).

Meanwhile, Dubai Municipality is making significant efforts to reduce the concentration of chemical substances in major buildings *via* Green Building Regulations & Specifications (Municipality Dubai, 2018). However, it has limitations as a fundamental solution to the problem because it simply regulates the indoor air concentration of some harmful substances generated from building materials (Steinemann et al., 2017). As one of several methods to solve this problem, functional building materials capable of adsorbing and decomposing indoor pollutants such as HCHO and VOCs are gradually spreading (Huangfu et al., 2020). Unlike eco-friendly building materials that emit fewer pollutants, functional building materials can objectively verify the specific performance inherent in building materials (Ratera and Veciana, 2012). This refers to building materials that have been proven effective in improving the indoor air environment. Functional building materials include moisture absorptive performance that can adequately control indoor humidity, adsorption, decomposition of harmful chemicals, deodorization, and antibacterial and antifungal performance (Yan, 2013). However, according to a survey by Dubai Municipality, some functional building materials in circulation do not have the effect of adsorbing pollutants (Municipality Dubai, 2020). The average adsorption rate of HCHO was investigated to be less than 40%, so the evaluation of the indoor air environment improvement function of the raw material itself added to these products is insufficient (Lu et al., 2010; Lin et al., 2020).

Considering the health and safety of residents and activating the application of materials with excellent performance and function, this paper aims to evaluate the performance of functional building materials and analyze the effect of improving the indoor air environment (Bribián et al., 2011). In addition, there is an increasing need to prove the objective effect of functional building materials by deriving an accurate performance evaluation method for functional building materials that can be produced, commercialized, and put to practical use from the manufacturing process of functional building materials (Sawada and Serizawa, 2018).

In this study, wallpaper, which occupies the most significant indoor area among interior finishing materials and has the most excellent applicability to actual sites, was mainly targeted. HCHO adsorption performance was evaluated by making functional wallpaper containing HCHO remover using ethylene urea ($C_5H_{10}N_2O_3$) material (Jin et al., 2017).

The research method is summarized as follows. First, investigate and analyze research trends and standards for functional building materials and related standards. Second, prepare five samples by adding 0% (no additive), 5%, 7%, 10%, and 15% of the $C_5H_{10}N_2O_3$ remover made of ethylene urea to the weight of the binder, respectively (Hematabadi et al., 2012). Third, by constructing an HCHO adsorption test system using a 20 L small chamber, changes in HCHO concentration over time by the prepared wallpaper samples are collected and analyzed. Fourth, evaluate the adsorption performance of functional wallpaper by calculating the HCHO adsorption rate, adsorption rate, ventilation rate conversion value, and accumulated adsorption amount, respectively (Shim and Choi, 2017).

2 Materials and methods

2.1 UAE functional materials status

A total of 153 products, including 117 available materials, 34 paints, and 2 adhesives, are currently distributed in the UAE from 88 companies (University, 2022). The product's primary

TABLE 1 Current Status of Functional Building Materials distributed in UAE.

Classification	Number of companies	Number of products	Functions					
			Moisture absorptive	Pollutants Absorptive	Antibacterial Antifungal	Far-infrared radiation	Negative ion emission	Deodorization
Imported	84	142	54	45	94	72	48	58
UAE	4	11	9	3	2	1	2	3
Total	88	153	63	48	96	73	50	61

functions are indoor humidity control, pollutant adsorption, antibacterial and antifungal, far-infrared radiation, negative ion emission, and deodorization (Chen et al., 2012). Table 1 summarizes the status of functional building materials distributed in the UAE by function.

UAE building material manufacturers develop functional materials that mix natural materials such as loess, charcoal, and diatomaceous earth (Municipality Dubai, 2021). However, the evaluation of pollutant adsorption and moisture absorption and the moisture-proof performance of these raw materials is insufficient (Zou et al., 2021). Although the development and distribution of functional building materials commonly used to improve indoor air quality have increased significantly, these building materials' objective effects, evaluation methods, and standards have not been established (Lan et al., 2021). In the case of some products, exaggerated advertisements about the adsorption performance of the product are being made, increasing consumer confusion. Some of the products in circulation did not have the effect of adsorbing chemically harmful pollutants (Kim et al., 2011). In particular, in the case of HCHO, the average adsorption rate was found to be less than 40% (Kibanova et al., 2012).

2.2 Previous research for functional material

2.2.1 Building materials

Belakroum et al. (2017) investigated changes in moisture content by experimenting with loess, wood, mortar, and charcoal to confirm the moisture absorption/desorption ability of eco-friendly and functional materials and then investigated the effect on indoor humidity control (Belakroum et al., 2018). Currently, building materials mixed with natural materials such as loess, charcoal, and diatomaceous earth are being developed in the UAE. Still, scientific evidence of the effect of improving the indoor air quality of these materials was reported to be insufficient (Belakroum et al., 2017).

Suresh and Bandosz (2018) developed a functional gypsum board that can reduce the concentration by adsorbing and decomposing HCHO in the indoor air and verified its performance through a real test (Suresh and Bandosz, 2018). As a result of the study, the developed functional gypsum board dropped to the lowest concentration level after 10 days (Blondeau et al., 2014). It showed a relatively significant decrease compared to the general gypsum board. It was found that silk wallpaper with low air permeability harmed the HCHO decomposition and adsorption performance of functional gypsum boards (Yu and Kim, 2013).

2.2.2 Measurements of previous studies

Vikrant et al. (2019) measured and analyzed the adsorption performance of HCHO and volatile organic compounds for functional building materials with pollutant adsorption and decomposition performance (Vikrant et al., 2019). The adsorption performance of samples was measured using the adsorption chamber system for ceiling and wall materials made of mineral fiber, loess soil, and charcoal (Zhou et al., 2020). As a result of the measurement, even if the adsorption performance is excellent, if re-release occurs, it cannot be called a building material with adsorption function, so it is suggested that re-release should be considered necessary.

Na et al. (2019) conducted an adsorption performance test focusing on HCHO on four types of functional building materials in the domestic market. As a result, all of the building materials tested showed an adsorption rate of 65% or more, higher than the excellent grade (60% or more) (Lubis et al., 2019).

2.2.3 Evaluation of previous studies

Recently, research on material evaluation for the development of functional materials has been actively conducted. Zhang et al. (2019) evaluated and verified the adsorption performance of BTEXS materials, including total volatile organic compounds (TVOC), using three types of porous natural minerals: diatomaceous earth, zeolite, and volcanic ash for the development of functional building

TABLE 2 Global Specifications related to performance evaluation of building materials.

Target measurement	Standard	Standard name
HCHO Adsorption	ISO 16000-23: 2009 (Global)	- Performance test for evaluating the reduction of HCHO - Concentrations by absorptive building materials
VOCs Adsorption	ISO 16000-24: 2009 (Global)	- Performance test for evaluating the reduction of VOCs - Carbonyl compounds without HCHO-concentrations by absorptive building materials
VOCs Adsorption	JIS A 1906: 2008 (Japan)	- Performance test of absorptive building materials to reduce indoor air pollution with Small Chamber Measurement of adsorption flux by supplying a constant concentration of contaminant air of VOCs and aldehydes without HCHO
HCHO Adsorption	JIS A 1905-1: 2007 (Japan)	- Performance test of absorptive building materials to reduce indoor air pollution with Small Chamber - Part 1: Measurement of adsorption flux with supplying constant concentration of HCHO
VOCs & Aldehyde Adsorption	KS I 3546: 2012 (South Korea)	- Evaluation method for VOCs and aldehyde reduction performance of pollutant-reducing building materials - Solid construction materials
VOCs & Aldehyde Adsorption	KS I 3547: 2012 (South Korea)	- Evaluation method for VOCs and aldehyde reduction performance of pollutant-reducing building materials - Liquid construction materials

materials. It was confirmed that there is a limit to the adsorption performance using only raw materials.

Nor et al. (2013) confirmed the excellent effect of improving the pollutant removal performance when metal oxides such as copper nitrate are impregnated with natural materials through a study on toluene removal using copper oxide-impregnated volcanic ash. It was also predicted that developing functional building materials using minerals through material modification would be necessary (Hua et al., 2012).

In another study, Park et al. (2015) used CFD analysis to examine the effect of reducing the concentration of contaminants of adsorbed building materials in office spaces. They confirmed that adsorbed building materials removed some toluene (Park et al., 2015; Nakahara et al., 2020).

2.3 Standards and specifications related to functional material

In major advanced countries, evaluating the amount of pollutant emission has been standardized to manage pollutants in building materials (Du and Li, 2020). According to the pollutant emission characteristics and materials to be assessed, the standards shown in Table 2 have been established. In addition, standards for evaluating the functionality of materials are prepared, and evaluation methods for moisture absorption and moisture-proof function and adsorption function have been developed (Wu et al., 2015).

Currently, the adsorption performance evaluation method of functional building materials is JIS A 1905-11, JIS A 1905-21 of Japan (SAI Global, 2015) (Test method for reducing indoor air pollution source of adsorption building materials by the small chamber method—Part 1, Part 2 February 2007) was enacted. In 2008, JIS A 1961 was passed to target substances from HCHO to volatile organic compounds and other aldehydes (Huang et al., 2019). In addition, ISO 16000-23, an HCHO adsorption performance evaluation standard based on JIS A 1905-1 and JIS A 1906, and ISO 16000-24, a volatile organic compound adsorption performance evaluation standard, were established in March 2008 as DIS status (Chang et al., 2015). It was later adopted as an international standard in December 2009 (Yu and Crump, 2011). In Korea, in 2012, the VOCs and aldehyde reduction performance evaluation method of pollutant-reducing building materials was established as the KS standard (Zheng et al., 2011).

2.4 Production of functional wallpaper with HCHO remover

In this study, an HCHO remover was added to the wallpaper manufacturing process, and the removal performance was evaluated according to the amount added (Figure 1) (Ghani et al., 2018). HCHO remover was prepared by mixing 35 wt% of Urea with 2 wt% of glycol to reduce viscosity and water (Jeon et al., 2020). Ethylene urea has the property of removing HCHO through a condensation reaction, so it is widely used as an HCHO remover (Wi et al., 2020). Urea (H_2NCONH_2) and HCHO produce monomethyl urea ($H_2NCONHCH_2OH$) by N-methylenation reaction as in Eq. 1. HCHO is decomposed as in Eq. 2 by the condensation reaction between the produced monomethyl urea and urea (Chen et al., 2017).

$$H_2NCONH_2 + HCHO \rightarrow H_2NCONHCH_2OH \quad (1)$$

$$H_2NCONHCH_2OH + H_2NCONH_2 \rightarrow H_2NCONHCH_2NHCONH_2 + H_2O \quad (2)$$

In this study, five types of wallpaper were produced by adding 0%, 5%, 7%, 10%, and 15% of the HCHO remover to the weight of the binder used for wallpaper production, respectively, to

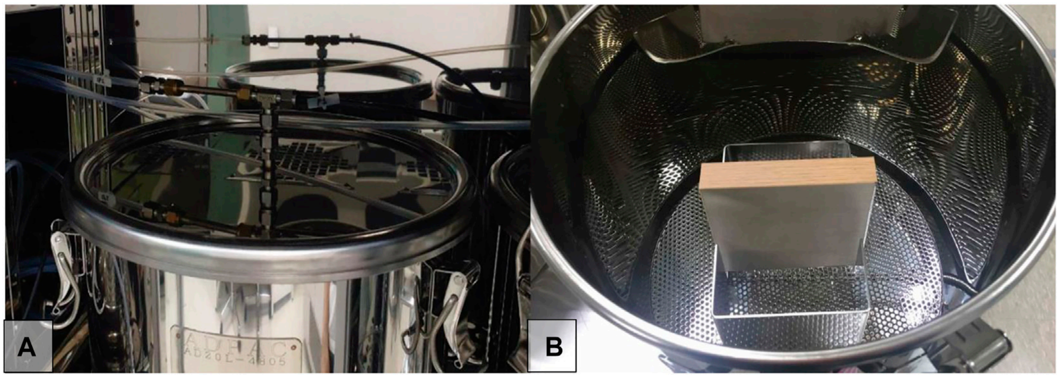

FIGURE 1
(A) 20 L Small Chamber when closed during the experiment and **(B)** Inside the 20 L Small Chamber showing the Wallpaper Sample.

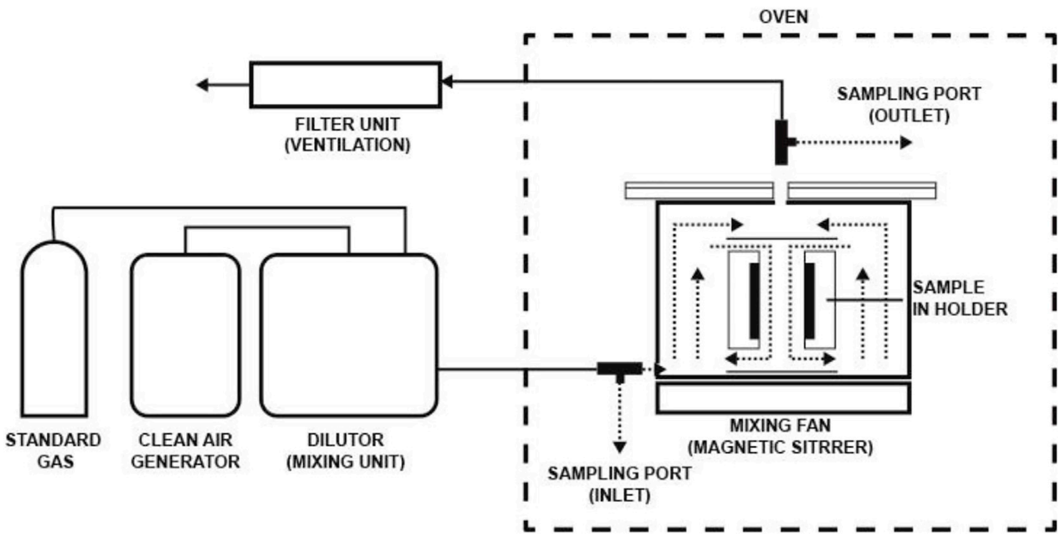

FIGURE 2
Diagram of HCHO adsorption test with 20 L small chamber.

comparatively analyze and confirm the adsorption performance of HCHO (Yue et al., 2021).

2.5 Measurement method

To evaluate the HCHO adsorption performance of functional wallpaper to which HCHO adsorbent is added, in the measurement method, ISO/DIS 16000-23, JIS 1905-1, JIS A1905-2, and JIS A 1906 (Table 2), the construction of the measurement system and the measurement plan were established and performed (Tiwari et al., 2017).

The flow rate of the 20 L small chamber was controlled to 167,000 μl/min using a mass flow controller (MFC) so that the measurement conditions in the chamber were maintained so that the ventilation rate was 0.5 times/h (Kim et al., 2010). The temperature was measured at 25°C ± 1°C and relative humidity (RH) at 50% ± 3%. HCHO gas having a concentration of 60 ppm was diluted using a pure air generator and then supplied into a small chamber (Figure 1). The feed concentration was 210 μg/m^3 (±10%). Figure 2 shows the composition of the measurement sample and the 20 L small chamber where the piece is installed, and the overall measurement system (An et al., 2010).

TABLE 3 The specification of high-performance liquid chromatography (HPLC).

Auto sampler	Model 410 (automix sample preparation, VARIAN)
Detector	Model 325 (UV/vis 360 nm,VARIAN)
Gradient pump	Prostar 230 (flow range 0.01–10 ml/min, Prostar)
Column	C18 column (250 mm × 4.6 mm, Omnispher 5)
Adsorption tube	Ozone Scrubber (WAT054420, Water)
	LP-DNPH (21014, Supelco)

TABLE 4 High-performance liquid chromatography (HPLC) HCHO analysis conditions.

HCHO analysis items	Conditions
Detector	UV/vis, 360 nm
Column	Omnispher 5 C18 Column (250 mm × 4.6 mm)
Mobile phase	ACN/Water (60/40 V/V)
Analysis time	20 min
Injection volume	20 µl
Column temperature	25°C
Flow rate	1.0 ml/min

The HCHO adsorption performance test was conducted for 10 days, and HCHO gas was supplied to the small chamber for 7 days after sample input (Lee and Kim, 2012). Samples were collected on days 1, 3, 5, and 7 using a DNPH-cartridge. The sampling capacity was 5 L (using two sides wallpapers sheets of 7.5 cm × 12 cm on a gypsum board of 6.35 mm) for 38 min at 133.000 µl/min (Park et al., 2011). The collected samples were analyzed using High-Performance Liquid Chromatography (HPLC). The specifications of HPLC used in the study (Table 3) and primary analysis conditions (Table 4) are as follows.

2.6 Calculation of adsorption rate, adsorption speed, ventilation rate conversion value, and integrated adsorption amount

The sample's adsorption rate and cumulative adsorption amount were calculated using the analyzed inlet and outlet concentrations of the 20 L small chamber. The formula for calculating the adsorption rate is (Eq. 3) (Zhu et al., 2019).

$$Absorption\ Rate = \frac{(C_{e,t} - C_{out,t})}{C_{e,t}} \times 100 \qquad (3)$$

$C_{e,t}$: Chamber Inlet Concentration ($\mu g/m^3$).$C_{out,t}$: Chamber Outlet Concentration ($\mu g/m^3$).

The pollutant adsorption rate (F) indicates the mass of the target material adsorbed per unit for a specified time from the start of the test. It is calculated as follows by the concentration difference between the inlet and outlet of the chamber, the chamber ventilation Q_c, and the surface area A of the sample (Eq. 4) (Zhang et al., 2021).

$$F = \frac{(C_{e,t} - C_{out,\,t}) \times Q_c}{A} \qquad (4)$$

F: Contaminant adsorption rate per unit time and area ($\mu g/m^2h$).Q_c: Amount of Chamber Ventilation (m^3/h).A: Surface area of the sample (m^2).

The sample's ventilation amount conversion value (Qeq) is converted into the ventilation amount by the amount of clean air introduced to achieve the same effect as the concentration reduction effect of building materials (Zhu et al., 2022). It is calculated as in Equation 5, and it means that it is constant regardless of the concentration of contaminants under the assumption that the surface concentration of the sample is 0 (Zong et al., 2021).

$$Q_{eq} = \frac{\left(\frac{C_{e,t}}{C_{out,t}} - 1\right) \times Q_c}{A} \qquad (5)$$

Q_{eq}: Adsorption performance sample ventilation rate conversion value (m^3/m^2h).

The accumulated adsorption amount S_c was calculated by the ventilation amount Q_c of the chamber and the standard gas supply time T_e (h) (Chen et al., 2022).

$$S_c = \sum_i (F_i \times \Delta T_{e,i}),\ (\Delta T_{e,i} = T_{e,i} - T_{e,i-1}) \qquad (6)$$

S_c: Accumulated adsorption amount ($\mu g/m^3$).*Te: Standard gas supply time* (h).

3 Results

To evaluate the HCHO adsorption performance of functional wallpaper, the adsorption performance was assessed for 7 days by comparing standard wallpaper without HCHO remover, and four types of functional wallpaper with different amounts of remover added. As evaluation items for quantitative comparison, HCHO concentration at the inlet/outlet for each sample, adsorption rate, ventilation rate conversion value, cumulative adsorption amount, and adsorption rate were selected and compared. Table 5 summarizes the adsorption rate, ventilation rate conversion value, accumulated adsorption amount, and adsorption rate according to the amount of HCHO remover added.

Figure 3 shows the results of the HCHO adsorption experiment for standard wallpaper with the addition of formaldehyde remover at 0 wt%. The traditional wallpaper

TABLE 5 Adsorption performance measurement result according to the amount of HCHO remover.

Addition Amount	Days	Adsorption rate ($\mu g/m^2h$)	Ventilation conversion (m^3/m^2h)	Accumulated adsorption amount ($\mu g/m^2$)	Adsorption rate (%)
0 wt%	1	7.04	0.038	1,006	15.92
	3	8.94	0.048		18.96
	5	5.85	0.031		12.91
	7	2.68	0.014		6.22
5 wt%	1	28.82	0.390	4,310	65.41
	3	28.24	0.378		64.68
	5	24.48	0.278		57.48
	7	22.64	0.210		50.42
7 wt%	1	32.72	0.524	4,856	71.82
	3	29.74	0.404		66.24
	5	28.80	0.378		64.72
	7	26.28	0.312		60.22
10 wt%	1	33.12	0.588	5,044	74.14
	3	29.72	0.440		68.12
	5	30.62	0.402		66.02
	7	28.08	0.356		62.45
15 wt%	1	37.02	0.746	5,738	78.42
	3	35.22	0.716		76.70
	5	33.16	0.680		76.74
	7	32.56	0.576		73.56

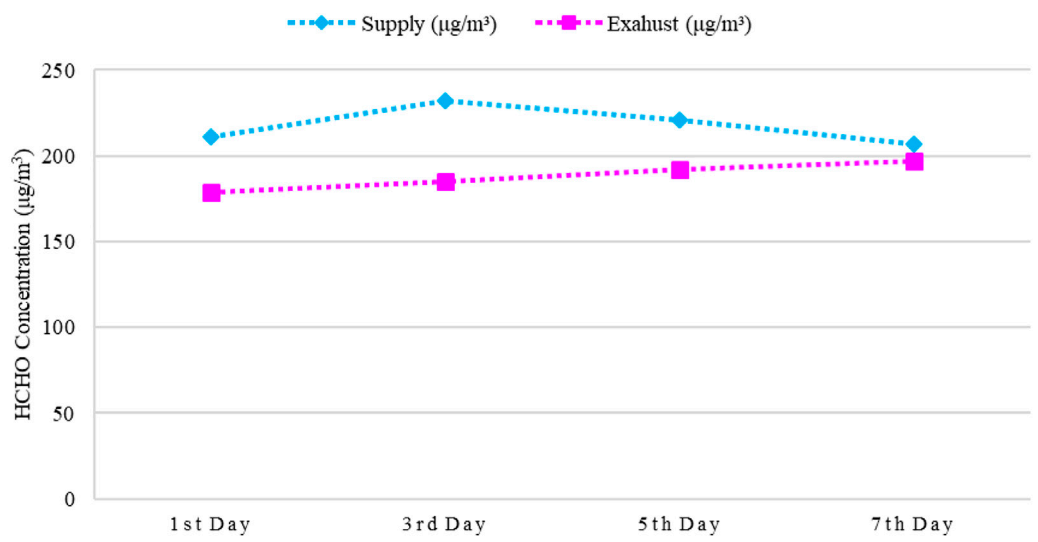

FIGURE 3
HCHO Adsorption Test Result (Normal wallpaper with 0 wt%).

without adding HCHO remover showed an adsorption rate of 15.93%, with a supply concentration of 214.74 $\mu g/m^3$ on the first day and an outlet concentration of 180.54 $\mu g/m^3$ on the first day. On the third day, it slightly increased to 18.94%. After that, the outlet concentration increased, and the adsorption rate decreased, showing an adsorption rate of 6.21% on the seventh day.

Figure 4 shows the results of the HCHO adsorption experiment with 5 wt% added wallpaper. When 5 wt% of HCHO remover was added, the first day supply concentration was 213.74 $\mu g/m^3$, and the outlet concentration was 73.93 $\mu g/m^3$, showing the highest adsorption rate of 65.41%. As time passed, the reduction rate of HCHO concentration decreased, showing an adsorption rate of 50.43% on the seventh day. The adsorption

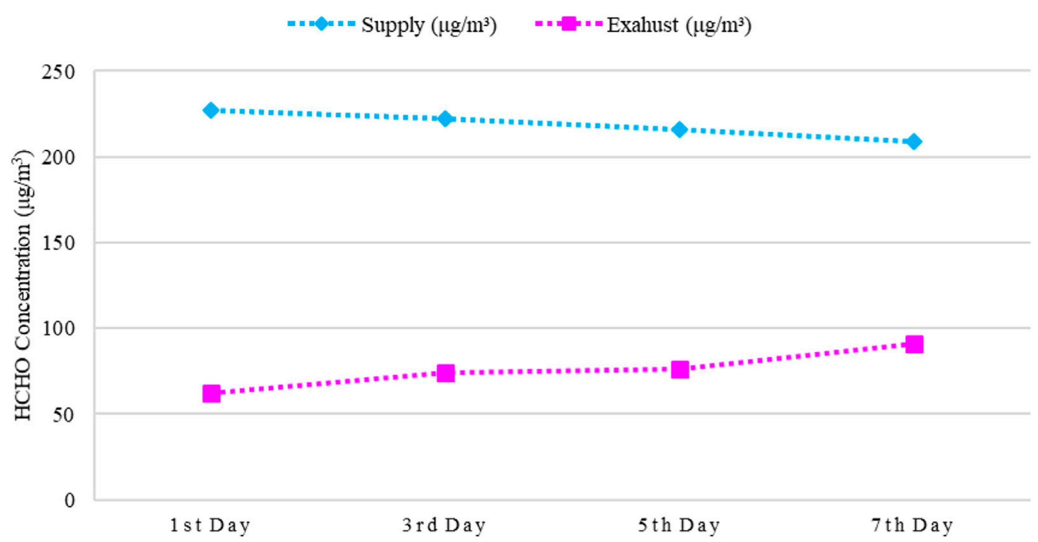

FIGURE 4
HCHO Adsorption Test Result (Normal wallpaper with 5 wt%).

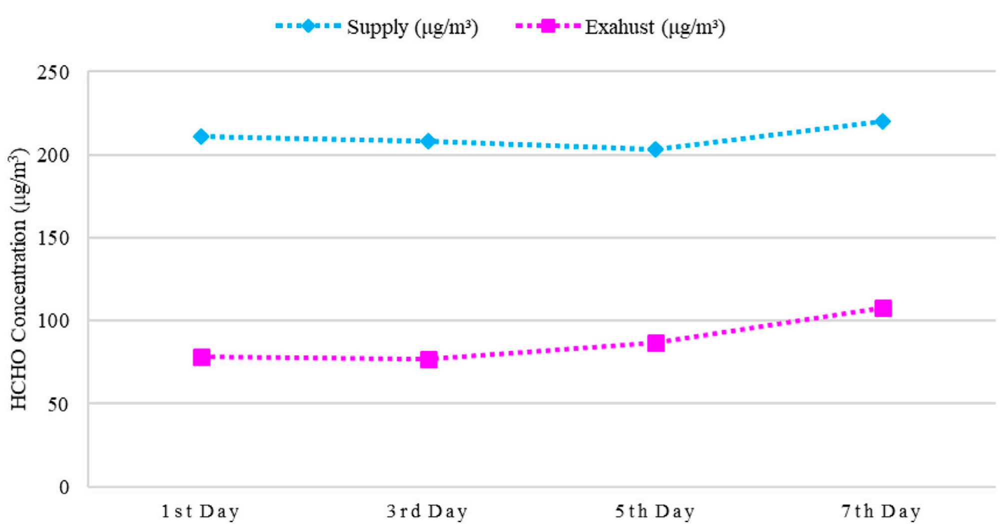

FIGURE 5
HCHO Adsorption Test Result (Normal wallpaper with 7wt%).

rate also reduced from the fifth day, and it was found that the HCHO removal performance gradually decreased. The cumulative adsorption amount for 7 days during the measurement period was 4.310 μg/m^2, which did not reach ISO 16000-24 standard for both the adsorption rate and the cumulative adsorption amount.

Figure 5 shows the HCHO adsorption experiment of 7wt% added wallpaper. The first day outlet concentration of wallpaper with 7wt% added was 62.28 μg/m^3, which showed an adsorption rate of 71.81% compared to the supply concentration of 220.92 μg/m^3. It showed an HCHO removal efficiency of 60.21%. The adsorption rate of 60.21% on the seventh day corresponds to a good grade of 60% or more, but the cumulative adsorption amount was 4.857 μg/m^2, which was lower than the ISO 16000-24 standard.

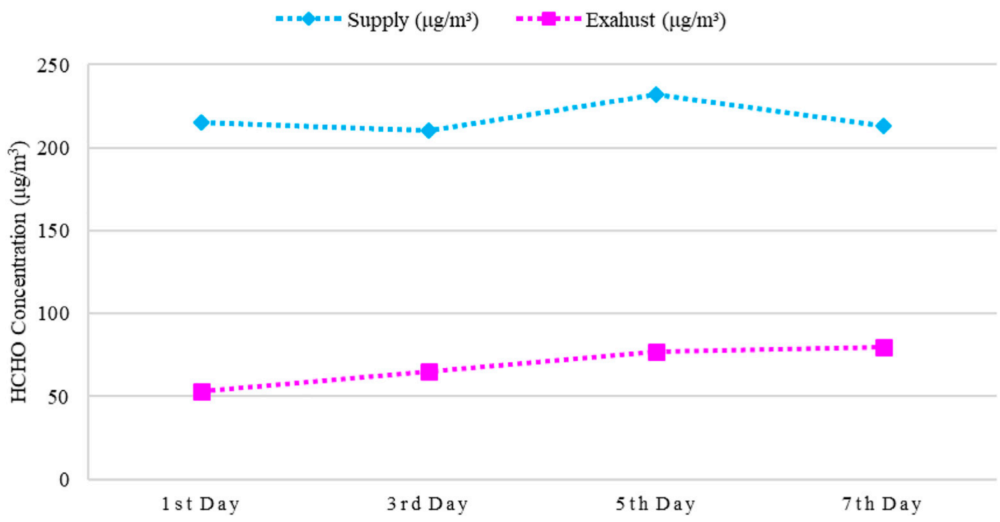

FIGURE 6
HCHO Adsorption Test Result (Normal wallpaper with 10 wt%).

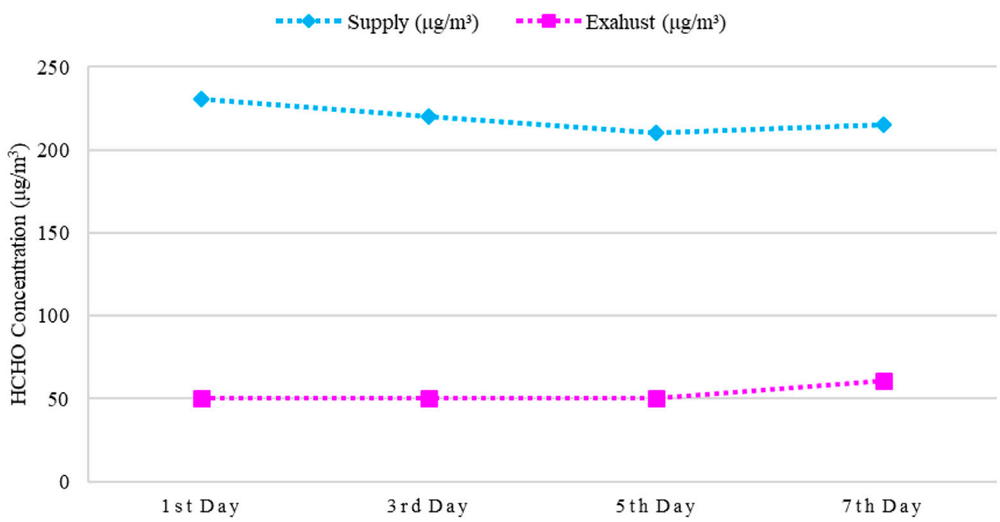

FIGURE 7
HCHO Adsorption Test Result (Normal wallpaper with 15 wt%).

As shown in Figure 6, the results of the adsorption test of wallpaper to which 10 wt% of HCHO remover was added showed an adsorption rate of 74.12% with an inlet concentration of 216.81 μg/m^3 and an outlet concentration of 56.12 μg/m^3 on the first day. The outlet concentration gradually increased, showing a formaldehyde adsorption rate of 63.45% on the seventh day. In the case of wallpaper with 10 wt% added, the adsorption rate was more than the ISO 16000-24 standard of 60%, but the cumulative adsorption amount was 5.042 μg/m^2, which fell short of the standard.

Figure 7 shows the results of the HCHO adsorption experiment of 15wt% added wallpaper. When 15 wt% was added, the adsorption rate was 78.40%, with an outlet concentration of 49.49 μg/m^3 on the first day. After that, on the seventh day, the adsorption rate was 73.58%, showing an adsorption rate of 70% during the test period, indicating a relatively small decrease in the adsorption rate compared to wallpaper to which a removal agent of another weight ratio was added. However, even in the case of wallpaper to which 15 wt% of HCHO remover was added, it was only applicable to the ISO 16000-24 standard of 60% or more and did not reach the ISO 16000-24 excellent grade of 85%. The accumulated adsorption amount was 5.736 μg/m^2, which did not meet the superb grade standard. There was no significant difference with the wallpaper to which 10 wt% of HCHO remover was added.

As a result of measuring the HCHO adsorption performance of five types of wallpaper prepared according to the conditions for adding the HCHO remover, the adsorption performance increased proportionally as the HCHO remover added increased. When the addition amount of the remover was 7% or more relative to the binder mass, the adsorption rate on the seventh day was 60% or more, which corresponds to the ISO 16000-24 standard. In the case of the accumulated adsorption amount, the maximum of 5.736 μg/m^2 for wallpaper with 15 wt% of HCHO remover added the most was lower than the ISO 16000-24 standard of 6.000 μg/m^2.

4 Discussion

Until now, UAE standards have focused only on the health aspects of domestic building materials that emit less harmful chemicals. However, in Japan and Korea, the government revised the construction of eco-friendly functional building materials, which was recommended in JIS A 1905/1906 and KS I 3546/3547, into a mandatory requirement in 2013 (Shim et al., 2019).

In the UAE, Dubai Municipality is working to improve the IAQ by preparing indoor air quality standards to protect the health and safety of residents from environmental diseases such as SBS and atopy (Business (2022), 2022). Therefore, it is necessary to prepare standards for the functional aspects of building materials such as adsorption and decomposition performance of harmful chemicals, moisture absorption, moisture-proof performance, and antibacterial/anti-fungal performance to activate the application of eco-friendly functional building materials with excellent performance and function.

Further studies are needed regarding more interior finishes materials, especially the ones in popular usage, including full-scale experiments to give precise data for the preparation of the UAE's IAQ indoor air quality standards to protect the health and safety of its residents.

5 Conclusion

In this study, to improve the HCHO adsorption performance of wallpaper, which has a relatively large indoor area among functional materials, in UAE, and has the most significant practical applicability, five samples were prepared by adding an HCHO remover made of ethylene urea material, and the adsorption performance was evaluated. Worth mentioning that the wallpaper quality used in UAE is considered from the high-quality types in terms of durability. Additionally, UAE's users may change their mood frequently (6 months to 1-year range) and therefore wallpapers are the best choice (Business (2022), 2022).

Functional wallpaper with HCHO remover added demonstrated HCHO removal effectiveness over a specified threshold, as opposed to conventional wallpaper. In the case of standard wallpaper, the adsorption rate on the seventh day was 6.21%, and the HCHO removal performance showed a difference in the adsorption rate and the cumulative adsorption amount according to the amount of the remover added. When the adsorption rate on the seventh day was compared, 5 wt% added resulted in 50.43%, 7 wt% in 60.21%, 10 wt% in 63.45%, and 15 wt% in 73.58%. The adsorption rate grade according to the ISO 16000-24 standard showed an excellent grade level of 60% or more when 7 wt%, 10 wt%, and 15 wt% were added based on the seventh day result. Therefore, the experiment was stopped on day 7, although it is recommended in the UNE 16000-9 are 28 days.

The cumulative adsorption amount also increased as the HCHO remover added increased. However, wallpaper added with 15 wt%, which showed the highest value, was 5.736 μg/m^2, which did not satisfy the excellent grade of 6.000 μg/m^2 of the ISO 16000-24 standard. The 15 wt% added wallpaper helps the superb quality with an adsorption rate of 70% or more, but the cumulative adsorption amount did not meet the standard.

When the amount of the HCHO remover is increased, the adsorption performance is judged to be improved in proportion to the amount added. It is believed that as the amount of additives other than binders used in the wallpaper process increases, the basic physical properties of the wallpaper may be weakened in proportion to this.

In addition, although a relatively large amount of 15% of the total binder mass was added, the results did not reach a good grade. Accordingly, it is judged that research on the development of functional materials with improved HCHO removal performance using various materials and the study of changes in the physical properties of wallpaper according to the number of additives in the wallpaper manufacturing process should be carried out together.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

All authors contributed significantly to this study. CJ and GE, NA and GE identified and secured the example buildings used in the study. The data acquisition system and installation of sensors were designed and installed by CJ and NA. NA and GE was responsible for data collection. CJ and NA performed data analysis. The manuscript was compiled by CJ and GE and reviewed by NA. All authors have read and agreed to the published version of the manuscript.

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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.

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