Nakhara: Journal of Environmental Design and Planning (2022)
Volume 21(1), Article 205
DOI: https://doi.org/10.54028/NJ202221205
Article Type: Research Article

A Comparative Study of TVOC and HCHO Emissions From Various Multilayer Built-in Furniture Components Based on ISO 16000-9:2006 Emission Test Chamber Methods

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Received 2021-07-31; Revised 2022-06-02; Accepted 2022-06-08

ABSTRACT

Multilayer materials of built-in furniture components emit volatile organic compounds (VOCs) into the indoor environment. Although many green building rating systems have set criteria for indoor environments, typical buildings in Thailand have not implemented these requirements, especially for local furniture. This study aimed to identify the magnitude of VOC emissions and the relationships between these VOC emissions and inner structures, finishing techniques used for built-in components, and the cost of interior built-in furniture built by local contractors. A total of 33 specimens of built-in components normally found in Thailand were prepared and wrapped in plastic before being transported to the test facility. The total volatile organic compound (TVOC) and formaldehyde (HCHO) emission rates were measured using emission test chambers, as per the ISO 16000-9 standard, with a size of 0.21 m^3, at a temperature of 23 °C, a relative humidity of 45%, an air exchange rate of 0.5 ACH, and a loading factor of 0.42 m^2m^{-3}. The measurements were conducted 3 days and 28 days after the specimens were unwrapped. It was found that specimens finished with coating techniques had the highest TVOC and HCHO emission rates, while those with single-layer materials that used covering techniques had the lowest TVOC and HCHO emission rates. The covering techniques were found to be cheaper but less durable than coating techniques. All specimens exhibited high emission concentrations in the chambers (i.e., more than the standard limit) even after 28 days. This should help raise awareness of the importance of selecting built-in furniture based on finishing techniques that make use of low-VOC materials, which are available on the market and provide better indoor air quality.

Keywords: ISO 16000-9, indoor air quality, volatile organic compounds, emission test chamber, multilayer built-in furniture

INTRODUCTION

Sustainable architecture design practice involves reducing energy and resources used while maximizing building occupant comfort and productivity. Most people spend a considerable amount of time indoors (Klepeis et al., 2001). There have been growing concerns about indoor environments, especially indoor air quality, in recent years because they directly affect the building occupants' health and, consequently, productivity (Takaro et al., 2011). Many modern construction and decoration materials in buildings are sources of pollution, such as volatile organic compounds (VOCs) and particulate matter (PM). VOCs are carbon-based organic chemicals that can evaporate completely or to a large extent at room temperature. VOCs present in indoor air are mainly emitted by building materials, interior decorations, furniture, and occupant activities (Becerra et al., 2020; Chao & Chan, 2001; Edwards et al., 2001; Kozielska et al., 2020; Schlink et al., 2004; Zuraimi et al., 2004). Many VOCs irritate the respiratory system and can cause headaches and dizziness. At high concentrations, some VOCs are toxic, and long-term exposure to certain VOCs may lead to chronic diseases or cancer (World Health Organization, 2010). VOCs are released at a much higher rate in the first stage of decoration (Holøs et al., 2019). Pilot studies in newly decorated apartments and offices in Thailand have shown that the spaces often have extremely high VOC concentration levels, and occupants are forced to carry out their activities in such environments for weeks before the emissions decrease to acceptable levels. Even though green building rating systems (i.e., LEED or WELL) have set requirements for indoor air quality, such as thresholds for VOCs in indoor air, ongoing monitoring systems of indoor air, and VOC restrictions on products, these requirements have not been implemented widely in Thailand due to lack of awareness. There are no data available on the magnitude of VOC emissions from built-in furniture commonly installed in Thailand.

VOCs commonly found in certain building materials include formaldehyde (HCHO), decane, butoxyethanol, isopentane, limonene, styrene, xylenes, perchloroethylene, methylene, chloride, toluene, and vinyl chloride. In measuring indoor air quality, total volatile organic compounds (TVOCs) and HCHO are often measured. The U.S. Green Building Council (USGBC) set optional guidelines for TVOCs and HCHO that would allow building developers to sample indoor air to verify that the levels of TVOCs and HCHO are within guideline limits. Table 1 shows the guidelines regarding TVOCs and HCHO according to LEED and WELL standards (International WELL Building Institute, 2020; U.S. Green Building Council, 2016).

According to LEED and WELL, projects in the United States are required to comply with the CDPH standard method (2010) for the testing and evaluation of volatile organic chemical emissions from indoor sources using environmental chambers version 1.1. Projects outside the United States can use (1) the CDPH standard method (California Department of Public Health [CDPH], 2010); (2) the German AgBB testing and evaluation scheme (Committee for Health-related Evaluation of Building Products [AgBB], 2010); or (3) ISO 16000-9 (International Organization for Standardization [ISO], 2006a), ISO 16000-11 (International Organization for Standardization [ISO], 2006b), ISO 16000-3 (International Organization for Standardization [ISO], 2010), ISO 16000-6 (International Organization for Standardization [ISO], 2011). These standards specify sampling, storage of samples, preparation of test specimens, air sampling methods, emission chamber requirements, and calculation methods.

Interior decoration finishes and coatings can potentially reduce or increase VOC emissions (Kim et al., 2010). The combined backing structures also affect VOC emissions, depending on their VOC contents and surface characteristics. Materials with identical coverings but different backing layers emit VOCs at different rates (Kwok et al., 2003).

This research studied TVOC and HCHO emissions from built-in furniture typically found in Thailand. The research objectives were to quantify the magnitude of VOC and HCHO emissions from built-in furniture and to identify the effects of different backing materials. Two sets of 33 specimens were examined for their TVOC and HCHO emission rates 3 and 28 days after the specimens were unwrapped. The methodology was based on ISO 16000-3, ISO 16000-6, ISO 16000-9, and ISO 16000-11.

Table 1

Guidelines Regarding TVOCs and HCHO According to LEED and WELL Standards

Contaminants		LEED V4		WELL V2	
		Limit	Measurement method	Limit	Measurement method
Air in all spaces: contaminant concentration	HCHO	27 ppb	ISO 16000-3, ASTM D5197, EPA TO11, EPA IP-6	50 μg/m³	ISO 16000-3, ASTM D5197, EPA TO-11 (or 11A), EPA IP-6 (or 6A), NIOSH 2016
	TVOCs	500 μg/m³	ISO 16000-6, EPA TO-1, 17, EPA Compendium Method IP-1	500 μg/m³	ISO 16000-6, EPA TO-17, ASTM D5197
Product applied on-site emission rate restriction using a test chamber	HCHO	9 μg/m³ after 336 hr	CDPH (2010), AgBB (2010), ISO 16000-3 ISO 16000-6 ISO 16000-9 ISO 16000-11	9 μg/m³ after 336 hr	CDPH (2010), AgBB (2010), ISO 16000-3 ISO 16000-6 ISO 16000-9 ISO 16000-11
	TVOCs	-	Must state the range of total VOCs after 336 hr in • ≤0.5 mg/m³ or less; • 0.5–5.0 mg/m³; • ≥5.0 mg/m³ or more	-	Must state the range of total VOCs after 336 hr in • ≤0.5 mg/m³ or less; • 0.5–5.0 mg/m³; • ≥5.0 mg/m³ or more

Figure 1

Example of Interior Decoration of a Studio Bedroom

MATERIALS AND METHODS

Materials

Built-in furniture is normally a main source of VOCs because it is usually built on site by local contractors with different skills and a range of material grades. A variety of materials are used in interior decoration to create an atmosphere that matches a client's budget, functional requirements, aesthetics, and living style (Figure 1). Materials selected for testing were based on their popularity in Thailand and their appearance, durability, and price from pilot surveys.

Built-in furniture can be made with two to more than four layers of materials, such as the structure or stud, backing, or finishing, which can be a covering or coating or both. Examples of materials used in each layer are the following:

A. Structure or stud: solid wood, medium-density fiberboard (MDF), oriented strand board (OSB), or particleboard.

B. Backing: plywood or cement board.

C. Finishing—covering: solid wood veneer, high-pressure laminate, melamine, soft furnishing, color-coated glass, or stone wall covering.

D. Finishing—coating: spray paint, paint, natural wood stain color, wood stain color, teak oil, lacquer, polyurethane varnish, thinner, acrylic putty, or shellac.

Binders can be latex, glue, plastic resin, adhesive, or silicone sealant. The price range can be divided into high, medium, and low, with the price tag mostly depending on the structure of the furniture (Figure 2). The more expensive furniture is made of solid wood stud; medium-priced furniture typically uses MDF and OSB, while low-cost furniture often uses particleboard for its structure.

Popular materials in Thailand for built-in furniture finishings are wood, OSB, MDF, veneer, plywood, cement board, marble, laminate, melamine, colored glass, soft cover, and wallpaper. Some materials require coatings, which can be teak oil, lacquer, wood stain, natural wood stain, or silicone. Each finishing can be backed up with different structures, which can affect their cost. The combinations of selected finishing techniques and structural materials that made up the total of 33 specimens tested in this research can be divided into two groups: coating technique materials (Table 2) and covering technique materials (Table 3).

Figure 2

Built-in Structural Materials of Furniture and Their Costs

Table 2

Built-in Furniture Combinations With Coating Techniques

Code	Structure	Backing	Covering	Coating	Binder	Picture
Teak oil						
1A1-TO	Solid wood stud	Plywood	Solid wood	Teak oil	Latex	
2A2-TO	Solid wood stud	Plywood	-	Teak oil	Latex	
3B2-TO	OSB			Teak oil	-	
Lacquer						
4A1-L	Solid wood stud	Plywood	Solid wood	Lacquer	Latex	
5A2-L	Solid wood stud	Plywood	-	Lacquer	Latex	
6A2-V-L	Solid wood stud	Plywood	Veneer	Lacquer	Latex	
7A3-L	Solid wood stud	Cement board	-	Lacquer	Latex	

Table 2 (Continue)

Code	Structure	Backing	Covering	Coating	Binder	Picture
8B1-L	MDF	-	-	Lacquer	-	
9B2-L	OSB	-	-	Lacquer	-	
Wood stain						
10A1-WT	Solid wood stud	Plywood	Solid wood	Wood stain	Latex	
11A2-WT	Solid wood stud	Plywood	-	Wood stain	Latex	
Natural wood stain						
12A1-NWT	Solid wood stud	Plywood	Solid wood	Natural wood stain	Latex	
13A2-NWT	Solid wood stud	Plywood	-	Natural wood stain	Latex	
Silicone						
14A2Ma-S	Solid wood stud	Plywood	Marble	Silicone	Cement glue	
15A3Ma-S	Solid wood stud	Cement board	Marble	Silicone	Cement glue	
16B1Ma-S	MDF		Marble	Silicone	Cement glue	
Spray paint						
17B1-SP	MDF			Spray paint	-	
18B2-SP	OSB			Spray paint	-	
Acrylic paint						
19B1-AP	MDF			Acrylic paint	-	
20B2-AP	OSB			Acrylic paint	-	

Table 3

Built-in Furniture Combinations With Covering Techniques

Code	Structure	Backing	Covering	Coating	Binder	Picture
Laminate						
21A1-L	Solid wood stud	Plywood	Laminate	-	Glue	
22B1-L	MDF		Laminate	-	Glue	
23C-L	Particleboard		Laminate	-	Glue	
Melamine						
24A2-Me	Solid wood stud	Plywood	Melamine	-	Glue	
25B1-Me	MDF		Melamine	-	Glue	
26C-Me	Particleboard		Melamine	-	Glue	
Colored glass						
27A2-G	Solid wood stud	Plywood	Colored glass	-	Silicone	
28A3-G	Solid wood stud	Cement board	Colored glass	-	Silicone	
29B1-G	MDF		Colored glass	-	Silicone	
Soft cover						
30A2-SC	Solid wood stud	Plywood	Soft cover	-	Latex	
31B1-SC	MDF		Soft cover	-	Latex	
Wallpaper						
32A2-WP	Solid wood stud	Plywood	Wallpaper	-	Latex	
33B1-WP	MDF		Wallpaper	-	Latex	

Equipment

Emission test chambers. The emission test chambers were constructed according to ISO 16000-9 (International Organization for Standardization [ISO], 2006a) with a smooth surface of 5-mm clear float glass that does not absorb emissions. The chamber volume was 0.21 m^2 (60 x 60 x 60 cm). Each side of the glazing pane was connected using odorless silicone. The chambers were left for 7 days before use.

Sampling equipment. TVOC concentrations were determined with an Industrial Scientific MX6 IBrid™ using the photo-ionization detection (PID) technique, which can detect most VOCs. The TVOC concentration could be read instantly on the equipment screen; however, HCHO cannot be detected with PID. In this study, HCHO concentration was measured using Standard GasTec Tubes by collecting 10 x 100 ml samples of air at 90-s intervals; the values were read from the scales printed on the tubes. The equipment used was new and well calibrated (Figure 3).

Sampling and Analysis

Two sets of 33 specimens were tested. The size of the specimens was 30 x 30 cm or 0.09 m^2. Specimens were produced and sent directly from the production line to the test facilities in plastic wrap by local contractors. TVOC and HCHO concentrations were collected on the 3rd day and the 28th day after the specimens were unwrapped.

Empty chambers were first measured to ensure their neutrality. Then, specimens were placed inside the chambers. Air was continuously fed in and out of the chambers at a steady velocity. Small electrical fans were placed inside the chambers to mix the air. The test conditions were a temperature of 23 °C, a relative humidity (RH) of 45%, an air change per hour (ACH) of 0.5, and a load factor of 0.42 m^2m^{-3}. Temperature and humidity were controlled and measured (Figures 4 and 5).

The area-specific emission rate of each specimen was obtained by Equation 1 (ISO, 2006a).

$$E = n.C.V_c/A \text{ or } E = n.C/L \qquad (1)$$

Where E= area-specific emission rate (µg.m^{-2}.h^{-1})

C = gas concentration (µg.m^{-3}) from measurement

A= specimen area (m^2) = 0.09 m^2

V_c = chamber volume (m^3) = 0.216 m^3

n = air change per hour (ACH) = 0.5 ACH

L = load factor = A/V_c $m^{-2}m^{-3}$

= 0.09/0.216 = 0.42 $m^{-2}m^{-3}$

Figure 3

TVOC and HCHO Measuring Equipment

TVOC measuring equipment **HCHO measuring equipment**

Figure 4

Emission Test Chamber Setup Diagram According to ISO 16000-9:2006

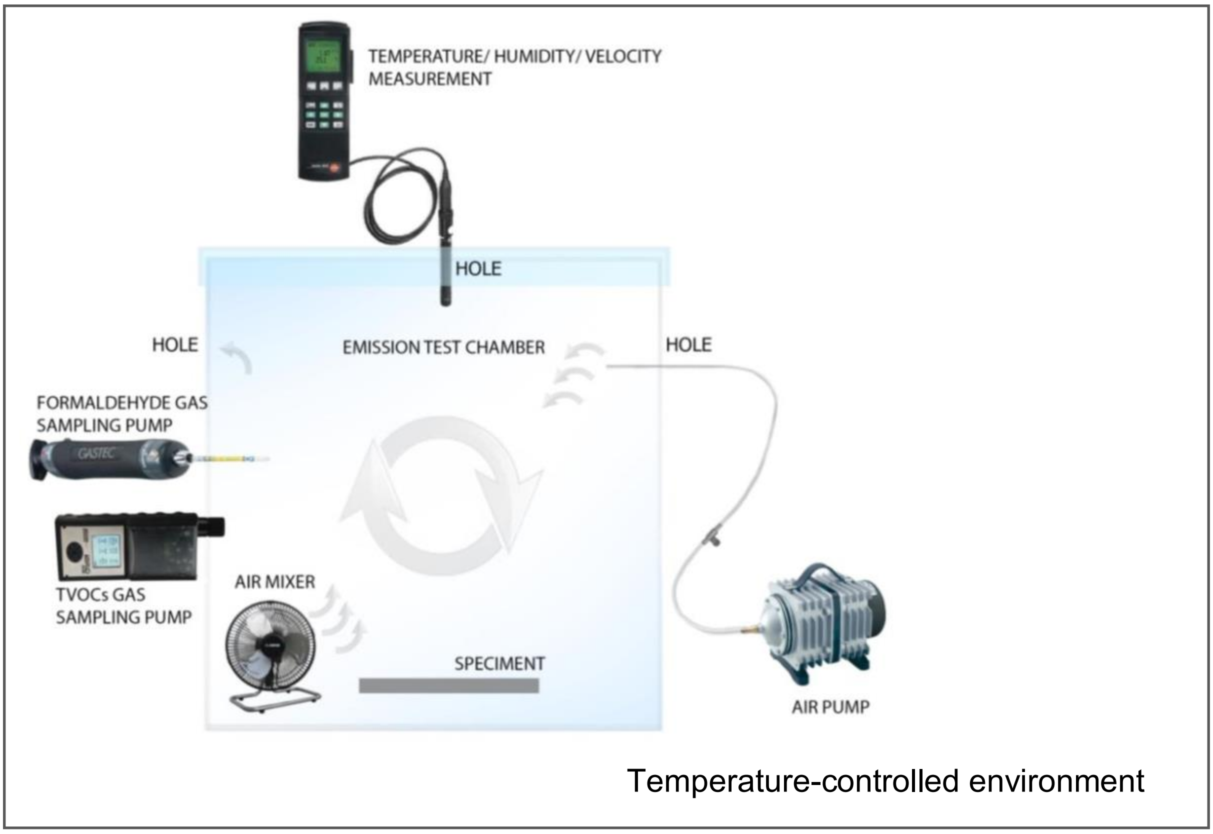


Figure 5

Emission Test Chambers in Use

RESULTS AND DISCUSSION

The results from the two sets of specimens were examined, and it was found that the two sets of results were in good agreement. The results from the second set of specimens were then used for discussion and analysis (Tables 4–5, Figures 6–8). All specimens emitted TVOCs and HCHO; however, it is clear that backing materials and the choice of coating or covering techniques greatly affected the specimens' emission rates.

Emission Concentration Compared with Standards

TVOCs were released from all specimens at a very high concentration on the 3rd day after the specimens were unwrapped. Specimens coated with teak oil exhibited the highest TVOC concentrations, with almost twice the TVOC concentrations of specimens coated with lacquer, 60–70 times more than specimens finished with a covering technique, and 1000 times more than the standard limit. The highest TVOC concentration came from a specimen made with a wood structure covered with plywood and solid wood that was coated with teak oil. This specimen had a TVOC concentration of 223,803 $\mu g.m^{-3}$, compared with the TVOC standard limit of 500 $\mu g.m^{-3}$. The specimens that gave off the lowest amount of TVOCs on the 3rd day were those covered with laminate or a soft covering.

TVOC concentrations were sharply lower on the 28th day; however, they were still 10–35 times higher than the standard limit for the coating technique and 1–20 times higher than the standard limit for the covering technique.

HCHO released from all specimens was over the standard limit, with emissions from the coated specimens being higher than those released from the covered specimens.

Effects of Different Coating and Finishing Techniques

It was found that coating with lacquer, wood stain, teak oil, or paint resulted in a much higher concentration of TVOCs compared with covering with melamine, laminate, or a soft covering. Covering techniques that required a coating as a final layer to prevent water seepage or to create a specific appearance, such as natural stone, needed a silicone coating that also emitted TVOCs at a high rate. Teak oil is the coating that released the highest amount of TVOCs, followed by spray paint, wood stain, acrylic paint, and silicone. Lacquer is the coating material that gave off the fewest TVOCs. It was found that, on the 28th day, spray paint was the coating that emitted the highest amount of TVOCs, even though it did not release the highest amount of TVOCs on the 3rd day. The difference between covered and coated specimens was pronounced; all covered specimens gave off fewer TVOCs on the 3rd day than all coated specimens did on the 28th day.

HCHO released from covered samples was constant from 3 to 28 days, while HCHO released from coated specimens was high initially but 40%–80% lower on the 28th day.

Backing Effect

Different backing materials with different surface characteristics have different effects on the emission rate depending on the coating or covering technique. Figure 8 shows that specimens with the same coating on different backing structures had different TVOC emission rates. These effects are noticeable for coated specimens. Specimens covered in solid wood and coated with teak oil or wood stain can absorb a certain amount of coating, resulting in higher TVOC and HCHO emission rates. For covered specimens, different backing materials have only a slight effect on the emission rates.

Table 4

TVOC and HCHO Concentrations and Area-Specific Emission Rates of Coating Technique Specimens

Specimen			Concentration				Area-specific emission (μg.m^{-2}h^{-1})			
			TVOCs (μg.m^{-3})		HCHO (ppm)		TVOCs		HCHO	
Finishing	Backing	Binder	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28	Day 3	Day 28
Teak oil	Wood-Plywood-Wood	Latex	223,803	41,227	266,433	49,079	0.25	0.15	357	214
	Wood-Plywood	Latex	180,613	22,903	215,016	27,266	0.25	0.15	357	214
	OSB	-	179,959	13,742	214,237	16,359	0.25	0.15	357	214
Lacquer	Wood-Plywood-Wood	Latex	98,159	13,742	116,856	16,359	0.25	0.10	357	142
	Wood-Plywood	Latex	67,402	7,198	80,241	8,569	0.25	0.10	285	142
	Wood-Plywood-Veneer	Latex	71,983	11,124	85,694	13,243	0.20	0.10	285	142
	Wood-Cement Board	Latex	80,490	9,816	95,822	11,685	0.25	0.10	285	142
	MDF	-	66,748	8,507	79,462	10,127	0.25	0.10	285	142
	OSB	-	66,094	7,198	78,683	8,569	0.25	0.05	285	142
Wood stain	Wood-Plywood-Wood	Latex	119,100	29,447	141,786	35,057	0.15	0.10	214	142
	Wood-Plywood	Latex	117,791	16,359	140,227	19,476	0.15	0.10	214	142
Natural wood stain	Wood-Plywood-Wood	Latex	135,460	34,028	161,262	40,510	0.15	0.10	214	142
	Wood-Plywood	Latex	125,644	18,323	149,576	21,813	0.15	0.10	214	142
Marble-Silicone	Wood-Plywood	Cement glue	119,754	13,742	142,565	16,359	0.25	0.05	357	71
	Wood-Cement Board	Cement glue	124,335	8,507	148,018	10,127	0.15	0.10	214	142
	MDF	Cement glue	80,490	9,816	95,822	11,685	0.25	0.10	214	71
Spray paint	MDF	-	192,392	51,697	229,038	61,544	0.25	0.10	357	214
	OSB	-	130,879	44,499	155,808	52,975	0.25	0.10	357	214
Acrylic paint	MDF	-	104,703	6,544	124,647	7,790	0.15	0.05	214	71
	OSB	-	92,924	5,889	110,624	7,011	0.15	0.05	214	71

Table 5

TVOC and HCHO Concentrations and Area-Specific Emission Rates of Covering Technique Specimens

Specimen			Concentration				Area-specific emission ($\mu g.m^{-2}h^{-1}$)			
			TVOCs ($\mu g.m^{-3}$)		HCHO (ppm)		TVOCs		HCHO	
Finishing	**Backing**	**Binder**	**Day 3**	**Day 28**	**Day 3**	**Day 28**	**Day 3**	**Day 28**	**Day 3**	**Day 28**
Laminate	Wood-Plywood	Cement glue	3,926	654	4,674	779	0.05	0.05	71	71
	MDF	Adhesive	2,617	654	3,116	779	0.05	0.05	71	71
	Particle-board	Adhesive	3,272	654	3,895	779	0.05	0.05	71	71
Melamine	Wood-Plywood	Cement glue	3,926	981	6,232	1,558	0.05	0.05	71	71
	MDF	Adhesive	3,272	654	3,895	779	0.05	0.05	71	71
	Particle-board	Adhesive	3,272	654	3,895	779	0.05	0.05	71	71
Color-coated glass	Wood-Plywood	Silicone	3,926	2,617	4,674	3,116	0.05	0.05	71	71
	Wood-Cement Board	Silicone	3,926	3,272	4,674	3,895	0.05	0.05	71	71
	MDF	Silicone	3,926	3,272	4,674	3,895	0.05	0.05	71	71
Soft cover	Wood-Plywood	Latex	4,580	654	5,453	779	0.05	0.05	71	71
	MDF	Latex	2,617	654	3,116	779	0.05	0.05	71	71
Wallpaper	Wood-Plywood	Latex	5,235	654	6,232	779	0.05	0.05	71	71
	MDF	Latex	3,926	1,309	4,674	1,558	0.05	0.05	71	71

Figure 6

TVOC Concentrations From Various Built-in Furniture Techniques

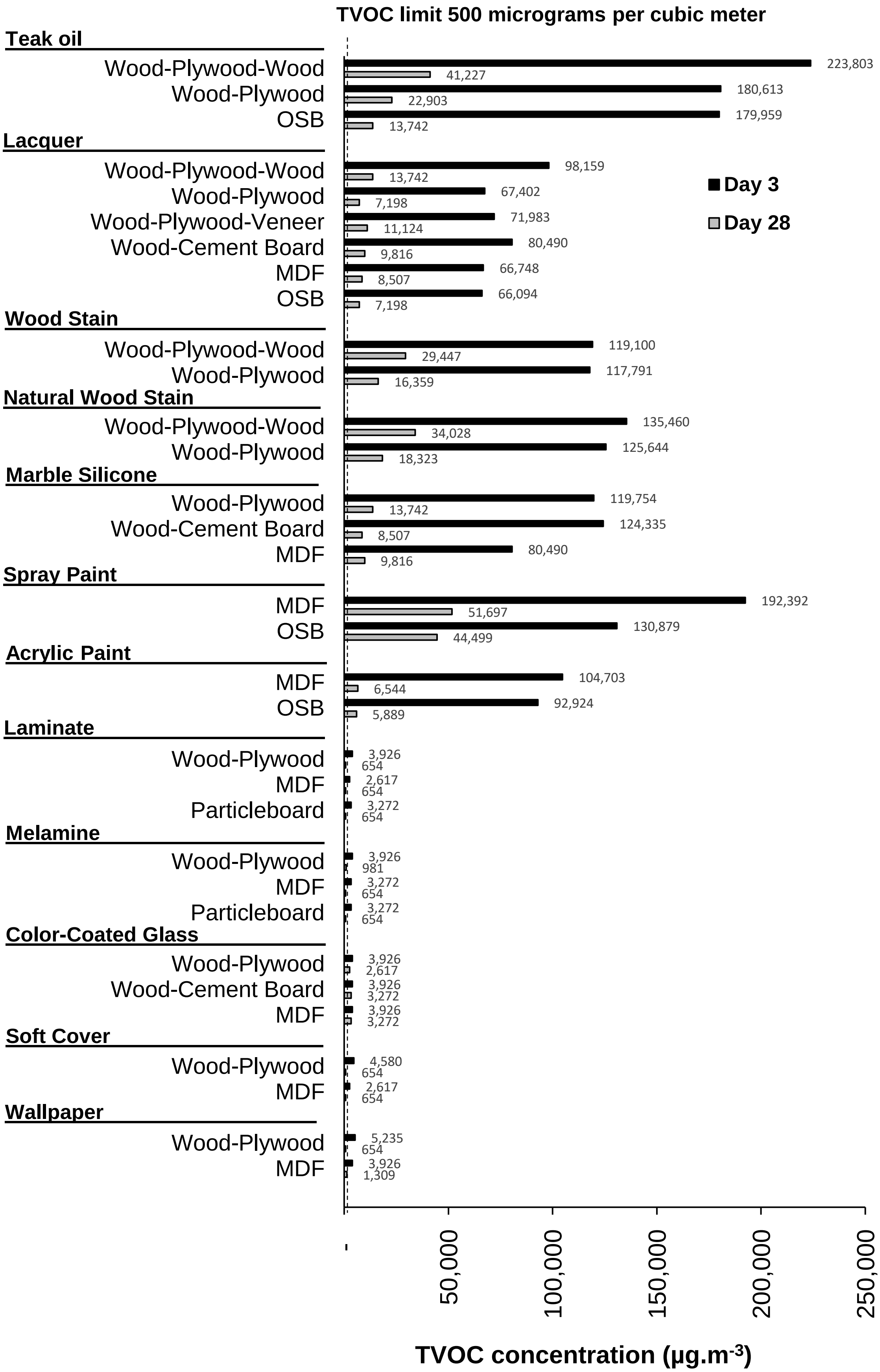


Figure 7

HCHO Concentrations From Various Built-in Furniture Techniques

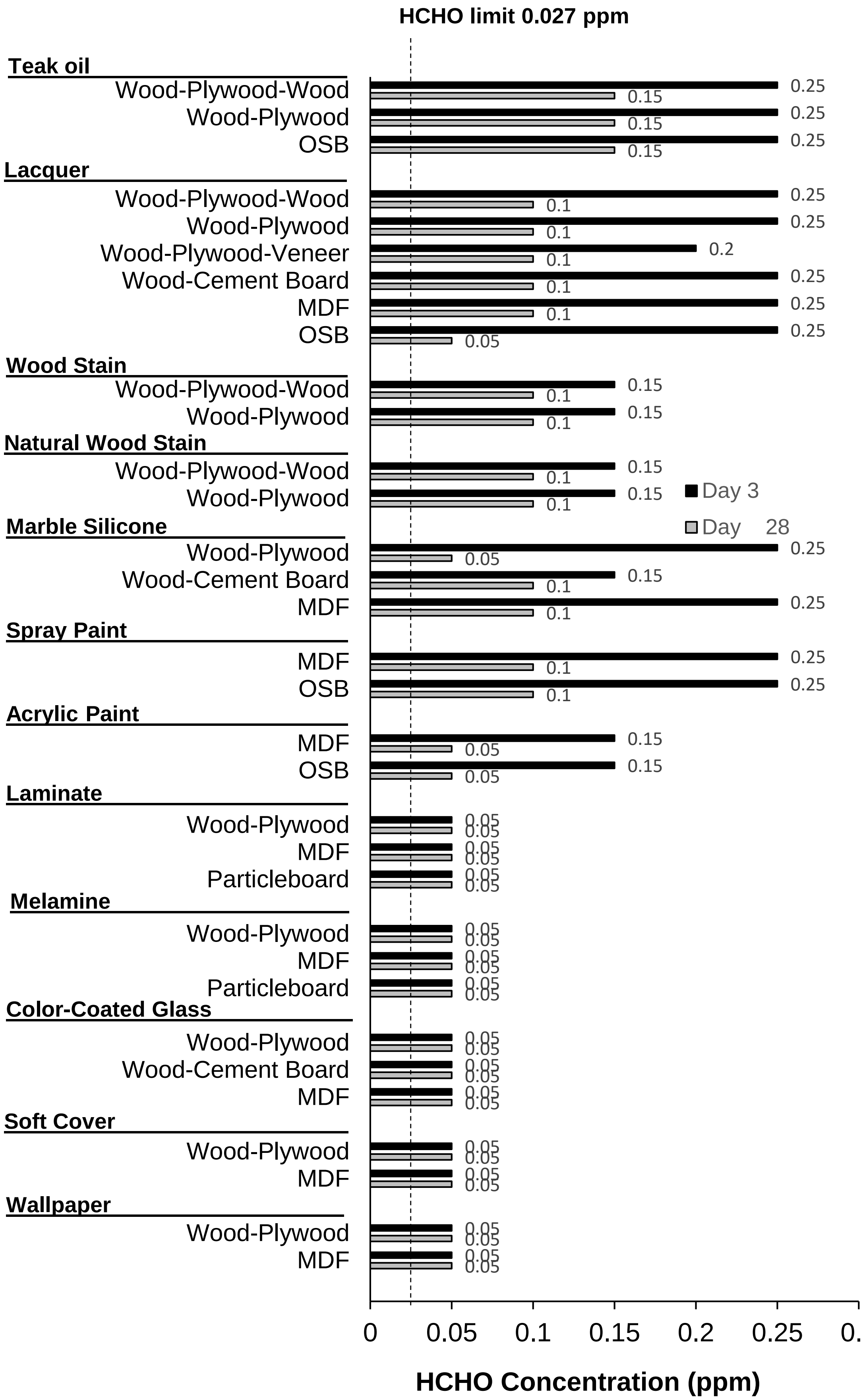
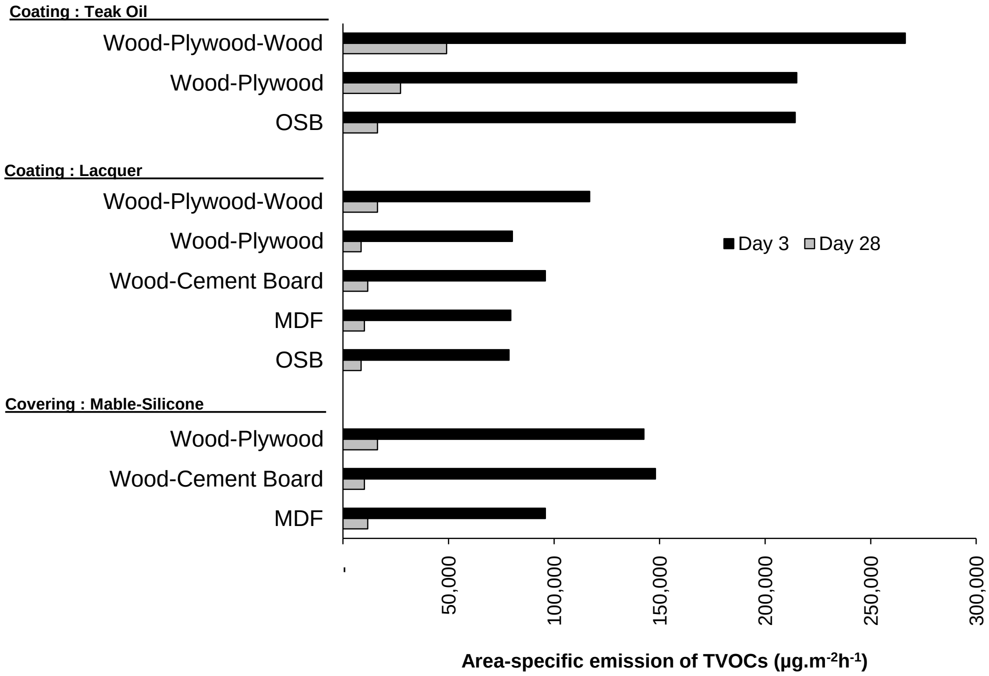


Figure 8

TVOC Concentration Comparison of Different Backings



CONCLUSIONS

Various built-in furniture specimens that are commonly found in Thai interior decoration were tested using environmental chambers. It was found that the levels of TVOC emissions from specimens coated with teak oil, wood stain, paint, and lacquer were higher than those of specimens covered with laminate, melamine, color-coated glass, or a soft covering when measured on the 3rd day after production. The emissions were greatly reduced on the 28th day; however, the TVOC concentrations were still higher than the standard limits for all specimens. For HCHO concentrations, all specimens failed to meet or exceeded the standard limit on both the 3rd and the 28th day after being unwrapped following production and transportation. The specimens' backing structure also affected their TVOC emission rates, depending on their surface characteristics. Specimens that used covering techniques were found to be cheaper but also less durable. The data from this study could assist owners and interior designers in choosing built-in furniture with appropriate appearance and techniques for finishing, coating, or covering that both match their decorative requirements and are healthy choices.

This research was carried out following the ISO 16000-9:2006 standard. In the U.S. CDPH standard method (2010) for the testing and evaluation of volatile organic chemical emissions from indoor sources using environmental chambers version 1.1, the sampling of emissions is preferred at 72 hr and 168 hr. That method could be used instead of ISO fer16000-9:2006 in future investigations. Additionally, even though the coating products used in this research passed the national standard called the Green Label, which specifies TVOC limits, the test results still showed very high concentrations of emissions. TVOC and HCHO emissions from various manufacturers within the same product category could be explored further in the future for more detailed and granular data about this important health issue.

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