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Performance of sorption- and photocatalytic oxidation-based indoor passive panel technologies

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ABSTRACT

Little information is available on the performance of commercially available indoor passive panel technologies (IPPT) based on sorptive and photocatalytic processes. In this paper, we studied 8 sorptive- and 3 photocatalytic oxidation (PCO)-based materials using controlled test chamber experiments. Four reference samples were used as controls. Sorptive-based samples were challenged with toluene and formaldehyde at 100 μg/m^3 to determine their removal rates. PCO-based samples were challenged with only toluene at 100 μg/m^3 to determine its removal rate and ozone and carbonyl by-product formations. Removal performance variations were wide across all IPPT samples although for every IPPT sample, its removal rate was better than its conventional counterpart. Most sorptive-based IPPT samples were not equally effective in removing toluene and formaldehyde. Painting on IPPT gypsum boards reduced their removal performance down to levels comparable to those of conventional gypsum boards. Toluene removal using PCO-based IPPTs were dependent on light used: only two PCO IPPTs are capable of performing under visible light. All PCO-based IPPTs generate ozone and carbonyls as by-products releasing up to 1.0 mg/h and 3.2 mg/h of ozone and formaldehyde respectively. This is a concern as exposures to ozone and formaldehyde have been known to be associated with negative health outcomes.

1. Introduction

Currently, there are new building materials and coating products available in the market that claim to enhance Indoor Air Quality (IAQ). This technology, known as indoor passive panel technology (IPPT), is intentionally designed to remove indoor air pollutants without requiring additional energy input beyond normal building operations. Typical materials are modified gypsum board, acoustic ceiling tiles, ceramic tiles, wallpaper and other coatings and pre-coated products relying on either sorptive or photocatalytic oxidation (PCO) processes [1–5]. The advantage of using IPPT is that it is not associated with increased ventilation, which can increase energy consumption. In addition, there are no mechanical forces involved in the uptake of pollutants onto the IPPT surfaces. As an alternative to conventional active "flow through" pollutant removal systems relying on HVAC fans, IPPT can remove indoor pollutants relying on normal airflow characteristics in ventilated rooms through contact on surfaces in occupied spaces [1,6]. Thus, IPPT has the potential to improve indoor air quality with little or no impact on energy consumption, making it a potentially attractive IAQ solution.

IPPTs use primarily sorptive and PCO-based processes to remove indoor air pollutants. Sorptive-based IPPTs rely on physical adsorption and/or chemisorption processes. Solid adsorbents used in sorptive-based IPPT include activated charcoal and other materials such as silica gel, activated alumina, zeolites, porous clay minerals, molecular sieves and SiO_2/TiO_2 composite adsorption modules [4,6,7]. PCO-based IPPTs rely on the use of photocatalysts on building materials, illuminated with either ultraviolet or visible light [5,6,8]. In theory, the photocatalyst absorbs photons of ultraviolet or visible light to cause oxidation and reduction reactions on the catalyst's surface. Highly reactive species such as hydroxyl radicals or ozone formed during these reactions have the potential to oxidize pollutants to mostly benign products such as carbon dioxide and water [5,6,8,9]. Yu and colleagues [10] proposed a combined system of photocatalytic oxidation and Trombe wall (PCO/TW), which can simultaneously realize space heating requirements and indoor formaldehyde removal while Salthammer and Fuhrmann [11] studied the effects of PCO paints in removing formaldehyde and toluene in a chamber experiment.

Despite the positive potential of IPPTs, these new products have not been tested in a standardised manner and there is no test program for

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consumers to evaluate their performance. The results of the published evaluations of these products in removing VOCs indicate a wide range in performance [1,12] or evaluated single technology (e.g. Refs. [5,7,10]). Indeed, little information regarding their performance is available to consumers beyond the general claims of the manufacturers. Furthermore, depending on technologies, several issues may be associated with its use as indicated in similar processes deployed in other applications. Firstly, some sorptive-based IPPTs may effectively adsorb certain gaseous indoor air pollutants (e.g., VOCs), but will not efficiently adsorb very volatile organic compounds (VVOCs) and low molecular weight gases such as formaldehyde. This has been noted in HVAC air cleaning applications [13]. Secondly, it is unclear if the IPPT will perform as well when the contact between indoor pollutants and IPPT materials is hindered through common building treatment such as painting [1]. Thirdly, PCO-based technology relying on conventional photocatalysts such as titanium dioxide (TiO_2) require UV light for activation. For these products, it is unclear if they will be effective for indoor applications [8]. Although new catalytic technologies relying on visible light have been recently introduced [3,5,8], there is little information on how effective these new technologies will be. Lastly, PCO-based IPPT may not just produce active agents to photocatalyse indoor air pollutants, but they may also produce harmful by-products such as formaldehyde [5,8,14].

Owing to the above points, we conduct a study on commercially available materials to provide an assessment of the: 1) performance of sorption-based IPPT products to remove airborne toluene and formaldehyde; 2) the impact of painting on removal performance of sorption-based IPPT products; 3) the performance of PCO- based IPPT products to remove airborne toluene under UV and visible light irradiation; and 4) the release of ozone and carbonyls as by-products from the use of PCO-based IPPT. We focussed on the use of toluene and formaldehyde in our experiments as these two are commonly found in the indoor environments of Canadian residences [15–17] and that their exposure has been known to be associated with negative health outcomes [18,20].

2. Materials and methods

2.1. Test samples and preparation

Test samples included in this study were obtained from IPPT products that have made claims of their VOC removal performance. IPPT samples that are sorptive- and PCO-based were obtained. Samples from flooring, ceiling panels and wall materials that present large amounts of surface area in indoor environments and used in many residential and commercial buildings were selected. For controls, reference samples made of stainless steel and conventional building material were also included for testing. Table 1 lists all the samples that were tested.

All sample materials were received directly from the manufacturer or retailer. The raw samples were then stored in their original packaging until they were prepared for testing. Prior to testing, all samples were placed in a 50 L electropolished stainless steel conditioning chamber, exposed to clean air at a ventilation rate of 1 h^{-1} at 23 °C and 50% RH, for 48 h. The test samples were conditioned to improve test

Table 1
List of samples tested.

Test ID[a]	Test samples	Description and market claims
Sorptive-based IPPT test		
SS_F/T	Stainless steel plate	Stainless steel plate
N_Gyp_F/T	Gypsum board	Normal gypsum board: used as wall and ceiling boards with moisture control feature.
S1_Gyp_F/T	IPPT gypsum fibreboard	IPPT gypsum fibreboard: used as wall, ceiling and floor fibreboards. It is reported as laminated with keratin and capable of “neutralising harmful VOCs”.
S2_Gyp_F/T	IPPT gypsum plasterboard	IPPT gypsum plasterboard: used as wall, ceiling and floor plasterboards. Described as plasterboard with formaldehyde absorption and decomposition performances.
S3_Gyp_F/T	IPPT gypsum board	IPPT gypsum board: used as wall and ceiling boards with formaldehyde-scavenging technology.
N_ACT_F/T	Acoustic tile	Normal mineral fiber ceiling tile
S_ACT_F/T	IPPT acoustic tile	Mineral fiber ceiling tile with special coating that actively removes up to 50% of the formaldehyde from the air.
CerTi_F/T	IPPT ceramic tile	Ceramic tile made of special material “Allophane” capable of absorbing formaldehyde and other VOC.
S_WP_F/T	IPPT wall paper	Wall paper that is designed as a wallcovering for decontamination of building interiors and made of spherical high-performance activated carbon adsorbents.
PN_Gyp_F/T	Painted gypsum board	Painted normal gypsum board: Painted N_Gyp_F/T sample
PS1_Gyp_F/T	Painted IPPT gypsum fibreboard	Painted S1_Gyp_F/T sample. Product can be painted with mineral paint to preserve air-purifying characteristics.
PS2_Gyp_F/T	Painted IPPT gypsum plasterboard	Painted S2_Gyp_F/T sample. Manufacturer advises to use water-based paint for surface finish in order to exercise its formaldehyde absorption and decomposition performances.
PCO-based IPPT test		
PCO_FL_UV	IPPT Hardwood flooring – irradiated with UV light	PCO_FL hardwood flooring irradiated with UV light alone. Product is claimed to be light-activated with air-purifying agent made of titanium dioxide activated PCO coating that breaks down toxic contaminants on contact.
PCO_FL_ LnF	IPPT Hardwood flooring – irradiated with visible light and no UV cut-off filters	PCO_FL hardwood flooring irradiated with visible light with no UV filter. Product is claimed to be activated by natural or artificial light.
PCO_FL_L	IPPT Hardwood flooring – irradiated with visible light and UV cut-off filters	PCO_FL hardwood flooring irradiated with visible light alone. Product is claimed to be activated by natural or artificial light.
PCO_WP_UV	IPPT wall paper – irradiated with UV light	PCO_WP wall paper irradiated with UV light. Wall paper designed for indoor environment.
PCO_WP_LnF	IPPT wall paper – irradiated with visible light and no UV cut-off filters	PCO_WP wall paper irradiated with visible light with no UV filter.
PCO_WP_L	IPPT wall paper – irradiated with visible light and UV cut-off filters	PCO_WP wall paper irradiated with visible light alone.
PCO_FB_UV	IPPT fabric material – irradiated with UV light	PCO_FB fabric material irradiated with UV light. Manufacturer claims that catalyst can be activated using visible light.
PCO_FB_LnF	IPPT fabric material – irradiated with visible light and no UV cut-off filters	PCO_FB fabric material irradiated with visible light with no UV filter. Manufacturer claims that catalyst can be activated using visible light.
PCO_FB_L	IPPT fabric material – irradiated with visible light and UV cut-off filters	PCO_FB fabric material irradiated with visible light alone. Manufacturer claims that catalyst can be activated using visible light.

[a] F/T – formaldehyde/toluene.