IDENTIFYING, QUANTIFYING AND CONTROLLING VOCS IN AN AIR-CONDITIONED OFFICE BUILDING – A SINGAPORE CASE STUDY

K.W.Tham[1], S.C.Sekhar[1], K.W.Cheong[1], N.H.Wong[1], H.K. Lee[2], Md. Amanullah[1], M.S. Zuraimi[1]

[1]School of Building and Real Estate, National University of Singapore, Singapore
[2] Department of Chemistry, National University of Singapore, Singapore

ABSTRACT

This case study conducted in a new air-conditioned building in Singapore was aimed at identifying, and assessing indoor levels of VOCs using a GC-MS method. The study identified 80 different compounds with Toluene appearing in all locations. Most VOCs detected were from building materials, adhesives, varnishes, sealing compounds, polyester carpets reflecting the age of the building and vehicular emissions reflecting the poor positioning of the air intake.

KEYWORDS: VOC, TVOC, GC-MS, air conditioning, office building

INTRODUCTION

The Indoor Air Quality research program at the National University of Singapore, initiated in 1992, has established that VOCs is a potentially important contaminant in air-conditioned office buildings. Measured by the infrared photo-acoustic (PAS) method, the TVOC levels averaged over a minimum continuous monitoring period of 72 hours have ranged between 0.55 ppm and 3.06 ppm Toluene equivalent [1,2]. The indoor-outdoor ratios vary between 0.97 and 2.71, while the inter-building TVOC ratio, a statistic derived by dividing the TVOC level of a building into the average TVOC level of all buildings studied, range between 0.58 and 1.74. The actual range between minimums and maximums are indeed much larger. In the light of the importance and usefulness of characterising (identifying and quantifying the constituents) the TVOCs for exposure assessment and control, as established in a number of prominent studies, a research project has recently been initiated to establish such detailed characterisation of VOCs in air-conditioned buildings in Singapore where the warm, humid climate necessitates continuous air-conditioning throughout the occupied hours over the entire year.

This paper presents the data from the study of a new air-conditioned building using GC-MS (Gas Chromatography, Mass Spectrometry) technique to identify and quantify the VOCs based on the metrics of "most common occurrence" and "highest concentrations" as reported in recent comparable studies [4,5]. Formaldehyde, for its very volatile nature, was excluded from this study due to the difficulty it poses to be quantified by conventional GC-MS method. The results provide an indication of the VOC contamination of a new air-conditioned office building in Singapore. The discussion focuses on the possible sources, ventilation parameters and plausible control strategies.

METHODS

Experimental Design

The study was conducted in a 6-storey office building in the western part of Singapore. The building is slightly more than one year old, and faces a major expressway a hundred metres away. From the outset, the identification of a "measurement floor" on the basis of its association with a dedicated air-handling unit (AHU) is emphasized. In a "measurement floor", typically spanning between 400-800 m^2 in Singapore, it is envisaged that 5 spatially distributed sampling points would provide a reasonable coverage for determining the variation in chemical contamination of the floor. Measurements are taken at the occupant breathing level and an ambient located in the fresh air intake stream. The measurements were conducted during occupied hours, when the AHU is in operation to facilitate an evaluation of the ventilation characteristics so as to provide an assessment of the adequacy of dilution as on exposure control strategy of the indoor VOCs. 20% of the building floor area is measured to provide a reasonable coverage occupied area of the building. This translates to one 'measurement floor'.

Sampling Locations

The 'measurement floor' for this building was the 6th floor. Figure 1 shows a schematic representation of the 'measurement floor'. During a walkthrough assessment of the floor, fairly strong emissions was detected from the building materials in location 2. It was pointed out that the premise was previously used for meetings. However, due to the strong emissions, the meetings have been relocated to another room. This floor is served by two AHUs employing a building automation system (BAS) controlled variable air volume (VAV) system. The two AHUs are located at opposite ends of the building, each serving respective sides and a common area with no physical separation. This is indicated by the cross hatched area in Figure 1. Fresh air is drawn directly from the outside in these two AHUs where it mixes with the recirculated air from the return ducts and subsequently distributed to the occupied spaces. Table 1 provides a plan of the locations where the measurements were conducted.

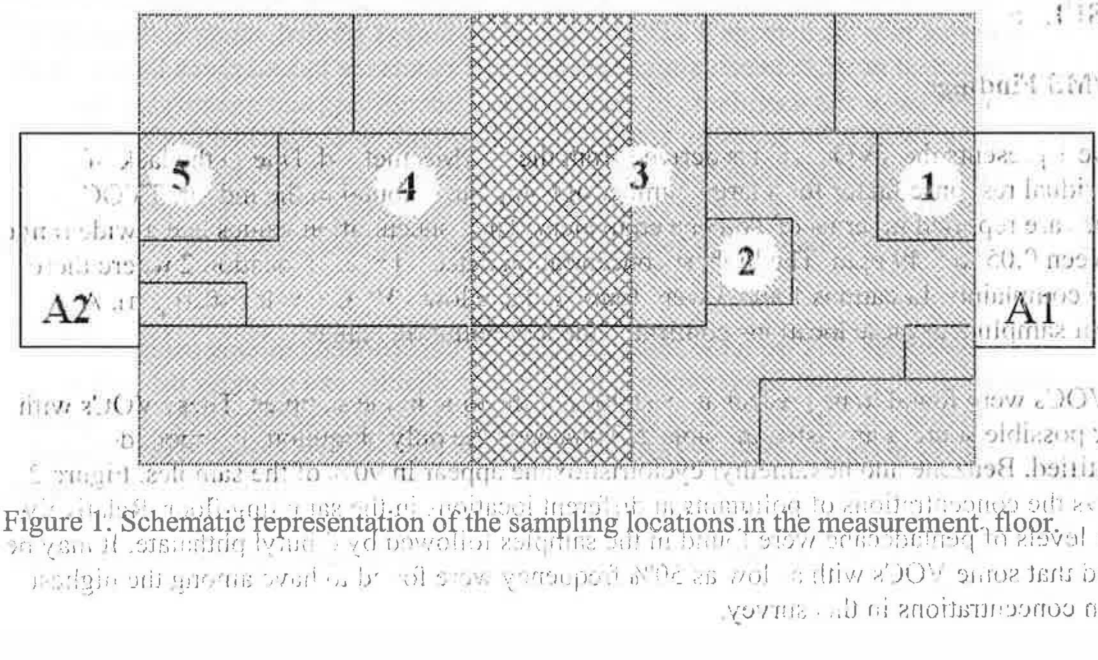

Figure 1. Schematic representation of the sampling locations in the measurement floor.

Measurement Techniques

In each sampling location, the VOCs were first enriched in a preconditioned multi sorbent (Tenax GR and Carbopack B) SKC stainless steel tubes (1/4" OD x 3.5"). During measurements, 2 litres of air was drawn through the tubes with the aid of Buck I. H. pumps at a sampling rate of 4.17 cc/min over 8 hours. The sampling flow was checked twice using a Mini-Buck air flow calibrator M-5 at the beginning and again at the end of sampling. All samples were then sealed using a stainless steel Swagelock caps, subsequently placed in ice-cooled containers and transported back to the laboratory.

For analysis, the tubes containing VOCs were placed on an Automated Thermal Desorber (Perkin-Elmer ATD 400) and leak checks were performed to ensure sample integrity. After purging for 1 minute with helium, the samples were thermally desorbed at 300°C for 3 minutes and transf rred to a cold trap containing Tenax TA as the focussing sorbent. Cryofocussing was done at -30°C. The trap was flash heated up to 300°C at a rate of 40°C/sec and the volatiles were transferred via a transfer line into a GC-MS system (Hewlett Packard 5190). The VOCs were separated on a 30m x 0.25mmx 0.25µm film thickness, HP 5MS Crosslinked 5% PH ME Siloxane capillary column with the following temperature programme: 40°C for 1 min, 15°C/min up to 105°C hold by 5 min followed by 20°C/min ramp to 245°C for 5 minutes. VOCs were identified using a Hewlett Packard 5973 MS detector and an NBS Library. Peak areas obtained were compared with those from the external standards provided by Scotty Specialty Gases. Due to numerous and diverse compounds detected, it was not possible to obtain all the different standards to evaluate individual responses. Therefore, toluene equivalence was used for some compounds.

Ventilation Studies

Ventilation studies were performed using SF_6 as a tracer gas and observing the decay in concentration at the 5 locations using photo acoustic spectroscopy (PAS), type 1312 and 1302 (Innova). The air exchange rate in the sampling locations was determined using the concentration decay method.

RESULTS

GC/MS Findings

Table 1 presents the TVOC values derived from the GC/MS method. Due to the lack of individual response factor for a large number of compounds found in the indoor, TVOC values are reported in terms of Toluene equivalent. The concentration values had a wide range between 0.05 to 5.49 ppm. The highest concentration detected was in location 2 where there were complaints. Locations 1 and 3 were found to have low TVOC levels (<0.1ppm). A repeat sampling at these locations confirmed the low pollution values.

19 VOCs were found to be present at least 40% of the time in the samples. These VOCs with their possible sources are listed in Table 2. Toluene is the only ubiquitous compound identified. Benzene and hexamethyl cyclotrisiloxane appear i 90% of the samples. Figure 2 shows the concentrations of pollutants at different locations in the sampling floor. Relatively high levels of pentadecane were found in the samples followed by dibutyl phthalate. It may be noted that some VOCs with as low as 50% frequency were found to have among the highest mean concentrations in this survey.

Table 1. Description and TVOC values of Sampling Locations

Location	Volume (m^3)	Primary function	Occu-pancy	ACH	TVOC conc. (ppm)	Remarks
1	59	Administrative	02	1.06	10.05	
2	54	Administrative	01	1.04	5.49	Strong emissions
3	400	Meetings	20	1.03	0.09	No meeting during sampling
4	127	Waiting area	00	0.80	2.91	
5	90	Administrative	03	0.79	2.37	
A1 (Ambient)	-	-	-	-	2.86	
A2 (Ambient)					4.98	

Table 2. TVOCs ranked by most common occurrence.

Rank	VOC	Freq/%	Plausible Sources
1	Toluene	100	Bioeffluent, vehicles, solvent, bldg material
2	Cyclotrisiloxane, hexamethyl	90	Printers, varnishes, sealing cpds
3	Benzene	90	Vehicles, plastic, rubber solvents, carpets
4	Benzaldehyde	70	Carpets, bldg materials
5	Phenol	70	Bioeffluent, bldg materials, vehicles
6	Pentadecane	70	Carpets, bldg materials
7	p-Xylene	60	Adhesives, floor covering, carpets, vehicles
8	Hexadecane	60	Carpets, bldg materials
9	Tetradecane	60	Carpets, bldg materials
10	Octadecane	60	Carpets, bldg materials
11	Ethylbenzene	60	Vehicles, solvents, bldg materials
12	1,3,5-Trimethylbenzene	60	Vehicles, solvents, carpets, bldg materials
13	Acetophenone	50	Solvents, SBR
14	Docosane	50	Carpets
15	Dibutyl phthalate	50	Carpets, plasticizer,
16	Octadecanoic acid, methyl ester	40	Paints, adhesives, cosmetics, furnishings
17	1,3-dimethyl benzene	40	Adhesives, consumer products
18	Styrene	40	Plastics, paints, SBR, bldg material
19	Alpha-methylstyrene	40	Plastics, paints, SBR, bldg material

DISCUSSIONS

The survey revealed that a broad range of VOCs were present inside the building. 80 different compounds were identified in the indoor environment. Most of the compounds detected are from building materials, adhesives, varnishes, sealing compounds, polyester carpets consistent with the 'newness' of the building. Toluene was found to be the most ubiquitous compound. Pentadecane was identified indoors with the highest mean concentrations due to the polyester carpet emissions [3] and also outdoors from the diesel emissions of large trucks [7] travelling along the major road. Organosiloxanes frequently detected was from printer emissions [12] and also from varnishes and adhesives [11].

Most Singaporean office buildings are not equipped with gas phase air filtration equipment in the fresh air intake or the recirculated air. This practice can and has led to IAQ problems as illustrated in this study. The siting of ambient 2 facing a major road has led to the ingress of vehicular pollutants in locations 4 and 5, where the detected compounds closely relate to vehicular emissions like benzene, toluene and aliphatic alkanes [5,7]. TVOC values obtained in location 2 were relatively high. This supports the complaints of strong emissions in that location. Tetradecane, heptadecane and hexadecane were found in this location at high levels. It can be seen from Figure that location 5 registered some VOCs with high concentrations. This may be due to the low ventilation rate in that location as reported in Table 1 or high emissions of compounds resulting in an accumulation to fairly high steady-state values. Being a new building, such phenomenon is normal and it is expected that the organic contaminants will decrease to a stable state within the next few months. Nevertheless, chemical filtering of the recirculated air along with changes in ventilation settings can help to reduce the levels of contaminants in these locations.

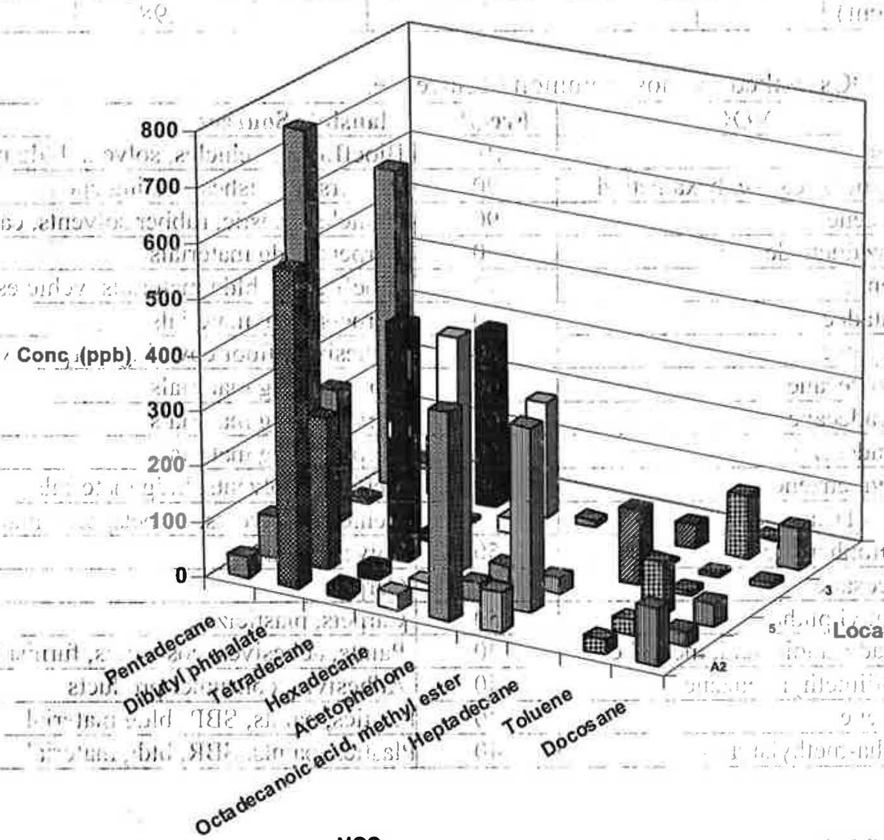

Figure 2. Concentrations of VOCs at different locations.

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