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EMISSIONS OF VOCs FROM BUILDING MATERIALS AND THE INDOOR AIR QUALITY OF A NEW NATURALLY VENTILATED OFFICE BUILDING

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ABSTRACT

This study investigated the sources and concentrations of volatile organic compounds (VOCs) including formaldehyde in the air of a new office and conference centre building. The building is naturally ventilated, and was designed to demonstrate a number of innovative approaches to environmental design. Occupant surveys have shown a high level of occupant satisfaction with the indoor environment. The building and furnishing materials were, however, quite typical of current office buildings; the building therefore represented a useful opportunity to study the emission of VOCs from materials and to demonstrate methods of identifying the sources of specific compounds that are found in the air. As would be expected in a new building, a wide range of VOCs and their sources were identified, but not at hazardous concentrations. The location with the highest total VOC concentrations was measured at 1411 $\mu g/m^3$ when the building was first occupied. This declined rapidly but remained above 500 $\mu g/m^3$ during the first year of monitoring. The chemical TXIB was dominant in the VOC measurements in the building and this was found to be emitted from the carpet tiles. Most VOCs had multiple sources.

KEYWORDS

VOCs, Formaldehyde, Building materials, Emission, Sources and concentrations, Commercial buildings, Natural ventilation, Indoor air quality

INTRODUCTION

The purpose of this on-going project is to understand the relationships between the sources and airborne concentrations of volatile organic compounds (VOCs) and formaldehyde in new buildings. The work has been carried out in a new office building at BRE's Garston site. The results will be used to formulate a database of the rates of emission from the wide range of products used in the construction and furnishing of the building and this will provide guidance for specifiers who wish to select low-emitting materials for their buildings.

The building is naturally ventilated, and was designed to demonstrate a number of innovative approaches to environmental design. Occupant surveys have shown a high level of occupant satisfaction with the indoor environment. The building and furnishing materials were, however, quite typical of current office buildings; the building therefore represented a useful opportunity to study the emission of VOCs from materials and to demonstrate methods of identifying the sources of specific compounds that are found in the air.

Some air quality measurements made during the first year since the building was completed in January 1997 have already been reported (Yu et al, 1999). The present paper reports the formaldehyde and the total VOCs (TVOC) concentration and the ten major individual compounds found in the air of the ground floor and the top floor of the office building over a three-year period from January 1997 to December 1999. Diffusive samplers were used for measuring the organic compounds in the air and these were strategically placed and exposed in the open plan offices on each floor and at an outdoor location. Samples of a wide range of materials used in the construction and fitting out of the building were collected. The chemical emissions from these materials and from some consumer products used in the building were identified using environmental chamber tests. The results of the emissions work were used to identify the main sources of the organic compounds found in the air.

DESCRIPTION OF THE BUILDING

The building consists of a three-storey office block and a conference centre, which was completed in January 1997 and was occupied from April 1997. The 2000 m^2 building contains a mixture of cellular and open plan offices, as well as seminar facilities. The office block floor plates measure 30 x 13.8 m and the minimum floor-to-ceiling height is 3 m. The building has many energy saving features and is naturally ventilated, combining stack ventilation with automatic control to draw air via ducts built into the sinusoidal ceiling slabs on the first and ground floors of the office block. The internal design conditions are a minimum indoor temperature in winter of 18°C, with 25°C not to be exceeded for more than 5% of the year and 28°C for not more than 1%. The maximum design ventilation rate is 10 air changes h^{-1}.

The ventilation rate and the environmental conditions in the building were monitored as part of the Natvent^{TM} project (1999) at two locations in the first floor office in August 1997 and in January 1998. The mean ventilation rates in the summer were 3.3 h^{-1} and 2.1 h^{-1} whereas in winter they were 0.78 h^{-1} and 0.74 h^{-1} respectively. The occupant control of ventilation of the top floor is by manual opening and closing of windows. This floor of the building was largely unoccupied until June 1999. The air leakage rate was measured at 50 Pa reference pressure using BREFAN (Perera & Tull, 1990); it was initially 17.34 $m^3h^{-1}m^{-2}$ of envelope area, but reduced to 15.22 $m^3h^{-1}m^{-2}$ in April 1999 after tightening work.

In the summer months during the study period, the relative humidity of the rooms was generally 55-65% and the temperature was generally 2-3°C below the target maximum of 25°C. In the winter, the relative humidity of the rooms was generally 30-45% and the temperature was generally 2-5°C above the design minimum of 18°C. An occupant evaluation survey was carried out prior to and after moving to the new office building and this found that the new building provided enhanced comfort and the level of satisfaction was higher than a range of other office buildings.

The building is carpeted throughout except the concourse area. The carpet tiles are synthetic fibre woven onto a mesh laminated to a tough, hard wearing polymeric backing. The cellular offices on the ground floor and first floor of the office building were partitioned with plasterboard and timber studs. All the interior doors and windows were timber framed; the timbers were vacuum treated and coated with lacquer. Medium density fibreboard (MDF) was used for wall panelling and for construction of window sills; these were either coated with emulsion paint, firetex paint, lacquer or vinyl lined. The undulating concrete air ducts in the sub-floor were insulated with mineral wool, with metal encased chipboard laying over the air-ducts to act as flooring. The carpet tiles were glued to the metal encased chipboard flooring. All the walls and ceilings were coated with emulsion paint. The top floor ceiling was constructed with 'Glulam' timber beam with exposed treated timber panels and joists. Pre-cast concrete curvature ceilings were installed in the ground floor and the first floor office areas. Parquet floor tiles were fixed with adhesives in the ground floor concourse area of the conference centre. Plywood was used to cover ducting in this area and for wall panelling and decking.

THE SAMPLING AND ANALYSIS OF VOCs IN THE NEW OFFICE BUILDING

Passive sampling methods (Yu et al, 1997) were used for monitoring VOCs and formaldehyde in the new office building for a three-year period from January 1997 – December 1999. The VOC passive sampler was a Perkin Elmer type adsorption tube containing Tenax TA and the formaldehyde passive sampler was a badge (GMD 570) containing a 2,4-dinitrophenylhydrazine coated filter paper. The passive samplers were strategically placed every month in the open plan offices on each floor and also in the concourse area and lecture theatre in the conference centre (Yu et al, 1999).

The VOC samplers were exposed for 28 days and were analysed by thermal desorption/gas chromatography using flame ionisation detection for quantification and ion trap detection for confirmation of the identities of compounds. The formaldehyde samplers were exposed for three days at 28-day intervals, and high performance liquid chromatography was used for the analysis.

During building construction, samples of the various types of building and furnishing materials were collected for analysis and sealed in cans or with aluminium foil. Some consumer products such as cleaning agents were also collected after the building had been occupied. These samples were then subject to emission testing using 2.4 L micro-chambers and 1 m^3 environmental test chambers, which have been described previously (Yu et al, 1997). The results were used to identify the VOCs released and compare these with the VOCs found in the different parts of the building atmosphere.

RESULTS AND DISCUSSION

Table 1 shows the concentrations of formaldehyde and some of the major VOCs and TVOC in the ground floor and top floor offices over the three-year period of monitoring. As would be expected in a new building, a wide range of VOCs and their sources were identified, but not at hazardous concentrations. The outdoor concentrations were much lower and, except for toluene, was not an important source of these compounds in the indoor air. The mean concentration for summer months (April to September) and winter months (October to March) is presented. Also included is the total number of individual compounds detected in the air by the sampling and analytical method. Figures 1 and 2 illustrate the changes in the indoor TVOC concentrations over the monitoring period.

In the ground floor office it took five months for the TVOC concentration to decline from a peak of 1225 $\mu g/m^3$ to about 400 $\mu g/m^3$. After six months, the concentration of TVOC was about 200-300 $\mu g/m^3$. The mean concentration of TVOC is generally higher in winter than summer, probably due to lower ventilation rates in winter. There are also other occasional rises in TVOC concentration as shown in Figure 1, which are probably due to differences in occupant activities. The TVOC concentration in the unoccupied top floor open plan office was consistently above the Australian indoor air quality (IAQ) guideline value (Dingle, 1993) of 500 $\mu g/m^3$ during the first year of monitoring. For the other two years it was mostly in the range 400-500 $\mu g/m^3$, which is higher than some other proposed targets for IAQ (European Concerted Action, 1992). The lower concentrations on the ground floor than the top floor probably occurred because of the higher ventilation rate on the ground floor, provided by the stack ventilation system. The top floor was mostly unoccupied during the three-year monitoring period and the windows were usually closed. With occupation, it is to be expected that concentrations would have declined more rapidly.

TABLE 1

MEAN WINTER AND SUMMER CONCENTRATIONS OF FORMALDEHYDE AND SOME VOCS (µg/m^3)

Ground Floor Open Plan Office:

	HCHO	TVOC	TXIB	Xylenes	Toluene	Texanols	Undecane	No. of VOCs
Summer 97	21	361	159	62	14	53	4	311
Winter 97	18	648	337	119	36	117	6	365
Summer 98	31	199	92	14	25	25	1	252
Winter 98	30	351	158	24	93	28	2	265
Summer 99	33	174	143	8	5	22	1	161
Winter 99	33	307	169	21	16	42	3	233

Top Floor Open Plan Office:

	HCHO	TVOC	TXIB	Xylenes	Toluene	Texanols	Undecane	No. of VOCs
Summer 97	33	628	242	25	14	29	21	345
Winter 97	19	1094	539	50	45	79	45	372
Summer 98	28	383	202	10	11	41	9	267
Winter 98	23	478	267	13	24	43	9	279
Summer 99	59	503	259	8	30	36	9	223
Winter 99*	37	409	214	12	49	22	5	259

* = October to December, HCHO = formaldehyde, TXIB = 2,2,4-trimethyl-1,3 pentanedioldiisobutyrate

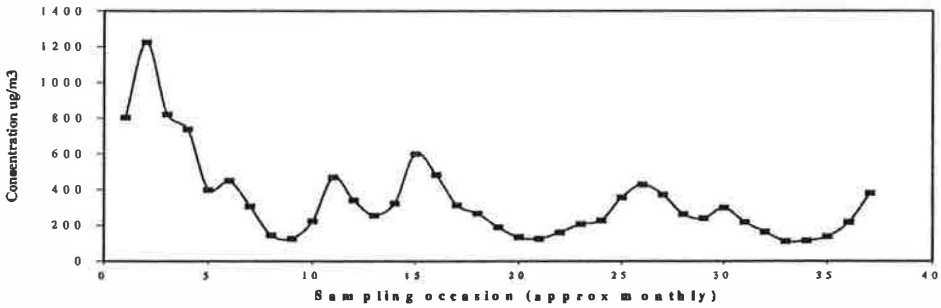

Figure 1: TVOC concentrations in the ground floor open plan office

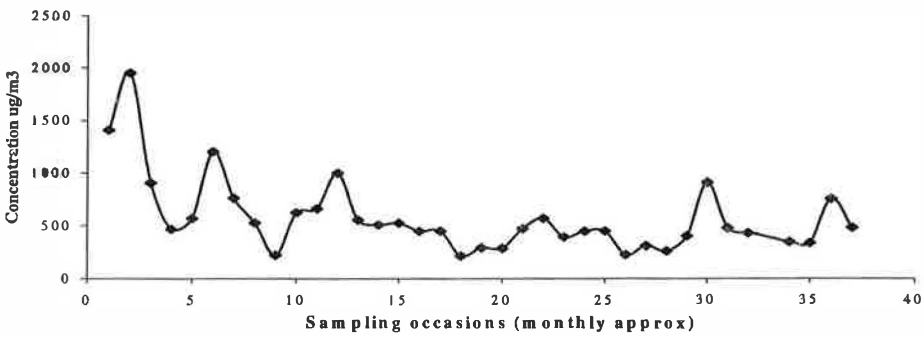

Figure 2: TVOC concentrations in the top floor open plan office

TABLE 2

THE TEN COMPOUNDS FOUND IN THE OPEN PLAN OFFICES AND IDENTIFIED EMISSION SOURCES

Upper half of table is 1st Year (7/1/97-12/1/97), lower half is 3rd Year (12/1/99-14/12/99)

Ground Floor Open Plan Office			Top Floor Open Plan Office		
Major VOCs		Source Materials	Major VOCs		Source Materials
1	TXIB	Carpet tiles	1	TXIB	Carpet tiles
2	Xylenes	Carpet, panel, pedestal, ceramic tile & wood adhesives; carpet tiles; chairs; coatings & lacquer; parquet tiles; treated timbers; paint & coated mineral wool floor insulation	2	2-Ethyl-hexanol	Carpet tiles; ceramic adhesives; sealant; paints
3	TMBs	Carpet, panel, pedestal, ceramic tile & wood adhesives; carpet tiles; chairs; coatings & lacquers; treated timbers; parquet tiles; paint & coated mineral wool floor insulation	3	Xylenes	Carpet, panel, pedestal adhesives; carpet tiles; chairs; coatings & lacquer & treated timbers; paint & coated mineral wool floor insulation
4	Texanols	Water-based paints	4	Undecane	Carpet tiles; pedestal & wood adhesives; paint, coatings; lacquers; sealant; chairs; treated timbers; coated mineral wool floor insulation; parquet tiles; cleaning products
5	Decane	Carpet tiles; pedestal & wood adhesives; paint, coatings; lacquers; sealant; chairs; treated timbers; coated mineral wool floor insulation; parquet tiles; cleaning products	5	Dodecane	Carpet tiles; pedestal & wood adhesives; paint, coatings; lacquers; sealant; chairs; treated timbers; coated mineral wool floor insulation; parquet tiles
6	Toluene	Carpet, panel & ceramic adhesives; sealant; chairs; paints; coatings & lacquers; treated timbers; parquet tiles; coated mineral wool floor insulation	6	Tridecane	Carpet tiles, treated timbers; chairs; coatings; lacquers; coated mineral wool; treated timbers
7	2-Ethyl-hexanol	Carpet tiles; ceramic adhesives; sealant; paints	7	Toluene	Carpet, panel & ceramic adhesives; sealants; chairs; paints; coatings & lacquers; treated timbers; parquet tiles; coated mineral wool floor insulation
8	Ethyl-benzene	Carpet, pedestal, ceramic & wood adhesives; sealant; chairs; coatings; paints; treated timbers	8	Unknown (RT 33.11)	Not identified
9	Butyl glycol	Water-based paints; floor polish	9	Decane	Carpet tiles; pedestal & wood adhesives; paint, coatings; lacquers; sealant; chairs; treated timbers; coated mineral wool floor insulation; parquet tiles; cleaning products
10	Phenol	Carpet tiles; chairs; plywood	10	TMBs	Carpet, panel, pedestal, ceramic tile & wood adhesives; carpet tiles; chairs; coatings & lacquer; treated timbers; parquet tiles; paint; coated mineral wool floor insulation
1	TXIB	See above	1	TXIB	See above
2	Xylenes	See above	2	Pinene	Timbers; plywood; wood-based furniture; parquet adhesives; chairs; MDF panels; wood coatings; polishes & cleaning products
3	Pinene	Timbers; plywood; wood-based furniture; parquet adhesives; chairs; MDF panels; wood coatings; polishes & cleaning products	3	Cyclo-hexane	Treated timbers; coatings
4	Toluene	See above	4	MEK	Carpet, parquet, pedestal & ceramic adhesives; sealant; treated timbers
5	TMBs	See above	5	Ethyl-acetate	Chipboard & furniture; timbers; plywood
6	Texanols	See above	6	Xylenes	See above
7	Ethyl-toluene	See above	7	Limonene	Timbers; parquet adhesives; chairs; air freshener; cleaning products & polishes
8	MEK	Carpet, parquet, pedestal & ceramic adhesives; sealant; treated timbers	8	2-ethyl-hexanol	Carpet tiles; sealant; paints
9	Hexanoic acid	Paint, wood coatings; timbers; chipboard furniture	9	Undecane	See above
10	Limon-ene	Timbers; parquet adhesives; chairs; polish; cleaning products; air freshener	10	Toluene	See above

TMBs = trimethylbenzenes, 4PC = 4 phenylcyclohexene, MEK= methylethylketone, RT= retention time (minutes)

The formaldehyde concentrations were below the World Health Organisation air quality guideline of 100 µg/m^3 (WHO, 1987). In contrast to the TVOC, the summer concentrations were generally higher than those in winter. This suggests that the source of formaldehyde was stronger in summer and this offset the effect of higher ventilation. It is known that the emission of formaldehyde from products such as wood-based panels that contain urea formaldehyde adhesives increases with temperature. The sources of formaldehyde emission found were the wood-based furniture products, MDF wall panels, parquet flooring, carpet tiles and to a lesser extent, plywood panels. The major emission sources for the 10 dominant VOCs found in the air of the building is shown in Table 2.

CONCLUSIONS

The building materials were found to be a source of a wide range of VOCs. For most of the major VOCs in the air there were multiple material sources. Single sources were found for TXIB, a plasticiser in flooring products and Texanols, coalescing solvents in water borne emulsion paints. Further work is examining the influence of consumer products such as cleaning materials on the IAQ and quantifying the strength of the sources identified in the office building. The results to date indicate that, as would be expected in a new building, the building materials and furnishing products are the dominant source of VOCs in the indoor environment of a new office building.

The building did not have unusually high VOC levels and the main point of this work was not to measure levels but to identify sources. IAQ should ideally be controlled by a combination of limiting emission sources and having well planned ventilation. To reduce VOC concentrations in buildings, it is necessary to choose materials that will produce a low pollution load in the indoor air. Increasingly, information on emissions from materials is becoming available and, therefore, systematic selection of low-polluting materials should become a standard element of designing buildings for good IAQ (CEN, 1998). The availability of material emission databases, such as that being developed in this project, will enable building designers in the future to specify materials that have the least adverse impact on the building air quality.

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