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Furry pet allergens, fungal DNA and microbial volatile organic compounds (MVOCs) in the commercial aircraft cabin environment

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There has been concern about the cabin environment in commercial aircraft. We measured cat, dog and horse allergens and fungal DNA in cabin dust and microbial volatile organic compounds (MVOCs) in cabin air. Samples were collected from two European airline companies, one with cabins having textile seats (TSC) and the other with cabins having leather seats (LSC), 9 airplanes from each company. Dust was vacuumed from seats and floors in the flight deck and different parts of the cabin. Cat (Fel d1), dog (Can f1) and horse allergens (Equ cx) were analyzed by ELISA. Five sequences of fungal DNA were analyzed by quantitative PCR. MVOCs were sampled on charcoal tubes in 42 TSC flights, and 17 compounds were analyzed by gas chromatography mass spectrometry (GC-MS) with selective ion monitoring (SIM). MVOC levels were compared with levels in homes from Nordic countries. The weight of dust was 1.8 times larger in TSC cabins as compared to LSC cabins ($p < 0.001$). In cabins with textile seats, the geometric mean (GM) concentrations of Fel d1, Can f1 and Equ cx were 5359 ng g^{-1} , 6067 ng g^{-1} , and $13\,703 \text{ ng g}^{-1}$ (GM) respectively. Levels of Fel d1, Can f1 and Equ cx were 50 times, 27 times and 75 times higher respectively, in TSC cabins as compared to LSC cabins ($p < 0.001$). GM levels of *Aspergillus/Penicillium* DNA, *Aspergillus versicolor* DNA, *Stachybotrys chartarum* DNA and *Streptomyces* DNA were all higher in TSC as compared to LSC ($p < 0.05$). The sum of MVOCs in cabin air (excluding butanols) was 3192 ng m^{-3} (GM), 3.7 times higher than in homes ($p < 0.001$) and 2-methyl-1-butanol and 3-methyl-1-butanol concentrations were 15–17 times higher as compared to homes ($p < 0.001$). Concentrations of isobutanol, 1-butanol, dimethyldisulfide, 2-hexanone, 2-heptanone, 3-octanone, isobutyl acetate and ethyl-2-methylbutyrate were lower in cabin air as compared to homes ($p < 0.05$). In conclusion, textile seats are much more contaminated by pet allergens and fungal DNA than leather seats. The use of seats with smooth surfaces should be encouraged. The MVOC levels differed between cabin air and homes.

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Environmental impact

The aircraft cabin environment is an important indoor environment and can influence the health of passengers and staff. There is little information on levels of allergens and moulds in commercial aircraft. We measured cat, dog and horse allergens and fungal DNA in settled dust in aircraft with either textile or leather seats. Moreover we measured microbial volatile organic compound (MVOC) levels in cabin air. Furry pet allergen levels in aircraft with textile seats were 27–75 times higher than in aircraft with leather seats, and higher than in Swedish schools. Fungal DNA levels were low. The sum of MVOCs in cabin air was higher than in Nordic homes. The allergen exposure in the cabin could be a problem for passengers with furry pet allergy.

1 Introduction

International Air Transport Association reported that commercial aircraft transported 2.8 billion people worldwide in the year 2011 and this is estimated to increase to around 3.5 billion people transported annually in 2015.¹ Cabin air quality is one

important issue when discussing medical issues associated with commercial flights.² The cabin environment quality is influenced by the airplane ventilation system,³ as well as material emissions and activities in the cabin.

Crowded indoor environments, such as schools and day care centers, can contain considerable amounts of pet allergens transferred by clothes or hair from homes of pet keepers.⁴ This can be a health problem for people with allergies. Very few studies were about furry pet allergy during flight. A study from New Zealand on cat allergen (Fel d1) contamination in public places reported that levels were higher on seats than on floors in

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domestic aircraft.⁵ In some airlines, small furry pets are allowed to be brought into the cabin with their hosts. It can be assumed that the material of the seats on airplanes could affect allergen levels on board. According to former studies, a larger amount of textile materials in a room can increase the levels of allergens in the dust.⁶

Since aircraft cabins are crowded environments, airborne transmission of pathogens, such as bacteria and viruses, has been of great concern. Modern aircraft have 30–50% air recirculation, but the recirculated air is mostly filtered through HEPA (High Efficiency Particulate Air) filters to remove particles, including microorganisms.^{7,8} Investigation of bacterial contaminations in cabins has found a number of potentially pathogenic bacteria.⁹ In addition, influenza virus and rhinovirus have been detected on aircraft air filters.¹⁰ The general conclusion is, however, that the major cause of an infection spreading is between people seated near each other in the cabin, and the contribution from the recirculated air is very small.^{11,12}

World Health Organization (WHO) has concluded that fungal contamination of indoor environments in damp and mouldy buildings is of health concern.¹³ Buildings usually have a damp barrier to prevent humidity from the indoor environment penetrating the walls of the construction. The aircraft wall has mineral insulation but no barrier to damp. The humidity evaporating from the passengers can enter the wall and condense, with potential for fungal and bacterial growth. This source of microbial exposure in the passenger and aircraft crew cabins has not been addressed previously. There are different ways to measure indoor mould exposure. The traditional method has been to sample air and measure the number of viable spores by cultivation on different media. Our previous study reported that, in aircraft, airborne viable bacteria and viable mould levels are low, and lower than in crew hotels used by the airline staff.¹⁴ Quantitative Polymerase Chain Reaction (qPCR) analysis is a new method to detect indoor fungi.^{15,16} It will detect the total amount of fungi irrespective of viability. It has been reported that fungal DNA levels are higher in buildings with risk constructions than in those with non-risk constructions.⁴ Risk constructions refer to building constructions which have a high risk of increased dampness, and non-risk constructions refer to building constructions which have a low risk of dampness. Moreover, in schools that had higher levels of some types of fungal DNA, respiratory symptoms in school children were more common.^{17–19} These school studies on fungal DNA have measured five sequences of fungal DNA, one was common for a large number of species (total fungal DNA), one was common for *Aspergillus* and *Penicillium* (*Asp/Pen*), and three were specific for fungi that produce particular mycotoxins: *Aspergillus versicolor* (*A. versicolor*), *Stachybotrys chartarum* (*S. chartarum*) and *Streptomyces*. These commonly detected moulds can produce different types of mycotoxins.^{19,20} *Aspergillus versicolor* has been reported to be a risk factor for daytime breathlessness and also wheezing.¹⁹ *Streptomyces* is Gram-positive spore-forming bacteria, which has been found originally in the soil.²¹ The *Streptomyces* DNA level in schools has been reported to be associated with doctor-diagnosed asthma¹⁹ and lower lung function.¹⁷

Another new method to detect microorganisms in building constructions is to measure the microbial volatile organic compounds, so-called MVOCs.²² MVOCs are emitted from moulds as well as bacteria. Associations between levels of some MVOCs in homes and mucosal symptoms, including rhinitis and conjunctivitis, have been reported, especially the compound 1-octen-3-ol.^{23,24} Levels of certain MVOCs, including 2-pentanol, 2-hexanone, 1-octen-3-ol and 2-pentylfuran, have been reported to be positively associated with sick building syndrome (SBS).²⁵ We found no previous studies on MVOC levels in the airplane cabin environment.

The aim of this study is: to measure the level of pet allergens, fungal DNA, and MVOCs in aircraft; to compare the levels of cat, dog and horse allergens and five sequences of fungal DNA between different parts of the aircraft; and also to compare the levels of cat, dog and horse allergens and fungal DNA between aircraft in cabins with textile seats and leather seats; finally, to compare the levels of MVOCs in aircraft with MVOC levels measured by the same methodology in a random sample of homes in Northern Europe.²⁵

2 Materials and methods

2.1 Selection of airplanes, companies, routes, types of aircraft

Dust samples were collected from 18 flights belonging to two airline companies, represented by TSC (textile seat company) and LSC (leather seat company), 9 flights from each company. Flights from TSC included four Airbus 340 airplanes, three Boeing 737 airplanes and two McDonnell Douglas MD-80 airplanes, while all airplanes from LSC were airbus models 320–340. TSC uses textile in both the flight deck and cabin seats, while LSC uses leather seats in cabin but textile seats in the flight deck. In each flight, four dust samples representing the flight deck (FD), the forward part of the cabin (FWD), the middle part of the cabin (MID) and the aft part of the cabin (AFT) were collected. One Boeing 737 MID sample was missing. Therefore, 35 dust samples from TSC and 36 dust samples from LSC were available for the studies. Airborne MVOCs were sampled in the cabin in TSC airplanes, during cruise, in 42 other aircraft (Boeing 767, Airbus 320 and Airbus 340). The levels of MVOCs were compared with previously collected data from a random sample of 92 homes in Reykjavik (Iceland), Uppsala (Sweden) and Tartu (Estonia).²⁵

2.2 Dust sampling

Dust sampling was performed while the airplane was on the ground, between flights, before the ordinary cleaning staff arrived to clean the cabin. Settled dust was collected by a vacuum cleaner with variable effect (Siemens Super XS din e 188W) operated at 1200 W. It was provided with a special dust collector (ALK Abello, Copenhagen, Denmark) equipped with a Millipore filter (pore size 6 µm). The filter is made of cellulose acetate, and according to the manufacturer it retains 74% of particles 0.3–0.5 µm, 81% of particles 0.5–1.0 µm, 95% of particles 1–10 µm and about 100% of larger particles (>10 µm).

Vacuum cleaning was performed for totally 4 minutes per sample, 2 minutes on upper surfaces (passenger seats) and 2 minutes on the floor as in previous school studies.^{6,17,27} For the sample from the cockpit all seats and floor areas were vacuumed. For each sample from the cabin, 10 passenger seats and the floor area below the seats were vacuumed. From each filter 100 mg of dust was taken for allergen analysis at our laboratory. The remaining dust was sieved through a 0.3 mm mesh screen to obtain the fine dust, weighed, and used for analysis of fungal DNA. All filters were sealed in plastic bags and stored at -20°C until dust samples were taken for allergen and fungal DNA analysis.

2.3 Allergen analysis

Samples of settled dust (100 mg) were extracted in 2 ml of phosphate buffered saline containing 0.05% Tween 20 (1/20 w/v) by rotating mixing for two hours at room temperature. The liquid was then centrifuged at 4500 rpm for 10 min followed by another centrifugation of the supernatant at 10 000 rpm for 10 minutes. The final supernatant was transferred into microtubes (Sarstedt, Germany) and stored frozen at -20°C until it was analyzed for the content of allergens. Enzyme-Linked Immunosorbent Assay (ELISA) was performed to determine the allergen levels of cat (Fel d1), dog (Can f1) (Indoor Biotechnologies Ltd, Manchester, UK), and horse (Equ cx) allergens (Mabtech, Stockholm, Sweden)²⁸ as previously described.^{27,29} The cat and dog allergen concentrations were presented as ng per g dust, while the horse allergen was presented as units per g dust (U g^{-1}), where 1 unit is a standard equal to 1 ng protein extracted from horsehair and dander (Allergon, Valinge, Sweden and NIBSC, Hertfordshire, UK). All samples were diluted at two levels, and samples with high concentrations were further diluted to check linearity. The detection limits for Fel d1, Can f1 and Equ cx were 50 ng per g, 160 ng per g and 80 ng per g dust.

2.4 Analysis of fungal DNA by qPCR

The method has been previously described.¹⁹ Briefly, fungal DNA was extracted from 10 mg of sieved dust and five multiplex reactions were performed in five separate tubes targeting the DNA of the following species: total fungi, *Aspergillus/Penicillium* (*Asp/Pen*), *Aspergillus versicolor* (*A. versicolor*), *Stachybotrys chartarum* (*S. chartarum*) and *Streptomyces*. The reaction targeting *A. versicolor* simultaneously amplified an internal positive control that was used to detect PCR inhibition. The oligonucleotides used for amplification and detection were designed using the design software Primer Express 2.0 (Applied Biosystems, Foster City, CA USA). Amplification and detection was performed on a 7300 Real-time PCR Instrument (Applied Biosystems, Foster City, CA USA) using the Taqman® Universal Master Mix (Applied Biosystems, Foster City, CA USA). The fungal DNA level was expressed as cell equivalents (CE), assuming one sequence per cell.¹⁹ The final result was presented as CE per g dust.

2.5 Analysis of MVOCs and plasticizers in cabin air

Airborne MVOCs were sampled on a charcoal tube (Anasorb 747, SKC Inc) (0.25 l min^{-1} ; 4 hours) during cruise. The tubes

were desorbed with 2 ml of methylene chloride, and analysed by selective ion monitoring (SIM) gas chromatography mass spectrometry (GC-MS) by Pegasus Lab AB, Uppsala, Sweden.^{22,26} The following 15 compounds were measured; 3-methylfuran, 2-butanol, 1-butanol, 2-pentanol, 3-methyl-1-butanol, dimethyldisulfide (DMDS), 2-hexanone, 2-heptanone, 1-octen-3-ol, 3-octanone, 2-methyl-1-butanol, ethylisobutyrate, isobutylacetate, ethyl-2-methylbutyrate and 2-pentylfuran. The total concentration of the selected MVOCs was calculated (12 compounds), by mass summation, excluding the butanols. The detection limit was 1 ng m^{-3} for all MVOCs.

2.6 Analysis of microbial growth in mineral insulation

We have analyzed one mineral insulation sample taken from the wall of one aircraft, when the interior of the wall was removed for a scheduled inspection. The sample was analyzed for total and viable moulds and bacteria by the CAMNEA method.³⁰ This method analyzes total levels of moulds and bacteria by staining and fluorescence microscopy. In addition, viable mould and bacteria were analyzed by cultivation on two media. We applied empirical reference values from the microbiological laboratory. According to the classification of mineral insulation published before, mineral insulations with total fungi or bacteria levels less than 10^4 organisms per g insulation were classified as normal, while mineral insulations with total fungi or bacteria levels more than 10^6 organisms per g insulation were classified as "elevated".³¹ The corresponding limits for viable moulds and bacteria were 10 times lower.

2.7 Statistical analysis

Concentrations of allergens, fungal DNA and MVOCs were calculated and presented as geometric mean (GM) and geometric standard deviation (GSD). For samples where the results were below the detection limit, half the detection limit was used when calculating GM values. The differences in allergen and fungal DNA between TSC and LSC groups and between different locations within the aircraft were tested by the Mann-Whitney *U* test (2 groups) and the Kruskal-Wallis test (more than 2 groups). MVOC levels in TSC were analyzed by the Mann-Whitney *U* test, and compared with data from the homes. For all tests, the significant level was $p < 0.05$. Median allergen concentrations were also calculated for later comparison with other studies.

3 Results

3.1 Furry pet allergen levels

The total weight of dust samples was 1.75 times higher in TSC cabins than in LSC cabins ($p < 0.001$). Concentrations of Fel d1, Can f1 and Equ cx in TSC cabins were 50 times, 27 times and 75 times higher respectively as compared to LSC cabins ($p < 0.001$). Amounts of Fel d1, Can f1 and Equ cx in TSC cabins were 87 times, 47 times and 132 times higher respectively as compared to LSC cabins ($p < 0.001$) (Table 1). Among TSC samples, samples from the flight deck and cabin had similar

Table 1 Pet allergens analysis between the flight deck and cabin as well as companies^a

		Flight deck				Cabin				<i>p</i> -Value
		<i>N</i>	AM	GM (GSD)	Range	<i>N</i>	AM	GM (GSD)	Range	
TSC	Total weight of the sample (g)	9	0.268	0.231 (1.78)	0.109–0.524	26	0.292	0.261 (1.68) ^d	0.68–0.626	0.473
	Fel d1 (ng g ⁻¹)	9	3883	3503 (1.60) ^b	2137–6516	26	6154	5359 (1.76) ^e	1452–13 795	0.035
	Can f1 (ng g ⁻¹)	9	2552	2413 (1.43) ^b	1254–4169	26	6551	6067 (1.51) ^e	1810–12 469	<0.001
	Equ ex (U g ⁻¹)	9	11 418	10 814 (1.41) ^b	7405–18 576	26	18 061	13 703 (2.16) ^e	2793–55 990	0.497
	Amount of cat allergen per sample (ng)	9	1071	807 (2.21) ^c	314–3091	26	2042	1399 (2.74) ^e	99–6912	0.076
	Amount of dog allergen per sample (ng)	9	722	568 (2.21) ^c	176–1448	26	2043	1584 (2.28) ^e	124–5697	0.003
	Amount of horse allergen per sample (U)	9	3083	2494 (2.08) ^c	806–5935	26	5818	3577 (2.96) ^e	191–23 091	0.345
LSC	Total weight of sample (g)	9	0.389	0.371 (1.37)	0.244–0.701	27	0.152	0.149 (1.26)	0.064–0.221	<0.001
	Fel d1 (ng g ⁻¹)	9	686	587 (1.82)	248–1187	27	182	107 (3.27)	25–502	<0.001
	Can f1 (ng g ⁻¹)	9	495	438 (1.71)	169–960	27	400	227 (2.52)	79–2850	<0.001
	Equ ex (U g ⁻¹)	9	1839	1761 (1.38)	1000–2751	27	343	183 (3.35)	39–1794	0.015
	Amount of cat allergen per sample (ng)	9	292	218 (2.25)	84–832	27	26	16 (3.11)	3–70	<0.001
	Amount of dog allergen per sample (ng)	9	213	162 (2.41)	62–581	27	62	34 (2.77)	5–402	<0.001
	Amount of horse allergen per sample (U)	9	714	653 (1.59)	308–1150	27	53	27 (3.52)	5–284	<0.001

^a Significant level is $p < 0.05$. ^b In the flight deck, the concentrations of cat, dog and horse allergens in TSC are significantly higher than in LSC. The p values are all < 0.001 . ^c In the flight deck, the amounts of cat, dog and horse allergens in TSC are significantly higher than in LSC. The p values are 0.004, 0.012 and 0.001 respectively. ^d In the cabin, the total weights of each sample are significantly higher in TSC than in LSC at p values < 0.001 . ^e In the cabin, the concentrations as well as the amounts of cat, dog and horse allergens in TSC are significantly higher than in LSC. The p values are all < 0.001 .

Table 2 Average fungal DNA levels in TSC and LSC flights^a

Fungal DNA (CE g ⁻¹)	Mean TSC			Mean LSC			<i>p</i> -Value
	AM	GM (GSD)	Range	AM	GM (GSD)	Range	
Total DNA (10 ⁴)	4.84	4.45 (1.57)	2.08–7.71	5.45	4.94 (1.69)	1.47–8.25	0.508
<i>Asp/Pen</i> DNA (10 ³)	7.79	7.64 (1.24)	4.86–9.61	1.92	1.56 (1.97)	0.70–4.47	<0.001
<i>A. vers</i> DNA	58.63	54.65 (1.50)	31–91	21.11	12.99 (4.10)	0–38	0.002
<i>Stachybotrys</i>	0.67	NA	0–2	0.00	NA	0–0	<0.001
<i>Streptomyces</i>	3.96	NA	1–6.67	0.78	NA	0–4	0.002

^a Significant level is $p < 0.05$. NA: not available. There were quite a few values over the detection limit, therefore the GM was not calculated.

total dust weight. Fel d1 and Can f1 concentrations were higher in cabin samples as compared to the flight deck ($p < 0.05$), and the amount of dog allergen was almost 2 times higher in cabin samples. In LSC aircraft, samples from the flight deck contained more dust than cabin samples. Moreover, LSC flight deck samples contained larger amounts and higher concentrations of Fel d1, Can f1 and Equ cx ($p < 0.05$) (Table 1). In TSC aircraft, median concentrations for Fel d1, Can f1 and Equ cx were 2285 ng g⁻¹, 2288 ng g⁻¹ and 9537 ng g⁻¹ respectively in the flight deck and 5520 ng g⁻¹, 6132 ng g⁻¹ and 12678 ng g⁻¹ respectively in the cabin. In LSC aircraft, median concentrations for Fel d1, Can f1 and Equ cx were 589 ng g⁻¹, 450 ng g⁻¹ and 1966 ng g⁻¹ respectively in the flight deck and 181 ng g⁻¹, 202 ng g⁻¹ and 232 ng g⁻¹ respectively in the cabin.

3.2 Fungal DNA levels

Total fungal DNA levels in vacuumed dust did not differ between TSC airplanes and LSC airplanes. However, the concentrations of *Asp/Pen* DNA, *A. versicolor* DNA, *S. chartarum* DNA and *Streptomyces* DNA were all higher in TSC than in LSC aircraft (Table 2). In TSC aircraft, the flight deck and the forward part of the cabin had similar fungal DNA levels. There is a trend that the aft part of cabin had higher fungal DNA levels, though the difference was not significant (Table 3).

3.3 MVOC levels

Levels of MVOCs in TSC were analyzed and compared with data on MVOC levels in the home environment from three Nordic countries. MVOC levels were different between airplanes and

Table 3 Fungal DNA level in different locations in TSC flights^a

Fungal DNA (CE g ⁻¹)	FD			FWD			AFT		
	AM	GM (GSD)	Range	AM	GM (GSD)	Range	AM	GM (GSD)	Range
Total DNA (10 ⁴)	4.19	3.86 (1.51)	2.42–7.55	4.03	3.63 (1.65)	1.70–6.95	6.29	5.08 (2.04)	1.51–15.37
<i>Asp/Pen</i> DNA (10 ³)	6.67	6.14 (1.58)	2.46–11.42	7.40	7.16 (1.3)	4.92–10.27	9.31	8.85 (1.42)	4.41–13.86
<i>A. vers</i> DNA	48.56	44 (1.61)	24–86	57.44	45 (2.22)	11–118	69.89	64 (1.59)	34–113
<i>Stachybotrys</i> DNA	0.44	NA	0–3	0.33	NA	0–1	1.22	NA	0–6
<i>Streptomyces</i> DNA	4.11	NA	1–8	1.56	NA	0–6	6.22	NA	2–12

^a NA: not available. There are quite a few values over the detection limit, therefore the GM was not calculated. FD: flight deck. FWD: forward part of the cabin. AFT: aft part of the cabin.

Table 4 MVOC levels in TSC flights and home indoor environment

MVOC	TSC (ng m ⁻³)				HOME (ng m ⁻³)				<i>p</i> -Value
	<i>N</i>	AM	GM (GSD)	Range	<i>N</i>	AM	GM (GSD)	Range	
Sum of MVOC	42	5307	3192 (2.992)	290–32 460	92	1254	862 (2.391)	50–7690	<0.001
3-Methylfuran	42	85	18 (6.330)	1–670	91	33	19 (2.999)	1–370	0.181
Isobutanol	42	3223	451 (2.086)	540–14 440	92	2452	1692 (2.295)	190–14 000	0.008
1-Butanol	42	724	564 (2.022)	80–4090	92	8808	6023 (2.320)	650–78 000	<0.001
2-Pentanol	42	49	8 (8.827)	1–1098	89	26	12 (4.011)	1–220	0.552
3-Methyl-1-butanol	35	5975	4372 (2.124)	1110–31 320	45	469	256 (3.246)	<1–5320	<0.001
Dimethyldisulfide	32	22	6 (6.209)	1–220	89	227	25 (5.984)	1–4080	<0.001
2-Hexanone	42	44	30 (2.267)	7–210	92	80	59 (2.267)	11–300	<0.001
2-Heptanone	42	91	70 (2.065)	18–450	92	440	312 (2.251)	40–3170	<0.001
1-Octen-3-ol	42	78	64 (1.865)	11–280	83	72	46 (2.515)	7–460	0.021
3-Octanone	29	11	7 (3.611)	<1–38	75	461	39 (1.758)	13–170	<0.001
2-Methyl-1-butanol	39	1404	1013 (2.123)	260–9410	42	110	67 (2.512)	10–940	<0.001
Ethyl isobutyrate	42	14	4 (6.818)	1–93	92	4	1 (3.185)	1–72	0.024
Isobutyl acetate	42	46	13 (8.741)	1–3000	40	210	53 (9.318)	1–2530	<0.001
Ethyl-2-methylbutyrate	39	13	9 (2.856)	<1–46	84	122	22 (7.706)	<1–2390	0.013
2-Pentylfuran	35	42	35 (2.352)	1–120	85	618	41 (4.466)	<1–46 000	0.712

homes (Table 4). The sum of MVOC concentration in the cabin environment was 3192 ng m⁻³ (GM), 3.7 times higher than in the homes ($p < 0.001$). Levels of 3-methyl-1-butanol and 2-methyl-1-butanol, 1-octen-3-ol and ethyl isobutyrate were 17, 15, 1.4 and 4 times higher in aircraft as compared to homes, respectively ($p < 0.05$). In contrast, isobutanol, 1-butanol, dimethyldisulfide, 2-hexanone, 2-heptanone, 3-octanone, isobutyl acetate and ethyl-2-methylbutyrate were lower in cabin air ($p < 0.05$). Additionally, levels of 3-methylfuran, 2-pentanol and 2-pentylfuran did not differ between aircraft and homes (Table 4).

3.4 Microbial growth in mineral insulation

Both the total bacteria level and the total fungi level of the mineral insulation sample were above the standard for the elevated level (10⁶ organisms per g insulation). The viable bacteria level was also elevated compared to the standard. Among viable species from the insulation sample, yeast and the Gram negative bacteria *Pseudomonas* sp. were identified.

4 Discussion

Levels of cat, dog and horse allergens in vacuumed dust were on average 27–74 times higher in aircraft with textile seats as

compared to those with leather seats. In addition, dust levels of specific fungal DNA, but not total fungal DNA, were higher in aircraft with textile seats. The sum of MVOC levels in cabin air was higher than in a random sample of homes, mainly because of the elevated levels of two pentanols in cabin air.

Different types of aircraft were included in the study which should have a reasonable representativeness of the airplanes used in commercial air transportation, but the leather textile samples were all taken from Airbus aircraft. However, the ventilation system has a similar design in all modern aircraft, using 30–50% air recirculation and air filtration of return air,^{7,8} so it is less likely that the type of aircraft would influence the levels of sampled pollutants. One limitation of the study is the small number of samples, but despite this limited study size, highly significant differences were found. Another limitation is that we did not perform personal or static air sampling to measure allergens and fungal DNA levels. However, other studies have shown significant correlation between vacuumed dust allergen levels and air allergen levels where airborne dust was sampled using Petri dish or electrostatic samplers with a long sampling time (correlation coefficients 0.27–0.58).^{32,33} A correlation coefficient of 0.65 between the endotoxin level in floor dust and in air has also been reported.³⁴ Moreover, studies

which have reported associations between furry pet allergens and asthmatic symptoms have all used allergen measurements in settled dust.^{29,35–37}

We found much higher levels of cat, dog and horse allergens in aircraft with textile seats as compared to leather seats. Cabins are cleaned on a regular basis in the airport, between flights, but the cleaning procedure only involves cleaning of the floor. This enables allergens to accumulate in the seats, especially in the textile material. Studies on allergen levels in schools found that textiles are reservoirs of allergens and irritants.^{6,35} The levels of cat, dog and horse allergens in aircraft with textile seats were higher than levels previously reported from Swedish schools.^{6,29,35} In cabins with textile seats, allergen levels were 6.4–13 times higher than in schools, while in cabins with leather seats, allergen levels were 20–30% of the school levels.²⁹ When compared to home levels, cat allergen levels in cat keepers' homes were much higher than in the cabin environment, but that was voluntary exposure. The main source of the allergens found in the cabin environment is most likely transfer of allergens from the home environment among those keeping cat or dogs or riding horses. In addition, some airline companies allow small pets to be kept in the cabin. We found only two previous studies measuring allergen contamination in the cabin environment.^{5,38}

We have no information on the number of pet keepers on board or the number of passengers sensitized to cats, dogs and horses. However, studies from northern Europe have shown that a relatively large portion of the population is sensitized to furry pets.³⁹ A study based on specific IgE levels from blood samples reported that 4.7%, 22.2% and 10% people were sensitized to cats in Iceland, Sweden and Estonia respectively.³⁹ Another study reported that 5.38% of people in Italy had positive skin reaction to the horse dander skin prick test.⁴⁰ These studies were based on testing of a randomly selected population. Studies from schools have demonstrated that cat allergen contaminations in the classroom can be a risk factor for asthma symptoms in sensitized children.^{35,36} In addition, cat, dog and horse allergens can cause allergic respiratory symptoms in sensitized subjects. Moreover, horse allergen but not cat or dog allergen has been reported to cause anaphylaxis in rare cases.⁴¹ Studies about the cabin environment concerning health have mainly focused on chemicals, bacterial pathogens, viral infections and allergic reactions to tree nuts and peanuts.^{42–44} Our study showed that furry pet allergen contamination in the cabin should also be considered as a risk factor.

Moulds may grow under moist conditions in indoor environments.¹³ In this study we used two different methods, measurement of fungal DNA and MVOCs, to measure fungal contamination in the aircraft. Since measurements of fungal DNA and MVOCs were done at different time periods, and under different conditions, we cannot compare DNA and MVOC levels measured in the same aircraft. We found no previous publication on measurements of fungal DNA or MVOCs in aircraft. Moreover, we found no previous data on fungal DNA in vacuumed dust from homes, using the same method for fungal DNA analysis as used in our study. However, when comparing our data on fungal DNA with data from European schools, the

total fungal level in the cabin was about one fifth of that in European classrooms.¹⁷ It is reasonable to compare with schools since they are also crowded indoor environments. In accordance with the data on allergen levels, we found higher levels of fungal DNA in aircraft with textile seats as compared to leather seats, suggesting that accumulation of moulds in textiles can also be a hygienic problem.

In contrast to the low levels of fungal DNA, levels of the sum of MVOCs were 3.7 times higher in cabin air as compared to randomly selected homes in three cities in Northern Europe, and levels of 3-methyl-1-butanol and 2-methyl-1-butanol, 1-octen-3-ol were elevated 17, 15 and 1.4 times. Many other MVOC compounds were found at lower levels in cabin air as compared to homes. MVOCs as damp indicators have been questioned. However, a home environment study showed that levels of 2-methyl-1-butanol and 1-octen-3-ol were elevated in homes with verified mould growth,⁴⁵ though with weak association. These two MVOC compounds were elevated in our study, and may indicate mould growth in the airplane. However, there are other possible sources for the elevated MVOC level. Both 3-methyl-1-butanol and 2-methyl-1-butanol can be produced by mould like *Mycobacterium*.⁴⁶ Besides, 3-methyl-1-butanol is widely used as a fragrance ingredient.⁴⁷ A possible microbial source would be microbial growth in the mineral insulation in the cabin wall. The sample we took from the mineral insulation contained elevated levels of total fungi and total bacteria according to the classification standard (more than 10⁶ organisms per g insulation). The health significance of indoor MVOCs is unclear but two home environment studies have found associations between levels of 1-octen-3-ol and Sick Building Syndrome (SBS).^{24,25} None of those studies found associations between the two pentanols and SBS. This suggests that MVOCs in cabin air may be of limited health significance.

5 Conclusion

In conclusion, levels of pet allergens in dust are much higher in aircraft with textile seats as compared to leather seats, and use of smooth materials on the seats in aircraft should be encouraged. Allergen levels in vacuumed dust from aircraft were higher than in schools, where allergen levels have been reported to cause allergic reactions in school children. The level of fungal DNA in dust was low as compared to other studies from buildings while the levels of some MVOCs were higher than in homes. Further studies are needed to identify the sources of MVOCs, especially the elevated levels of two pentanols, in cabin air.

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