Passenger aircraft ventilation system design challenges and solutions

Douglas S. Walkinshaw, PhD., P.E.

April 2005

Passenger Aircraft Ventilation System Design Challenges

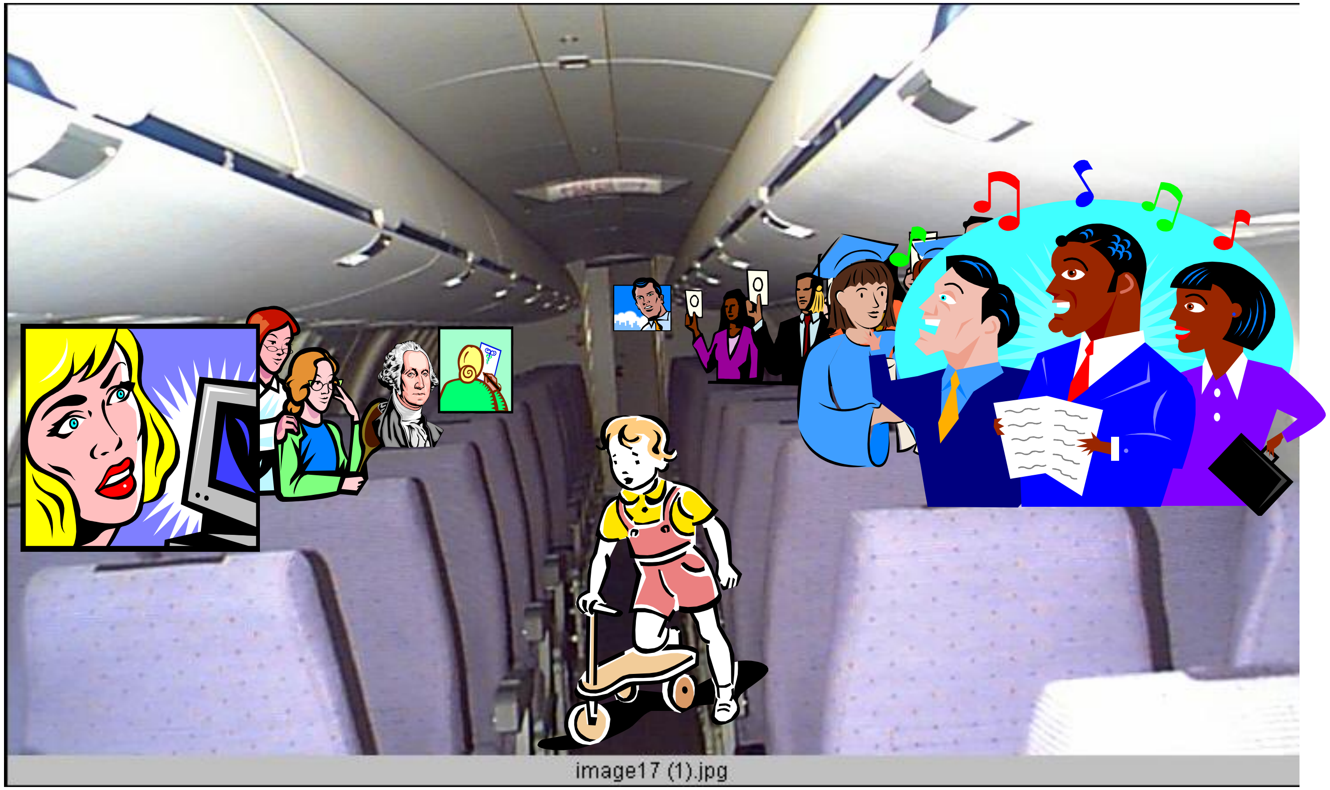

Figure 1. A passenger aircraft ventilation system must cope with higher occupancy densities, a wider range of occupant ages, health conditions and activities, more unusual ventilation air contaminants, lower ventilation air moisture content and more severe fire safety challenges than any other public space ventilation system.

Current ventilation norms

Factor	Building offices vs. Aircraft cabins
Fire, biological/chemical agent release	Building offices – escape in minutes Aircraft cabins – escape often not possible
Occupant contagion	Building offices – 7 persons/10,000 ft3, Aircraft cabins – 230 persons/10,000 ft3
Air flow rate (outdoor + recirculation air)	Building offices – 50 L/s/person (100 CFM/p) Aircraft cabins – 7.5-10 L/s/person (15-20 CFM/p)
Dust and allergens	Building offices – Fleecy chairs, carpets with low traffic Aircraft cabins – Fleecy chairs, carpets with high traffic
Relative humidity	Building offices – 20-65% Aircraft cabins – 5-25%
Volatile organic compounds	Building offices – copier, human Aircraft cabins – human, combustion, anti-corrosion treatment
Indoor/outdoor air exchange rate	Building offices – > 18 L/s/person filtered low outdoor air VOCs Aircraft cabins – > 3.75 L/s/p unfiltered bleed air VOCs, ozone
Outdoor temperature environment	Buildings: - 20F to +110F Aircraft : - 55F to +110F
Blood oxygen content (BLOC)	Building offices – air pressure = 0.9 to 1 atm; BLOC = 95-100% Aircraft cabins – air pressure = 0.75 atm, BLOC = 85-90%

Table 1. Current ventilation norms: aircraft passenger cabins versus buildings

Six ventilation design challenges addressed in this presentation

Challenge #	Aircraft Ventilation Challenge
1	Unusually contaminated ventilation air.
2	Exposure to occupant-generated pathogens and VOCs.
3	Limited biological/chemical agent release, fire fighting and smoke control capability
4	Low occupied space humidity and fuselage condensation.
5	Fuselage offgasing on the ground.
6	Passenger cabin thermal discomfort due to warm fuselage on the ground on sunny days, and cold fuselage during cruising flight.

Table 2. Aircraft ventilation design challenges and a set of solutions

AIRCRAFT VENTILATION DESIGN CHALLENGE #1
Contaminated ventilation (engine bleed) air

ENGINE BLEED AIR CONTAMINATION SOURCES

a. Ingestion of other aircraft engine fume exhaust
b. Bearing oil leaks
c. Deicer ingestion
d. Oil coated ventilation ducts which sorb and later desorb these contaminants

Table 3. Aircraft ventilation air contaminants

AIRCRAFT VENTILATION DESIGN CHALLENGE #1
Contaminated ventilation (engine bleed) air

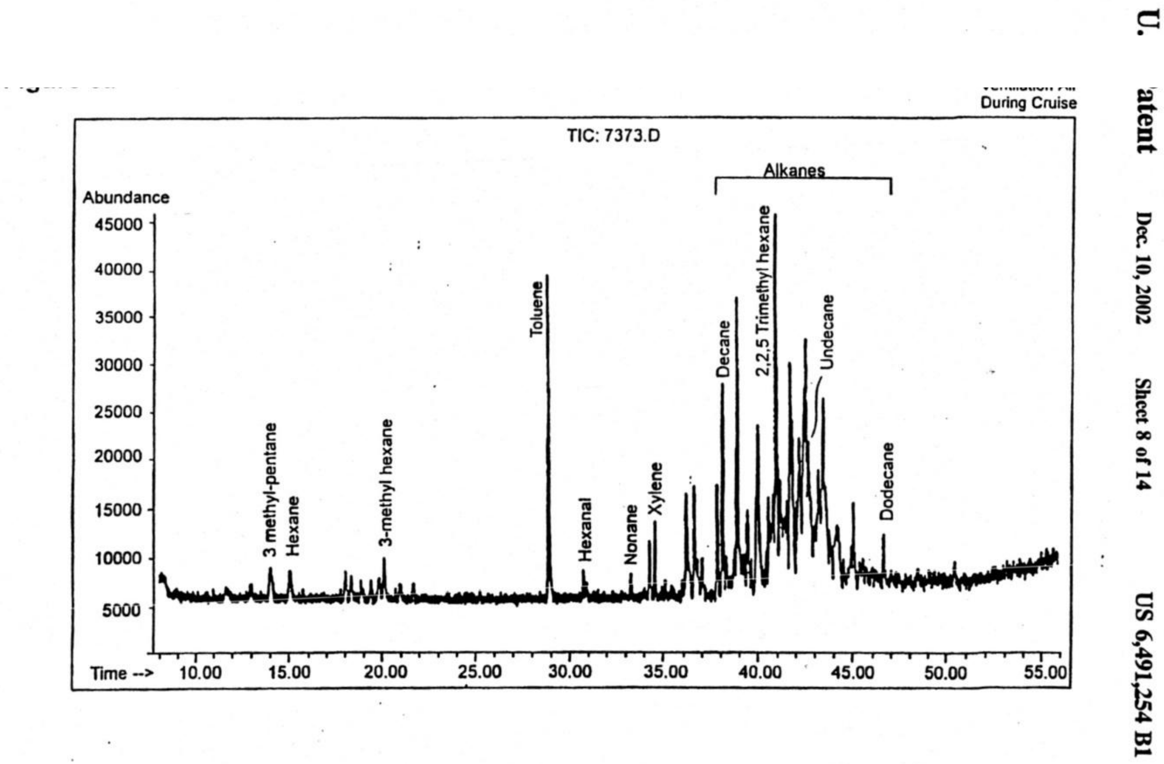

Figure 2. Volatile organic compound chromatogram for bleed air during flight, TVOC = 270 ug/m^3. The dominant branched alkanes are typically associated with fuels and solvents. Their origin could have been the oil coating the ducts acting as a sorbent of, for example, earlier ingested engine exhaust fumes.

AIRCRAFT VENTILATION DESIGN CHALLENGE #1

Contaminated ventilation (engine bleed) air

Compound name	Aircraft ventilation air ug/m3 (ref 2,3)		Air outside office buildings, ug/m3 (ref 1)	
	Bleed air study by Fox	Bleed air study by Nagda	AM	SD
Ethanol	36.0	118.7	0.0	0.0
Acetone	9.7	18.7	3.0	2.7
Acetaldehyde	8.8	15.6	1.0	1.2
Toluene	5.5	8.6	3.8	5.9
Propionaldehyde	4.0	7.4	0.8	1.3
Methylene chloride	1.6	6.7	1.8	2.5
m/p-Xylene	3.4	5.6	0.5	0.5
o-Xylene	1.6	3.9	0.0	0.0
Tetrachloroethylene	1.5	2.2	0.0	0.0
Benzene	0.0	0.0	1.0	1.0

Table 3. Some volatile organic compound concentrations found in cabin ventilation air versus averages for the same VOCs in the air found outside office buildings.

AIRCRAFT VENTILATION DESIGN CHALLENGE #2

Occupant-generated pathogen & volatile organic compounds (VOCs)

a. Aircraft ventilation and air circulation per person rates are lower than in any other public indoor environment.

b. High aircraft cabin occupancy density creates peak occupant generated pathogen and VOC exposures sooner than in any other public indoor environment.

c. Ceiling supply air diffusers are remote from perimeter seats, exacerbating the pathogen and VOC exposure loads in near the cabin liner.

Table 4. Reasons for high occupant generated pathogens and VOCs in commercial aircraft passenger cabins.

AIRCRAFT VENTILATION DESIGN CHALLENGE #2

Occupant-generated pathogen & volatile organic compounds (VOCs)

Compound name	Aircraft cabin air, ug/m3 (ref 2,3)		Office buildings, ug/m3 (ref 1)	
	Cabin air low GM	Cabin air high GM	AM	SD
Ethanol	324.0	1,116.0	81.1	82.3
Toluene	6.6	68.0	11.0	7.5
Acetone	40.8	58.9	26.3	8.9

Table 5. Three dominant volatile organic compounds found in aircraft cabin air versus their concentration averages in some office buildings.

AIRCRAFT VENTILATION DESIGN CHALLENGE #2

Occupant-generated pathogen & volatile organic compounds (VOCs)

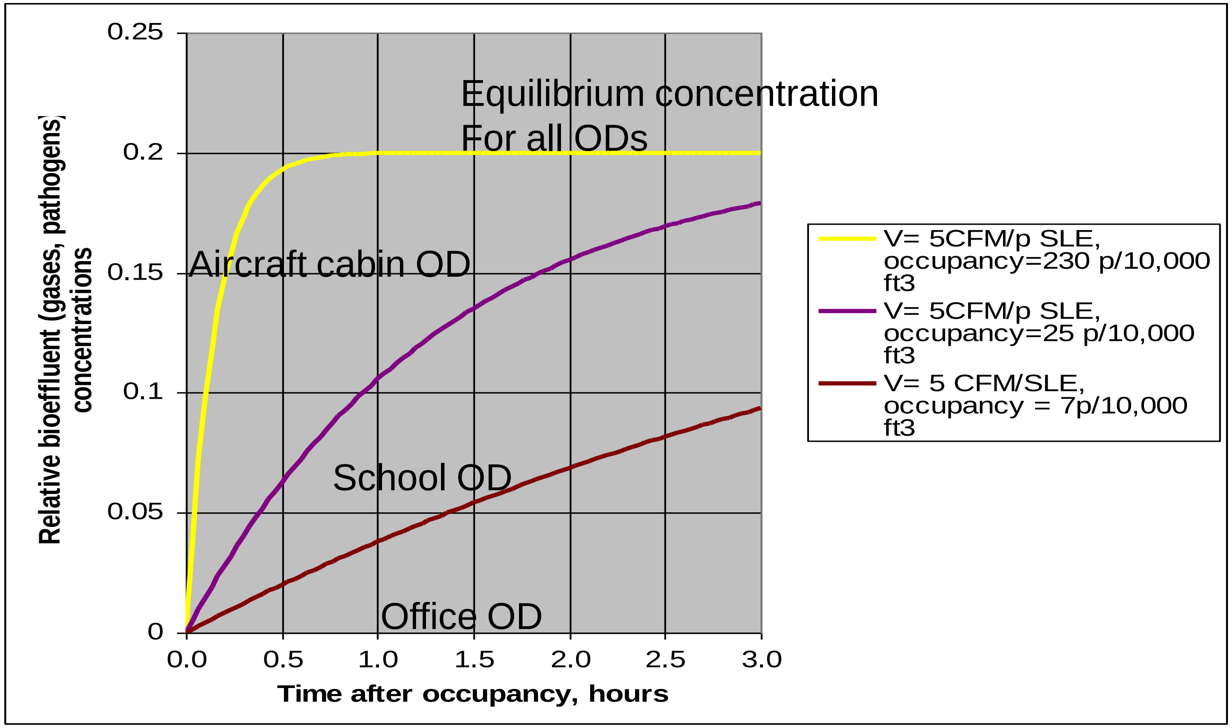

Figure 3. The impact of occupancy density on occupant-generated pathogen and VOC exposures. Aircraft ODs are higher and movement more limited than in any other common public space, creating higher occupant-generated VOC and pathogen exposures in aircraft cabins than in any other public space.

AIRCRAFT VENTILATION DESIGN CHALLENGE #3

Limited firefighting, smoke, biological and chemical agent control capability

a. Fire in the cavity behind the liner currently cannot be extinguished using Halon as phosgene will be produced which could enter the cabin and kill the occupants.

b. Smoke in the cavity behind the liner can enter into the cabin.

c. Smoke, biological and chemical agents released in the occupied space currently can only be exhausted at the floor in most aircraft. This is inefficient as convection currents tend to move these agents in the opposite direction.

Table 6. Problems with current emergency air contaminant removal measures in aircraft passenger cabins.

AIRCRAFT VENTILATION DESIGN CHALLENGE #4

Occupied space humidity and fuselage condensation

The generally accepted minimum relative humidity for comfort is 20% to 65%. The optimal relative humidity range for health is 40-50%. Typically neither of these ranges are met in aircraft for two reasons:

a. The low moisture content of the ventilation air creates aircraft occupied space humidities of 10% or lower, during international flights. Such low occupied space humidity can cause respiratory and eye discomfort. For some with respiratory problems, it can result in acute health problems.

b. Aircraft occupied spaces generally are not humidified. This is because humid cabin air passes through openings in the occupied space liner onto the cold fuselage behind. Here the moisture condenses creating a number of problems. These include added dead weight, deterioration of the insulation, wiring and fuselage, microbial growth and drips through the liner onto the occupants and furnishings below.

Table 7. Fuselage condensation – the reason why aircraft passenger occupied spaces are not humidified

AIRCRAFT VENTILATION DESIGN CHALLENGE #4

Occupied space humidity and fuselage condensation

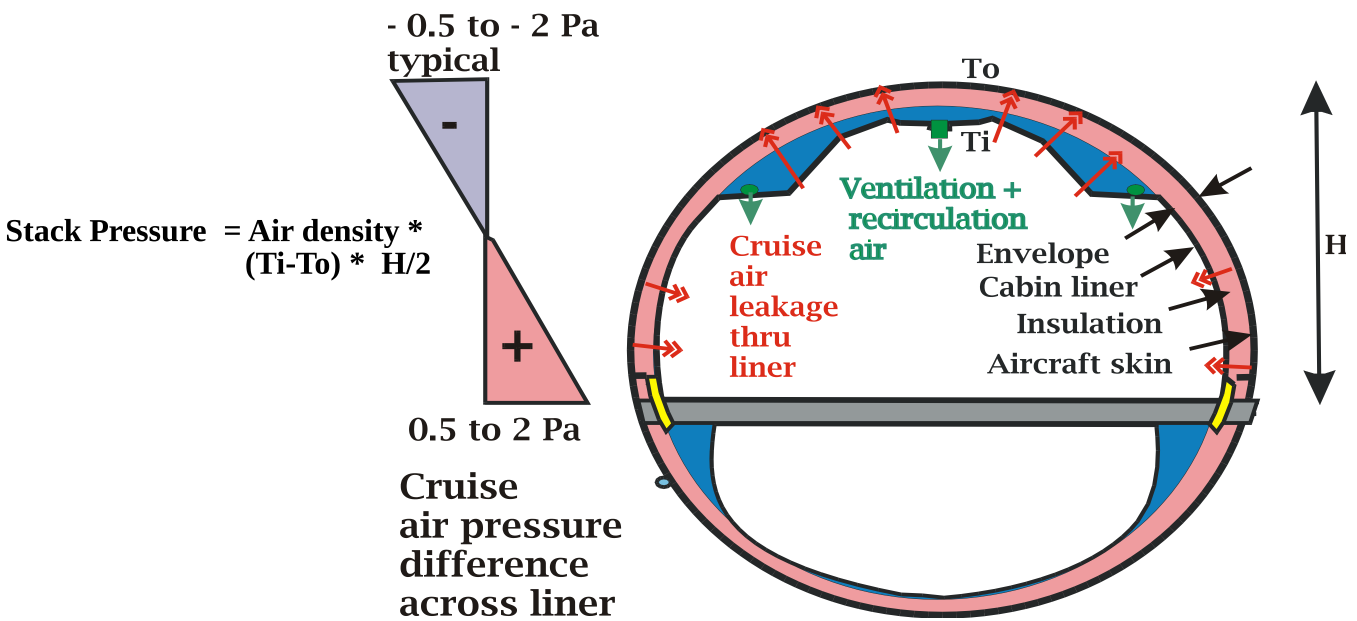

Figure 4. STACK PRESSURES create air circulation flows between the occupied space and the fuselage cavity behind the liner. This air circulation deposits occupied space air humidity as condensate on the cold fuselage. Stack pressures are created by the thermal gradient between the occupied space and the outdoor air, which can exceed 70 Celsius degrees during cruise.

AIRCRAFT VENTILATION DESIGN CHALLENGE #5

Fuselage offgasing

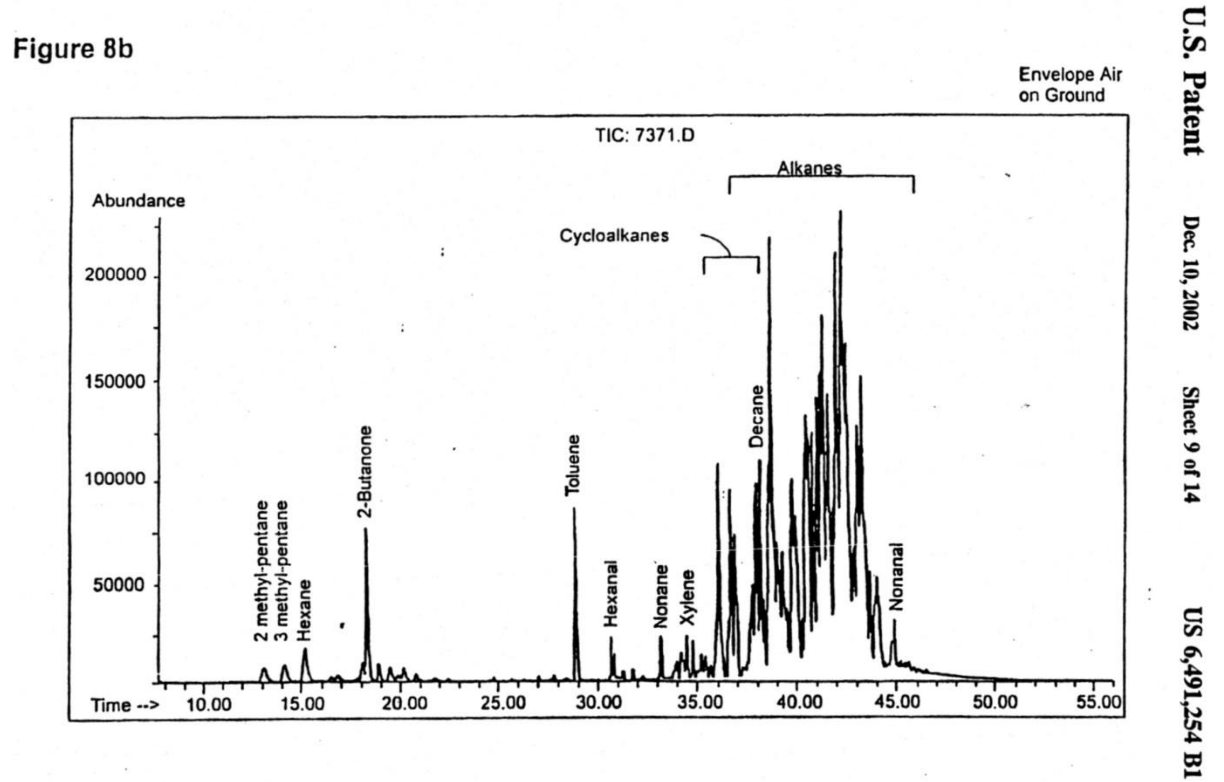

Figure 5. Volatile organic compound chromatogram for fuselage (envelope) VOCs at take-off, TVOC = 22,000 ug/m^3. VOCs primarily originated with anti-corrosion treatment oil. These VOC concentrations are highest before take-off with the fuselage heated in a summer sun. Other fuselage VOC sources include wet insulation and microbial growth.

AIRCRAFT VENTILATION DESIGN CHALLENGE #5

Fuselage offgasing and microbial growth

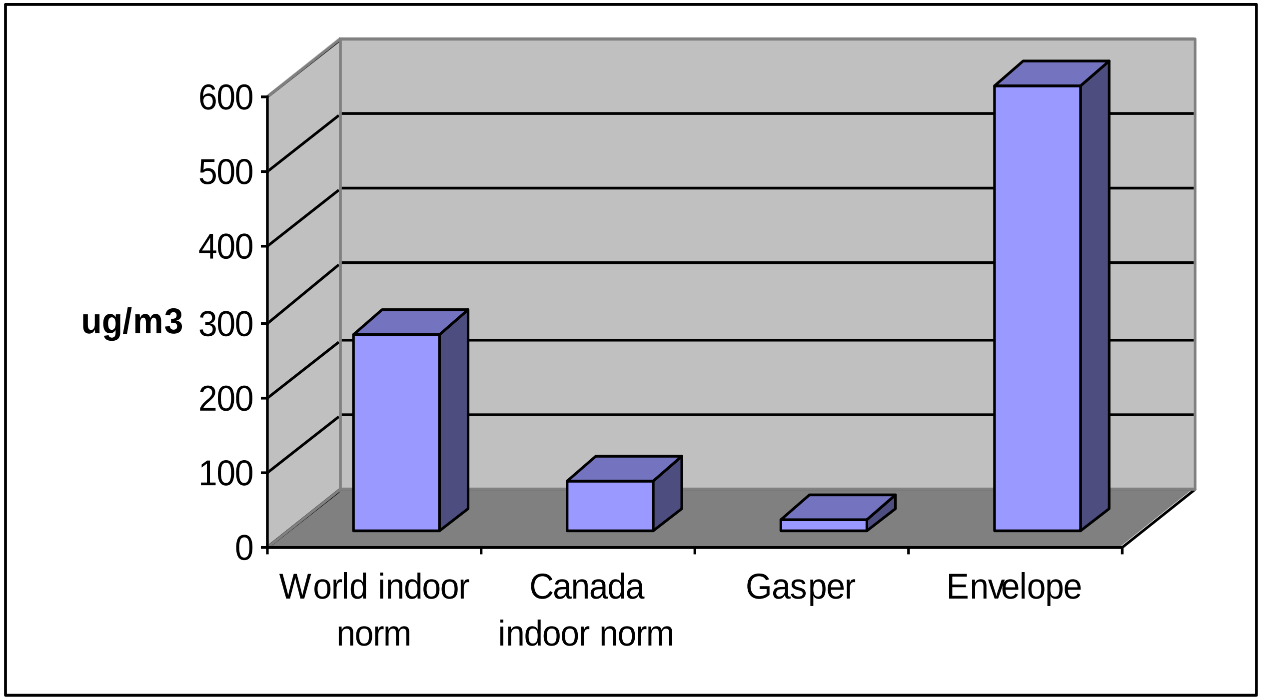

Figure 6. Envelope and gasper microbial volatile organic compounds (MVOCs). Samples taken while on the runway. MVOCs were higher than indoor air norms in the fuselage envelope behind the occupied space liner, and lower in the gasper bleed air. The MVOC primary origin in the envelope likely was the insulation.

AIRCRAFT VENTILATION DESIGN CHALLENGE #6
Thermal discomfort

a. On the ground, during boarding and prior to take-off, aircraft occupied spaces can be uncomfortably warm. In part this is because the aluminum skin and cavity behind the liner heat rapidly in the sun to temperatures well in excess of 100F. The forced air circulation cannot keep up with this thermal load.

b. In the air during cruise, the cavity behind the liner cools under external temperatures in excess of –50 F, reaching its cold soak condition in about an hour. This can make for cool occupied spaces, particularly under low occupancies and during sleeping periods on international flights.

Table 8. Occupied space thermal discomfort is caused in part by high fuselage external thermal loads.