**Table 3 — Carpet Test Parameters**

| Test | Carpet Area ($m^2$) | Carpet Mass (g) | Adhesive Mass (g) | Airflow (lpm) | Average Velocity (m/s) | Average Turbulence ($k/u^2$) |
|---|---|---|---|---|---|---|
| 4 | 0.124 | 29.7 | 59.10 | 6.67 | 0.04 | 0.003 |
| 5 | 0.124 | 301.5 | 55.20 | 6.67 | 0.10 | 0.004 |
| 6 | 0.123 | 300.0 | 51.35 | 6.65 | 0.22 | 0.008 |
| 6r1 | 0.124 | 328.3 | 50.60 | 6.65 | 0.26 | 0.008 |
| 6r2 | 0.123 | 300.8 | 55.00 | 6.65 | 0.26 | 0.008 |
| 7 | 0.124 | 299.5 | 59.00 | 6.65 | <0.04 | 0.077 |
| 8 | 0.122 | 299.2 | 58.00 | 6.67 | 0.26 | 0.212 |

Source: Low, et al.

increased TVOC emission rates. However, subsequent emissions appeared to be unaffected by increasing air velocity or turbulence. This would seem to indicate there was little benefit to be gained in increasing the velocity in the earlier stages. When air velocity was reduced, according to the researchers, turbulence had a greater impact on emission rates.

4-PC concentrations were very low, compared to the other compounds. However, the researchers note, 4-PC became detectable only after about 50 hours. The researchers conclude that this would indicate that 4-PC, emitted from the carpet, is of less concern than the VOCs emitted from the adhesive, at least during the first several hundred hours after installation (the time frame for the experiment).

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## Researcher Calls for Airlines to Increase Outside Air for Passengers

One of the persistent complaints about the indoor environment from the general public concerns the air quality in commercial aircraft. In fact, ASHRAE currently has a group working on a standard for aircraft cabin air quality, a process that is in its early stages. Now, a researcher from the University of Victoria (Victoria, British Columbia) contends that airlines could reduce disease transmission and bring about "system saving" by either eliminating air recirculation or using HEPA filters. Martin B. Hocking reports his conclusions in the *American Industrial Hygiene Journal* (Vol. 59, 1998, pp. 446-454).

Hocking bases much of his argument on measured and predicted carbon dioxide concentrations in aircraft. He starts by showing that the time to any given $CO_2$ concentration in an enclosed space is very closely related to the volume. While this is probably intuitive, Hocking provides calculations showing that as the volume decreases, the time it takes to reach the acceptable limit drops off sharply. For example, in a 25,000-liter space with one resting person — assuming an initial $CO_2$ concentration of 357 parts per million (ppm) — it would take nearly an hour to reach the commonly accepted limit of 1,000 ppm. However, if that space were reduced to 1,000 liters, it would take only 2.3 minutes. Current commercial aircraft, Hocking notes, allow between 1,000 and 2,000 liters of air space per passenger.

Hocking says that as available space declines, systems become less resilient or tolerant of periods of nonventilation. Therefore, he says, to maintain a set $CO_2$ concentration, small spaces require more air exchange than would be theoretically predicted.

### Aircraft Design

Aircraft have several characteristics that make them different than office buildings or other ground-based structures when it comes to ventilation and air quality. The foremost problem faced by aircraft is the need to control the pressure within the cabin when flying at high altitudes. Usually, commercial aircraft maintain cabin pressure equivalent to 8,000 to 10,000 feet above sea level.

This means that air brought in from the outside, which will be at the pressure appropriate to the cruising altitude, must be raised to a pressure that will maintain the cabin pressure. The compressors on the jet engines accomplish this, but heat the air, which must then be cooled by outside air. When the flight crew bleeds off air to use for cabin ventilation, the engines suffer a slight power loss, meaning higher fuel costs.

To overcome this, some aircraft manufacturers have moved from a single-pass ventilation system to one that allows aircraft to recirculate up to 50% of the cabin air. However, this recirculation has several effects. While Hocking says the main result is the potential spread of disease, other effects are potentially beneficial. For example, recirculated air would have a higher relative humidity than outside air, which is quite dry once it is heated and introduced to the cabin. In fact, one problem many people face with airline flight is low humidity.

The recirculation may also reduce ozone concentrations in the cabin, although Hocking says that an onboard catalytic converter should take care of the ozone anyway.

Hocking provides extensive data on aircraft ventilation rates and capabilities (see Table 4). He also shows measured and calculated $CO_2$ concentrations (see Table 5). The measured concentrations come from 1989 and 1994, with significant improvement in the 1994 measurements. The calculations in Table 5 are based on the data in Table 4.

## Conclusions

Hocking argues that maintaining a $CO_2$ concentration at the 1,000-ppm level would increase passenger comfort and decrease the risk of disease transmission. He cites numerous diseases that are spread through airborne routes, and he claims that in the confined space of a passenger cabin, recirculation increases the risk of infection.

**Table 4 — Ventilation Capacities of Some Aircraft**

| Aircraft Type | Air Exchange Rate (ach) | | Cabin Volume ($m^2$) | Ventilation Capacity (l/s) | Passenger Seating | Ventilation per Passenger (l/s) |
|---|---|---|---|---|---|---|
| | Early Surveys | Later Surveys | | | | |
| ***Without recirculation*** | | | | | | |
| Boeing 727-100 | 22.9 | | 151 | 961 | 131 | 7.3 |
| Boeing 727-200 | 26.4 | 18.8 | 165 | 862-1,210 | 147 | 5.9-8.2 |
| Boeing 737-100 | 26.1 | | 120 | 870 | 115 | 7.6 |
| Boeing 737-200 | 23.9 | 17.7 | 131 | 644-870 | 130 | 5.0-6.7 |
| Lockheed L1011-1/100 | 17.8 | | 537 | 2,655 | 238 | 11.2 |
| Lockheed L1011-50 | 19.3 | | 494 | 2,648 | 400 | 6.6 |
| MD DC9-30 | 27.3 | | 124 | 940 | 119 | 7.9 |
| MD DC9-50 | 22.9 | 18.8 | 148 | 773-941 | 139 | 5.6-6.8 |
| MD DC10-10 | 22.8 | | 419 | 2,654 | 287-400 | 9.2-6.6 |
| ***With recirculation*** | | | | | | |
| Airbus Industrie 310 | 9.7 | | 334 | 900 | 234-260 | 3.5-3.8 |
| Boeing 737-300 | 14.2 | 15.0 | 149 | 588-621 | 126 | 4.7-4.9 |
| Boeing 747 | 14.7 | 20.0 | 790 | 3,226-4,389 | 452-482 | 6.7-9.7 |
| Boeing 757 | 15.6 | 14.0 | 276 | 1,073-1,196 | 188 | 5.7-6.4 |
| Boeing 767-200 | 10.4 | 10.3 | 319 | 913-922 | 220 | 4.2 |
| Boeing 767-300 | | 11.1 | 428 | 1,320 | 261 | 5.1 |
| MD MD80 | 19.7 | | 173 | 947 | 172 | 5.5 |
| MD DC10-40 | 14.9 | | 419 | 1,734 | 380 | 4.6 |

Source: M.B. Hocking

According to Hocking, a single-pass ventilation system brings air to a passenger's face and then to the floor, where it exhausts to the outside. In this scenario, an infected person might be a danger to his or her seatmates and a few other surrounding people due to air turbulence within the cabin. A recirculation system, however, takes the air, perhaps containing viruses or bacteria, from near the floor, mixes it with outside air, and recirculates it to the entire cabin.

**Table 5 — Calculated and Measured $CO_2$ Concentrations (ppm)**

| | Measured Concentrations | | | Calculated Concentrations |
|---|---|---|---|---|
| | 1989 Flights (92) | | 1994 Flights (158) | |
| | Smoking | Non-smoking | | |
| Mean | 1,562 ± 685 | 1,765 ± 660 | 785 | 1,145 |
| Minimum | 597 | 766 | 464 | 771 |
| Maximum | 4,943 | 3,157 | 1,552 | 1,682 |
| **Distribution (%)** | | | | |
| <1,000 | 13 | 13 | 75 | 28 |
| 1,000-1,500 | 34.5 | 30.5 | 25 | 64 |
| 1,500-2,000 | 34 | 17 | | 8 |
| 2,000-2,000 | 18 | 26 | | 0 |
| >2,500 | 3 | 13 | | 0 |

Source: M.B. Hocking

Hocking suggests that if airlines are to use recirculation, they should also install and maintain HEPA filters to remove potentially infectious particles. Finally, Hocking recommends that the fresh air supply be kept at 15 cubic feet per minute per person during taxiing, ascent, and descent.

He supports his recommendations with an economic analysis that shows airlines save $60,000 per aircraft per year with recirculation systems. While this seems like a large sum, it works out to about $1 per passenger trip, based on a 200-seat aircraft that makes 300 trips per year. The figures would be different for larger or smaller aircraft and for longer flights. He contends that passengers have an interest in avoiding illness and therefore might be willing to pay the extra average cost of $1.

While the airlines claim large savings, Hocking argues that this is a "one-stakeholder saving" and not a "system saving." The passengers who become ill, as well as their families and employers, must bear the cost of the illness caused by the airline saving money.

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# Case Study

*[In each issue, **IEQS** presents a case study on an indoor air investigation in a particular building. The information in the cases comes from various sources, including published material, reports in the public record, and, in some cases, reports supplied by the consultants involved in the case. **IEQS** presents a variety of approaches to investigation and mitigation implemented by consultants with a broad range of experience, philosophies, and expertise. Inclusion of a particular case study in the newsletter does not imply **IEQS**'s endorsement of the investigative procedures, analysis, or mitigation techniques employed in the case. **IEQS** invites readers to submit comments, suggestions, and questions concerning the case. At the discretion of the editors, correspondence may be presented in a future issue.]*

## Investigators Link Building IEQ and Environmental Illness

This case involves a hospital complex, where IEQ problems went on for more than six years and affected hundreds of workers, causing what physicians described as environmentally induced dysfunction (EID). Despite the correction of the problems that caused the illnesses, 85 workers from the hospital still suffer from adverse health effects, keeping them out of work on long-term disability.

The case focuses on the illnesses suffered by the workers and the correlation of the syndrome to the building conditions. Roy A. Fox, M.D., a physician at the hospital, reports on