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Air Quality On Commercial Aircraft

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ASHRAE is developing a standard to ensure cabin air quality 1) is safe for flight and occupants; 2) minimizes the potential for adverse health effects; and 3) is comfortable to occupants. ASHRAE Technical Committee 9.3, Transportation Air Conditioning, issued a work statement for the study, "Relate Air Quality and Other Factors to Symptoms Reported by Passengers and Crew on Commercial Transport Category Aircraft." The study's purpose is to support the development of ASHRAE Standard Project Committee 161P, *Air Quality in Transport Category Commercial Aircraft*. The study has four distinct parts:

- Conduct a literature search to determine possible causal factors that may contribute to reported symptoms and help differentiate between symptoms caused by air quality from those caused by other factors.
- Prepare a comfort questionnaire (using an existing questionnaire as an outline) and use it to poll passengers and crew on flights where air quality testing is being conducted.
- Develop a testing protocol to measure aircraft cabin contaminants and environmental parameters.
- Conduct air quality monitoring on the ground and during flight on eight commercial flights.

A unique aspect of this study was the concurrent measurement of cabin contaminants and environmental parameters with the administration of comfort questionnaires to passengers and crewmembers. The objective of the project, because of limited funds, was not to collect large amounts of data, whereby significant correlations between contaminant levels and passenger responses could be revealed. Rather, the objective was to develop an air quality testing protocol and comfort questionnaire to determine if this type of research could be successful, and to make recommendations that would enhance the overall effectiveness of future studies.

Literature Search

The literature search began by identifying factors that may impact human health and comfort or may influence perceptions of health and comfort aboard modern aircraft. Next, a series of bibliographic databases was searched to identify literature relevant to these factors. Results of each search were recorded by factor name using a bibliographic management software product. To complete the documentation of the literature search, bibliographic citations were arranged as they related to the specific subject headings. The subject headings are described in *Table 1*.

After compiling the previously identified factors, several bibliographic databases were systematically searched using each factor or combination of factors to identify related literature. For instance, to identify literature related to diabetes and air travel, the terms "diabetes" and "air travel" or "aircraft" were used in the database search engines.

In addition to bibliographic database searches, the Library of Congress catalog was searched for books related to the identified factors. To identify published and unpublished documents, reports, and technical papers from the Federal Aviation Administration (FAA) and the National Aeronautics and Space Administration (NASA), available document search engines were used on web sites for each of the agencies.

About the Authors

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Subject	Factors
Cabin Environment	acrolein, altitude and cabin pressurization, bacteria, carbon dioxide, carbon monoxide, comfort, disease transmission, environmental tobacco smoke, formaldehyde, fungi, noise, oxygen, ozone, radiation, relative humidity, temperature, thermal degradation products, ventilation and volatile organic compounds
Health & Comfort	age, asthma, alcohol, bronchitis, cardiovascular conditions, circadian rhythms, crowding, diabetes, disabilities, drugs, gender, obesity, odor, medication, mood, motion, phobias and psychopathology, respiratory conditions and vibration
Health Effects	auditory and vestibular, cardiovascular, cancer, death, reproductive, respiratory, lymphatic and ocular

***Table 1:** Literature search subject headings about health and comfort factors that may impact passengers and crews.*

Comfort Questionnaire

The unique challenge in developing the comfort questionnaire was collecting sufficient data upon which to draw conclusions or correlations, while remaining unobtrusive to revenue-generating passengers and working flight crew. The object was to determine what factors associated with flying had the most impact on passenger comfort and to determine if the passengers believed flying contributed to any adverse health symptoms. The comfort questionnaire included 72 questions or rating categories and consisted of five different sections:

- Current and past flight information (e.g., reason for flying, departure time, seat number) – 12 questions.
- Cabin temperature and airflow information – 6 questions.
- Passenger and flight attendant information (e.g., age, height, weight, passenger health) – 15 questions.
- Aircraft and airline information (e.g., seat comfort, storage capacity, lavatories, odors) – 25 questions.
- Symptoms (e.g., back problems, eye irritation, sore throat, headache, ear problems) – 14 questions.

Test Methods and Equipment

The selected test methods and equipment needed to reflect the unique environment of the aircraft cabin and the need to be unobtrusive. Monitoring equipment selected for this study was lightweight, portable and innocuous. Sensors for the CO_2, CO, O_3, O_2, cabin pressure, temperature and humidity were housed in a single unit equipped with a data logging device. Where possible, direct reading instruments were used to monitor environmental parameters and contaminants so that a complete flight duration profile could be obtained. When monitoring for total volatile organic compounds (VOC), ethanol, formaldehyde and acrolein, time-integrated sampling was performed to ensure that an acceptable level of detection could be achieved. All monitoring equipment used onboard was tested for electromagnetic radiation interference (EMI).

Prior to conducting onboard air quality monitoring, several sensors (CO_2, CO, O_2 and O_3) were tested at reduced pressures to determine correction factors for the monitoring equipment. The testing was conducted in the B-3 altitude chamber at the U.S. Air Force School of Aerospace Medicine, Armstrong Labs at Brooks Air Force Base in San Antonio, Texas. The measurements collected onboard in the aircraft cabin were corrected to reflect the data collected in the altitude testing chamber.

The types of contaminants measured on the aircraft included many of the same contaminants that are measured when evaluating building air quality including carbon monoxide, ozone, respirable particulates, biological organisms (bacterial and fungal), and VOCs. Environmental parameters that were measured included carbon dioxide, cabin pressure, oxygen, relative humidity, temperature and noise. *Table 2* lists the test equipment and test methods used, the contaminant or environmental parameter that was measured, and the type of sampling performed.

Aircraft Type

Air quality monitoring was performed on eight Boeing 777 commercial airline flights operated by a U.S. carrier. Four of the flights were domestic and were between 1,000 and 1,500 miles (1600 and 2400 km) in length and four were international and were greater than 3,000 miles (4800 km). The actual monitoring was performed between July 9 and July 22, 1998. The cabin configuration included 231 seats in coach class, 49 in business class and 12 in first class. The number of crewmembers ranged from 14 to 17. The combined mean load factor for the eight flights was 91.7%.

The 777 is Boeing's newest airplane design and was developed to fill the size gap between the 767 and 747. During normal operation, the air supplied via the cabin ventilation system is a mixture of outside air and filtered recirculated cabin air. The system is designed to provide approximately 10 cfm (4.7 L/s) per person of outside air and 10 cfm (4.7 L/s) per person of filtered recirculated air for a total air supply of 20 cfm (9.4 L/s) per person. The outside air supplied to the cabin environmental control system (ECS) is engine bleed air that comes from the compressor stages of the engine core. Prior to cabin entry, the bleed air passes through an ozone converter that catalyzes the dissociation of ozone to oxygen molecules. The ozone converter is designed to help reduce atmospheric ozone plumes that can be encountered when flying at altitudes as high as 39,000 feet (11 900 m). After leaving the ozone converter, the air passes through the air-conditioning packs and is cooled from approximately 400°F (204°C) to approximately 55°F to 65°F (12.8°C to 18.3°C).

The outside air then travels to a mixing manifold where it is combined with an equal amount of filtered recirculated air. The filters used to clean the recirculated air are high-efficiency particulate air type (HEPA-type) filters. After leaving the mixing chamber, the air travels, via risers, from below the floor system

Testing Equipment/ Test Method	Contaminant/ Environmental Parameter	Type of Sample
Air Quality Monitor	CO_2, CO, O_3, O_2, Pressure, Temperature, Humidity	Direct-reading: Data Logging with 5 minute averaging
Aerosol Monitor	Respirable Suspended Particulate (RSP)	Direct-reading: Time Weighted Average (TWA)
NIOSH Method 1500 &1400 (Sampling Pump & Charcoal Sorbent Tube)	Total Volatile Organic Compounds (TVOC) & Ethyl Alcohol	Time Integrated
EPA Method T011-A (Sampling Pump & Silica Gel Sorbent Tube)	Formaldehyde & Acrolein	Time Integrated
Portable Compact Air Sampler (RODAC Plates with Agar)	Bacteria & Fungi	Grab Sample
Integrating Impulse Sound Level Meter	Noise	Direct-reading: Instantaneous Measurements

Table 2: Testing equipment and test method specifications used in this in-flight research project.

to the air distribution system, which runs overhead the entire length of the aircraft cabin. Return air grilles, which run the entire length of the cabin and serve as the entry point for recirculated air traveling back to the mixing manifold, are located in the sidewalls near the floor.[1]

Sampling Locations

The Boeing 777 has five separate seating sections: first class, forward business class, aft business class, forward coach class and aft coach class. Air quality monitoring was performed in one coach class location on all eight flights. On each flight, the monitoring was performed during boarding, ascent and descent, while the aircraft was aloft and during deplaning. In three flights, monitoring was performed in the rear section of coach class (all in Row 43) and in five flights monitoring was performed in the forward section of coach class (once each in Rows 18, 20, 21, 25 and 27). Limited monitoring for some contaminants and environmental parameters (CO_2, CO, O_3, O_2, pressure, temperature and humidity) also was performed in business class, lavatories and the aft galley.

For the majority of the monitoring, the recirculation fans were turned on, which resulted in approximately 50% outside bleed air and 50% filtered recirculated air being supplied to the aircraft cabin. However, on the international flights, limited monitoring also was performed with the recirculation fans turned off. This resulted in 100% outside bleed air being supplied to the aircraft cabin for approximately 30 minutes near the midpoint of each international flight.

Results Of Air Quality Monitoring

Table 3 provides a summary of the results of the air quality monitoring conducted on the eight flights. The results listed in the table reflect conditions in which the aircraft was aloft and the ventilation system was operating normally (50% outside bleed air and 50% filtered recirculated air). CO_2 means for the eight flights ranged from 1,252 ppm to 1,758 ppm with an overall mean of 1,469 ppm. The mean CO_2 concentration for domestic flights was 1,613 ppm, while the mean level for international flights was 1,405 ppm. When the recirculation fans were turned off, the mean CO_2 measurement was reduced to 798 ppm.

Limited CO_2 measurements were also collected in the aft galley. Mean CO_2 levels in the aft galley were 2,840 ppm with a maximum five-minute mean of 4,915 ppm. The 4,915 ppm measurement was observed in close proximity to a bin of dry ice in the aft galley. After the air quality monitor was moved to a more central location in the galley, the CO_2 concentration subsequently dropped to approximately 2,500 ppm. Based on this information, it is likely that the increased CO_2 levels in the aft galley are caused by the sublimation of dry ice that is used to cool beverages served on the flights.

Carbon monoxide was below the limit of detection (LOD) for the sensor (0.1 ppm) for 72% of the five-minute mean periods while the aircraft was aloft. The highest five-minute mean of CO recorded was 7.0 ppm and this occurred in the aft galley during the food preparation and service portion of the flight. The mean O_3 level was 46 ppb for domestic flights, 53 ppb for international flights, and 51 ppb for all flights. The highest five-minute mean of O_3 recorded was 122 ppb during an international flight between Washington and London. Mean O_3 levels during boarding and deplaning were 62 ppb and 77 ppb, respectively.

Total VOC concentrations for all flights ranged from 0.11 ppm (0.38 mg/m^3) to 0.43 ppm (1.5 mg/m^3) with a mean of 0.25 ppm (0.9 mg/m^3). Further analysis of the TVOC samples, by the laboratory, indicated the ethyl alcohol portion of the sample represented between 85% and 95% of the total sample, in seven of the eight samples. In the other sample, ethyl alcohol represented approximately 58% of the entire sample. Two of eight formaldehyde samples and all eight acrolein samples collected were less than detectable levels. The remaining six formaldehyde samples ranged from 3.2 ppb to 4.9 ppb.

The time-weighted mean for RSP was below detectable levels (<10 *ug*/m^3) for all monitored flights. The mean O_2 level for all flights while the aircraft was aloft was 21.1%. The highest five-minute mean recorded was 23.0% and the lowest five-minute mean was 18.3%. It should be noted that the 18.3% measurement was recorded just after the ascent stage of the

Contaminants/ Environmental Parameter	Domestic Mean	International Mean	Maximum	Minimum
Carbon Dioxide (ppm)	1,613	1,405	1,959	942
Carbon Monoxide (ppm)	89% of measurements were <0.1 ppm	62% of measurements were <0.1 ppm	7	<0.1
Ozone (ppb)	46	53	122	<20
Oxygen (%)	21.0	21.2	23.0	18.3
Temperature (°F)/(°C)	73.0/22.8	73.6/23.1	79.0/26.1	64.0/17.8
Humidity (%)	16.5	12.9	27.8	8.8
Pressure (feet)/meters	6,950/2,120 (max)	6,950/2,120 (max)	6,950/2,120	Not Applicable
Total VOC (ppm)	0.19	0.39	0.43	0.11
Formaldehyde (ppb)	50% of measurements were <0.5 ppb	3.3	4.9	<0.5
Acrolein (ppb)	100% of samples collected were < 1.5 ppb			
Respirable Particulate (ug/m³)	<10	<10	Not Available	Not Available
Bacteria (cfu/m³)	50–244 (range)	39–113 (range)	244	39
Fungi (cfu/m³)	<1–37 (range)	<1–13 (range)	37	<1
Noise (dBA)	70–80 (range)	70–80 (range)	110 (take-off)	70

Table 3: Summary of air quality monitoring results.

flight, and as a result, the sensor may have been influenced by abrupt pressure changes. Other parameters that were being measured (i.e., CO_2, O_2 and CO) did not change significantly, indicating that it was unlikely that the O_2 concentration dropped as sharply as the sensor indicated. The highest altitude-equivalent pressure recorded for both domestic and international flights was 6,950 ft (2120 m).

Overall, microbial sampling results indicated that airborne bacteria and fungi concentrations were relatively low, when compared to levels typically found in buildings, especially during flight when the aircraft environmental control system is operating.[2] The highest concentrations of fungi and bacteria were collected during the boarding and deplaning process when passengers were active and moving about the cabin. Also, the microbial sampling did not reveal any bacterial pathogens. Two fungi were isolated that are potential human pathogens, *Aspergillus niger* and *Paecilomyces variotti.*

The temperature range for all flights while the aircraft was aloft was 64°F to 79°F (17.8°C to 26.1°C) with a mean of 73.4°F (23°C). The temperature range for all flights, while the plane was on the ground (during boarding and deplaning), was 67.1°F to 86°F (19.5°C to 30°C). A limited number of spot temperature measurements were also collected at locations throughout the aircraft cabin to evaluate the effectiveness of the ECS in maintaining the temperature setting at the control panel. Results of the spot measurements indicated that the cabin temperature can vary by as much as 5°F to 10°F (1.6°C to 3.2°C) from the temperature setting at the control panel. The mean relative humidity for all flights, while the aircraft was aloft and the recirculation fans were turned on, was 14% with a low five-minute mean of 8.8%. When the recirculation fans were turned off and all supply air was coming from the outside, the mean relative humidity level dropped to 7.9% and the minimum was 6.4%. During take-off, sound-level measurements ranged from 80 dBA to 110 dBA. Sound-level readings while the plane was aloft ranged from 70 dBA to 80 dBA.

Type of Flight	Outside Air Per Person (cfm)/(L/s)	Filtered Recirculated Air Per Person (cfm)/(L/s)
Domestic	8.1/3.8	10/4.7
International	9.6/4.5	10/4.7

Table 4: Outside and filtered recirculated air summary.

Outside Air Supply

A summary of the amount of outside (bleed) air and filtered recirculated air per person is provided in *Table 4*. The amount of filtered recirculated air as listed in the table was provided by Boeing and was not actually measured. The recirculated air is filtered using a HEPA-Type filter and is provided in approximately the same quantity as the outside air. The amount of outside air was calculated using information obtained from ANSI/ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*, Appendix D.[3] The equation is:

$$V_o = N/[(C_s - C_o)\times 60]$$

where: V_o = outside airflow rate per person (L/s)

N = CO_2 generation rate per person (0.3 L/min. used)

C_s = CO_2 concentration in cabin (mean values, 0.001613 and 0.001405, used)

C_o = CO_2 concentration in outdoor air (0.0003 used from Standard 62-1989)

Comfort Questionnaire Survey

Approximately 930, or 43%, of the passengers completed a questionnaire. In addition to passengers, 27 or approximately 26%, of the flight attendants completed a questionnaire. Approximately 76% of all passenger respondents were seated in coach class and approximately 57% of all passenger respondents were male.

Aircraft Factor Responses

The results of the comfort questionnaire aircraft factor responses are provided in *Table 5*. Using a seven-point scale (1 for very poor; 4 for average, and 7 for excellent), the comfort questionnaire polled passengers and flight attendants on a variety of factors associated with the aircraft and the airline.

The highest percentage of passengers rated the following factors as poor or very poor (1 or 2): legroom, underseat storage capacity, ticketing/check-in, back support and head support. The highest percentage of flight attendants rated the following factors as poor or very poor (1 or 2): cabin air humidity, back support, leg room, seat comfort and underseat storage capacity. The highest percentage of passengers rated the following factors as very good or excellent (6 or 7): flight attendants, aircraft, cabin appearance, inflight services and overhead bin capacity. The highest percentage of flight attendants rated the following factors as very good or excellent (6 or 7): flight attendants, beverage services, in-flight services, airline pre-board and aircraft. Overall, flight attendants had a tendency to rate factors considerably lower than passengers. Flight attendants rated factors as poor or very poor 13.6% of the time, whereas passengers rated factors as poor or very poor 5.7% of the time.

How would you rate each of the following factors on this flight?	Passengers (Percent Responding)			Flight Attendants (Percent Responding)		
	Very Poor to Poor 1–2	Average 3–5	Good to Excellent 6–7	Very Poor to Poor 1–2	Average 3–5	Good to Excellent 6–7
Cabin Quietness	7.8	69.6	22.6	15.8	52.6	31.6
Cabin Appearance	0.8	46.6	52.6	0	50	50
Seat Access	5.9	55	39.1	11.1	50	38.9
Seat Width	8.6	57	34.5	17.6	58.8	23.5
Seat Cushion Comfort	6.1	62.8	31.1	18.8	62.5	18.8
Head Support	9.7	62.6	27.7	5.9	76.5	17.6
Back Support	10.2	61.4	28.4	50	25	25
Leg Room	15.7	50.4	33.9	35.3	35.3	29.4
Seat Comfort	7	65.9	27.1	23.5	47.1	29.4
Overhead Bin Capacity	2.4	52.4	45.2	5.6	38.9	55.6
Underseat Storage Capacity	12.2	62.6	25.2	22.2	61.1	16.7
Cabin Air Humidity	5.6	66.9	27.4	50	44.4	5.6
Cabin Air Odor	3.6	60.4	36.1	11.8	76.5	11.8
Cabin Air Quality	3.2	60.8	36	17.6	76.5	5.9
Ear Pressure	3.2	64.5	32.3	11.8	70.6	17.6
Lavatories	2.3	61.8	36	5.9	76.5	17.6
Lavatory Odors	2.5	59.4	38	11.8	82.4	5.9
Smoothness of Flight	2.7	59.6	37.7	11.8	70.6	17.6
In-Flight Services	2.6	48	49.4	0	17.6	82.4
Aircraft	1.7	45.6	52.7	0	50	50
Overall Comfort	4.9	55.9	39.3	0	57.1	42.9
Airline Pre-Board	8.9	58.2	32.9	0	40	60
Ticketing/Check-In	10.9	51.7	37.3			
Beverage Service	2.3	51.1	46.6	0	16.7	83.3
Flight Attendants	1.5	42.3	56.2	0	6.3	93.8

Table 5: Comfort questionnaire aircraft factor responses.

Except for the flight attendants poor rating of cabin humidity, none of the other air quality factors were rated particularly low or high, including cabin air odor, cabin air quality or lavatory odors. Of the passengers that responded to the comfort questionnaire, only 3.5% rated odors as poor or very poor (1 or 2 on a scale of 1 to 7) and only 3.2% indicated that air quality was poor or very poor. 92.5% of passengers rated odors a 4 or above (average to excellent) and 91.5 % rated air quality a 4 or above. For the 27 flight attendants that completed the comfort questionnaire, 11.8% rated odors as poor or very poor and 17.7% rated air quality as poor or very poor. 76.5% of flight attendants rated odors a 4 or above and 64.7% rated air quality a 4 or above.

Symptom Responses

Results of the comfort questionnaire symptom responses are provided in *Table 6*. Also, using a seven-point scale (1 for greatly associated; 4 for somewhat associated and 7 for not associated), respondents were asked "If you are experiencing any of the following (symptoms), to what extent do you feel that flying on this aircraft has contributed?" Analyses of the questionnaire responses indicated that flight attendants were more likely than passengers to relate symptoms to flying in 13 out of the possible 14 categories. The only symptom that passengers were more likely to relate to flying was "legs, buttocks numbness." Flight attendants responses indicated that the symptoms most associated with flying were skin dryness or irritation; dry or stuffy nose; stomach discomfort; dry, itchy or irritated eyes; back, joint muscle pain; and feet, ankle swelling. Passenger's responses indicated that the symptoms most likely associated with flying were dry or stuffy nose; legs, buttocks numbness; back, joint, muscle pain; feet, ankle swelling; dry, itchy or irritated eyes; and ear problems.

Cabin Temperature and Airflow Responses

On the comfort questionnaire, passengers and flight attendants were asked to rate both temperature and airflow, before and during, the flight. The temperature rating was based on a seven-point rating scale with a "1" indicating it was too hot, a "4" indicating it was just right and a "7" indicating it was too cold. *Table 7* provides results of the temperature responses on the comfort questionnaire for both passengers and flight attendants. While approximately 75% of both passengers and flight attendants found the temperature acceptable, a large number of passengers believe the temperature is too cold both before and during the flight. Flight attendants were more likely to find the temperature acceptable than passengers.

Table 8 provides results of the air movement responses on the comfort questionnaire for both passengers and flight attendants. More than 80% of passengers, both before and during the flight, indicated the air movement was acceptable. More than 80% of flight attendants also indicated the air movement was acceptable before the flight. However, only 66% of flight attendants indicated the air movement was acceptable during the flight.

Conclusions and Recommendations

As discussed previously, the objective of this research was not to collect large amounts of data whereby all potential health hazards and correlations could be identified, but rather to develop a standardized testing protocol and questionnaire that could serve as a basis for future research activities. Another important objective was to identify problem areas and provide recommendations for improving future studies.

One major challenge that researchers face when evaluating cabin air quality on commercial aircraft is recruiting airline companies that will allow researchers onboard to conduct the studies. The hesitancy likely arises out of concern for the disruption that these types of studies may cause passengers and crew and not because the airline companies do not want to cooperate. It is important to understand that regardless of how well an aircraft is designed, proper testing can only occur after

If you are experiencing any of the following, to what extent do you feel that flying on this aircraft has contributed?	Passengers (Percent Responding)			Flight Attendants (Percent Responding)		
	Great Extent 1 – 2	Somewhat 3 – 5	Not At All 6 – 7	Great Extent 1 – 2	Somewhat 3 – 5	Not At All 6 – 7
Back, Joint, Muscle Pain	6.1	19.6	32.4	22.2	25.9	22.2
Feet, Ankle Swelling	7.6	17.5	32.1	18.5	29.6	22.2
Leg, Buttocks Numbness	7.5	18.9	29.6	7.4	7.4	51.9
Dry, Itchy or Irritated Eyes	7.3	17.3	33	22.2	37	3.7
Dry or Stuffy Nose	9.7	19.9	30.5	29.6	37	7.4
Sore, Dry Throat	4.8	12.8	37	11.1	33.3	22.2
Shortness of Breath	0.9	3.8	45.3	3.7	22.2	37
Dizziness, Faintness or Lightheadedness	1.4	4.3	44.9	11.1	33.3	25.9
Headache	3.8	9.4	40.5	14.8	25.9	29.6
Stomach Discomfort	2.5	8.7	41.6	25.9	18.5	25.9
Skin Dryness or Irritation	4.4	10.5	38.4	37	33.3	0
Nausea or Motion Sickness	2.6	4.8	43.4	14.8	11.1	44.4
Ear Problems	8.9	14.7	33.2	18.5	25.9	29.6
Sinus Pain	2.9	7.3	41.9	18.5	7.5	44.4

Table 6: Comfort questionnaire symptom responses.

How would you rate the cabin temperature?			
Percent Responding			
Portion of Flight/ Respondent	Too Hot (1 or 2)	Acceptable (3, 4 or 5)	Too Cold (6 or 7)
Before Take-Off			
Passengers	6.0	75.5	18.5
Flight Attendants	11.5	76.9	11.5
During The Flight			
Passengers	2.0	73.7	24.3
Flight Attendants	11.1	81.5	7.4

Table 7: Comfort questionnaire temperature responses.

How would you rate the cabin air movement?			
Percent Responding			
Portion of Flight/ Respondent	Stagnant (1 or 2)	Acceptable (3, 4 or 5)	Drafty (6 or 7)
Before Take-Off			
Passengers	8.4	81.6	10.0
Flight Attendants	14.8	81.5	3.7
During The Flight			
Passengers	3.1	83.7	13.3
Flight Attendants	22.2	66.7	11.1

Table 8: Comfort questionnaire airflow responses.

the aircraft is fully operational with passengers and crew onboard. Further, future researchers must clearly understand the unique environment of the aircraft cabin and the need to be sensitive to conducting studies on and around revenue-generating passengers and working crew. To adequately address the cabin air quality issue, researchers will always require support from the airline industry. Working closely with industry groups and flight attendant organizations to assist in garnering support from the major airlines will be important if additional effective research is to be conducted.

In future studies, the comfort questionnaire should more clearly define the responses that will be considered acceptable versus unacceptable. The comfort questionnaire used in this study required respondents to rate a variety of factors using a seven-point scale, however, it did not clearly define the responses that would be considered acceptable versus unacceptable. As a result, the researchers had to decide the numeric values that would be considered acceptable versus unacceptable.

There were not enough data collected to make definitive conclusions about air quality onboard commercial aircraft. However, the information that was collected, including the air quality monitoring data, the responses to the comfort questionnaire and the information gathered during the literature search, indicated there were not significant air quality-related health hazards present for either the passengers or the crew. In addition, analysis of the data collected during the study revealed no statistically significant correlations between any of the air quality contaminants or environmental parameters measured and the comfort questionnaire responses. However, to accurately identify these types of correlations, more studies would have to be conducted on different airlines and on different aircraft.

Overall, passengers who completed the comfort questionnaire showed very little displeasure with items related to air quality including cabin air humidity, cabin air odor, cabin air quality and lavatory odors. Again, more studies would have to be conducted on different airlines and on different aircraft to determine if this trend holds true. Additional flight attendant data is also needed to determine if flight attendants throughout the industry rate air quality factors as poorly as they did during this study. Further, to determine if flight attendant perceptions and symptoms are related to time spent in the cabin, responses should be compared to those of frequent flyers who log a greater number of air miles.

Additional research is needed to identify the comfort levels for the contaminants and environmental parameters in the aircraft cabin environment. For example, Standard 62-1989 states that "comfort (odor) criteria are likely to be satisfied if the ventilation rate is set so that 1,000 ppm CO_2 is not exceeded." The 1,000 ppm level is set to satisfy the body odor perception of 80% of unadapted (visitors) persons walking into a occupied space from a relatively odor free space. Of the passengers that responded to the comfort questionnaire, 92.5% rated odors a 4 or above (average to excellent) and 91.5% rated air quality a 4 or above. While this limited data cannot be considered conclusive, it does suggest that mean CO_2 levels of approximately 1,500 ppm, as identified during this study, may be an acceptable level for passenger comfort. More data needs to be collected from a variety of airlines and aircraft to further substantiate this theory.

References

1. The Boeing Company. 1995. "The Airplane Cabin Environment—Issues Pertaining to Flight Attendant Comfort" January.

2. Wick, R. and L. Irvine. 1995. "The microbiological composition of airliner cabin air." *Aviation, Space, and Environmental Medicine*, March.

3. ANSI/ASHRAE Standard 62-1989, *Ventilation for Acceptable Indoor Air Quality*. ■

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