The Airplane Cabin Environment

Issues Pertaining to Flight Attendant Comfort

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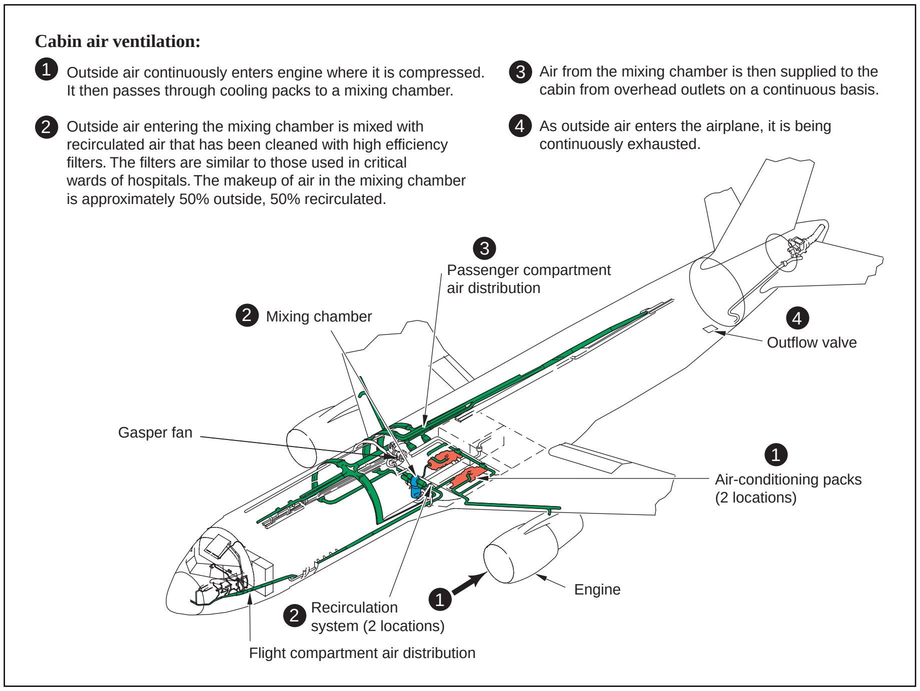
Introduction

The purpose of this paper is to examine some of the conflicting information written recently on the subject of cabin air quality by looking at the perceptions and facts of the cabin air as they are currently known. In addition, environmental issues and factors affecting in-flight service attendants and their comfort are addressed.

Many articles of late have been written on the subject of cabin air quality, with the presumption that the quality of cabin air is dependent upon its source. That is, the air reprocessed by nature, outside air, is “clean,” but the air reprocessed by the aircraft environmental control system is “not clean.” Consequently, since newer model airplanes reprocess a portion of the cabin air, the general theme of these articles is that the air supplied to the cabin is of poor quality. The belief is that outside air ventilation is low and the use of recirculation systems supposedly results in a buildup of contaminants, spread of disease, insufficient oxygen for breathing and high carbon dioxide levels.

Do these articles contain misconceptions or facts, or are there other factors that are more likely causing symptoms attributed to air quality? Such symptoms as fatigue, headaches, nausea, dizziness, eye and nose irritation and respiratory problems have been reported on occasion by flight attendants. Before delving into perceptions and facts relevant to cabin air quality, a brief discussion of Boeing design approach and philosophy of an airplane’s ventilation system is in order.



Cabin air ventilation:

① Outside air continuously enters engine where it is compressed. It then passes through cooling packs to a mixing chamber.

② Outside air entering the mixing chamber is mixed with recirculated air that has been cleaned with high efficiency filters. The filters are similar to those used in critical wards of hospitals. The makeup of air in the mixing chamber is approximately 50% outside, 50% recirculated.

③ Air from the mixing chamber is then supplied to the cabin from overhead outlets on a continuous basis.

④ As outside air enters the airplane, it is being continuously exhausted.

Figure 1. 767 airplane ventilation system

How an Airplane Ventilation System Works

The outside air supplied to the cabin of the 767 airplane is provided by the engine compressors, cooled by air-conditioning packs located under the wing center section, and mixed with an equal quantity of filtered recirculated air. This is shown in figure 1, and is typical of modern generation airplanes. Approximately 20 cubic feet per minute (cfm) of air per passenger is provided, of which half is filtered recirculated air and half is outside air. This results in a complete cabin air exchange every two to three minutes (20 to 30 air changes per hour). The high air exchange rate is necessary to control temperature gradients, prevent stagnant cold areas, maintain air quality and dissipate smoke and odors in the cabin. High outside airflow rates are also necessary to maintain overall cabin temperature control and cabin pressurization**.**

Due to the large quantity of air entering the relatively small volume of the cabin, as compared to a building, precise control of the airflow patterns is required to give

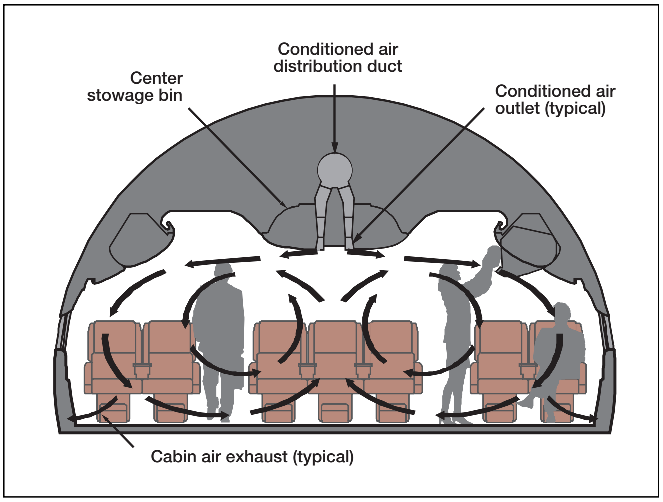


Figure 2. Typical main cabin airflow patterns

comfort without draftiness. As shown in figure 2, air enters the passenger cabin from overhead distribution outlets that run the length of the cabin. These outlets are designed to create carefully controlled circular airflow patterns in the cabin.

Air is supplied and exhausted from the cabin on a continuous basis. The exhaust air leaves the cabin through return air grilles located in the sidewalls near the floor, and running the length of the cabin on both sides. The exhaust air is continuously extracted from below the cabin floor (lower lobes), creating a pressure differential which moves more exhaust air through the return air grilles to the lower lobes. In the 767 airplane, this exhaust air is extracted from the lower lobe aft of the wings by an outflow valve which purges the air overboard, and forward of the wings by the recirculation fans. The cabin ventilation system is designed and balanced so that air supplied at one seat row leaves at approximately the same seat row, minimizing airflow in the fore and aft directions. By controlling fore and aft airflow, the potential for spreading passenger generated contaminants is minimized.

Perceptions and Facts of the Cabin Environment

An examination of recent popular articles finds some striking pronouncements regarding the in-flight environment. The overall perception is that cabin air quality is poor on newer model airplanes due to lower outside airflow and the incorporation of recirculation systems.

Specific perceptions are that airplane ventilation systems can cause (1) a buildup of contaminants, (2) spread of disease, (3) a decrease in the quantity of oxygen and (4) high carbon dioxide levels. It has been suggested that these factors in the cabin air can cause sickness, fatigue, dizziness, nausea, headaches, eye and nose irritation and respiratory problems among passengers and flight attendants.

(1) Contaminant buildup in the cabin

Perception

A perception persists that there is a buildup of contaminants in the cabin on newer model airplanes, due to the incorporation of recirculation systems and a subsequent reduction in the outside airflow.

Facts

Credible scientific investigations of cabin air quality have been conducted by the National Academy of Sciences,[19] United States Department of Transportation (DOT),[23] National Institute for Occupational Safety and Health (NIOSH),[20] independent research groups[1, 2] and airplane manufacturers. Results of cabin air quality studies are shown in table 1.

As study results show, the high efficiency filtration system and large quantity of outside airflow supplied to the cabin maintain low particulate levels in the cabin. The high outside airflow also maintains low gaseous levels of volatile organic compounds (VOC), carbon dioxide (CO_2), carbon monoxide (CO) and odors not removed by the filtration system.

Table 1. Test results of cabin air quality studies

Item	Average measured (ppm)	ACGIH (ppm)	ASHRAE (ppm)	Comments
CO_2[a, b]	600 – 1,500	5,000	1,000	ASHRAE value is a surrogate for body odor
CO[a]	0.6/1.4	25	–	Average nonsmoking zone/smoking zone
Microbial[a] aerosols	Very low	–	–	Equal to or lower than in the common home
Ozone[a]	0.02	0.1	0.05	
Particulates[a]	40/175 RSP	10,000 TSP	260 TSP	μg/m3, nonsmoking/smoking zones
NO_2[b]	Very low	3	–	
SO_2	Very low	2	–	
Volatile organic[b, c] compounds	1.8 – 3.2	1,000	–	Too low to quantify, except during food service when ethanol (alcohol) was served

RSP - respirable suspended particulate

TSP - total suspended particulate

ACGIH values are time weighted average—8-hour workday, 40-hour workweek

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers

ACGIH - American Conference of Governmental Industrial Hygienists

a. United States Department of Transportation report no. DOT-P-15-89-5, Airliner Cabin Environment: Contaminant Measurements, Health Risks and Mitigation Options, December, 1989

b. National Institute for Occupational Safety and Health, HETA 90-226-2281, Health Hazard Evaluation Report, Alaska Airlines, January, 1993

c. Manufacturer testing

Low contaminant levels in the cabin are realized also due to the tight control over outgassing of components used in the airplane furnishings; direct control over the location of passengers relative to the supply air and exhaust; the effectiveness of the recirculation system to remove essentially all microbials and particulates from the recirculated air; the dry, sterile and dust-free outside supply air during flight; and the supply of a much larger quantity of outside airflow per cubic volume of space compared to most environments.

(2) Spread of disease, due to recirculation system

Perception

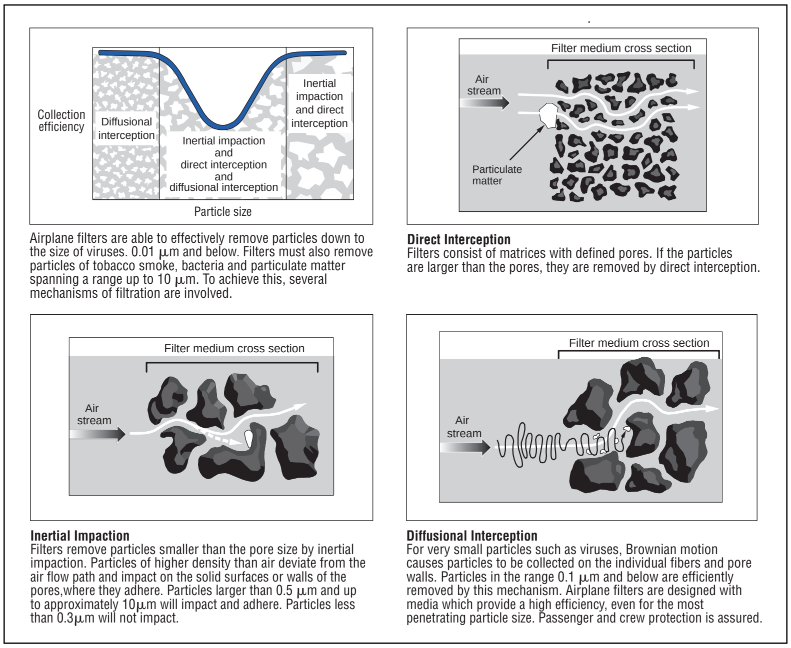
A persistent perception is that there is a spread of disease on modern airplanes due to the recirculation system.

A documented study used to support this perception was the occurrence of an outbreak of infectious disease among passengers of an airplane, following a three-hour delay without the ventilation system operating. In 1979, because of an engine malfunction, an airliner with 54 persons on board was delayed on the ground for three hours, during which time the airplane ventilation system was turned off. The airplane had a 100 percent outside air system, with no recirculation. Within three days of the incident, 72 percent of the passengers became ill with influenza. One passenger (the index case) was ill while the airplane was delayed.[19]

Facts

Three hours on an airplane with the ventilation system shut off does not reflect proper use of the cabin environmental control systems. Boeing believes that had the ventilation system been operating during the delay, the possibility of other passengers becoming ill would have been minimal. Full operation of the air-conditioning packs is recommended when passengers are on board. An exception to this is for no-pack takeoffs in which the air-conditioning packs are shut off for a short duration on takeoff only, but not the recirculation fans.

To remove particulates and biological particles from the recirculated air, filter assemblies installed on all current Boeing airplanes contain a high efficiency particulate air type filter (HEPA-type) that has a minimum efficiency of 94 percent to 99.97 percent D.O.P. as measured by MIL-STD-282. A HEPA-type filter is rated using 0.3 micron size particles. To get an idea of this size, the width of a human hair averages 70 microns in diameter. A filter's efficiency increases over time as particulates become trapped by the filter. Due to the overlap of capture mechanisms within a filter, the efficiency also increases for particles smaller and larger than the most penetrating particle size (MPPS). For an airplane filter, the MPPS is about 0.1 to 0.2 microns. Filter capture mechanisms are illustrated in figure 3.



Airplane filters are able to effectively remove particles down to the size of viruses. 0.01 µm and below. Filters must also remove particles of tobacco smoke, bacteria and particulate matter spanning a range up to 10 µm. To achieve this, several mechanisms of filtration are involved.

Direct Interception
Filters consist of matrices with defined pores. If the particles are larger than the pores, they are removed by direct interception.

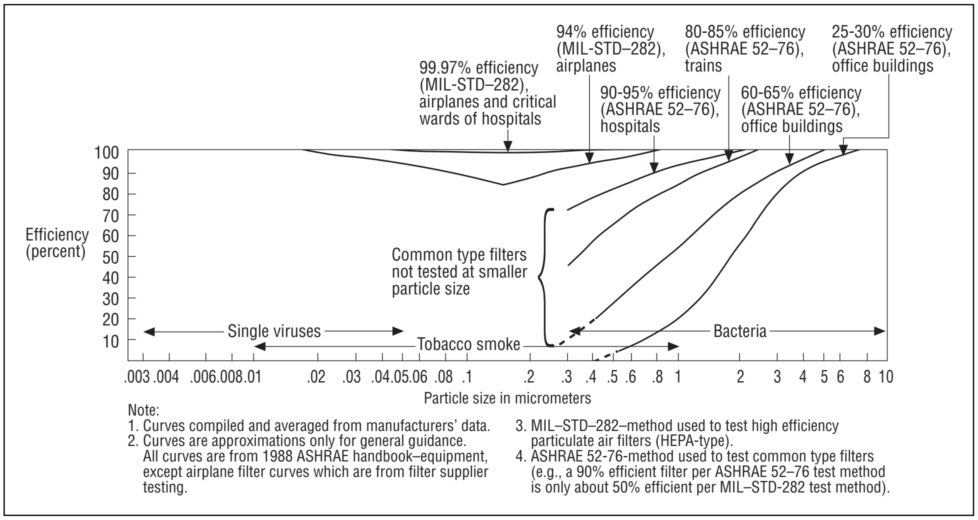
Inertial Impaction
Filters remove particles smaller than the pore size by inertial impaction. Particles of higher density than air deviate from the air flow path and impact on the solid surfaces or walls of the pores,where they adhere. Particles larger than 0.5 µm and up to approximately 10µm will impact and adhere. Particles less than 0.3µm will not impact.

Diffusional Interception
For very small particles such as viruses, Brownian motion causes particles to be collected on the individual fibers and pore walls. Particles in the range 0.1 µm and below are efficiently removed by this mechanism. Airplane filters are designed with media which provide a high efficiency, even for the most penetrating particle size. Passenger and crew protection is assured.

Figure 3. Filter capture mechanisms

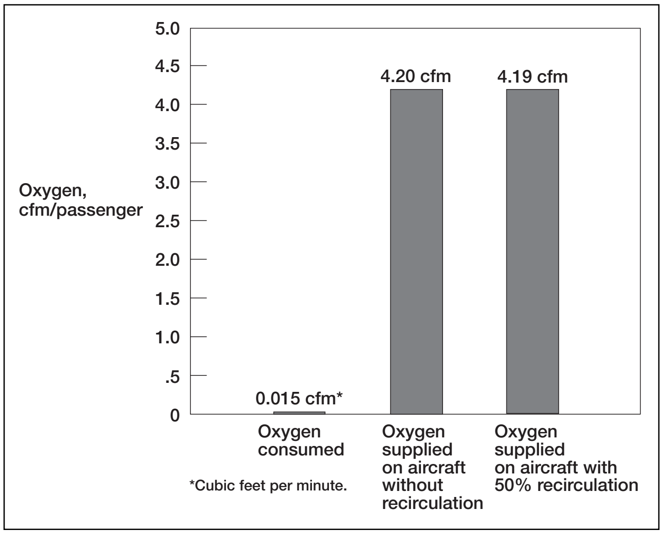
The efficiency of the filter to remove .003 micron particles from the air is in excess of 99.9+ percent. Most bacteria (99 percent) are larger than 1 micron. Viruses are approximately .003 to .05 microns in size. Test results of a DOT study conducted on 92 randomly selected flights showed that bacteria and fungi levels measured in the airplane cabin are similar to or lower than those found in the common home.[23] These very low microbial contaminant levels are due to the large quantity of outside airflow and high filtration capability of the recirculation system.

The recirculation filters used on current Boeing airplanes are similar to filters used in critical wards of hospitals, such as organ transplant and burn units, and to those used in industrial "clean" rooms. By comparison, filtration systems in typical buildings are not capable of removing microbial contaminants, including bacteria and viruses, from the recirculated air. Buildings typically recirculate 65 percent to 95 percent of the air. Consequently, a building's ventilation system must control microbial contaminants by dilution with outside air. Figure 4 compares the filter efficiencies of various filtration systems.



Note:
1. Curves compiled and averaged from manufacturers' data.
2. Curves are approximations only for general guidance. All curves are from 1988 ASHRAE handbook–equipment, except airplane filter curves which are from filter supplier testing.
3. MIL–STD–282–method used to test high efficiency particulate air filters (HEPA-type).
4. ASHRAE 52-76-method used to test common type filters (e.g., a 90% efficient filter per ASHRAE 52–76 test method is only about 50% efficient per MIL–STD-282 test method).

Figure 4. Comparison of filter efficiencies of various filtration systems



*Cubic feet per minute.

Figure 5. Oxygen consumption vs. oxygen supplied

(3) Low oxygen levels on newer model airplanes

Perception

There is a perception that the cabin oxygen content on newer model airplanes is decreased, due to lower outside airflow rates, compared to older model airplanes. Another aspect of this perception is that available oxygen is reduced for passengers and flight attendants, while it is increased for the flight crew.

Facts

The amount of oxygen available is essentially unchanged, with or without a recirculation system. Humans at rest consume approximately .015 cfm of oxygen,[28] while the ventilation system provides approximately 4.19 cfm of oxygen per person, as shown in figure 5. This is about 279 times more oxygen per minute per person than can be physically consumed. Consequently, the quantity of oxygen in the passenger cabin and flight deck remains essentially constant throughout a flight. It is scarcely affected by passenger and crew respiration since it is replaced in much larger quantities compared to the human consumption rate.

(4) High carbon dioxide levels, due to recirculation

Perception

A perception commonly stated is that carbon dioxide (CO_2) levels are too high in the passenger cabin on newer model airplanes with recirculation systems.

This perception stems from the observation that cabin levels at times exceed the CO_2 level set by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) in 1989 as a surrogate for odor and contaminant control in a building environment.[4]

Facts

Cabin CO_2 levels are in no way near levels of health concern. CO_2 levels during flight average 600 ppm to 1,500 ppm.[1, 2, 20, 23] The National Aeronautics and Space Administration (NASA) has reported on extensive studies of the effects of elevated CO_2 levels.[22] These studies show that prolonged exposure (weeks) at concentrations of CO_2 in air less than 5,000 ppm cause no known biochemical or other effect; concentrations between 5,000 and 30,000 ppm cause adaptive biochemical changes which may be considered a mild physiological strain; and concentrations above 30,000 ppm may cause pathological changes in basic physiological functions. Figure 6 shows respiratory effects of increased CO_2 concentrations.

Figure 7 shows CO_2 concentrations in the cabins of airplanes with and without recirculation systems, and limits set by occupational and comfort standards. Both the

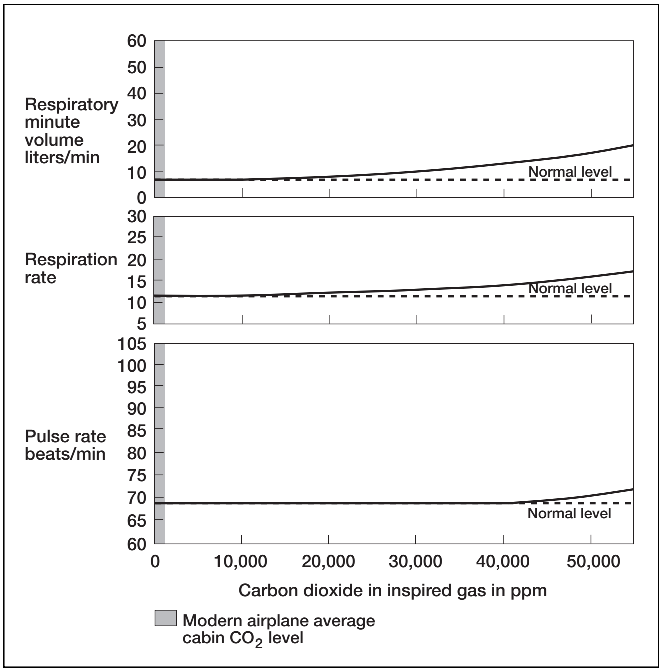


Figure 6. Respiratory effects of increased CO_2 concentrations

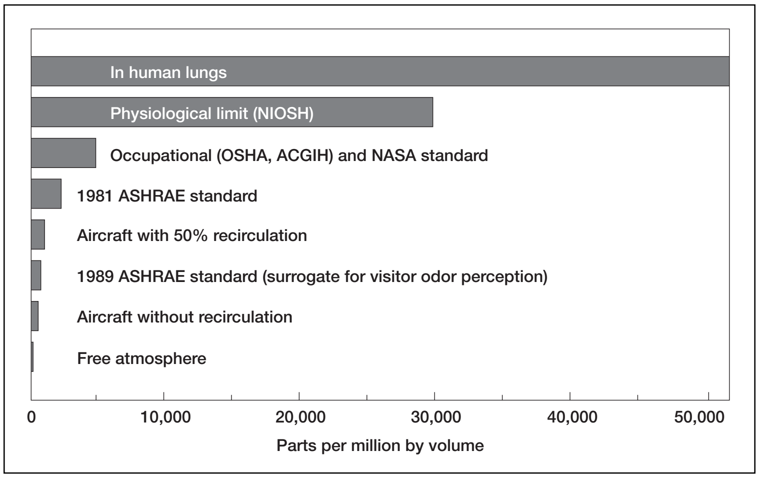


Figure 7. CO_2 concentrations in airplanes, and health and comfort standards

Occupational Safety and Health Administration (OSHA) and the American Conference of Governmental Industrial Hygienists (ACGIH) have set an extended exposure limit of 5,000 ppm for CO_2. This value was chosen to provide a good margin from systemic effects. The Federal Aviation Administration (FAA) is considering adopting a concentration of 5,000 ppm as a limit for airplanes.

This level is considered to be appropriate because there are no documented safety or health benefits associated with a lower value.[21] Airplane cabins with recirculation systems are significantly below 5,000 ppm. As a matter of interest, CO_2 concentration in the human lungs averages about 52,000 ppm.[28]

Why, then, did ASHRAE come up with a CO_2 level of 1,000 ppm for buildings? A brief look into the history of the ASHRAE 62 standard is in order.

ASHRAE defines acceptable indoor air quality as *air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80 percent or more) of the people exposed do not express dissatisfaction.*[3, 4] The ASHRAE standard is set to satisfy comfort and health requirements, with comfort being the more stringent and difficult parameter to satisfy.

From 1936 until 1981, the recommended outside airflow supplied to buildings was 10 cfm per person. This amount of airflow was considered adequate to control contaminant levels in buildings.[15] In the late 1970s, due to the energy crisis, ASHRAE came out with the ASHRAE (62-1981) standard which reduced the outside airflow requirement to 5 cfm per person, thus saving energy. This standard also provided a hard limit for CO_2 itself to satisfy comfort, indicating an adequate limit of 5,000 ppm. However, a CO_2 limit of 2,500 ppm was chosen by ASHRAE to allow for an additional margin in accounting for variations, and to ensure that 5,000 ppm would not likely be exceeded.[3]

The incorporation of the ASHRAE (62-1981) standard, coupled with new building design, resulted in an increase in air quality related complaints such as headaches, eye irritation, drowsiness, fatigue, stuffiness and dizziness. These types of complaints led to coining of the term “sick building syndrome” (SBS).

Many subsequent studies have determined that the predominant cause of SBS is contaminants given off from the building and its interior furnishings, and not from the building occupants.[17, 18] By reducing the outside airflow from 10 cfm to 5 cfm per person and constructing new and tighter buildings, there was an increase in building-produced contaminant levels that culminated in SBS.

In the early 1980s, three studies were conducted to determine the outside airflow required to satisfy the body odor perception of 80 percent of *visitors* walking into an occupied space (figure 8).[5, 8, 16] The results of these tests were considered appropriate for buildings meeting the ASHRAE comfort requirement that the air in an environment must be acceptable to at least 80 percent of the people exposed, and the fact that a building is typically entered frequently.

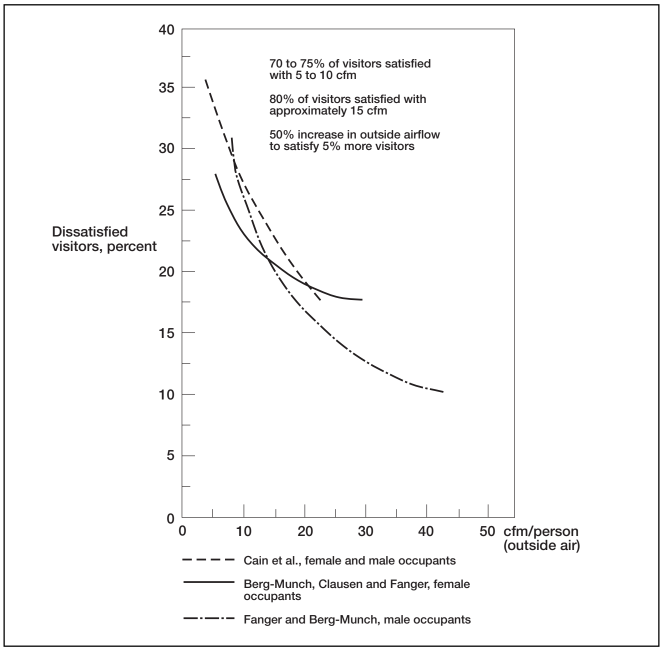


Figure 8. Odor acceptance of visitors in a room

Based on the results of these three studies, in 1989 ASHRAE established a new standard (62-1989).[14, 15] The new standard sets a minimum outside airflow per occupant at 15 cfm, which corresponds to a CO_2 concentration of 1,000 ppm.[4] In the new standard, ASHRAE uses CO_2 as a surrogate—an indicator of the adequacy of ventilation in a building environment. If a building CO_2 concentration is held to below 1,000 ppm, the outside airflow of 15 cfm per person is being met, satisfying the ASHRAE comfort criteria for odor. This amount of outside airflow also easily exceeds the health criteria by controlling contaminants given off from the building environment. This new standard satisfies the comfort of *visitors* and, by providing more airflow than necessary for health, satisfies health requirements as well.

Two of the same studies used to derive the ASHRAE (62-1989) standard also looked at the amount of outside airflow necessary to satisfy the odor perception of the *occupants* acclimated to the environment. These studies discovered that over 90 percent of the acclimated *occupants* were satisfied with an outside airflow of approximately 5 cfm, the results of which are shown in figure 9.[5, 8]

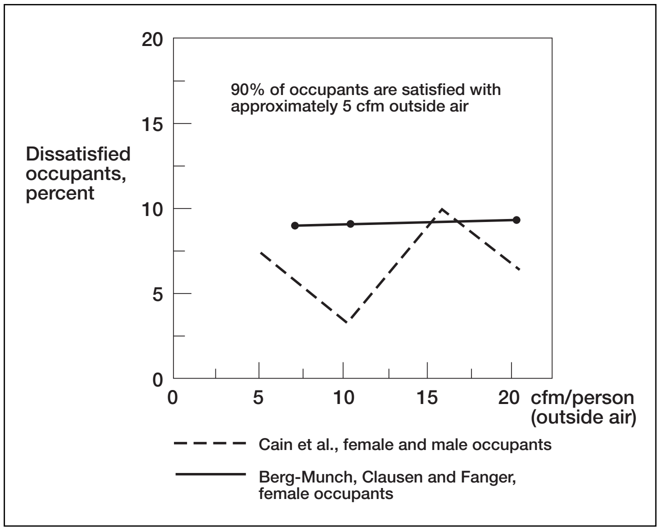


Figure 9. Odor acceptance of occupants in a room

Airplanes have no *visitors* to the cabin in flight but do have acclimated *occupants*. Consequently, the outside airflow required to satisfy *visitors* does not apply. Since airplanes typically supply 10 cfm of outside airflow per person, is there a chance of SBS from an accumulation of contaminants given off by the airplane, as can occur from contaminants given off by a building? This is very unlikely.

The air in the airplane cabin is completely exchanged with outside air 10 to 15 times per hour compared to a typical building's 1 to 2.5 times per hour (figure 10). The building rate is based on the 1988 ASHRAE handbook-equipment recommendation of total (recirculated and outside) air changes of 4 to 10 per hour, resulting in 1 to 2.5 outside air changes per hour with 75 percent recirculated air.

The large quantity of outside airflow supplied to the cabin is required to maintain temperature control in the very harsh operating environment of the airplane. As a direct comparison, the outside airflow supplied in an airplane cabin per cubic volume of space is 4 to 15 times higher per minute than a cubic volume of space in a building.

This means that the contaminants given off from the airplane itself are held to extremely low levels. For instance, if an airplane cabin gave off the same quantity of contaminants per unit volume as a building, the equilibrium gaseous contaminant levels in the airplane would be 4 to 15 times lower than in the building, and microbial particulate levels would be approximately 8 to 30 times lower. This is due to the high quantity of outside airflow, and because the filtration systems on modern airplanes are designed to remove virtually all microbial aerosols and particulates

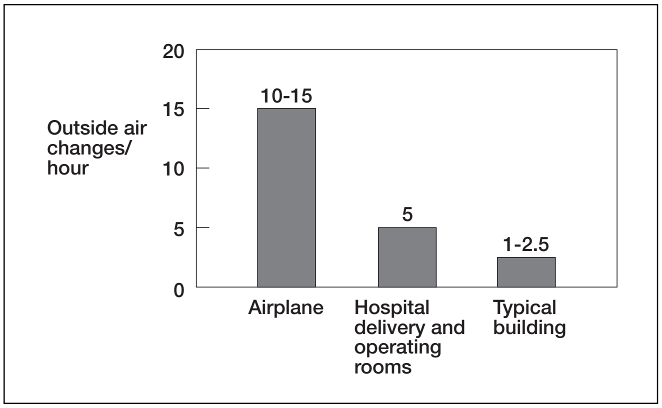


Figure 10. Air exchange rates in different environments

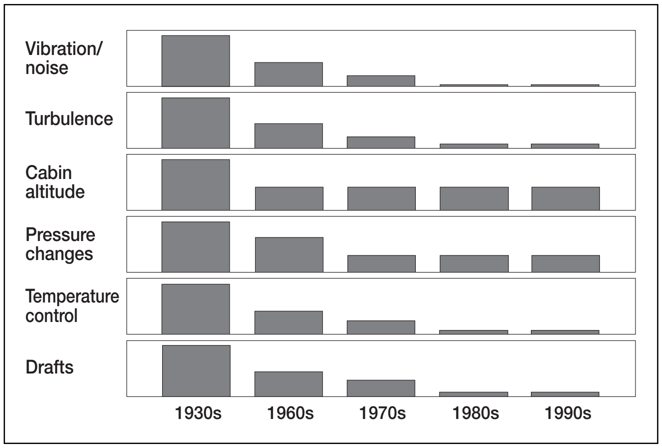


*Figure 11. Predominant stressors of the past**

from the recirculated air. Building recirculation systems are not. Consequently, unlike a building, in an airplane it is predominantly the contaminants given off from the *occupants* (passengers) that must be controlled, such as body odors, microbial aerosols and CO_2. This is effectively accomplished as previously shown in table 1 test results.

In addition to the much higher outside air exchange rates and filtration capabilities of airplanes compared to buildings, the quality of the outside air supplied during flight is higher than that supplied in most buildings at ground level.

The ASHRAE Technical Committee (TC) 9.3 has realized the misuse by some in applying the (62-1989) standard to airplanes. In June of 1994, ASHRAE TC 9.3 formed a new subcommittee for aircraft, with a charter to derive an air quality standard specific to aircraft.

Environmental Stressors

If cabin air quality is not the cause of the symptoms experienced by some flight attendants, then what is? Atypical cases have been reported, such as ingesting of jet fuel through the engines when an airplane is on the tarmac. This is not a reflection of a deficiency in the airplane's ventilation system, but a mistake in the operational procedures outside the airplane. Aside from such atypical cases, there are factors that are believed to be contributors to such symptoms as the headaches, nausea, fatigue, stress and illness experienced on occasion by some flight attendants.

Since the inception of in-flight service in the 1930s, flight attendants have had to cope with an ever changing mix of environmental stressors. Figure 11 shows that early environmental stressors included vibration, noise, turbulence, cabin altitude, high rates of cabin pressure changes and cold.

The first official flight attendants were nurses who flew on a Boeing Trimotor in 1930. Passengers and crew had to endure vibration, and cotton was stuffed into ears to counter noise. Cabin altitudes of up to 15,000 feet were encountered without a cabin pressurization system. Blankets were provided when flying at altitudes above the capacity of the heating system. Cabin pressurization changes were at the mercy of the airplane's descent performance and high velocity vertical wind shear. Chewing gum was distributed to help keep the air pressure across the eardrums equal during rapid and sometimes unpredictable cabin pressure changes. Motion sickness was the biggest complaint of passengers and flight attendants alike.[6]

Past stressors, such as vibration, noise and turbulence, are still experienced by flight attendants. Although their magnitude has greatly diminished since the 1930s, the time of exposure has increased. Furthermore, there is a new set of stressors, including jet lag, workload and low relative humidity. All of these, combined with cabin altitude and flight duration, are environmental factors of in-flight service that can affect the comfort of today's flight attendants. The relative magnitude of impact of these factors from the 1930s to the present is shown in figure 12. Other environmental factors, such as ozone and tobacco smoke, are highly dependent on flight routes, destinations and airlines. Their relative magnitude of impact is shown in figure 13.

**Authors' view only.*

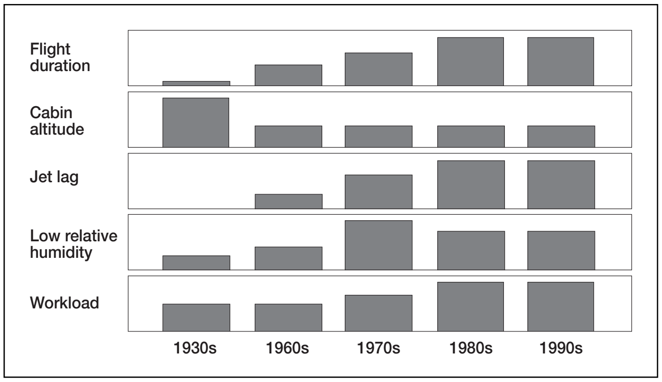


*Figure 12. Predominant stressors of the present**

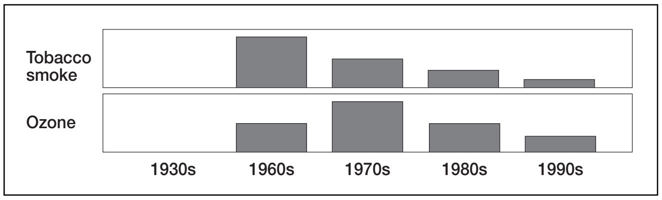


*Figure 13. Other stressors**

Flight duration

While many of the environmental stressors experienced by the early flight attendants were far more severe than those of today, exposure to them was of short duration, with flight stages averaging little more than an hour.[6] Over the years flight stages have steadily increased, particularly on international flights, with nonstop flights of 12 to 14 hours now common. Figure 14 shows the increase in average stage length of domestic and international flights since 1950.[25]

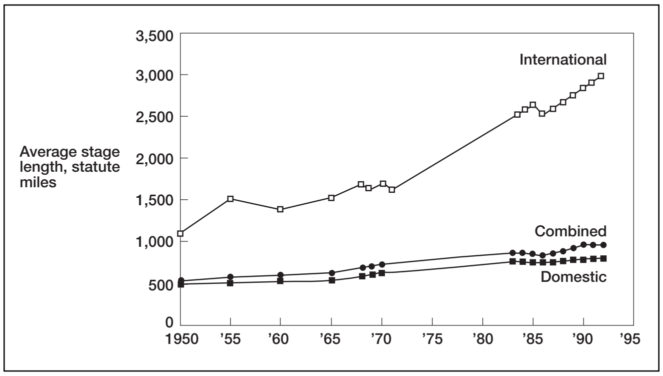


Figure 14. Stage length increases

Cabin altitude

Cabin altitude and pressure changes are much smaller in magnitude on today's high altitude pressurized jets than they were during the days of the Trimotor. However, due to increases in flight duration, it is believed that cabin altitude can be a stressor of some flight attendants.

Although the percentage of oxygen in cabin air remains virtually unchanged (21 percent) at all normal flight altitudes compared to sea level, the partial pressure of oxygen decreases with increasing altitude. This is because with increasing altitude air is less densely packed, resulting in fewer molecules of oxygen available for each breath. At a maximum cabin altitude of 8,000 feet, the partial pressure of oxygen is about 74 percent of the sea level value. A typical 767 transatlantic flight will cruise at 35,000 to 39,000 feet, resulting in a cabin altitude of 5,400 to 7,000 feet. Figure 15 shows the 767 cabin altitude schedule.

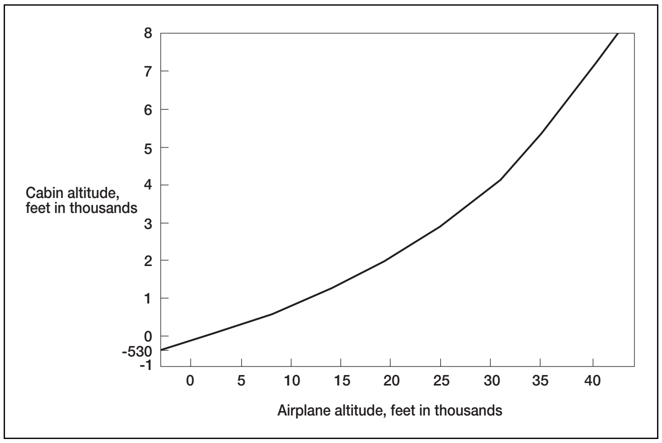


Figure 15. 767 airplane cabin altitude schedule

The lower partial pressure of oxygen with increasing altitude is an important phenomenon, since it is the partial pressure of oxygen in the lungs that forces oxygen into the blood across the lung's alveoli.[27, 28] Consequently, at 5,000 to 8,000 feet, the oxygenation of the arterial blood is reduced from the sea level value. It is believed that the increase in cabin altitude, combined with longer flight durations, can lead to low grade hypoxia (reduced tissue oxygen levels) in certain segments of the population and that this effect can be a factor in causing fainting, headaches, fatigue and stress, in combination with other stressors discussed in this paper. However, research by the National Academy of Sciences has concluded that *pressurization of the cabin to an equivalent*

**Authors' view only.*

altitude of 5,000 to 8,000 feet is physiologically safe—no supplemental oxygen is needed to maintain sufficient arterial oxygen saturation.[19]

Jet lag

Jet lag is a stressor of flight attendants. The main cause of jet lag is traveling to a different time zone without giving the body a chance to adjust to new night-day cycles. The scientific term for this is circadian rhythm upset. In general, the more time zones crossed during a flight, the more the biological clock is disturbed. Common symptoms of jet lag are sleeplessness or tiredness, loss of appetite or appetite at odd hours and a general feeling of fatigue.[12, 13]

Due to the nature of their work, it is not possible for flight attendants to become acclimatized to jet lag.[12] It generally takes the body's biological clock about one day per time zone crossed to adjust.[13] Consequently, on long flights, it could take up to 12 days to adjust to the new night-day cycles. By way of comparison, the first flight attendants had to adjust to only one time zone disruption of their circadian rhythms.[6]

Workload

The workload of flight attendants may have increased in modern air travel: longer flights, longer aisles and more amenities to offer passengers. Depending upon the airline and the particular flight, it is not uncommon for a flight attendant to serve food and drinks to 40 to 60 passengers. While the actual level of activity is considered "light," it is more difficult to push a heavy cart down an aisle at 8,000 feet than at sea level.

In addition, flight attendants work in close proximity to passengers from all over the world. Close contact with a large number of people on each flight can potentially expose them to contagions, another possible cause of stress.

Cabin Humidity/Dehydration

Low humidity in the cabin is caused by the frequent renewal of cabin air with outside air. Since the outside temperature at typical cruising altitudes is very low (-45^{0}F to -85^{0}F), it contains little moisture. It is this very dry air that is supplied to the cabin.

During flight, the relative humidity in the cabin ranges from approximately 5 percent to 35 percent, with an average of 15 percent to 20 percent.[1, 20, 23] This is similar to the dry summer climate of the southwestern United States or typical wintertime indoor levels. A low humidity environment has been shown to inhibit fungal and bacterial growth.[19]

However, exposure to such an environment without sufficient fluid intake will dehydrate the body through perspiration and respiratory water loss. Dehydration can lead to headaches, tiredness and fatigue. [11, 24] In addition, low humidity can cause drying of the nose, throat and eyes, and it can irritate contact lens wearers. Dehydration, as well as the associated symptoms of a low humidity environment, can be reduced by following recommendations designed to mitigate them.[7]

Ozone

An increase in the incidence of encountering high levels of ambient ozone occurred with the inception of high altitude long-range commercial aircraft in the 1970s.

Pan American World Airways was principal in recognizing ozone as a stressor after several flight attendants complained of symptoms on some flights but not on others. Certain of Pan Am's long polar flights at relatively high altitudes were associated with transient episodes of chest pain, coughing, shortness of breath, fatigue, headaches, nasal congestion and eye irritation in physically active crew members. The determination from studies conducted by NASA and the FAA was that these symptoms were caused by ozone. In 1980, the FAA established a standard for cabin ozone concentration.[19]

Ozone is present in the atmosphere as a consequence of the photochemical conversion of oxygen by solar ultraviolet radiation. Ozone concentration increases with increasing latitude, is maximal during spring and often varies with weather systems, resulting in high ozone plumes descending to lower altitudes. Figure 16 shows ambient ozone concentrations over eastern North America for the month of March at various latitudes.[26]

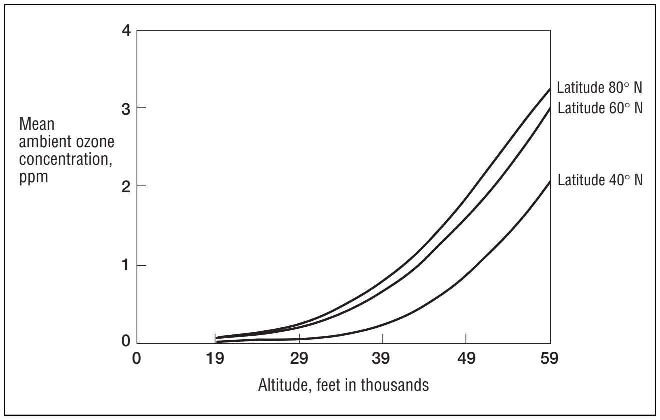


Figure 16. Ambient ozone distribution

It is difficult to predict temporary areas with high ambient ozone concentrations since they vary with the seasons and weather systems and can appear with little or no warning. This situation can lead to an airplane flying through an area of high ozone concentration.

FAA requirements specify maximum levels of ozone, based upon flight altitude and time of exposure.[9] Ozone dissociates to oxygen molecules (O_2) by the catalyzing action of a noble catalyst such as palladium, which is used in catalytic ozone converters installed on some airplanes. Further dissociation occurs when ozone contacts airplane ducting, interior surfaces and the airplane recirculation system. The recirculation system also decreases the potential ozone exposure by allowing less use of outside air.

Environmental tobacco smoke

A flight attendants' survey conducted by a European airline indicated that smoky air caused by environmental tobacco smoke (ETS) was their number one complaint.[19] Working in a smoking environment can be uncomfortable. ETS can irritate the eyes, nose and throat, and may have long-term health effects.[23]

Currently, there are no direct governmental, occupational or ambient standards for ETS in any environment. An indirect method of controlling ETS in the airplane cabin is to control the concentration of carbon monoxide (CO) and respirable suspended particulates (RSP), which are tracer constituents of ETS and for which standards do exist. This method does not take into account the other constituents present in ETS.

In a DOT study conducted on 92 randomly selected airplanes, measured CO levels in the smoking section(s) during peak smoking averaged 0.5 to 2 ppm. The FAA specifies a limit for CO of 50 ppm.[10] RSP concentrations in the smoking sections averaged 175 $\mu g/m^3$.[23] The Occupational Safety and Health Administration sets a permissible exposure limit of 5,000 $\mu g/m^3$ for RSP.

Smoking is banned in the United States on domestic flights of less than six hours; however, it is still allowed on many international flights. Highly efficient recirculation filters remove virtually all of the tobacco smoke particulates from the recirculated air, but not gases such as CO. Some international airlines are taking steps to minimize the impact of smoking on airplanes by offering smoke-free flights and by providing tightly controlled partitioned areas for standing-room-only smoking.

Conclusion

The symptoms experienced by flight attendants, such as fatigue, headaches, tiredness, nausea and illness—often attributed to cabin air quality—are more likely due to an interaction of factors that include cabin altitude, flight duration, jet lag, turbulence, noise, work levels, dehydration, an individual's health and stress. Efforts to improve the working environment of flight attendants must be focused on these factors.

As many recent air quality studies have shown, the cabin is a healthful environment, meeting all applicable safety and health regulations and standards.[1,2,20,23]

However, the cabin also is a unique environment. As average flight durations continue to increase, the combined effects of jet lag, low cabin humidity, cabin altitude, workload and other environmental stressors will continue to be compounding factors on the general comfort of flight attendants.

The stressors may be alleviated by awareness of the physiological factors involved and by following recommendations designed to mitigate them.[7]

The occurrence of ozone in the atmosphere is variable, depending on season, latitude, altitude and weather systems. Ozone can be easily controlled to low levels in the cabin with the use of catalytic ozone converters.

As world health organizations become more active in reducing or eliminating smoking in public places, these improvements will continue to transfer to the airplane environment on a wider scale.

Additional studies of the effects of exposure to elevated cabin altitudes on comfort during flight should be considered.

Current indoor air quality standards such as the ASHRAE (62-1989) standard have been shown to work well for building design, but have not been shown to apply to airplanes. The ASHRAE Technical Committee 9.3, "Transportation Air-Conditioning," recognizes this and recently established a subcommittee for aircraft, comprised of individuals that includes flight attendants, manufacturers, component suppliers, governmental regulators and health experts. It is the mission of this new subcommittee to further research the airplane cabin environment and look in detail at all possible causes of flight attendant and passenger symptoms and complaints.

The end goal is an ASHRAE air quality standard for commercial aircraft which will specify cabin air content and characteristics to assure acceptable levels of safety, health and comfort for passengers and flight crew.

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The first official flight attendants were nurses who flew on a Boeing Trimotor in 1930 for United Airlines.