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Measurement of Thermal Comfort and Indoor Air Quality Aboard 43 Flights on Commercial Airlines

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Key Words
Thermal comfort · Aircraft · Air-conditioning · ASHRAE Standard 55-92 · ASHRAE Standard 62-89

Abstract
This paper reports the results of thermal comfort and indoor air quality measurements aboard aircraft from 43 flights on commercial airlines with a duration of more than 1 h. The measurements were performed continuously during the whole flight (from the departure gate to the arrival gate), and the parameters monitored were temperature, relative humidity and carbon dioxide concentration. The results were then compared with the ASHRAE Standards for the thermal comfort (ASHRAE Standard 55-92) and indoor air quality (ASHRAE Standard 62-89). The evaluation of the indoor air quality was based mainly upon comparison of the carbon dioxide concentrations measured with standards and recommendations for the indoor environment. Overall, the levels of relative humidity were far lower than the limit set by the ASHRAE Standard 55-92. The levels of carbon dioxide on most flights were higher than that recommended by the ASHRAE Standard 62-89. The results of this study, mainly the low level of humidity and high concentrations of carbon dioxide, led us to expect that the crew and the passengers would have been dissatisfied with their degree of thermal comfort and the quality of the air in the cabin. This conclusion is based simply on a comparison of our measurements with the values stated in the ASHRAE Standards. However, we must bear in mind that these were developed for an indoor environment at atmospheric pressure. More research is needed to study the validity of these standards for sub-atmospheric conditions.

Introduction

Acceptable quality of indoor environment in aircraft passenger cabins is of importance to the comfort, health and well-being of passengers and crew as well as the crew's performance and productivity during the flight. Recently, there have been reports of nausea, headaches, dizziness, fatigue, mucosal irritation, and in an extreme case, passengers and crew fell mysteriously ill during a flight [1–3]. As examples, it was reported that in four separate incidents, air travellers may have been exposed to tuberculosis by infected members of the flight crew or other passengers [2], and in another incident, 72% of the passengers became ill due to the outbreak of influenza [3]. Such inci-

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dents show the inadequacy of the ventilation system to provide and distribute sufficient air through the passenger cabin and the inefficiency of the filtration system at trapping bacteria. Other symptoms, such as nausea, fatigue, headaches and eye irritation are similar to those observed in the so-called sick building syndrome reported among the occupants of office buildings investigated during the past decade [4].

Improving the quality of the indoor environment has been a major concern in commercial aviation following the energy crisis of the 1970s, when the search to save energy forced the aviation industry to re-design the mechanical system in new planes to re-circulate part of the ventilated air. This modification has increased the risk of poor indoor air environment or what, by analogy, could be called 'sick plane syndrome' [2] in the passenger cabin. The quality of the environment in commercial aircraft has been studied by several researchers [5–9].

This paper reports the results of thermal comfort and indoor air quality studies on 43 flights, each with a duration of more than 1 h. The measurements were performed continuously during the whole flight (from the departure gate to the arrival gate) and the parameters monitored were temperature, relative humidity (RH) and carbon dioxide concentration. The results were then compared with the ASHRAE standards for thermal comfort and indoor air quality. The evaluation of the indoor air quality was based mainly upon comparison of the measured carbon dioxide concentrations with those given in the ASHRAE Standards. Carbon dioxide is an excellent indicator of indoor air quality.

Aircraft Mechanical Ventilation System

Commercial flights travel at an altitude of 10,000–15,000 m, where the temperature is around –60 °C, and the air is almost dry. At this altitude, the air is so thin that a person would become confused and lethargic in less than a minute. Even at an altitude of only 2,500 m, the unconstrained volume of air is 30% greater than at sea level, and the atmospheric pressure correspondingly reduced. Therefore, to create an acceptable atmosphere, air taken in at altitude has to be compressed and heated to the proper pressure and temperature and then conditioned in an environmental control unit before it is introduced into the cabin.

In commercial aircraft, the source of ventilation air is the engine compressor bleed air which has a temperature and pressure much higher than that required for space heating or cooling requirements. This air is passed through heat exchangers, where it is cooled to the required comfort temperature. A flow-controlled valve, controlled manually by the crew or automatically, regulates the quantity of air through the heat exchangers. By controlling the quantity, this valve controls the temperature of the air through the heat exchangers. A zone re-heating system in the cabin provides further control of the cabin temperature. The flow-controled valve also allows crews to adjust airflow rate when the aircraft is carrying less than a full load of passengers. Figure 1 shows a schematic drawing of a typical air distribution system in a commercial aircraft [10]. As shown in this schematic, each aircraft has two identical air conditioning systems, which are designed to work independently or in parallel.

The air entering the main duct is distributed in the passenger cabin through the full-length grilled outlets situated on the sidewalls below the storage bins and from overhead diffusers in the passenger compartment entry way. Exhaust air is removed through the floor level grilles alongside the wall via the left and right tunnels, to the outflow valves. The cabin pressure is controlled by regulating the amount of the exhaust air: the planes are designed and constructed to maintain an air pressure that is at least equivalent to the air pressure at 2,500 m above sea level (around 560 mm Hg).

The mechanical ventilation system in an aircraft built before the 1980s delivers up to 5.7 m^3 of outdoor air per person per minute corresponding to a nominal air exchange rate of 23–27 per hour (depending on the volume of the passenger cabin). However, the mechanical ventilation system of a more modern aircraft only delivers about half of that amount, although this is still more than the air exchange in, say, commercial buildings. The total amount of air delivered in the more modern craft is unchanged, and the amount is made up from re-circulated air from the passenger cabin. Fulton [11] has documented the possible causes of aircraft mechanical system deficiency in providing sufficient air, distribution and filtration.

Methods

The measurements were carried out during the summer of 1996. A total of 43 flights were investigated in four commercial aeroplane types; Airbus 320, DC9, Boeing 767 and Airbus 340. A portable air sampler (CO_2, temperature and RH logger; Progeco Tech., Montreal, Canada) was used to measure carbon dioxide, and to monitor air temperature and RH. The monitoring was undertaken between the hospitality and first class cabins: the air samplers were programmed to monitor every 5 min for the duration of the flight. On all flights, the measurements started from the time of boarding and continued until the landing.

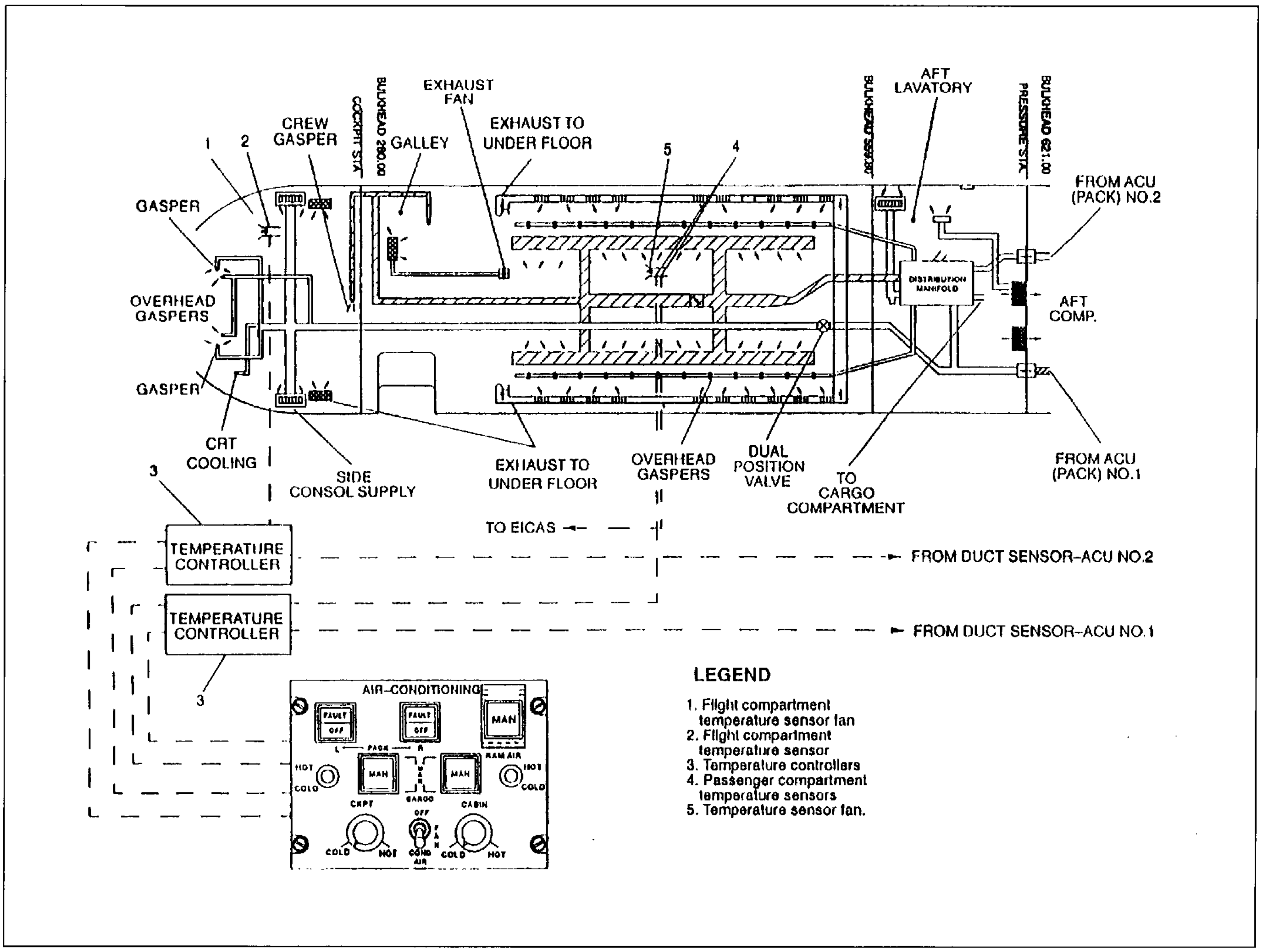

Fig. 1. Typical air distribution system.

Results

Thermal Comfort

Air temperature and RH were the parameters used as indicator of passengers' thermal comfort. The air temperature was set by the crew and was controlled automatically in the passenger cabin. The data recorded are grouped by aircraft types. Table 1 shows the air temperature and RH for Airbus 320. Data for DC9, Boeing 767 and Airbus 340 are given in tables 2–4. For each flight, the number of passengers and the altitude are also given. Figures 2–5 show the temperature, carbon dioxide concentration and RH for 4 flights as a function of time. Under summer conditions (a cooling season) ASHRAE Standard 55-92 [12] recommends the mean ambient temperature should be in the range of 23–26 °C and the minimum level of RH 30%. As indicated in table 1, the air temperature was often below the recommended range, and the RH was always too low.

Tables 1–4 show that the mean air temperature was not regulated very well throughout most flights and was rarely within the range recommended in the ASHRAE Standard 62-89 [13]; generally the air temperature fell to the cooler side of the comfort zone for summer conditions. As an example, the fourth column in table 1 shows the range of air temperatures in Airbus 320 flights. Temperature ranges were from a low of 19–22 °C (7/25A) to a high of 20–26 °C (8/4A). The column of mean air temperatures shows that only 2 (6/27 and 7/1) out of 15 flights satisfied the requirement for summer conditions. Overall

Table 1. Airbus 320 flight measurements summary

Flight No.	Altitude m	Load (max. 137 Pax)	Temp. °C	Avg. temp, °C	Lowest RH, %	CO_2 levels ppm	Avg. CO_2 ppm
6/27	11,900	–	23–24	23.8	5.4	742–1,368	835.7
6/28	11,300	32	21–23	22.0	3.3	293–664	386.0
6/28A	11,600	–	21–23	21.9	3.7	449–1,016	538.5
7/1	11,900	86	21–24	23.4	1.8	390–938	455.0
7/2	11,300	90	21–22	20.9	4.9	351–997	434.6
7/3	11,900	65	21–22	21.4	6.2	469–781	565.2
7/3A	11,300	62	20–23	22.2	5.2	449–840	532.5
7/5	10,700	137	20–22	21.6	13.1	566–1,172	753.3
7/5A	11,900	49	19–23	22.0	2.6	430–723	478.3
7/6	11,300	50	20–23	21.0	2.7	390–958	451.3
7/25	–	60	20–22	21.2	5.8	606–1,114	758.0
7/25A	–	4	19–22	20.2	4.4	312–625	408.0
8/2	8,500	130	22–24	22.9	18.5	781–1,446	1,091.2
8/2A	8,500	128	20–24	21.7	18.2	781–1,231	975.9
8/2B	8,200	57	21–25	22.8	15.3	625–1,271	821.0
8/2C	11,300	137	22–24	22.6	7.6	684–1,622	913.6
8/4	10,700	103	20–24	22.8	2.5	508–1,329	598.2
8/4A	11,300	105	20–26	22.8	2.4	508–2,013	773.7
8/5	–	–	21–23	22.0	2.3	371–957	446.0
8/8	10,700	101	21–23	21.8	4.3	547–1,075	527.8
8/9	9,450	98	21–24	22.2	2.2	781–1,290	1,003.8
8/10	11,300	63	?	?	?	488–1,035	562.0

Table 2. DC 9 flight measurements summary

Flight No.	Altitude m	Load (max. 92 Pax)	Temp, °C	Avg. temp. °C	Lowest RH, %	CO_2 levels ppm	Avg. CO_2 ppm
6/28	10,700	84	20–24	20.9	11.1	605–1,211	785
6/29	7,900	26	20–24	21.5	23.0	309–703	497
6/30	9,750	60	20–22	20.8	10.9	430–1,407	790
6/30A	9,750	?	20–24	22.1	8.6	547–1,250	847
6/30B	10,050	92	21–24	22.8	6.9	567–1,446	732
7/6	10,700	75	21–24	22.4	7.1	567–996	706
7/6A	10,050	60	20–26	22.0	7.3	371–1,172	573
7/30	9,450	52	22–23	22.7	17.0	625–1,055	840
7/30A	10,050	60	22–25	22.8	10.8	508–1,113	741
7/30B	8,500	49	21–22	21.5	9.8	430–645	512
8/1	9,450	65	20–21	20.3	19.4	567–1,290	751
8/lA	9,350	75	21–21	21.0	12.5	723–1,309	877
8/lB	10,050	66	21–23	22.1	12.0	625–1,387	746
8/lC	8,200	44	23–24	22.9	15.5	–	–
8/9	10,700	65	23–27	23.8	12.3	645–1,368	850

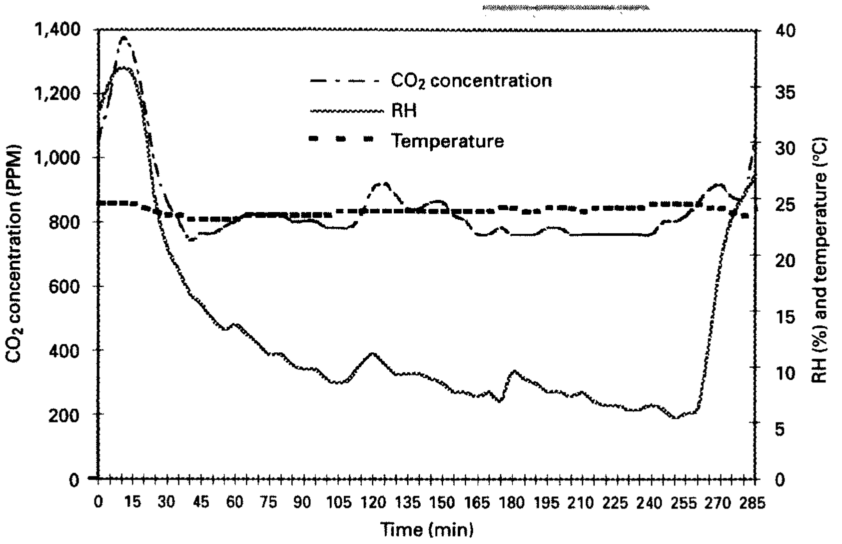

Fig. 2. CO_2 concentration, RH and temperature for the Airbus 320 (Flight 6/27).

Table 3. Boeing 767 flight measurements summary

Flight No.	Altitude m	Load Pax	Temp. °C	Avg. temp. °C	Lowest RH, %	CO_2 levels ppm	Avg. CO_2 ppm
7/10	12,200	187/203	22–23	22.9	2.33	488–782	536
7/18	11,900	185/203	22–24	22.8	4.51	684–1,348	773
7/22	10,700	85/195	22–24	23.0	7.63	430–820	602
7/22A	11,900	70/195	22–25	23.2	2.3	430–977	565
7/23	10,700	35/195	22–27	23.4	1.8	469–801	565

Table 4. Airbus 340 flight measurement summary

Flight No.	Altitude m	Load Pax	Temp. °C	Avg. temp. °C	Lowest RH, %	CO_2 levels ppm	Avg. CO_2 ppm
7/23	11,900	177/284	19–24	21	3.3	469–1,114	726

the data shows that average air temperatures were between 21 and 24°C.

In defining the ASHRAE comfort zone for thermal comfort, two assumptions are made concerning activity level and the effect of clothing. The activity level is a measure of metabolic rate per unit of body surface area (measured in mets, 1 met = 58.2 $W \cdot m^{-2}$ and light activity, mainly sedentary, is rated at 1.2 met, moderate activity at 2 met and high activity at 4 met). In this work, we assumed an activity level of 1.2 met, although this might be a little on the high side for passengers during a flight. However, owing to lack of sufficient data, 1.2 met was considered to be an acceptable value. The effect of clothing on heat transfer from the body is measured in clo (1 clo = 0.1555 $m^2 \cdot °C \cdot W^{-1}$) and a business suit would be judged as 1 clo while nudity has a value of 0 clo). The ASHRAE Standard 55-92 [12] assumes a clothing value of 0.5 clo for summer conditions. The clo value depends on

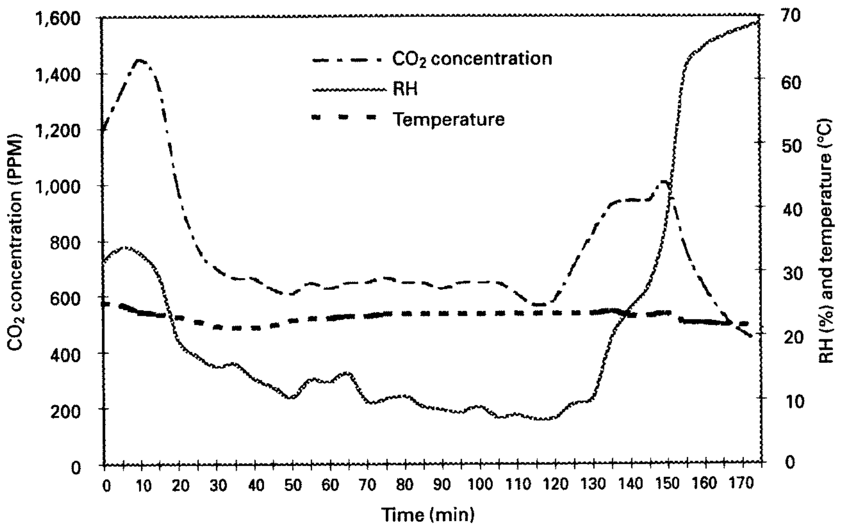

Fig. 3. CO_2 concentration, RH and temperature for the DC 9 (Flight 6/30B).

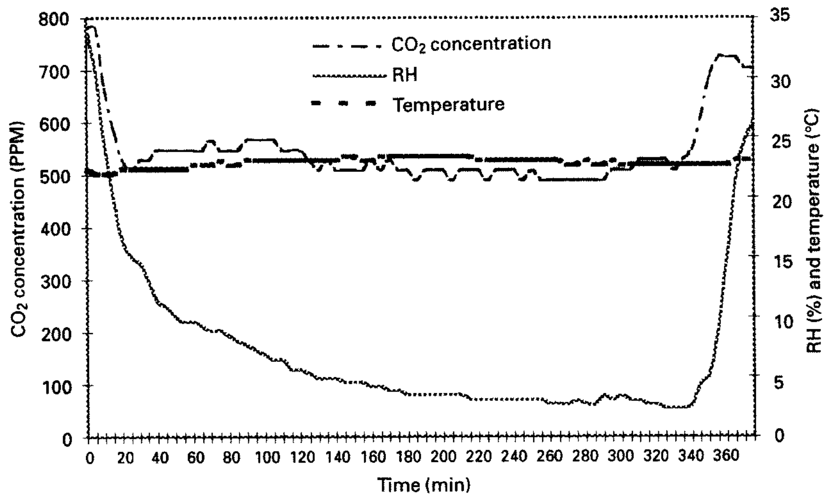

Fig. 4. CO_2 concentration, RH and temperature for the Boeing 767 (Flight 7/10).

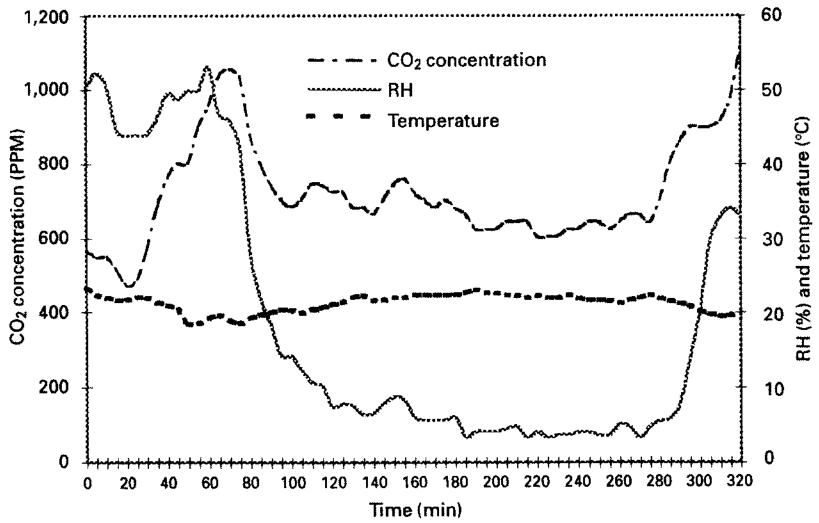

Fig. 5. CO_2 concentration, RH and temperature for the Airbus 340 (Flight 7/23).

Table 5. PMV and PPD given by ASHRAE Standard 55–92 for A320 (for 0.5 clo and 0.1 m·s^{-1} air velocity; results in the parentheses are for 0.15 m·s^{-1} air velocity)

Flight No.	Average temp. °C	Lowest RH, %	PMV	PPD
6/27	23.8	5.4	–1.19 (–1.40)	35 (46)
6/28	22.0	3.3	–1.84 (–2.07)	69 (80)
6/28A	21.9	3.7	–1.87 (–2.10)	71 (81)
7/1	23.4	1.8	–1.35 (–1.57)	43 (55)
7/2	20.9	4.9	–2.23 (–2.46)	86 (92)
7/3	21.4	6.2	–2.04 (–2.27)	79 (87)
7/3A	22.2	5.2	–1.75 (–1.98)	64 (76)
7/5	21.6	13.1	–1.92 (–2.15)	73 (83)
7/5A	22.0	2.6	–1.84 (–2.07)	69 (80)
7/6	21.0	2.7	–2.21 (–2.43)	85 (92)
7/25	21.2	5.8	–2.11 (–2.34)	82 (89)
7/25A	20.2	4.4	–2.49 (–2.71)	93 (97)
8/2	22.9	18.5	–1.40 (–1.63)	45 (58)
8/2A	21.7	18.2	–1.85 (–2.08)	69 (80)
8/2B	22.8	15.3	–1.46 (–1.69)	49 (61)
8/2C	22.6	7.6	–1.59 (–1.82)	56 (68)
8/4	22.8	2.5	–1.55 (–1.79)	54 (66)
8/4A	22.8	2.4	–1.55 (–1.79)	54 (66)
8/5	22.0	2.3	–1.85 (–2.08)	69 (80)
8/8	21.8	4.3	–1.91 (–2.14)	72 (83)
8/9	22.2	2.2	–1.77 (–2.01)	66 (77)

Table 6. PMV and PPD given by ASHRAE Standard 55–92 for A320 (for 1.0 clo and 0.1 m·s^{-1} air velocity; results in parentheses are for 0.15 m·s^{-1} air velocity)

Flight No.	Average temp. °C	Lowest RH, %	PMV	PPD
6/27	23.8	5.4	–0.21 (–0.31)	6 (7)
6/28	22.0	3.3	–0.68 (–0.80)	15 (18)
6/28A	21.9	3.7	–0.69 (–0.82)	15 (19)
7/1	23.4	1.8	–0.33 (–0.44)	7 (9)
7/2	20.9	4.9	–0.94 (–1.07)	24 (29)
7/3	21.4	6.2	–0.81 (–0.94)	19 (23)
7/3A	22.2	5.2	–0.61 (–0.73)	13 (16)
7/5	21.6	13.1	–0.71 (–0.84)	16 (20)
7/5A	22.0	2.6	–0.68 (–0.80)	15 (18)
7/6	21.0	2.7	–1.11 (–1.26)	31 (38)
7/25	21.2	5.8	–0.86 (–0.99)	20 (26)
7/25A	20.2	4.4	–1.12 (–1.26)	31 (38)
8/2	22.9	18.5	–0.33 (–0.45)	7 (9)
8/2A	21.7	18.2	–0.65 (–0.78)	14 (18)
8/2B	22.8	15.3	–0.39 (–0.50)	8 (10)
8/2C	22.6	7.6	–0.49 (–0.61)	10 (13)
8/4	22.8	2.5	–0.48 (–0.60)	10 (13)
8/4A	22.8	2.4	–0.48 (–0.60)	10 (13)
8/5	22.0	2.3	–0.68 (–0.81)	15 (19)
8/8	21.8	4.3	–0.72 (–0.85)	16 (20)
8/9	22.2	2.2	–0.63 (–0.75)	13 (17)

surroundings, for example, whether a person is standing or sitting in a chair. When seated, a clothing value equivalent, in clo, of the seat can be deduced and the total clo value of the passenger can be corrected by adding the clo of the seat. The correction value is proportional to the amount of chair surface area in contact with the body. This modification lifts the average level by 0.5 clo, so increasing the insulation value to 1.0 clo [14]. We carried out our calculations with both the assumed value of 0.5 clo, for clothing alone (see the results in table 5) and using the seat-modified value of 1.0 clo (see the results in table 6).

To evaluate thermal comfort of the passengers during a flight, we used the indices: predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) as described in ISO 7730 [15]. Using the assumed values for met and clo and the measured average air temperature and RH, the PMV and PPD could be calculated. PMV is based on a 7-point scale and gives values over the range of +3 to –3, corresponding to a hot to cold thermal sensation. The ideal is zero which is 'thermal neutrality'. Since the air velocity was not measured in this study, the indices were calculated for two air velocities: 0.1 m·s^{-1} and 0.15 m·s^{-1}. Table 5 shows the calculated PMV and PPD values for the A320. As expected from the air temperature and level of RH, PMV values were found to be much below zero with lower values still for an air velocity of 0.15 m·s^{-1}. The values of thermal sensation at an air velocity of 0.1 m·s^{-1} ranged from cool (PMV = –1.19) to cold (PMV = –2.49) with PPDs for these PMVs of 35 and 93%. Table 6 shows the PMV and PPD values calculated using the modified clo value. As expected, this extra clo insulation can help more passengers to accept the thermal environment. The highest PPD values drop from 93 to 31% for comparable values of air temperature and RH. These data also show that there is no relationship between the number of passengers and the cabin mean air temperature.

There is no humidification system for the air in the aircraft, and humidity is only generated by water vapour from the breath and perspiration of passengers. Therefore, the level of humidity would be expected to decrease as the number of passengers decreases or when the ratio of outside air to re-circulated air increases. Food preparation in the galleys could increase humidity, but usually air from galleys is not exhausted to the passenger cabin. For safety, through reducing icing and corrosion, the mechanical systems are designed to remove as much of the water from the air as possible.

The RH levels were very low on all flights and did not meet even the lower limit of thermal comfort in ASHRAE Standard 55-92 [12], which recommends that RH should be between 30 and 70%. The average value was 7% on all the flights tested and reached values as low as 2%. One interesting result is that the RH level in the DC9 which uses 100% of 'fresh' air, was higher than the RH level in the newer aircraft models (Boeing 767, Airbus 320 and Airbus 340) which recycled air. The mean level of RH was below 10% in 17 out of 21 flights for the Airbus 320, 5 out of 15 for the DC9 and 4 out of 5 for the Boeing 767. Detailed investigation of the indoor climate of buildings has shown that low-level humidity causes symptom in the eyes and upper respiratory tract [16]. Therefore, it would be expected that the low level of humidity found in this study would produce acute effects such as local irritation of the eyes, and mucous membranes of the mouth and respiratory tract. Contact lens wearers particularly could suffer from eye irritation. Our observations suggest that the quality of thermal comfort in the passenger cabins on the flights studied was not acceptable.

Figures 2–5 show the variations in temperature, RH and carbon dioxide concentrations for typical Airbus 320, Boeing 767, Airbus 340 and DC9 flights. The figures show that while all parameters vary during the flight, the variation of RH is particularly large. As the flight gets under way, the level of RH decreases quickly below the ASHRAE Standard minimum of 30% to a level which may be as low as 2%.

Ventilation Performance

Carbon dioxide concentration was used as the indicator of ventilation performance and indoor air quality. No other specific contaminants were measured. The carbon dioxide in cabin air is largely anthropogenic, and the amount produced depends on the level of human activity. It has been suggested that carbon dioxide exhalation by passengers during a flight could be as high as 0.18 cfm (cubic feet per minute; 0.5 liters$\cdot$min^{-1}) per person due to factors such as food or alcohol consumption and environmental stress [6]. The range of carbon dioxide levels on the flights studied and the mean concentrations are given in tables 1–4. These tables show that the levels of carbon dioxide concentration on all flights were lower than 5,000 ppm. The US Federal Aviation Administration [17] recently proposed that the allowable carbon dioxide concentration in aircraft should be lowered to 5,000 ppm. Regarding higher levels, Part 25 of Airworthiness Standard: Transport Category Aeroplanes states that 'carbon dioxide in excess of 30,000 ppm is considered hazardous for crew members'. The level of 5,000 ppm can be achieved with an outdoor air ventilation rate of 2.5 cfm per person. Five thousand parts per million is the level set by the ACGIH [18] as a time-weighted average. That is, workers should not be exposed to an average of more than 5,000 ppm over the period of a week (8 h/day; 40 h/week). The ASHRAE Standard 62-89 [13] sets a concentration of 1,000 ppm carbon dioxide as the threshold level for acceptable indoor air quality and suggests that levels higher than 1,000 ppm indicate lack of ventilation. A level of 1,000 ppm can be achieved with an outdoor air ventilation rate of 10 cfm per person. Inspection of our data shows that the levels on many of the flights exceeded for a time the limit recommended by ASHRAE. Overall, a carbon dioxide level of 1,000 ppm was exceeded in 13 out of 22 flights for Airbus, 11 out of 15 for DC9 flights and 1 out of 5 for Boeing 767 flights. It is worth noting that even though the DC9 has a system running on 100% 'fresh air', a higher percentage of flights on this type of aircraft experienced carbon dioxide levels exceeding 1,000 ppm.

The distribution of the air is uniform for each cabin section and is not on a per passenger basis. The levels of carbon dioxide, therefore, only indicate the concentration in the first-class section where the measurements were taken, which has two to three times more fresh air than the economy-class section. It seems reasonable, therefore, that the level of carbon dioxide in the economy class would have been higher since the number of passengers per unit area in the economy class is two to three times greater than in first class. Figures 2–5 also show the variation in carbon dioxide concentrations with respect to time for several flights. As would be expected, high levels occurred during the take off and landing, when engine power requirements reduce the amount of compressed air available for ventilation. The level of carbon dioxide drops at cruising altitudes, when more compressed air is available for ventilation.

Since the passengers produce the carbon dioxide, it would be expected that fewer of them on board would result in better air quality. The results, however, show that high levels occurred even when some of the flights carried less than 70% of their full passenger capacity (tables 1–4). This is probably due to the fact that the rate of air circulation is controlled by the pilot and crews and the ventilation rate was kept low for the given flight, since the pilot/crews were mainly concerned with saving energy rather than passenger comfort.

Discussion

An effective ventilation system is essential for providing acceptable indoor air quality and thermal comfort for passengers. In the 43 flights studied, the level of RH was far lower than the limit set by the ASHRAE Standard 55-92 [12]. The level of carbon dioxide, for at least some of the time, for most of the flights, was higher than recommended in ASHRAE Standard 62-89 [13]. The air temperature in the cabins was not very well regulated throughout most flights. From these results, in particular the low level of humidity and high level of carbon dioxide, one would expect that the crew and the passengers were dissatisfied with the thermal comfort and quality of the air on board the aircraft.

These conclusions are simply drawn by comparing our measurements with the recommendations in the two ASHRAE Standards. However, these are based on health and comfort considerations for an indoor environment at an atmospheric pressure around 1 bar. As an example, ASHRAE Standard 55-92 on 'thermal environment conditions for human occupancy' is based almost entirely on data from climate chamber studies at normal atmospheric pressure. It also derives largely from work with healthy and young subjects. This suggests there may be some limitations to the use of the ASHRAE Standards in aircraft cabins at altitude. First, all passengers are not healthy and/or young. The elderly and disabled persons are groups of special concern [19, 20]. During the flight, the cabin air pressure is allowed to decrease to around 0.8 bar (around 600 mm Hg) or lower. There is no data in the literature to prove the validity of these standards to groups of passengers who may be neither young nor healthy, and who are at sub-atmospheric pressure, for both thermal comfort and health. It is, however, well established that the effect of various indoor air contaminants on the human body may be intensified under sub-atmospheric conditions. That may translate as: the acceptable contaminant concentrations and the comfort zone, as given in ASHRAE Standards, may need to be re-examined for application to aircraft cabins during flight.

References

1 Harding R: Cabin air quality in aircraft. BMJ 1994;308:247–248.
2 Kiernan V: Ill feeling over sick plane syndrome. New Scientist 1993;139:7.
3 Gox JE, Miro C: Congress holds hearings on airliner cabin IAQ. ASHRAE J 1993;35:14.
4 Haghighat F, Donnini G: Impact of psycho-social factors on perception of the indoor air environment studies in 12 office buildings. Building Environ 1998;34:479–503.
5 Malmfors T, Thorburn D, Westlin A: Air quality in passenger cabins of DC-9 and MD-80 aircraft. Environ Technol Lett 1989;10:613–628.
6 Nagda NL, Koontz MD, Konheim AG: Carbon dioxide levels in commercial airline cabins. ASHRAE J 1991;August:35–38.
7 Nagda N, Koontz MD, Konheim AG: Measurement of cabin air quality aboard commercial airlines. Atmos Environ 1992;26A:2203–2210.
8 O'Donnell A, Donnini G, Nguyen VH: Air quality, ventilation, temperature and humidity in aircraft. ASHRAE J 1991;April:42–46.
9 Eatough D, Caka FM, Carford J, Braithwaite S: Environmental tobacco smoke in commercial aircraft. Atmos Environ 1992;26A:2211–2218.
10 Canadair: Canadair Regional Jet Maintenance Training manual, 1992.
11 Fulton HB Jr: A pilot's guide to gain air quality and fire safety. NY State J Med 1985;85:384–388.
12 ASHRAE 1992: ANSI/ASHRAE Standard 55-1992, Thermal Environmental Conditions for Human Occupancy. Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1992.
13 ASHRAE 1989: ANSI/ASHRAE Standard 62-1989, Ventilation for Acceptable Indoor Air Quality. Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1989.
14 Donnini G, Molina C, Lai HC, Lai HO, Chang CY, Laflamme M, Nguyen VH, Haghighat F: Field study of occupant comfort and office thermal environment in a cold climate. ASHRAE Trans 1997;103:205–220.
15 ISO 7730: (International Organisation for Standardisation) Moderate Thermal Environments – Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort. Geneva, 1984.
16 Menzies R, Tamblyn RM, Farant J, Hanley J, Nunes F, Tamblyn RT: The effect of varying levels of indoor air supply on the symptoms of sick building syndrome. New Engl J Med 1993;328:821–827.
17 Federal Aviation Administration: 'Federal Aviation Regulation'. Washington DC, 1993, 25.831.
18 American Conference of Government Industrial Hygienists: Threshold Limit Values. Cincinnati, 1991.
19 Marshall VW: Aging in Canada: Social Perspectives. Don Mills, Fitzhenry and Whiteside, 1980, pp 20–30.
20 Haghighat F, Donnini G, Giorgi G, Megri AC: Responses of disabled persons to thermal environments, submitted.