Committee on the Toxicity of Chemicals in Food, Consumer Products and the Environment.

Carbon monoxide and carbon dioxide in aircraft cabin air

Introduction

1. In 2007, the Committee on Toxicity (COT) published a statement on aircraft cabin air, relating to organophosphate (OP) compounds, the cabin air environment, ill-health in aircraft crews and the possible relationship to smoke/fume events in aircraft (COT, 2007). Subsequently, the COT reviewed the results of Department for Transport (DfT) - funded aircraft cabin environment research commissioned in response to recommendations made by COT in 2007, after which the COT issued a position statement on cabin air (COT, 2013).

2. The COT has now been asked by DfT to investigate if any new data have been published and to re-evaluate their previous view in the original statement from 2007 (COT, 2007) and position statement from 2013 (COT, 2013). Following the May 2022 COT meeting, the request of COT was further refined to: “Is there evidence of exposure to chemical contaminants in cabin air that could have long-term health impacts, either from acute exposures or due to long-term low level exposures including mixtures, e.g., of VOCs?”.

3. The levels of VOCs in aircraft compared with other modes of transport (TOX/2022/46) and work environments (TOX/2022/55) were presented in the September 2022 and October 2022 meetings, respectively.

4. Following the September 2022 COT meeting, it was agreed that consideration should also be made of whether there is evidence that exposure to carbon monoxide (CO) or carbon dioxide (CO_2) in cabin air could have long-term health impacts.

Background

5. The COT reviewed an introductory paper on this topic on cabin air in May 2022 (TOX/2022/30), which provided a full background to the Committee's previous conclusions. The scope of the work was expanded to include volatile organic compounds (VOCs) and semi-volatile organic compounds (sVOCs), on which there has been more focus in recent years. Papers on VOCs and sVOCs in aircraft compared with other modes of transport (TOX/2022/46) and work environments (TOX/2022/55) were presented at the September 2022 and October 2022 meetings, respectively. Following discussion, the scope of work was also extended to cover CO and CO_2.

6. The current paper provides a narrative on the concentrations of CO and CO_2 reported in aircraft. Health effects observed following exposure to CO and CO_2 will also be presented as well as regulatory standards in aircraft.

7. The studies identified for CO_2 are summarised in paragraphs 12 - 44 and for CO from paragraphs 45 - 59. A comparison of levels to regulatory standards and concentrations that cause adverse health effects is provided in the summary from paragraphs 60 and 70, respectively.

Literature search

8. A literature search was carried out to collate concentration data on CO and CO_2 in aircraft. Search terms used are presented in Annex 1.

9. A number of reports cited in previous papers on VOCs in aircrafts (TOX/2022/46 and TOX/2022/55) were also included, such as European Aviation Safety Authority (EASA, 2014), Crump et al. (2011) and Spengler et al. (2012).

10. Only literature that presented concentration data in tabular format were included in the analysis (i.e., not extracted from figures or graphs). Papers presenting data as figures were excluded. All data were included in analyses.

11. Eleven papers for the literature search were identified for inclusion based on their title and abstract.

Carbon dioxide

Lee et al. (1999)

12. Lee et al. (1999) investigated 16 flights originating from Hong Kong for cabin air quality. Carbon dioxide was measured in an Airbus 330 and Boeing 747-400 from June 1996 to August 1997 and were sampled every 5 minutes (Table 1). To note, this paper reports data covering a time when smoking was still permitted in aircraft as smoking was prohibited onboard all flights from September 1997.

Table 1. Mean, minimum and maximum concentrations of CO_2 in Airbus 330 and Boeing 747-400.

Flight	**Mean conc. (ppm)**	**Min conc. (ppm)**	**Max conc. (ppm)**
A	1.170	629	2195
B	906	612	1565
C	686	642	1492
D	1557	855	2900
E	1052	1052	2368
F	1097	863	2043
G	716	479	1826
H	728	423	1911
I	967	760	1491
J	701	538	1347
K*	884	418	4752
L*	868	530	4088
M	683	509	2303
N	733	427	1489
O*	1024	624	1994
P	1000	702	1946

*Flight in which smoking was permitted. It should be noted that smoking was prohibited on all flights in 1997.

Fox (2000)

13. Fox (2000) performed air quality monitoring to identify possible air contaminants entering an aircraft that may affect the comfort of passengers. To note, this paper reports data covering a time when smoking was still permitted in aircraft as smoking was prohibited onboard all flights from September 1997.

14. Measurements of CO_2 were made in revenue flights with a full load of passengers, in non-revenue flights with charcoal filters with filters at the end of their service life, and non-revenue flights with new carbon filters installed. Air samples were measured by on-line measurements taken during flights from the cockpit supply air, cabin supply air and air within the AFT galley. Flights originated from US.

15. Results for cabin supply air are presented in Table 2. No results were given for cockpit supply air or the AFT galley.

Table 2. Mean concentrations of CO_2 in cabin supply air.

	Mean conc. (ppm) 100% Fresh air non-revenue flight	**Mean conc. (ppm) 100 % Fresh air revenue flight**	**Mean conc. (ppm) 40% Re-circulated air revenue flight**	**Mean conc. (ppm) Charcoal filter non-revenue flight**
CO_2	480	ND	3800	ND

Nagda et al. (2000)

16. Nagda et al. (2000) published a detailed review of studies reporting measurements of cabin air quality, including CO2, that had been carried out between 1986 and 1998 and reported measurements in studies of up to approximately 100 flights in US (

17. Table 3). It should be noted that smoking was banned on domestic flights of less than six hours in 1989 and was totally prohibited in 1997. Therefore, some studies included in the review may have allowed smoking on board the aircraft.

Table 3. Mean, minimum and maximum concentrations of CO_2 cited in a literature review.

CO_2 (ppm)	**Nagda et al. 1989**	**O'Donnell 1991**	**CSS 1994**	**Consumers Union 1994**	**Spengler et al. 1997**	**CSS 1999**
Mean	1756	719	1162	NR	1400	1509
Min	765	330	NR	464	1200	942
Max	3157	2170	NR	1552	1800	1959

NR=not reported; CSS = Consolidated Safety Services

Lindgren and Norbäck (2002)

18. Lindgren and Norbäck (2002) investigated cabin air quality and in-flight exposure to a range of pollutants, including CO_2 during intercontinental flights between Scandinavia and Asia (Beijing, Osaka, Tokoyo, Japan) and North America (New York, Seattle, USA). To note, this paper reports data covering a time when smoking was still permitted in aircraft as smoking was prohibited onboard all flights from September 1997.

19. Twenty-six intercontinental flights between Scandinavia and Asia or North America were investigated between November 1995 and November 1998. A Boeing 767-300 aircraft with 190 seats was used on all flights. Smokers' seats in the tourist class (row 21-39) were located near the AFT (back) galley and smokers in business class (rows 1-17) were located near the middle section.

20. The air conditioning pack on a Boeing 767-300 gives 2800 cubic feet per minute of fresh outside air and the same flow of filtered air, resulting in personal outdoor air flow rate of approximately 6.6 l/s per person in a full aircraft.

21. Measurements for CO_2 were made in the AFT and FWD (forward) galley (part of the cabin area) in 24 of the 26 flights (Table 4).

Table 4. Mean, SD, minimum and maximum concentrations of CO_2 in the AFT and FWD galley.

	Mean conc. (ppm)	**SD conc. (ppm)**	**Min conc. (ppm)**	**Max conc. (ppm)**
AFT galley	734	151	415	1488
FWD galley	637	183	410	1406

22. Carbon dioxide was also measured in the AFT and FWD galley during cruising and non-cruising conditions in five flights (Table 5).

Table 5. Mean, SD, minimum and maximum concentrations of CO_2 in the AFT and FWD galley during cruising and non-cruising conditions.

	Mean conc. (ppm) Non-cruising	**SD (ppm) Non-cruising**	**Min conc. (ppm) Non-cruising**	**Max conc. (ppm) Non-cruising**	**Mean conc. (ppm) Cruising**	**SD (ppm) Cruising**	**Min conc. (ppm) Cruising**	**Max conc. (ppm) Cruising**
AFT galley	1656	877	694	3686	734	151	415	1488
Forward galley	1232	541	417	2490	637	183	410	1406

MacGregor et al. (2008)

23. MacGregor et al. (2008) investigated CO and CO_2 in four commercial flights from two airlines within USA in April 2004.

24. Test flights were conducted on two MD-80 aircraft, a B737-800, and a B757-200. These were commercial aircraft carrying revenue passengers and flight time ranged from 3 to 4 hours. During the flight, both cabin and bleed air were monitored. Cabin air measurements were made in the coach passenger cabin. Bleed air measurements involved coordination with the pilot to shut off the environmental control system (ECS) recirculation fans during cruising for a few minutes. This ensured that only bleed air was used for cabin ventilation. Sampling was conducted continuously throughout the flight hence during different flight phases (boarding, take-off, cruise, and descent).

25. Data for CO_2 for the different flight phases are given in Table 6.

Table 6. Mean concentrations of CO_2 during different flight phases in four flights.

	Mean conc. (ppm) Flight 1	**Mean conc. (ppm) Flight 2**	**Mean conc. (ppm) Flight 3**	**Mean conc. (ppm) Flight 4**
Boarding	1896	1434	1518	1797
Take-off/ascent	1408	1018	1024	1210
Cruise	1344	982	1127	998
Descent	1458	1053	968	815
Disembarking	1429	1073	1305	723

Lindgren et al. (2007)

26. Lindgren et al. (2007) investigated the influence of air humidification in aircraft on perception of cabin air quality amongst airline crew during which CO_2 levels were measured in business class, tourist class and the flight deck, with and without humidification.

27. Eight direct return flights from Stockholm to Chicago were investigated from December 2001 to October 2002. The duration of each flight was 8-9 hours. Four of the flights were performed with an air humidification device switched on when going to Chicago and switched-off when travelling in the opposite direction. The other four flights had the inverse humidification sequence. The air humidification device was switched on 20 minutes after take-off and off 30 minutes before landing.

28. A Boeing 767-300 aircraft with 204 seats was used on all flights. The aircraft has a cabin volume of 428 m^3 and a ventilation capacity of 1320 l/s. The ventilation system normally provides approximately 50% fresh air and 50% recirculated air to the passenger cabin. The outside airflow rate should be approximately 15 air changes per hour in the cabin or an outside airflow of 10 l/s per passenger in a full aircraft. All flights investigated had full passenger complements.

29. Measurements for CO_2 were made at 1-minute intervals in the business and tourist class and in the flight deck (Table 7).

Table 7. Mean, minimum and maximum concentrations of CO_2 in business class, tourist class and the flight deck.

	Mean conc. (ppm) Control	**Min conc. (ppm) Control**	**Max conc. (ppm) Control**	**Mean conc. (ppm) Humidified**	**Min conc. (ppm) Humidified**	**Max conc. (ppm) Humidified**
Business class	1120	940	1320	1160	1080	1300
Tourist class	1160	1060	1300	1200	960	1400
Flight deck	800	710	1000	830	760	960

Spengler et al. (2012)

30. Spengler et al. (2012) monitored cabin air in 83 US flights between February 2008 and August 2010 as part of a Federal Aviation Agency/ American Society of Heating, Refrigerating and Air-Conditioning Engineer (FAA/ASHRAE) study of onboard environmental conditions and passenger and crew responses. The flights measured were taken by three different US

airlines (airline A – 20 flights; airline B – 39 flights; airline C – 21 flights). Environmental parameters measured included relative humidity, cabin pressure, temperature, and cabin sound levels. Flight characteristics including flight duration, flight departure time, aircraft model, flight date and season, aircraft capacity and occupancy loads were also collected. Measurements were recorded continuously, at one-minute intervals, from 10,000 feet ascent through 10,000 feet descent.

31. Continuous measurements of CO_2 were performed (Table 8 and Table 9).

Table 8. Mean, SD, minimum and maximum concentrations of CO_2 across all flights and aircraft types

	Mean conc. (ppm)	**SD (ppm)**	**Min conc. (ppm)**	**Max conc. (ppm)**
CO_2	1404	297	863	2056

Table 9. Mean concentrations of CO_2 in six aircraft.

	Mean conc. (ppm) B737-300	**Mean conc. (ppm) B737-700**	**Mean conc. (ppm) A380**	**Mean conc. (ppm) B747**	**Mean conc. (ppm) B767**	**Mean conc. (ppm) B777**
CO_2	1457	1383	1253	1131	1319	1499

32. Lindgren and colleagues carried out several studies investigating cabin air quality on international flights (Lindgren & Norbäck, 2002; Lindgren et al., 2007).

EASA (2014)

33. The EASA carried out monitoring on aircraft equipped with traditional engine bleed systems (main study) as well as in a Boeing 787 aircraft (B787,

Dreamliner), which are equipped with electrical air compressors instead of engine bleed air systems (EASA, 2014).

34. In total, measurements were carried out on 69 European flights between July 2015 and June 2016, using eight types of aircraft/engine configurations. In the main study only bleed air supplied aircraft (61 flights) were investigated, while the B787 sampling covered 8 flights with the alternative no-bleed air supply system. Two sets of measurement equipment were installed in the flight deck and the cabin respectively during regular passenger in-flight operations. Overall, samples were taken at defined flight phases (taxi-out, take off and climb, descent and landing, complete flight).

35. Data for CO_2 from short- and long-haul flights from the main study are presented in Table 10 and from the B787 study in Table 11.

Table 10. Mean, minimum and maximum concentrations of CO_2 in short- and long-haul aircraft (main study).

	Mean conc. (ppm) Short haul aircraft	**Min conc. (ppm) Short haul aircraft**	**Max conc. (ppm) Short haul aircraft**	**Mean conc. (ppm) Long haul aircraft**	**Min conc. (ppm) Long haul aircraft**	**Max conc. (ppm) Long haul aircraft**
Flight deck	835	629	1918	753	594	1976
Cabin	1417	1050	2771	1282	955	2674

Table 11. Mean, minimum and maximum concentrations of CO_2 in B787 Dreamliner aircraft.

	Mean conc. (ppm)	**Min conc. (ppm)**	**Max conc. (ppm)**
Flight deck	603	473	1229
Cabin	1242	968	2019

Guan et al. (2015)

36. Guan et al. (2015) monitored real-time CO_2 concentrations in six commercial flights.

37. Six commercial flights were randomly selected in March 2013. Flight destinations covered different cities in China, and flight durations varied from 92 to 185 minutes. Only Boeing 737-800 aircraft were used in the study to exclude influence from aircraft type.

38. The CO_2 concentrations both in supply air and re-circulated air were continuously recorded every 30 seconds during the whole flight (Table 12).

Table 12. Mean, minimum and maximum concentrations of CO_2 in cabin supply air and re-circulated air.

	Mean conc. (ppm) Supply air	**Min. conc. (ppm) Supply air**	**Max. conc. (ppm) Supply air**	**Mean conc. (ppm) Recirculated air**	**Min. conc. (ppm) Recirculated air**	**Max. conc. (ppm) Recirculated air**
Flight 1	655	533	1405	976	793	1845
Flight 2	713	600	1485	1102	939	1102
Flight 3	727	498	1452	1096	893	1096
Flight 4	693	456	905	948	850	948
Flight 5	583	503	961	848	735	848
Flight 6	763	602	1095	1004	810	1004

Cao et al. (2019)

39. Cao et al. (2019) investigated real-time CO_2 concentrations in passenger cabins in US domestic flights.

40. Measurements were made in 179 US domestic flights from July 2007 to September 2009. The study involved 24 aircraft types, seven aircraft series, 10 airlines and 58 flight routes. Most aircraft models were short- to medium-range narrow-body twin-engine jet airliners, in which the conditioned air was delivered by means of diffusers placed high in the cabin and returned through grilles at bottom sides of the cabin. The median sampling duration was 1 h 14 min and samples were taken at intervals of 10, 30 or 60 seconds. Carbon dioxide was measured mainly in economy class. Results are presented in Table 13.

Table 13. Mean, SD, minimum and maximum concentrations of CO_2 in different aircraft.

	Mean conc. (ppm)	**SD**	**Min conc. (ppm)**	**Max conc. (ppm)**
Airbus A319	1228	112	1003	1635
Airbus A320	1175	382	682	2990
Boeing B737-300	1479	111	1032	1773
Boeing B737-400	1808	65	1656	1937
Boeing B737-500	1124	49	1000	1220
Boeing B737-700	1261	188	850	2947
Boeing B737-800	1288	316	661	2976
Boeing B757	1438	284	703	2992
Boeing B767-300	1234	160	756	1662
Bombardier CR-7	1903	160	1094	2209
Bombardier CR-9	1451	265	658	2616
Bombardier CRJ-100	889	160	620	1620
Bombardier CRJ-140	1398	79	1264	1566
Bombardier CRJ-150	969	127	793	1233

	Mean conc. (ppm)	**SD**	**Min conc. (ppm)**	**Max conc. (ppm)**
Bombardier CRJ-200	1070	173	721	1442
Embraer E-135	1417	185	1143	2077
Embraer E-145	1201	403	682	2054
Embraer E-170	1097	160	855	1352
Embraer E-175	1162	200	686	2137
Embraer E-190	1771	233	1392	2340
MD DC-9	1340	320	934	1951
MD-80	897	111	659	1094
MD-88	1321	264	514	2979
MD-90	1251	416	656	2993
Mean of all aircraft	1353	290	514	2993

Yu et al. (2021)

41. Yu et al. (2021) investigated the in-cabin environment in four Chinese domestic flights during April 2019.

42. The four airliners executed two domestic round trips in China (E1 and E2 from Nanjing Lukou International Airport to Guangzhou Baiyun International Airport; E3 and E4 from Nanjing Lukou International Airport to Haikou Meilan International Airport). Flight duration of each single trip was approximately 2 hours.

43. Due to the limitation of the instrument availability, CO_2 was only measured during the E3 and E4 flights, which took place on an Airbus 320. The E3 flight had 174 seats while the E4 flight had 158 seats, and both were fully loaded. The E3 aircraft was older than the E4 aircraft (5.9 years vs 3.6 years). Samples of CO_2 were taken close to the rear-mounted jet engines (Table 14).

Table 14. Mean, SD, minimum and maximum concentrations of CO_2 in a return flight in China.

	Mean conc. (ppm) E3	**SD E3**	**Min conc. (ppm) E3**	**Max conc. (ppm) E3**	**Mean conc. (ppm) E4**	**SD E4**	**Min conc. (ppm) E4**	**Max conc. (ppm) E4**
CO_2	1557	117	1304	2135	1323	104	1069	1861

He et al. (2021)

44. He et al. (2021) collated on board CO_2 concentrations reported in aircraft over the last 30 years (Table 15). Many authors investigated the effect of smoking on CO_2 levels prior to the ban on smoking in the 1990s.

Table 15. Mean, SD, minimum and maximum concentrations of CO_2

	Test position	**Date**	**Flight type**	**Mean conc. (ppm)**	**SD**	**Min conc. (ppm)**	**Max conc. (ppm)**
Holcomb and NAS 1988	-	Earlier than 1983	-	-	-	550	1200
Malmfors *et al*. 1989 (Sweden)	Seat	1988	DC-9, MD-80	1265	80	850	1930
Nagda *et al*. 1992 (US)	Economy class seat	1989	B727, B737 DC9, L1011	1562	685	597	4943
Nagda *et al*. 1992 (US)	Economy class seat	1989	B727, B737 DC9, L1011	1756	660	765	3157
O'Donnell *et al*. 1991 (US)	-	1991	Short haul flight	719	233	330	2170
CCS 1994 (US)	-	-	-	1162	-	-	-

	Test position	**Date**	**Flight type**	**Mean conc. (ppm)**	**SD**	**Min conc. (ppm)**	**Max conc. (ppm)**
Spengler 1997 (US)	-	1996	-	1400	-	1200	1800
Haghighat *et al*. 1999 (Canada)	Near first class	1996	A320, A340, B767, DC9	674	178	386	1091
Lee *et al*. 1999 (Hong Kong)	Business class seat	1996-1997	B747-400	925	70	868	1024
Lee *et al*. 1999 (Hong Kong)	Business class seat	1996-1997	B747-400, A340, A330	937	239	683	1557
Pierce *et al*. 1999 (US)	Economy class seat	1998	B777	1469	-	1252	1758

	Test position	**Date**	**Flight type**	**Mean conc. (ppm)**	**SD**	**Min conc. (ppm)**	**Max conc. (ppm)**
Waters *et al*. 2002 (US)	Economy class seat	-	-	1387	351	664	4328
Lindgren *et al*. 2002 (US)	AFT and FWD galley	1995-1998	B767-300	734	151	415	1488
Nagda *et al*. 2001 (US)	Economy class seat	1999-2000	B737, B767, B747	1380	-	800	2390
Waters *et al*. 2002 (US)	Economy class seat	-	-	1387	351	874	2328
Ross *et al*. 2003 (UK)	Economy class seat	2002-2003	Bae146, B737-300	1316	-	780	1806
Spicer *et al*. 2004 (US)	Economy class seat	2004	MD80, B757-800	1229	164	723	1896
Cao *et al*. 2018 (US)	Economy class seat	2007-209	A319/320, B737,	1353	290	514	2993

	Test position	**Date**	**Flight type**	**Mean conc. (ppm)**	**SD**	**Min conc. (ppm)**	**Max conc. (ppm)**
			B757, B767				
Spengler *et al*. 2012 (US)	Economy class seat	2008-2010	B737, B767, B777	1404	297	863	2056
Giaconia *et al*. 2013 (Italy)	Economy class ceiling	2011	A319	1192	151	734	2213
Li *et al*. 2014 (China)	Economy class seat	2013	B737	1079	70	976	1151

Carbon monoxide

Lee et al. (1999)

45. Lee et al. (1999) investigated 16 flights originating from Hong Kong for indoor air quality. Carbon monoxide was measured in Airbus 330 and Boeing 747-400 from June 1996 to August 1997 and were sampled every 5 minutes (Table 16). To note, this paper reports data covering a time when smoking was still permitted in aircraft as smoking was prohibited onboard all flights from September 1997.

Table 16. Mean, minimum and maximum concentrations of CO in Airbus 330 and Boeing 747-400.

Flight	**Mean conc. CO (ppm)**	**Min conc. CO (ppm)**	**Max conc. CO (ppm)**
A	-	-	-
B	-	-	-
C	-	-	-
D	-	-	-
E	-	-	-
F	-	-	-
G	-	-	-
H	-	-	-
I	2.1	1.0	3.0
J	1.9	1.0	3.0
K*	2.6	2.0	3.0
L*	2.2	2.0	6.0
M	2.0	1.0	3.0
N	2.0	1.0	4.0
O*	3.0	2.0	5.0
P	2.4	2.0	4.0

* Flight in which smoking was permitted. It should be noted that smoking was prohibited on all flights in 1997.

Fox (2000)

46. Fox (2000) performed air quality monitoring to identify possible air contaminants entering the aircraft that may affect the comfort of passengers. Study details are given in paragraph 14. To note, this paper reports data covering a time when smoking was still permitted in aircraft as smoking was prohibited onboard all flights from September 1997.

47. Results for cabin supply air are presented in Table 17. No results were given for cockpit supply air or the AFT galley.

Table 17. Mean concentrations of CO in cabin supply air.

	Mean conc. (ppm) 100% Fresh air non-revenue flight	**Mean conc. (ppm) 100 % Fresh air revenue flight**	**Mean conc. (ppm) 40% Re-circulated air revenue flight**	**Mean conc. (ppm) Charcoal filter non-revenue flight**
CO	4.5	ND	4.2	ND

Nagda et al. (2000)

48. Nagda et al. (2000) published a detailed review of studies reporting measurements of cabin air quality, including CO, that had been carried out between 1986 and 1998 and reported measurements in studies of up to approximately 100 flights in US (Table 18). It should be noted that smoking was banned on domestic flights of less than six hours in 1989 and was totally prohibited in 1997. Therefore, some studies included in the review may have allowed smoking on board the aircraft.

Table 18. Mean, minimum and maximum concentrations of CO cited in a literature review (Nagda et al., 2000).

CO (ppm)	**Nagda et al. 1989**	**O'Donnell 1991**	**CSS 1994**	**Consumers Union 1994**	**Spengler et al. 1997**	**CSS 1999**
Mean	0.6	1.6	-	-	0.7	NR
Min	ND	1	-	-	0.8	<0.1
Max	1.3	4.0	-	-	1.3	7

NR=not reported; ND=not detected

EASA. (2014)

49. The EASA carried out monitoring on European aircraft equipped with traditional engine bleed systems (main study) as well as in a Boeing 787 aircraft, which are equipped with electrical air compressors instead of engine bleed air systems (EASA, 2014). Study details are given in paragraph 34.

50. Data for CO from short- and long-haul flights from the main study are presented in Table 19.

Table 19. Mean, minimum and maximum concentrations of CO in aircraft (main study) and in B787 Dreamliner aircraft.

	Mean conc. (ppm) Main study	**Min conc. (ppm) Main study**	**Max conc. (ppm) Main study**	**Mean conc. (ppm) B787**	**Min conc. (ppm) B787**	**Max conc. (ppm) B787**
Flight deck	<LOD	<LOD	4.8	<LOD	<LOD	0.6
Cabin	<LOD	<LOD	3.0	<LOD	<LOD	1.6

MacGregor et al. (2008)

51. MacGregor et al. (2008) investigated CO in four commercial flights from two airlines within USA in April 2004. Study details are given in paragraph 24.

52. Carbon monoxide only exceeded the limit of detection of 2 ppm on one occasion, during which a concentration of 3.7 ppm was measured for 1 minute during boarding on Flight 1.

Crump, Harrison and Walton (2011)

53. Crump et al. (2011) carried out a project to analyse cabin air for CO in normal operations during all phases of flight e.g., climb, cruise and descent. A total of 100 European flights in five different aircraft types were monitored including a Boeing 757 cargo aircraft, Boeing 757, Airbus A320/1, Bae 146, and Airbus A319 passenger aircraft.

54. Maximum values for CO in air (all samples for all 100 flights and all flight phases) are presented in Table 20. Overall, levels of CO did not exceed safety or health limits. These included 100 mg m^3 (87 ppm) for 15 minutes averaging time, 60 mg m^3 (52 ppm) for 30 minutes averaging time, 30 mg m^3 (26 ppm) for 1 hour averaging time, 10 mg m^3 (9 ppm) for 8 hours averaging time (WHO 2000 as cited in Crump et al. 2011). WHO (2010 as cited in Crump et al. 2011) retained 15 min and 8 h values but modified the 1 h value to 35 mg m^3 (31 ppm) and introduced a new 24 h guideline value of 7 mg m^3 (6 ppm). Department for Communities and Local Government (DCLG, 2006 as cited in Crump et al. 2011) used the same values as WHO (2000). Committee on the Medical Effects of Air Pollutants (COMEAP, 2004 as cited in Crump et al. 2011) used the same values as WHO (2000).

55. Authors noted that concentrations recorded during nine flights were equivalent to the 8 h TWA health limit.

Table 20. CO concentrations in different flight sectors.

CO (ppm)	**<1**	**1**	**2**	**3-5**	**>5**
No. of flight sectors (n)	6	45	23	6	1*

*A further 9 sectors had values >5 ppm, but equipment malfunction is strongly suspected. All occurred as a sequential block in Part 4, and in each case the instrument recorded a constant level of 9-10 ppm throughout almost the entire flight. Since this deviation of ±1 ppm is within the analogue-to-digital conversion "jitter" of the instrument, the likelihood of this being a correct estimate of flight deck CO concentration is extremely small.

Spengler et al. (2012)

56. Spengler et al. (2012) monitored cabin air in 83 US flights between February 2008 and August 2010 as part of a Federal Aviation Agency/ American Society of Heating, Refrigerating and Air-Conditioning Engineer (FAA/ASHRAE) study of onboard environmental conditions and passenger and crew responses. Study details are given in paragraph 30.

57. Continuous measurements of CO were performed but levels did not exceed the instrument's level of detection of 1 ppm for any flight.

Yu et al. (2021)

58. Yu et al. (2021) investigated the in-cabin environment in four Chinese domestic flights in April 2019. Study details are given in paragraph 42.

59. Due to the limitation of the instrument availability, CO was only measured during the E3 and E4 flights, which took place on an Airbus 320. The E3 flight had 174 seats while the E4 flight had 158 seats, and both were fully loaded. The E3 aircraft was older than the E4 aircraft (5.9 years vs 3.6 years). Samples of CO were taken close to the rear-mounted jet engines (Table 21).

Table 21. Mean, SD, minimum and maximum concentrations of CO in a return flight in China.

	Mean conc. (ppm) E3	**SD E3**	**Min conc. (ppm) E3**	**Max conc. (ppm) E3**	**Mean conc. (ppm) E4**	**SD E4**	**Min conc. (ppm) E4**	**Max conc. (ppm) E4**
CO	0.12	0.26	0.00	1.18	0.01	0.02	0.00	0.12

Overview of standards and guidelines

60. Various standards, guidelines and regulations exist related to air quality in aircraft, including levels for CO and CO2. Table 22 shows specific upper limits for CO and CO2 from Europe, US, and China (Chen et al., 2021) and Table 23 and Table 24 show air quality guidelines and workplace exposure limits in Europe and UK for CO and CO_2, respectively (Lowther et al., 2021).

Table 22. Aircraft regulatory values for CO and CO_2 in Europe, US, and China (cited in Chen et al., 2021)

	FAR (US) (ppm)	**ASHRAE (US) (ppm)**	**JAR (EU) (ppm)**	**CS (EU) (ppm)**	**BS-EN4618 (EU; withdrawn*) (ppm)**	**CCAR (China) (ppm)**
CO_2	5000	1100	30000	5000	20000; 15 min 5000; peak 2000	5000
CO	50	9; TWA 10 min 50; 1 min peak	50	50	50; peak 25; TWA 1 hr 10; TWA 8 hr	50

* withdrawn as a result of a decision of the European committee CEN/BT 31/2013
TWA=time weight average; FAR=Federal Aviation Regulations; ASHRAE=American Society of Heating, Refrigerating and Air-Conditioning Engineers; JAR=Joint Airworthiness Requirements; CCAR=Chinese civil aviation regulations; CS = Certification Specifications

Table 23. Air quality guidelines and workplace exposure limits for CO_2 in Europe and UK

British Standard (BS EN 16798-1:2019). Residential and non-residential (ppm)	**BB101—Department for Education. Good indoor air quality in schools (ppm)**	**EH40/2005 Workplace exposure limits. (ppm)**
1000 (good IAQ) 1750 (poor IAQ)	1000 (good IAQ) 1200 (acceptable/ medium IAQ) 1500 (acceptable / max IAQ) 1750 (needs additional ventilation/	5000; 8-hour PEL

PEL = Permissible exposure limit (Workplace exposure limit); DfE = Department for Education

Table 24. Air quality guidelines and workplace exposure limits for CO Europe and UK.

WHO Air quality guidelines (mg/m^3)	**WHO AQG and interim target (mg/m^3)**	**Directive on ambient air quality and cleaner air for Europe. (mg/m^3)**	**UK National Air Quality Objectives of the Air Quality Strategy. (mg/m^3)**	**EH40/2005 Workplace exposure limits. (mg/m^3)**
100 (87 ppm) for 15 min 35 (30 ppm) for 1 hour 10 (8.7 ppm) for 8 hours	7 (6 ppm); 24-hour interim target 1 4 (3.4 ppm); 24-hour AQG	10 (8.6 ppm) Maximum daily 8-hour mean	10 (8.6 ppm) Running 8-hour mean	23 (20 ppm); 8-hour limit LTEL 117 (100 ppm); 15 min limit STEL

CO: 1 ppm = 1.165 mg/m^3 and 1 mg/m^3 = 0.858 ppm.
WHO = World Health Organisation; AQG = Air quality guideline; EC = European Commission; WEL = Workplace exposure limit; LTEL = Long-term exposure limit; STEL = short-term exposure limit

Comparison of levels in aircraft with regulatory values

61. The mean and maximum CO_2 concentrations reported in aircraft flying worldwide (Figure 1 and Figure 2) identified in this study were compared with EU, US and Chinese aircraft standards (Table 22) and air quality standards (Table 23). Similarly, Figure 3 and Figure 4 show mean and maximum CO_2 concentrations reported in aircraft flying within EU, compared to EU standards.

62. The mean and maximum CO concentrations reported in aircraft flying worldwide (Figure 6 and Figure 7) were compared to EU, US and Chinese aircraft standards (Table 22) and air quality standards (Table 23), and those flying within EU (Figure 8 and Figure 9) were compared with EU standards.

63. Data showing CO_2 and CO concentrations measured before and after the ban on smoking on flights was implemented in 1997 are also presented (Figure 5 and Figure 10, respectively).

64. For CO_2, all mean and maximum concentrations measured in aircraft worldwide are below the regulatory values for aircraft set by FAR, CS and CCAR (5000 ppm) and the 8-hour PEL of 5000 ppm (EH40/2005) (Figure 1). The mean concentrations are also largely lower than the value indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm) (Figure 2). However, many of the reported mean and maximum concentrations are higher than the ASHRAE standard (1100 ppm) (Figure 1) and the maximum concentrations exceed the value indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm) (Figure 2).

65. In EU flights, the mean and maximum concentrations of CO_2 are below the aircraft regulatory value set by CS (5000 ppm) (Figure 3) and the PEL (5000 ppm) (Figure 4). Mean values are below the acceptable maximum indoor air quality in schools (1500 ppm) but maximum values exceed the value indicating poor air quality for residential and non-residential (1750 ppm)(Figure 4).

66. If considering data before and after the ban on smoking was implemented worldwide, data showed there was a decreasing trend following the ban (Figure 5).

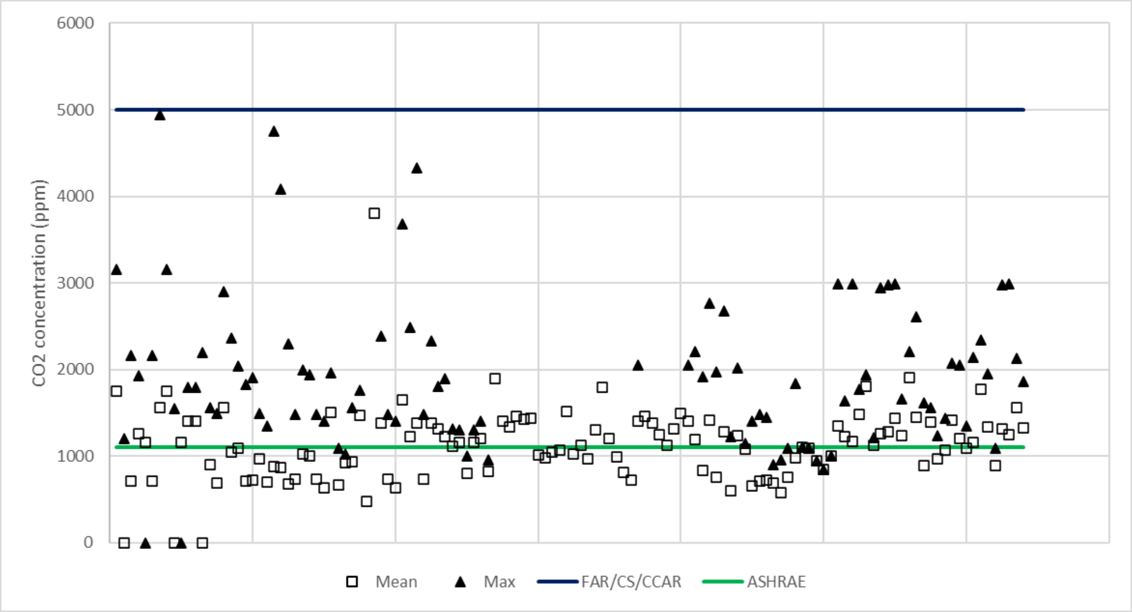

Figure 1. Mean and max concentrations of CO_2 in aircraft flying worldwide compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

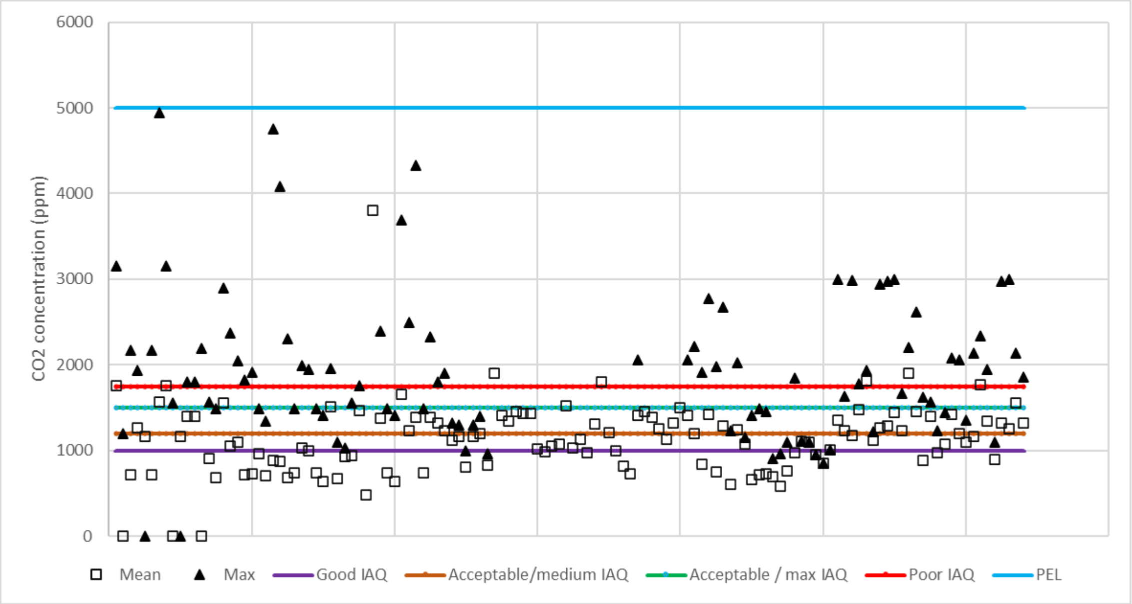

Figure 2. Mean and max concentrations of CO_2 in aircraft flying worldwide compared with air quality standards. X-axis shows data from 1987 (left) to 2021 (right)

Mean and max concentrations of CO_2 in aircraft flying worldwide compared with air quality standards. X-axis shows data from 1987 (left) to 2021 (right)

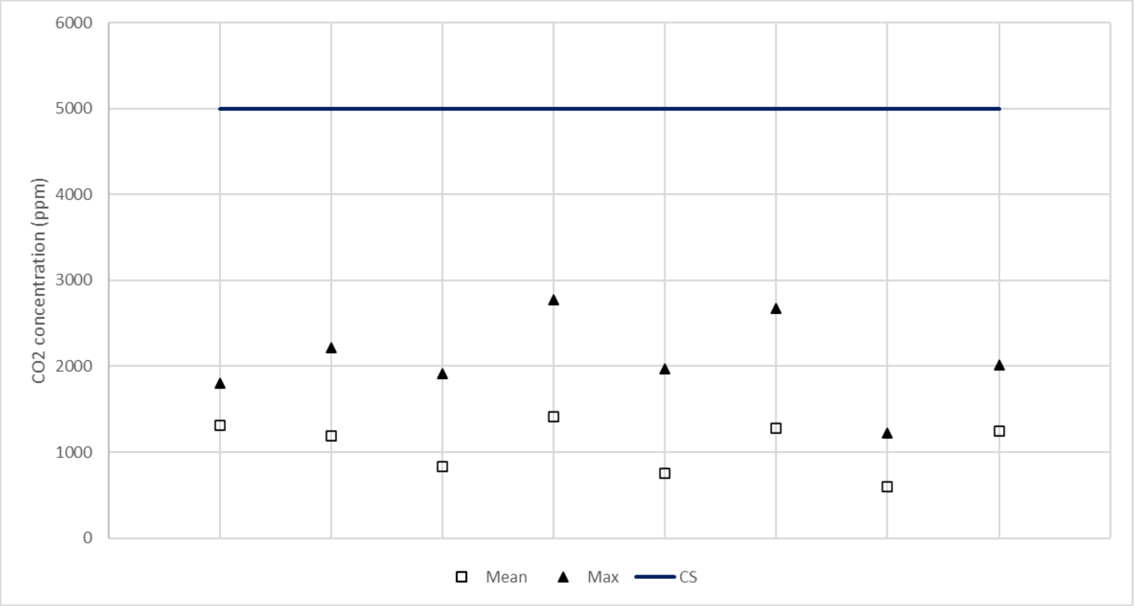

Figure 3. Mean and max concentrations of CO_2 in aircraft flying in EU compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

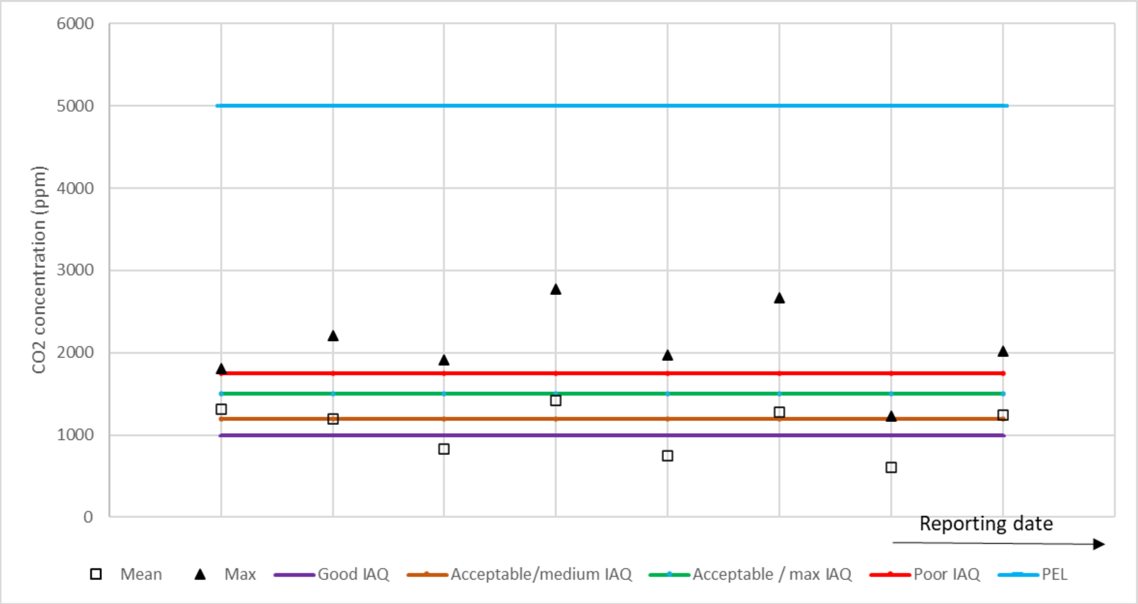

Figure 4. Mean and max concentrations of CO_2 in aircraft flying in EU compared with air quality standards. X-axis shows data from 1987 (left) to 2021 (right)

Mean and max concentrations of CO_2 in aircraft flying worldwide before or after the smoking ban in 1997. X-axis shows data from 1987 (left) to 2021 (right)

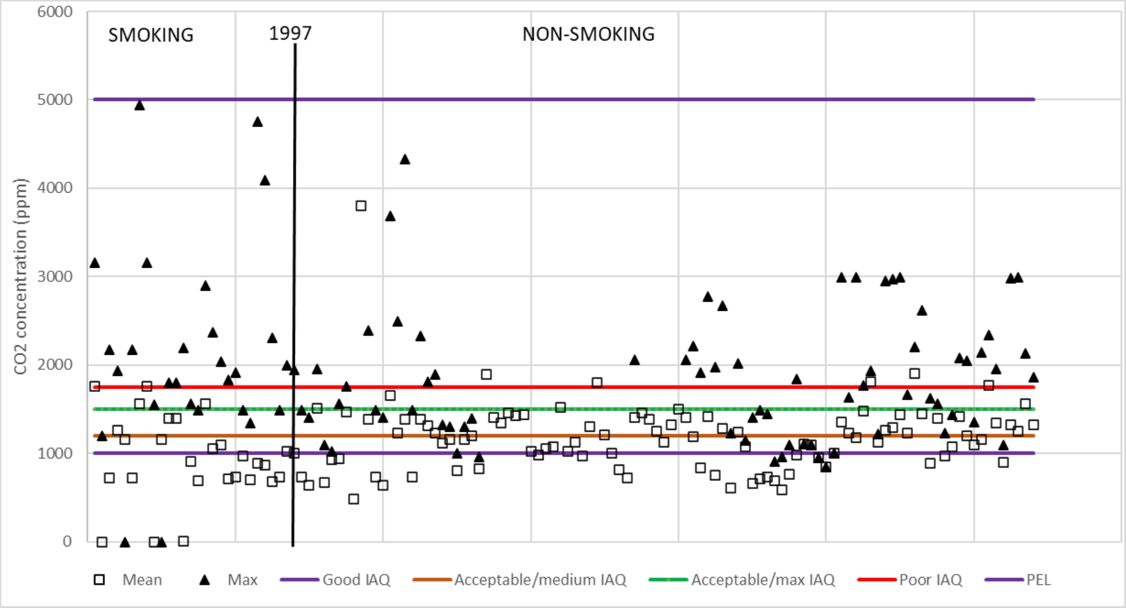

Figure 5. Mean and max concentrations of CO_2 in aircraft flying worldwide before or after the smoking ban in 1997. X-axis shows data from 1987 (left) to 2021 (right)

67. For CO, the mean and maximum concentrations measured in aircraft worldwide were below all regulatory values for aircraft (Figure 6). They were also below the air quality standards, with the exception of the World Health Organisation (WHO) Air Quality Guideline (AQG) of 4 mg/m^3 (3.4 ppm) (Figure 7).

68. In EU flights, no mean concentrations were presented as all were lower than the limit of detection but the maximum concentrations are below aircraft regulatory values (Figure 8) and most air quality standards apart from the WHO AQG of 4 mg/m^3 (3.4 ppm) (Figure 9).

69. If considering data before and after the ban on smoking was implemented worldwide, CO concentrations appear largely unaffected (Figure 10).

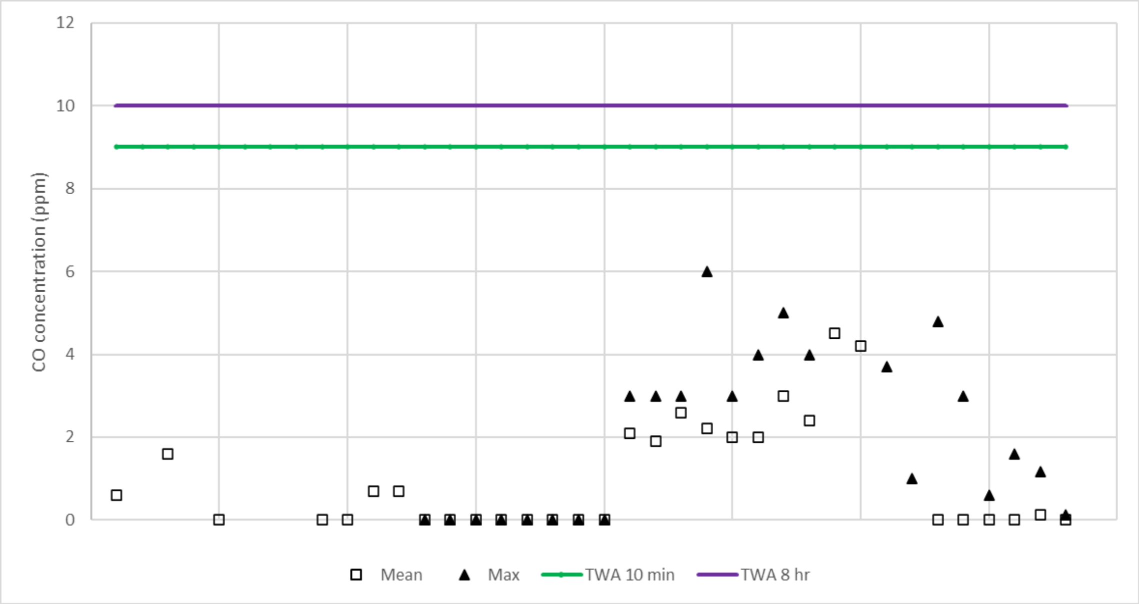

Figure 6. Mean and max concentrations of CO in aircraft flying worldwide compared with aircraft standards. X-axis shows data from 1987 (left) to 2021 (right)

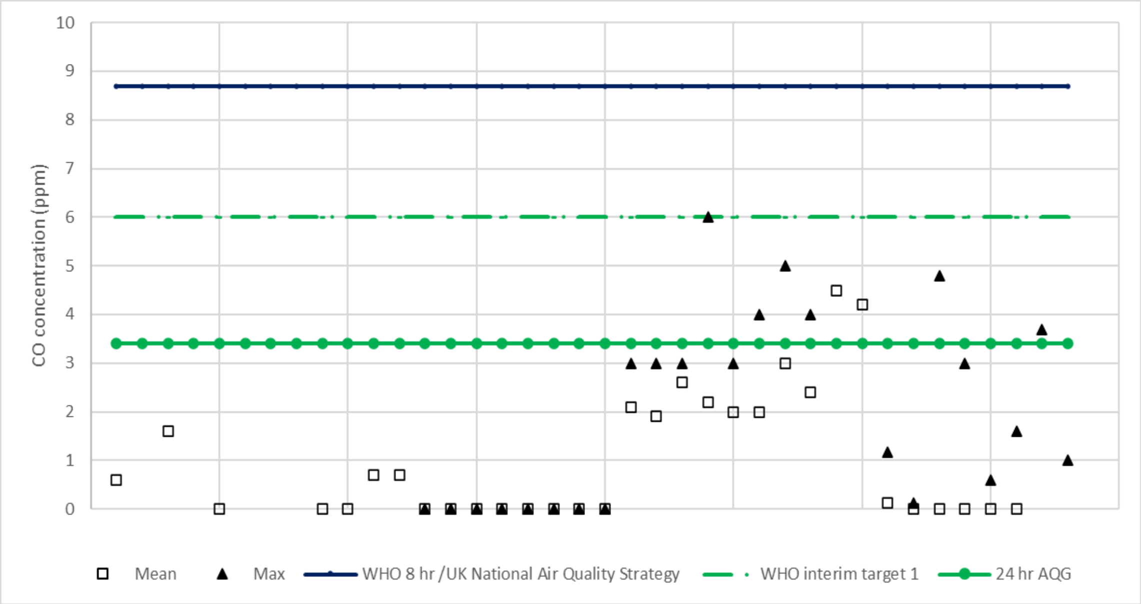

Figure 7. Mean and max concentrations of CO in aircraft flying worldwide from 1987-2021 compared with air quality standards. X-axis shows data from 1987 (left) to 2021 (right)

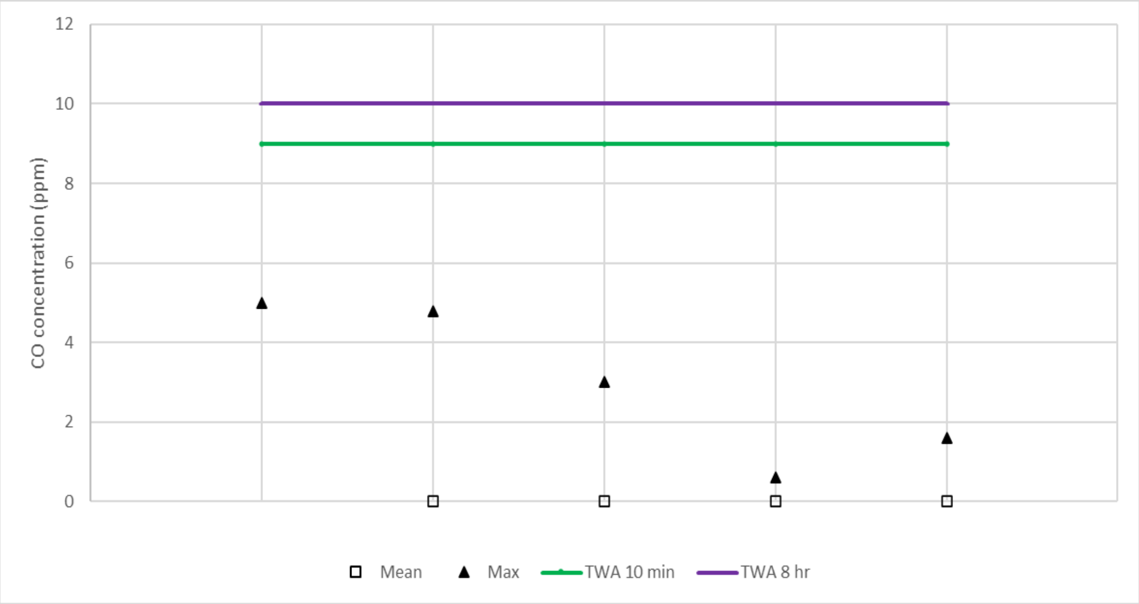

Figure 8. Mean and max concentrations of CO in aircraft flying in EU compared with air quality standards. X-axis shows data from 1987 (left) to 2021 (right)

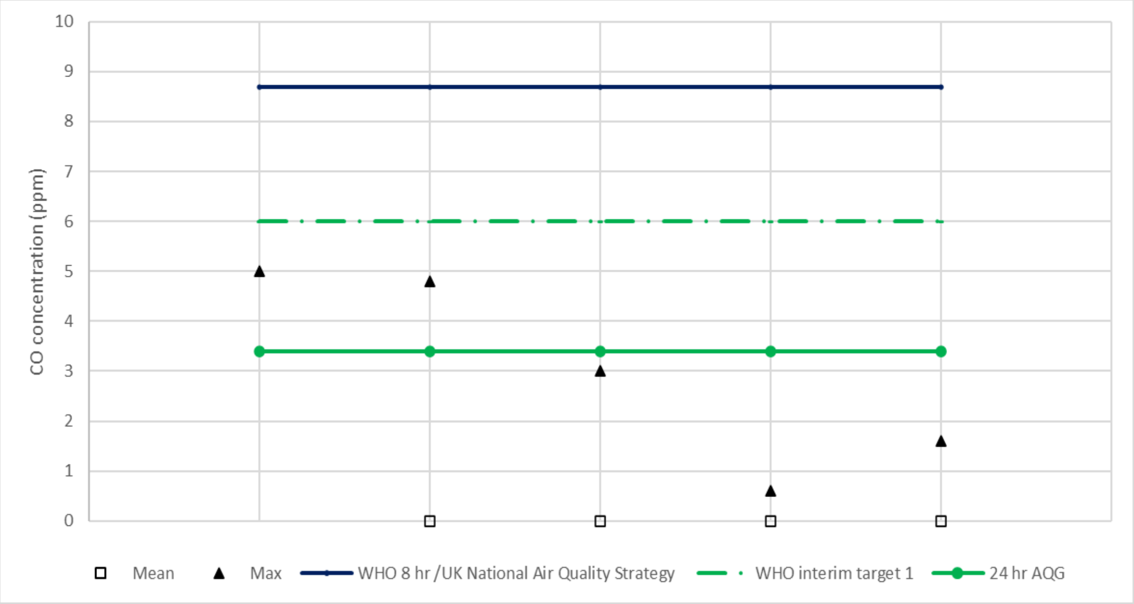

Figure 9. Mean and max concentrations of CO in aircraft flying in EU compared with air quality standards. X-axis shows data from 1987 (left) to 2021 (right)

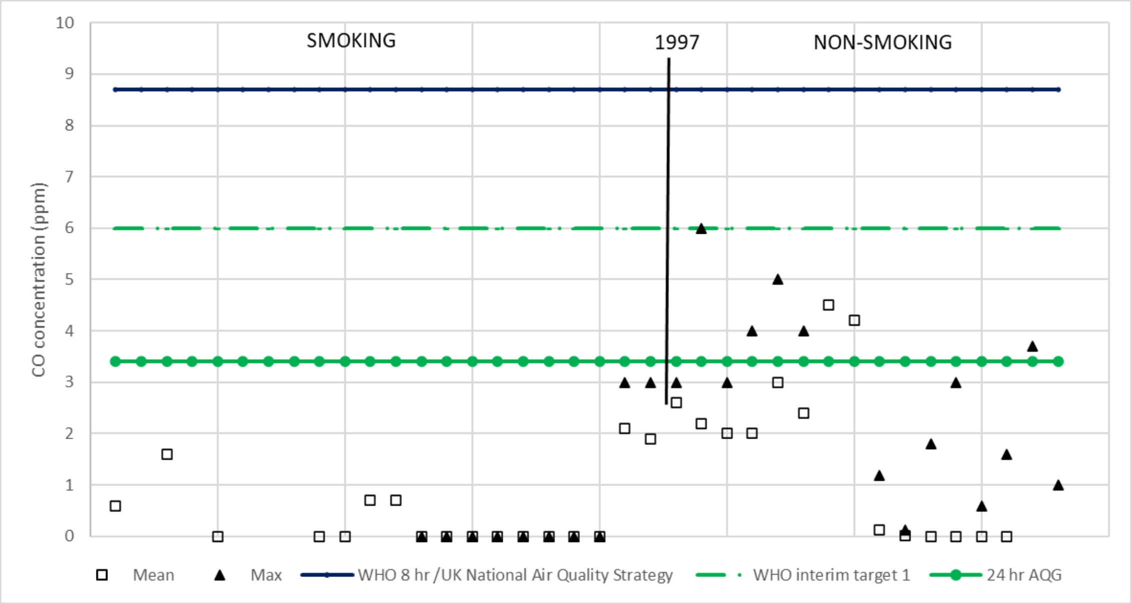

Figure 10. Mean and max concentrations of CO_2 in aircraft flying worldwide before or after the smoking ban in 1997. X-axis shows data from 1987 (left) to 2021 (right)

Health effects

Carbon dioxide

70. Carbon dioxide is a product of respiration but as well as causing hypoxia, it also acts as a toxicant (Permentier et al., 2017).

71. A recent review by Lowther et al. (2021) investigated the potential impact of low levels of CO_2 on cognitive performance, respiratory effects, neurological effects and irritation to the upper airway, and whether effects were due to CO_2 itself or if CO_2 was acting as an indicator of the indoor environment.

72. Various studies reported changes in heart rate, increase in peripheral blood circulation and CO_2 in blood circulation at 700-4000 ppm CO_2, which could be linked to reductions in cognitive performance, moderate reductions in cognitive function and negative cognitive effects at 1000 ppm, decreased test performance (increased number of errors, reduced test scores and reductions in markers of decision making) at 1400-1500 ppm and reduced performance at 1750 ppm (Lowther et al., 2021).

73. At 400-1900 ppm CO_2 was reported to cause daytime, but not nocturnal, breathlessness, >1000 caused coughing whereas other studies failed to show coughing at 1000-3000 ppm, and 2000 ppm caused wheezing in some studies but not others and <2000 ppm caused reductions in forced expiratory volume and forced vital capacity (Lowther et al., 2021).

74. 100 ppm CO_2 caused neurological symptoms and irritation such as dry throat, tiredness, dizziness but not eye dryness, nose itching, runny nose, stuffy nose, sneezing, skin dryness or irritability and irritation of the upper airway system generally was seen at CO_2 concentrations >1000 ppm, although several studies showed no irritation at such concentrations (Lowther et al., 2021)(Table 25).

Table 25. Relationship between CO_2 and effects on cognitive performance (Lowther et al., 2021).

CO_2 (ppm)	**Symptoms**
700-1000	Reduction in decision making, decreased cognitive function, higher ventilation rate, changes in heart rate variation and an increase in peripheral blood circulation.
1000-1500	Decreased cognitive function
1500-2000	Reduced decision making
4000	Reduced concentration
>5000	Tiredness, increased diastolic blood pressure, increased respiratory frequency and volume (indicative of greater mental effort)

75. The highest mean value of CO_2 reported in aircraft was 1903 ppm and the maximum value was 4752 ppm. Such concentrations are above concentrations reported to potentially reduce decision making, cognitive function and concentration (Figure 11).

76. There is some uncertainty reported regarding the association with low levels of CO_2 and whether it is an indicator of air quality or a cause of the health effects per se, as described above. Moreover, it should be noted that

there are also uncertainties in the extrapolation between buildings and aircraft as the air exchange and ventilation in aircraft are more controlled compared to buildings.

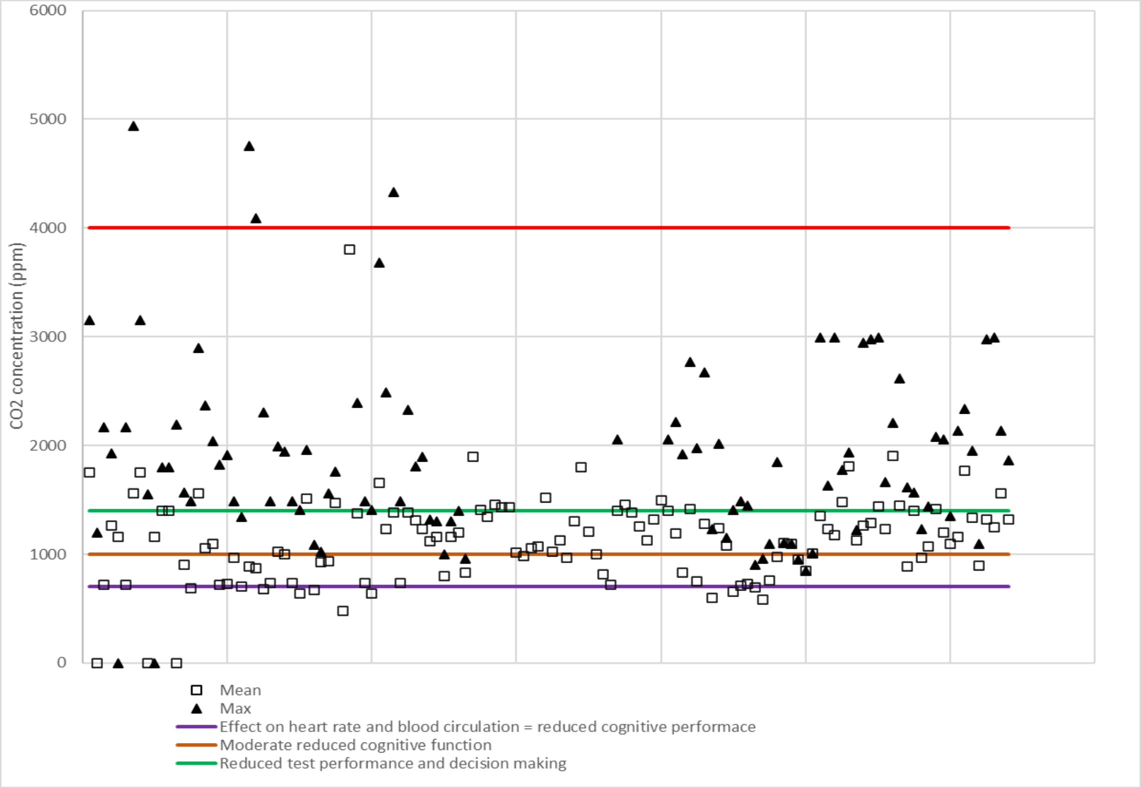

Figure 11. Mean and max concentrations of CO_2 compared with concentrations that may cause adverse health effects.

Carbon monoxide

77. Carbon monoxide binds with haemoglobin to form carboxyhaemoglobin. When bound, the rate at which oxygen is delivered to tissue is reduced, thereby causing hypoxia.

78. The most common symptoms observed following acute CO exposure include neurobehavioural/cognitive changes including visual and auditory sensory effects, fine and sensorimotor performance, cognitive effects and brain electrical activity at 30-160 ppm (5-20 % COHb) and acute and delayed onset neurological impairment (headache, dizziness, drowsiness, weakness, nausea, vomiting, confusion, disorientation, irritability, vertigo, alteration in consciousness, visual disturbances, convulsions and coma) at 160-1000 ppm (20-60 % COHb). Delayed neurological sequelae may also occur including

cognitive and behavioural effects within 2 to 40 days following initial exposure (UKHSA, 2022; Oh and Choi, 2022).

79. Chronic exposure to low concentrations of CO may cause lethargy, headache, nausea, flu-like symptoms, and cardiovascular issues. Neuropsychological symptoms may also occur including anxiety, psychomotor dysfunction, loss of balance and changes in sleep, memory, vision and smell (UKHSA, 2022). It has also been suggested that prolonged exposure (days-months) to low concentrations of CO may have subtle effects on the brain (Townsend and Maynard, 2002).

80. Table 26 shows the symptoms that may be associated with carboxyhaemoglobin (COHb) levels in humans (Higgins, 2005).

81. The correlation between air concentrations of CO and equivalent predicted blood COHb levels is shown in Table 27. It should be noted that there is considerable uncertainty surrounding such dose conversions, and steady-state requires exposures of approximately 16-24 hours. Exposures to lower levels of carbon monoxide for longer durations and exposure to higher levels for shorter durations that achieve similar blood COHb levels may not yield equivalent responses (ATSDR, 2012).

Table 26. Relationship between COHb and symptoms observed (Higgins, 2005).

COHb (%) in blood	Estimated CO conc* (ppm)	Symptoms
10	70	No appreciable effect except shortness of breath on vigorous exertion, possible tightness across forehead
20	120	Shortness of breath on moderate exertion, occasional headache
30	220	Headache, easily fatigued, judgement disturbed, dizziness, dimness of vision
40-50	350-520	Headache, confusion, fainting, collapse
60-70	800-1200	Unconsciousness, convulsions, respiratory failure, death if exposure continues
80	1950	Immediately fatal

Table 27. Correlation between CO concentration in air and blood COHb levels (ATSDR, 2012).

COHb (%)	CO (ppm)	COHb (%)	CO (ppm)
0.25	0.1	11	80
0.32	0.5	14	100
0.39	1	20	120
0.50	2	24	200
1.0	5	30	220
1.8	10	38	400
2.5	15	48	600
3.2	20	56	800
6.1	40	60-70	800-1200
8.7	60	80	1950
10	70		

82. The highest mean value of CO reported in aircraft was 3.7 ppm and the maximum value was 7 ppm. Such concentrations would not be expected to

cause appreciable health effects as are below concentrations reported to cause adverse health effects (Figure 12).

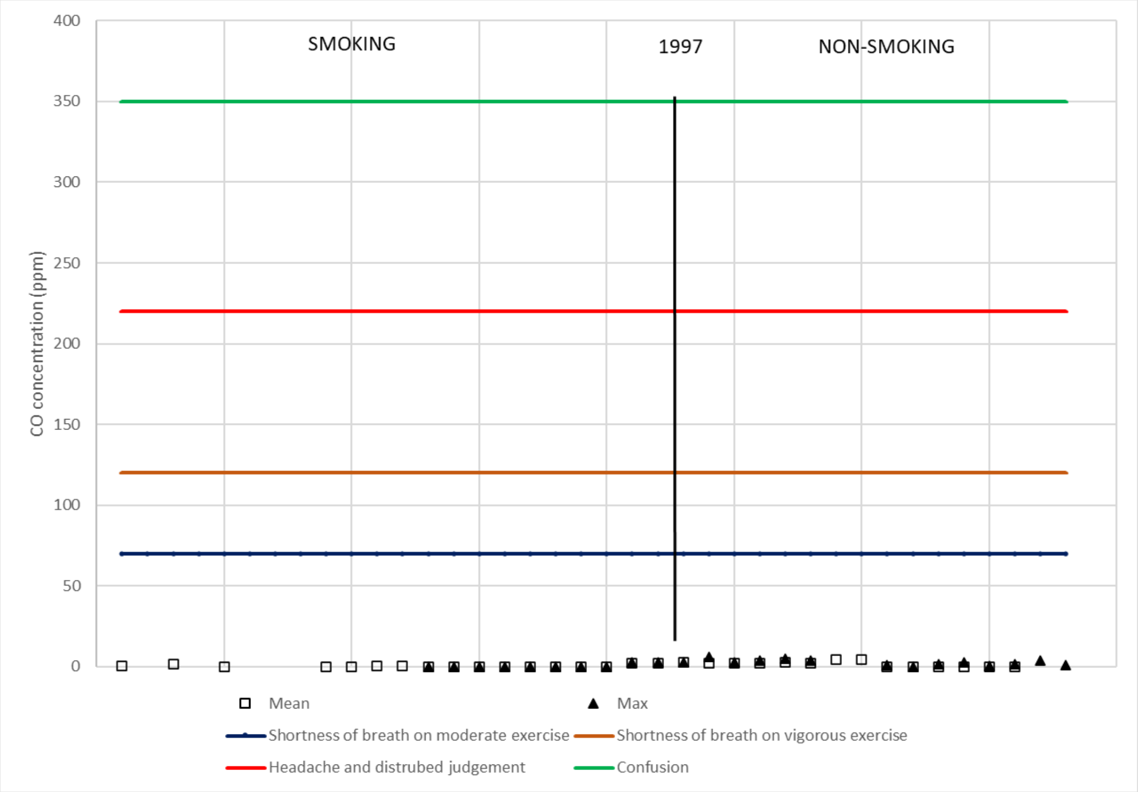

Figure 12. Mean and max concentrations of CO compared with concentrations that may cause adverse health effects.

Summary

83. Levels of CO and CO_2 in aircraft were collated and compared with regulatory values in aircraft, air quality standards as well as levels that cause adverse health effects.

84. For CO_2 measured in aircraft worldwide, many mean and maximum concentrations exceed the ASHRAE aircraft standard (1100 ppm) and maximum concentrations exceed values indicating poor air quality for residential and non-residential (1750 ppm) and the acceptable maximum indoor air quality in schools (1500 ppm).

85. In EU flights, maximum concentrations also exceed values indicating poor air quality for residential and non-residential (1750 ppm) and the

acceptable maximum indoor air quality in schools (1500 ppm), but mean and maximum concentrations are lower than CS aircraft standards (5000 ppm)

86. For CO, mean and maximum concentrations measured in aircraft worldwide are below all regulatory values for aircraft and air quality standards, with the exception of the World Health Organisation (WHO) Air Quality Guideline (AQG) of 4 mg/m^3 (3.4 ppm). No mean data are available for EU flights but maximum concentrations are below regulatory values for aircraft and air quality standards, with the exception of the WHO AQG.

87. Following the ban on smoking in commercial flights in 1997, CO_2 and CO concentrations showed a slight decreased trend or appeared largely unaffected, respectively.

88. All concentrations of CO_2 and CO reported are below levels that are reported to cause adverse health effects. Therefore, no adverse health effects are anticipated following exposure to the reported levels of CO and CO_2 in aircraft.

Questions on which the views of the Committee are sought

89. Members are invited to consider this paper and in particular the following questions:

i. Do members want additional information on any of the papers presented?

ii. What conclusions would the COT wish to make on the potential for carbon dioxide or carbon monoxide in aircraft cabin air to have a health impact following acute or long-term exposure?

IEH Consulting under contract supporting the UK HSA COT Secretariat
December 2022

References

ATSDR. (2012). Toxicological profile for carbon monoxide. https://www.atsdr.cdc.gov/toxprofiles/tp201.pdf

BB101 – Department for Education (DfE) (2018). Guidelines on Ventilation, Thermal Comfort and Indoor Air Quality in Schools, UK. https://www.gov.uk/government/publications/building-bulletin-101-ventilation-for-school-buildings

British Standard. BS EN 16798-1:2019. Energy Performance of Buildings—Ventilation for Buildings—Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoustics—Module M1-6. https://knowledge.bsigroup.com/products/energy-performance-of-buildings-ventilation-for-buildings-indoor-environmental-input-parameters-for-design-and-assessment-of-energy-performance-of-buildings-addressing-indoor-air-quality-thermal-environment-lighting-and-acoustics-module/tracked-changes

Cao, X., Macnaughton, P., Cadet, L. R., Cedeno-Laurent, J. G., Flanigan, S., Vallarino, J., Donnelly-McLay, D., Christiani, D. C., Spengler, J. D., & Allen, J. G. (2019). Heart rate variability and performance of commercial airline pilots during flight simulations. International Journal of Environmental Research and Public Health, 16(2). https://doi.org/10.3390/ijerph16020237

Chen, R., Fang, L., Liu, J., Herbig, B., Norrefeldt, V., Mayer, F., Fox, R., & Wargocki, P. (2021). Cabin air quality on non-smoking commercial flights: A review of published data on airborne pollutants. Indoor air, 31(4), 926-957. https://doi.org/10.1111/ina.12831

Crump, D., Harrison, P., & Walton, C. (2011). Aircraft Cabin Air Sampling Study; Part 1 of the Final Report. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84921666561&doi=10.4028%2fwww.scientific.net%2fAMM.629.388&partnerID=40&md5=7edc41661e8b42b65b6e8710b6aa8875

Directive 2088/50/EC on ambient air quality and cleaner air for Europe (2008). https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008L0050&from=en

EASA. (2014). Preliminary cabin air quality measurement campaign. Final Report EASA_REP_RESEA_2014_4. https://www.scopus.com/inward/record.uri?eid=2-s2.0-84921666561&doi=10.4028%2fwww.scientific.net%2fAMM.629.388&partnerID=40&md5=7edc41661e8b42b65b6e8710b6aa8875

Fox, R. B. (2000). Air quality and comfort measurement aboard a commuter aircraft and solutions to improve perceived occupant comfort levels. ASTM Special Technical Publication(1393), 161-183. https://doi.org/10.1520/stp14494s

Guan, J., Li, Z., & Yang, X. (2015). Net in-cabin emission rates of VOCs and contributions from outside and inside the aircraft cabin. Atmospheric Environment, 111, 1-9. https://doi.org/10.1016/j.atmosenv.2015.04.002

He, J., Yin, Y., Yang, X., Pei, J., Sun, Y., Cui, X., & Chen, Q. (2021). Carbon dioxide in passenger cabins: Spatial temporal characteristics and 30-year trends. Indoor air, 31(6), 2200-2212. https://doi.org/10.1111/ina.12874

Higgins, C. (2005). Causes and clinical significance of increased carboxyhemoglobin. https://acutecaretesting.org/en/articles/causes-and-clinical-significance-of-increased-carboxyhemoglobin

HSE (2005). EH40/2005 Workplace Exposure Limits. Health and Safety Executive. https://www.hse.gov.uk/pubns/priced/eh40.pdf

Lee, S. C., Poon, C. S., Li, X. D., & Luk, F. (1999). Indoor air quality investigation on commercial aircraft. Indoor air, 9(3), 180-187. https://doi.org/10.1111/j.1600-0668.1999.t01-1-00004.x

Lindgren, T., & Norbäck, D. (2002). Cabin air quality: Indoor pollutants and climate during intercontinental flights with and without tobacco smoking. Indoor air, 12(4), 263-272. https://doi.org/10.1034/j.1600-0668.2002.01121.x

Lindgren, T., Norbäck, D., & Wieslander, G. (2007). Perception of cabin air quality in airline crew related to air humidification, on intercontinental flights. Indoor air, 17(3), 204-210. https://doi.org/10.1111/j.1600-0668.2006.00467.x

Lowther, S.D., Dimitroulopoulo, A., Foxall, K., Shrubsole, C., Cheek, E., Gadeberg, B., & Sepai, O. (2021). Low level carbon dioxide indoors - a pollution indicator or a pollutantt? A health-based perspective. Perspective. Environments, 8, 125. https://doi.org/10.3390/environments8110125

MacGregor, I. C., Spicer, C. W., & Buehler, S. S. (2008). Cocentrations of selected chemical species in the airliner cabin environment. Journal of ASTM International, 5(8). https://doi.org/10.1520/JAI101639

Nagda, N. L., Rector, H. E., Li, Z., & Space, D. R. (2000). Aircraft cabin air quality: A critical review of past monitoring studies. ASTM Special Technical Publication(1393), 215-235. https://doi.org/10.1520/stp14496s

Oh, S. and Choi, S-C. (2022). Acute carbon monoxide poisoning and delayed neurological sequelae: a potential neuroprotection bundle therapy. Neural Regen Res. 10(1), 36–38. doi: 10.4103/1673-5374.150644

Permentier, K., Vercammen, S., Soetaert, S., & Schellemans, C. (2017). Carbon dioxide poisoning: a literature review of an often forgotten cause of intoxication in the emergency department. Int J Emerg Med, 10(1), 14. https://doi.org/10.1186/s12245-017-0142-y

Spengler, J. D., Vallarino, J., McNeely, E., & Estephan, H. (2012). In-Flight/Onboard Monitoring: ACER's Component for ASHRAE 1262, Part 2 (Indoor air, Issue. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85104860532&doi=10.1111%2fina.12831&partnerID=40&md5=eac1996703ee96b0317d064a5609295c

Townsend, C.L. and Maynard, R. L. (2002). Effects on health of prolonged exposure to low concentrations of carbon monoxide. Occup Environ Med, Vol. 59 Issue 10, 708-11 https://10.1136/oem.59.10.708

UK National Air Quality Objectives of the Air Quality Strategy. https://uk-air.defra.gov.uk/assets/documents/Air_Quality_Objectives_Update.pdf

UKHSA. (2022). Carbon monoxide: toxicological overview. https://www.gov.uk/government/publications/carbon-monoxide-properties-incident-management-and-toxicology/carbon-monoxide-toxicological-overview

WHO (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. https://apps.who.int/iris/handle/10665/345329.

Yu, N., Zhang, Y., Zhang, M., & Li, H. (2021). Thermal condition and air quality investigation in commercial airliner cabins. Sustainability (Switzerland), 13(13). https://doi.org/10.3390/su13137047

List of Abbreviations and glossary

AFT	Back
AQG	Air quality guideline
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineer
CCAR	Chinese civil aviation regulations
CCOHS	Canadian Centre for Occupational Health and Safety
CO	Carbon monoxide
COMEAP	Committee on the Medical Effects of Air Pollutants
CO_2	Carbon dioxide
COHb	Carboxyhaemoglobin
COT	Committee on Toxicity
CS	Certification Specifications
CSS	Consolidated Safety Services
DCLG	Department for Communities and Local Government
DfE	Department for Education
DfT	Department for Transport
EASA	European Aviation Safety Authority
EC	European Commission
FAA	Federal Aviation Agency
FAR	Federal Aviation Regulations
FWD	Forward
ECS	Environmental control system
JAR	Joint Airworthiness Requirements
LTEL	Long-term exposure limit
OP	Organophosphate
PEL	Permissible exposure limit
STEL	Short-term exposure limit
sVOC	Semi-volatile organic compounds
TWA	Time weighted average
VOC	Volatile organic compounds

WEL	Workplace exposure limit
WHO	World Health Organisation

COMMITTEE ON TOXICITY OF CHEMICALS IN FOOD, CONSUMER PRODUCTS AND THE ENVIRONMENT (COT)

Carbon monoxide and carbon dioxide in aircraft cabin air

Search terms

90. Search terms for Scopus and PubMed are presented below.

Scopus:
(TITLE-ABS-KEY ("carbon monoxide" OR "carbon dioxide") AND TITLE-ABS-KEY (aircraft OR airplane OR aeroplane OR "flight deck") AND TITLE-ABS-KEY ("cabin air")) AND (EXCLUDE (LANGUAGE , "German")): 52

PubMed:
(((("carbon monoxide"[Title/Abstract] OR "carbon dioxide"[Title/Abstract]) OR (carbon monoxide[MeSH Terms])) OR (carbon dioxide[MeSH Terms])) AND (aircraft[Title/Abstract] OR airplane[Title/Abstract] OR aeroplane[Title/Abstract] OR "flight deck"[Title/Abstract])) AND ("cabin air"[Title/Abstract]): 15

91. Inclusion criteria

- Peer reviewed publications
- Relevant reviews
- Papers presenting data in tables or in narrative form

92. Exclusion criteria

- Studies not reporting original results, including comments, letters or editorials
- Papers without an abstract
- Papers only presenting data in figures
- Papers concerned only with methodology