



BSI Standards Publication

Cabin air quality on civil aircraft — Chemical compounds

National foreword

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Cabin air quality on civil aircraft - Chemical compounds

Qualité de l'air en cabine d'avions civils et Composés
chimiques

Kabinenluftqualität in Verkehrsflugzeugen - Chemische
Parameter

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European foreword

This document (CEN/TR 17904:2022) has been prepared by Technical Committee CEN/TC 436 “Cabin air quality”, the secretariat of which is held by AFNOR.

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Introduction

Air quality on civil aircraft requires particular attention, given the characteristics of the cabin environment.

An environmental control system (ECS) is used to regulate the aircraft cabin pressure, temperature and ventilation supply air to provide a safe and comfortable environment for the passengers and air crew. The aircraft cabin by design and operation is enclosed and is a densely occupied environment (with only a small amount of per person dilution volume), creating the potential for elevated levels of bio-effluents in the cabin, such as carbon dioxide (see Annex A). ECS architecture on civil passenger aircraft can be broadly separated in two categories: bleed air ECS systems and bleed free ECS systems (see Annex A). Most aircraft manufactured today, and nearly all aircraft in service, have bleed air ECS.

This document focuses on the chemical compounds potentially present in cabin air. It sets out recommendations and supporting annexes to enable airline operators, manufacturers and suppliers to identify - and either prevent or mitigate - exposure to contaminants in the cabin air, with particular emphasis on bleed air contaminants sourced to or generated from engine oil and hydraulic fluid. This includes some limited measures intended to protect workers assigned to troubleshoot and service the aircraft ventilation supply air systems.

NOTE Aircraft accident investigation agencies, aviation regulators from the EU and US, and the International Civil Aviation Organization (ICAO) have recognized that bleed air contamination can compromise flight safety.

The recommendations in this document take into account that the fluids used in aviation (including jet engine oils) and their pyrolysis products are complex mixtures. Some of these mixtures contain organophosphates, ultra-fine particles, and other chemical compounds.

The recommendations in the document take into account current and developing legal frameworks in order to enable the industry to meet their legal obligation to provide a safe environment for air crew and passengers. This document also acknowledges, at the European Commission level, the value of using the Precautionary Principle in relation to risk management, and the use of risk assessment in this industry to protect workers and the environment.

Within this document, emphasis is placed upon exposure prevention, sensor technology, worker training, reporting systems, and collation of data and information from air crew and passengers. Safety Management Systems (SMS) can be a useful tool to enable operators to apply these measures to monitor and respond to system degradation.

This document does not define acceptability/suitability for health, comfort, safety, or airworthiness of the cabin air.

Annex I contains a summary of maximum levels of the marker compounds listed in Annex B that have been published.

1 Scope

This document defines recommendations dealing with the quality of the air on civil aircraft concerning chemical compounds potentially originating from, but not limited, to, the ventilation air supplied to the cabin and flight deck.

A special emphasis is on the engine and APU bleed air contaminants potentially brought into the cabin through the air conditioning, pressurization and ventilation systems.

This document is applicable to civil aircraft in operation from the period that is defined as when the first person enters the aircraft until the last person leaves the aircraft.

This document recommends means to prevent exposure to certain type of chemical compounds, including those that could cause adverse effects, taking into account the Precautionary Principle.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

3.1

adverse effect

change in morphology, physiology, growth, development or lifespan of an organism which results in impairment of its functional capacity or impairment of its capacity to compensate for additional stress or increased susceptibility to the harmful effects of other environmental influences

[SOURCE: ISO 13073-3:2016, 2.1]

3.2

aerosol

system of solid particles and/or liquid droplets suspended in gas

3.3

air crew

people working on an aircraft in the period that is defined as when the first person boards the aircraft until the last person leaves the aircraft, including pilots and cabin crew

3.4

airline operator

entity authorized by an Air carrier Operator Certificate (AOC) from its national Civil Aviation Authority to operate civil transport aircraft flights for commercial carriage of passengers, cargo or mail

Note 1 to entry: The airline operator holds responsibility for compliance with civil aviation authority regulations on its flights, including when the relevant tasks are performed by sub-contractors.

[SOURCE: ISO 16412:2005, 3.3, modified — The terms originally defined were “operator”, “airline” and “carrier”.] [2]

3.5

auxiliary power unit

APU

gas turbine-powered unit delivering rotating shaft power, compressor air, or both, which is not intended for direct propulsion of an aircraft

[SOURCE: EASA CS Definitions] [3]

3.6

best available technology

BAT

most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular technologies for providing, in principle, the basis to mitigate, or eliminate exposure to contaminants in cabin air

[SOURCE: Council Directive 2008/1/EC, modified] [4]

3.7

bleed air

air bled off the compressor stages of the aircraft engines or APU, prior to the combustion chamber; source of ventilation air

3.8

cabin air

air within the section of an aircraft in which passengers and/or air crew travel (including the cabin and flight deck)

3.9

cabin material

cabin interior which includes seats, flooring, walls, cabinets and overhead bins

3.10

chemical compound

chemical element or compound on its own or admixed as it occurs in the natural state or as produced, used, or released, including release as waste, by any work activity, whether or not produced intentionally and whether or not placed on the market

[SOURCE: Council Directive 98/24/EC Art. 2(a)] [5]

3.11

contaminant

substance emitted into the air adversely affecting air quality

[SOURCE: ISO 4225:2020] [6]

3.12

early warning system

system or a procedure to detect the presence of contaminants that may require intervention

3.13

electrical-environmental control system

E-ECS

bleed-free ECS

3.14**environment control system****ECS**

system of an aircraft which provides ventilation supply air, temperature control, and cabin pressurization for the crew and passengers

3.15**fresh air (see also: outside air)**

air taken from outside the vehicle

Note 1 to entry: In this document, the vehicle is the aircraft.

3.16**fumes**

odorous, gaseous emission of compound(s) and/or aerosols which may be sourced to the cabin/flight deck ventilation supply air vents and is not visible

3.17**hazardous**

substance or mixture fulfilling the criteria relating to physical hazards, health hazards, or environmental hazards

[SOURCE: Regulation (EC) No 1272/2008 “CLP”, Article 3] [7]

Note 1 to entry: (i) any chemical agent which meets the criteria for classification as hazardous within any physical and/or health hazard classes laid down in Regulation (EC) No 1272/2008 of the European Parliament and of the Council, whether or not that chemical agent is classified under that Regulation; and(ii) any chemical agent which, whilst not meeting the criteria for classification as hazardous in accordance with point (i) may, because of its physico-chemical, chemical or toxicological properties and the way it is used or is present in the workplace, present a risk to the safety and health of workers, including any chemical agent that is assigned an occupational exposure limit value under Article 3.

[SOURCE: Directive (EC) No 98/24, Article 2]

Note 2 to entry: This definition of hazardous is different to the definition applied in the airworthiness context.

3.18**marker compound**

chemical compound representing/indicating specific/potential sources of airborne contaminants in the cabin air

3.19**outside air (see also: fresh air)**

air taken from outside the vehicle

[SOURCE: ISO 19659-1:2017, 3.4.1] [8]

Note 1 to entry: In this document, the vehicle is the aircraft.

3.20**real-time sampling**

use of online monitoring using instrumental analysers with sensors; the output describes the change in concentration of the analyte(s) as a function of time during the sampling period

3.21

risk analysis

systematic use of available information to identify hazards and to estimate the risk

[SOURCE: ISO/IEC Guide 51:2014, 3.10] [9]

3.22

safety management system

SMS

administrative framework that is designed to manage safety risks in workplaces and is applied to enable the operator to systematically monitor and respond to fume events

3.23

sensor

electronic device that senses a physical condition or chemical compound and delivers an electronic signal proportional to the observed characteristic

[SOURCE: ISO/IEC TR 29181-9:2017,3.14] [10]

3.24

soot

particulate matter with a particle size of 0 nanometres (nm) to 10 nm produced and deposited during or after combustion

[SOURCE: EN ISO 472:2013, 2.1278 modified] [11]

3.25

steady state

condition during single engine power setting characterized by stable temperature and bleed pressure

[SOURCE: SAE (2018)] [12]

3.26

supply air

air introduced into an enclosure by mechanical means including engines, APU, onboard electric compressors, or ground supply units

3.27

time-integrated sampling

either passive or active sampling methodology, followed by analysis of the collected sample in dedicated equipment or a laboratory; the output describes the average concentration of the analyte(s) during the sampling period

3.28

transient operating condition

condition other than steady state engine power setting characterized by unstable temperature and/or changing pressure; examples include engine start, take-off top-of-descent and changes in engine regime including changing the power setting from idle to take off power and back

3.29**ultra-fine particles**

ultra-fine particles (UFP) or ultrafine dust are the most commonly used definitions of airborne particles with a diameter between 1 and 100 nanometres (nm)

[SOURCE: ISO 2007] [13]

4 Cabin air quality — chemical compounds**4.1 Chemical compounds in cabin air**

The presence and concentration of many chemical compounds have been measured in the cabin air and are reported in numerous studies, providing a large database of chemical compounds. Most of these data were collected in the cabin or flight deck during normal operating conditions and not during a reported “fume event” (see 4.4). Some of these data were collected directly from a bleed air source.

Monitoring the cabin air for the presence of appropriate chemical marker compounds is a method to indicate the source(s) of contamination, rather than to assess any health effects of exposure.

4.2 Sources of chemical compounds

Chemical compounds can be sourced to the outside environment and can also originate from the aircraft itself. These may include, but are not limited to the following:

- engine oil;
- hydraulic fluid;
- engine exhaust;
- fuel (unburned and vapours);
- de-icing fluid;
- chemical products used to wash engines or turbines;
- occupants;
- cabin materials and cleaning products;
- air conditioning equipment; and
- faulty/failed electrical items.

An overview of a subset of the chemical compounds associated with some of these sources that may be introduced to the cabin air is provided in Annex G.

4.3 Sources of engine oil leakage in the bleed air system

The presence of oil fumes in the cabin air can, in some instances, be linked to the oil lubrication system. A description of the oil lubrication system, the seal technology, and possible contamination of the cabin air with engine oil are discussed in Annex H.

4.4 Fume event

A fume event is characterized by the presence of fumes in the cabin, emanating from the ventilation supply air vents which can indicate the presence of a specific contamination of the ventilation supply air (e.g., engine oil, hydraulic fluid, de-icing fluid) that has originated from or entered the engine or APU.

Alternatively, the presence of fumes and/or aerosols in cabin may emanate from a source within the cabin (e.g., galley ovens, electrical faults).

4.5 Marker compounds

A subset of marker compounds that can be present in cabin air is listed in Annex B, Table B.1. These marker compounds are associated with major contaminant sources from bleed air and outside air. They are deemed to be useful markers for these specific sources of air contamination in the aircraft environment.

Table B.2 lists “reliability ratings” (A through C) for each marker compound, intended to assist the reader in determining which combination of compounds to monitor for each source of contamination listed in 4.2.

Annex I lists published studies that, together, include measurement data for 14 of the 16 marker compounds in Annex B. The maximum value of each measured compound was commonly reported so is provided in Table I.1 for comparison purposes.

4.6 Environmental control systems (ECS)

The purpose of the ECS is to provide ventilation supply air and regulate the aircraft cabin pressure and temperature in order to provide a safe and comfortable environment for the passengers and crew.

Most commercial passenger aircraft are equipped with an ECS that processes bleed air from engine compressors, whilst some ECS process air from electrical compressors. Airborne chemical compounds can be introduced into the cabin air through the aircraft ventilation supply air system. Further details on these two types of ECS are provided in Annex A.

5 Precautionary Principle and hierarchy of controls

5.1 General

Airborne chemical agents can be sourced to the ventilation supply air (e.g., engine oil, hydraulic fluid, de-icing fluid, and exhaust fumes) and the aircraft cabin surfaces, equipment, and occupants (see Clause 4). Exposure to these chemical agents can be prevented/minimized through the application of the design and maintenance measures in this document, all of which should be planned and implemented according to the Precautionary Principle (see 5.2) and the hierarchy of controls (see 5.3).

The objective of these design and maintenance measures is to prevent/minimize onboard exposure to airborne contaminants, with a special emphasis on the ventilation supply air. This can be accomplished by:

- a) implementing an onboard monitoring system that gives, at the earliest possible time, an indication of a system degradation or change in the cabin air quality (see Clause 7). This allows for appropriate operational and/or maintenance actions intended to enhance flight safety and protect the health of crew and passengers;
- b) using portable monitoring equipment (see 7.3) based on the presence of selected chemical marker compounds (see Annex B) as an additional maintenance monitoring and troubleshooting tool; and
- c) adopting other design, operational, and maintenance measures (see Clause 8 and Annex F).

The chemical marker compounds listed in Annex B (see Table B.1) are deemed to be the most reliably associated with the primary contaminant sources (see 4.2) and are, thus, an appropriate basis for onboard and portable monitoring equipment (see Clause 7). However, alternative methods could be also applied to indicate the presence of a specific contaminant source (e.g. by pattern recognition; see 7.1 and Annex D).

In addition to these design and maintenance measures, recommended administrative measures (i.e., medical monitoring, standardized reporting, airline worker training/education) are described in Clauses 9, 10 and 11.

Also, examples of “best practice” exposure control measures are described in Annex F, and supplemental information on relevant aircraft systems and contaminant sources is provided in the remaining annexes.

5.2 Precautionary Principle

Airline operators, maintenance organisations and manufacturers should apply the Precautionary Principle while performing a risk assessment to characterize the risks of exposure to the main contamination sources listed in Clause 4.

As a part of this risk assessment for aircraft engines and APUs that supply bleed air, manufacturers should measure engine and APU-generated contaminants over the full range of engine power settings expected to occur in service, including on-wing testing and transient power settings, and should assess the potential for fluid loss during normal operation, as well as accidental leaks, spillage, and overfills.

Airline operators should perform a risk assessment on cabin air contamination, including risks that cannot be avoided. For most carcinogens and mutagens, it is not feasible to identify levels below which exposure cannot lead to adverse effects.

Based on these risk assessments, airline operators, maintenance organisations, and manufacturers should apply the Precautionary Principle and the hierarchy of controls (see 5.3) to mitigate the risks of onboard exposure to airborne contaminants. This should include designing systems to minimize fluid emissions during the full range of normal operations.

For additional information on the Precautionary Principle, see Annex C.

5.3 Hierarchy of controls

Airline operators, maintenance organisations and manufacturers should apply the hierarchy of controls to prevent occupant exposure to airborne chemical agents, as follows:

- avoid risks;
- evaluate risks that cannot be avoided;
- control risks at the source;
- eliminate or reduce hazardous chemical exposures by the design and organization of system;
- adapt to technical progress;
- replace the dangerous by the non-dangerous, less dangerous, or safe;
- develop a coherent overall prevention policy which covers technology, organization of work, working conditions, and the influence of factors related to the working environment;
- give appropriate instructions to the workers; and
- give collective protective measures priority over individual protective measures.

Airline operators, maintenance organisations and manufacturers should address potential hazards at the source by the application of Best Available Technology (BAT), such as filters, to minimize the presence of outside air and engine/APU-generated contaminants in the ventilation supply air.

NOTE 1 BAT has been used successfully as a mean to prevent or reduce/minimize exposure to chemical agents.

NOTE 2 Examples of elimination of oil-contaminated bleed air sourced to a mechanical failure, malfunction, or fluctuations in the efficiency of engine seals could be the inclusion of a bleed free architecture, and/or oil free bearing systems.

NOTE 3 See Directive 89/391/EEC [14] (OSH Framework directive) for further information on the hierarchy of controls. Aircraft-specific applications of the hierarchy of controls are listed in the next two sections.

5.4 Elimination measures

Aircraft manufacturers should take into account the Precautionary Principle and the hierarchy of controls in the design of the ventilation supply air system to eliminate occupant exposure to the airborne chemical agents sourced to the ventilation supply air system listed in 4.2, as follows:

- a) ensure breathing air conducive to a safe and comfortable environment for air crew and passengers in all phases of flight, without design features that experience has shown to be hazardous;
- b) not cause harm, ill-health, or adverse effects (impairment or incapacitation) to air crew;
- c) not cause harm, ill-health or adverse effects (impairment or incapacitation) to passengers;
- d) provide monitoring and notification systems (see Clause 7) to provide an alert regarding system degradation or a change in the cabin air quality (per EASA CS 25.1309) [15] which could require maintenance or pilot intervention; and
- e) be assessed using a risk analysis which includes normal and accidental leaks, fluid contamination, spillage, overfills, the effects on occupants, and an assessment of the mixture of potential contaminants.

Aircraft manufacturers should also design the ventilation supply air system to facilitate maintainability of the system by cleaning or replacement of parts.

NOTE Existing airworthiness requirements describe how to analyse the potential for degraded or impaired crew performance or incapacitation due to contamination of the ventilation supply air with engine oil and other aircraft fluids, and to apply an SMS that reflects the full range of operating conditions.

Manufacturers should review service data from airline operators and reporting systems when assessing the frequency of cabin air contamination events.

5.5 Mitigation measures

When elimination by design is not possible, airline operators, aircraft and engine manufacturers, and maintenance organisations, where applicable, should apply the Precautionary Principle (see 5.2) and hierarchy of controls (see 5.3) to prevent/minimize exposure to chemical compounds, particularly those sourced from the aircraft ventilation supply air system, as follows:

- applying designs with mitigation measures such as filters (see Clause 6) and air monitoring (see Clause 7);
- applying preventive and corrective maintenance measures (see Clause 8); and

- implementing administrative mitigation measures such as medical monitoring (see Clause 9), reporting and analysis (see Clause 10), and airline worker training (see Clause 11).

Airline operators and manufacturers should give priority to collective protective measures over individual protective measures, as set out in the hierarchy of controls.

Airline operators and manufacturers should apply the principle of substitution to reduce hazards in relation to products utilized in aviation and engineering solutions. The dangerous should be substituted by the non-dangerous or the less dangerous, according to manufacturing specifications.

Airline operators and manufacturers should document procedures to prevent and mitigate cabin air contamination, including in the aircraft maintenance manual (AMM) and troubleshooting manual (TSM) (see Clause 8).

Aircraft and engine manufacturers, maintenance organisations, and airline operators should also apply the “best practice” measures listed in Annex F, as they impact design, maintenance, and operation.

6 Filtration

6.1 General

Aircraft manufacturers and suppliers should design and install any ventilation supply air filtration systems to remove airborne contaminants (particulate, aerosol, and gaseous) associated with the sources listed in 4.2 in order to prevent/minimize occupant exposure in the occupied zones of the aircraft. Airline operators should operate maintain and replace the filtrations systems, per aircraft manufacturer requirements. Filtration systems can process contaminants in the outside air stream, the recirculated air stream, or both.

NOTE The terms “filter” and “filtration” are understood to include (a) devices intended to capture particles/gases in the air stream; (b) air cleaning technologies designed to remove impurities from air through chemical reactions; (c) or both.

6.2 Recirculation cabin air filtration

Aircraft manufacturers should design ventilation supply air systems to ensure that recirculated ventilation supply air is passed through a high-efficiency particulate air (HEPA) filter, or equivalent, before it is supplied to the cabin in order to prevent the recirculation of particles through the ventilation system.

NOTE 1 Particles can contain chemical compounds and pathogens.

NOTE 2 For certain ECS architecture, recirculation filtration may not be an option during certain operations.

Aircraft manufacturers should design the filters and their mountings to prevent unintentional bypassing of unfiltered air and to prevent filter overloading. HEPA filters should meet one or more of the following standards, or equivalent:

- IEST-RP-CC001; Type A or higher (99,97 % collection efficiency for 0.3-micron particles);
- EN 1822-1; Type H13 (99,95 % overall collection efficiency at the most penetrating particle size MPPS); and
- ISO 29463-1; Type ISO 35 H (99,95 % overall collection efficiency at the most penetrating particle size MPPS).

When recirculation fans are turned on, airline operators should operate and replace these filters and their mountings, all according to manufacturer recommendations.

Alternative technologies and test methods may be used if they provide equivalent or better removal efficiency and the test methods are approved by a cognizant authority.

6.3 Catalytic conversion filtration

If an aircraft is equipped with catalytic converters to remove ozone gas from the outside air stream inflight, then the manufacturer and airline operator should ensure that the devices are designed and maintained according to the relevant regulations.

Devices that utilize catalytic conversion can be used to prevent/reduce exposure to/recirculation of certain gaseous compounds, including but not limited to some of the sources of contaminants in the ventilation supply air and cabin air, as defined in Annex B.

NOTE For more information on the standard to which aircraft ventilation systems must be designed regarding allowed ozone concentrations as a function of cabin altitude, see EASA CS 25.832 [16].

7 Air monitoring

7.1 General

Airline manufacturers should install, and airline operators should operate and maintain, air monitoring equipment intended to identify the presence of at least the following contaminant sources: engine oil, hydraulic fluid, engine exhaust/fuel, and de-icing fluid (see Annex B). When available technology allows, the monitoring data should also distinguish between these contaminant sources. The monitoring recommendations in Clause 7 also apply to maintenance organisations, where applicable.

The primary monitoring objective is to distinguish between normal conditions and system degradation, such as fume events (see 4.4) that may require pilot and/or maintenance intervention. Monitoring the air for those contaminant sources is intended to prevent/reduce onboard exposure.

All air monitoring should be planned and conducted consistent with defined objectives (see 7.2). Specifically, the location of each sensor should be defined according to the potential source of contamination (e.g. engine versus APU), the marker compound(s), and the physical constraints related to the sensor itself (e.g. temperature, pressure, and humidity conditions).

All monitoring equipment should be calibrated and suitable for the intended use (i.e. suitable limit of detection, response time, accuracy, and reliability) and sampling environment to ensure that the data collected is reliable according to the objectives sought (see Annex E).

Where available, sensor technology that can be integrated into the aircraft systems and interpreted in real-time (see 7.3.1) should be used to achieve the recommendations of this section. When real-time sensor technology is available but cannot be integrated into aircraft systems, then a portable real-time device should be used. Real-time sensor data could also be analysed post-flight.

Data collected with portable sampling equipment used for time-integrated measurement methods (see 7.3.2) may also be useful, either to supplement real-time data collected onboard or to perform a routine system inspection/maintenance for any of the airborne contaminant sources listed in Annex B.

The following approaches can be applied, either in isolation or in combination, to identify the contamination source:

- a) indicative chemical marker compounds;
- b) pattern recognition; and
- c) differential measurement.

See Annex D for further information on these approaches.

All sampling data should be carefully interpreted in the context of the sampling conditions.

Cross-sensitivities should be taken into account.

7.2 Air monitoring planning/development

7.2.1 Overview

In coordination with aircraft manufacturers, airline operators should establish a monitoring strategy according to EN ISO 16000-1, in order to define the most appropriate methodology to be utilized and to ensure that the integrity of the measurement data are maintained.

Sampling equipment should be securely located and should not interfere with aircraft operations, nor alter the air. Monitoring should be part of a planned approach to prevent or reduce exposure.

Competent persons, with the skill, knowledge, practical experience and training should plan and oversee monitoring. Trained air crew can manage aircraft-integrated monitoring equipment.

Monitoring objectives should be defined as part of the air monitoring strategy for both real-time and time-integrated measurements, as applicable.

7.2.2 Overview of sampling environment and objectives

The airline operator should prepare an overview of the environment that is to be sampled, ongoing operations, materials/products used in that environment, and the pollutants that may be generated from those materials. The airline operator should incorporate air monitoring methodologies into SMS manuals.

7.2.3 Defining flight phases and whether occupied or unoccupied

Most of the recommended contaminant monitoring is likely to be collected continuously by the airline operator, across all phases of flight (including ground-based operations) when the aircraft is occupied (see 7.1 and 7.3.1).

In addition, to meet the sampling objectives, it may assist the airline operator to collect data for maintenance troubleshooting during specific phases of flight or engine/APU power settings, and only on an unoccupied aircraft.

The airline operator should use Table 1 below to reference the general flight phases, with or without passengers, during which measurements should be taken.

Tests with the ECS or E-ECS (Electrical Environmental Control System) in full cold or full hot condition may not be possible with passengers on board due to comfort reasons. Among all possible aircraft system configurations, Table 1 summaries the combinations of possible aircraft system settings. For each measurement, these system configuration details should be recorded.

Table 1 — Possible aircraft system configuration settings by flight phase

Flight phases	Aircraft system configuration and control settings				
	ECS or E-ECS ^b	Humidifier	APU bleed	Engine bleed	Ground air supply unit
Engine start ^a	ON or OFF	OFF	ON or OFF	OFF to ON	ON or OFF
APU start ^a	ON or OFF	OFF	OFF to ON	ON or OFF	
Ramp	FULL HOT FULL COLD 20 °C to 25 °C or actual ^c	ON or OFF ^c	ON or OFF ^c	OFF	ON or OFF ^c
Ramp de-icing ^a	OFF	OFF	OFF	OFF to ON	
Taxi out	20 °C to 25 °C or actual	ON or OFF ^c	ON or OFF ^c	ON or OFF ^c	
Take-off	20 °C to 25 °C or actual	ON or OFF	OFF	ON	
Climb	20 °C to 25 °C or actual	ON or OFF	OFF	ON	
Cruise	20 °C to 25 °C or actual	ON or OFF	OFF	ON	
Descent	20 °C to 25 °C or actual	ON or OFF	OFF	ON	
Taxi in	20 °C to 25 °C or actual	ON or OFF	20 °C to 25 °C or actual	ON	
Engine Shutdown ^a	ON or OFF		ON or OFF	ON to OFF	
APU shutdown ^a	ON or OFF		ON to OFF	ON or OFF	
^a Airline operators should commence measurements before engine/APU start to ensure bleed air valve opening is recorded. Measurements should continue until after engine/APU shutdown to include situations where the bleed valve does not fully close/slow to close or fails to close. ^b With ECS or E-ECS in “full hot” or “full cold” setting, measurements should be performed without passenger on board and with all air outlets (gaspers) closed. ^c The selected ECS or E-ECS settings or aircraft system configuration are exclusive and should be compatible.					

7.2.4 Defining sampling locations

Options for sampling locations should include the ventilation supply air system (upstream or downstream of the mix manifold) and the ambient cabin air.

The most reliable sampling location for ventilation supply air system-sourced contaminants is in the outside air stream, upstream of the mixing manifold. However, it may not be practical to sample there, given the high temperature and pressure. Sampling the mixture of bleed and recirculated air downstream of the mixing manifold will dilute any ventilation supply air system-sourced contaminants and the sampled air is likely to also contain contaminants generated within the cabin environment.

Settled contaminants on cabin and ventilation ducting surfaces are also a source of qualitative data.

7.3 Air monitoring methodology

7.3.1 Real-time monitoring

In addition to the primary monitoring objective defined in 7.1, airline operators should use real-time monitoring to:

- a) guide air crew to isolate a source of abnormal contamination, as early as possible (e.g., on a bleed air architecture, air crew could isolate an engine or APU bleed source);
- b) guide maintenance troubleshooting, either in real time or after landing; and
- c) provide, on bleed air architecture, data trends over time that could indicate necessary engine/APU maintenance.

NOTE Real-time monitoring assesses changes in contaminant levels as a function of time which can allow an airline operator to identify a range of conditions that require intervention, ranging from the early stages of abnormal leakage through degraded engine/APU seals to component failures.

To accomplish these objectives, sensors should be designed and operated to measure relevant marker compounds (see Annex B), and the data should be relayed to a system for interpretation. The system may either identify changes in the levels of marker compounds over time or compare the real-time sensor data to stored data collected under normal/intervention conditions, for example.

Airline operators should also use real-time monitoring to:

- d) provide useful information on the efficiency of the filtration system (see Clause 6);
- e) indicate that the filtration system is not performing as intended and if servicing/replacement is necessary, in addition to scheduled maintenance; and
- f) provide in-service feedback on the performance of other ventilation supply air system components (e.g., pre-coolers, air exchangers, ECS, filtration systems, ozone/VOC converters, ventilation ducting, etc.).

7.3.2 Time-integrated monitoring

Airline operators should use time-integrated monitoring methods for compounds for which suitable real-time sensors are unavailable.

These methods are recommended to support ground-based troubleshooting in cases where real-time sampling data does not readily identify the contaminant source. Time-integrated methods are suitable for measuring average levels of certain contaminants during routine operations and can supplement qualitative analyses of the chemical contents of an aircraft-installed filter or of wipe samples collected onboard. However, the limitations of time-integrated methods are notable; specifically, the data will not provide early notification of an exposure, which is the primary goal of onboard monitoring. Generally, time-integrated sampling data should be interpreted carefully because the data only defines the average concentration of a contaminant over the sampling period.

When time-integrated methods are selected over real-time methods to measure one or more of the contaminants listed in Table B.1, the rationale for not using real-time methods should be documented, including the relevant limitations, as well as the list of the standards that specify the general requirements for the competence to carry out tests and/or calibrations, and to apply laboratory methods (EN 482 [17], EN ISO 22065 [18], EN 838 [19], EN 13890 [20] and EN ISO/IEC 17025 [21]).

When the sampling strategy is defined and the sampling data are interpreted, the following factors should be considered:

- a) flight phase(s);
- b) duration of each sampling period;
- c) the duration of the flight;
- d) potential for variations in concentration within and between flight phases; and
- e) challenges of reproducing inflight conditions during ground operations.

The user of the time-integrated monitoring method (or monitoring equipment) should ensure that it is compatible with the range of and fluctuations in onboard environmental factors (e.g. temperature, humidity, pressure). The user should also ensure that the analytical method is suitable for the suspected contaminant source, considering potential interferences which may consist of a complex mixture of compounds.

Before and after the sampling period, flows should be checked by means of a calibrated flow measurement device. Sample duration and sample volume should be defined by the monitoring objective(s) and will depend on the detection limit of the chosen method. For some time-integrated sampling methods, the limit of detection is low enough that the sampling duration can be short.

NOTE 1 Collection of time-integrated measurement data combines air sampling methods with subsequent laboratory analysis of the sampling media.

NOTE 2 Time-integrated sampling systems typically consist of a pump connected via a tube to the sampling media (collection or adsorption media).

NOTE 3 Time-integrated sampling does not define concentration as a function of time. Variability in concentration as a function of time can provide insight into the contaminant source when interpreted as a function of flight phase and engine power setting, for example.

In-flight sampling is conducted in a reduced and variable pressure environment, both of which will affect the volume of air that the pump actively draws across the sampling media. To address this, sampling should be performed either with mass-flow controllers correcting for pressure changes, or with pumps that have automatic constant flow, assuring sampling is maintained within $\pm 5\%$ of the initial set point and resulting in a constant flow velocity during the whole flight.

If passive sampling methods are considered, the limitations should be recognized.

The airline operator should send the air or media samples to an analytical laboratory with a demonstrated ability to produce precise and accurate test and calibration data, both for standard methods (as contained in Annex E), and for laboratory-developed methods. If no standardized method exists, adapted or novel methods or devices are allowed, providing they meet the primary monitoring objective (see 7.1).

8 Preventative and corrective actions

8.1 General

Airline operators should develop and implement the operational and maintenance recommendations in 8.2 – 8.5 to both prevent and remedy the presence of airborne chemical compounds (see Annex B), with an emphasis on compounds sourced to the ventilation supply air system. Airline operators should collaborate with manufacturers, where applicable. Additional recommendations are listed in Annex F.

These measures should be incorporated into aircraft maintenance manuals and crew manuals, as appropriate.

8.2 Preventative measures pre-flight

- a) To prevent overfilling of the oil reservoirs, airline operators should install an instructional placard on each oil reservoir that clearly indicates the appropriate filling level and should develop/implement a task card to train maintenance workers to:
 - i) refer to the placard when filling the reservoir;
 - ii) service the engine/APU after appropriate shut-down sequence (where relevant) and within specified timeframe; and
 - iii) follow procedures intended to ensure an accurate reading and logging of oil level/additions.

NOTE 1 Further guidance can be found in ASHRAE (2018) Air quality within commercial aircraft, ANSI/ASHRAE Standard 161–2018, ISSN 1041 2336, Section 8.7 – Engine oil.

- b) To prevent overfilling of the hydraulic fluid reservoirs, airline operators should install an instructional placard on hydraulic fluid reservoir that clearly indicates the appropriate filling level and should develop/implement a task card to train maintenance workers to:
 - i) refer to the placard when filling;
 - ii) service within specified timeframe (where appropriate); and
 - iii) follow procedures intended to ensure an accurate reading and logging of hydraulic fluid level/additions.

NOTE 2 Further guidance can be found in ASHRAE (2018) Air quality within commercial aircraft, ANSI/ASHRAE Standard 161–2018, ISSN 1041 2336, Section 8.6 – Hydraulic fluid.

8.3 Corrective measures in-flight

Airline operators should develop approved smoke/fumes checklist procedures for conditions that are not associated with fire when fumes are suspected to be present. The procedures should include pilots' use of the oxygen mask in the 100 %/EMERGENCY position in order to ensure 100 % oxygen under positive pressure.

These checklist procedures should include steps to enable pilots to attempt to isolate the source of supply air contamination inflight, when conditions allow.

8.4 Corrective measures post-flight

Airline operators should use maintenance task cards to enable maintenance workers to reliably identify and remedy contaminant sources post-flight based on the location and nature of sensor data, and data from standardized crew reporting forms. Maintenance task cards should employ a systematic approach to enable maintenance workers to troubleshoot aircraft systems to locate the presence of airborne contaminants according to each ventilation supply air source (e.g. APU, engine #1, engine #2, electric compressors). Troubleshooting tasks could include, but are not limited to: pack isolation procedures; visual inspection of engines/APU/ECS components and ducting that leads from bleed sources; boroscope inspection; review of oil consumption records; inspection of opened engine cowlings; aircraft walk around that includes check for evidence of fluid streaking around APU inlet; consideration of possible environmental causes; and cabin filter analysis.

Maintenance task cards should direct workers to review oil/hydraulic servicing records and assess the systems for evidence of overfilling, especially if a mechanical defect/failure is not apparent. These task cards should explicitly state that APU-sourced fumes can manifest in-flight, after the APU has been turned off.

Maintenance task cards should instruct maintenance staff to systematically inspect and clean systems downstream of an identified source of contamination, which may include ECS components and downstream air distribution/trim air ducting.

Specific to pack burn procedures, task cards for maintenance staff should be developed and implemented to:

- a) isolate the ducting downstream of the packs by routing the pack burn air overboard, where possible;
- b) ensure that the aircraft is unoccupied during a pack burn or, if not possible, at least ensure that occupants wear suitably protective equipment; and
- c) inspect and either clean or replace soiled downstream components.

NOTE Further guidance can be found in ASHRAE (2018) Air quality within commercial aircraft, ANSI/ASHRAE Standard 161–2018, ISSN 1041 2336, Section 8.2, Remedies (b) and A3.1.

Airline operators should ensure that reported ventilation supply air contamination events are investigated and analysed according to best practices in order to address root causal factors to prevent repeat events.

8.5 Aircraft Maintenance Manual (AMM)

The maintenance task cards, and the measures described in the aircraft maintenance manual (AMM) should be made available to the pilots to support their decision to accept the aircraft back into service.

9 Monitoring of air crew and passengers

9.1 Monitoring air crew

Operators should monitor the health of air crew. Monitoring air crew is another source of information about cabin air quality.

Air crew should be monitored at:

- the commencement of employment (typically pre-engagement medical); and
- after all contaminated air fume events using the current best available technology.