



AEROSPACE RECOMMENDED PRACTICE

ARP85™

REV. G

Issued 1943-01
Revised 2019-09
Reaffirmed 2024-10

Superseding ARP85F

Air Conditioning Systems for Subsonic Airplanes

RATIONALE

The purpose of this revision is to update references that have changed since the previous publication of ARP85.

ARP85G has been reaffirmed to comply with the SAE Five-Year Review policy.

TABLE OF CONTENTS

1.	SCOPE.....	4
1.1	Purpose.....	4
1.2	Field of Application.....	4
2.	REFERENCES.....	4
2.1	Applicable Documents.....	4
2.1.1	SAE Publications.....	5
2.1.2	U.S. Government Publications.....	6
2.1.3	Airlines for America (A4A) Publications.....	6
2.1.4	EASA Publications.....	6
2.1.5	AIA Publications.....	7
2.1.6	ICAO Publications.....	7
2.1.7	Other Applicable References.....	7
2.2	Related Publications.....	7
2.2.1	SAE Publications.....	7
2.2.2	ASHRAE Publications.....	7
2.3	Defintions.....	7
3.	SYSTEM DESIGN RECOMMENDATIONS.....	8
3.1.1	Requirements Imposed Via Regulations.....	8
3.1.2	System Design Recommendations for Safety.....	9
3.1.3	Failure Considerations.....	10
3.2	Comfort.....	10
3.2.1	Ventilation.....	11
3.2.2	Air Distribution Recommendations.....	16
3.2.3	Compartment Temperature Recommendations.....	17
3.2.4	Cabin Humidity.....	19
3.2.5	Compartment Noise Recommendations.....	19
3.3	Cockpit Interface.....	20
3.3.1	Operating Controls.....	21
3.3.2	Operating Indications.....	21
3.3.3	Dispatch Indications.....	21

SAE Executive Standards Committee Rules provide that: "This report is published by SAE to advance the state of technical and engineering sciences. The use of this report is entirely voluntary, and its applicability and suitability for any particular use, including any patent infringement arising therefrom, is the sole responsibility of the user."

SAE reviews each technical report at least every five years at which time it may be revised, reaffirmed, stabilized, or cancelled. SAE invites your written comments and suggestions.

Copyright © 2024 SAE International

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, transmitted, in any form or by any means, electronic, mechanical, photocopying, recording, or otherwise, or used for text and data mining, AI training, or similar technologies, without the prior written permission of SAE.

TO PLACE A DOCUMENT ORDER: Tel: 877-606-7323 (inside USA and Canada)
Tel: +1 724-776-4970 (outside USA)
Fax: 724-776-0790
Email: CustomerService@sae.org
http://www.sae.org

SAE WEB ADDRESS:

Full document details: SAE ARP85G

For more information on this standard, visit
<https://www.sae.org/standards/content/ARP85G/>

Documents

Standard, visit Sharing Hub

3.4	Economics.....	22
3.4.1	Acquisition.....	22
3.4.2	Operation.....	22
3.4.3	Support.....	23
3.5	Emissions.....	24
3.5.1	Ramp Noise.....	24
3.5.2	Air Exhaust Temperature.....	25
4.	COMPONENT DESIGN RECOMMENDATIONS:.....	25
4.1	General Component Design Recommendations.....	25
4.1.1	Materials and Processes.....	25
4.1.2	Component Failure Concept.....	25
4.1.3	Rotating Equipment Containment.....	25
4.1.4	Rotating Equipment Overspeed Spin.....	26
4.1.5	Contamination.....	26
4.1.6	Strength.....	26
4.1.7	Proof Pressure.....	26
4.1.8	Burst Pressure.....	27
4.1.9	Fluid Leakage.....	27
4.1.10	Bonding and Grounding.....	27
4.2	Specific Component Design Recommendations.....	28
4.2.1	Heat Exchangers.....	28
4.2.2	Air Cycle Machines.....	28
4.2.3	Moisture Control.....	29
4.2.4	Valves and Controls.....	30
4.2.5	Sensors and Controls.....	32
4.2.6	Humidifiers.....	34
4.2.7	Fans and Ejectors.....	34
4.2.8	Ground Cart Connections.....	34
4.2.9	Vapor Cycle Components.....	34
4.3	Component Equipment Installation.....	35
5.	SYSTEM ARCHITECTURE CONSIDERATIONS.....	35
5.1	Candidate Systems.....	35
5.2	Optimization Techniques.....	42
5.2.1	Minimizing Fresh Airflow.....	42
5.2.2	Minimizing Ram Airflow.....	44
6.	PRESSURIZATION DESIGN GUIDELINES.....	44
6.1	Pressure Controls.....	44
6.2	Redundant Pressure Sources.....	44
6.3	Pressure Relief System.....	44
6.4	Cabin Depressurization.....	44
6.5	Cabin Leakage.....	45
7.	AMBIENT CONDITIONS.....	45
7.1	Performance Standards.....	45
7.1.1	Hot Day Performance.....	45
7.1.2	Cold Day Performance.....	45
7.2	Operational Conditions.....	46
7.2.1	Ground Operations.....	46
7.2.2	In-Flight Operations.....	50
7.3	Ground Non-Operating.....	50
8.	NOTES.....	50
8.1	Revision Indicator.....	50

Figure 1	Irritation versus dilution	13
Figure 2	Effect of dilution index on occupant satisfaction	13
Figure 3	Example of a temperature control system	33
Figure 4A	Basic vapor cycle	37
Figure 4B	Enhanced vapor cycle (two-stage compressor and economizer)	37
Figure 4	Examples of vapor cycle	37
Figure 5A	Simple cycle (turbine fan).....	38
Figure 5B	Bootstrap cycle (turbine compressor)	38
Figure 5C	Simple/bootstrap cycle (three-wheel ACM).....	38
Figure 5	ACM cycle examples.....	38
Figure 6A	Low-pressure water separator	39
Figure 6B	High-pressure water separation (partial flow)	39
Figure 6C	High-pressure water separation	39
Figure 6	Examples of water separators	39
Figure 7A	Compressor recirculation (shoestring) cycle	40
Figure 7B	Chilled recirculation cycle (upstream recirc)	40
Figure 7C	Chilled recirculation cycle (downstream recirc)	40
Figure 7	Integrated recirculation ACM	40
Figure 8	Design temperatures for equipment performance	47
Figure 9	Ambient humidity.....	48
Figure 10	Extreme ambient humidity.....	49
Table 1	Outside air requirements.....	11
Table 2	Airborne contaminants requirements	11
Table 3	Fuel burn penalties.....	23

1. SCOPE

This SAE Aerospace Recommended Practice (ARP) contains guidelines and recommendations for subsonic airplane air conditioning systems and components, including requirements, design philosophy, testing, and ambient conditions.

The airplane air conditioning system comprises that arrangement of equipment, controls, and indicators that supply and distribute air to the occupied compartments for ventilation, pressurization, and temperature and moisture control. The principal features of the system are:

- a. A supply of outside air with independent control valve(s).
- b. A means for heating.
- c. A means for cooling (air or vapor cycle units and heat exchangers).
- d. A means for removing excess moisture from the air supply.
- e. A ventilation subsystem.
- f. A temperature control subsystem.
- g. A pressure control subsystem.

Other system components for treating cabin air, such as filtration and humidification, are included, as are the ancillary functions of equipment cooling and cargo compartment conditioning.

The interface with the major associated system, the pneumatic system (Chapter 36 of ATA 100) is at the inlet of the air conditioning shutoff valves. This boundary definition aligns with that in the ATA 100 Specification.

1.1 Purpose

The purpose of this ARP is to provide guidance for the design, installation, and analysis of subsonic airplane air conditioning systems.

1.2 Field of Application

This ARP applies to subsonic airplane air conditioning systems within the ATA 100 Specification, Chapter 21. ATA Chapter 21 covers the air conditioning system that maintains passenger and crew environment, and ATA 21 also encompasses cabin pressure control systems. This ARP does contain cabin pressurization control guidelines; however, the focus is on air conditioning systems. Refer to ARP1270 for detailed recommendations on cabin pressure control systems.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR860	Aircraft Electrical Heating Systems
AIR910	Ozone in High Altitude Aircraft
ARP986	Guide for Qualification Testing of Aircraft Air Valves
AIR1168/3	Aerothermodynamic Systems Engineering and Design
AIR1168/8	Aircraft Fuel Weight Penalty Due to Air Conditioning
AIR1204	Control of Water Carryover from the Environmental Control System and Condensation on the Structure
AIR1539	Environmental Control System Contamination
AIR1600	Animal Environment in Cargo Compartments
AIR1609	Aircraft Humidification
AIR1826	Acoustical Considerations for Aircraft Environmental Control System Design
AIR4766	Air Quality for Commercial Aircraft Cabins
AIR4766/1	Air Quality for Commercial Aircraft Cabin Particulate Contaminants
AIR4766/2	Airborne Chemicals in Aircraft Cabins
ARP86	Heater, Airplane, Engine Exhaust Gas to Air Heat Exchanger Type
ARP89	Aircraft Compartment Automatic Temperature Control Systems
ARP147	Environmental Control Systems Terminology
ARP699	High Temperature Pneumatic Duct Systems for Aircraft
ARP731	General Requirements for Application of Vapor Cycle Refrigeration Systems for Aircraft
ARP1270	Aircraft Cabin Pressurization Criteria
ARP1796	Engine Bleed Air Systems for Aircraft
AS8040	Heater, Aircraft Internal Combustion Heat Exchanger Type

2.1.2 U.S. Government Publications

2.1.2.1 U.S. Department of Defense Publications

Available from the Document Automation and Production Service (DAPS), Building 4D, 700 Robbins Avenue, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

JSSG-2009	Department of Defense Joint Services Specification Guide, Air Vehicle Subsystems
MIL-HDBK-310	Department of Defense Handbook, Global Climatic Data for Developing Military Products
MIL-STD-1472	Department of Defense Design Criteria Standard, Human Engineering
MS33562	Detail Specification Sheet, Connection, Aircraft Ground Air Conditioning, 8 Inch

2.1.2.2 Code of Federal Regulations (CFR) Publications

Available from the United States Government Printing Office, 732 North Capitol Street, NW, Washington, DC 20401, Tel: 202-512-1800, www.gpo.gov.

14 CFR Part 23	Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
14 CFR Part 25	Airworthiness Standards: Transport Category Airplanes
14 CFR Part 27	Airworthiness Standards: Normal Category Rotorcraft
14 CFR Part 29	Airworthiness Standards: Transport Category Rotorcraft
14 CFR Part 33	Airworthiness Standards: Aircraft Engines
14 CFR Part 121	Certification and Operations: Domestic, Flag and Supplemental Air Carriers and Commercial Operators of Large Aircraft
14 CFR Part 135	Operating Requirements: Commuter and on Demand Operations and Rules Governing Persons Onboard Such Aircraft
AC 25-20	Advisory Circular: Pressurization, Ventilation and Oxygen Systems Assessment for Subsonic Flight including High Altitude Operation

2.1.3 Airlines for America (A4A) Publications

Available from Airlines for America (A4A), 1301 Pennsylvania Avenue, NW, Suite 1100, Washington, DC 20004, Tel: 202-626-4000, www.airlines.org.

Specification 100	Manufacturers' Technical Data.
MSG-3	Operator/Manufacturer Scheduled Maintenance Development, Volume 1 - Fixed Wing Aircraft

2.1.4 EASA Publications

Available from European Aviation Safety Agency, Ottoplatz, 1, D-50679 Cologne, Germany, Tel: +49 221 8999 000, www.easa.europa.eu.

CS-25	Certification Specifications for Large Aeroplanes
CS-APU	Auxiliary Power Units
CS-E	Certification Specifications and Acceptable Means of Compliance for Engines

2.1.5 AIA Publications

Available from Aerospace Industries Association, 1000 Wilson Boulevard, Suite 1700, Arlington, VA 22209-3928, Tel: 703-358-1000, www.aia-aerospace.org.

Airline Industry Standard: World Airlines Technical Operations Glossary (WATOG) - 14th Edition, 1992.

2.1.6 ICAO Publications

Available from International Civil Aviation Organization, 999 University Street, Montreal, Quebec H3C 5H7, Canada, Tel: +1 514-954-8219, <http://www.icao.int/>.

Annex 16, Vol. 1 Environmental Protection, Volume I - Aircraft Noise. Fifth Edition.

2.1.7 Other Applicable References

W. W. Thayer, "Tobacco Smoke Dilution Recommendations for Comfortable Ventilation," presented at ASHRAE 1982 annual meeting, Toronto, Canada, 27 June to 1 July, 1982.

P. F. Halfpenny and P. S. Starrett, "Control of Odor and Irritation Due to Cigarette Smoking Aboard Aircraft," ASHRAE Journal, March 1961, p. 39-44.

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Aerospace Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AS4073 Air Cycle Air Conditioning Systems for Military Air Vehicles

2.2.2 ASHRAE Publications

Available from ASHRAE Headquarters, 1791 Tullie Circle, NE, Atlanta GA 30329, Tel: 800-527-4723 (U.S. and Canada only) or 404-636-8400, www.ashrae.org.

ASHRAE Std 161-2018 Air Quality for Aircraft Cabins

2.3 Definitions

APU: Auxiliary power unit.

cfm: Cubic feet per minute.

CFR: Code of Federal Regulations.

CS: Certification specification.

ECS: Environmental control system.

HEPA: High-efficiency particulate air (refers to a high-efficiency air filter).

ppmV: Parts per million, by volume.

RH: Relative humidity.

TRI-HUB BURST: A failure condition whereby a high-speed rotating part disintegrates into three major pieces, each of which transmit about 1/3 of the total energy to the containment vessel.

VOC: Volatile organic compound (refers to a vaporous substance found in the airstream).

For other definitions, refer to ARP147.

3. SYSTEM DESIGN RECOMMENDATIONS

The major elements of air conditioning system design are as follows:

1. Ensure safety of airplane occupants, ground crews, and maintenance personnel.
2. Provide comfortable environment for passengers and crew.
3. Provide cockpit interfaces that minimize workload for flight crews.
4. Be cost effective to operate and maintain.
5. Be compatible with the environment.

The following is an overview description of an airplane air conditioning system:

The air conditioning system may accept high-pressure, high-temperature fresh air from the main engines, from separate compressors, from an APU, from ground carts, or from a fixed ground supply. The flow of supply air should be controlled and the air conditioned to control temperature and remove excess moisture. Sufficiently redundant air supplies should be provided to ensure continuity of ventilation, control of temperature, and pressurization following reasonable probable failures. Conditioned air may be distributed to both occupied and unoccupied areas. This requires control of supply and exhaust air for each of these areas. Venting requirements for lavatories, galleys, cargo compartments, etc., should be considered. Each of the air conditioning system functions should include monitors to the extent necessary to permit efficient crew control and problem diagnosis.

Other documents covering aspects of cabin air conditioning are ARP1270, which deals with pressurization controls; AIR1609, which covers added moisture; AIR1204, which deals with control of free water in the cabin air supply; AIR4766/1, which deals with particulate contamination; AIR1600, which covers animal environments; AIR1826, which covers the acoustic environment; and ASHRAE Standard 161-2018, which covers aircraft cabin air quality design parameters

This section provides applicable safety requirements for air conditioning systems.

3.1.1 Requirements Imposed Via Regulations

The air conditioning system shall comply with airworthiness requirements, the scope of which should be defined in the airplane specification. Design should also be regulated by the airplane specification. In the event of conflict, airworthiness requirements should prevail.

Regulatory bodies include the United States Federal Aviation Administration (FAA) and the European Aviation Safety Agency (EASA). The FAA regulates the design of airplanes by 14 CFR Part 25. The EASA regulates design by CS-25, which represents the combined requirements of the Airworthiness Authorities of the participating European nations. The 14 CFR Part 25 and CS-25 applicable requirements include the following paragraphs:

- a. 25.561 Emergency Landing Conditions - General
- b. 25.831 Ventilation
- c. 25.832 Cabin Ozone Concentration
- d. 25.833 Heating Systems
- e. 25.841 Pressurized Cabins

- f. 25.843 Tests for Pressurized Cabins
- g. 25.853 Compartment Interiors
- h. 25.855 Cargo and Baggage Compartments
- i. 25.856 Thermal/Acoustic Insulation
- j. 25.863 Flammable Fluid Fire Protection
- k. 25.1163 Powerplant Accessories
- l. 25.1301 Equipment, Function and Installation
- m. 25.1309 Equipment, Systems and Installations
- n. 25.1322 Warning, Caution and Advisory lights
- o. 25.1438 Pressurization and Pneumatic Systems
- p. 25.1461 Equipment Containing High-Energy Rotors

(14 CFR Parts 23, 27, and 29 have equivalent requirements to those listed in 14 CFR Part 25 for rotorcraft and small airplanes.)

In addition, sections of Subpart D of 14 CFR Part 25 and CS25 are applicable to air conditioning system components.

Operating rules based on FAA or EASA regulations are applied individually by the nation of registry. Adequate provision shall be made in systems design to ensure that it is possible for the airplane operators to meet their relevant requirements. These requirements are established by regulations such as 14 CFR Part 121 and Civil Aviation Authority - Air Navigation Order.

Departure from convention in design or in operating environment may result in special airworthiness requirements being imposed. The requirements may be identified as special conditions until they are incorporated into the U.S. Code of Federal Regulations, EASA, and other regulations. The existence and interpretation of such special conditions should be established at the outset.

3.1.2 System Design Recommendations for Safety

All aspects of the air conditioning system design should consider the safety of the passengers and crew. The safety considerations include the following:

- a. All parts of rotating components containing very high amounts of energy should be contained in the event of failure.
- b. Noxious or toxic substances should be prevented from entering the cabin or flight deck either through the primary air conditioning system or the recirculation system. Special attention should be given to hydraulic fluids, fluorocarbon fluids, fuel vapors, and lubricants.
- c. Any combination of reasonably probable failures should not result in excessively high or low temperatures in the cockpit or cabin.
- d. For all components located in an area where flammable fluids or vapors might leak, there should be means to minimize the probability of fluid or vapor ignition in accordance with 14 CFR 25.863.
- e. Select nonmetallic materials that have the lowest practicable smoke density and toxicity rating.
- f. Mount equipment installed in the cockpit or cabin strongly enough to prevent serious injury to occupants in the event of a minor (wheels up) crash landing. Use design load factors per 14 CFR 25.561.

- g. Ensure that fans do not start fires in the event of motor protector failure.
- h. Ensure that carbon dioxide released from dry ice used in galleys or in cargo compartments does not cause a hazard.
- i. Filter galley exhaust air to prevent the accumulation of flammable oils in the exhaust ducts. The filters should not burn and should not permit a fire to pass through them into the ducts.
- j. Provide protective devices for all electric heaters where failures can cause fires or unacceptable temperatures.
- k. Adequate instrumentation/indication should be provided to ensure that significant failures do not go undetected.
- l. The design should require a minimum use of flight crew operating procedures, especially where incorrect use of procedures can cause a subsequent failure or potentially hazardous operating condition.
- m. All electrical equipment located in a zone potentially subjected to (combustible) flammable vapors should meet explosion proof criteria.
- n. Air flow sufficient to maintain cabin pressure should be maintained under any combination of reasonably probable failures.
- o. Air supplied to the cabin shall be free from substances that can impair safe operation of the aircraft (refer to CS-E, CS-APU, and 14 CFR Part 33.75.)

The design of inlets and surface insulation should be such that no metallic surface which can be touched by occupants for prolonged periods exceeds 120 °F (49 °C) when the air conditioning system has reached its stabilized operating condition, or 140 °F (60 °C) during transient operation. For plastic or wood surfaces, 156 °F (69 °C) and 185 °F (85 °C) apply, respectively (MIL-STD-1472, paragraph 5.13.4.6).

3.1.3 Failure Considerations

A fault and failure analysis should be conducted to determine the need for safety devices such as overpressure and over temperature protective features and pressure relief functions, etc. Included in the analysis should be complete loss of electrical power, loss of one or more packs in multiple pack systems, loss of pressure regulation, loss of temperature control at both inlet and outlet, and any other failures or faults which may have adverse effects.

The air conditioning system inevitably requires electrical power. It is important that the following functions are maintained in the event of the loss of electrical power.

- a. Air supply for ventilation, pressurization, and smoke removal.
- b. Control of cabin pressure.

It is in the above context that the functional difference between a normally open, normally closed, or latching solenoid valve and a motorized valve is most evident. This is especially important when considering electrical system failures that leave only essential or battery power available.

Additional reliability considerations are found in 4.1.2.

3.2 Comfort

The aspects of air conditioning system design that contribute to occupant comfort are:

- a. Ventilation.
- b. Air distribution.
- c. Compartment temperature.

- d. Compartment humidity.
- e. Cabin noise.
- f. Air quality.

3.2.1 Ventilation

For the purposes of this document, ventilation shall refer to outside (fresh) air ventilation. The ventilation rate refers to the air change rate: the rate at which cabin air is exchanged with outside (fresh) air.

3.2.1.1 Ventilation Requirements

The occupied compartments shall be ventilated whenever the airplane is in operational service. The minimum outside air ventilation rate required by various regulatory bodies is as shown in Table 1:

Table 1 - Outside air requirements

FAA	EASA
0.55 lb/min/occupant (= 10 CFM at 8000 feet) (14 CFR 25.831)	10 CFM/crew in crew compartment (CS 25.831)
0.4 lb/min/occ for failure conditions exceeding 5 minutes (AC 25-20)	0.4 lb/min/passenger with loss of an air source for periods exceeding 5 minutes (= 7.26 CFM at 8000 feet) (AMC 25.831)

Ventilation rates affect CO and CO₂ concentrations in the cabin. Ozone concentration is influenced by ventilation rate as well (and, on some airplanes, may be controlled by a dedicated ozone converter); Table 2 gives the requirements applicable to CO and CO₂, as well as O₃:

Table 2 - Airborne contaminants requirements

	FAA	EASA
CO ₂ *	0.5% Vol	0.5% Vol
CO*	50 ppmV	50 ppmV
O ₃	0.25 ppmV, sea level equivalent above FL320 Plus 0.1 ppmV, sea level equivalent, time-weighted average during any 3-hour interval above FL270**	

* Source of CO and CO₂ requirements: CS and 14 CFR 25.831.

** Refer to AIR910 for complete ozone maximum requirements.

3.2.1.2 Ventilation Recommendations

To minimize energy consumption, the air conditioning system should operate to provide the minimum required ventilation rate, except when it is desirable to increase the ventilation rate to accomplish the following:

- a. Meet compartment temperature demand; it may not be possible to cool or heat the compartment to the desired temperature with the system supplying conditioned air at the minimum ventilation rate.
- b. Clear smoke from the compartment.

To meet the ventilation requirement, the air conditioning system should operate from the normally available on-board air sources (e.g., main engine, auxiliary, or APU compressor bleed). It should also be possible to operate on the ground from external sources. AIR4766 provides information on cabin air quality; AIR4766/1 and AIR4766/2 provide information regarding particulate and gaseous air contamination, respectively.

A ram air or auxiliary ventilation source should be considered if, under minimum equipment dispatch conditions, reasonably probable failures can result in the loss of all ventilation. This auxiliary ventilation may consist of a ram circuit supplying the normal distribution system, or provisions for manipulating cabin pressure control valves to draw ambient air through the cabin and flight deck, through door seals, negative relief valves, hatches, etc.

Other ventilation recommendations are to provide a draft-free environment with uniform air distribution and temperatures and good air mixing (see 3.2.2).

3.2.1.2.1 Air Quality and Quantity

The quality of air in the cabin depends on the quantity and quality of outside air supplied, contamination generated within the cabin, and the contamination removal efficiency of the air conditioning system.

The quality of outside air is dependent on the source. On the ground, air from adjacent aircraft engine exhaust or nearby ground vehicles can be ingested into the air conditioning system. Turbine engine air sources may also contain contaminants; refer to AIR1539. CS-E, CS-APU, and 14 CFR 33.75 also provide guidance on main engine and APU contamination of air conditioning air.

AIR4766 provides information on cabin air quality; AIR4766/1, AIR4766/2, and AIR1539 provide information regarding particulate and gaseous air contamination, respectively.

Contaminant sources within the aircraft include occupants, cargo, and non-metallic cabin furnishings such as carpets or plastics. In some circumstances, insecticide and cleaning agents may also be present.

Finally, air conditioning systems may be configured to remove contaminants. Systems that employ recirculation of cabin air should use particulate filters. HEPA-type filters are capable of removing certain microbial contaminants. It is also possible to remove gases, VOC, bioaerosols, and other contaminants through the use of adsorbents or catalytic reactors.

3.2.1.2.2 Smoking

Smoking is banned on virtually all commercial flights, so the applicability of this section may be limited to certain business or other private aircraft. In general, this section is no longer applicable to commercial aircraft.

The most challenging ventilation function in many applications is to dilute tobacco smoke to acceptable levels¹.

A number of tests have been run (Thayer, 1982) in which smoker and nonsmoker response to various dilution indices was obtained. The dilution index (D.I.) is defined as the liters of fresh air per milligrams of tobacco burned. Figure 1 shows how irritation varies with dilution index, and Figure 2 shows the percentage of smokers and nonsmokers who reported the irritation levels as acceptable.

In the tests of Halfpenny and Starrett (1961), the mean smoking rate was found to be 13.4 mg/min per smoker; unless other specific smoking data are available, it is recommended that the mean plus one standard deviation (3.6 mg/min) be used for design purposes. The recommended design rate is then 17 mg/min per smoker.

¹ 14 CFR 121.317(c) [change 75, Amendment 121-213, effective Feb. 25, 1990] defines FAA requirements applicable to domestic, flag, and supplemental air carriers and commercial operators of large aircraft

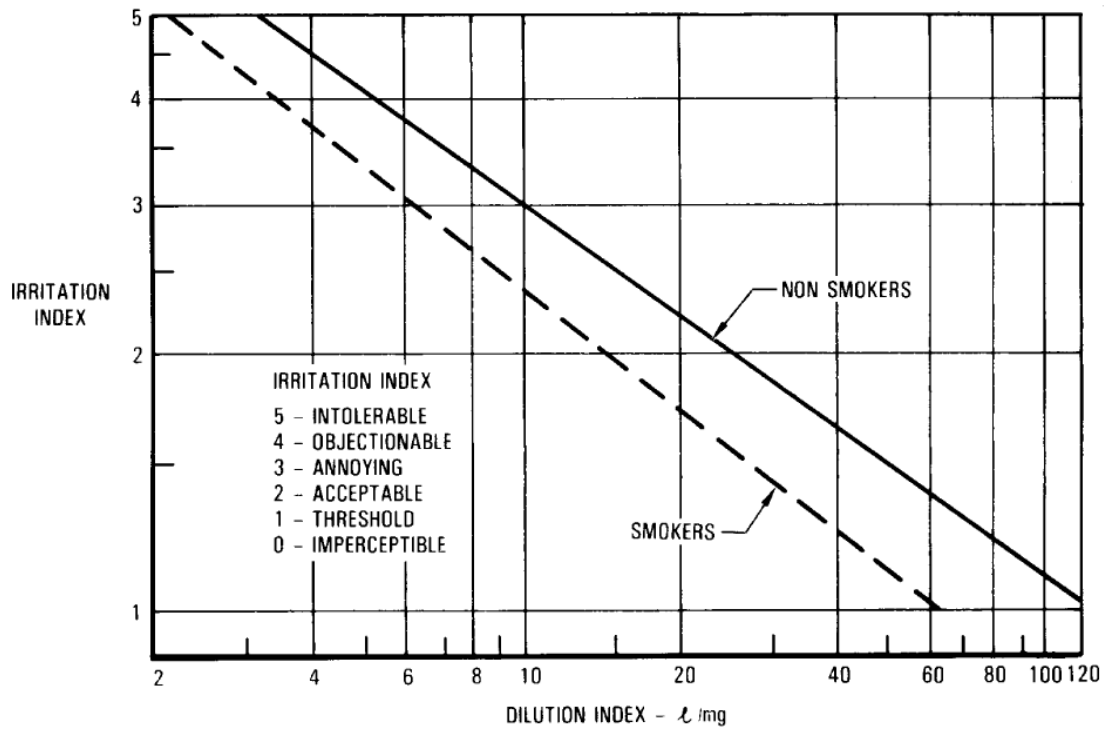


Figure 1 - Irritation versus dilution

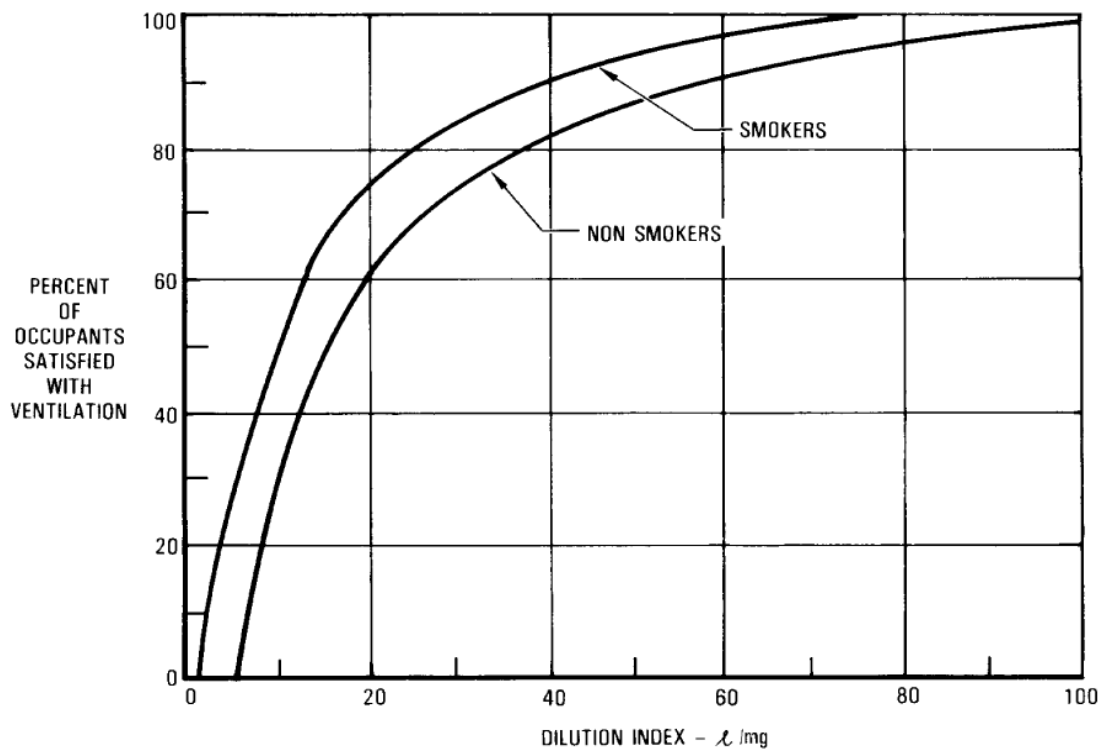


Figure 2 - Effect of dilution index on occupant satisfaction

3.2.1.2.2.1 Smoking Zones

The data of Figure 2 may be used, along with an estimated smoking rate of 17 mg/min per smoker, to calculate the ventilation necessary to obtain any desired acceptance rate in a smoking zone.

Ventilation should be at a level so that at least 80% acceptance by smokers is achieved in the smoking zone. To achieve an 80% acceptance level, the D.I. should be 24 l/mg (Figure 2). At a smoking rate of 17 mg/min, per smoker, the ventilation rate is 408 l/m (14.4 cfm) per smoker.

The size and location of smoking zones vary with airlines and routes. There may be as many as three different smoking zones on a large wide-bodied airplane, and as many as 45% of the total seats assigned to smoking zones on long flights. Some airlines flying shorter legs assign as few as 23% of the seats to smoking zones.

3.2.1.2.2.2 Minimum Fresh Air Ventilation Rate

The minimum fresh air ventilation rate specified in 3.2.1.1 is generally established to meet CO₂ levels and control odors. Temperature control and distribution needs may establish higher ventilation rates than is required for CO₂ and odor control. In addition, if air is recirculated from smoking zones into nonsmoking zones, it should be filtered to remove gaseous contaminants and aerosols, or it should be diluted with enough fresh air to achieve a D.I. of 60 l/mg, which is acceptable to 90% of the nonsmokers. Equation 1 shows how the recirculation and fresh air quantities may be established in a nonsmoking zone.

$$\text{Fresh Air} = \text{Re circulated Air} \left\{ \frac{\text{D.I. Required}}{\text{D.I. Smoking Zone}} \right\} - 1 \quad (\text{Eq. 1})$$

Thus, if a 60 l/mg D.I. is required, and the smoking zone D.I. is 24 l/mg, then the minimum ratio of fresh to recirculated air is 1.5:1.

Smaller airplanes, such as business and executive aircraft, commuters, and small and large military transports, may allow smoking zones. The D.I. for these airplanes is based on the total smoke generated and total fresh air supplied. To achieve a 90% acceptance of the ventilation by nonsmokers, a 60 l/mg D.I. is required for the entire cabin. Based on a smoking ratio of 17 mg/min per smoker and 1/3 smokers, the fresh airflow is $60 \times 17 \times 1/3 = 340$ l/mg (12 cfm) per passenger. The air distribution system for these types of airplanes should ensure good mixing to achieve a uniform D.I.

3.2.1.2.3 Ventilation Flow Control

The air conditioning system should contain a means to control airflow to satisfy one or more of the following:

- a. Maintain a specified ventilation rate to the cabin.
- b. Provide an adequate supply of fresh air.
- c. Provide sufficient cabin inflow to be compatible with the cabin pressure and temperature requirements.
- d. Limit the amount of airflow in the cabin to keep noise and drafts to an acceptable level.
- e. Limit the amount of engine bleed airflow to conserve engine fuel.
- f. Control air flow for smoke clearance.

The flow control device or system includes a means for sensing downstream pressure or the airflow rate and the required valving to modulate the airflow to meet a prescribed airflow schedule. ASHRAE Standard 161 provides information for verifying flow rates throughout an aircraft cabin.

3.2.1.2.3.1 Flow Sensing

The method of airflow sensing should be selected based on an evaluation of the accuracy required to meet the flow schedule and limits desired and the ease of interfacing with the modulating valve. Some techniques for flow sensing include the following:

- a. Venturi: The pneumatic duct is constricted in a smooth venturi section, usually with a gradual taper on the outlet for pressure recovery. The differential pressure is measured between inlet and throat. This differential pressure can be used as a signal pressure for a mechanical servo controller. Or, the differential pressure can be converted to an electrical signal through the use of a pressure sensor. An electronic controller can then calculate flow. An air inlet temperature can be used in the calculation to enhance accuracy. The venturi can be a constriction of the duct flow area, or as an alternative a boosted-pitot can be used. This is a smaller venturi placed inside the duct with pneumatic sense lines connecting with the sensing elements located outside the duct. The boosted pitot must be positioned in the duct to get a representative flow signal.
- b. Heated-element: Sometimes referred to as a hot-wire anemometer, this is a device with a heated probe that is placed in the air stream to measure the cooling effect of airflow going past the probe. The air flow rate is a function of the cooling effect. Since the cooling effect is also a function of the air temperature, this must be factored into the flow calculation. The calculation can be done by electronics onboard the sensor or in a remotely mounted controller.
- c. Flow scheduling: Discussed in 3.2.1.2.3.4.

3.2.1.2.3.2 Flow Modulation

A valve to modulate air flow to achieve the desired flow is placed upstream of the other air conditioning system components. The valve to modulate airflow should be designed in conjunction with the flow-sensing device and sized to handle the airflows required by the air conditioning system. If other airplane systems require airflow, such as avionics cooling, that additional airflow should be considered when sizing the valve. Other features that should be considered for the airflow modulation valve are as follows:

- a. A remote means to open and close the valve to modulate or shut off system airflow.
- b. A method to mechanically override the airflow modulation device to allow manual operation to open and close the valve and lock it in the closed position.
- c. Flow scheduling: Discussed in 3.2.1.2.3.4.
- d. A means to modulate the valve towards closed should an over temperature be sensed in the system.

3.2.1.2.3.3 Inlet/Outlet Flow Control Variables

For the normal operating range, the flow control device or system upstream of the air conditioning pack may see the following range of variables for subsonic airplane air conditioning systems:

- a. Inlet pressure from 10 to 60 psig (69 to 414 kPa gage).
- b. Inlet temperature from 100 to 500 °F (37.8 to 260 °C).
- c. Uncontrolled inlet pressure rate of change 40 psi/s (276 kPa/s).
- d. Variable downstream restriction resulting in a 5 to 40 psig (34 to 276 kPa gage) pressure demand.