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ASHRAE 62-1989

ASHRAE™ STANDARD

AIVC

Ventilation for Acceptable Indoor Air Quality

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CONTENTS

Section	Page
Foreword	1
1. Purpose	3
2. Scope	3
3. Definitions	3
4. Classification	5
5. Systems and Equipment	5
6. Procedures	7
7. References	15
Appendix A	16
Appendix B	16
Appendix C	17
Appendix D	22
Appendix E	24
Appendix F	24
Appendix G	24
Appendix H	25

This Foreword is not part of this Standard but is included for information purposes only.

FOREWORD

ASHRAE's first ventilation standard was ASHRAE Standard 62-73, "Standard for Natural and Mechanical Ventilation" (see Ref i). The standard provided a prescriptive approach to ventilation by specifying both minimum and recommended outdoor air flow rates to obtain acceptable indoor air quality for a variety of indoor spaces. This standard is still referenced in many building codes and was referenced by ASHRAE's first energy Standard, 90-75 (see Ref ii), which specified use of the minimum outdoor air flow rates from 62-73. The revised energy standard, 90A-1980 (see Ref iii), also took this approach.

Under the normal five-year review cycle, the multidisciplinary standards project committee appointed in 1978 addressed the question of whether these minimum values could be defended under all conditions. The revised Standard 62-1981, "Ventilation for Acceptable Indoor Air Quality" (see Ref. iv), recommended outdoor air flow rates for smoking-permitted and for smoking-prohibited conditions in most spaces. The 1981 standard also introduced an alternative air quality procedure to permit innovative, energy-conserving ventilation practices. The alternative procedure allowed the engineer to use whatever amount of outdoor air he deemed necessary if he could show that the levels of indoor air contaminants were held below recommended limits. However, some of the users of Standard 62-1981 found the application of the different ventilation rates for smoking and nonsmoking areas confusing, and the recommended maximum concentration of formaldehyde was challenged. For these reasons and in the light of rapidly changing technology, ASHRAE authorized an early review of Standard 62-1981 beginning in January 1983.

This revised Standard retains the two procedures for ventilation design, the Ventilation Rate Procedure and the Air Quality Procedure. The goals of achieving acceptable indoor air quality and of minimizing energy consumption appear to imply a compromise. An interdisciplinary committee of engineers, architects, chemists, physiologists, product manufacturers, and industry representatives has endeavored to achieve the necessary balance between energy consumption and indoor air quality in this Standard. It must be recognized, however, that the conditions specified by this Standard must be achieved during the operation of buildings as well as in the design of the buildings if acceptable indoor air quality is to be achieved. To facilitate this, the Standard includes requirements for ventilation design documentation to be provided for system operation. The purpose of the Standard is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects. For substantive information on health effects, the Standard must rely on recognized authorities and their specific recommendations. Therefore, with respect to tobacco smoke and other contaminants, this Standard does not, and cannot, ensure the avoidance of all possible adverse health effects, but it reflects recognized consensus criteria and guidance.

The Appendices are not part of this standard but are included for information purposes only.

Upon publication of this revised standard, an addendum process will be initiated to update references to other standards and government publications.

References

i. *ASHRAE Standard 62-73 (ANSI B 194.1-1977), Standards for Natural and Mechanical Ventilation.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA. 1977.

ii. *ASHRAE Standard 90-75, Energy Conservation in New Building Design.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA. 1975.

iii. *ANSI/ASHRAE/IES Standard 90A-1980, Energy Conservation in New Building Design.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA. 1980.

iv. *ASHRAE Standard 62-1981, Ventilation for Acceptable Indoor Air Quality.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA. 1981.

1. PURPOSE

To specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to avoid adverse health effects.

2. SCOPE

This Standard applies to all indoor or enclosed spaces that people may occupy, except where other applicable standards and requirements dictate larger amounts of ventilation than this Standard. Release of moisture in residential kitchens and bathrooms, locker rooms, and swimming pools is included in the scope of this Standard.

3. DEFINITIONS (see Fig. 1)

absorption: the process of one substance entering into the inner structure of another.

acceptable indoor air quality: air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction.

adsorption: the adhesion of a thin film of liquid or gases to the surface of a solid substance.

air-cleaning system: a device or combination of devices applied to reduce the concentration of airborne contaminants, such as microorganisms, dusts, fumes, respirable particles, other particulate matter, gases, and/or vapors in air.

air conditioning: the process of treating air to meet the requirements of a conditioned space by controlling its temperature, humidity, cleanliness, and distribution.

air, ambient: the air surrounding an object.

air, exhaust: air removed from a space and not reused therein.

air, makeup: outdoor air supplied to replace exhaust air and exfiltration.

air, outdoor: air taken from the external atmosphere and, therefore, not previously circulated through the system.

air, recirculated: air removed from the conditioned space and intended for reuse as supply air.

air, return: air removed from a space to be then recirculated or exhausted.

air, supply: that air delivered to the conditioned space and used for ventilation, heating, cooling, humidification, or dehumidification.

air, transfer: the movement of indoor air from one space to another.

air, ventilation: that portion of supply air that is outdoor air plus any recirculated air that has been treated for the purpose of maintaining acceptable indoor air quality.

chemisorb: to take up and hold, usually irreversibly, by chemical forces.

concentration: the quantity of one constituent dispersed in a defined amount of another (see Appendix A).

conditioned space: that part of a building that is heated or cooled, or both, for the comfort of occupants.

contaminant: an unwanted airborne constituent that may reduce acceptability of the air.

dust: an air suspension of particles (aerosol) of any solid material, usually with particle size less than 100 micrometers (μm).

energy recovery ventilation system: a device or combination of devices applied to provide the outdoor air for ventilation in which energy is transferred between the intake and exhaust airstreams.

exfiltration: air leakage outward through cracks and interstices and through ceilings, floors, and walls of a space or building.

fumes: airborne particles, usually less than 1 micrometer in size, formed by condensation of vapors, sublimation, distillation, calcination, or chemical reaction.

gas: a state of matter in which substances exist in the form of nonaggregated molecules, and which, within acceptable limits of accuracy, satisfies the ideal gas laws; usually a highly superheated vapor.

infiltration: air leakage inward through cracks and interstices and through ceilings, floors, and walls of a space or building.

microorganism: a microscopic organism, especially a bacterium, fungus, or a protozoan.

natural ventilation: the movement of outdoor air into a space through intentionally provided openings, such as windows and doors, or through nonpowered ventilators or by infiltration.

occupied zone: the region within an occupied space between planes 3 and 72 in. (75 and 1800 mm) above the floor and more than 2 ft (600 mm) from the walls or fixed air-conditioning equipment (see ASHRAE Standard 55-1981, Ref.1)

odor: a quality of gases, liquids, or particles that stimulates the olfactory organ.

oxidation: a reaction in which oxygen combines with another substance.

particulate matter: a state of matter in which solid or liquid substances exist in the form of aggregated molecules or particles. Airborne particulate matter is typically in the size range of 0.01 to 100 micrometers.

plug flow: a flow regime where the flow is predominately in one direction and contaminants are swept along with the flow.

smoke: the airborne solid and liquid particles and gases that evolve when a material undergoes pyrolysis or combustion. Note: chemical smoke is excluded from this definition.

total suspended particulate matter: the mass of particles suspended in a unit of volume of air when collected by a high-volume air sampler.

respirable particles: respirable particles are those that penetrate into and are deposited in the nonciliated portion

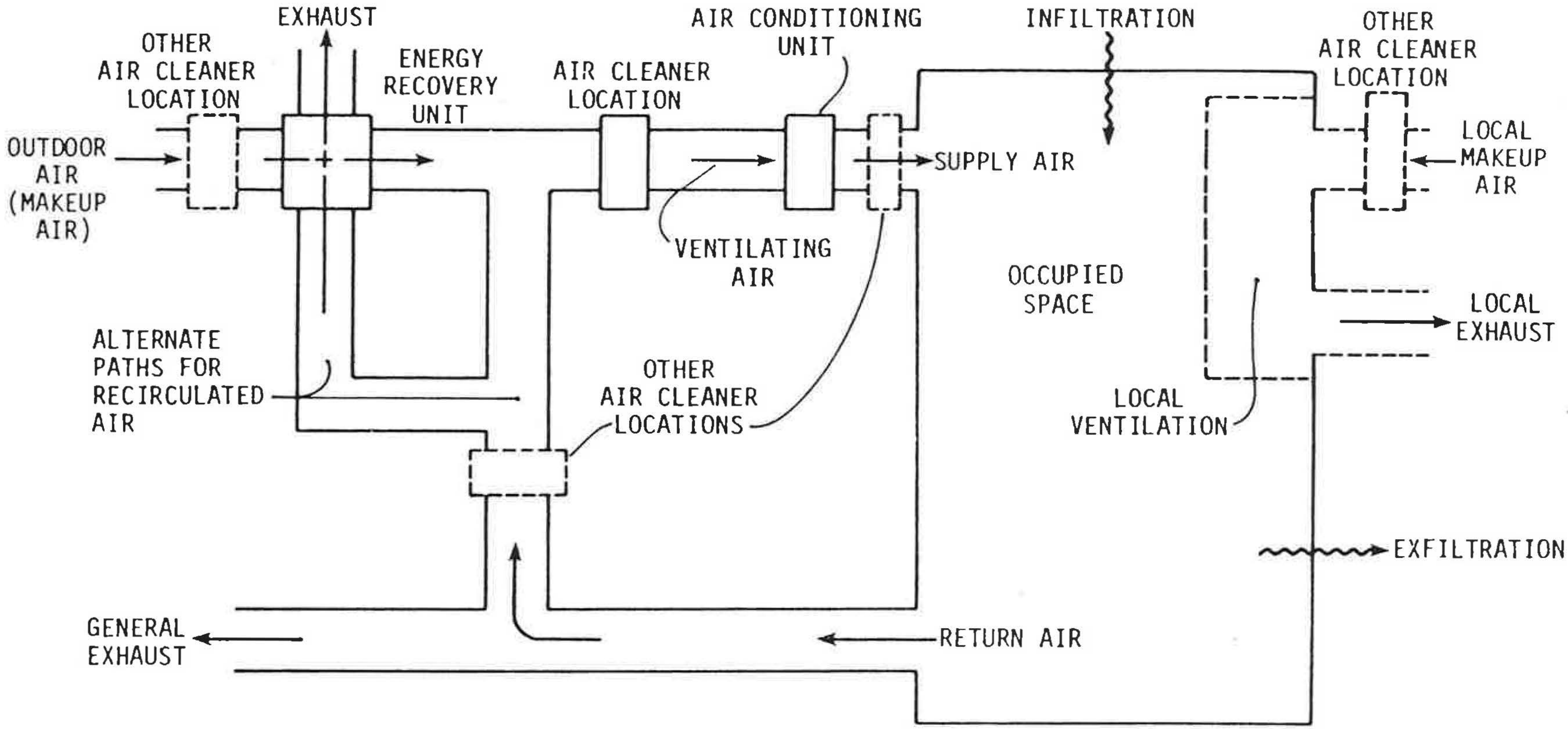

Fig. 1 Ventilation System

of the lung. Particles greater than 10 micrometers aerodynamic diameter are not respirable.

vapor: a substance in gas form, particularly one near equilibrium with its condensed phase, which does not obey the ideal gas laws; in general, any gas below its critical temperature.

ventilation: the process of supplying and removing air by natural or mechanical means to and from any space. Such air may or may not be conditioned.

4. CLASSIFICATION

This Standard specifies alternative procedures to obtain acceptable air quality indoors:

4.1 Ventilation Rate Procedure: Acceptable air quality is achieved by providing ventilation air of the specified quality and quantity to the space (see 6.1). or

4.2 Indoor Air Quality Procedure: Acceptable air quality is achieved within the space by controlling known and specifiable contaminants (see 6.2).

Whenever the Ventilation Rate Procedure is used, the design documentation should clearly state that this method was used and that the design will need to be re-evaluated if, at a later time, space use changes occur or if unusual contaminants or unusually strong sources of specific contaminants are to be introduced into the space. If such conditions are known at the time of the original design, the use of the Indoor Air Quality Procedure may be indicated.

The Indoor Air Quality Procedure could result in a ventilation rate lower than would result from the first procedure, but the presence of a particular source of contamination in the space may result in increased ventilation requirements. Change in space use, contaminants, or operation may require a re-evaluation of the design and implementation of needed changes.

5. SYSTEMS AND EQUIPMENT

5.1 Ventilating systems may be mechanical or natural. When mechanical ventilation is used, provision for air flow measurement should be included. When natural ventilation and infiltration are relied upon, sufficient ventilation shall be demonstrable. When infiltration and natural ventilation are insufficient to meet ventilation air requirements, mechanical ventilation shall be provided. The use of energy recovery ventilation systems should be considered for energy conservation purposes in meeting ventilation requirements.

5.2 Ventilating systems shall be designed and installed so that the ventilation air is supplied throughout the occupied zone. The design documentation shall state assumptions that were made in the design with respect to ventilation rates and air distribution.

5.3 Ventilating systems shall be designed and installed so that they do not cause conditions that conflict with ASHRAE Standard 55-1981, "Thermal Environmental Conditions for Human Occupancy" (Ref. 1).

5.4 When the supply of air is reduced during times the space is occupied (e.g., in variable-air-volume systems), provision shall be made to maintain acceptable indoor air quality throughout the occupied zone.

5.5 Ventilating systems should be designed to prevent reentrainment of exhaust contaminants, condensation or freeze-ups (or both), and growth of microorganisms. Makeup air inlets and exhaust air outlets shall be located to avoid contamination of the makeup air. Contaminants from sources such as cooling towers, sanitary vents, vehicular exhaust from parking garages, loading docks, and street traffic should be avoided. This is a special problem in buildings where stack effect draws contaminants from these areas into the occupant space. Where soils contain high concentrations of radon, ventilation practices that place crawlspaces, basements, or underground ductwork below atmospheric pressure will tend to increase radon concentrations in buildings and should be avoided (see Appendix C).

5.6 Ventilating ducts and plenums shall be constructed and maintained to minimize the opportunity for growth and dissemination of microorganisms through the ventilation system. Construction also shall comply with applicable standards such as NFPA 90A, 90B, and SMACNA (Refs. 2-6).

5.7 Contaminants from stationary local sources within the space shall be controlled by collection and removal as close to the source as practicable. (See Ref 7, "Industrial Ventilation—Manual of Recommended Practice.")

5.8 Fuel-burning appliances, including fireplaces located indoors, shall be provided with sufficient air for combustion and adequate removal of combustion products. When infiltration supplies all or part of the combustion air, the supply rate of air shall be demonstrable (Appendix B shows one method of demonstrating adequate combustion air). The operation of clothes dryers and exhaust fans may require introduction of additional makeup air to avoid interference with fuel-burning appliances. Combustion system, kitchen, bathroom, and clothes dryer vents shall not be exhausted into attics, crawlspaces, or basements.

5.9 Airborne particulate contaminants vary in size, as shown in Fig. 2. Microorganisms, dusts, fumes, smoke, and other particulate matter may be captured by air filters. Many bacteria (99% exceed 1 micrometer in size) are attached to larger particles such as human skin flakes. Viruses generally occur in clusters or in and on other particles. Lung-damaging particles that may be retained in the lungs are 0.2 to 5 micrometers in size (see Fig. 2). When it is necessary to remove particulate contaminants, air filters or dust collectors should be used. Dust collectors, not air filters, should be used where the dust loading equals or exceeds 10 mg/m^3 (4 grains/1000 ft^3). Air filters and dust collectors shall be selected for the particle size and loading encountered. Filters shall be tested in accordance with ASHRAE Standard 52-76 (Ref 8) or MIL Std 282 (Ref 9). Dust collectors may be wet, dry, or electrostatic as required by particle size and loading (see Table 1, Chapter 11, *ASHRAE Handbook—1983 Equipment Volume* (Ref 10).

5.10 When compliance with this section does not provide adequate control of gaseous contaminants, methods based on sorption with or without oxidation or other scientifically proven technology shall be used. Such methods may be tailored to deal with a specific contaminant. A commonly used sorbent is activated carbon. The selection of gaseous contaminant control equipment for recirculation systems must consider the concentration, toxicity, annoyance, and odor properties of the contaminants present and the levels to which these must be reduced to be effective in maintaining air quality. The performance of gaseous contaminant removal devices often depends strongly on the physical and chemical properties of the individual contaminants present, on the temperature and humidity of the air, on the air velocity through the device, and its loading capacity.

5.11 High humidities can support the growth of pathogenic or allergenic organisms (see Ref 20). Examples include certain species of fungi, associated mycotoxins, and dust mites. This growth is enhanced by the presence of materials with high cellulose, even with low nitrogen content, such as fiberboard, dust, lint, skin particles, and dander. Areas of concern include bathrooms and bedrooms. Therefore, bathrooms shall conform to the ventilation rates in Table 2.3. Relative humidity in habitable spaces preferably should be maintained between 30% and 60% relative humidity (see Ref 11) to minimize growth of allergenic or pathogenic organisms.

5.12 Microbial contamination in buildings is often a function of moisture incursion from sources such as stagnant water in HVAC air distribution systems and cooling towers. Air-handling unit condensate pans shall be designed for self-drainage to preclude the buildup of microbial slime. Provision shall be made for periodic in-situ cleaning of cooling coils and condensate pans. Air-handling and fan coil units shall be easily accessible for inspection and preventive maintenance. Steam is preferred as a moisture source for humidifiers, but care should be exercised to avoid contamination from boiler water or steam supply additives. If cold water humidifiers are specified, the water shall originate from a potable source, and, if recirculated, the system will require frequent maintenance and blow-down. Care should be exercised to avoid particulate contamination due to evaporation of spray water. Standing water used in conjunction with water sprays in HVAC air distribution systems should be treated to avoid microbial buildup. If the

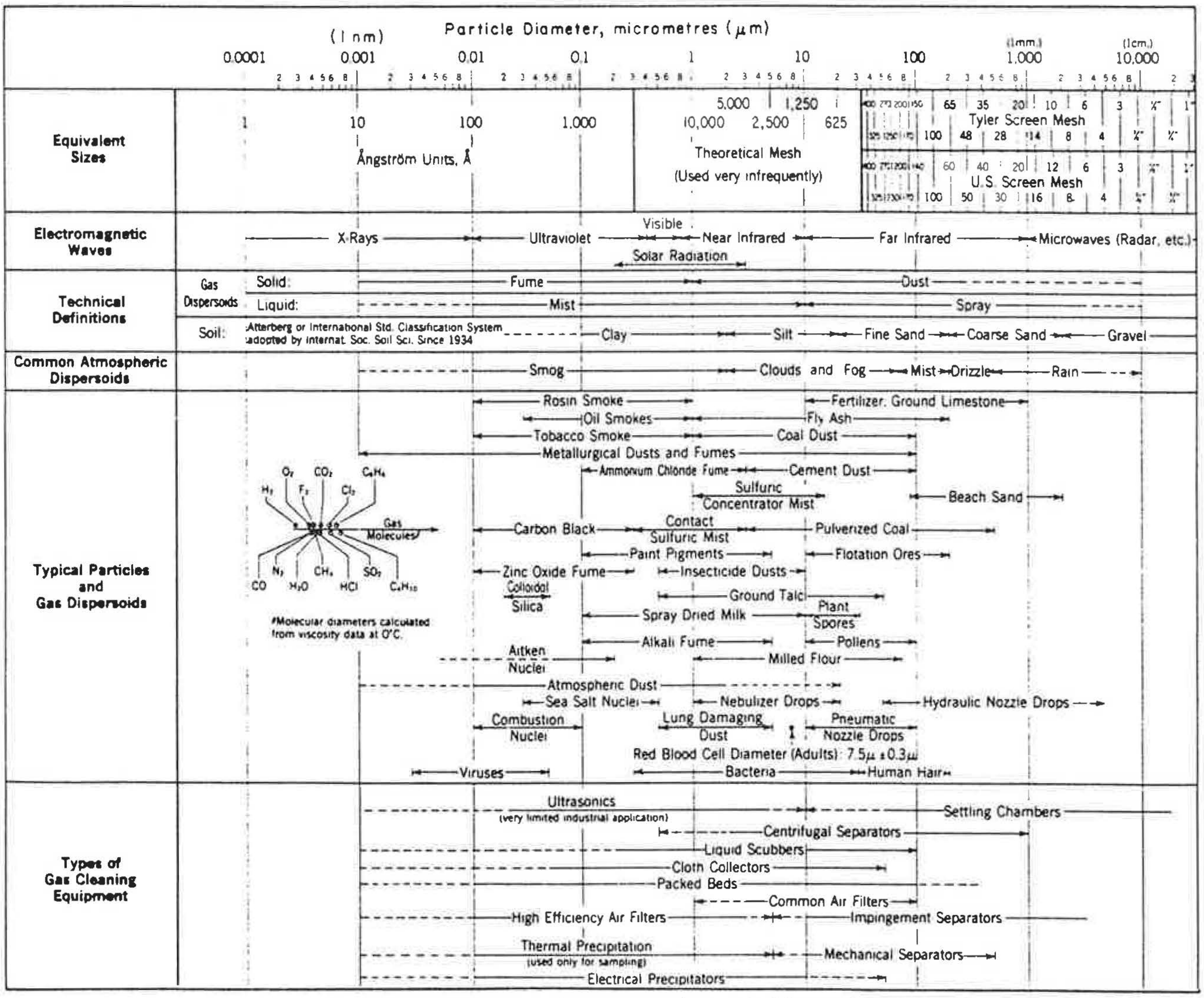

Fig. 2 Characteristics of Particles and Particle Dispersoids

Courtesy of Stanford Research Institute.

systems should be treated to avoid microbial buildup. If the relative humidity in occupied spaces and low velocity ducts and plenums exceeds 70%, fungal contamination (for example, mold, mildew, etc.) can occur. Special care should be taken to avoid entrainment of moisture drift from cooling towers into the makeup air and building vents.

6. PROCEDURES

Indoor air quality is a function of many parameters including outdoor air quality, the design of enclosed spaces, the design of the ventilation system, the way this system is operated and maintained, and the presence of sources of contaminants and the strength of such sources. This Standard deals with the design of a ventilation system as it is affected by all these factors, so that an acceptable level of indoor air quality can be provided. Design documentation shall clearly state which assumptions were used in the design so that the limits of the system in removing contaminants can be evaluated by others before the system is operated in a different mode or before new sources are introduced into the space.

Indoor air should not contain contaminants that exceed concentrations known to impair health or cause discomfort to occupants. Such contaminants include various gases, vapors, microorganisms, smoke, and other particulate matter. These may be present in makeup air or be introduced from indoor activities, furnishings, building materials, surface coatings, and air-handling and air treatment components. Deleterious factors include toxicity, radioactivity, potential to induce infection or allergies, irritants, extreme thermal conditions, and objectionable odors.

The Ventilation Rate Procedure (6.1) provides one way to achieve acceptable air quality. This procedure prescribes the rate at which ventilation air must be delivered to a space and various means to condition that air. The ventilation rates in Table 2 are derived from physiological considerations, subjective evaluations, and professional judgments (see Refs 12-18).

The Indoor Air Quality Procedure (6.2) provides an alternative performance method for achieving acceptable air quality. This procedure uses one or more guidelines for the specification of acceptable concentrations of certain contaminants in indoor air but does not prescribe ventilation rates or air treatment methods.

TABLE 1
National Primary Ambient-Air Quality Standards for Outdoor Air as Set by the U.S. Environmental Protection Agency (Ref 19)

Contaminant	Long term: Concentration ug/m^3	Long term: Concentration ppm	Long term: Averaging	Short term: Concentration ug/m^3	Short term: Concentration ppm	Short term: Averaging
Sulfur dioxide	80	0.03	1 year	365	0.14	24 hours
Total Particulate	75[a]	—	1 year	260	—	24 hours
Carbon monoxide				40.000	35	1 hour
Carbon monoxide				10,000	9	8 hours
Oxidants (ozone)				235[b]	0.12[b]	1 hour
Nitrogen dioxide	100	0.055	1 year			
Lead	1.5	—	3 months[c]			

[a] Arithmetic mean

[b] Standard is attained when expected number of days per calendar year with maximal hourly average concentrations above 0.12 ppm (235 ug/m^3) is equal to or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50

[c] Three-month period is a calendar quarter.

6.1 Ventilation Rate Procedure:

This procedure prescribes:

- the outdoor air quality acceptable for ventilation
- outdoor air treatment when necessary
- ventilation rates for residential, commercial, institutional, vehicular, and industrial spaces
- criteria for reduction of outdoor air quantities when recirculated air is treated by contaminant-removal equipment
- criteria for variable ventilation when the air volume in the space can be used as a reservoir to dilute contaminants.

6.1.1 Acceptable Outdoor Air. This section describes a three-step procedure by which outdoor air shall be evaluated for acceptability:

Step 1: Contaminants in outdoor air do not exceed the concentrations listed in Table 1 as determined by one of the following conditions:

(a) Monitoring data of government pollution-control agencies, such as the U.S. Environmental Protection Agency (EPA) or equivalent state or local environmental protection authorities, show that the air quality of the area in which the ventilating system is located meets the requirements of Table 1. Conformity of local air to these standards may be determined by reference to the records of local authorities or of the National Aerometric Data Bank, Office of Air Quality Planning and Standards, EPA, Research Triangle Park, NC 27711, or

(b) The ventilating system is located in a community similar in population, geographic and meteorological settings, and industrial pattern to a community having acceptable air quality as determined by authorities having jurisdiction, or

(c) The ventilating system is located in a community with a population of less than 20,000 people, and the air is not influenced by one or more sources that cause substantial contamination, or

(d) Air monitoring for three consecutive months, as required for inclusion in the National Aerometric Data Bank, shows that the air quality meets or exceeds the requirements of Table 1 (as specified in Ref 19).

Step 2: If the outdoor air is thought to contain any contaminants not listed in Table 1, guidance on acceptable concentration levels may be obtained by reference to Appendix C.

Outdoor air requirements for ventilation of industrial building occupancies not listed in Table 2 may be determined by procedures presented in *1986 Industrial Ventilation—A Manual of Recommended Practice*, 1986 ed., published by the American Conference of Governmental Industrial Hygienists (ACGIH) (Ref 7).

Step 3: If after completing steps 1 and 2 there is still a reasonable expectation that the air is unacceptable, sampling shall be conducted in accordance with NIOSH pro-

TABLE 2
OUTDOOR AIR REQUIREMENTS FOR VENTILATION*
2.1 COMMERCIAL FACILITIES (offices, stores, shops, hotels, sports facilities)

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements				Comments
		cfm/ person	L/s person	cfm/ ft²	L/s/ s·m²	
Dry Cleaners, Laundries						Dry-cleaning processes may require more air.
Commercial laundry	10	25	13			
Commercial dry cleaner	30	30	15			
Storage, pick up	30	35	18			
Coin-operated laundries	20	15	8			
Coin-operated dry cleaner	20	15	8			
Food and Beverage Service						
Dining rooms	70	20	10			
Cafeteria, fast food	100	20	10			
Bars, cocktail lounges	100	30	15			Supplementary smoke-removal equipment may be required.
Kitchens (cooking)	20	15	8			Makeup air for hood exhaust may require more ventilating air. The sum of the outdoor air and transfer air of acceptable quality from adjacent spaces shall be sufficient to provide an exhaust rate of not less than 1.5 cfm/ft² (7.5 L/s·m²).
Garages, Repair, Service Stations						
Enclosed parking garage				1.50	7.5	Distribution among people must consider worker location and concentration of running engines; stands where engines are run must incorporate systems for positive engine exhaust withdrawal. Contaminant sensors may be used to control ventilation.
Auto repair rooms				1.50	7.50	
Hotels, Motels, Resorts, Dormitories				cfm/room	L/s-room	Independent of room size.
Bedrooms				30	15	
Living rooms				30	15	
Baths				35	18	Installed capacity for intermittent use.
Lobbies	30	15	8			
Conference rooms	50	20	10			
Assembly rooms	120	15	8			
Dormitory sleeping areas	20	15	8			See also food and beverage services, merchandising, barber and beauty shops, garages.
Gambling casinos	120	30	15			Supplementary smoke-removal equipment may be required.
Offices						
Office space	7	20	10			Some office equipment may require local exhaust.
Reception areas	60	15	8			
Telecommunication centers and data entry areas	60	20	10			
Conference rooms	50	20	10			Supplementary smoke-removal equipment may be required.
Public Spaces						
Corridors and utilities				0.05	0.25	
Public restrooms, cfm/wc or urinal		50	25			Mechanical exhaust with no recirculation is recommended.
Locker and dressing rooms				0.5	2.5	
Smoking lounge	70	60	30			Normally supplied by transfer air, local mechanical exhaust; with no recirculation recommended.
Elevators				1.00	5.00	Normally supplied by transfer air.

* Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to control CO_2 and other contaminants with an adequate margin of safety and to account for health variations among people, varied activity levels, and a moderate amount of smoking. Rational of CO_2 control is presented in Appendix D.

**Net occupiable space.

cedures (see Refs 21 and 22). Local and national aerometric data banks may contain information on some unregulated pollutants. Finally, acceptable outdoor air quality should be evaluated using the definition for acceptable indoor air quality in Section 3.

TABLE 2
OUTDOOR AIR REQUIREMENTS FOR VENTILATION* (*Continued*)
2.1 COMMERCIAL FACILITIES (offices, stores, shops, hotels, sports facilities)

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements cfm/ person	L/s person	cfm/ ft²	L/s · m²	Comments
Retail Stores, Sales Floors, and Show Room Floors						
Basement and street	30			0.30	1.50	
Upper floors	20			0.20	1.00	
Storage rooms	15			0.15	0.75	
Dressing rooms				0.20	1.00	
Malls and arcades	20			0.20	1.00	
Shipping and receiving	10			0.15	0.75	
Warehouses	5			0.05	0.25	
Smoking lounge	70	60	30			Normally supplied by transfer air, local mechanical exhaust; exhaust with no recirculation recommended.
Specialty Shops						
Barber	25	15	8			
Beauty	25	25	13			
Reducing salons	20	15	8			
Florists	8	15	8			Ventilation to optimize plant growth may dictate requirements.
Clothiers, furniture				0.30	1.50	
Hardware, drugs, fabric	8	15	8			
Supermarkets	8	15	8			
Pet shops				1.00	5.00	
Sports and Amusement						
Spectator areas	150	15	8			When internal combustion engines are operated for maintenance of playing surfaces, increased ventilation rates may be required.
Game rooms	70	25	13			
Ice arenas (playing areas)				0.50	2.50	
Swimming pools (pool and deck area)				0.50	2.50	Higher values may be required for humidity control.
Playing floors (gymnasium)	30	20	10			
Ballrooms and discos	100	25	13			
Bowling alleys (seating areas)	70	25	13			
Theaters						Special ventilation will be needed to eliminate special stage effects (e.g., dry ice vapors, mists, etc.)
Ticket booths	60	20	10			
Lobbies	150	20	10			
Auditorium	150	15	8			
Stages, studios	70	15	8			
Transportation						Ventilation within vehicles may require special considerations.
Waiting rooms	100	15	8			
Platforms	100	15	8			
Vehicles	150	15	8			
Workrooms						
Meat processing	10	15	8			Spaces maintained at low temperatures (−10 °F to + 50 °F, or −23 °C to + 10 °C) are not covered by these requirements unless the occupancy is continuous. Ventilation from adjoining spaces is permissible. When the occupancy is intermittent, infiltration will normally exceed the ventilation requirement. (See Ref 18).

* Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to control CO_2 and other contaminants with an adequate margin of safety and to account for health variations among people, varied activity levels, and a moderate amount of smoking. Rational of CO_2 control is presented in Appendix D.
**Net occupiable space.

6.1.2 Outdoor Air Treatment. If the outdoor air contaminant levels exceed the values given in 6.1.1 (Table 1), the air should be treated to control the offending contaminants. Air-cleaning systems suitable for the particle size encountered should be used. For removal of gases and vapors, appropriate air-cleaning systems should be used. Where the best available, demonstrated, and proven technology does not allow for the removal of contaminants, the amount of outdoor air may be reduced during periods of high contaminant levels, such as those generated by rush-hour

TABLE 2
OUTDOOR AIR REQUIREMENTS FOR VENTILATION* (*Concluded*)
2.1 COMMERCIAL FACILITIES (offices, stores, shops, hotels, sports facilities)

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	Outdoor Air Requirements cfm/ person	L/s person	cfm/ ft²	L/s/ s·m²	Comments
Photo studios	10	15	8			
Darkrooms	10			0.50	2.50	
Pharmacy	20	15	8			
Bank vaults	5	15	8			
Duplicating, printing				0.50	2.50	Installed equipment must incorporate positive exhaust and control (as required) of undesirable contaminants (toxic or otherwise).

2.2 INSTITUTIONAL FACILITIES

Application	Estimated Maximum** Occupancy P/1000 ft² or 100 m²	cfm/ person	L/s person	cfm/ ft²	L/s/ s·m²	Comments
Education						
Classroom	50	15	8			
Laboratories	30	20	10			Special contaminant control systems may be required for processes or functions including laboratory animal occupancy.
Training shop	30	20	10			
Music rooms	50	15	8			
Libraries	20	15	8			
Locker rooms				0.50	2.50	
Corridors				0.10	0.50	
Auditoriums	150	15	8			
Smoking lounges	70	60	30			Normally supplied by transfer air. Local mechanical exhaust with no recirculation recommended.
Hospitals, Nursing and Convalescent Homes						
Patient rooms	10	25	13			Special requirements or codes and pressure relationships may determine minimum ventilation rates and filter efficiency. Procedures generating contaminants may require higher rates.
Medical procedure	20	15	8			
Operating rooms	20	30	15			
Recovery and ICU	20	15	8			
Autopsy rooms				0.50	2.50	Air shall not be recirculated into other spaces.
Physical Therapy	20	15	8			
Correctional Facilities						
Cells	20	20	10			
Dining halls	100	15	8			
Guard stations	40	15	8			

* Table 2 prescribes supply rates of acceptable outdoor air required for acceptable indoor air quality. These values have been chosen to control CO_2 and other contaminants with an adequate margin of safety and to account for health variations among people, varied activity levels, and a moderate amount of smoking. Rationale for CO_2 control is presented in Appendix D.
**Net occupiable space.

traffic. The need to control offending contaminants may depend on local regulations that require specific control measures.

6.1.3 Ventilation Requirements. Indoor air quality shall be considered acceptable if the required rates of acceptable outdoor air in Table 2 are provided for the occupied space.

Exceptions:

1. Where unusual indoor contaminants or sources are present or anticipated, they shall be controlled at the source or the procedure of 6.2 shall be followed.

2. For those areas within industrial facilities not covered by Table 2, refer to footnote 15 of *Threshold Limit Values and Biological Exposure Indices for 1986-87*, American Conference of Governmental Industrial Hygienists (Ref 23).

Table 2 lists the required ventilation rates in cfm (L/s) per person or cfm/ft² (L/s·m²) for a variety of indoor spaces. In most cases, the contamination produced is presumed to be in proportion to the number of persons in the space. In other cases, the contamination is presumed to be chiefly due to other factors and the ventilating rates given are based on more appropriate parameters. Where appropriate, the table lists the estimated density of people for design purposes.

Where occupant density differs from that in Table 2, use the per occupant ventilation rate for the anticipated occupancy load. The ventilation rates for specified occupied spaces listed in Table 2 were selected to reflect the consensus that the provision of acceptable outdoor air at these rates would achieve an acceptable level of indoor air quality by reasonably controlling CO_2, particulates, odors, and other contaminants common to those spaces. (Appendix D shows the outdoor air needed to control occupant-generated CO_2 under various conditions.)

Human occupants produce carbon dioxide, water vapor, particulates, biological aerosols, and other contaminants. Carbon dioxide concentration has been widely used as an indicator of indoor air quality. Comfort (odor) criteria are likely to be satisfied if the ventilation rate is

TABLE 2.3[a]
OUTDOOR REQUIREMENTS FOR VENTILATION OF RESIDENTIAL FACILITIES
(Private Dwellings, Single, Multiple)

Applications	Outdoor Requirements	Comments
Living areas	0.35 air changes per hour but not less than 15 cfm (7.5 L/s) per person	For calculating the air changes per hour, the volume of the living spaces shall include all areas within the conditioned space. The ventilation is normally satisfied by infiltration and natural ventilation. Dwellings with tight enclosures may require supplemental ventilation supply for fuel-burning appliances, including fireplaces and mechanically exhausted appliances. Occupant loading shall be based on the number of bedrooms as follows: first bedroom, two persons; each additional bedroom, one person. Where higher occupant loadings are known, they shall be used.
Kitchens[b]	100 cfm (50 L/s) intermittent or 25 cfm (12 L/s) continuous or openable windows	Installed mechanical exhaust capacity[c]. Climatic conditions may affect choice of the ventilation system.
Baths, Toilets[b]	50 cfm (25 L/s) intermittent or 20 cfm (10 L/s) continuous or openable windows	Installed mechanical exhaust capacity[c]
Garages: Separate for each dwelling unit	100 cfm (50 L/s) per car	Normally satisfied by infiltration or natural ventilation
Common for several units	1.5 cfm/ft² (7.5 L/s/ft²)	See "Enclosed parking garages," Table 2.1

[a] In using this table, the outdoor air is assumed to be acceptable.
[b] Climatic conditions may affect choice of ventilation option chosen.
[c] The air exhausted from kitchens, bath, and toilet rooms may utilize air supplied through adjacent living areas to compensate for the air exhausted. The air supplied shall meet the requirements of exhaust systems as described in 5.8 and be of sufficient quantities to meet the requirements of this table.

set so that 1000 ppm CO_2 is not exceeded. In the event CO_2 is controlled by any method other than dilution, the effects of possible elevation of other contaminants must be considered (see Refs 12-18).

6.1.3.1 Multiple Spaces. Where more than one space is served by a common supply system, the ratio of outdoor to supply air required to satisfy the ventilation and thermal control requirements may differ from space to space. The system outdoor air quantity shall then be determined using Equation 6-1 (see Refs 24 and 25).

$$Y = X/[1 + X - Z] \qquad (6\text{-}1)$$

where

$Y = V_{ot}/V_{st}$ = corrected fraction of outdoor air in system supply

$X = V_{on}/V_{st}$ = uncorrected fraction of outdoor air in system supply

$Z = V_{oc}/V_{sc}$ = fraction of outdoor air in critical space. The critical space is that space with the greatest required fraction of outdoor air in the supply to this space.

V_{ot} = corrected total outdoor air flow rate

V_{st} = total supply flow rate, i.e., the sum of all supply for all branches of the system

V_{on} = sum of outdoor air flow rates for all branches on system

V_{oc} = outdoor air flow rate required in critical spaces

V_{sc} = supply flow rate in critical space

Equation 6-1 is plotted in Fig. 3. The procedure is as follows:

1. Calculate the uncorrected outdoor air fraction by dividing the sum of all the branch outdoor air requirements by the sum of all the branch supply flow rates.

2. Calculate the critical space outdoor air fraction by dividing the critical space outdoor air requirement by the critical space supply flow rate.

3. Evaluate Equation 6-1 or use Fig. 3 to find the corrected fraction of outdoor air to be provided in the system supply.

Rooms provided with exhaust air systems, such as kitchens, baths, toilet rooms, and smoking lounges, may utilize air supplied through adjacent habitable or occupiable spaces to compensate for the air exhausted. The air supplied shall be of sufficient quantity to meet the requirements of Table 2. In some cases, the number of persons cannot be estimated accurately or varies considerably. In other cases, a space may require ventilation to remove contamination generated within the space but unrelated to human occupancy (e.g., outgassing from building materials or furnishings). For these cases, Table 2 lists quantities in cfm/ft² (L/s·m²) or an equivalent term. If human carcinogens or other harmful contaminants are suspected to be present in the occupied space, other relevant standards or guidelines (e.g., OSHA, EPA) must supersede the ventilation rate procedure.

When spaces are unoccupied, ventilation is not generally required unless it is needed to prevent accumulation of contaminants injurious to people, contents, or structure. Design documentation shall specify all significant assumptions about occupants and contaminants.

6.1.3.2 Recirculation Criteria. The requirements for ventilation air quantities given in Table 2 are for 100% outdoor air when the outdoor air quality meets the specifications for acceptable outdoor air quality given in 6.1.1. While these quantities are for 100% outdoor air, they also set the amount of air required to dilute contaminants to acceptable levels. Therefore, it is necessary that at least this amount of air be delivered to the conditioned space at all times the building is in use except as modified in 6.1.3.4.

Properly cleaned air may be recirculated. Under the ventilation rate procedure, for other than intermittent variable occupancy as defined in 6.1.3.4, outdoor air flow rates may not be reduced below the requirements in Table 2. If cleaned, recirculated air is used to reduce the outdoor air flow rate below the values shown in Table 2, the Air Quality Procedure, 6.2, must be used. The air-cleaning system for the recirculated air may be located in the recirculated air or in the mixed outdoor and recirculated airstream (see Fig. 1).

The recirculation rate for the system is determined by the air-cleaning system efficiency. The recirculation rate must be increased to achieve full benefit of the air-cleaning system. The air-cleaning used to clean recirculated air should be designed to reduce particulate and, where necessary and feasible, gaseous contaminants. The system shall be capable of providing indoor air quality equivalent to that obtained using outdoor air at a rate specified in Table 2. Appendix E may be referenced for assistance in calculating the air flow requirements for commonly used air distribution systems.

6.1.3.3 Ventilation Effectiveness, Ev: Outdoor air for controlling contaminant concentration can be used for dilution or for sweeping the contaminants from their source. The values in Table 2 define the outdoor air needed in the occupied zone for well-mixed conditions (ventilation effectiveness approaches 100%). The ventilation effectiveness is defined by the fraction of the outdoor air delivered to the space that reaches the occupied space.

Ventilation effectiveness may be increased by creating a plug flow situation. If the flow pattern is such that the ventilation air flows past the contaminant source and sweeps the contaminant toward an exhaust, the contaminant concentration in the exhaust can be greater than that for the well-mixed condition. Ventilation effectiveness can then be greater than that which would be realized with perfect mixing. Local exhaust systems operate in this way. With perfect mixing between the ventilation air and the air in a space, ventilation effectiveness is 100%. With perfect mixing, Ev = 1.0. It is, however, not uncommon to find some of the ventilation air bypassing the occupants (moving from supply to exhaust without fully mixing in the occupied zone) and achieving Ev values as low as 0.5 (see Ref 26). Such flow conditions should be avoided. The ability of the ventilation air to mix in the occupied zone can be improved through recirculation or active mixing of the air in the space. Additional information about ventilation effectiveness can be found in Appendix F.

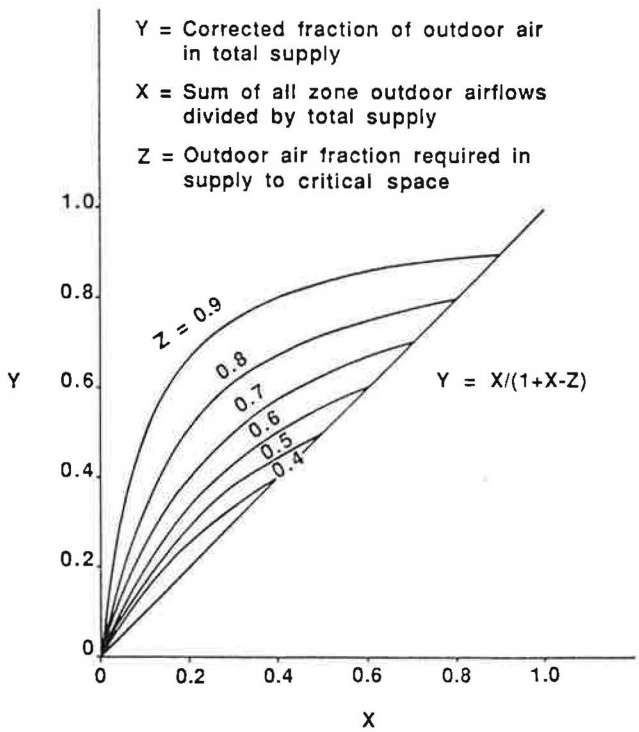

Fig. 3 Ventilation Reduction in Multiple Zones Supplied from a Common Source

6.1.3.4 Intermittent or variable occupancy. Ventilating systems for spaces with intermittent or variable occupancy may have their outdoor air quantity adjusted by use of dampers or by stopping and starting the fan system to provide sufficient dilution to maintain contaminant concentrations within acceptable levels at all times. Such system adjustment may lag or should lead occupancy depending on the source of contaminants and the variation in occupancy. When contaminants are associated only with occupants or their activities, do not present a short-term health hazard, and are dissipated during unoccupied periods to provide air equivalent to acceptable outdoor air, the supply of outdoor air may lag occupancy. When contaminants are generated in the space or the conditioning system independent of occupants or their activities, supply of outdoor air should lead occupancy so that acceptable conditions will exist at the start of occupancy. Figures 4 and 5 show lag or lead times needed to achieve acceptable conditions for transient occupancy (see Appendix G for rationale). Where peak occupancies of less than three hours duration occur, the outdoor air flow rate may be determined on the basis of average occupancy for buildings for the duration of operation of the system, provided the average occupancy used is not less than one-half the maximum. Caution should be exercised for spaces that are allowed to lag and may be affected, due to pressure differences, by contaminants entering from adjacent spaces, such as parking garages, restaurants, etc.

6.2 Indoor Air Quality Procedure: This procedure provides an alternative performance method to the Ventilation Rate Procedure for achieving acceptable air quality. The Ventilation Rate Procedure described in 6.1 is deemed to provide acceptable indoor air quality, ipso facto. Nevertheless, that procedure, through prescription of required ventilation rates, provides only an indirect solution to the control of indoor contaminants. The Indoor Air Quality Procedure provides a direct solution by restricting the concentration of all known contaminants of concern to some specified acceptable levels. It incorporates both quantitative and subjective evaluation.

6.2.1 Quantitative Evaluation. Table 1 furnishes information on acceptable contaminant levels in outdoor air. This table also applies indoors for the same exposure times. For additional information on contaminants in the outdoor air, see 6.1.1. Table 3 contains limits for four other indoor contaminants. Three of these are limits set by other bodies as indicated in the table. The limit for CO_2 was selected based on the rationale outlined in Appendix D. Other potential contaminants for which definite limits have not been set are discussed in Appendix C. Tables C-1 and C-3 do not include all known contaminants that may be of concern, and these concentration limits may not, ipso facto, ensure acceptable indoor air quality with respect to other contaminants.

Human occupants produce carbon dioxide, water vapor, particulates, biological aerosols, and other contaminants. Carbon dioxide concentration has been widely used as an indicator of indoor air quality. A limit of 1000 ppm CO_2 is recommended to satisfy comfort (odor) criteria. In the event CO_2 is controlled by any method other than dilution, the effects of the possible elevation of other contaminants must be considered.

In recent years a number of indoor contaminants have received increased attention and emphasis. Some of these contaminants, such as formaldehyde or other vapor phase organic compounds, are generated by the building, its contents, and its site. Another important group of contaminants is produced by unvented indoor combustion. The presence and use of consumer and hobby products, as well as cleaning and maintenance products, introduce a range of largely episodic releases of contaminants to the indoor environment (see Ref 30).

There are also complex mixtures, such as environmental tobacco smoke (see Ref 31), infectious and allergenic biologic aerosols, emanations from human bodies, and

PROCEDURE

a. Compute the air capacity per person in the space in ft^3 (m^3).
b. Find the required ventilation rate, in cfm (L/s) per person.
c. Enter Figure 2 with these values and read the maximum permissible ventilation lag time after occupancy from the intersection of a and b.

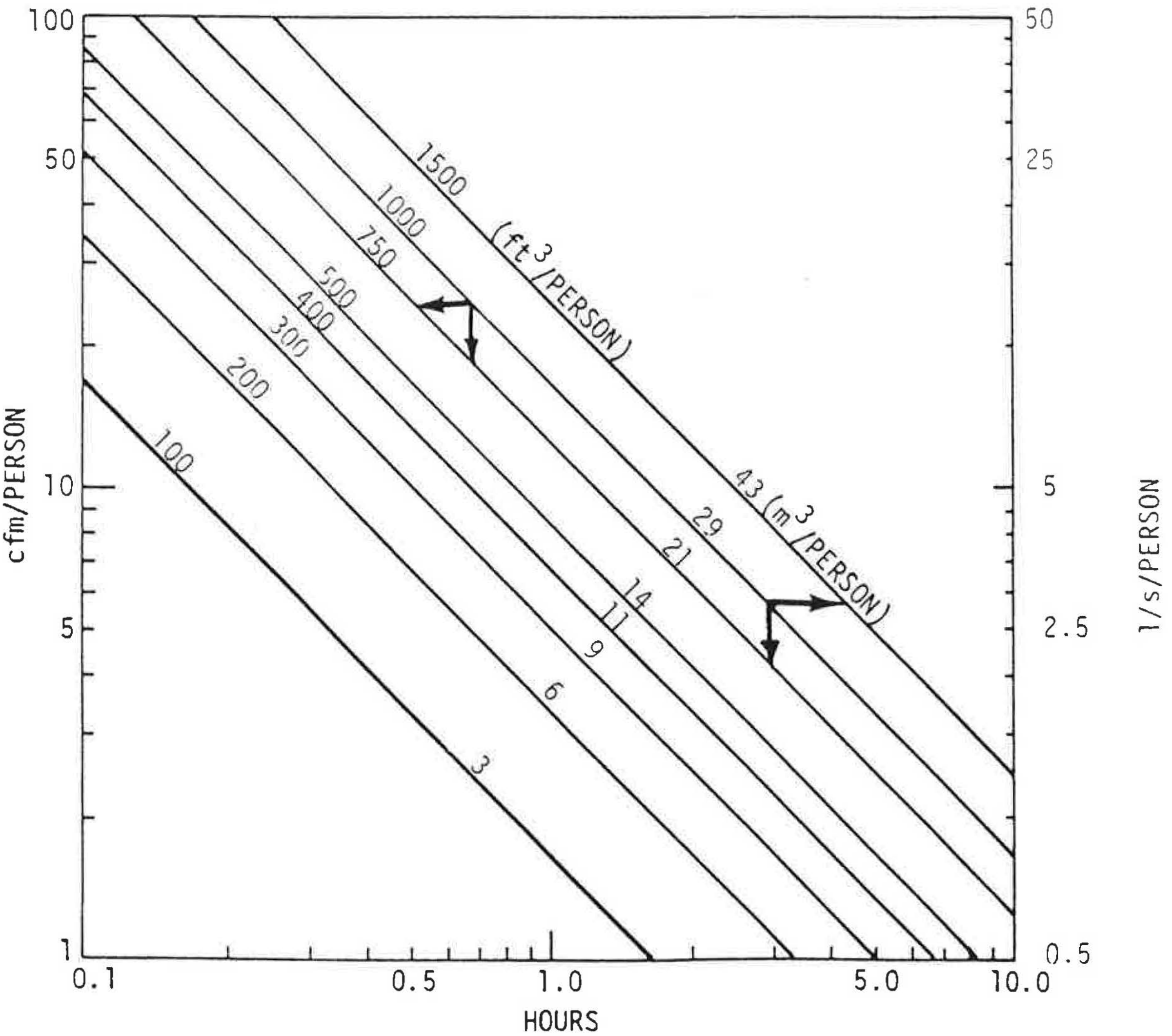

Fig. 4 Maximum Permissible Ventilation Lag Time

TABLE 3
GUIDELINES FOR SELECTED AIR CONTAMINANTS OF INDOOR ORIGIN

Contaminant	Concentration	ppm	Exposure Time	Comments
Carbon Dioxide	1.8 g/m³	1000*	Continuous	See Appendix D
Chlordane	5 ug/m³	0.0003	Continuous	Reference 27
Ozone	100 ug/m³	0.05	Continuous	Reference 28
Radon gas	0.027 WL		Annual Average	Reference 29, Paragraph 12.6 (background 0.002- 0.994WL)

*This level is not considered a health risk but is a surrogate for human comfort (odor). See Section 6.1.3 and Appendix D.

emanations from food preparation. Precise quantitative treatment of these contaminants can be difficult. To some degree, adequacy of control must rest upon subjective evaluation.

In the case of some odorless biologic aerosols, subjective evaluation is irrelevant. Application of generally acceptable technology, and vigilance regarding adverse influences of reduced ventilation, must therefore suffice. Appendix C contains information on standards and guidelines for selected air contaminants. Uniform governmental policies regarding limits on exposure to environmental carcinogens have not yet emerged.

PROCEDURE

a. Compute the air capacity per person in the space in ft³ (m³).
b. Find the required ventilation rate, in cfm (L/s) per person.
c. Enter Figure 3 with these values and read the minimum required ventilation lead time before occupancy from the intersection of a and b.

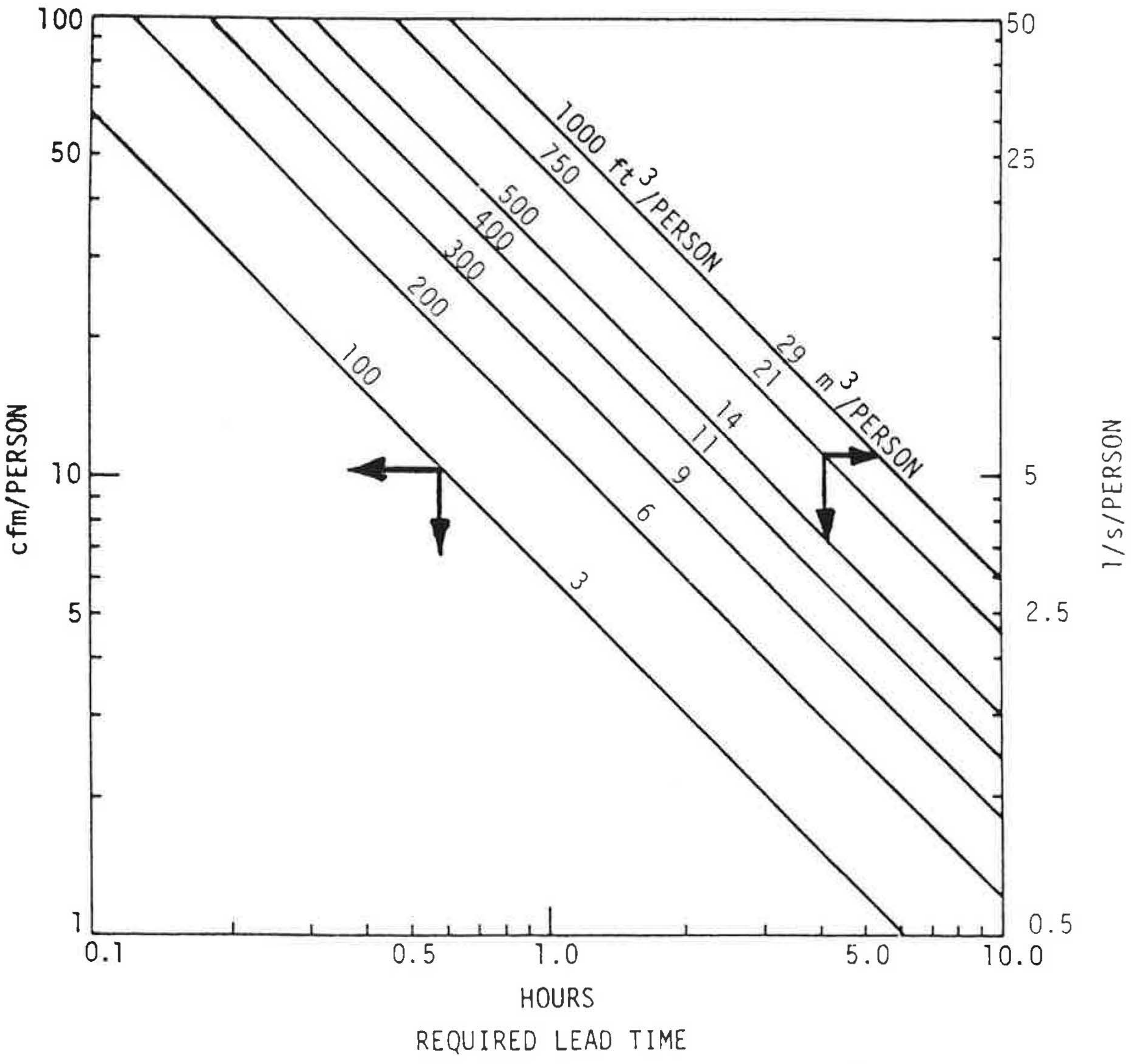

Fig. 5 Minimum Ventilation Time Required Before Occupancy of Space

6.2.2 Subjective Evaluation. Various indoor air contaminants may give rise to odor that is of unacceptable intensity or character or that irritates the eyes, nose, or throat. In the absence of objective means to assess the acceptability of such contaminants, the judgment of acceptability must necessarily derive from subjective evaluations of impartial observers. One method that may be used for measuring subjective response is described in Appendix C. Caution should be used in any subjective evaluation procedure to avoid unacceptable concentrations of other contaminants.

6.2.3 Air Cleaning. Recirculation criteria are defined in 6.1.3.2 for use with the Ventilation Rate Procedure. Recirculation with air-cleaning systems is also an effective means for controlling contaminants when using the Indoor Air Quality Procedure. The allowable contaminant concentration in the occupied zone can be used with the various system models in Appendix E to compute the required outdoor air flow rate. The air-cleaning system efficiency for the troublesome contaminants present, both gaseous and particulate, may be adequate to satisfy the Indoor Air Quality criteria of 6.2.1 and 6.2.2. However, contaminants that are not appreciably reduced by the air-cleaning system may be the controlling factor in design and prohibit the reduction of air below that set by the Ventilation Rate Procedure.

6.3 Design Documentation Procedures. Design criteria and assumptions shall be documented and should be made available for operation of the system within a reasonable time after installation. See Sections 4 and 6 as well as 5.2 and 6.1.3 regarding assumptions that should be detailed in the documentation.

7. REFERENCES

[1] *ANSI/ASHRAE Standard 55-1981, Environmental Conditions For Human Occupancy.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., Atlanta, GA. 30329. 1981.

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[9] U.S., Department of Defense. *MIL Standard 282 Filter Units, Protective Clothing, Gas-Masks.* Available from Global Engineering, Documents, P.O. Box 2504, 2625 Hickory St., Santa Ana, CA 92707.

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[20] Morey, P.R., W.G. Jones, J.L. Clere, and W.G. Sorenson. 1986. "Studies on sources of airborne microorganisms and on indoor air quality in a large office building. In *Managing Inddor Air for Health and Energy Conservation, Proceedings of the ASHRAE Conference IAQ '86,* pp. 500-509. Atlanta: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc.

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* Listed standards were referenced at the time of public review in September 1986. The users may wish to refer to more current issues of these referenced standards.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX A

CONVERSION FACTORS (A-1)

Parts per million and mass per unit volume

Measurement of airborne concentration of substances is generally converted to 77 °F (25 °C) and 29.92 in. Hg (760 mm Hg) pressure. Vapors or gases are often expressed as parts per million (ppm) by volume and are also frequently expressed in units of mass per unit volume, commonly in the following units:

milligram per cubic meter (mg/m^3); microgram per cubic meter ($\mu g/m^3$);
milligram per cubic foot (mg/ft^3); grains per cubic foot (gr/ft^3).

The ppm values may be converted to mass per unit volume values as follows:

ppm × molecular weight/24,450 = mg/L
ppm × molecular weight/0.02445 = $\mu g/m^3$
ppm × molecular weight/24.45 = mg/m^3
ppm × molecular weight × 28.3/24,450 = mg/ft^3
ppm × molecular weight × 28.3/64.8/24,450 = gr/ft^3

Airborne particle count concentrations measured in million particles per cubic foot (mppcf) or million particles per cubic meter (= particles per cubic centimeter, cc) can be converted approximately to mass per unit volume as follows when density and mass median diameter have not been determined:

mppcf × 6 (approximately) = mg/m^3
particles per cc × 210 (approximately) = mg/m^3

Units for Measuring Radon Progeny Concentrations and Exposures

Airborne concentrations of radon progeny, like radon itself, can be specified in picocuries per liter (pCi/L) or equivalent units. For radiation protection purposes, it has been useful to characterize radon progeny concentrations in terms of the total alpha energy emitted as a result of decay of the short-lived progeny (polonium 218 to polonium 214) to lead 210, a long-lived radionuclide. This "potential alpha energy concentration" (PAEC) is an indicator of potential dose to the lung, which, in turn, may be associated with increased lung cancer incidence on the basis of epidemiological studies (see Ref A-2) and other evidence.

The conventional unit for PAEC is the working level (WL), which has a value of 1.3×10^5 MeV/L, the potential alpha energyper unit volume that would be associated with air containing approximately 100 pCi/L of each of the short-lived progeny. For an arbitrary mixture with polonium 218 concentration (Ia), lead 214 concentration (Ib), and bismuth 214 concentration (Ic), the PAEC is approximately equal to (0.10 Ia + 0.51 Ib + 0.37 Ic) (WL/100, pCi/L). The associated exposure unit, working level month (WLM), is the exposure that an individual would experience remaining in 1 WL of progeny for 173 hours (an average working month).

If a volume were to have a constant source of radon and no mechanisms (other than radioactive decay) for removal of radon or its progeny from the enclosed air, the activity concentrations of each radionuclide (given in pCi/L) would eventually reach a state where all were numerically equal. Such a condition (referred to as "equilibrium") is never achieved in practice because of removal mechanisms such as ventilation and progeny "plateout." Ventilation both reduces the radon concentration and decreases the ratio of progeny to their parents below one. Plateout, the attachment of progeny to walls and other surfaces, also decreases this ratio.

The equilibrium condition of radon and its progeny is conventionally indicated by an "equilibrium factor" (F) that is the ratio of actual progeny PAEC to the PAEC were each offspring to have the same activity concentration as that of the radon actually present. Thus F = PAEC/(radon concentration/100), where the PAEC is given in WL and the radon concentration in pCi/L. In spaces with low progeny-removal rates, F is close to one. In houses, equilibrium factors have usually been found to lie in the range of 0.2 to 0.8, although factors above and below this range have sometimes been found. Taking 0.5 as a typical equilibrium factor, the annual exposure associated with a constant radon concentration of 1 pCi/L may be calculated as follows:

exposure rate for 1 pCi/L =

$$0.5\,(1\ \text{pCi/L})\left(\frac{1\ \text{WL}}{100\ \text{pCi/L}}\right)\left(\frac{1\ \text{WLM}}{1\ \text{WL} \times 173\ \text{h}}\right)\left(\frac{8760}{\text{year}}\right)$$

$$= 0.25\ \text{WLM/year}$$

References for Appendix A

A-1. *Conversion Units and Factors Relating to Atmospheric Analysis, Recommended practice for ASTM-D-1914-68.* American Society of Testing and Materials, 1916 Race Street, Philadelphia, PA 19103. 1983.

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This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX B

POSITIVE COMBUSTION AIR SUPPLY

Fuel-fired appliances equipped with an open draft hood for control of combustion chamber draft must exhibit a positive flow of air into the draft hood whenever combustion is present. Measurements is made when building infiltration is low, i.e., the inside-outside temperature difference should be no more than 30 °F (18 °C) and wind velocity is no more than 5 mph (2.2 m/s). Commonly used exhaust fans, such as kitchen and bathroom exhaust fans, should be turned on, and fireplaces that have no dedicated combustion air supply should be operated simultaneously with all external doors and windows closed. Flow of room air into the draft hood under these conditions must indicate a 40% dilution of the products of combustion going up the stack (see Ref B-1). The dilution ratio for products of combustion can be determined by measuring the room air temperature entering the draft hood, the stack temperature downstream from the draft hood, and the flue temperature at the combustion chamber outlet just upstream of the draft hood before the draft hood dilution air cools the flue gas. Then

$$(T_f - T_s)/(T_s - T_r) = 0.40$$

T_f = flue temperature
T_s = stack temperature
T_r = room temperature

If the stack temperature exceeds

$$T_s = (T_f + 0.4T_r)/1.4$$

under the measurement conditions defined above, a positive supply of outside combustion air is needed for safe operation of the furnace. Reliable measurements of the stack temperature may be difficult because of nonuniformities across the stack due to incomplete mixing. (Methods based on pressure measurements can also be used.) Cold stack conditions may cause special problems (see Ref B-2).

Power burners have a blower to supply combustion air. There must be enough air supplied to this type of burner to ensure that the burner blower produces the pressure rise specified by the manufacturer. If a building is so tight that the blower cannot achieve its rated pressure rise, a positive supply of outdoor air must be provided. Care must be exercised with oil burners, however, if cold outdoor air is ducted directly to the burner. The low air temperature may degrade atomization and burner efficiency. The outdoor air provided should be tempered by heat loss from the stack and furnace jacket.

REFERENCES

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B-2. *Residential Combustion Venting Failure: A Systems Approach*. Research Div., Canada Mortgage and Housing Corp, 682 Montreal Rd., Ottawa, Canada, K1A OP7, July 30, 1987, 145 pp. 1987.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX C
GUIDANCE FOR THE ESTABLISHMENT OF AIR QUALITY CRITERIA FOR THE INDOOR ENVIRONMENT

The ventilation rates recommended in Table 2 are based on existing practice in indoor environments that contain the specified occupant density and for activities that can normally be expected to take place in such environments. Whenever building materials, cleaning and maintenance materials, or specialized human activities introduce large quantities of specific contaminants into the building atmosphere there may be occupant complaints and special measures should be considered to alleviate them.

Threshold Limit Values for Chemical Substances in the Work Environment Adopted by ACGIH is obtainable from the Publications Office, American Conference of Governmental Industrial Hygienists, 6500 Glenway Avenue, Building D-7, Cincinnati, OH 45211-4438 (see Ref C-1; Ref C-2 is the West German counterpart). This publication provides 8-hour, 15-minute, and instantaneous case limits. It is a source of concentration limits for many chemical substances and physical agents for industrial hygiene use. In light of the constantly changing state of knowledge, the document is updated annually. It cautions the user, "The limits listed in this book are intended for use in the practice of industrial hygiene as guidelines or recommendations in the control of potential health hazards and for no other use."

Industrial health practice attempts to limit worker exposure to injurious substances at levels that do not interfere with the work process and do not injure the workers' health. The elimination of all effects, e.g., unpleasant smells or mild irritation, is not attempted. Regulations are based on the results of accumulated experience with worker health and of animal experiments, carefully evaluated by groups of competent experts. Exposure and effects are related to dose of the injurious substance. Dose includes both the concentration of the substance and the time during which it is present. Since concentration commonly varies with time, dose is conveniently expressed as a time, weighted average concentration (TWA), short-term exposure limit (STEL), or threshold limit value (TLV). Regulations of the U.S. Occupational Safety and Health Administration are TWAs in most cases. Industrial exposures are regulated on the basis of a 40-hour work week with 8- to 10-hour days. The remainder of the time exposure is anticipated to be substantially lower for the pollutant of concern. For contaminants where standards or guidelines have not been established, it has been customary to assume as a first guide that a concentration of 1/10 TLV would not produce complaints in a nonindustrial population in residential, office, school, or other similar environments. The 1/10 TLV may not provide an environment satisfactory to individuals who are extremely sensitive to an irritant. In any event, where standards or guidelines do not exist, expert help should be sought in evaluating what level of such a chemical or combination of chemicals would be acceptable.

Guidelines have been established for a number of chemicals and metals that may be found in the outdoor air, as shown in Refs C-3 through C-9. Most would normally be found only in areas near certain industrial facilities, but some may be found in residential areas. These references are offered as sources of information when the quality of the outdoor air is suspect.

Tables C-1 and C-2 present lists of North American standards and guidelines for acceptable concentrations of substances in the indoor and outdoor environment. Table C-3 presents a summary of Canadian exposure guidelines for residential indoor air quality. Table C-4 presents a list of substances evaluated by a working group on indoor air quality research of the World Health Organization. These tables are presented as further background information when using the Indoor Air Quality Procedure.

Many contaminants have odors or are irritants that may be detected by human occupants or visitors to a space. The air can be considered acceptably free of annoying contaminants if 80% of a panel of at least 20 untrained observers deems the air to be not objectionable under representative conditions of use and occupancy. An observer should enter the space in the manner of a normal visitor and should render a judgment of acceptability within 15 seconds. Each observer should make the evaluation independently of other observers and without influence from a panel leader. Users of this method are cautioned that the method is only a test for odors. Many harmful contaminants will not be detected by this test. Carbon monoxide and radon are two examples of odorless contaminants.

References for Appendix C

C-1. *TLVs Threshold Limit Values and Biological Exposure Indices for 1986-87*. American Conference of Governmental Industrial Hygienists, 1986, 6500 Glenway, Building D-7, Cincinnati, OH 45211-4438. (Airborne concentrations of substances to which nearly all workers may be repeatedly exposed, day after day, without adverse effect; updated yearly.) 1986.

C-2. *Verein Deutscher Ingenieure, Handbuch Reinhaltung der Luft*. Maximale Imissions-Werte. VDI 2310, September 1974. (West German counterpart of TLVs at Ref C-1.

C-3. Newill, V.A. *Air Quality Standards*. Table III, pp. 462-487, in Vol. V of Stern, A.C. (ed.), *Air Pollution*, 3rd ed. Academy Press, New York, NY (national, by county, ambient air quality standards). 1977.

C-4. Government of Ontario, Regulation 296 under the Environmental Protection Act, Revised Regulations of Ontario, Toronto (current update of Ontario, Canada, ambient air quality criteria).

C-5. Martin, W., and A.C. Stern, *The World's Air Quality Standards*. Vol. II. *The Air Quality Management Standards of the United States*, Table 17, pp. 11-38, October 1974 (available from *NTIS PB-241-876*; National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161). 1974.

C-6. U.S. National Academy of Sciences, Committee on Toxicology, National Research Council, Guides for Short-Term Exposure of the Public to Air Pollutants. Microfiche or photocopies of these may be obtained from the National Technical Information Services, by order number. For example: *Ammonia PB-244-336, November 1972; Hydrochloric Acid PB-203-464, August 1971*.

C-7. U.S. Environmental Protection Agency, Code of Federal Regulations, Title 40, Part 61 (current national emission standards for hazardous air pollutants).

C-8. U.S. Environmental Protection Agency, National Air Toxics Information Clearinghouse Data Base, Report on State and Local Agency Air Toxics Activities, July 6, 1986 (tabulation of reporting states and communities published standards and guidelines for toxic air pollutants). 1986.

C-9. U.S. Environmental Protection Agency, Code of Federal Regulations, Title 40, Part 50 (current national ambient air quality standards).

TABLE C-1
STANDARDS APPLICABLE IN THE UNITED STATES FOR COMMON INDOOR AIR POLLUTANTS[a]

Pollutant	Indoor Standards	Outdoor Standards	Industrial Workplace Standards
Asbestos	Consumer Product Safety Commission has banned use of asbestos in artificial logs for fireplaces, in patching compounds, and in certain garments (16 C.F.R. 1304, 1305, 1500.17(a)(7)); voluntary ban on use in hairdryers (C-10) EPA regulates use in schools (40C.F.R 763.100) and removal projects (40 C.F.R. 763.120); bans installation of friable asbestos for facility insulation (40 C.F.R. 61.150) (C-11) (C-7)	National Emissions Standard: no visible emissions; may also comply by cleaning emissions as specified before particulate asbestos material escapes to air (EPA, 40 C.F.R 61.140 et seq.) (C-7) State air quality limits: CT 0.0010 ug/m³ 8 hr. MA 0.0001 fb/cm³ 24 hr. NC 0.0100 ug/m³ 24 hr. NY 5.0000 ug/m³ 1 yr. VA 2.0000 ug/m³ 24 hr. (all TLV based-fibers longer than 5 microns)* (NATICH Data Base, 1986) (C-8)	0.2 fiber/cm³ 8 hr. TWA (optically measured longer than 5 microns)(OSHA, 29 C.F.R. 1910.1001(c) (C-12) 2.0 fiber/ml, 8 hr. TWA (Mine Safety and Health Admin., 30 C.F.R. (56.5001(b), 57.5001(b)) (C-13)
Carbon Monoxide (See Table 1)		National Ambient Air Quality Primary Standard: 10 mg/m³ (9 ppm) 8 hr. avg. 40 mg/m³ (35 ppm) 1 hr. avg. (EPA, 40 C.F.R. 50.8) (C9) State air quality limits: CT 10000. ug/m³ 8 hr. NV 1.3100 mg/m³ 8 hr. (NATICH Data Base, 1986) (C-8)	55 mg/m³ (50 ppm) 8 hr. TWA (OSHA, 29 C.F.R. 1910.1000, Table Z-1) (C-12) Mine Safety and Health Admin. uses ACGIH TLV* (30 C.F.R. 57.5001(a)) (C-13)
Formaldehyde	Federal: 0.4 ppm target ambient level, HUD standard for manufactured homes, achieved through product emissions standards of .2 and .3 ppm (HUD, 24 C.F.R. 3280.308, 1984) (C-14) State: 0.4 ppm standard for indoor exposure (MN statute 144.495, 1985) (C-15)	No federal standard. State air quality limits: CT 12.00 ug/m³ 8 hr. IL 0.0150 ug/m³ 1 yr. IN 18.000 ug/m³ 8 hr. MA 0.2000 ug/m³ 24 hr. NC 300.00 ug/m³ 15 min. NV 0.0710 mg/m³ 8 hr. NY 2.0000 ug/m³ 1 yr. VA 12.000 ug/m³ 24 hr. (NATICH Data Base, 1986) (C-8)	1 ppm 8 hr. TWA-PEL[b] 2 ppm 15-min. STEL[c] (OSHA, 29 C.F.R. 1910.1000, Table Z-2; OSHA issued a final rule Dec. 4, 1987 (52 FR 46168) lowering a previous standard to the above levels, which was effective on Feb. 2, 1988). Mine Safety and Health Admin. uses ACGIH TLVs (30 C.F.R. 57.5001(a)) (C-13)
Lead (See Table 1)	CPSC has banned in paint for consumer use or use on consumer products (16 C.F.R. 1303) (C-10)	National Ambient Air Quality Primary and Secondary Standard: 1.5 ug/m³ max. arithmetic mean over calendar qtr. (EPA, 40 C.F.R. 50.12) (C-9) State air quality limits: CT 1.500 ug/m³ 8 hr. IL 0.500 ug/m³ 24 hr. MA 0.680 ug/m³ 24 hr. NV 0.004 mg/m³ 8 hr. VA 2.500 ug/m³ 24 hr. (NATICH Data Base for lead powder, 1986) (C-8)	50 ug/m³ 8 hr. TWA (OSHA, 29 C.F.R 1910.1025(c)) (C-12) Mine Safety and Health Admin. uses ACGIH TLV (30 C.F.R 57.5001(a)) (C13)
Nitrogen Dioxide (See Table 1)		National Ambient Air Quality Primary and Secondary Standards: 100 ug/m³ (0.053)ppm annual arithmetic mean (EPA, 40 C.F.R. 50.11) (C-9) State air quality limits: CT 120.0 ug/m³ 8 hr. NV 0.143 mg/m³ 8 hr. (NATICH Data Base, 1986) (C-8)	(5 ppm) ceiling 9 mg/m³ (OSHA, 29 C.F.R. 1910.1000, Table Z-1) (C12) Mine Safety and Health Admin. uses ACGIH TLV (30 C.F.R. 57.5001(a)) (C-12)

[a]Most ACGIH TLVs are referenced in western nations' standards, including Canada, Western Europe, and Australia.

[b]PEL—Permissible exposure limit
[c]STEL—Short-term exposure limit

TABLE C-1
STANDARDS APPLICABLE IN THE UNITED STATES FOR COMMON INDOOR AIR POLLUTANTS[a] *(Concluded)*

Pollutant	Indoor Standards	Outdoor Standards	Industrial Workplace Standards
Ozone (See Table 1 and 3)	FDA prohibits devices (e.g., germicides, deodorizers) that result in more than 0.05 ppm in occupied enclosed spaces such as homes, offices, or hospitals, or that result in any releases in places occupied by the ill or infirm (21 C.F.R. 801.415) (C-16)	National Ambient Air Quality Primary and Secondary Standards: 235 ug/m^3 (0.12 ppm) max. hourly avg (EPA, 40 C.F.R. 50.9) (C9) State air quality limits: CT 235.0 ug/m^3 1 hr. NV 0.005 mg/m^3 8 hr. (NATICH Data Base, 1986) (C-8)	0.2 mg/m^3 (0.1 ppm) 8 hr. TWA (OSHA, 29 C.F.R. 1910.1000, Table Z-1) (C12) Mine and Safety and Health Admin. uses ACGIH TLV (30 C.F.R. and 57.5001(a)) (C-13)
Particulates (See Table 1)		National Ambient Air Quality Primary Standard: 75 ug/m^3 annual geom. mean 260 ug/m^3 maximum 24 hr. Secondary Standard: 60 ug/m^3 annual geom. mean 150 ug/m^3 maximum 24 hr. (EPA, 40 C.F.R. 50.6, 50.7) (C-9)	
Radon (See Table 3)		National Emission Standard for Radon-222 emissions from underground uranium mines—requires bulkhead construction (EPA, 40 C.F.R. 61.22) (C-7) National Emissions Standard for Radionuclide Emissions (excluding Radon-220, 222) from DOE facilities, other federal facilities, and NRClicensed facilities: 25 mrem/y whole body 75 mrem/7 critical organ (EPA, 40 C.F.R. 61.92, 61.102) (C-7)	1.0 WL radon progeny maximum 4 WLM radon progeny calendar year (Mine Safety and Health Admin., 30 C.F.R. 57.5038, 57.5039) (C-13)
Sulfur Dioxide (See Table 1)		National Ambient Air Quality Primary Standard: 80 ug/m^3 (0.03 ppm)annual arithmetic mean 365 ug/m^3 (0.14 ppm) 24 hr. Secondary Standard: 1300 ug/m^3 (0.5 ppm) 3 hr. (EPA, 40 C.F.R. 50.4, 50.5) (C-9) State air quality limits: CT 860.0 ug/m^3 8 hr. NV 0.119 mg/m^3 8 hr. TN 1.200 ug/m^3 1 yr. (NATICH Data Base, 1986) (C-8)	13 mg/m^3 (5ppm) 8 hr. TWA (OSHA, 29 C.F.R. 1910.1000, Table Z-1) (C12) Mine Safety and Health Admin. uses ACGIH TLV (30 C.F.R. 57.5001(a)) (C-13)

[a]Most ACGIH TLVs are referenced in western nations' standards, including Canada, Western Europe, and Australia.

TABLE C-2
GUIDELINES USED IN THE UNITED STATES FOR COMMON INDOOR AIR POLLUTANTS

Pollutant	Indoor Guidelines	Outdoor Guidelines	Industrial Workplace Guidelines
Asbestos			0.2-2.0 fibers/cm^3 8 hr. TLV-TWA (depending on type of fiber) (fibers longer than 5 microns) (ACGIH, 1986-87) (C-1)

TABLE C-2
GUIDELINES USED IN THE UNITED STATES FOR COMMON INDOOR AIR POLLUTANTS (*Concluded*)

Pollutant	Indoor Guidelines	Outdoor Guidelines	Industrial Workplace Guidelines
Carbon Monoxide			55 mg/m^3 (50 ppm) 8 hr. TLV-TWA 440 mg/m^3 (400 ppm) 15 min. STEL (ACGIH, 1986-87) (C-1)
Chlordane	NAS recommendation for military housing: (C-17) 5 µg/m^3 maximum		
Formaldehyde			1.5 mg/m^3 (1 ppm) 8 hr. TLV-TWA 3 mg/m^3 (2 ppm) 15 min. STEL (ACGIH, 1986-87) (C-1) 1.2 mg/m^3 (1 ppm) 8 hr. TWA 2.5 mg/m^3 (2 ppm) 15 min. STEL (American Industrial Hygiene Assn., 1986) (C20) NAS recommendations for manned spacecraft: (C-18) 1.0 mg/m^3 (1.0 ppm) 60 min. 0.1 mg/m^3 (0.1 ppm) 90 days 0.1 mg/m^3 (0.1 ppm) 6 mo. Navy Submarine Atmospheric Control Manual, levels set by Naval Research Laboratory: (C-19) 3.0 ppm 1 hour 1.0 ppm 24 hour 0.5 ppm 90 days
Lead Dust and Fumes			0.15 mg/m^3 8 hr. TLV-TWA (ACGIH, 1986-87) (C-1)
Nitrogen Dioxide			6 mg/m^3 (3 ppm) 8 hr. TLV-TWA 10 mg/m^3 (5 ppm) 15 min. STEL (ACGIH, 1986-87) (C-1) NAS recommendation for manned spacecraft: (C-18) 4 mg/m^3 (2.0 ppm) 60 min. 1.0 mg/m^3 (0.5 ppm) 90 days 1.0 mg/m^3 (0.5 ppm) 6 mo.
Ozone			0.2 mg/m^3 (0.1 ppm) 8 hr. TLV-TWA 0.6 mg/m^3 (0.3 ppm) 15 min. STEL (ACGIH, 1986-87) (C-1)
Radon (See Table 3)	EPA 1986 recommendation for homes: 4 p Ci/l or less-can be reached in most homes At 4-20 pCi/l-take action to reduce within a few years At 20-200 pCi/l-reduce within several months At 200 pCi/l or above,reduce within several weeks or relocate until levels are reduced (EPA, "A Citizen's Guide to Radon," August 1986) (C-21) (EPA, "Radon Reduction Methods, A Homeowner's Guide," August 1986) (C22)		
Sulfur Dioxide			5 mg/m^3 (2 ppm) 8 hr. TLVTWA 10 mg/m^3 (5 ppm) 15 min. STEL (ACGIH, 1986-87) (C-1) NAS recommendation for manned spacecraft (C-18) 13 mg/m^3 (5.0 ppm) 60 min. 3 mg/m^3 (1.0 ppm) 90 days 3 mg/m^3 (1.0 ppm) 6 mo.

TABLE C-3*
SUMMARY OF CANADIAN EXPOSURE GUIDELINES FOR RESIDENTIAL INDOOR AIR QUALITY

Contaminant	Acceptable Exposure Ranges: ASTER[g]	Acceptable Exposure Ranges: ALTER[h]	Page
Aldehydes (total)	$\Sigma c_i/C_i<1$[a]	—	16
Carbon dioxide	—	× 6 300 mg/m³ (<3 500 ppm)	17
Carbon monoxide	<11 ppm—8 h[b] <25 ppm—1 h[b]	—	18
Formaldehyde		[d]Action Level 120 µg/m³ (0.10 ppm) Target Level 60 µg/m³ (0.05 ppm)	26
Nitrogen dioxide	<480 µg/m³ (<0.25 ppm)—1 h	<100 µg/m³ (<0.05 ppm)	19
Ozone	<240 µg/m³ (<0.12 ppm)—1 h	—	21
Particulate matter[e]	<100 µg/m³—1 h	<40 µg/m³	21
Sulphur dioxide	<1 000 µg/m³(<0.38 ppm)—5 m	<50 µg/m³ (<0.019 ppm)	23
Water vapor	30-80% R.H.—summer 30-55% R.H.—winter[f]	—	24
Others See below[i]	Minimize exposure	Minimize exposure	28-36

[a] C_i = 120 µg/m³ (formaldehyde); 50 µg/m³ (acrolein); 9000 µg/m³ (acetaldehyde), and C_i are respective concentrations measured over a five-minute period.

[b] Units given only in parts per million so that guidelines are independent of ambient pressure.

[c] See Aldehydes (total).

[d] Although the epidemiological studies conducted to date provide little convincing evidence that formaldehyde is carcinogenic in human populations, because of this potential, indoor levels should be reduced as much as possible.

[e] <2.5 µm mass median aerodynamic diameter—MMMD.

[f] Unless constrained by window condensation.

[g] ASTER—Acceptable short-term exposure range

[h] ALTER—Acceptable long-term exposure range.

[i] Other contaminants of concern: biological agents; chlorinated hydrocarbons; pest control products; product aerosols; fibrous materials; lead; polycyclic aromatic hydrocarbons (PAHs); and tobacco smoke.

*From Ref C-23, p.41.

TABLE C-4
WHO WORKING GROUP CONSENSUS OF CONCERN ABOUT INDOOR AIR POLLUTANTS AT 1984 LEVELS OF KNOWLEDGE*

Pollutant[a]	Concentrations[b] reported	Concentrations[b] of limited or no concern	Concentraton[b] of concern	Remarks
Tobacco smoke (passive smoking)				
Respirable particulates	0.05-0.7	<0.1	>0.15	Japanese standard 0.15 mg/m
CO	1-1.5	<2	>5	indicator for eye irritation (only from passive smoking)
Nitros-dimethylamine	(1-50) × 10^{-6}	—	—	Mutagens under investigation for carcinogenicity
NO_2	0.05-1	<0.19	>0.32	
CO		2% COHb	3% COHb	99.9%[c]
	1-100	<11	>30	Continuous exposure
Radon and Progenys	10-3000 Bq/m³	-0	70 Bq/m³	Swedish standard for new houses
Formaldehyde	0.05-2	<0.06	>0.12	Long- and short-term
SO_2	0.02-1	<0.5	>1.35	SO_2 alone short-term
CO_2	600-9000	<1800	>12000	Japanese standard 1800 mg/m³
O_3	0.04-0.4	0.05	0.08	
Asbestos	<10 fibres/m³	-0	10^5 fibre/m	For long-term exposure
Mineral fibres	<10 fibres/m³	—	—	Skin irritation
Organics				
Methylene chloride	0.005-1	—	350 260	TLV[d] NIOSH[e] recommendations
Trichlormethene	0.0001-0.02	—	270 135	TLV NIOSH recmmendations
Tetrachloroethene	0.002-0.05	—	335	TLV
1.4 Dichlorobenzene	0.005-0.1	—	450	TLV
Benzene	0.01-0.04	carcinogen	carcinogen	
Toluene	0.015-0.07	—	375	TLV
m.p.-Xylene	0.01-0.05	—	435	TLV
n-Nonane	0.001-0.03	—	1050	ILO (1980)
n-Decane	0.002-0.04	—	—	
Limonene	0.01-0.1	—	560	TLV turpentine

[a] All gases were considered on their own without other contaminants.

[b] Typical ranges of concentration given in mg/m³ unless otherwise indicated and for short-term expossures

[c] According to Environmental Health Criteria No. 4, Geneva World Health Organization, 1977

[d] TLV (threshold limit values) established by the American Conference of Governmental Industrial Hygienists (19831984). These values are for occupation exposures and should be considered as extreme upper limits for nonoccupational populations for very short-term exposures

[e] National Institute for Occupational Safety and Health (NIOSH), USA

[f] International Labor Organization (ILO)

— = no meaningful numbers can be given because of insufficient knowledge

*From Ref C-24, Table 3.

C-10. U.S. Consumer Products Safety Commission, Code of Federal Regulations, Title 16, Parts 1303, 1304, 1305 and 1500 (ban of certain commercial practices and hazardous substances regulation).

C-11. U.S. Environmental Protection Agency, Code of Federal Regulation, Title 40, Part 763 (national asbestos regulations).

C-12. U.S. Occupational Safety and Health Administration, Code of Federal Regulations, Title 29, Part 1910 (toxic and hazardous substances).

C-13. U.S. Mine Safety and Health Administration, Code of Federal Regulations, Title 30, Parts 56.5001, 57.5001, 57.5038 and 57.5039 (air quality).

C-14. U.S. Department of Housing and Urban Development, Code of Federal Regulations, Title 24, Part 3280.308 (formaldehyde emission controls for manufactured homes).

C-15. State of Minnesota, Minnesota Laws of 1985, Chapter 216, Section 144.495 (formaldehyde rules for new housing units). 1985.

C-16. U.S. Food and Drug Administration, Code of Federal Regulations, Title 21, Part 801 (maximum acceptable levels of ozone).

C-17. U.S. National Academy of Sciences, Committee on Toxicology, An Assessment of the Health Risks of Seven Pesticides Used in Termite Control (chlordane in military housing), August 1982.

C-18. U.S. National Academy of Sciences, National Research Council, Report of the Panel on Air Quality in Manned Spacecraft of the Committee on Toxicology. *Atmospheric Contaminants in Spacecraft*. June 1972.

C-19. U.S. Naval Research Laboratory, *Navy Submarine Atmospheric Control Manual* (current update of Table 3-7, unclassified defense information).

C-20. American Industrial Hygiene Association, Occupational Exposure and Work Practice Guidelines for Formaldehyde. July 24, 1986.

C-21. U.S. Environmental Protection Agency. *A Citizen's Guide to Radon*. August 1986.

C-22. U.S. Environmental Protection Agency. *Radon Reduction Methods, A Homeowner's Guide*. August 1986.

C-23. Canada Department of National Health and Welfare. *Exposure Guidelines for Residential Indoor Air Quality*. Ottawa. April 1987.

C-24. World Health Organization, Report on a WHO meeting, August 21-24, 1984. *Indoor Air Quality Research*. EURO Reports and Studies 103, Regional Office for Europe. Copenhagen, Denmark.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX D
RATIONALE FOR MINIMUM PHYSIOLOGICAL REQUIREMENTS FOR RESPIRATION AIR BASED ON CO_2 CONCENTRATION

Oxygen is necessary for metabolism of food to sustain life. Carbon and hydrogen in foods are oxidized to CO_2 and H_2O, which are eliminated by the body as waste products. Foods can be classified as carbohydrates, fats, and proteins, and the ratio of carbon to hydrogen in each is somewhat different. The respiratory quotient (RQ) is the volumetric ratio of carbon dioxide produced to oxygen consumed. It varies from 0.71 for a diet of 100% fat to 0.8 for a diet of 100% protein and 1.00 for a diet of 100% carbohydrates (see Ref D-1). A value of RQ = 0.83 applies to a normal diet mix of fat, carbohydrate, and protein.

The rate at which oxygen is consumed and carbon dioxide is generated depends on physical activity. These relationships are shown in Fig. D-2 (see Ref D-2). The breathing rate is shown also. A simple mass balance equation gives the outdoor air flow rate needed to maintain the steady-state CO_2 concentration below a given limit.

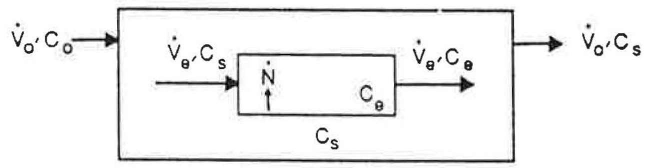

Fig. D-1. Two Chamber Model

$$V_o = N/(C_s - C_o) \qquad \text{(D-1)}$$

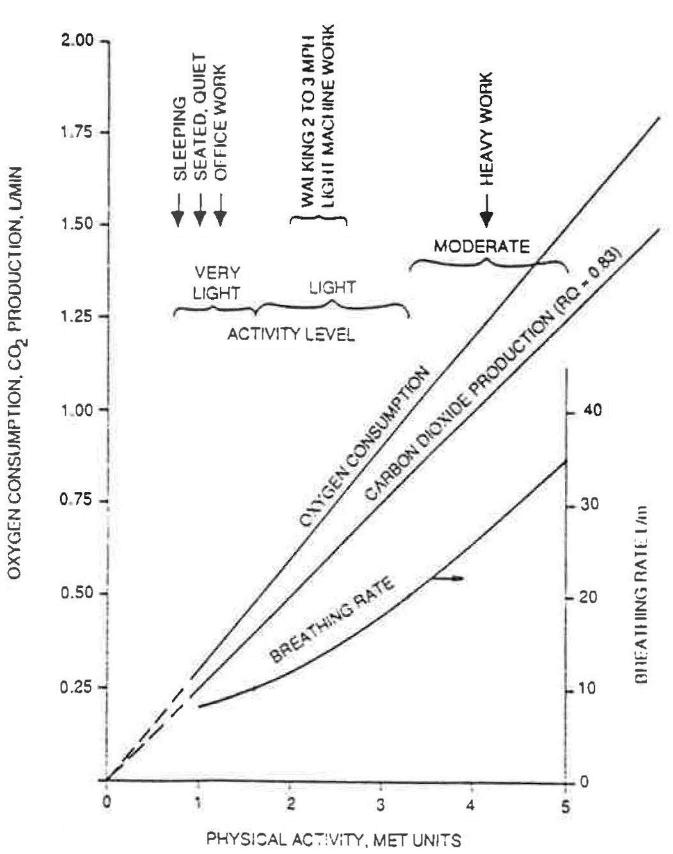

Fig. D-2 Maximum Permissible Ventilation Lag Time

where

V_o = outdoor air flow rate per person
V_e = breathing rate
N = CO_2 generation rate per person
C_e = CO_2 concentration in exhaled breath
C_s = CO_2 concentration in the space
C_o = CO_2 concentration in outdoor air

Thus, for an activity level of 1.2 met units (1.0 met = 18.4 Btu/h·ft^2), the CO_2 generation rate is 0.30 L/min. If the maximum space concentration is to be held to 0.1% and the outdoor concentration is 0.03%, the outdoor air flow needed is,

$$V_o = (0.30)/[(0.001-0.0003) \times 60]$$
$$= 7.0 \text{ L/s}$$
or 15 cfm per person

Figure D-3 shows the outdoor air flow rate required as a function of physical activity and steady-state room concentration. If the activity level is greater than 1.2 met, the required ventilation must be increased to maintain the same carbon dioxide level.

Also the decrease in oxygen content of the room air can be found from Eq D-1 also.

$$C_o - C_s = N/V_o \qquad \text{(D-2)}$$

The term N now has a negative value with respect to its use in Eq D-1 since oxygen is consumed rather than generated.

$$C_s = C_o - N/V_o \qquad \text{(D-3)}$$

The oxygen consumption rate is 0.36 L/min when the activity level is 1.2 met. For ventilation at a rate of 15 cfm (429 L/m) and an activity level of 1.2 met units, the room oxygen level will be reduced from an outdoor concentration to 20.9%. Thus the oxygen content of the room is reduced from 21% to 20.9%, a change of only 0.5%. The carbon dioxide is raised from the background of 0.03% to 0.1%, a change of 230%. Thus dilution of carbon dioxide is clearly more significant than replacing oxygen.

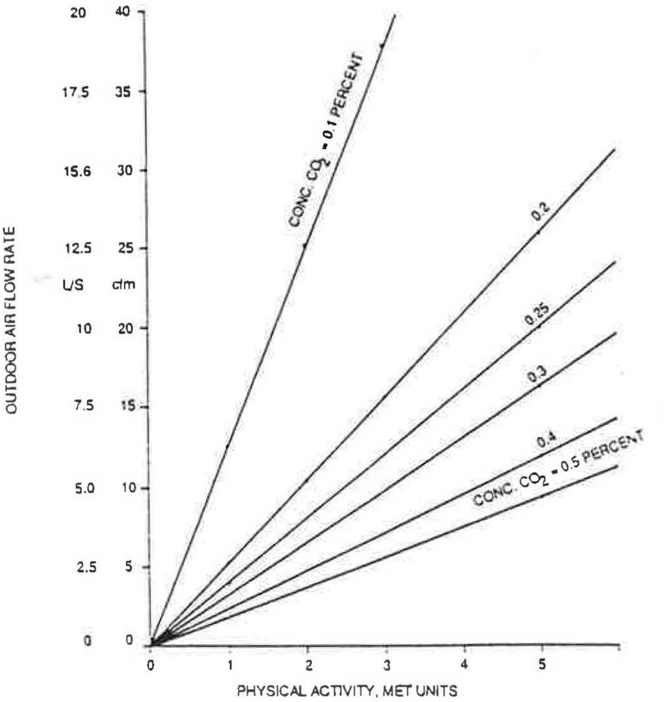

Fig. D-3 Minimum Ventilation Time Required Before Occupancy of Space

REFERENCES

D-1. McHattie, L.A. *Graphic Visualization of the Relations of Metabolic Fuels: Heat: O_2, CO_2, H_2O: Urine N. J. Applied Physiology*, 15, (4): 677-683. 1960.

D-2. *ASHRAE Handbook—1985 Fundamentals Volume*, Chapter 8. American Society of Heating, Refrigerating, and AirConditioning Engineers, Inc., Atlanta, GA 30329. 1985.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX E
PROCEDURE FOR USE OF CLEANED RECIRCULATED AIR

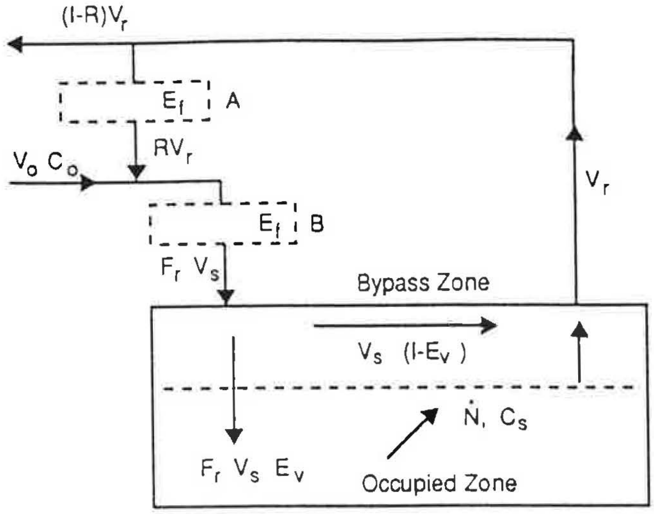

Fig. E-1 Recirculation and Filtration

A, B	= *Filter Location*	*Subscripts*	
V	= *Volumetric Flow*	*f*	= *filter*
C	= *Contaminate Concentration*	*o*	= *outdoor*
E	= *Efficiency or Effectiveness*	*r*	= *return*
F_r	= *Flow Reduction Factor*	*s*	= *supply*
$\dot{N}$	= *Contaminate Generation Rate*	*v*	= *ventilation*
R	= *Recirculation Flow Factor*		

The amount of outdoor air specified in Table 2 may be reduced by recirculating air from which offending contaminants have been removed or converted to less objectionable forms. Formaldehyde, for example, may be oxidized to water and carbon dioxide. The amount of outdoor air required depends on the contaminant generation in the space, the contaminant concentrations in the indoor and the outdoor air, the filter location, the filter efficiency for the contaminants in question, the ventilation effectiveness, the supply air circulation rate, and the fraction recirculated.

Figure E-1 shows a representative system. A filter may be located in the recirculated airstream (location A) or in the supply (mixed) airstream (location B). The ventilation effectiveness will depend on the location of the supply outlet, the return inlet, and the design and performance of the supply diffuser. Figure E-1 is

Table E-1 Required Outdoor Air or Space Contaminant Concentration with Recirculation and Filtration

Class	Required Recirculation Rate				Required Outdoor Air	Space Contaminant Concentration	Required Recirculation Rate
	Filter Location	Flow	Temperature	Outdoor Air			
I	None	VAV	Constant	100%	$V_o = \frac{N}{E_v F_r (C_s - C_o)}$	$C_s = C_o + \frac{N}{E_v F_r V_o}$	Not applicable
II	A	Constant	Variable	Constant	$V_o = \frac{N - E_v RV_r E_f C_s}{E_v (C_s - C_o)}$	$C_s = \frac{N + E_v V_o C_o}{E_v (V_o + RV_r E_f)}$	$RV_r = \frac{N + E_v V_o (C_o - C_s)}{E_v E_f C_s}$
III	A	VAV	Constant	Constant	$V_o = \frac{N - E_v F_r RV_r E_f C_s}{E_v (C_s - C_o)}$	$C_s = \frac{N + E_v V_o C_o}{E_v (V_o + F_r RV_r E_f)}$	$RV_r = \frac{N + E_v V_o (C_o - C_s)}{E_v F_r E_f C_s}$
IV	A	VAV	Constant	Proportional	$V_o = \frac{N - E_v F_r RV_r E_f C_s}{E_v F_r (C_s - C_o)}$	$C_s = \frac{N + E_v F_r V_o C_o}{F_r E_v (V_o + RV_r E_f)}$	$RV_r = \frac{N + E_v F_r V_o (C_o - C_s)}{E_v F_r E_f C_s}$
V	B	Constant	Variable	Constant	$V_o = \frac{N - E_v RV_r E_f C_s}{E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v V_o (1 - E_f) C_o}{E_v (V_o + RV_r E_f)}$	$RV_r = \frac{N + E_v V_o [(1 - E_f) C_o - C_s]}{E_v E_f C_s}$
VI	B	VAV	Constant	Constant	$V_o = \frac{N - E_v F_r RV_r E_f C_s}{E_v [C_s - (1 - E_f) C_o]}$	$C_s = \frac{N + E_v V_o (1 - E_f) C_o}{E_v (V_o + F_r RV_r E_f)}$	$RV_r = \frac{N + E_v V_o [(1 - E_f) C_o - C_s]}{E_v F_r E_f C_s}$
VII	B	VAV	Constant	Proportional	$V_o = \frac{N - E_v F_r RV_r E_f C_s}{E_v F_r [C_s - (1 - E_f)(C_o)]}$	$C_s = \frac{N + E_v F_r V_o (1 - E_f) C_o}{E_v F_r (V_o + RV_r E_f)}$	$RV_r = \frac{N + E_v F_r V_o [(1 - E_f) C_o - C_s]}{E_v F_r E_f C_s}$

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a schematic of a typical system with the supply outlet and the return inlet in the ceiling. It is possible for some supply air to flow directly from the supply to the return, bypassing the occupied zone of the room. This reduces the effectiveness of the ventilation supplied to the space (see Appendix F).

All of the exhaust is shown in Fig. E-1 as being taken from the return airstream. Many systems will have part or all of the exhaust taken directly from the space. If the exhaust air is taken from the ceiling area, it will be subject to the same loss of ventilating efficiency as if it were taken from the return air flow. See Appendix F for its effect on ventilating efficiency, E_v. The exhaust air flow, V_e, is then equal to all of the exhaust air flow regardless of whether it is taken from the return air or from the room. Then:

$$V_e = V_o \quad \text{(E-1)}$$

let V_e^{I} be the portion of air exhausted form the return duct, and V_e^{II} be the portion exhausted directly from the room. Then:

$$V_e = V_e^{I} + V_e^{II} \quad \text{(E-2)}$$

and

$$V_r = V_s - V_e^{II} \quad \text{(E-3)}$$

The material balance at the supply outlet is:

$$V_s = V_o + RV_r = (V_e^{I} + V_e^{II}) + RV_r \quad \text{(E-4)}$$

$$RV_r = V_s - (V_e^{I} + V_e^{II}) \quad \text{(E-5)}$$

RV_r is the recirculated air and V_r is the return air. Therefore:

$$R = [V_s - V_e^{I} + V_a^{II})]V_r \quad \text{(E-6)}$$

Variable-air-volume (VAV) systems reduce the circulation rate when the thermal load is satisfied. This is accounted for by a flow reduction factor *Fr*. The supply air temperature is normally held constant in a VAV system. Constant-volume systems require a variable supply air temperature. VAV systems also may have a constant or proportional outdoor air flow rate.

A mass balance for the contaminant may be written to determine the space contaminant concentration for each of the system arrangements. The various permutations for the air-handling and distribution systems are described in Table E-1. There are seven variations. The mass balance equations for computing the space contaminant concentration for each system are presented in Table E-1.

If the allowable space contamination is specified, the equations in Table E-1 may be solved for the outdoor flow rate V_o. When the outdoor air flow rate is specified, the equations may be solved for the resulting contaminant concentration as shown in Table E-1.

Filters are effective for removing particles. They are less effective or ineffective in removing gases and vapors. Therefore, when designing a filtration system, consideration must be given to contaminants that are poorly filtered or not filtered at all. The ventilating rate may only be reduced until some contaminant reaches its maximum acceptable limit.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX F
VENTILATION EFFECTIVENESS

Stratification Model. A model for ventilation effectiveness can be derived by considering a typical HVAC air-handling system as shown schematically in Fig. F-1. It is possible that a fraction, S, of the supply air may bypass directly to the return inlet without mixing at the occupied level, i.e., below the dotted line in Fig. F-1.

The total outdoor air in the supply air is V_{os}.

The fraction of the supply air that stratifies and bypasses directly to the return is designated by S. The amount of outdoor air supplied to the space is:

$$V_{os} = V_o + R \times S \times V_{os} \quad \text{(F-1)}$$

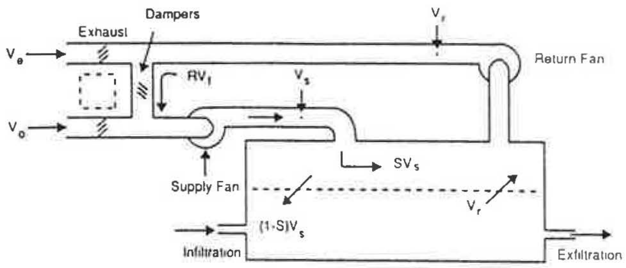

Fig. F-1. Typical Air Distribution System

The amount of unvitiated (unused) air that is exhausted is:

$$V_{oe} = (1 - R)S\,V_{os} \quad \text{(F-2)}$$

The ventilation efficiency then can be defined as:

$$E_v = [V_o - V_{oe}]/V_o \quad \text{(F-3)}$$

Combining equations F-1, F-2, and F-3,

$$E_v = [1 - S]/[1 - RS] \quad \text{(F-4)}$$

Equation F-4 defines the effectiveness with which the outdoor air is circulated to the occupied space in terms of a stratification or mixing factor *s* and the recirculation factor *r*. If there is no exhaust flow, $r = 1$ and the effectiveness = 100%. If, however, there is both stratified flow and recirculation, outdoor air can pass through the system without ever being used to dilute contaminants at the occupied level. This ventilation loss also represents an energy loss.

REFERENCE

F-1. Janssen, J.E. *Ventilation Stratification and Air Mixing, Indoor Air*, Vol. 5. Proc. of the 3rd Intern. Conference on Indoor Air Quality and Climate, Stockholm, Sweden, 1984. Sponsored by USEPA, ASHRAE, GRI, EPRI and European organizations. 1984.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX G
RATIONALE FOR LAG OR LEAD TIME FOR TRANSIENT OCCUPANCY

When spaces such as classrooms, auditoriums, or offices are unoccupied for several hours and then occupied, operation of the ventilation system may be delayed to use the capacity of the air in the space to dilute contaminants. This applies to cases where the inside contaminants are associated only with human occupancy and where contaminants are dissipated by natural means during long vacant periods. The operation of the ventilation system can then be delayed until the concentration of contaminants reaches the acceptable limit associated with the minimum ventilation requirements at steady state.

The concentration of any contaminant C in the absence of ventilation in a given space of volume v is expressed as follows:

$$C_t = \frac{Nt}{v} \quad \text{(G-1)}$$

where N is the contaminant generation rate and t is time. The contaminant concentration C_s under a steady-state condition with ventilation rate V is:

$$C_s = \frac{N}{V} \quad \text{(G-2)}$$

The maximum permissible ventilation delay time after the space is occupied is when C equals C_s, or:

$$t = \frac{v}{V} \quad \text{(G-3)}$$

This equation is plotted in Fig. 4 for various ventilation rates in cfm/person (L/s per person) and space volume in ft^3/person (L/person). When contaminants are generated independent of people or their activities, and the contaminants do not present a short-term health hazard, ventilation may be shut off during unoccupied periods. In these cases, however, ventilation must be provided in advance of the time of occupancy, so that acceptable conditions will exist for people at the start of occupancy. It is impractical to operate the ventilation system at the minimum requirement until steady state is reached, because this is approached asymptotically with time and may take several hours to reach practical equilibrium. An engineering estimate of a permissible contaminant level of 1.25 times the steady-state value has, therefore, been selected as the maximum level at the time of occupancy. The occupants would, for a time, be subjected to somewhat higher contaminant concentrations than the steady-state value. It is postulated that the factor of safety implicit in the concentrations in 6.1.3 are adequate so that, for practical purposes, the required air quality is provided over the entire occupancy period.

When an initially contaminated room with a level of concentration C_i is diluted by a given rate of ventilation V, the time required to lower the concentration to a fraction X above the final steady-state concentration level can be expressed as follows:

$$t = \frac{v}{V} ln \left[\frac{(C_i)\, V/N - 1}{X} \right] \qquad \text{(G-4)}$$

where:

t = time
v = room volume
V = ventilation rate
N = contaminant generation rate
C_i = initial concentration

Figure 5 is a plot of this relationship, where C_i is assumed to be approximately 10 times the steady-state value and X = 0.10.

This Appendix is not part of this Standard but is included for information purposes only.

APPENDIX H
RATIONALE FOR REDUCING OUTDOOR AIR WHEN LOADS ON A MULTI-ZONE SYSTEM ARE UNEQUAL

Building HVAC systems often serve more than one room or zone. When the ventilating requirements for different rooms or zones are unequal, some of the return air is recirculated, and exhaust is taken from the return air, it is possible to reduce the fraction of outdoor air in the total supply below that required for the critical space, i.e., the space with the greatest ventilation requirement. Derivation of the formula that specifies the fraction of the outdoor air required in the total supply is as follows:

A two-chamber model may be used as shown in Fig. H-1. One chamber, represented by subscript c, represents the critical zone or zone with the highest ventilation load. The other chamber represents the sum of the other zones or rooms that require a smaller fraction of outdoor air in their supplies than the critical zone.

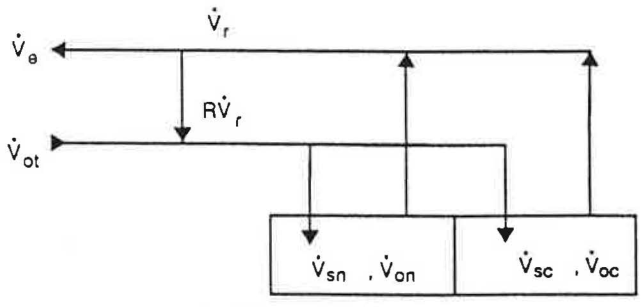

Fig. H-1. Multi-Zone Model

V_e = exhaust from the system
V_{ot} = outdoor air supply corrected to account for recirculation
V_{st} = total supply air flow
V_r = return air flow
V_{oi} = outdoor air flow supplied to zone i
V_{on} = outdoor air supplied to critical zone i

$$V_{on} = \sum_{i=1}^{n} V_{oi}$$

V_{si} = supply air flow to zone i
V_{sn} = sum of supply flows to all zones

$$V_{sn} = \sum_{i=1}^{n} V_{si}$$

V_{oc} = outdoor air supplied to critical zone
V_{sc} = supply air flow to critical zone
F = fraction of outdoor air in supply to critical zone

$$F = V_{oc}/V_{sc} \qquad \text{(H-1)}$$

R = fraction of return air that is recirculated, i.e.,

$$R = [(V_r - V_e)/V_r] = [V_{st} - V_{ot})/V_{st}] \qquad \text{(H-2)}$$

Note that

$$V_{on} = \sum_{i=1}^{n} V_{oi} \qquad \text{(H-3)}$$

and

$$V_{sn} = \sum_{i=1}^{n} V_{si} \qquad \text{(H-4)}$$

Then, by definition for the critical zone,

$$V_{oc}/V_{sc} \geq V_{on}/V_{st} \qquad \text{(H-5)}$$

Thus, if the supply contains a fraction of outdoor air needed to satisfy the critical zone, the other zones will be overventilated and their return will contain unvitiated or "unused" outdoor air. A fraction, R, of the return air then can be recirculated to supply some of the outdoor air needed by the critical zone. This will reduce the amount of outdoor air needed by the system.

If F is the fraction of outdoor air in the supply to the critical zone, the flow rate of unvitiated (unused) outdoor air in the return from the overventilated zones is,

$$FV_{st} - V_{on} \qquad \text{(H-6)}$$

The fraction of this unvitiated return air that is recirculated is

$$R[FV_{st} - V_{on}] \qquad \text{(H-7)}$$

The total amount of useable outdoor air, V_{st}, in the supply then is,

$$V_{ot} + R\,[FV_{st} - V_{on}] \qquad \text{(H-8)}$$

The ventilation requirement of the critical space is met when the supply air, V_{st}, contains a fraction of outdoor air equal to,

$$FV_{st} = V_{ot} + R[FV_{st} - V_{on}] \qquad \text{(H-9)}$$

From the definitions of the recirculation fraction, R, given by Eq H-2,

$$FV_{st} = V_{ot} + [(V_{st} - V_{ot})/V_{st}][FV_{st} - V_{on}] \qquad \text{(H-10)}$$

Equation H-10 can now be solved for the total outdoor air, or fresh air needed to satisfy all zones.

$$FV_{st} = V_{ot} + FV_{st} - FV_{ot} - V_{on} + V_{ot}\,V_{on}/V_{st} \qquad \text{(H-11)}$$

$$O = V_{ot}[1 - F + V_{on}/V_{st}] - V_{on} \qquad \text{(H-12)}$$

Therefore,

$$V_{ot} = V_{on}/[1 + V_{on}/V_{st} - F] \qquad \text{(H-13)}$$

or substituting the value for F and dividing both sides of the equation by the total supply V_{st}:

$$V_{ot}/V_{st} = [V_{on}/V_{st}]/[1 + ([V_{on}/V_{st}) - (V_{oc}/V_{sc})] \qquad \text{(H-14)}$$

Equation H-14 can be written

$$Y = X/(1 + X - Z) \qquad \text{(H-15)}$$

where

$Y = V_{ot}/V_{st}$, the corrected fraction of outdoor air in the total supply

$X = V_{on}/V_{st}$, the uncorrected fraction of outdoor air in the total supply

$F = V_{oc}/V_{sc}$, the fraction of outdoor air in the supply of the critical zone.

POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effects on the indoor and outdoor environment of the systems and components in their responsibility, while maximizing the beneficial effects which these systems provide, consistent with the accepted standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor or outdoor environment to a greater extent than specified by the standards as established by itself and other responsible bodies.

As an on-going goal, ASHRAE will, through its Standards Committee and extensive technical committee structure, continue to generate up-to-date standards where appropriate and adopt, recommend and promote those new and revised standards developed by other responsible organizations.

Through its Handbook, appropriate chapters will contain up-to-date standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with research and dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations which is pertinent, as guides to updating standards.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use, and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.