62.1 User's Manual

ANSI/ASHRAE Standard 62.1-2004

Ventilation for Acceptable Indoor Air Quality

Published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., with support from the Air-Conditioning and Refrigeration Institute, the National Institute of Standards and Technology, and the U.S. Green Building Council.

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The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is the world's foremost technical society in the fields of heating, ventilation, air conditioning, and refrigeration. Its 55,000 members worldwide are individuals who share ideas, identify the need for and support research, and write the industry's standards for testing and practice. The result of these efforts is that engineers are better able to keep indoor environments safe and productive while protecting and preserving the outdoors for generations to come.

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ASHRAE Research contributed significantly to the material in this book.

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1791 Tullie Circle

Atlanta, GA 30329

Printed in the United States of America.

ISBN 1-931862-80-X

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General Information

The explanatory material, detailed information, figures, and examples contained within this User's Manual are provided to aid the user in designing, installing, and operating buildings in accordance with *Standard 62.1-2004* (referred to in this Manual as *Standard 62.1* or simply the Standard).

Standard 62.1 was written to be code-enforceable, and therefore contains only mandatory language. This Manual does not reproduce the requirements of the Standard, but rather paraphrases and explains them. Intended to be used in conjunction with the Standard, this Manual:

- Offers information on the intent and application of *Standard 62.1;*
- Explains the Standard through the use of sample calculations and examples;
- Encourages the user to apply the principles of good indoor air quality and effective ventilation when designing buildings and building systems;
- Provides useful reference material to assist designers in efficiently completing a successful and compliant design;
- Gives guidance to building operation and maintenance personnel.

This Manual also instructs the user in the application of tools used for compliance with *Standard 62.1-2004*. In particular, a spreadsheet is distributed with this User's Manual that assists in the Ventilation Rate Procedure calculations.

Audience

This User's Manual is intended to be used by:

- Architects and engineers who must apply the Standard to the design of their buildings;
- Those manufacturers of systems and components who choose to provide the industry with complying equipment;
- Plan examiners and field inspectors who will be charged with enforcing the Standard in areas where it is adopted as code;
- General and specialty contractors who must construct buildings in compliance with the Standard; and
- Operators and maintainers who must ensure the compliance of the building throughout its lifespan.

Addenda

Standard 62.1 is a dynamic document undergoing continuous maintenance, with addenda, errata, and interpretations issued throughout its life. As of the publication date of this User's Manual, there have been no approved addenda to *Standard 62.1-2004*. In the future, however, the ASHRAE committee responsible for maintaining the Standard (SSPC 62.1) is expected to approve addenda.

When using this Manual to comply with a code based on *Standard 62.1*, check whether any addenda have been incorporated in that code, and read those addenda carefully. Addenda are posted on the ASHRAE Web site, at www.ashrae.org.

Also, if the adopted code references a version of the Standard prior to 2004, then the information contained within this Manual may not apply.

Official Interpretations

The Standing Standards Project Committee (SSPC) 62.1 provides official interpretations of the Standard upon written request. Interpretations are restricted to the words contained within the Standard itself and cannot encompass design reviews and/or proposals for changes. Address requests for interpretations to the Manager of Standards, ASHRAE, 1791 Tullie Circle, NE, Atlanta, GA, 30329-2305.

The SSPC usually assigns the request to a subcommittee, which then reviews it and develops an interpretation. This interpretation is then voted on by the full committee. A common timeframe for a response is six to twelve months. See informative Appendix G of the Standard for more information on requesting an interpretation.

Interpretations are also posted on the ASHRAE Web site, at www.ashrae.org.

Standard 62.1 Organization

Standard 62.1 is divided into nine sections and eight appendices. Sections 1, 2, and 3 are administrative and do not contain any requirements:

- *Section 1—Purpose* states the purpose of the Standard.
- *Section 2—Scope* describes where the Standard does and does not apply.
- *Section 3—Definitions* provides definitions of terms that are used throughout the Standard.

Sections 4 through 8 are the technical sections of the Standard and contain the technical requirements for the design, installation and operation of ventilation systems in buildings, as well as additional requirements that apply to features of the building other than these systems.

- *Section 4—Outdoor Air Quality* requires that the site and the quality of outdoor air be evaluated to determine whether special design considerations such as cleaning of the outdoor air are needed.
- *Section 5—Systems and Equipment* includes specific requirements for the design of ventilation systems in buildings, as well as the building envelope.
- *Section 6—Procedures* presents methods for determining the volumetric airflow rate of outdoor air that must be brought into the building through the HVAC system(s), as well as requirements for filtration and cleaning of the outdoor air.
- *Section 7—Construction and System Startup* contains requirements that apply during the construction and startup phase of new construction projects.
- *Section 8—Operations and Maintenance* outlines requirements for the operation and maintenance of building ventilation systems after they are constructed.

In addition to the nine primary sections, the Standard contains a Foreword and eight appendices. The Foreword provides a historical perspective on the development of the Standard. The following Appendices are normative and therefore part of the Standard:

- *Appendix A*—Multiple Zone Systems;
- *Appendix E*—Ventilation Rates for Health Care Facilities, Residential Buildings, and Vehicles.

The remaining Appendices are informative and not part of the Standard.

- *Appendix B*—Summary of Selected Air Quality Guidelines;
- *Appendix C*—Rationale for Minimum Physiological Requirements for Respiration Air Based on CO_2 Concentration;
- *Appendix D*—Acceptable Mass Balance Equations for Use with Indoor Air Quality Procedure;
- *Appendix F*—Separation of Exhaust Outlets and Outdoor Air Intakes;
- *Appendix G*—Application and Compliance;
- *Appendix H*—Addenda Description Information.

Organization and Use of the User's Manual

In general, the chapters of this User's Manual follow the organization of the Standard. To aid the user in correlating requirements of the Standard with the explanations in the User's Manual, all major headings in the Manual contain section number references in parentheses. Sections in the Standard are referenced using the symbol "§". For example, a discussion of natural ventilation begins with the heading "Natural Ventilation (§ 5.1)". This allows the user to quickly refer to § 5.1 of the Standard, which gives the requirements for natural ventilation. The corollary is that each section of the Standard has a corresponding section in the User's Manual.

Data and Analysis Tools

The following is a list of tools and documents may be useful to fully apply the Standard. Some of these items, as noted, are only applicable to specific sections of the Standard:

- A current copy of *Standard 62.1-2004* with errata and interpretations.
- Copies of any published addenda to *Standard 62.1-2004*.
- A personal computer and spreadsheet software to run the 62MZCalc spreadsheet, distributed on CD with this Manual.
- Referenced documents such as the 2001 ASHRAE *Handbook—Fundamentals*, the 2000 ASHRAE *Handbook—HVAC Systems and Equipment*, and the 2003 ASHRAE *Handbook—HVAC Applications*.

Acknowledgments

Architectural Energy Corporation (AEC) managed the creation of this User's Manual under contract to the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), Inc. This project was co-sponsored by the Air-Conditioning and Refrigeration Institute (ARI), the National Institute of Standards and Technology (NIST), and the U.S. Green Building Council (USGBC).

Charles Eley oversaw the development of this Manual, performed technical editing, and provided additional elucidating material with regard to the Standard's requirements. Emily Anicich managed the review cycles, comments, and other components of the project. She also edited, indexed, and produced the document. Dale Nelson designed, created, and produced the graphical illustrations in this Manual. Zelaihka Akram provided "pinch hitter" production support on meeting certain deadlines.

Larry Schoen of Schoen Engineering authored Chapters 1, 2, 5, 7, and 8. Steve Taylor of Taylor Engineering wrote the Ventilation Rate Procedure portion of Chapter 6, as well as the Appendix on CO_2 Demand-Controlled Ventilation. Chris Muller of Purafil, Inc. composed Chapter 4 and the Indoor Air Quality Procedure portion of Chapter 6. Larry, Steve, and Chris also provided the original concepts and sketches for many of the graphics included in this Manual.

A Project Management Subcommittee (PMS) chaired by Roger Hedrick guided the project and helped reach resolution on issues as they surfaced. The document benefited greatly from the careful review of the following members of the PMS: Roger Hedrick (GARD Analytics), Andy Persily (NIST), Lynn Bellenger (Pathfinder Engineers), Dennis Stanke (Trane), Eli Howard (SMACNA), Jim Coggins (Select Energy Services), and Brian Rock (University of Kansas). The document further benefited from the review of the following members of SSPC 62.1: Joe Fisher (Cullum Constructors Inc.), Walter L. Raynaud (Raynaud Engineering), and Leon Alevantis (California Department of Health Services). Roger L. Howard (York International) and Waller S. Clements (Waller Clements Consulting) also provided valuable feedback.

1. Purpose

Overview (§ 1.1)

Standard 62.1 sets minimum ventilation rates and specifies the quality of indoor air that is both acceptable to human occupants and minimizes negative effects on their health.

Both occupant perception (but not thermal comfort, which is excluded since it is covered in ASHRAE *Standard 55*) and health issues affect the acceptability of indoor air quality. Therefore, both are relevant to this Standard. Furthermore, its purpose is broader than minimum ventilation rates, encompassing such subjects as moisture control, control of certain contaminant sources, maintenance, and air cleaning.

Indeed, the impact of indoor air quality on health, stated broadly in the Purpose of *Standard 62.1*, is addressed in a number of ASHRAE documents. It remains an important factor in the development and implementation of standards and guidelines that benefit the general public.[1]

Regulatory Application (§ 1.2)

ASHRAE's intentions for regulatory use of the Standard (such as use in codes) include construction of new buildings, additions to existing structures, as well as those specific changes to existing buildings explained in § 7 and § 8.

Existing Buildings (§ 1.3)

While ASHRAE intends the use of the principles, materials, and methods described in the Standard for the improvement of air quality in an existing building, it has not written the material with the regulation of existing buildings in mind, nor has it checked that each provision of the Standard is appropriate for such use.

Therefore, adoption of the Standard as a whole for the building codes, leases, and maintenance contracts of existing buildings can impose requirements that ASHRAE did not consider, some of which may be unreasonable.

Standard 62.1 is intended for guidance in the process of improving indoor air quality in existing buildings. For instance, it could be useful if applied with skilled judgment in IAQ evaluations of existing buildings, improvements to existing spaces, IAQ research studies, property condition surveys, etc.

Users who wish to refer to the Standard for regulatory or contractual use (including building codes, leases and maintenance contracts) should read carefully those sections that they wish to invoke, as well as Appendix G of the Standard.

1. Ad Hoc Committee on Health Impacts in Standards, Report to the Board of Directors, February 6, 2000.

2. Scope

Spaces Covered (§ 2.1)

This Standard sets minimum ventilation rates for all indoor or enclosed spaces with human occupants. In instances where other applicable standards and requirements specify higher ventilation rates, the higher rates should be implemented. Such other applicable standards and requirements may include occupational safety and health regulations, information provided in material safety data sheets (MSDSs), and local building codes.

The scope of *Standard 62.1-2004* still includes all residential spaces, including the ventilation rates in Table 6-1 and Appendix E. Rates that apply strictly to low-rise residential spaces have been removed from the body of the Standard and placed in Appendix E to facilitate the change described in the next paragraph.

Now that *Standard 62.2* for low-rise residential buildings has been approved and released,[2] it is ASHRAE's intention to remove from *Standard 62.1* all those provisions that apply to low-rise residential buildings. However, this action requires a full public review process to meet ASHRAE and ANSI procedural requirements.

Laboratories & Industrial Spaces (§ 2.2)

An industrial space is defined as an indoor environment mainly dedicated to production and/or manufacturing processes. The primary occupants of this space are involved in these processes. Laboratory spaces are not defined in the Standard, but according to participants in a recent ASHRAE forum (7/2/03), they are rooms or buildings where relatively small amounts of hazardous materials are used in scientific research, testing, teaching, or clinical practice. The processes in either of these or similar space types may generate contaminants with characteristics and in quantities dictating that principles of worker safety and industrial hygiene be used to define contaminant control strategies, including ventilation.

Additional requirements for laboratory, industrial and other spaces may be dictated by workplace and other standards, as well as by the processes occurring within the space. The scope of *Standard 62.1-2004* includes laboratory and industrial spaces. However, ASHRAE recognizes that these minimum requirements may be inappropriate for some spaces. For instance, occupational safety or other standards may require the use of special capture ventilation or personal protective equipment that is not covered in this Standard. It should be noted that these additional requirements relate only to industrial spaces and not non-industrial spaces (such as offices) located in industrial facilities. The latter are covered in the scope of the Standard just like similar spaces in non-industrial facilities. On the other hand, requirements related to many aspects of systems (e.g., drain pans and airstream surfaces) would apply to all space types.

2. This residential ventilation standard was approved by the American National Standards Institute (ANSI) in 2003.

No Retroactive Application (§ 2.3)

Users who wish to make retroactive application mandatory are cautioned that this was not ASHRAE's intention, nor has ASHRAE checked that each provision of the Standard is appropriate for such use.

Adoption of the Standard as a whole for existing buildings can impose requirements that ASHRAE did not consider, some of which might be impractical or unreasonable. Users who wish to refer to the Standard for regulatory or contractual use (including building codes, leases and maintenance contracts) should read those sections that they wish to invoke and use informative Appendix G to guide them. This appendix contains suggestions for code adoption authorities.

Contaminants, Not Thermal Comfort (§ 2.4)

The Standard considers the chemical, physical, biological, and thermal qualities of indoor air—especially as they relate to the dual aspects of its purpose: comfort and health.

For example, ozone is a chemical contaminant and particulate matter is a physical contaminant—both of which are considered in § 4. Legionella is a biological contaminant that is considered in § 5. Humidity is a condition taken into account in several sections, including the relative humidity restriction in § 5. However, the purpose of the humidity requirement is to reduce the possibility of biological contamination (an air quality goal) and not to make occupants feel cool and dry (a thermal comfort goal).

Thermal comfort is not within the scope of this Standard. For thermal comfort requirements, see ASHRAE *Standard 55—Thermal Environmental Conditions for Human Occupancy.*

Example 2-A—New Administrative Wing of Industrial Facility

Q

A designer for a new administrative wing of an industrial facility is following internal policy that all designs meet ASHRAE *Standard 62.1*. The wing contains a small industrial production room. What portions of the new or existing facility are within the scope of ASHRAE *Standard 62.1*?

A

The new wing is within the scope of the Standard, in accordance with § 2.3. Even the production room is covered since industrial spaces are not exempted. Not only do the ventilation rate requirements apply in the production room and the rest of the addition, but so do all the other requirements, for example, outdoor-air filtration in § 4 and airstream surfaces in § 5. Additional occupational safety or other standards may have even stricter requirements.

With regard to the existing facility, there is insufficient information to address its applicability. The Standard is not intended to be applied retroactively when used as a mandatory regulation or code in accordance with § 2.3, but any regulatory or code body still has that option, and an internal policy can certainly invoke such requirements. The decision made by such bodies should be informed by the fact that ASHRAE did not write or intend the requirements to be for retroactive mandates and issues of practicality or reasonableness may arise.

Example 2-B—Retroactive Application of the Standard

Q

A government agency is a prospective tenant in an existing office building. The lease requires that the space meet ASHRAE *Standard 62.1-2004*. Five years ago, the air handler and all the ductwork were replaced and are in excellent condition. Will the requirements of *Standard 62.1* require replacement of the five-year-old air handler?

A

The air handler may or may not need replacement or modification to meet the new requirements in § 5. Even if it is in excellent condition, it should be examined carefully in light of the new requirements in *Standard 62.1-2004*. In general, the requirements of the Standard should be evaluated on an individual basis for their applicability in existing buildings to achieve effective upgrades and to avoid triggering requirements that might be unreasonable or impractical.

Example 2-C—Survey Indicates 35% Dissatisfaction

Q

A survey of occupant satisfaction in a school building found that 35% of teachers and students were dissatisfied with air quality. Is the building compliant with the Standard?

A

The building is compliant with the Standard as long as it is designed, constructed, operated, and maintained to meet the requirements of § 4, § 5, § 6, § 7, and § 8 regardless of the level of occupant satisfaction or dissatisfaction. This high a level of dissatisfaction may warrant further investigation. While checking into occupant complaints may be advisable, it is not required by the Standard.

Limitations of the Standard (§ 2.5)

Indoor air quality is acceptable when there are no known contaminants at concentrations determined to be harmful to building occupants, as determined by cognizant authorities, and when a substantial majority (80% or more) of those persons exposed to the indoor air do not express dissatisfaction with its quality. This definition does not create any criteria in terms of maximum concentrations of contaminants or verification that occupants are satisfied.

Acceptable indoor air quality is difficult to define, and therefore, difficult to achieve. The Standard represents the collective knowledge and judgment of ASHRAE and the individuals and organizational representatives who serve on its committees. The body of the Standard contains the requirements intended to meet the indoor air quality goal, but it neither guarantees nor requires its achievement. Achievement of 80% satisfaction or elimination of harmful concentrations of known contaminants is not required to comply with the Standard. The following paragraphs describe some of the reasons why.

The ventilation rates in the Standard were chosen based upon a normal space without unusual contaminants. However, achieving agreement among experts on the exact characteristics of a normal space, as well as just what constitutes an unusual contaminant, can be challenging, especially when writing a standard in mandatory and enforceable language. Even an excess of usual contaminants, such as common office supplies, can easily overwhelm the capability of ordinary dilution ventilation.

The Standard does not cover all of the many factors that affect a human occupant's acceptance of indoor air quality, such as:

- Air temperature,
- Noise,
- Lighting,
- Psychological stress, and
- Humidity.

However, research and practice have shown that low temperature correlates with improved perception of air quality.[3] Annoyances in the space such as noise and bad lighting may not directly affect occupants' perception of air quality, but may decrease their tolerance and therefore their ability to accept the quality of the indoor air.

What is acceptable to one person or group may not be acceptable to another. Sensitive populations (such as children, the infirm, or the elderly) can succumb to infectious agents or irritations even as a population of healthy adults remains unaffected. Odor perception varies among people and even among different populations of healthy adults. Context can also affect acceptability. For instance, an odor that is acceptable in a cafeteria might be unacceptable in a fine restaurant.

The Standard addresses certain contaminants in outdoor air under specific circumstances. For example, § 4 sets requirements for the evaluation of local and regional air quality and § 6 specifies the removal of particulate matter and ozone in some cases. However, there are many other contaminants in outdoor air that can adversely impact indoor air quality. Some of these contaminants, such as nitrogen dioxide or carbon monoxide, are not required by this Standard to be removed from air, even though they are regulated contaminants with published acceptable levels.[4] Even for contaminants that are covered, such as ozone, low levels may result in irritation either directly or indirectly from indoor chemical reactions.[5]

The Standard does not prohibit further enhancements to buildings, systems, and practices beyond the minimum requirements.

3. Fanger, P.O., "The New Comfort Equation For Indoor Air Quality," *ASHRAE Journal* (October 1989): 33–38
4. National Primary and Secondary Ambient Air Quality Standards, Code of Federal Regulation, Title 40 Part 50 as amended July 1, 1987, U.S. Environmental Protection Agency.
5. Weschler, C. J., "Chemical Reactions Among Indoor Pollutants: What We've Learned In The New Millennium" *Indoor Air* 14 (August 2004): 184.

3. Definitions, Abbreviations & Acronyms

Definitions

The Standard contains definitions for the following terms:

Acceptable indoor air quality

Air-cleaning system

Air conditioning

Air, ambient

Air, exhaust

Air, indoor

Air, makeup

Air, outdoor

Air, recirculated

Air, return

Air, supply

Air, transfer

Air, ventilation

Breathing zone

Cognizant authority

Concentration

Conditioned space

Contaminant

Energy recovery ventilation system

Exfiltration

Industrial space

Infiltration

Mechanical ventilation

Microorganism

Natural ventilation

Net occupiable space

Occupiable space

Odor

Readily accessible

Ventilation

Volume, space

Zone

Abbreviations & Acronyms

The following is a list of abbreviations and acronyms used in this Manual.

µg	microgram
AABC	Associated Air Balance Council
AC	air conditioning
ACGIH	American Conference of Governmental Industrial Hygienists
AIRS	Aerometric Information Retrieval System
AMCA	Air Movement and Control Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	American Society for Testing and Materials
BOMA	Building Owners & Managers Association (now known as BOMA International)
C	Celsius
cfm	cubic feet per minute
CO	carbon monoxide
CO_2	carbon dioxide
COC	contaminant of concern
db	dry-bulb
DCV	demand-controlled ventilation
DDC	direct digital control
dp	dewpoint
DX	direct expansion
EPA	Environmental Protection Agency
ETS	environmental tobacco smoke
F	Fahrenheit
fpm	feet per minute
ft	feet
hr	hour
HVAC	heating, ventilating, and air conditioning
IAQ	indoor air quality
IAQP	Indoor Air Quality Procedure
in.	inch
kg	kilogram
L	liter
lb	pound
LEED	Leadership in Energy and Environmental Design
m	meter
mdb	mean coincident dry-bulb
MERV	minimum efficiency reporting value
mg	milligram
mil	one thousandth of an inch
ml	milliliter
mm	millimeter
MSDS	Material Safety Data Sheet
MW	molecular weight
mwb	mean coincident wet-bulb
NAAQS	National Ambient Air Quality Standards
NEBB	National Environmental Balancing Bureau
NFPA	National Fire Protection Association
NISTIR	National Institute of Standards and Technology Interagency Report
No.	number
NOx	oxides of nitrogen
O&M	operations and maintenance
O_3	ozone
OA	outdoor air
OAQPS	Office of Air Quality Planning and Standards
oz	ounce
Pa	pascal
PC	personal computer
PM_{10}	particulate matter with an aerodynamic diameter less than or equal to a nominal 10 micrometers
$PM_{2.5}$	particulate matter with an aerodynamic diameter less than or equal to a nominal 2.5 micrometers
ppbv	parts per billion, volumetric
ppm	parts per million
rh	relative humidity
SHR	sensible heat ratio (sensible heat divided by total heat)

SMACNA	Sheet Metal and Air Conditioning Contractors' National Association
SO_2	sulfur dioxide
SSPC	Standing Standards Project Committee
T	time
TABB	Testing Adjusting and Balancing Bureau
TVOC	total volatile organic compounds
USGBC	United States Green Building Council
UL	Underwriters Laboratories
VAV	variable air volume
Vdc	volts direct current
VOC	volatile organic compound
VRP	Ventilation Rate Procedure
w.g.	water gauge
wb	wet-bulb
wc	water column
yr	year

4. Outdoor Air Quality

Overview

Standard 62.1 continues the tradition of its previous versions by specifying minimum ventilation rates and indoor air quality that will be acceptable to the human occupants of a building. It considers chemical, physical, and biological contaminants that can affect air quality—yet acknowledges the fact that the standards may not achieve acceptable indoor air quality in all buildings. This is especially so in areas where the outdoor air is of a questionable quality and may not be clean enough for use in general ventilation.

When the quality of outdoor air is poor, ventilation may not be effective in improving indoor air quality. Bringing in contaminated outdoor air may only result in diluting one group of pollutants while increasing levels of another. For example, internally generated bioeffluents may be diluted, but levels of combustion gases may increase.

A similar situation could occur if local outdoor sources of pollutants (such as auto exhaust, trash storage, industrial activities, etc.), were to be carried into the building by the HVAC system.

The act of bringing in outdoor air in these two cases can increase the odor and irritation level of ventilation air. Therefore, these buildings may be unable to achieve acceptable indoor air quality without air cleaning—even if they meet all the requirements of this Standard.

Regional Air Quality (§ 4.1)

For reasons such as those just described, the Standard requires that an investigation of outdoor air quality be performed in accordance with § 4.1 and § 4.2 prior to the completion of the ventilation system design. Results of this investigation must be documented according to § 4.3.

The status of compliance with national ambient air quality standards must be determined for the geographic area of the building site. In the United States, compliance status is either in "attainment" or "nonattainment" with the Environmental Protection Agency's (EPA) National Ambient Air Quality Standards (NAAQS).

The Clean Air Act (last amended in 1990) charged the Environmental Protection Agency (EPA) with the responsibility of setting the NAAQS. In other parts of the world, compliance is per the prevailing regional air quality standards.

A distinction between primary and secondary standards was made in the Clean Air Act.

- Primary standards are set to protect the health of the public, including sensitive populations such as asthmatics, children, and the elderly.
- Secondary standards are set to protect public welfare, such as decreased visibility and damage to crops, animals, vegetation, and buildings.

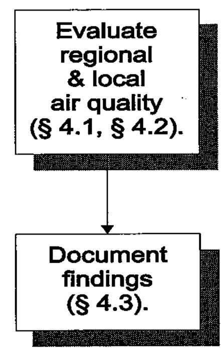


Figure 4-A—Outdoor Air Quality Flow Chart

The EPA Office of Air Quality Planning and Standards (OAQPS) establishes the NAAQS based on six principle pollutants (called "criteria" pollutants[6]):

- Ozone,
- Particulate matter,
- Carbon monoxide,
- Sulfur oxides,
- Nitrogen dioxide, and
- Lead.

Because of the different effects each pollutant has, some pollutants have standards for both long-term and short-term averaging times. The short-term standards are designed to protect against acute or short-term health effects, while the long-term standards are designed to protect against chronic health effects.

6. Further discussion of criteria pollutants can be found at http://www.epa.gov/oar/oaqps/montring.html#criteria.

Table 4-A—NAAQS Table (Table 4-1 in the Standard)

CONTAMINANT	LONG-TERM AVERAGING µg/m³	ppm		SHORT-TERM AVERAGING µg/m³	ppm	
Sulfur Dioxide	80	0.03	1 year	365*	0.14*	24 hours
Particles (PM_{10})	50†	–	1 year	150*	–	24 hours
Carbon Monoxide				40,000*	35*	1 hour
Carbon Monoxide				10,000*	9*	8 hours
Oxidants (Ozone)				235‡	0.12‡	1 hour
Nitrogen Dioxide	100	0.055	1 year			
Lead	1.5	–	3 months‖			

** Not to be exceeded more than once a year*

† Arithmetic mean

‡ Standard is attained when expected number of days per calendar year with maximum hourly average concentrations above 0.12 ppm (235 µg/m³) is equal to or less than 1, as determined by Appendix H to subchapter C, 40 CFR 50.

‖ Three month period is a calendar quarter

The maximum concentrations of the criteria pollutants are shown in Table 4-A. This table shows only the primary standards, as these are the ones of concern to Standard 62.1.[7]

When an area does not meet the threshold concentration of one or more of the criteria pollutants, it may be subject to the formal rule-making process that designates it as nonattainment.[8] See Figure 4-B for a map of counties designated as nonattainment for one or more of the criteria pollutants at the time of publication. The technical details underlying these classifications are discussed in the Code of Federal Regulations, Part 81 (40 CFR 81).[9]

The EPA's ambient air quality monitoring program[10] is carried out by state and local agencies and consists of monitoring stations that measure the criteria pollutants.

The data collected from the air pollution monitors is combined into several databases that aid in diagnosing problem areas. The Aerometric Information Retrieval System (AIRS) is one of the largest databases containing monitoring information and can be a primary source of outdoor air quality data needed for compliance with § 4.1.[11] However, § 4.1 does not require consultation of underlying raw data. All it requires is the determination of compliance status, which in the United States is either attainment or nonattainment.

7. For the full and latest NAAQS, visit http://www.epa.gov/air/criteria.html.
8. "Nonattainment" is a term used to describe a geographic area that does not meet the national ambient air quality standards (NAAQS).
9. *Green Book Nonattainment Areas for Criteria Pollutants—Criteria Pollutants,* U.S. EPA, Washington, D.C., http://www.epa.gov/oar/oaqps/greenbk/o3co.html
10. The Ambient Air Monitoring Program, United States Environmental Protection Agency, Washington, D.C., http://www.epa.gov/oar/oaqps/qa/monprog.html#Top
11. For more information about the AIRS Database, visit: http://www.epa.gov/airs/ or http://www.epa.gov/air/data/. For more general information about the EPA's outdoor air quality monitoring programs, visit: http://www.epa.gov/oar/oaqps/montring.html, http://www.epa.gov/oar/oaqps/qa/monprog.html, or http://www.epa.gov/ttn/amtic/.

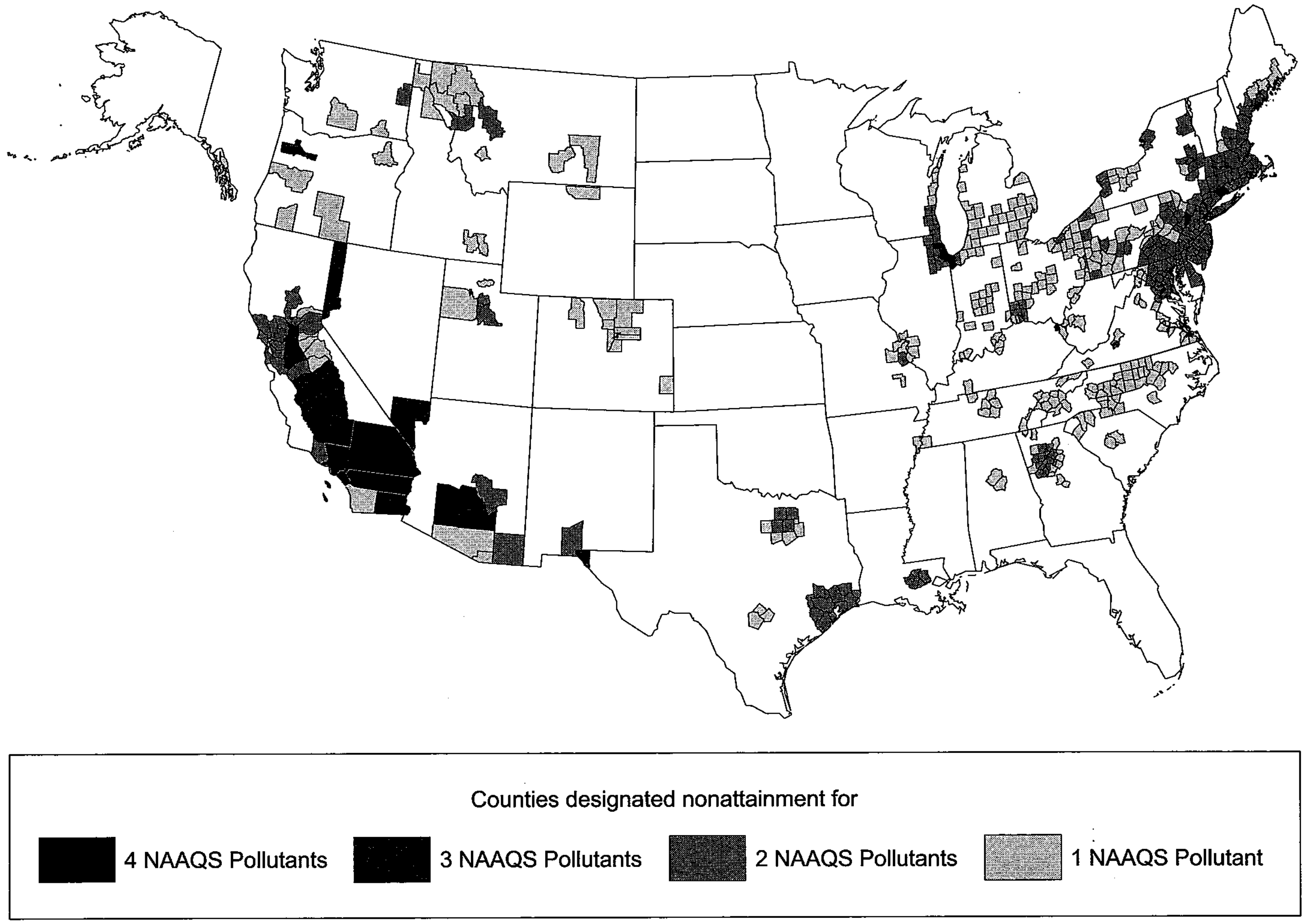


Figure 4-B—Counties Designated Nonattainment for One or More NAAQS Pollutants

Local Air Quality (§ 4.2)

An observational survey of the building site and its immediate surroundings must be conducted during hours the building is expected to be normally occupied. This is to identify additional potential local sources of contaminants that may be of concern if allowed to enter the building. Sources of local contaminants could include reentrainment of building exhaust, emissions from surrounding facilities, or activities going on near the building. For example, site-specific contaminant sources should be noted and efforts made to identify likely contaminant types and their potential impact (odors, irritation, allergic reactions, etc.) on building occupants. The relationship of a building's outdoor air intake(s) to those local sources identified, along with prevailing winds and building geometry, can be very important factors. This is especially true for ground-level intakes.

Examples of local sources of contamination could include:

- Toilet/kitchen exhaust;
- Exhaust from smoking lounges;
- Exhaust from restaurants;
- Print shop/photo developing exhaust;

- Cooling towers;
- Automobile traffic;
- Parking garages;
- Dumpsters,
- Loading docks;
- Helicopter pads;
- Emergency generators;
- Manufacturing plants;
- Industrial facilities;
- Landfills.

Documentation (§ 4.3)

The information gathered during outdoor air quality investigation must be documented and reviewed with the building owners and/or their representatives.

Regional Air Quality Compliance

Air quality data, including attainment[12] or nonattainment status, must be obtained from one of the EPA's ambient air quality monitoring databases (such as AIRS) and included in the report. If multiple monitors exist near the site, you may wish to supplement compliance status with data from the one in closest proximity to the building, or the one upwind of prevailing breezes.

Local Air Quality

The Standard suggests including the following in the completed air quality investigation; however, this information is not required.

- *Date and time of observations*: As noted above, the survey must be done during a time when the building is expected to be normally occupied and when local pollutant sources might have the greatest impacts on building

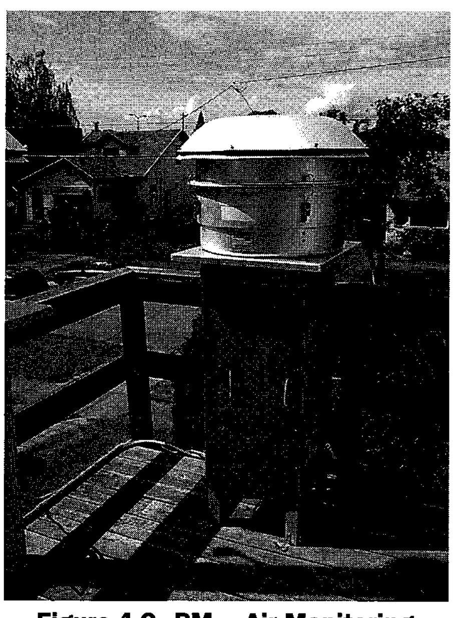


Figure 4-C—PM_{10} Air Monitoring Sampler

Photo courtesy Oregon Department of Environmental Quality.

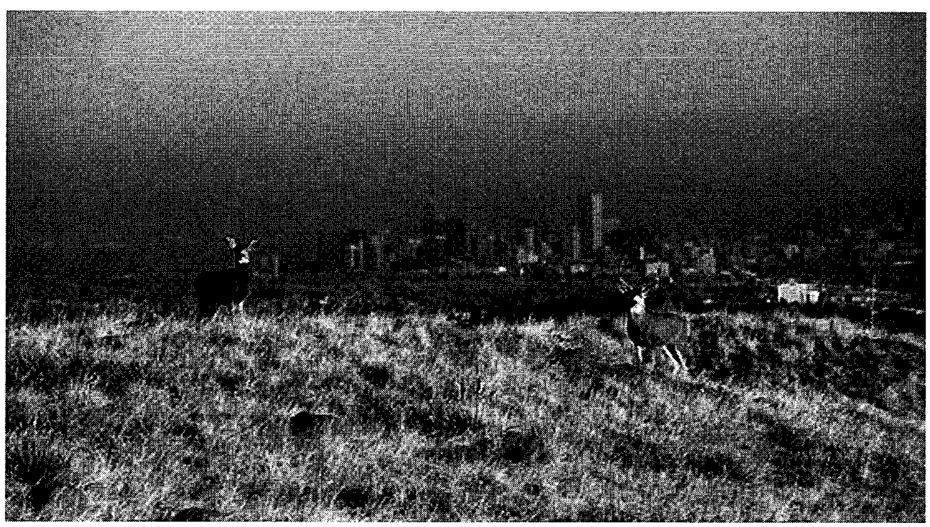


Figure 4-D—Denver Air Quality

Denver has a history of air quality problems. Because of the local topography and weather patterns, pollution from urban sources is sometimes suspended over the metropolitan area, resulting in a "brown cloud" over the region. The EPA has classified the Denver/Boulder region as a nonattainment area for carbon monoxide (CO) and particulate matter (PM). Photo courtesy National Renewable Energy Laboratory.

12. "Attainment" is a term used to describe a geographic area that meets or does better than the national ambient air quality standards (NAAQS).

occupants (e.g., morning/afternoon rush hours for automobile exhaust, lunch hour for cooking/food odors).

- *Area surveyed*: The local survey might include the building perimeter, areas where outdoor air openings are likely to be located, the roof, and all locations of main public access. Loading docks, general work areas, and special use areas may also be important to include.
- *Description of nearby facilities with potential pollution impact on the site*: It may be useful to include the locations and types of nearby commercial properties (restaurant, dry cleaner, etc.), industrial facilities, manufacturing plants, food processing facilities, power plants, incinerators, etc.
- *Observation of odors or irritants*: Depending on the time and date of the local survey, suspected local sources of odors or irritants might not be observed. These may be seasonal in nature, or may be the result of batch processing or batch-type operations at nearby facilities. In the event that first-hand efforts to gauge the type and relative severity of odor/irritant episodes first hand are not feasible or practical, the designer may have to rely on occupant reports, observations, and experiences.
- *Description of visible plumes or air contaminants*: Source location(s), appearance, persistence in the air (continuous or batch-type), etc., of dust or smoke plumes from nearby facilities or installations may be valuable information for a complete site survey.

Figure 4-E—Air Monitoring Station

Photo courtesy Oregon Department of Environmental Quality.

- *Description of nearby sources of vehicle exhaust*: Vehicle exhaust ingested from outdoors can become a major indoor air pollutant source. Location of major highways and roads, public transportation routes, traffic signals, parking garages, etc., may be valuable information for the complete site survey.
- *Direction of prevailing winds*: This information can be obtained by direct monitoring (check to see if the building has a wind gauge or weather station), from local weather stations, the National Climatic Data Center website,[13] or the U.S. National Weather Service.[14] Carefully consider the sources that are located upwind..

Summary

Compliance with § 4 requires determination of the status of compliance with NAAQS and an observational survey of the building site and its immediate surroundings. These findings must be documented and

13. National Climatic Data Center, Asheville, North Carolina, http://www.ncdc.noaa.gov/oa/ncdc.html
14. National Oceanic and Atmospheric Administration, National Weather Service, United States Department of Commerce, Silver Spring, MD, http://www.nws.noaa.gov/

reviewed with the building owners. Documentation must include a conclusion relative to the acceptability of outdoor air quality.

If the building is located in a nonattainment area for criteria pollutants and/or if there are local sources of contamination of type(s) and concentration(s) that might prove problematic upon introduction into the building, consideration may be given to the design features that will reduce the presence of such contaminants. This may include appropriate selection of air intake locations, and whether or not to incorporate an airside economizer and special air cleaning systems in the design of the makeup air handling system(s). See § 5.6 for specific requirements for clearances of air intakes from contaminant sources.

If outdoor air is deemed to be unacceptable for general ventilation, and air cleaning is be considered or is going to be used, one might also consider the use of the IAQ Procedure (§ 6.3) in lieu of the Ventilation Rate Procedure (§ 6.2) for the ventilation system design. The use of air cleaning with recirculation could allow for a reduction in the amount of outdoor air required with a concurrent reduction in associated operational energy costs. Regardless, the designer must review the results of the evaluation with the building owner or client, so that they can make informed decisions related to outdoor source contaminants.

5. Systems & Equipment

Overview

This section discusses general requirements of ventilation systems and equipment. Section 5.1 addresses natural ventilation systems and § 5.2, § 5.4, and § 5.5 address mechanical ventilation systems. All other sections include requirements that may apply to both passive and mechanically ventilated systems. In many cases, the requirements apply only when particular features of the building or system are present.

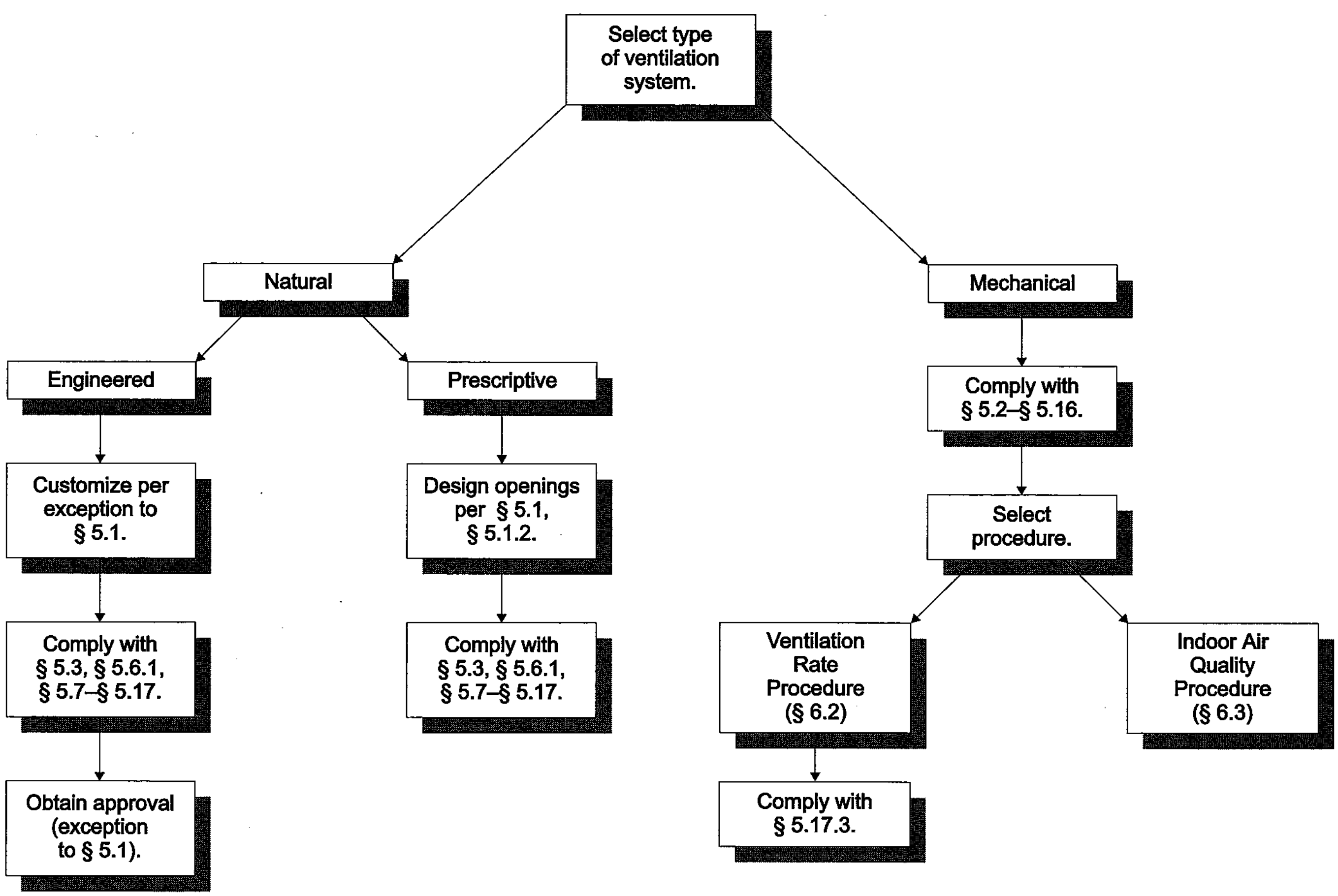


Figure 5-A—Systems & Equipment Flow Chart

Natural Ventilation (§ 5.1)

Natural ventilation systems must be designed to meet the prescriptive requirements of this section, except for engineered natural ventilation systems approved by the authority having jurisdiction. In either case, natural ventilation systems are permitted in lieu of, or in conjunction with, mechanical ventilation systems.

Studies of naturally ventilated buildings have shown fewer sick building complaints overall. Relative to natural ventilation, mechanical air conditioning (with or without humidification) was consistently associated with an increase of approximately 30–200% in the incidence of one or more sick building syndromes, although the reasons for this are not fully understood.[15]

However, under some atmospheric and wind conditions, natural ventilation may not provide sufficient airflow to ensure acceptable indoor air quality. Because operable openings such as windows and doors must be open, and occupants may or may not sense unacceptable contaminant levels, negative health effects can result. Natural ventilation should be used with caution in spaces with unusually high indoor source strengths where contaminant concentrations may rise to unacceptably high levels when natural ventilation systems are disabled, such as during inclement weather.

Prescriptive Requirements (§ 5.1.1 and § 5.1.2)

The prescriptive requirements for natural ventilation are as follows:

- Naturally ventilated spaces must be permanently open to and within 25 ft (8 m) of operable wall or roof openings to the outdoors, the openable area of which is a minimum of 4% of the net-occupiable[16] floor area being naturally ventilated. (The net occupiable floor area is measured from the inside surfaces of the walls, excluding permanently enclosed obstructions such as shafts and columns.)
- Where openings are covered with louvers, insect screens, or otherwise obstructed, openable area must be based on the free unobstructed area through the opening.
- Where interior spaces without direct openings to the outdoors are ventilated through adjoining rooms, the opening between rooms must be permanently unobstructed and have a free area of not less than 8% of the area of the interior room nor less than 25 ft^2 (2.3 m^2).
- The means to open required operable openings must be readily accessible[17] to building occupants whenever the space is occupied.

The 4% and 8% criteria have been selected to be consistent with model building codes in the United States.

Exception to Prescriptive Requirements (Exception to § 5.1)

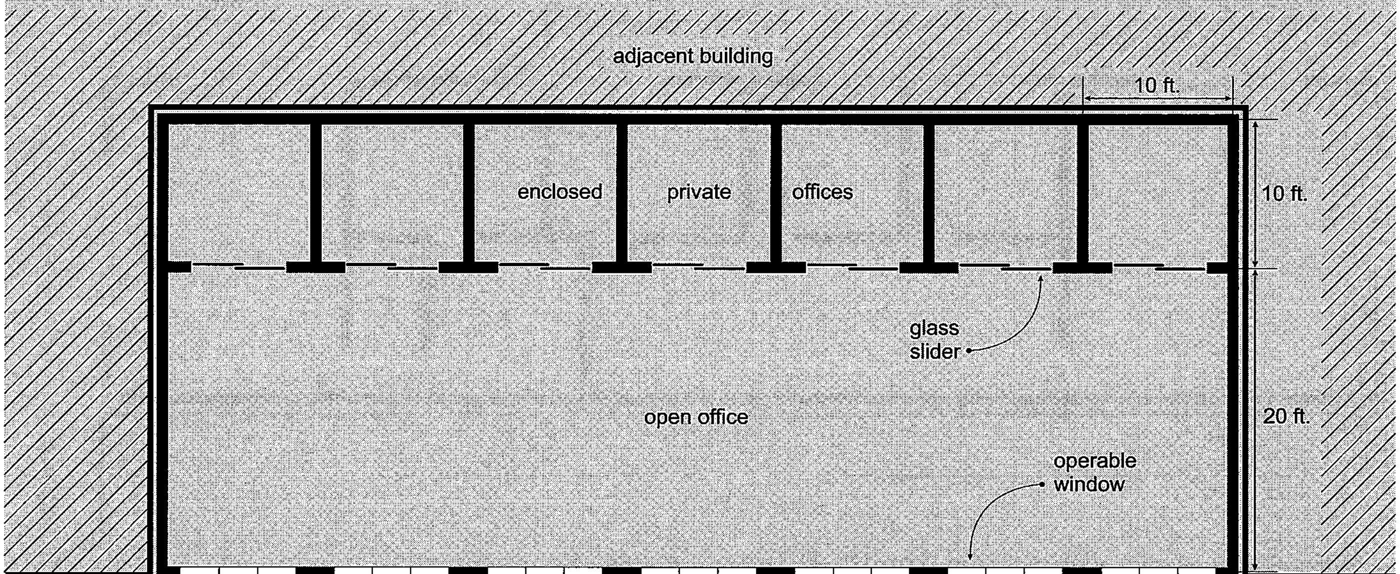
The Standard has an exception for engineered natural ventilation systems when approved by the authority having jurisdiction. Such systems may comply without meeting the prescriptive requirements described above. For instance, a room that exceeds 25 ft (8 m) in depth can comply with the Standard if the natural ventilation system is engineered and approved by the authority having jurisdiction as sufficiently ventilated by perimeter windows or other means.

Engineered natural ventilation systems are not explicitly defined by the Standard, but might be expected to take local wind conditions into account, use stack effects, and take advantage of other natural forces to move air through the building in an acceptable manner. The burden is on the design professional to engineer a naturally ventilated system that works, but no specific pass/fail criteria are given by the Standard.

15. Seppanen et al., "Association of ventilation system type with SBS symptoms in office workers," *Indoor Air* 12 no. 2 (June 2002): 98
16. Defined as an enclosed space intended for human activities, the term occupiable space excludes those spaces intended for other purposes, such as storage rooms and equipment rooms that are occupied only upon occasion and for brief periods of time.
17. "Readily accessible" describes the quality of being able to reach a control or device quickly, without having to climb over or remove obstacles. Those individuals for whom ready access is required should not be required to resort to portable ladders, chairs, or other climbing aids.

Example 5-A—Naturally Ventilated Enclosed Private Offices on Interior

Q



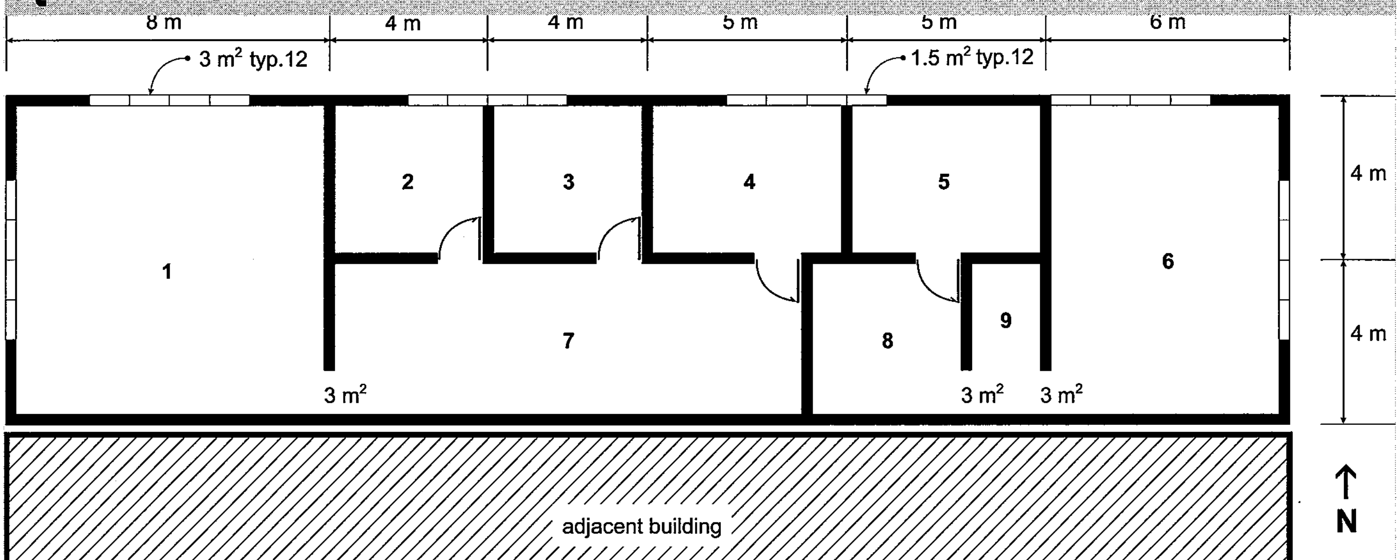
An open office area is located along an exterior wall that has operable windows. The space has a depth of 20 ft. A series of 10 ft x 10 ft private offices are located in the back of the space. Each private office has a sliding glass door that is 6 ft X 8 in. high and 6 ft wide (rough opening). Do the private offices meet the prescriptive requirements for natural ventilation?

A

No, the example does not meet the requirements for two reasons. The openings between the private offices and the open office are not "permanently unobstructed" since the sliding glass doors may be closed. A permanently unobstructed free area of at least 8 ft^2 is required for each private office (8% of 100 ft^2). Finally, the back of the offices are more than 25 ft from an operable window so they do not meet the requirements. The depth of the open office area would need to be 15 ft or less for the 10 ft deep private offices to meet this requirement.

Example 5-B—Natural Ventilation Prescriptive Requirements

Q



Which of the spaces numbered 1 through 9 meets the prescriptive requirements for natural ventilation?

A

Spaces 1, 2, 3, 4, 6, and 9 meet the requirements. Spaces 5, 7, and 8 do not. See the following table for a summary of the tests of the prescriptive criteria. Spaces 1, 2, 3, 4, and 6 all have direct opening areas larger than 4% and therefore qualify as naturally ventilated spaces. Spaces 7 and 8 are connected to naturally ventilated spaces through permanently unobstructed openings. Space 8 is within eight meters of the north wall, but the opening to the north has a door so this does not count. The space is more than eight meters from the east wall which has the permanently unobstructed opening, therefore, it does not meet the requirement.

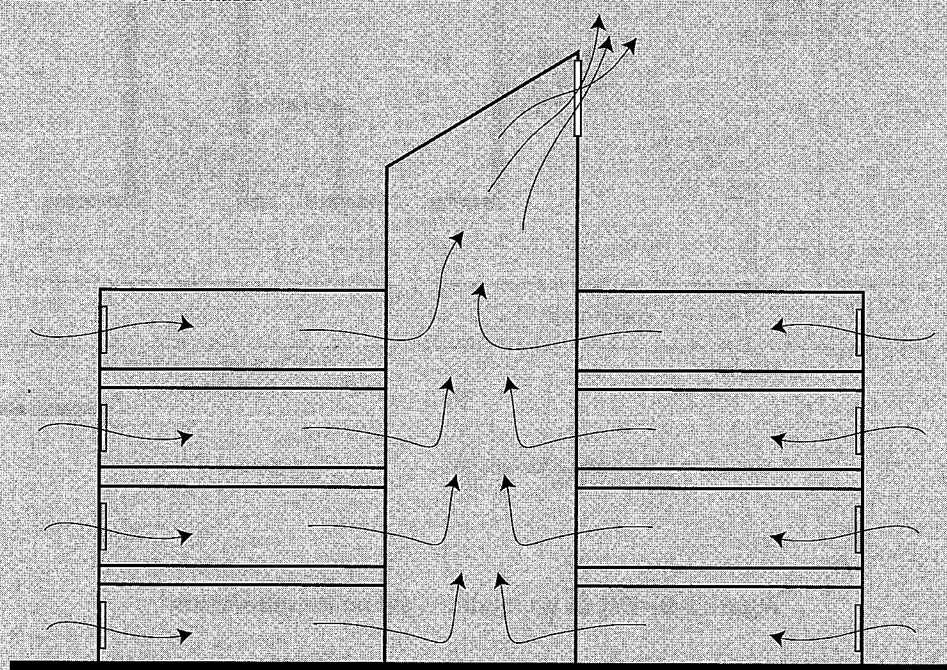
Space No.	Width (m)	Depth (m)	Floor Area (m^2)	Gross Window Area (m^2)	Direct Opening Area (m^2)	Direct Opening (%)	Meets Direct Criterion?	Indirect Opening Area (m^2)	Indirect Opening Area (%)	Meets Indirect Criterion?	Within 8 m of Opening?	Meets Prescriptive?
1	8	8	64	24	4.8	7.5%	Y	-	-	N	Y	Y
2	4	4	16	6	2.4	15%	Y	-	-	N	Y	Y
3	4	4	16	6	2.4	15%	Y	-	-	N	Y	Y
4	5	4	20	4.5	1.8	9%	Y	-	-	N	Y	Y
5	5	4	20	1.5	0.6	3%	N	-	-	N	Y	N
6	6	8	48	12	4.8	10%	Y	-	-	N	Y	Y
7	12	4	48	-	-	-	N	3	6.3%	N	N	N
8	4	4	16	-	-	-	N	3	18.8%	Y	N	N
9	2	4	8	-	-	-	N	3	37.5%	Y	Y	Y

Space no. is the number of the space shown on the figure above.
Width is the dimension of the room from left to right of figure shown.
Depth is the dimension of the room from top to bottom of figure shown.
Floor area is the width multiplied by the length.
Direct opening area is the area of the operable opening (20% of the gross window area for 3 m² windows, 40% of the gross window area for the 1.5 m² windows) direct from the room to the outdoors.
Direct opening in percentage is the direct opening area divided by the floor area.
Direct criteria are met if the direct opening percentage is greater than 4%.
Indirect opening area is the area of the opening between the interior area and the directly ventilated adjoining room.
Indirect opening in percentage is the indirect opening area divided by the floor area.
The indirect criteria are met if the indirect opening percentage is greater than 8%.
Meets prescriptive criteria only if within 8 m of wall and either the direct criteria or the indirect criteria are met.

Example 5-C—Engineered Natural Ventilation System

Q

A designer uses a central atrium space with openings at the top of the atrium. The atrium creates a thermal stack effect that draws outside through the exterior walls across the occupied spaces and into the atrium space, where it is exhausted at the top. Computational fluid dynamics are used to show that the ventilation rate through the occupied spaces is maintained at adequate levels for average wind conditions and temperature for each month. The distance between the exterior walls and the atrium walls is 70 ft so spaces in the center of the occupied space are more than the prescriptive requirement of 25 ft. Does this system qualify as an engineered natural ventilation system and is it exempt from the prescriptive natural ventilation requirements of the Standard?



A

Yes, it may be considered an engineered system, provided the authority having jurisdiction approves. The burden is on the design engineer to document, convince, or otherwise demonstrate to the authority having jurisdiction that the system maintains adequate ventilation rates.

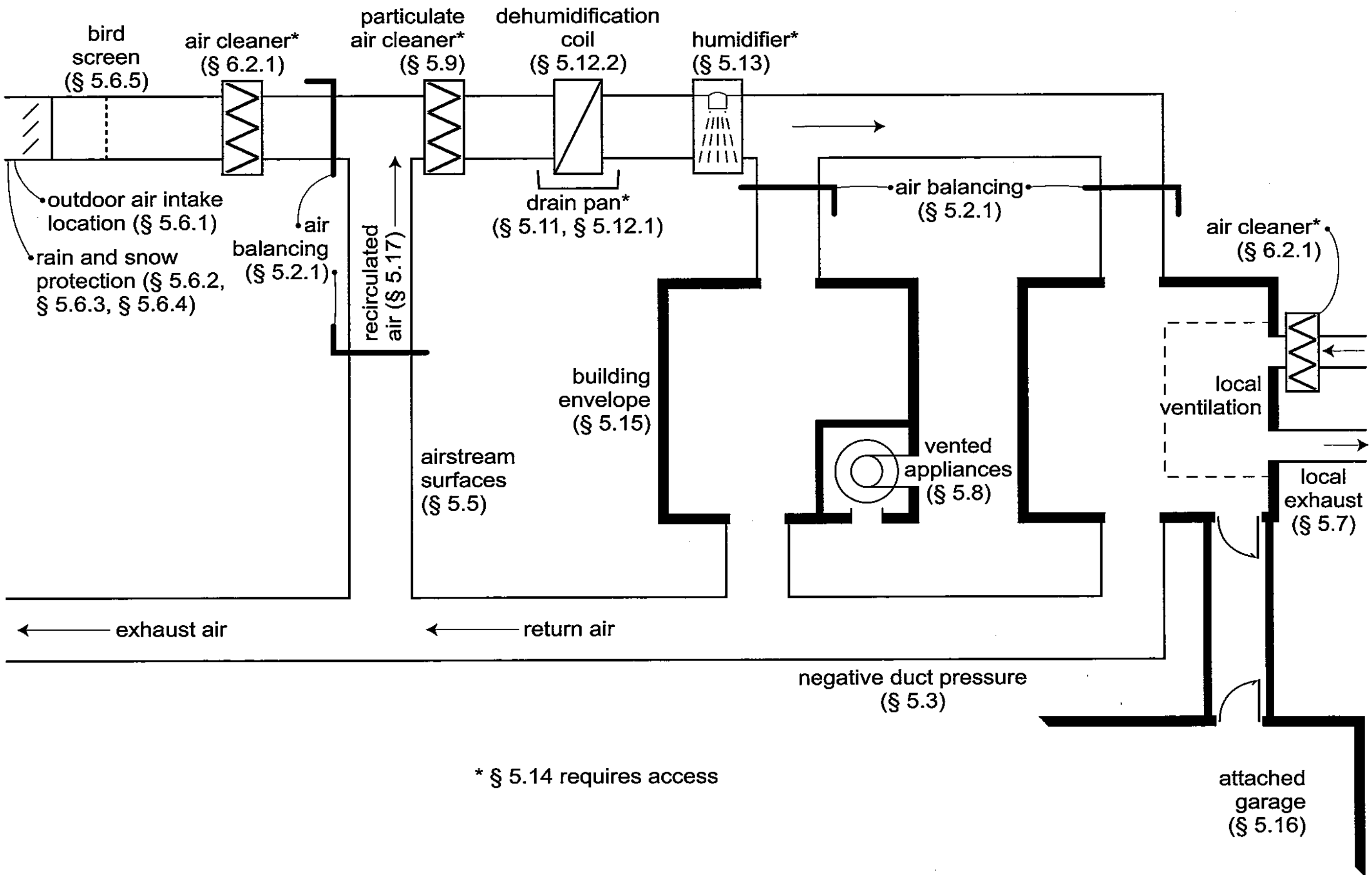


Figure 5-B—Key to Ventilation System Requirements

Ventilation Air Distribution (§ 5.2)

This subsection handles three specific requirements related to air balancing, plenum systems, and design documentation.

Designing for Air Balancing (§ 5.2.1)

Mechanical ventilation systems are required to include a means of adjustment such that the minimum ventilation airflow specified in § 6 can be maintained under any load condition. In many systems, this will include manual dampers to adjust the main outdoor air intake mixture and the supply airflow to each ventilation zone, as well as a means to adjust fan capacity, often by adjusting fan speed. After installation, actual airflow values are adjusted to match those specified in the design documents.

Plenum Systems (§ 5.2.2)

Some systems are configured so that a ceiling or floor plenum is used as a mixing chamber to both recirculate return air and to distribute ventilation air to terminal units. These terminal units may be above the ceiling or beneath the floor. It is not sufficient to deliver the correct total amount of outdoor air into the plenum and assume that it arrives in the proper quantity at each terminal. The system must be engineered so that the correct quantity of air arrives at each ventilation zone, as mandated by § 5.2.2. While this performance requirement does not dictate the exact method of engineering, direct ducting of the air to each terminal unit satisfies the requirement. After the system is constructed, tracer gas testing may be used to confirm that adequate outdoor air is reaching each unit, but this is a field verification procedure, not a design procedure. Section 5.2.2 doesn't specifically require such field verification. Another acceptable option is to provide separate outdoor air inlets for each ventilation zone.

Figures 5-C through 5-F show some examples of correct and incorrect ways to provide outdoor air to a plenum system. Figure 5-C is correct because outdoor air is directly ducted, however, this is not truly a plenum system. Figure 5-D is correct because the outdoor air is provided close to each unit. Figure 5-E, on the other hand, is incorrect, because air is supplied in the vicinity of one unit only and under ordinary circumstances will not reach the other unit. This could only meet the requirement if is could be shown that sufficient air gets to the remote system, perhaps by mixing between the zones. Figure 5-F is correct because air is discharged close to each unit with a means to balance.

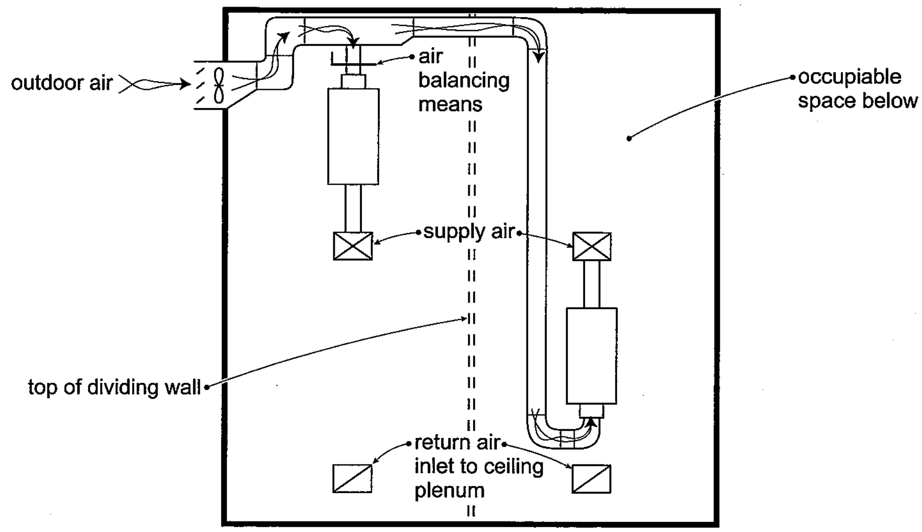


Figure 5-C—Correct Plan of Plenum System With Direct Ducting

This design meets the requirement because balancing dampers may be adjusted to ensure that the proper share of outdoor air is delivered to each fan system.

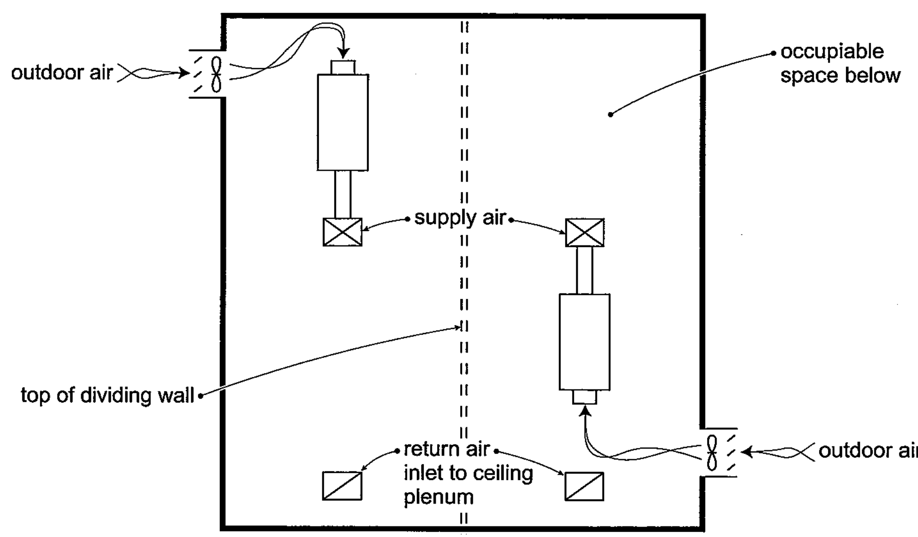


Figure 5-D—Correct Plan of Plenum System With Separate Outdoor Air Inlets

In this case, the design meets the requirements because outdoor air is provided separately to each ventilation zone.

Documentation (§ 5.2.3)

Design documentation for air distribution is required to include all of the following:

- Minimum requirements for air balance testing such as measurement procedures and tolerances or reference to applicable national standards for measuring and balancing airflow;
- Ventilation rate-related assumptions, such as zone delineation and area, occupancy category, occupant density, primary airflow, etc.;
- Air distribution-related assumptions, such as supply air temperature, diffuser location, zone air distribution effectiveness, system ventilation efficiency, etc.

Sample national standards (U.S.) for air balancing include:

- AABC *National Standards for Total System Balance:* 2002 6th edition, Associated Air Balance Council, aabchq.com.
- ASHRAE *Standard 111-1988*: Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems.
- NEBB *Procedural Standards for Testing, Adjusting, Balancing of Environmental Systems*: 1998 6th Edition, National Environmental Balancing Bureau, nebb.org.

In addition to the above, the design documentation may include its own minimum air balance requirements.

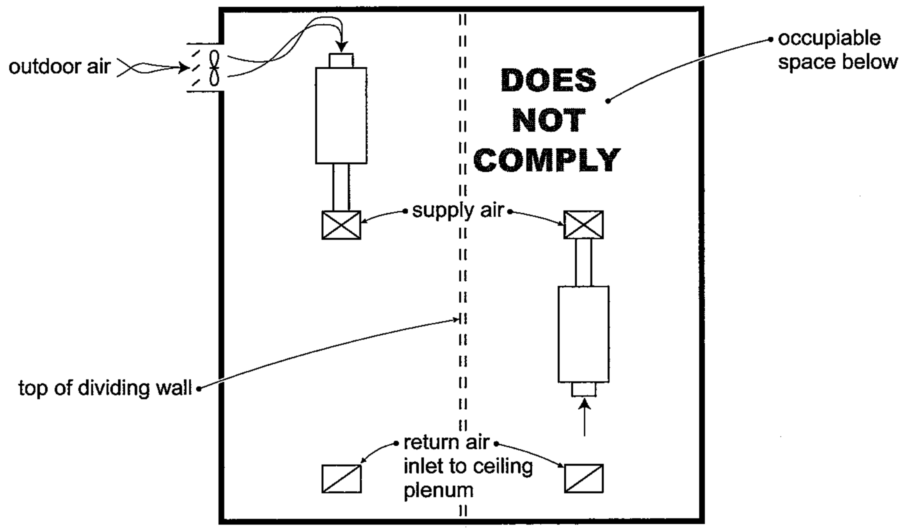


Figure 5-E—Incorrect Plan of Plenum System

In this case, outdoor air ventilation is provided to one ventilation zone, but not the other. This could only meet the requirement if it could be shown that sufficient air gets to the remote system, perhaps by mixing between the zones.

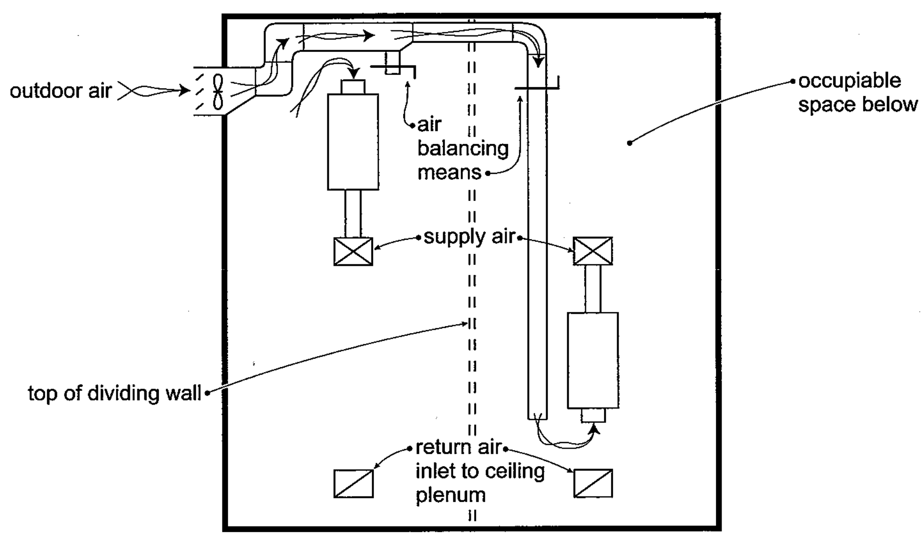


Figure 5-F—Correct Plan of Plenum System With Discharge Near Terminal Ends

Though the ducts are not connected to the terminal units, they discharge near them, with balancing means available to provide correct airflow to each.

Design documentation must always include the ventilation rate and air distribution assumptions since these are building-specific and not given in the above standards. The scope, detail and format for presentation of this data is not specified and it may vary from building to building. This documentation may be used for any number of purposes, such as showing conformance with this Standard, informing the building operator of design intent, and adapting the ventilation system to future building modifications.

Example 5-D—Balancing in Accordance with *Standard 111-1988*

Q

The specification for a new ventilation system states that it must be balanced in accordance with ASHRAE *Standard 111-1988* and the plans show the air quantities. Does this meet the documentation requirement?

A

No. In order to be complete, the documentation must also include assumptions related to outdoor air ventilation rate (such as zone design population and zone floor area), zone air distribution effectiveness (such as supply air temperature and diffuser arrangement), and system ventilation efficiency (such as system type, supply airflow rates at design conditions, and minimum airflow settings). See § 6.

Exhaust Duct Location (§ 5.3)

Exhaust ducts that convey potentially harmful contaminants must have a negative pressure, with respect to the spaces in which they travel. The negative pressure must be maintained in such a way that exhaust air cannot leak into occupied spaces,[18] supply ducts, return ducts, outdoor air ducts, or plenums. Compliance with this requirement generally requires that the exhaust fan be located outdoors or very close to the location where the air is exhausted from the building. An exception to this rule allows neutral or positive pressure in ducts in such systems, provided that the ducts are sealed in accordance with SMACNA Seal Class A.[19] See Figures 5-G, 5-H, and 5-I.

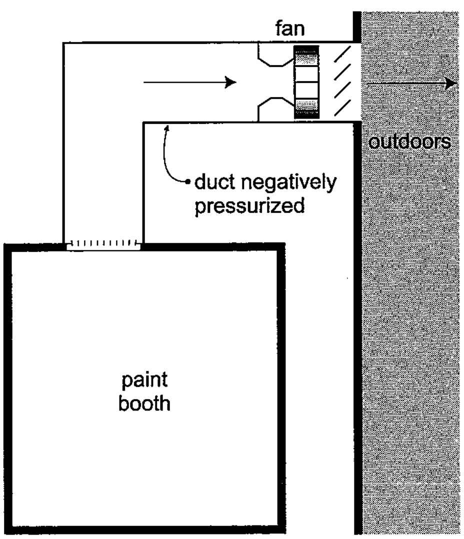


Figure 5-G—Correct Exhaust Duct, Negatively Pressurized

The fan is located at the exterior wall where the contaminated air is exhausted.

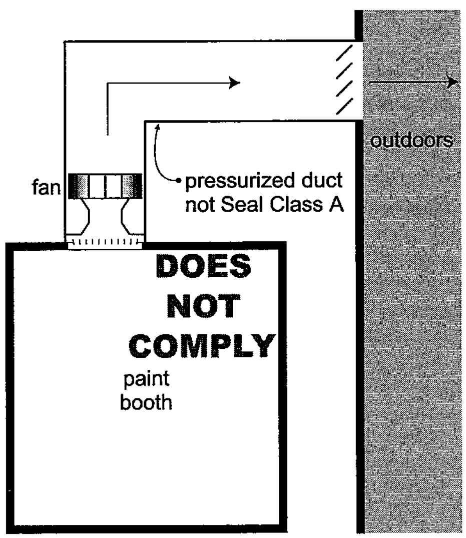


Figure 5-H—Incorrect Exhaust Duct, Pressurized and Not Seal Class A

The portion of the ductwork downstream of the exhaust fan will be have a positive pressure relative to the space the duct is traveling through and this design does not meet the requirements.

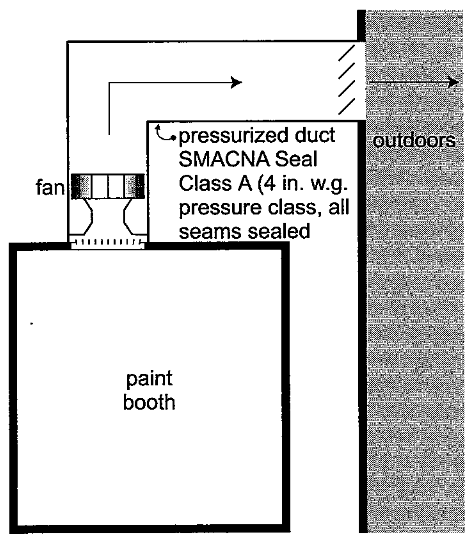


Figure 5-I—Correct Exhaust Duct, Pressurized and Seal Class A

18. The Standard uses the term "occupied space," as well as "occupiable space." For the purposes of the Standard, the terms "occupiable space" and "occupied space" are interchangeable and mean the same thing.
19. Seal Class A is fully described in *HVAC Duct Construction Standards—Metal and Flexible*, (SMACNA 1995). It requires that ducts be constructed to 4 in. w.g. (1 kPa) Static Pressure Class and that all transverse joints, longitudinal seams, and duct wall penetrations be sealed with gaskets, adhesives, welding, or other prudent methods.

Ventilation System Controls (§ 5.4)

Mechanical ventilation systems must include manual or automatic controls that enable the fan system to operate whenever the spaces served are occupied. The system must be designed to maintain the minimum outdoor airflow as required by § 6 under any load condition. To caution designers against underventilation in some VAV systems at part-load conditions, the Standard notes that variable air volume (VAV) systems with fixed outdoor air damper positions must comply with this requirement at minimum supply airflow. To comply, most VAV systems will need special design considerations and often features such as outdoor airflow sensors, modulating dampers, injection fans, etc. Two classes of controls are required by § 5.4: an on/off enabling control for the fan and a part-load control to assure proper airflow.

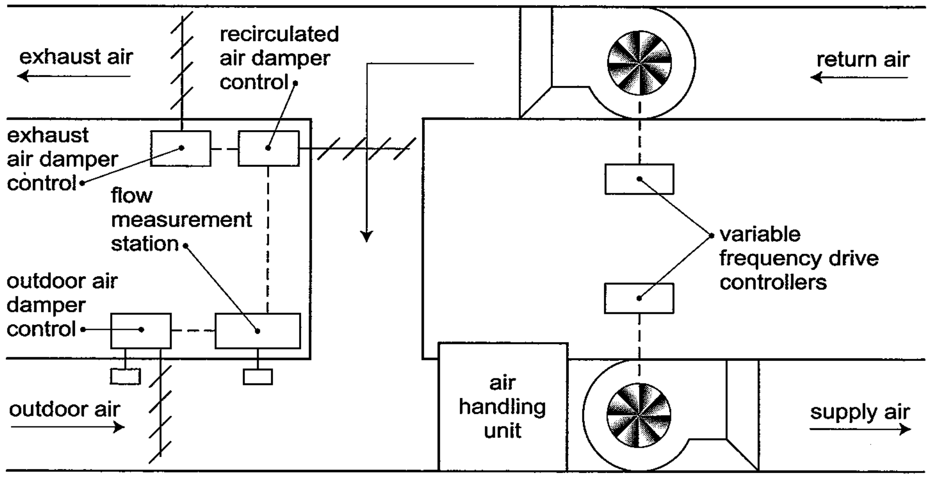


Figure 5-J—Typical Ventilation System Controls

- The on/off control can be a simple manual switch on a thermostat, an occupancy sensor, or an automated energy management and control system.
- Part-load control for ventilation requires careful planning, even in the apparently straightforward case of a constant-volume, single zone system.

Constant-Volume, Single Zone Systems

If the thermostat in such a system has a fan on/off/auto switch and the switch is left in the auto position, the fan will cycle off when the temperature setpoint is reached. If the fan system also supplies outdoor ventilation air, the cycling fan causes the outdoor air supply and ventilation to be discontinuous. Since many untrained people do not understand this, the switch is often placed in the auto position, resulting in inadequate ventilation. Several solutions are available to meet the requirement for such a system:

- Provide on/off fan control only, with no fan auto position. Be aware, however, that continuous operation of a constant volume fan may result in high relative humidity control problems due to cycling the cooling coil and running the fan constantly (in some climates, during some weather conditions). In this case, reheat or other humidity control systems may be required to allow the fan to run constantly without raising space relative humidity at part-load conditions. See § 5.10 for dehumidification requirements.
- Provide a separate dedicated outdoor air system that operates independent of zone temperature control and supplies dehumidified ventilation air to each space whenever it is occupied.
- Provide excess outdoor air when the system is running and a minimum fan-on timer when the space is occupied (see § 6.2.6.2).
- Provide occupancy sensors, such as those based on motion or indoor CO_2 concentrations, that will automatically start the fan when increased ventilation is required, overriding the temperature controls (see § 6.2.7).

Variable Air Volume System

In the past, the part-load ventilation requirement has been neglected in many VAV systems.

In most cases, an active control system must be provided at the air intake and sometimes at the zone level to ensure minimum rates are maintained. A major consideration with VAV systems is that the negative pressure behind the outdoor air intake in the mixed air plenum will typically vary with supply air volume. At low supply airflow rates this negative pressure will decrease and sufficient outdoor airflow may not be maintained with a fixed outdoor air intake damper position—or even if a dedicated fixed minimum air intake is used.

Air intake measuring devices include those that measure intake volume directly by measuring air velocity through an outdoor air duct or inlet of fixed area, (e.g. duct-mounted pitot or hot-wire anemometer) or differential pressure across a fixed orifice (e.g. wide-open damper or other non-adjustable, duct-mounted obstruction). If the system includes an outdoor air economizer, a separate minimum outdoor air damper may also be required to ensure adequate velocity across the outdoor air intake for an accurate measurement (see Figure 5-J).[20] Note that a fixed-speed, outdoor-air fan without control devices will not maintain rates within the required accuracy unless the fan curve is relatively steep with respect to changes in pressure, and/or if the pressure changes in the mixing plenum are relatively small compared to the fan total pressure requirement. Using return air, outdoor air, and mixed air temperatures or CO_2 concentrations to measure air intake percentage is usually inaccurate when the outdoor and indoor values are close together and thus should only be used with caution. Similarly, measuring outdoor air by taking the difference between supply- and return-airflow measurements will also seldom meet reasonable accuracy requirements due to cumulative errors in airflow measurement and the generally small outdoor airflow rate relative to supply- and return-airflow rates.

At the VAV box, which typically modulates primary airflow in response to temperature in the space, it is tempting to have low minimum-air-flow settings on the boxes, in the interest of energy conservation and maximizing diversity for efficient system sizing. Depending upon the VAV system, various measures may be appropriate. See the discussion of dedicated outdoor air systems in the preceding discussion of Constant-Volume, Single Zone Systems and consider the following additional measures.

- Increase VAV box minimum settings.
- Dynamically enrich the supply air with more outdoor air as VAV boxes close.
- Apply special solutions, such as occupancy sensors that override thermostats and supply more primary airflow to rooms in which variations in thermal load and occupancy are highly disparate, such as conference areas, those with heavy glazing, or those with high internal equipment heat gains.
- Provide transfer air in addition to primary supply air. See § 6.

See the discussions under § 6 for more details on designing systems to maintain required ventilation air.

20. For a full discussion, see Krarti, M. et al. "Techniques for Measuring and Controlling Outside Air Intake Rates in Variable Air Volume Systems," Final Report on ASHRAE RP-980 (1999).

Airstream Surfaces (§ 5.5)

All airstream surfaces in equipment and ducts in the heating, ventilating, and air conditioning system must meet criteria for resistance to microbial growth and erosion.

Resistance to Mold Growth (§ 5.5.1)

Surfaces that are used to convey air must be resistant to mold growth in accordance with a standardized test method, such as Underwriters Laboratories (UL), Inc. 181[21] or American Society for Testing and Materials (ASTM) C 1338.[22] A general exception is made for sheet metal surfaces and metal fasteners.

Several conditions must exist for mold to grow. It needs a source of food, which can include paper or other organic materials—and it needs a source of moisture. Mold will grow faster when temperature and humidity conditions are within a suitable range. While metal, fiberglass, and mineral surfaces (commonly used in duct construction) are not organic matter and do not provide a direct source of food—organic matter can collect on them. For this reason, the Standard cautions that microbial growth (mold and bacteria, for instance) can occur on non-organic surfaces when they are located in the airstream surface and continuously wetted.

Resistance to Erosion (§ 5.5.2)

Airstream surface materials must not break away, crack, peel, flake off, or show evidence of delamination or continued erosion. The potential for erosion must be evaluated in accordance with the UL 181 Erosion Test. Again, a general exception is made for sheet metal surfaces and metal fasteners.

Materials that break away can end up clogging filters, fans, turning vanes, diffusers, and dampers, thereby reducing airflow. Or they can go all the way through the distribution system and enter the occupied space. Furthermore, the rough surfaces left on the original substrate and at the collection points of the breakaway materials can more easily collect organic matter, which, in turn, can result in the growth of mold.

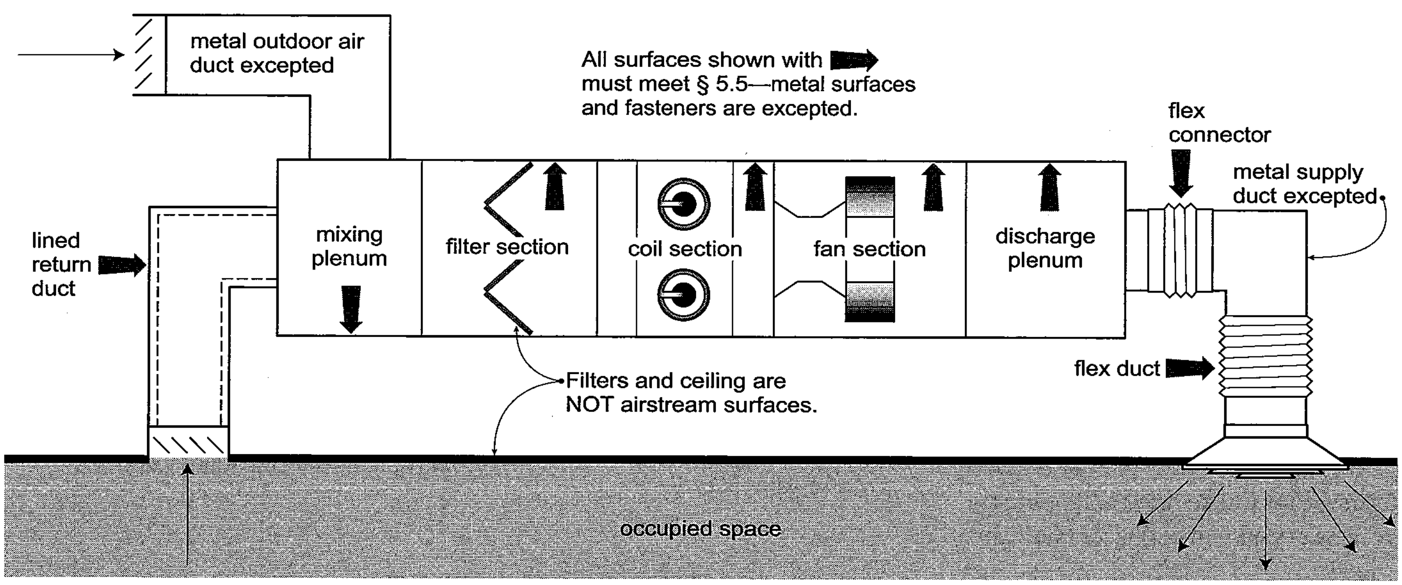


Figure 5-K—Airstream Surfaces

21. UL 181, Factory Made Air Ducts and Air Duct Connectors, 9th ed. (UL Northbrook, IL 1996).
22. ASTM C 1338-00, Standard Test Method for Determining Fungi Resistance of Insulation Materials and Facings (ASTM West Conshohocken, PA 2001).

Outdoor Air Intakes (§ 5.6)

Since outdoor contaminant sources can lead to unacceptable indoor air quality, § 5.6 requires a minimum separation between common outdoor contaminant sources and outdoor air intakes.

Because liquid water in the air distribution system can lead to microbial growth, this section includes requirements intended to limit the intrusion and entrainment of precipitation.

Bird screening must be provided at the outdoor air intakes to control contaminants related to bird nesting.

Location (§ 5.6.1)

Outdoor air intakes, including doors and windows that are required as part of a natural ventilation system, must be located such that the shortest distance from the intake to any specific potential outdoor contaminant source is equal to or greater than the separation distance listed in Table 5-A (Table 5-1 in the Standard). The information gathered in the survey required by § 4.2 may be useful in meeting these requirements.

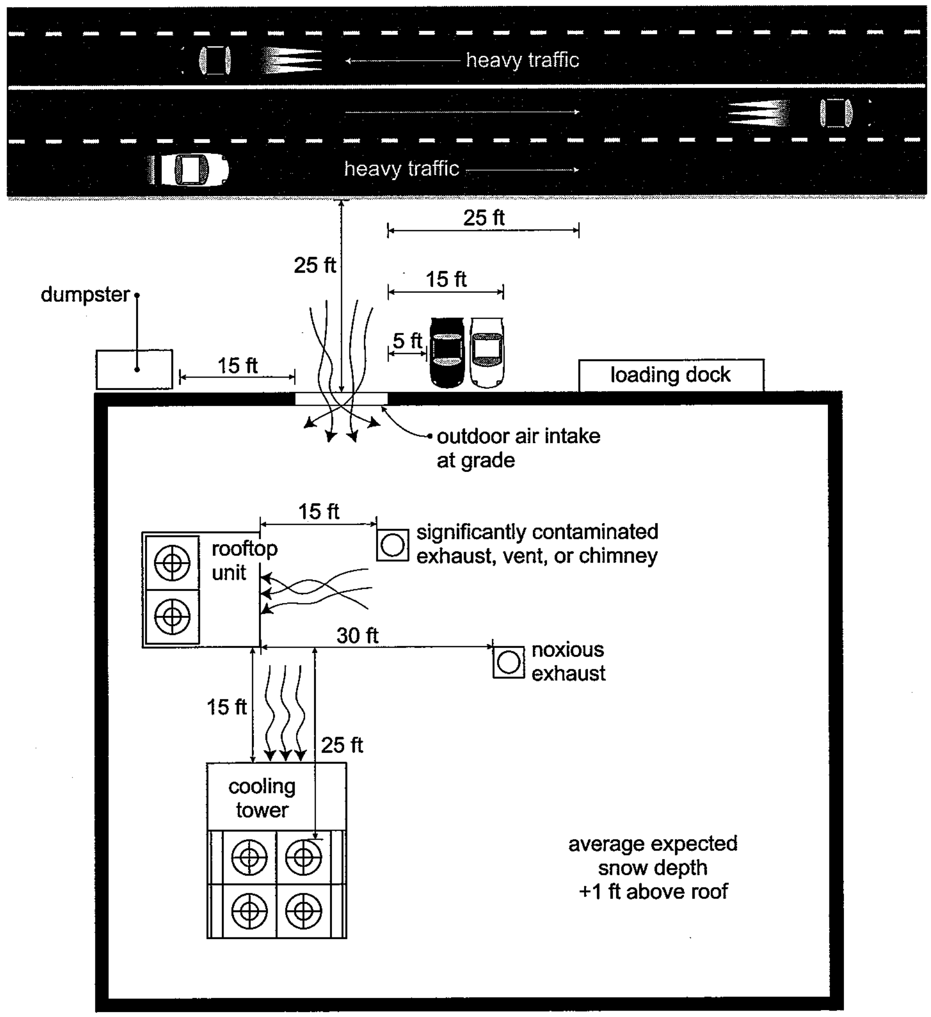


Figure 5-L—Outdoor Air Intake Locations

The minimum separations specified in Table 5-A and Figure 5-L may be decreased if it can be shown that an equivalent or lesser rate of introduction of contaminants will result. This may apply, for instance, where walls or other obstructions are constructed to physically separate the pollutant source from the air intake, the contaminant volume is small, or if the contaminants are directed with velocity away from the intake. While any valid method may show this equivalency, a method specifically recognized by the Standard is given in Appendix F.

Appendix F requires that the separation distance (L) be determined by one of three methods:

- Table F-1 of the Standard;[23]

23. Note that Table F-1 specifies separation distances from air with significant contaminant or odor intensity and noxious or dangerous particles. These two categories are very similar to Class 3 and Class 4 air, respectively, as described in § 5.17.1. Table F-2, used in Equation F-1, also lists these two categories of air.

Table 5-A—Air Intake Minimum Separation Distance

This is a reproduction of Table 5-1 from Standard 62.1-2004.

OBJECT	MINIMUM DISTANCE ft	m
Significantly contaminated exhaust (Note 1)	15	5
Noxious or dangerous exhaust	30	10
Vents, chimneys and flues from combustion appliances and equipment (Note 4)	15	5
Garage entry, automobile loading area, or drive-in queue	15	5
Truck loading area or dock, bus parking/idling area	25	7.5
Driveway, street or parking place	5	1.5
Thoroughfare with high traffic volume	25	7.5
Roof, landscaped grade, or other surface directly below intake (Note 7)	1	0.30
Garbage storage/pick-up area, dumpsters	15	5
Cooling tower intake or basin	15	5
Cooling tower exhaust	25	7.5

Additional information about selected notes to the table (see Standard for all notes).

Note 1 of the table describes significantly contaminated exhaust as exhaust air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor. This description gives considerable latitude to the designer in determining what constitutes significantly contaminated exhaust, or noxious and dangerous exhaust as listed in Table 5-A. Material Safety Data Sheets (MSDSs) may be helpful in making this determination, as will the American Conference of Governmental Industrial Hygienists (ACGIH) and ASHRAE references. If in doubt, the designer should err on the side of caution and make the more conservative determination; consult the manufacturer or supplier of the chemical or chemical-producing component; and/or engage the services of an industrial hygienist or other health professional.

Note 4 allows for shorter separation distances are permitted when determined in accordance with other codes related to combustion equipment. For more information, the designer can generally consult the manufacturer of the combustion equipment, who should be well versed in the ratings and approvals of their products.

Note 7 discusses the increase in height above the roof required where snow accumulation is expected, based on expected average snow depth. Expected average snow depths are not normally published. Building codes often give ground snow load (P_g) in lb/ft^2, but this number is not applicable for two reasons: it is a maximum design number for structural purposes and not an average.; it is given in area density of snow, again for structural purposes, and not in depth. For sophisticated methods of predicting estimated snow depth, consult the work done by the U. S. National Severe Storms Laboratory (http://www.nssl.noaa.gov/teams/watads/public_html/snow/snow.htm) the Department of the Interior's Bureau of Reclamation (Super, A.B. and E.W. Holroyd "Snow Accumulation Algorithm for the WSR-88D Radar: Final Report" Bureau of Reclamation Report R-98-05 (Denver, CO, July 1998) and/or the Hydro-Meteorological Prediction Center (http://www.eas.slu.edu/CIPS/Presentations/CIPSworkshop/junkersnow/sld001.htm). The National Climatic Data Center lists mean snow depths for a number of U.S. locations by day of the year, with summary by month. Visit http://www5.ncdc.noaa.gov/climatenormals/clim20-02/ and access the NWS_SNOW_MNDPTH_fmt.dat file.

- Equation F-1 of the Standard(discussed in the following paragraph); or
- Any other method approved by the authority having jurisdiction that shows adequate dilution.

Once L is determined, the "stretched string" method can be used, in most cases.[24] The "stretched string" method uses the metaphor of a string stretched from the closest point of the opening

24. The "stretched string" method may not be used in all cases. For example, Appendix F has additional requirements for laboratory or fume hood exhaust, noxious or dangerous air, and exhaust outlets that terminate in equipment wells that also enclose and outdoor air intake.

emitting contaminants to the closest point of the outdoor air intake (or operable window, skylight, door opening).

For example, if a wall separates an intake from an exhaust as shown in Figure 5-M, the distance S is taken from the exhaust outlet in a straight line to the top of the wall, over the wall, then in a straight line to the intake. In this case, S = S1 + S2 + S3.

In order to optimize L, Equation F-1, unlike Table 5-A or Table F-1, takes into account additional factors such as exhaust airflow rate, discharge velocity, and direction. This calculation will often allow shorter separation distances between exhaust and intake than those in the Tables.

Even where the required minimum separation distances are maintained, entrainment of pollutants may still occur depending on wind conditions, building geometry, and exhaust design. An analysis of the airflow patterns around buildings and exhaust plume behavior is described in the 2001 ASHRAE *Handbook—Fundamentals*, Chapter 14. Such analysis is not required by the Standard.

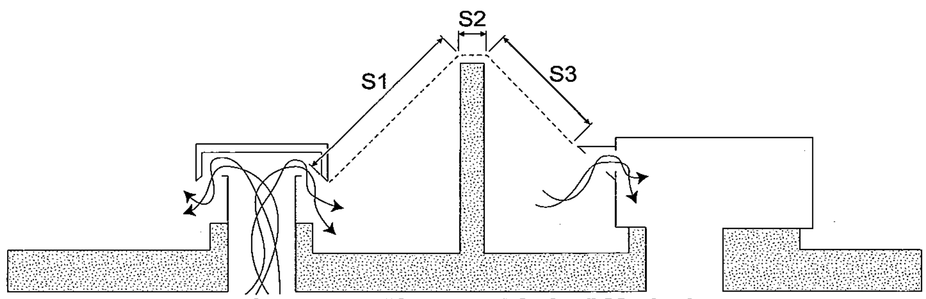


Figure 5-M—"Stretched String" Method

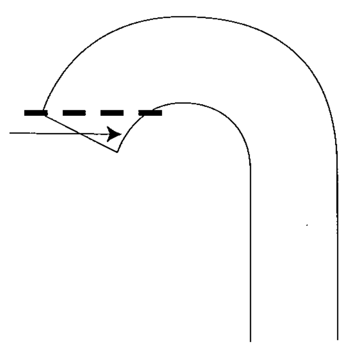


Figure 5-N—Correct Rain Hood
Dashed line represents the horizontal plane. Air and water cannot enter without passing upward through horizontal plane.

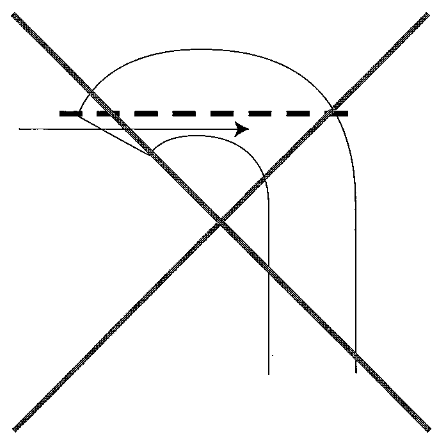


Figure 5-O—Incorrect Rain Hood
Dashed line represents the horizontal plane. Air and water can enter without passing upward through horizontal plane.

Rain Entrainment and Intrusion (§ 5.6.2 and § 5.6.3)

Water in the air distribution system can lead to microbial growth; therefore the Standard sets requirements for controlling rain that may enter the outdoor air intakes of the mechanical ventilation system. Mechanical ventilation systems must be designed to manage rain in accordance with any one of several industry standards: UL 1995 Section 58; Air Movement and Control Association's (AMCA) *Standard 500-L-99* or equivalent; or AMCA 511-99. Generally, manufacturers will test air intakes according to these standards and comply with them. As an alternative, the designer may use a rain hood in accordance with § 5.6.2(d) or just manage the water that penetrates the intake opening by providing a drainage area and/or moisture removal devices per § 5.6.2(e).

Generally, the designer will want to do the following, as applicable:

- When selecting manufactured equipment that has an outdoor air intake, confirm that it has been designed and tested in accordance with one of the above-named industry standards or their equivalent.

- When selecting louvers, choose louver styles and sizes that result in less than 0.01 oz/ft^2 (3 g/m^2) of water penetration at the maximum intake velocity. This water penetration rate should be determined for a minimum 15 minute test duration in accordance with AMCA Standards.
- When designing or selecting an outdoor air intake hood or gooseneck, the highest point of the opening must be no lower than the tallest portion of the intake's throat. This minimizes rain ingress. The intake's face velocity must be no more than 500 fpm, also to minimize rain intrusion. Downward-facing intakes are recommended to further minimize this potential problem and to reduce the effect of wind direction on the airflow rate.[25] The hood described in § 5.6.2(d) is intended to prevent air from entering without passing upward, thus preventing driving horizontal rain from entering. See Figures 5-N and 5-O.
- When the above cannot be achieved, manage the water that penetrates the intake by providing a drainage area and/or moisture removal devices, such as a mist eliminator.

Snow Entrainment (§ 5.6.4)

In addition to the previously described procedures for managing rain, certain climates dictate that measures be taken to manage melted snow blown or drawn into the system, which can also lead to

25. Rock, B. A. and Moylan, K.A., "A Designer's Guide to Placement of Ventilation Air Intake Louvers," 806-RP Final Project Report (ASHRAE 1988).

Example 5-E—Snow Depth in Chicago

Q

How high should an outdoor air intake be located above the roof in suburban Chicago?

A

If the expected average snow depth is known to be 2 ft (0.6 m), add 1 ft (0.3 m) to this number to find the 3 ft (0.9 m) required height of the intake above the roof. The following calculation method is not required by the Standard, but is presented as one quantitative method to deal with the general requirement of § 5.6.4.

1. Find the design snow load from the building code,* often presented in map form. In the case of suburban Chicago, this would be 25 lb/ft^2 (120 kg/m^2).

2. Adjust the maximum to an average using an adjustment factor, if known. In this example, an an adjustment factor of 50% factor is used (for illustration purposes only).

$$25\ \text{lb/ft}^2 \times 0.50 = 12.5\ \text{lb/ft}^2$$
$$(120\ \text{kg/m}^2 \times 0.50 = 60\ \text{kg/m}^2)$$

3. Convert the snow weight determined in the previous step to snow depth by dividing by the density of snow. Snow density can vary considerably† from 3–50 lb/ft^2 (0.05–0.80 g/cm^3, or 50–800 kg/m^3). If the snow density is known for an area, use it. In this example, 7 lb/ft^3 (110 kg/m^3) is used.

$$\frac{12.5\text{lb}/\text{ft}^2}{7\text{lb}/\text{ft}^2} = 2\text{ft} \qquad \frac{60\text{kg}/\text{m}^2}{110\text{kg}/\text{m}^3} = 0.6\text{m}$$

4. Add 1 ft (0.3 m) to the expected average snow depth to find the required height of the outdoor air intake above the roof.

$$2\ \text{ft} + 1\ \text{ft} = 3\ \text{ft}$$
$$(0.6\ \text{m} + 0.3\ \text{m} = 0.9\ \text{m})$$

** The City of Chicago has its own building code. This example is based on a suburban jurisdiction using more universally available code: the 2003 International Building Code, International Code Council, www.iccsafe.org, pp. 280–281. The code adopted in the particular jurisdiction should be consulted.*

† http://www.crrel.usace.army.mil/cerd/snowload/Emergency_Snow_Removal.htm

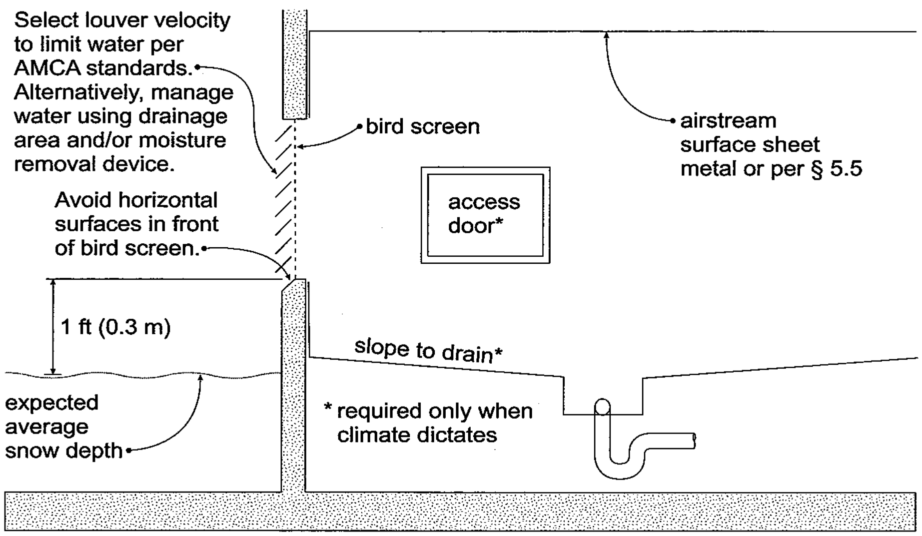


Figure 5-P—Outfoor Air Intake to Prevent Snow Intrusion

microbial growth. The decision about whether this is required is left to the designer, but the measures to be taken are prescriptive: provide both access doors to permit cleaning and pitch the outdoor air duct or plenum to drains designed in accordance with the requirements of § 5.11.

Bird Screens (§ 5.6.5)

Outdoor air intakes must include a corrosion resistant screen designed to prevent penetration by a ½ in. (13 mm) diameter probe. The screen must be located (or other measures must be taken) to prevent bird nesting within the outdoor air intake. The simplest way to do this is to locate the screen just behind outside of the louver and avoid horizontal surfaces where birds may land and/or nest. Any horizontal surface may be subject to bird nesting. Novel methods that may prevent bird nesting include netting, spikes, coils, and visual/auditory scare devices.

Local Capture of Contaminants (§ 5.7)

Equipment such as photo process machines, clothes driers, and grinding machinery may have exhaust duct collars for connecting ductwork that collect and remove contaminants. The Standard requires that the discharge from such equipment be ducted directly to the outdoors. Equipment may discharge indoors only if it is specifically designed for this and it is installed in accordance with the manufacturer's recommendations.

If the discharge airflow from these devices is large, the space may become depressurized. While makeup air may be desirable, it is not required by the Standard. For whole building depressurization limitations, see § 5.10.2.

Combustion Air (§ 5.8)

Combustion processes consume oxygen and produce water vapor, carbon dioxide, and contaminants from incomplete combustion. Vented appliances must be installed with vents, flues, or chimneys that remove the combustion products to the outdoors.

Unvented appliances may discharge directly to the indoors but only when this is allowed by the industry listings and approvals for these appliances. Examples of unvented appliances include kerosene heaters, certain gas-cooking appliances, certain gas-fired space heaters, decorative (fireplace) appliances, and direct-fired makeup air units. Unvented appliances should be properly maintained so that they do not produce high levels of hazardous combustion products, such as carbon monoxide.

Direct-vent appliances draw combustion air directly from the outdoors and all combustion gases are discharged to the outdoors through a flue or vent. Some appliances use fans to force or induce a draft to the combustion chamber. Mechanical codes cover the different types of vents in more detail.[26]

Building and mechanical codes address the proper indoor use of fuel-burning appliances, in terms of both combustion air and venting of combustion products. *Standard 62.1*, in general, does not call for anything stricter. It requires that:

- Fuel-burning appliances, both vented and unvented, be provided with sufficient air for combustion and adequate removal of combustion products, in accordance with manufacturer instructions; and
- Products of combustion from vented appliances be vented directly outdoors. The Standard allows the discharge of combustion products from unvented appliances.

The Standard does not require specific measures for makeup air to combustion appliances. For whole building depressurization limitations, see § 5.10.2.

26. See NFPA 54, National Fuel Gas Code, National Fire Protection Association, Quincy, MA, www.nfpa.org

Particulate Matter Removal (§ 5.9)

The Standard requires that particulate filters or air cleaners with a minimum efficiency reporting value (MERV) of not less than 6 when tested in accordance with ASHRAE *Standard 52.2-1999* (reference 15) be provided upstream of all cooling coils or other devices with wetted surfaces through which air is supplied to an occupied space.

The purpose of this requirement is to reduce the accumulation of contaminants in the ventilation system where wet surfaces are present. Dirt accumulation on wet surfaces provides a substrate that may lead to microbial growth which may in turn cause the ventilation system to become a source of contaminants. In addition to reducing the rate of accumulation of particulate matter, filtration also reduces the level of airborne particles that may be harmful to humans, such as airborne microorganisms and respirable particles.

Dehumidification Systems (§ 5.10)

The Standard specifies a 65% upper design limit on relative humidity for mechanical systems with dehumidifying devices and controls; however, the Standard does not set a lower limit. The purpose of the upper limit is to provide a safety factor in the occupied space that will reduce the likelihood of surface conditions at or close to the dewpoint temperature which can result in microbial growth. A low humidity limit, while recommended by previous versions of the Standard, is no longer included because the data supporting such a limit for IAQ purposes is limited and inconsistent. A low humidity limit may still be desired for other reasons related to space use. The Standard also specifies whole building pressurization by requiring net mechanical system intake airflow, again in buildings that employ dehumidification, to reduce the infiltration of moist outdoor air (which can cause condensation, material damage, and microbial growth on building surfaces during cooling operation).

Relative Humidity (§ 5.10.1)

HVAC systems that have dehumidification capability must be designed to control relative humidity to a maximum of 65% when analyzed at either of the following design conditions:

- At the peak outdoor dewpoint design conditions and the concurrent (simultaneous) indoor design latent load, or
- At the lowest space-sensible heat ratio expected to occur and the concurrent (simultaneous) outdoor condition.

System performance, which results from both system configuration and control methods, must be analyzed (in terms of space-relative humidity) at one of these alternative conditions, in addition to the more common calculations at peak dry-bulb. The outdoor air dry-bulb, solar load, and space sensible heat ratio may be significantly different at outdoor dewpoint design conditions and the resulting space relative humidity may be significantly different than when calculated at the more common peak outdoor dry-bulb design conditions. Depending on the control strategy employed, the latent coil capacity may need to be larger at the alternate conditions to achieve acceptable space humidity—and even the total heat to be removed, if the space humidity design goal is very low.

Meeting this requirement may affect cooling coil capacity, but it is even more likely to affect system configuration and control. The following are some of the additional considerations in designing at the alternate dewpoint conditions:

- An automatic control system that reduces airflow rate rather than raising supply air temperature in response to reduced sensible load is more likely to result in acceptable relative humidity. This is because raising supply air temperature can reduce the ability of the cooling coil to remove moisture, i.e., reduce the latent capacity.

- If the supply air temperature is raised in response to reduced sensible load, the designer must consider the effect on room relative humidity. This may result in the need to dehumidify by subcooling and reheating the air, provide supplemental dehumidification, provide bypass control, or include other design features to directly or indirectly control space humidity.
- There may be an increase in cooling coil latent capacity and, less frequently, total capacity. (See § 5.11.4 for moisture management requirements.)

Exfiltration Through the Building Envelope (§ 5.10.2)

If allowed to enter air-conditioned space, moist outdoor air can condense on cool building surfaces. In addition, infiltrating air is unfiltered and can interfere with proper operation of mechanical ventilation systems. To address this issue, the Standard requires that the volume of outdoor air brought into the building be greater than the exhaust airflow. The excess air must leave the building, usually through cracks and openings in the envelope. The resulting positive pressure (ignoring wind and stack effects) needs to be maintained whenever the mechanical systems are dehumidifying, since those are the outdoor conditions under which this type of condensation is expected to occur. Positive pressure in hot, humid climates can also reduce interstitial moisture and resultant microbial growth. See § 5.15 for additional guidance for hot, humid climates.

Pressurization is a minimum requirement to limit excessive infiltration of high dewpoint outdoor air but it does not prevent a number of other conditions that can occur, for example:

- Even though the building as a whole may have more outdoor air intake than exhaust, stack and wind effects can cause large regions, such as entire levels or façades, to be negatively pressurized;
- Individual zones within the building may be required to have neutral or negative pressure, such as some laboratory and industrial spaces;
- A building that is excessively pressurized may cause damage to the structural integrity of the building envelope, or cause other problems, such as difficulty opening doors;
- The Standard does not require excess intake air (i.e., positive building pressure) when the mechanical systems are not dehumidifying. In fact, positive pressure differentials across the building envelope in cold weather can result in condensation in the wall cavities when indoor moisture loads are significant.

Example 5-F—Dehumidification in Virginia

Q

A 1000 ft^2 day care center in Richmond, VA is designed for ten people and is to be mechanically ventilated, cooled, and dehumidified using a constant volume rooftop unit controlled by a thermostat. The indoor design conditions are 70°F at 60% rh, and 1% outdoor design conditions are to be used. What are the design parameters for this single zone system to meet ASHRAE *Standard 62.1-2004*? What equipment selection parameters arise from these design conditions?

A

The required outdoor air ventilation is 10 people * 10 cfm/person + 0.18 cfm/ ft^2 * 1,000 ft^2 = 280 cfm, assuming that zone air distribution effectiveness is 1.0 (see § 6).

Calculate the coil cooling loads at the design dry-bulb and coincident wet-bulb conditions, which are 92°F dry-bulb/75°F wet-bulb. Assuming a 55°F supply air temperature at design, loads are shown in the table that follows. Space-relative humidity rises to about 63% at the dry-bulb design condition. While not required by the Standard, the cooling system will normally be designed to meet the sensible and latent loads at these conditions.

Recalculate the space and ventilation cooling loads and resulting space-relative humidity at the design dewpoint condition (referred to in the 2001 ASHRAE *Handbook—Fundamentals*, Chapter 27, as the "design dehumidification" condition) in accordance with § 5.10.1—in Richmond, 75°F dewpoint / 82°F dry-bulb. We analyze this space as though it had simple dry-bulb-modulating control, such as a chilled-water valve controlled by a room thermostat.* The resulting loads and space-relative humidity are shown in the table and psychrometric chart that follow. This example makes the simplifying assumption that return air conditions are the same as room air conditions. These conditions are indicated as "RA" on the psychrometric charts. Note that at the test conditions in § 5.10.1 the resulting room humidity is 75%, which does not meet the 65% limit.

To meet the required humidity limit, one of the following part-load strategies may be employed:

- Dynamically reduce airflow using variable air volume or more simply, a two-speed fan to meet part-load conditions (be sure to follow the part-load ventilation requirements of § 5.4).
- Employ reheat and control of cooling and reheat coils from humidity measurement. Be sure to consider energy consumption and possible sources of recovered heat, such as hot gas.
- Employ bypass of return air (not mixed air) around the cooling coil to meet part-load conditions.
- Employ a dedicated outdoor air system with dehumidification capability.

Had the building been located in a drier climate (with a lower design dewpoint), the 65% design limit may have been met at the test condition and no additional consideration would be needed.

**A modulating chilled water coil "unloads" on a coil curve and delivers air at a higher dewpoint (dp) and higher dry-bulb (db) temperature at part load. A cycling DX coil delivers air at very low dp, low db when "on" and at higher dp and higher db when "off" (how high depends on cycle rate). Some coil simulation analyses by equipment manufacturers indicate that a cycling DX coil, on average, follows the same coil curve as the modulating coil. This means that with either coil, the average leaving air dewpoint is about the same. Each coil delivers supply air at about the same db and dp, so a basic constant volume system without reheat or bypass, for instance, has about the same success in controlling space relative humidity indirectly, whether it uses a DX coil or a chilled water coil. The DX coil removes a lot of moisture when on, and re-evaporates some moisture when off, while the modulating coil removes a little moisture all the time.*

Richmond, VA,
1000 square foot daycare room,
Indoor design conditions: 70°F, 60% rh (*Standard 62.1-2004* requires a minimum of 65% rh)
Ten people, 280 cfm outdoor air calculated per § 6

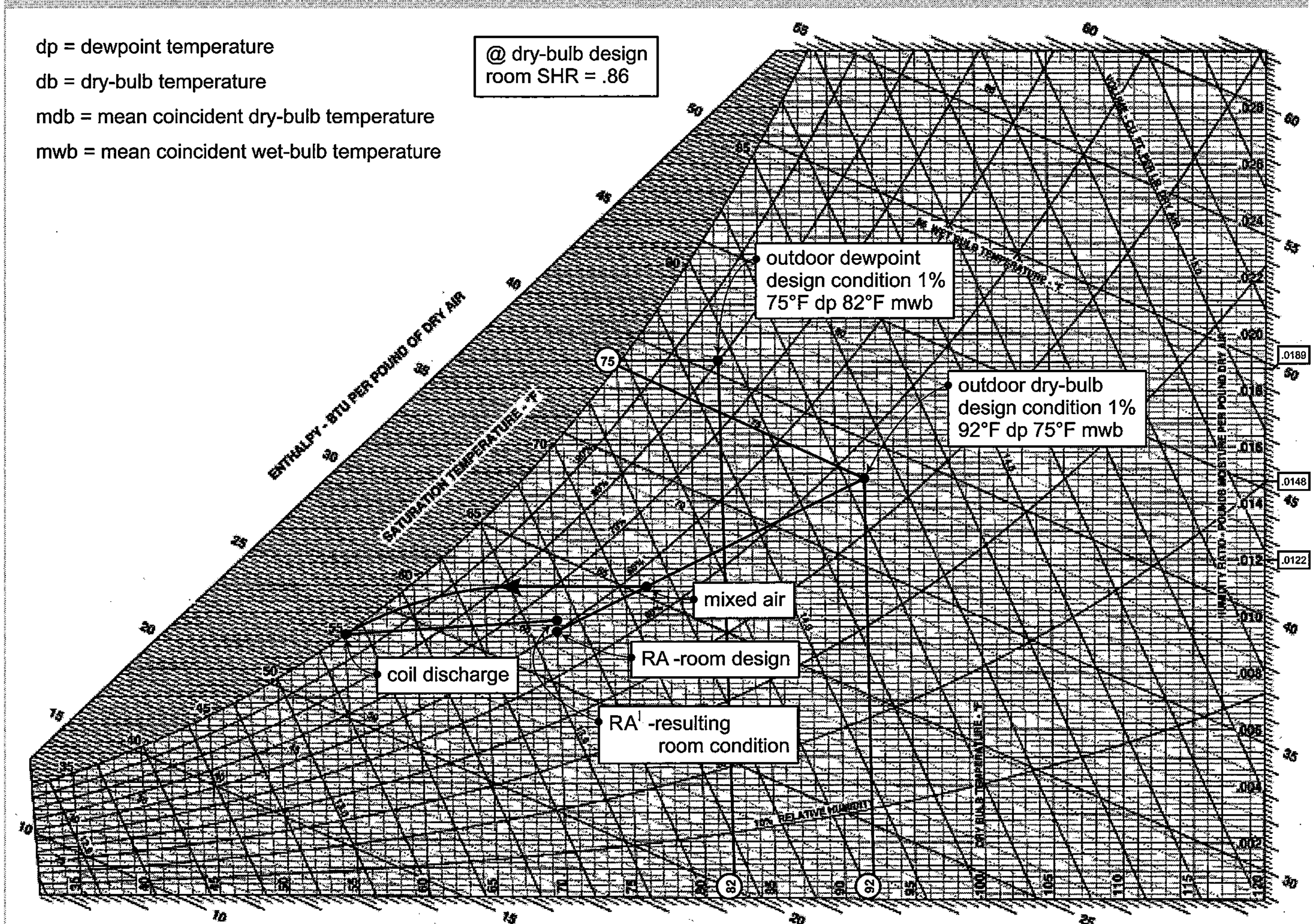
I. Loads as often calculated for peak air-conditioning load
Space loads in Btu/h at 1% peak dry-bulb design, 92°F db, 75°F mwb
Assumed supply air temperature: 55°F
Supply airflow: 960 cfm
Mixed air temperature: 76.4°F

	SENSIBLE	LATENT	TOTAL	SHR
Lighting	7000		7000	
People	2500	2500	5000	
Walls	2000		2000	
Roof	2000		2000	
Solar	2000		2000	
Space Total	15,500	2500	18,000	0.86
Ventilation	6780	5290	12,070	
TOTAL	22,280	7790	30,070	0.74

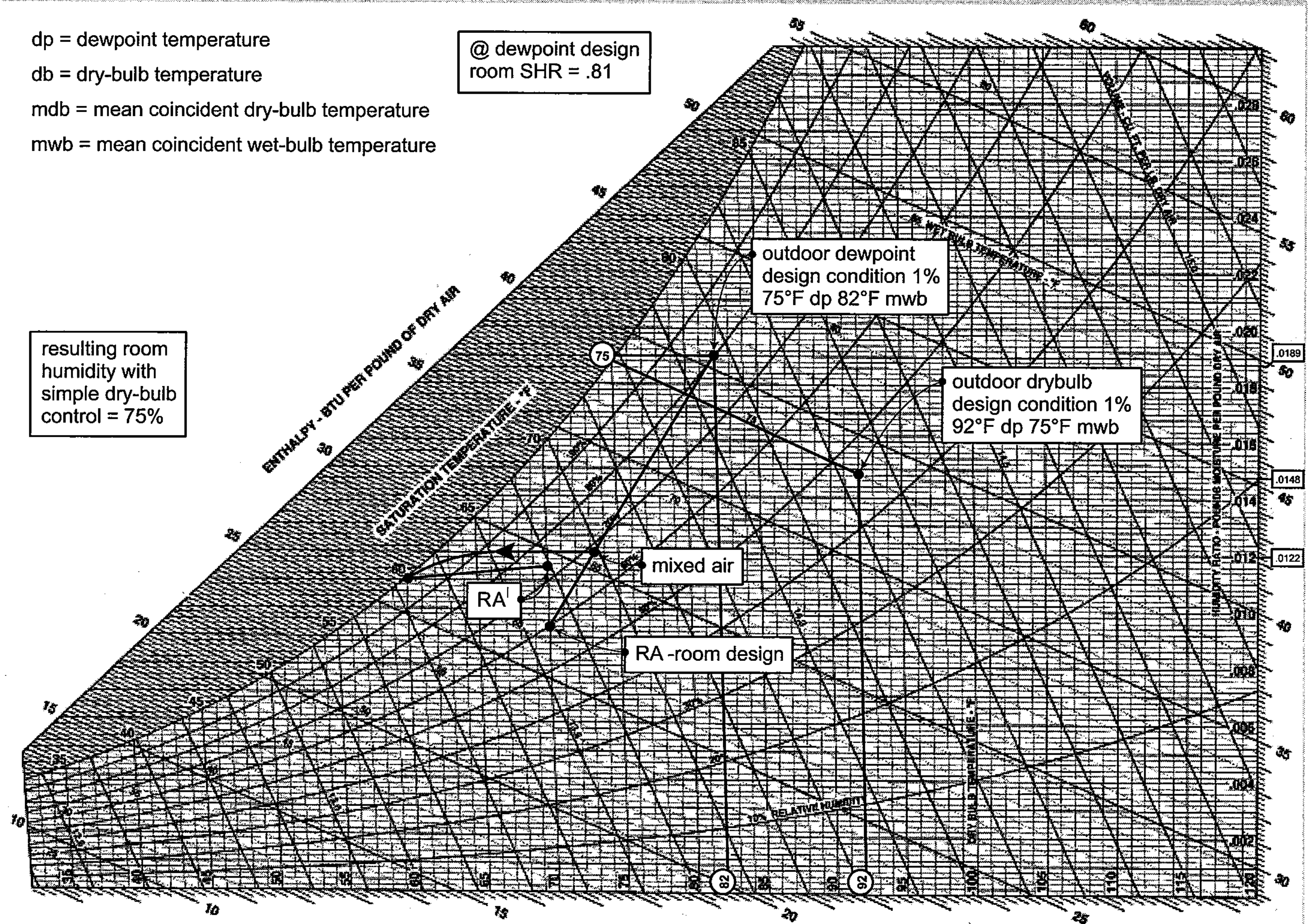
II. Loads calculated for peak outdoor dewpoint design conditions as required by § 5.10.1.1
Space loads at 1% peak dewpoint design, 75 dp, 82 mdb
Effective supply air temperature calculated: 59.8°F
Supply airflow: 960 cfm
Mixed air temperature: 73.5°F

	SENSIBLE	LATENT	TOTAL	SHR
Lighting	7000	0	7000	
People	2500	2500	5000	
Walls	1090	0	1090	reduced due to outdoor dry-bulb
Roof	0	0	0	zero due to cloudiness, rain, and lower outdoor dry-bulb
Solar	0	0	0	zero due to cloudiness and lower outdoor dry-bulb
Space Total	10,590	2500	13,090	0.81*
Ventilation	3700	10,840	14,540	adjusted for outdoor test condition—higher humidity & lower dry-bulb
TOTAL	14,290	†13,340	27,630	0.52‡

* *Room SHR is lower*
† *Coil latent is nearly double and sensible is about 2/3*
‡ *Coil SHR*



PSYCHROMETRIC PROCESS AND RESULTING ROOM CONDITIONS AT DRY-BULB DESIGN



PSYCHROMETRIC PROCESS AND RESULTING ROOM CONDITIONS AT DEWPOINT DESIGN

Drain Pans (§ 5.11)

The Standard requires that drain pans under cooling coils or dehumidification coils be designed to prevent standing water and to limit water droplet carryover. Either of these can lead to surfaces that are wet for extended periods of time, increasing the potential for microbial growth. The specific requirements in § 5.11 include drain pan slope, size, and drain outlet size.

The § 5.11 requirements apply to the design and construction of all pans in ventilation systems intended to collect and drain liquid water, including their outlets and seals. This requirement specifically includes pans that:

- Handle snowmelt from an outdoor air duct or plenum (§ 5.6.4);
- Drain condensate from dehumidifying cooling coils and condensate-producing heat exchangers (§ 5.12.1); and
- Those located under obstructions like eliminators, coils, or evaporative media in the absorption distance of a humidifier or water-spray system (exception to § 5.13.2).

Some manufacturers of equipment use the phrase "IAQ drain pan" to refer to equipment that meets these requirements. When specifying or selecting equipment, designers should include or look for more specific information to confirm that the drain pan slope and each of the other requirements of the Standard are met. Manufactured equipment must be installed as close as possible to level, so that the proper slope of the drain pan is preserved.

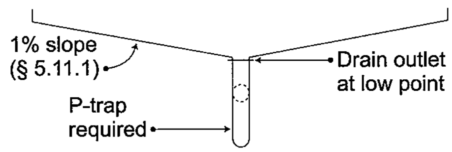


Figure 5-Q—Compliant Drain Pan, End View

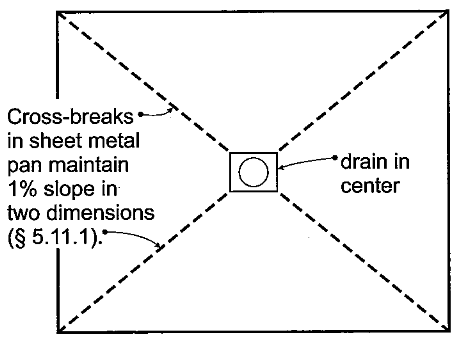


Figure 5-R—Compliant Drain Pan, Plan View

Details of custom field-erected drain pans should be sufficiently specified and carefully constructed to comply with all the requirements. Section 5.11 does not cover pans that are not part of a ventilation system, for instance, those under domestic water heaters.

Drain Pan Slope (§ 5.11.1)

Pans must be sloped at least 1/8 in. per foot (10 mm per meter)—which corresponds to 1%—from horizontal toward the drain outlet or must be otherwise designed to assure that water drains freely from the pan, whether the fan is on or off. Many drain pans have no slope at all, or worse yet, slope away from the drain or have low spots that retain stagnant water. Since all drain pans have both a width and a length,

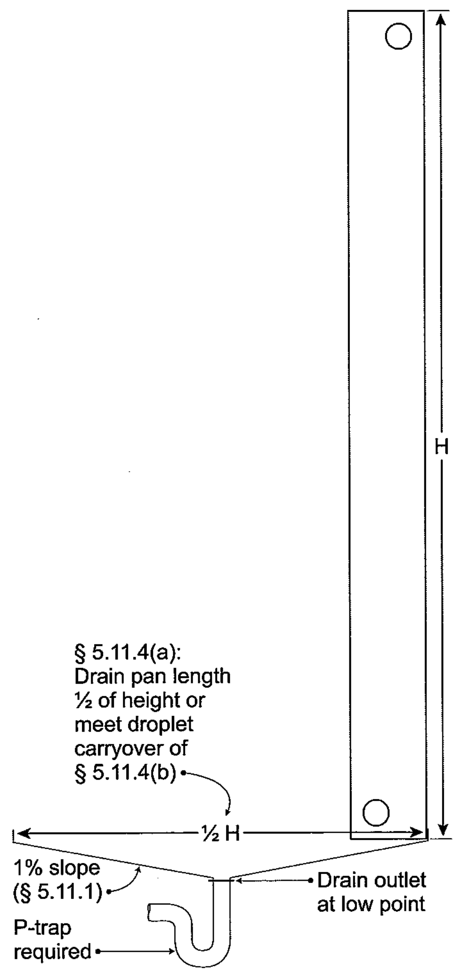


Figure 5-S—Compliant Drain Pan, Side View

very often a slope in two dimensions must be maintained. See Figures 5-Q, 5-R, and 5-S.

Drain Outlet (§ 5.11.2)

The drain pan outlet must be located at the lowest point(s) of the drain pan and must be of sufficient diameter to preclude drain pan overflow under any normally expected operating condition.

For simplicity, many drain lines are the same size as the drain pan connection fitting. Plumbing piping design materials are good sources for a full discussion of gravity drainage.[27]

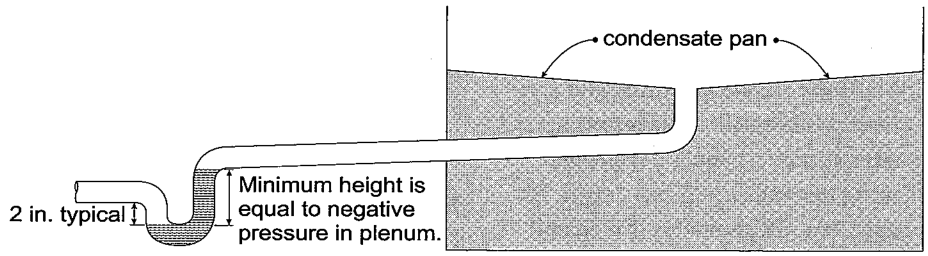


Figure 5-T—Condensate Drain Pan With a Plenum Under Negative Pressure

Drain Seal (§ 5.11.3)

For configurations that result in negative static pressure at the drain pan relative to the drain outlet (such as a draw-through unit), the drain line is required to include a P-trap or other sealing device designed to maintain a seal against the entry of ambient air while allowing complete drainage of the drain pan under any normally expected operating condition—whether the fan is on or off.

Trap failures due to freeze-up, drying out, breakage, blockage, and/or improper installation can compromise the seal against air entry through the condensate drain line. Although these are not specifically covered in § 5.11.3, they are covered generally by the performance requirement to maintain the seal. Traps with insufficient height between the inlet and outlet on draw-through systems can cause the drain to back-up when the fan is on, possibly causing drain pan overflow or water droplet carryover into the duct system. The resulting moist surfaces can become sources of biological contamination. Seasonal variations, such as very dry or cold weather, may adversely affect trap operation and condensate removal.

Pan Size (§ 5.11.4)

The drain pan must span the entire width of the water-producing device/assembly and be positioned beneath it to collect all the water.

For horizontal airflow configurations, the drain pan length begins at the upstream face or edge of the water-producing device or assembly and extends downstream to a distance of either:

- One half of the installed vertical dimension of the water-producing device or assembly, or
- As necessary to limit water droplet carryover beyond the drain pan to 0.0044 oz per ft^2 (1.5 ml per m^2) of face area per hour under peak-sensible and peak-dewpoint design conditions, considering both latent-load and coil-face velocity.

While manufacturers may have access to testing apparatuses that will allow designing to the second criterion, many designers will prefer to design to the first prescriptive requirement. Note that pipe bends that are not in the airstream (for instance on the outside of an air handler) are not required by § 5.11.4 to have a pan, even though this may be worth considering.

27. For example, see the latest edition of the ASPE Data Books, American Society of Plumbing Engineers, Chicago, IL, aspe.org.

Finned-Tube Coils and Heat Exchangers (§ 5.12)

Finned-tube coils collect dirt and can thereby promote microbial growth. Coil surfaces can be cleaned, but proper cleaning depends upon coil depth, fin spacing, and fin geometry. Since coil depth, fin spacing, and fin geometry combine to determine coil pressure drop, coil pressure drop is used in § 5.12 as a surrogate measure of the relative difficulty of coil cleaning, one that is better than just using the depth of finned-tube coils. Table 5-B shows typical pressure drops for various coils and is included to assist with evaluation of the requirements.

Drain Pans (§ 5.12.1)

A drain pan (per § 5.11) is required beneath all dehumidifying cooling coil assemblies and all condensate-producing heat exchangers.

Finned-Tube Coil Selection for Cleaning (§ 5.12.2)

Section 5.12.2 limits coil pressure drop as a surrogate measure for cleanability. Individual finned-tube coils must result in no more than 0.75 in. wc (187 Pa) pressure drop when dry coil face velocity is 500 fpm (2.54 m/s). See Table 5-B for sample coil configurations and their resultant pressure drop.

When multiple finned-tube coils are in series, they may be considered separate coils that meet the 0.75 in. wc (187 Pa) pressure drop individually, provided that they have adequate intervening access space(s) of at least 18 in. (457 mm) between them. Otherwise, the coils must be considered in combination and both together must meet the pressure drop criterion. Section 5.14.3 requires access doors to the intervening space.

An exception waives the pressure drop requirement when clear and complete instructions for access and cleaning of both upstream and downstream coil surfaces are provided.

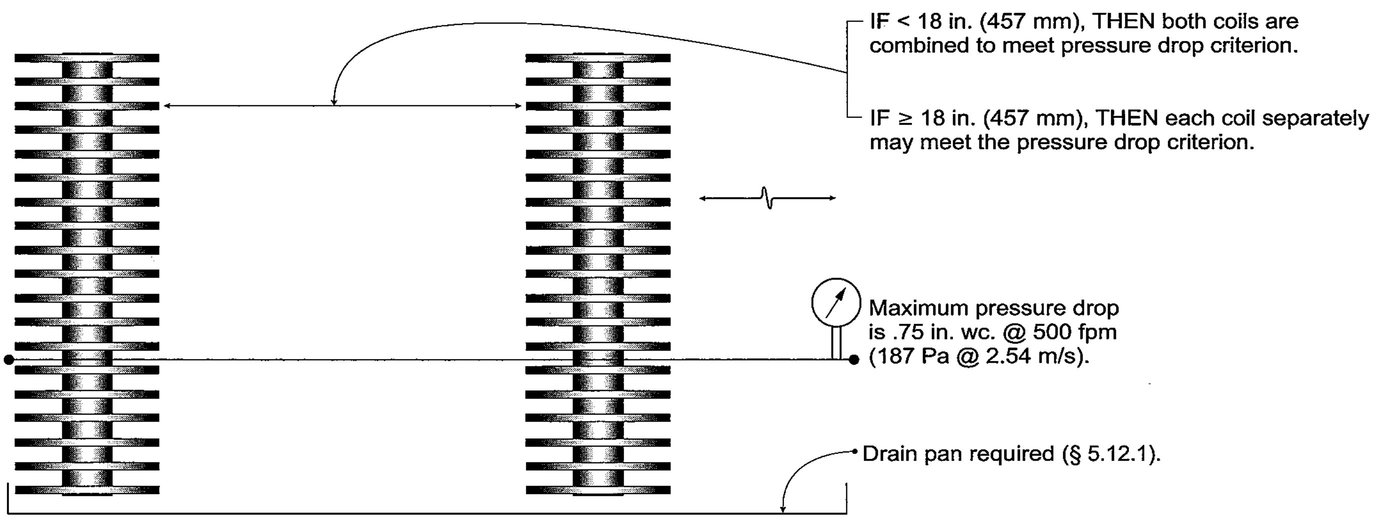


Figure 5-U—Finned Tube Coil Cleanability

Table 5-B—Typical Dry Coil Pressure Drop in Inches of H_2O at 500 fpm

ROWS	90 FINS/FT	120 FINS/FT	150 FINS/FT	168 FINS/FT
4	0.30	0.35	0.41	0.47
6	0.45	0.52	0.62	0.71
8	0.60	0.69	0.83	0.94
10	0.65	0.85	1.13	1.31
12	0.78	1.03	1.36	1.57

NOTE: These values are representative examples only. Actual coil pressure drop depends on coil geometry, including fin depth, thickness, and heat transfer "enhancement."

Humidifiers & Water-Spray Systems (§ 5.13)

The Standard has requirements for the design of humidifiers and water-spray devices; again the purpose is to reduce the chances of microbial growth. The requirements apply to steam and direct-evaporation humidifiers, air washers, and other water-spray systems.

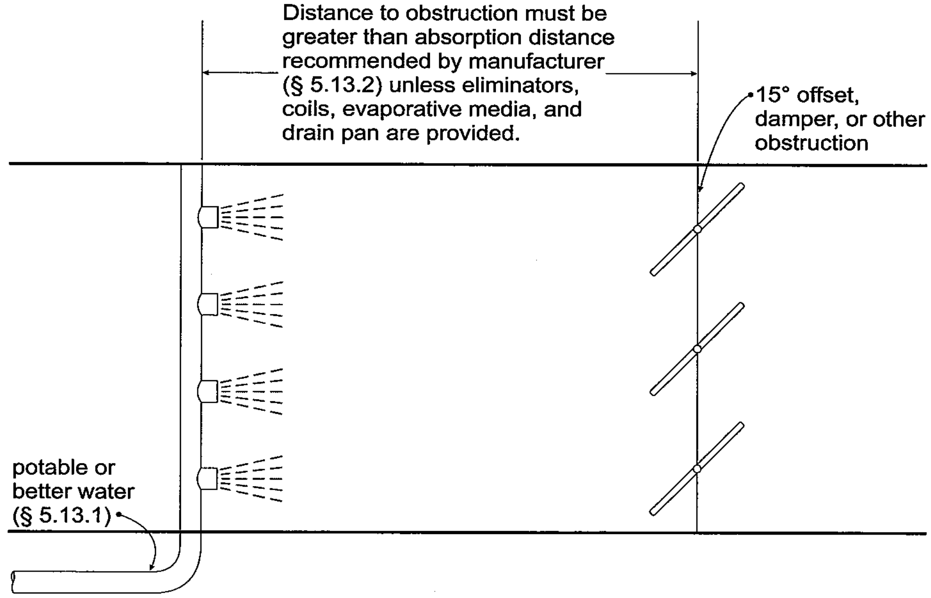


Figure 5-V—Humidifier/Water Spray System

Water Quality (§ 5.13.1)

Water used in these devices evaporates and is breathed by building occupants. Therefore, the water must originate directly from a potable source or from a source with equal or better water quality than a potable source. Drinking water standards generally contain limits on the type and amount of biological material. Section 5.13.1 does not require any additional treatment if potable water is used. However, if a non-potable water source is used, it must have equal or better quality, which can be achieved by treatment and verified by testing.

Obstructions (§ 5.13.2)

Humidification devices, not based on steam, introduce liquid water droplets into the airstream. Air cleaners or ductwork obstructions that are installed downstream of humidifiers or water spray systems must be located a distance equal to or greater than the absorption distance recommended by the humidifier or water spray system manufacturer. Examples of ductwork obstructions include turning vanes, volume dampers, and duct offsets greater than 15 degrees. The absorption distance is the downstream dimension after which the water droplets introduced by the humidifier have evaporated. The purpose of § 5.13.2 is to avoid any water that may drop out of the airstream due to impingement on these obstructions.

However, if the obstructions are equipment such as eliminators, coils, or evaporative media, then an exception allows them to be located within the absorption distance if used with a drain pan complying with the requirements of § 5.11.

Access for Inspection, Cleaning & Maintenance (§ 5.14)

The Standard requires access for periodic inspection, routine maintenance, and cleaning of air handling equipment. Inspection and cleaning are necessary to avoid the buildup of dirt and debris and, in some situations, microbial growth within air distribution systems.

Figure 5-W is a graphical illustration of these requirements.

Equipment Clearance (§ 5.14.1)

Section 5.14.1 requires that ventilation equipment be installed with sufficient working space for inspection and routine maintenance (e.g., filter replacement and fan-belt adjustment and replacement).

Manufacturer's literature generally gives the required service clearances. Such clearances should take into account door swings and space for personnel to stand and move tools and materials in and out. The National Electric Code[28] covers specific service workspace requirements for electrical equipment that may be part of or near ventilation systems.

Ventilation Equipment Access (§ 5.14.2)

While § 5.14.1 covers the workspace around equipment, § 5.14.2 requires access doors, panels, or other means of sufficient size to allow convenient and unobstructed access for the inspection, maintenance, and calibration of all ventilation system components. Section 5.14.2 enumerates the following examples of ventilation system components for which such access is required: air handling units, fan-coil units, water-source heat pumps, other terminal units, controllers, and sensors.

Air Distribution System (§ 5.14.3)

Section 5.14.3 addresses specific access requirements for sub-assemblies and components of larger air distribution systems. It requires that access doors, panels, or other means must be provided in ventilation equipment, ductwork, and plenums. Such required access doors, panels, or other means must be located and sized to allow convenient and unobstructed access for inspection,

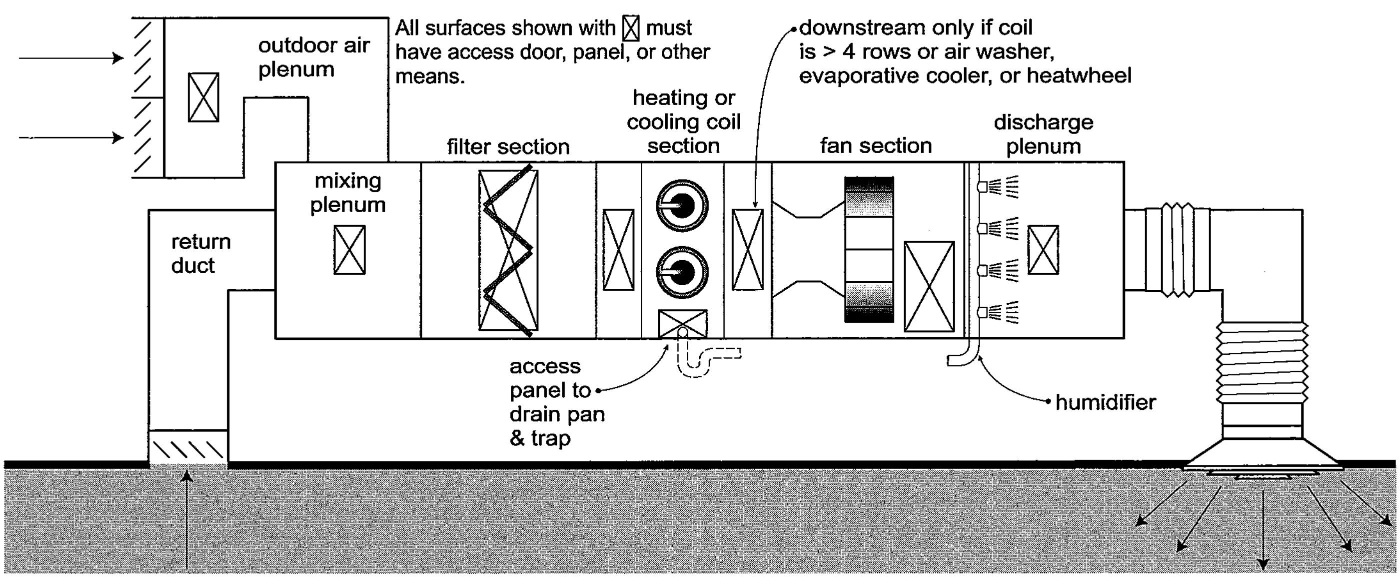


Figure 5-W—Air Distribution System Access

28. National Fire Protection Association, NFPA 70-2002, Quincy, MA, www.nfpa.org.

cleaning, and routine maintenance of the following sub-assemblies and components:

- Outdoor air intake areaways or plenums;
- Mixed air plenums;
- Upstream surface of each heating, cooling and heat recovery coil or coil assembly having a total of four rows or less;
- Both upstream and downstream surface of each heating, cooling and heat recovery coil having a total of more than four rows as well as air washers, evaporative coolers, heat wheels and other heat exchangers;
- Air cleaners;
- Drain pans and drain seals;
- Fans;
- Humidifiers.

Building Envelope & Interior Surfaces (§ 5.15)

Section 5.15 contains requirements to reduce the possibility that the building envelope and cold interior surfaces will contribute to indoor air quality problems. Uncontrolled condensation within the building will result in wet materials and an increased potential for microbial growth. Condensation occurs on surfaces that are below the dewpoint of the air. Insulating cold surfaces, in combination with the 65% rh requirement (see § 5.10), reduces the likelihood of condensation on building materials.

Building Envelope (§ 5.15.1)

The building envelope (including roofs, walls, fenestration systems, and foundations) must comply with the following:

Weather Barrier

A weather barrier or other means must be provided to prevent liquid water penetration into the envelope. This is a basic waterproofing requirement that protects against the entry of precipitation, surface water, and groundwater. Some building materials and systems, however, are designed to handle a certain degree of water penetration. For instance, some wall systems allow water to penetrate the exterior surface of the envelope and then drain the water safely away before it impacts the wall system. For this reason, an exception allows engineered envelopes that allow incidental water penetration to occur without resulting in damage to the envelope construction.

Vapor Retarder

An appropriately placed vapor retarder (or other means) must be provided to limit water vapor diffusion to prevent condensation on cold surfaces within the envelope. However, some materials are designed so that they may be exposed to large seasonal humidity variations without vapor retarders. These materials transmit the moisture and manage it without harmful condensation. For this reason, an exception allows an engineered envelope that allows incidental condensation to occur without resulting in damage to the envelope construction. The purpose of a vapor retarder is to slow the rate of water vapor diffusion through the building envelope. While some materials with a permeance below a certain value are generally classified as vapor retarders, all envelope materials have some resistance to water vapor diffusion. Therefore, when designing the building envelope, the vapor retarding properties of all materials in the envelope relative to each other will have an impact on the overall performance of the construction. The potential for moisture transport through the building envelope and for moisture accumulation within the envelope is a function of all the materials in the envelope relative to each other, as well as the climate and indoor conditioning. There are a number of published resources available,[29] including chapters 23 and 24 of the 2001 ASHRAE *Handbook—Fundamentals*, that provide guidance on designing building envelopes with regard to heat and moisture transfer. They also discuss the relative positions of the thermal insulation, air barrier system, and vapor retarding materials. In addition, computer programs are available to analyze the potential for moisture accumulation in greater detail.[30] Some general guidance exists in terms of locating the vapor retarder within the building envelope, but every design needs to be considered individually with regard to its unique features and the climate in which it will be located. In cold climates, locating the vapor retarder towards the inner, or warm side of the building envelope assembly, and avoiding other vapor retarding materials located towards the exterior of the assembly will minimize the possibility of moisture accumulation within the construction. In hot, humid climates, the risk of moisture being trapped within the envelope is reduced by having only one low-permeability vapor retarding layer and locating it towards the outer, or warm side of the building envelope assembly, while avoiding the use of other vapor retarding materials (such as certain vinyl wall covering and paints) located towards the interior of the assembly. Some specialized materials are designed so that they may be exposed to large seasonal humidity variations without vapor retarders. These materials transmit the moisture and manage it without harmful condensation.

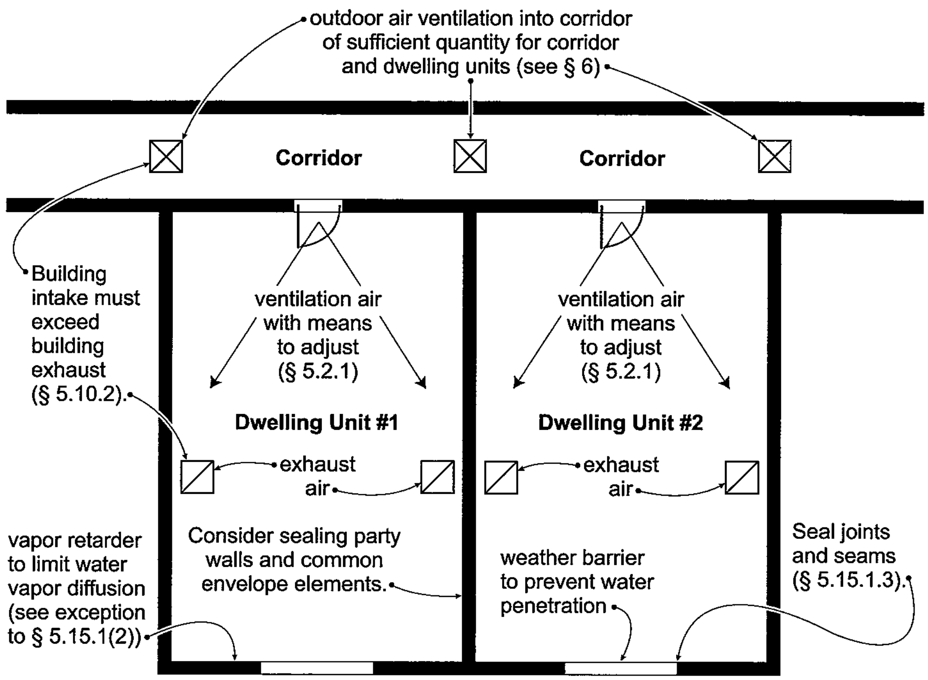


Figure 5-X—Sample Application of Subsections to Multifamily Dwelling Units

Caulking and Sealing

Exterior joints, seams, or penetrations in the building envelope that are pathways for air leakage must be caulked, gasketed, weather-stripped, provided with continuous air barrier, or otherwise sealed to limit infiltration through the envelope and reduce uncontrolled entry of outdoor air moisture and pollutants. The purpose of such sealing of the building envelope is to reduce the potential for moisture accumulation and to reduce air infiltration. Moisture accumulation in the envelope can result in microbial contamination of buildings. Excessive infiltration allows unconditioned and unfiltered outdoor air to enter the building and can interfere with the ability of the HVAC system to properly dehumidify (as required by § 5.10.1). In humid climates, infiltration can be a significant source of moisture introduction into the space. Moisture and air leakage problems can be caused by thermal envelope design defects such as thermal bridges, poorly positioned insulating and vapor retarding materials, and discontinuities in air

29. Brand, R. *Architectural Details for Insulated Buildings* (New York: Van Nostrand Reinhold 1990). Lstiburek, J. et al, *Moisture Control Handbook* (New York: Van Nostrand Reinhold 1993). Treschel, H. *Moisture Control in Buildings* (ASTM Manual Series, MNL 18, 1994).
30. For example, MOIST, a PC program for predicting heat and moisture transfer in building envelopes, United States Building and Fire Research Laboratory, NIST, http://www.bfrl.nist.gov/863/moist.html.

barrier systems. Despite the best design intentions, thermal envelope defects can still occur in a building. Principles and specific design strategies to avoid these defects are discussed in a number of resources.[31]

Soil Gases

Where soils contain high concentrations of radon or other soil gas contaminants, the local authority having jurisdiction may have additional requirements such as sub-slab depressurization. Radon is best controlled by keeping it out of the building. This can be achieved during building design and construction by sealing entry routes and depressurizing the soil. Using ventilation to continuously pressurize occupied spaces below grade is another method of reducing radon entry. These measures are not required by *Standard 62.1-2004.* Figure 5-X illustrates several requirements of § 5.15 and other sections of the Standard.

Condensation on Interior Surfaces (§ 5.15.2)

Condensation can occur on exposed pipes or other surfaces that are colder than the dewpoint temperature of the surrounding air. For instance, in a return air plenum containing supply air ductwork, the dewpoint surface temperature of the supply ductwork may be lower than the dewpoint temperature of the return air, if it is uninsulated, thus resulting in condensation.

Section 5.15.2 requires insulation on pipes, ducts, and other surfaces within the building whose surface temperatures can be expected to be below the surrounding dewpoint temperature. Provide insulation system thermal resistance and material characteristics sufficient to maintain a surface temperature above the dewpoint, as this will prevent condensation from forming on the exposed surface. "Material characteristics" generally means a vapor retarder. If porous insulation wraps a pipe, vapor enters the insulation and condenses where the temperature is colder. Designers should also minimize the existence and impact of thermal bridges, areas where insulation is not continuous and where surface temperatures may drop below the surrounding dewpoint temperature.

There are two exceptions to this requirement for insulation on cold surfaces.

- The first is where condensate will wet only surfaces that can be managed to prevent or control microbial growth.
- The second exception is where local practice has demonstrated that condensation does not result in microbial growth. This exception recognizes that condensation on a cold surface does not always result in microbial growth and allows for the experience of local practice.

The requirements of this section are based on preventing condensation and do not consider energy usage, which is covered by ASHRAE *Standard 90.1.* Note that insulation of supply ducts in plenums may be required by other codes and standards or may be required to prevent excessive heat gain to the supply air.

31. Brand, R. *Architectural Details for Insulated Buildings* (New York: Van Nostrand Reinhold 1990). Lstiburek, J. et al, *Moisture Control Handbook* (New York: Van Nostrand Reinhold 1993). Treschel, H. *Moisture Control in Buildings* (ASTM Manual Series, MNL 18, 1994). Persily, A. K. *Envelope Design Guidelines for Federal Office Buildings* NISTIR 4821 (Geithersburg, MD: NIST 1993).

Example 5-G—Cold Water Pipe Insulation

Q

Is insulation required on exposed cold water pipes in a tiled restroom?

A

Not if the surfaces can be managed to prevent microbial growth, for instance, by regular cleaning.

Buildings with Attached Parking Garages (§ 5.16)

To limit the entry of vehicular exhaust into occupied spaces, § 5.16 requires that buildings with attached parking garages do one of the following:

- Maintain the adjacent occupied space pressure above the garage pressure;
- Use a vestibule to provide an airlock between the garage and the occupied spaces; or
- Otherwise be designed to minimize migration of air from the attached parking garage into the occupied spaces of the building.

To meet these criteria, elevators that serve both a vehicle garage and occupied floors may require lobbies or vestibules at the garage level. The flow of garage contaminants into occupied floors can be accelerated due to the stack effect. Elevator doors generally do not seal well enough to provide an adequate infiltration barrier, so maintaining positive pressure in the occupied space may be difficult. See Figure 5-B for a graphical illustration of this requirement.

Air Classification & Recirculation (§ 5.17)

Section 5.17 classifies air in various types of spaces as well as that which is exhausted from building spaces with respect to contaminant and odor intensity. It also limits the recirculation of lower quality air into spaces that contain air of higher quality. This requirement applies when using the Ventilation Rate Procedure (see § 6.2). It is based on tabular information classifying air from a variety of space types and in some specific airstreams.

Classification (§ 5.17.1)

Tables 6-1, 5-2, and 5-3 (from the Standard) classify air from each space type or in exhaust airstreams according to one of the following categories:

- CLASS 1: Air with low contaminant concentration, low sensory-irritation intensity, and inoffensive odor, suitable for recirculation or transfer to any space.
- CLASS 2: Air with moderate contaminant concentration, mild sensory-irritation intensity, or mildly offensive odors. Class 2 air also includes air that is not necessarily harmful or objectionable, that is suitable for recirculation or transfer to any space with Class 2 or Class 3 air that is utilized for the same or similar purpose and involves the same or similar pollutant sources. Class 2 air is not suitable for recirculation or transfer to spaces with Class 1 air, or dissimilar spaces with Class 2 or Class 3 air.

- CLASS 3: Air with significant contaminant concentration, significant sensory-irritation intensity, or offensive odor that is suitable for recirculation within the same space. Class 3 air is not suitable for recirculation or transfer to any other spaces.
- CLASS 4: Air with highly objectionable fumes; gases; or potentially dangerous particles, bioaerosols, or gases at concentrations high enough to be considered harmful. Class 4 air is not suitable for recirculation or transfer within the space or to any other space.

For space types or airstreams that are not listed in Tables 6-1, 5-2, or 5-3, the air classification of the listed space or airstream that is most similar in terms of occupant activities and building construction must be used.

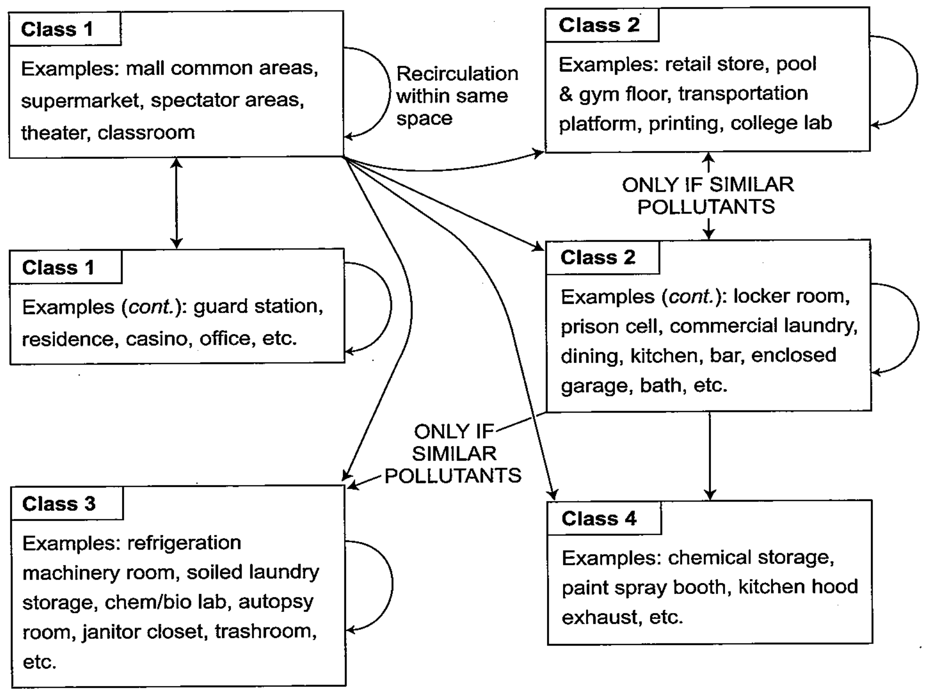


Figure 5-Y—Recirculation Restrictions for Classified Air

Arrows show allowed recirculation or transfer paths. All other pathways are prohibited.

Section 5.17.1 does not address recirculation or transfer of air from smoking areas to non-smoking areas and spaces that are expected to include smoking do not have a classification in Table 6-1, 5-2, or 5-3. Section 6.2.9 prohibits recirculation of air from smoking spaces to non-smoking spaces.

Re-Designation (§ 5.17.2)

Section 5.17.2 discusses how the classification of air may be changed by processes such as air cleaning, energy recovery, and mixing.

This section allows air cleaning to be used for the purpose of reclassifying air, leaving a space or location to a cleaner classification. Air classes 2, 3, and 4 could be cleaned in this way, subject to the approval of the authority having jurisdiction. The appropriate air cleaning system will address the contaminants in the air to meet the subjective criteria for the new classification. Limitations on the use of this reclassified air for recirculation purposes must be in accordance with its new classification and § 5.17.3.

A mixture is classified with the highest class of its constituents. For example, air returned from both a Class 1 and a Class 2 space served by a common system must be designated as Class 2 air.

Energy recovery resulting in 10% or less cross-contamination from Class 2 or 5% or less from Class 3 does not affect the classification of Class 1 air. Energy in the exhaust stream can be a significant loss and energy recovery systems recapture this energy for the intake air. Some energy recovery systems have a small amount of cross-contamination between the exhaust and intake streams in the process of recovering energy. If the amount of contamination is smaller than the limits given above, then for the purposes of this Standard, Class 1 intake air need not be reduced to Class 2 or 3 because of this contamination.

Recirculation Limitations (§ 5.17.3)

These requirements are addressed in the previous discussion on § 5.17.1. Consult Figure 5-Y. Spaces ancillary to Class 2 spaces that are normally Class 1 may be designated Class 2 to simplify HVAC system design. See Example 5-H.

Documentation (§ 5.17.4)

Design documentation must indicate the justification for classification of air from any location not listed in Tables 6-1, 5-2, or 5-3.

Example 5-H—Classification of Office in Restaurant

Q

Does § 5.17 require that the manager's office in a restaurant have a separate system from the restaurant seating area?

A

No. Normally the office would be Class 1, while the seating area of the restaurant would be Class 2, requiring a separate ventilation system for the office. However, § 5.17.3 allows designation of the office as Class 2, since it is ancillary to the restaurant, which is a Class 2 space. Thus, the office becomes Class 2 as well, and the restaurant, including the office, can be served by a single system. Although it is not required by the Standard, increasing the outdoor air rates for the office to match those of the dining area may be appropriate.

6. Procedures

General (§ 6.1)

Section 6 of *Standard 62.1* establishes procedures for calculating minimum ventilation rates for mechanical ventilation systems. Because these rates form the foundation of the ventilation system design, this section is generally considered one of the most important sections of the Standard and is the section most commonly referenced in building codes and HVAC design criteria. Section 6 does not apply to natural ventilation systems, which instead must comply with the ventilation requirements in § 5.1.

Since the 1981 version of *Standard 62*, two procedures have been offered for determining minimum ventilation rates required for compliance: the Ventilation Rate Procedure (VRP) and the Indoor Air Quality Procedure (IAQP).

- The VRP is a prescriptive procedure in which outdoor air intake rates are predetermined for various space types (occupancy categories) based on contaminant sources and source strengths that are typical for the space type. The rates are intended to dilute and exhaust odorous bioeffluents from occupants and odorous and sensory irritant contaminants from other sources common to that type of space. The VRP is intended to reduce concentrations to meet the sensory satisfaction of a substantial majority (greater than about 80%) of adapted occupants[32] within the space.
- The IAQP is a performance-based procedure. Rather than prescribing rates based on occupancy category, rates are calculated based on contaminant source strengths and desired indoor concentrations. The IAQP allows designers to take credit for source-control and removal measures, such as selection of low-emitting materials and gas-phase air cleaning devices. The IAQP may also be used where the design is intended to attain specific target contaminant concentrations or specific levels of acceptability of perceived indoor air quality. For instance, the design can be targeted to satisfy a higher or lower proportion of occupants than 80%—or to focus on unadapted people (often called visitors) as opposed to adapted occupants.

The decision as to which of the two design procedures to use is influenced by the design of the ventilation system and spaces served by the system, the activities expected to occur in the space, and the desired level of acceptability of air quality. The VRP is based on typical spaces—those with contaminant source strengths commonly found in the listed category—and based on achieving reasonable levels of adapted occupant satisfaction with space air quality. If spaces are believed to have unusual contaminant sources or unusually high source strengths, or if a higher level of acceptance is desired, then the IAQP may be the more appropriate design procedure.

Both procedures may be used within the same building. For instance, if a space is expected to have an unusual source of contaminants (e.g. from a piece of machinery), the IAQP may be applied to only this space and only for a small number of contaminants while the VRP is used to determine rates for other spaces in the building. In this case, outdoor air intake flow for the entire system would be determined following the VRP, even though some zone ventilation requirements are determined using the IAQP.

Another significant factor in deciding which procedure to use is the willingness of the ventilation system designer to take on the level of design and analysis effort and the additional risk and responsibility that the IAQP entails. Historically, the VRP has been by far the most commonly used procedure. This is mostly due to perceived simplicity (reduced design time) and perceived reduction in risk (exposure to lawsuits) related to possible future indoor air quality complaints. The

32. Adapted occupants are people who have occupied a space for a sufficient period of time that their sensory perceptions have become desensitized to some air contaminants, in particular bioeffluents (contaminants emitted by people, such as body odor), adaptation to which usually only takes a few seconds. Adaptation to other contaminants such as environmental tobacco smoke (ETS) and volatile organic compounds (VOCs) can take much longer or not occur at all. People who have yet to adapt to air contaminants (unadapted occupants) are often called "visitors" to the space.

IAQP requires the designer to make many more assumptions in calculations, such as which contaminants to consider and what concentrations are acceptable, assumptions that are effectively built into the VRP. These assumptions are usually judgment calls on the part of the designer, who may or may not be well equipped to make them, and may be questioned should air quality problems ever occur in the building.

Finally, another consideration in the selection of procedure is possible limitations placed by building codes or incentive programs. For instance, the U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) program requires that outdoor air rates be determined using only the VRP.

Ventilation Rate Procedure (§ 6.2)

Revisions from Prior Versions

The VRP prescribes ventilation rates for typical occupancy categories. Prescribed rates were expressed as volumetric airflow rate per person (cfm/person or L/s-person) for most occupancy categories in the initial 1973 version of *Standard 62* and up through the 2001 version. The procedure was significantly revised by Addendum 62n, approved by ASHRAE in June 2003 and ANSI in January 2004. Changes include the following.

- Prescribed ventilation rates are now calculated as the sum of an occupant-related component (expressed as volumetric airflow per person) and a building-related component (expressed as volumetric airflow per unit floor area) for each occupancy category. The occupant component is intended to dilute odorous bioeffluents from occupants and other sensory contaminants that result directly from occupant activities. It is proportional to the number of people expected to occupy the space. The building area-based component is intended to dilute sensory contaminants emitting from materials and furnishings within the space, and from non-occupant activities and processes taking place within the space. It is proportional to the occupiable floor area of the space.
- The efficiency of the air distribution system in delivering outdoor air to the breathing zone of the space is explicitly included in the rate calculation method. This includes the effectiveness of the zone air distribution, including the effects of outlet placement and design and supply air temperatures, and the efficiency of systems serving multiple spaces that require different outdoor airflow fractions.
- The occupant ventilation rate component was based on achieving sensory satisfaction of a substantial majority of adapted occupants. Rates in the 1989 to 2001 versions of the Standard were primarily targeted toward satisfying unadapted visitors.
- Time averaging for varying occupant loads is addressed more explicitly and based more on fundamental principles than prior versions of the Standard.
- The procedure is now written in code-enforceable language, meaning that language is mandatory (no recommendations or "should" statements, only "shall" statements) and requirements are explicit (no vague statements such as "where required" or "to the extent possible").

Rationale for Revisions

This section explains the rationale behind the VRP ventilation rates, which helps users of the Standard to understand how to apply and enforce the requirements. As will be evident from the following discussion, there is a limit to the precision with which the required ventilation rates can be determined. While indoor air quality field and laboratory research was used to determine the rates, the research is incomplete and many questions remain regarding what ventilation rates are actually needed for various levels of acceptability for the wide range of occupancy categories covered by the Standard and indeed what level of acceptability should be considered a minimum. Given this uncertainty and the wide range of contaminant sources and source strengths that occur in buildings even within the same occupancy category, the rates prescribed by *Standard 62.1* should be considered approximate in their ability to achieve the desired performance target and may or may not always result in acceptable indoor air quality. (See the caveat in § 2.5.)

Two Component Approach and Additivity

The contaminants in indoor spaces that ventilation is intended to dilute are generated primarily by two types of sources:

- Occupants (bioeffluents) and their activities (e.g. use of office machinery such as copy machines); and
- Off-gassing from building materials and furnishings.

There is little doubt or controversy about the existence of these two sources; the difficulty is how to determine the magnitude of the ventilation rate required to dilute each source and how the contaminants generated by various sources interact with each other. For a space of a given occupancy type experiencing typical occupant activities and constructed with typical materials and furnishings, the strength of sources associated with occupants and their activities is approximately proportional to the number of occupants. This has been widely confirmed by research (discussed in subsequent paragraphs). Less fully supported by research is the premise that for each space type, the source strength of building materials and furnishings is approximately proportional to the room floor area. How the individual contaminants emanating from these sources interact with each other and with the sensation and irritation of occupants is even less understood and more controversial. The impact of contaminants on people can be:

- Additive (1+2=3);
- Independent, strongest source dominates (1+2=2);
- Synergistic (1+2=4); or
- Antagonistic (1+2=1).

While all four effects occur in buildings, the majority of research suggests that the predominant form of interaction (impact on people) is additivity. This means that while the chemical nature of the various contaminants in indoor air may differ, they tend to behave in an additive fashion with respect to their impact on occupant perception of odor and irritation. Therefore the ventilation rate required to control both people-related sources (V_p) and building-related or area-based sources (V_a) is the sum of the ventilation required to control each of them alone at the breathing zone (V_{bz}). This is expressed in the following equation.

$$V_{bz} = V_p + V_a \qquad \text{6-A}$$

If we assume that the occupant component is proportional to the number of people and the building area component is proportional to the building area, the additivity concept for the ventilation required in the breathing zone of a space can be expressed by the following equation.

$$V_{bz} = R_p P_z + R_a A_z \qquad \text{6-B}$$

The concept of additivity has been demonstrated in both laboratory[33] and field settings.[34] In these studies, the researchers measured the level of perceived indoor air quality from humans and different types of building materials and furnishings alone and in combination. They then compared the total source strength when the sources were combined with the sum of the source strengths of the individual sources. In general, the agreement was good, though of course not perfect.

The results of other studies have questioned the appropriateness of additivity.[35] These particular studies are also the subject of debate and conclude that additivity needs to be studied more, not discarded. While one can debate this research, additivity is more productively considered as simply a

33. Iwashita, G. and K. Kimura "Addition of Olfs from Common Air Pollution Sources Measured with Japanese Subjects" CIB Working Group WG77: *Indoor Climate* (1995). Lauridsen, J. et al. "Addition of Olfs for Common Indoor Pollution Sources" *Healthy Buildings* 3 (1988): 189–195.
34. Wargocki, P. et al. "Field Study of Addition of Indoor Air Sensory Pollution Sources" *Indoor Air* 4 (1996): 307–312.

calculation method to deal with two types of sources, those that depend primarily on the number of people (contaminants from occupant activities and occupants themselves) and those that depend primarily on building floor area (contaminants from building materials and furnishings).

This construct avoids the need to make assumptions about occupant density (people per unit floor area), which is an important advantage since occupant density can vary over a wide range within a single occupancy category. (The rate-per-person construct of prior versions of the Standard implicitly includes a fixed assumption of the occupancy density, often resulting in over-ventilation in zones with high occupant densities.) The additivity construct also reduces concerns about over- (or under-) ventilation of densely (or sparsely) occupied spaces.

Determining Component Ventilation Rates

Once the form of the equation was selected, the next step was to determine the values of each component (R_p and R_a in Equation 6-B) for each occupancy category. The rates were based on research, experience, and judgment as described below:

- *Research On the Occupant Component*: There have been a number of laboratory and field studies of the amount of ventilation air required to dilute occupant-generated odors and irritants.[36] These studies have fairly consistently shown that about 15 cfm (7.5 L/s) will satisfy a substantial majority (about 80%) of unadapted persons (visitors) in the space. Later studies showed that a significant adaptation occurs for bioeffluents,[37] but less to building materials.[38] While the data for adapted occupants are less extensive, a 1983 study[39] shows that about 5 cfm (2.5 L/s) will satisfy a substantial majority of adapted occupants.
- *Research on the Building Component*: There have been several studies of the source strengths associated with sensory pollutants from the building itself, rather than from the occupants. The results of these studies indicate a fairly wide range of building source strengths. This is not too surprising given the breadth of building designs and usages. When these source strengths are converted to ventilation requirements required to satisfy about 80% of unadapted visitors to a space, the mean value for offices and classrooms is about 0.39 cfm/ft^2 (2.0 L/s-m^2), 0.53 cfm/ft^2 (2.7 L/s-m^2) for kindergartens and 0.66 cfm/ft^2 (3.3 L/s-m^2) for assembly halls.[40] More recent research supports these values.[41]
- *Research on Overall Rates in Office Buildings*: By far the most common subject of field studies was office

35. Bluyssen, P.M. and H.J.M. Cornelissen "Addition of Sensory Pollutant Loads—Simple or Not, That is the Question" ASHRAE *Design, Construction, and Operation of Healthy Buildings* (1998) 161–168
36. Berg-Munch, B. et al. "Ventilation Requirements For The Control Of Body Odor In Spaces Occupied By Women" *Environ. Int.* 12 (1986): 195–200. Cain, W.S., et al. "Ventilation Requirements In Buildings" *Atmospheric Environment* 17 no. 6 (1983): 1183–1197. Fanger, P.O. and B. Berg-Munch "Ventilation And Body Odor" *Proceedings of An Engineering Foundation Conference on Management of Atmospheres in Tightly Enclosed Spaces* (ASHRAE 1983): 45–50. Iwashita, G. et al. "Indoor Air Quality Assessment Based on Human Olfactory Sensation" *Journal of Architectural Planning and Environmental Engineering* 410 (1990): 9–19.
37. Berg-Munch, B. et al. "Ventilation Requirements For The Control Of Body Odor In Spaces Occupied By Women" *Environ. Int.* 12 (1986): 195–200.
38. Gunnarsen, L. and P. O. Fanger "Adaptation to Indoor Air Pollution" *Healthy Buildings* 3 (Stockholm, Sweden 1988): 157–167. Gunnarsen, L. "Adaptation and Ventilation Requirements" *Fifth International Conference on Indoor Air Quality and Climate* 1 (Toronto, Canada 1990): 599–604.
39. Cain, W.S., et al. "Ventilation Requirements In Buildings" *Atmospheric Environment* 17 no. 6 (1983): 1183–1197. Fanger, P.O. and B. Berg-Munch "Ventilation And Body Odor" *Proceedings of An Engineering Foundation Conference on Management of Atmospheres in Tightly Enclosed Spaces* (ASHRAE: 1983): 45–50
40. Fanger, P.O. et al. "Air Pollution Sources in Offices and Assembly Halls" *Energy and Buildings* 12 (1988): 7–19. Pejtersen, J. et al. "A Simple Method to determine the Olf Load in a Building" The Fifth International Conference on Indoor Air Quality and Climate, *Indoor Air* 1 (1990): 537–542. Pejtersen, J. et al. "Air Pollution Sources in Kindergartens" IAQ 91 *Healthy Buildings* (1991): 221–224. Thorstensen, E. et al. "Air Pollution Sources and Indoor Air Quality in Schools" The Fifth International Conference on Indoor Air Quality and Climate *Indoor Air* 1 (1990): 531–536.
41. Wargocki, P. et al. "Perceived Air Quality and Sensory Pollution Loads in Six Danish Office Buildings" *Indoor Air* (2002)

buildings. Several field studies indicate that an outdoor air supply of 20 cfm (10 L/s) per person is very likely to be associated with lower rates of sick building syndrome symptoms (and presumably more acceptable perceived indoor air quality) in office spaces.[42] These measured ventilation rates include the combined impacts of occupant and building sources as well as some degree of ventilation system efficiency.

- *Experience*: Experience with successful existing buildings was considered, including buildings built under the 1981 Standard when outdoor air rates were a third or less of the rates required after 1989. However, this experience, already largely anecdotal, must be tempered by the fact that actual ventilation rates in buildings are unlikely to be equal to the values required by the Standard at the time they were built. Research indicates that actual ventilation rates measured in buildings typically do not correspond to rates required by the version of *Standard 62.1* effective at the time, the building code under which the building was designed, or even to the design values indicated on construction drawings.[43] One study encompassing about 3000 individual ventilation rate measurements in more than a dozen office buildings found that about half the measured outdoor air ventilation rates were below the design values.[44] The European Audit Project study of 56 office buildings in nine countries found that ventilation rates varied by a factor of two above or below the designed ventilation rates.[45] Nevertheless, anecdotal experience provides a useful reality test to limit proposed ventilation rates so that they are neither overly high nor low.

- *Judgement*: Because of the limited breadth of available research (most focus only on offices, for instance) and the imprecise nature of research results and anecdotal experience in existing buildings, to a very large extent ventilation rates were determined based on the experience and judgment of the committee members who developed the Standard over the last 10 years. It should be noted that prior versions of the Standard were even more reliant on committee judgment since even less research was available at the time.

The development of the VRP rate table began first with offices since they were the subject of the most research.

Starting with the occupant ventilation component (R_p), the fact that the Standard was targeted for use in building codes as a minimum standard led to the decision to use 5 cfm (2.5 L/s) per person as the base rate, since research has shown that this rate will satisfy a substantial majority of adapted occupants. This value is based on occupant-related contaminants from adults at a sedentary activity level consistent with office spaces, and therefore must be adjusted upwards for some other occupancy categories where the occupants are more active. It also must be adjusted upwards in some occupancy categories to account for contaminants generated by occupant activities, such as art and science classrooms.

To determine the building component (R_a), the committee reviewed the available research on occupant perception of odors from non-occupant sources in offices, schools and other building types. The mean ventilation rate noted in the studies of office buildings to achieve 80% satisfaction by adapted occupants was 0.4 cfm/ft^2 (2 L/s-m^2), and the lowest value was about 0.03 cfm/ft^2 (0.15 L/s-m^2).[46]

42. Mendell, M.J. "Non-Specific Symptoms in Office Workers" *Indoor Air* 3 no. 4 (1993): 227–236. Seppanen, O.A. et al. "Association of Ventilation Rates and CO_2 Concentrations with Health and Other Responses in Commercial and Institutional Buildings" *Indoor Air* 9 no. 4 (1999): 226–252. Apte, M.G. et al. "Associations Between Indoor CO_2 Concentrations and Sick Building Syndrome Symptoms in US Office Buildings" *Indoor Air* 10 no. 4 (2000): 246–257
43. Persily, A.K. and Gorfain, J. *Analysis of Ventilation Data from the U.S. Environmental Protection Agency Building Assessment Survey and Evaluation (BASE) Study*, NISTIR 7145 (NIST December 2004)
44. Persily, A.K. "Ventilation Rates in Office Buildings" (ASHRAE IAQ 1989) *The Human Equation: Health and Comfort* 128–136
45. Bluyssen, P.M. et al. *European Audit Project to Optimize Indoor Air Quality and Energy Consumption in Office Buildings* (1995)
46. Fanger, P.O. et al. "Air Pollution Sources in Offices and Assembly Halls, Quantified by the Olf Unit." *Energy and Buildings* 12 (1988): 7–19. Pejtersen, J.L. et al. "A Simple Method to determine the Olf Load in a Building." The Fifth International Conference on Indoor Air Quality and Climate, *Indoor Air* 1 (1990): 537-542

Table 6-A—R_a and R_p Values by Occupancy Type

Occupant Component		
CATEGORY	R_p	DISCUSSION
0	0 cfm (0 L/s) per person	Applies to spaces where the ventilation requirements are assumed to be so dominated by building related sources, due to the typically very low and transient nature of the occupancy, that the occupant component may be ignored. Examples include storage rooms and warehouses.
1	5 cfm (2.5 L/s) per person	Applies to spaces where primarily adults are involved in fairly passive activities similar to sedentary office work.
2	7.5 cfm (3.5 L/s) per person	Applies to spaces where occupants are involved in higher levels of activity (though not strenuous), thereby producing higher levels of bioeffluents, or are involved in activities associated with increased contaminant generation. Examples include lobbies and retail stores.
3	10 cfm (5 L/s) per person	Applies to spaces where occupants are involved in more strenuous levels of activity (though not at an exercise-like level), or are involved in activities associated with even higher contaminant generation. Examples include most classrooms and other school occupancies.
4	20 cfm (10 L/s) per person	Applies to spaces where occupants are involved in very high levels of activity, or are involved in activities associated with very high contaminant generation. Examples include beauty salons, dance floors, and exercise rooms. Hair sprays, shampoos, etc., are considered occupant-related rather than building-related.
Building Component		
CATEGORY	R_a	DISCUSSION
1	0.06 cfm/ft^2 (0.3 L/s-m^2)	Applies to spaces where building related contaminants are generated at rates similar to office spaces. Examples include conference rooms and lobbies.
2	0.12 cfm/ft^2 (0.6 L/s-m^2)	Applies to spaces where building related contaminants are generated at rates significantly higher than those for offices. Examples include typical classrooms and museums.
3	0.18 cfm/ft^2 (0.9 L/s-m^2)	Applies to spaces where building related contaminants are assumed to be generated at an even higher rate. Examples include laboratories and art classrooms.
4	0.30 cfm/ft^2 (1.5 L/s-m^2)	These last two categories apply to three unusual spaces, all in the Sports and Entertainment category, for which there is no people-based ventilation requirement (R_p = 0). For that reason, and because of their unique natures, the building ventilation requirements are elevated to five to eight times the base rate.
5	0.48 cfm/ft^2 (2.4 L/s-m^2)	

Based on these data, and again in the context of establishing code minimum requirements, the value of 0.06 cfm/ft^2 (0.30 L/s-m^2) was identified as the base rate to handle building sources for offices. When combined with the base occupant rate of 5 cfm (2.5 L/s) per person, typical occupant densities, and typical ventilation system efficiencies (more on ventilation efficiency below), this building component rate results in an overall ventilation rate of about 20 cfm (10 L/s) per person for office spaces, consistent with engineering experience and the office building research referenced above.

The next step was to determine occupant and building rates for the other occupancy categories listed in the VRP table. As noted above, there are insufficient hard research results to identify specific values of R_p and R_a for each space type. Therefore, most of the rates are based on professional judgment, engineering experience, and a subjective assessment of the relative contaminant source strength from materials within the space relative to the base office occupancy.

To reflect the inherently approximate nature of ventilation rates determined in this fashion, the values of R_p and R_a for each occupancy type are based on simple multiples of the base rates, as outlined in Table 6-A.

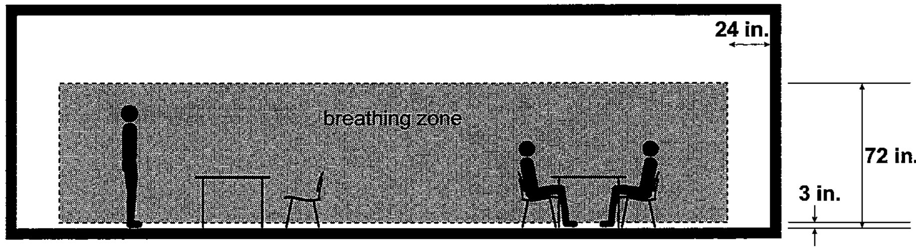


Figure 6-A—Breathing Zone

Ventilation Efficiency

The breathing zone is that region within an occupied space between three planes: 3 and 72 inches (75 and 1800 mm) above the floor and more than 2 feet (600 mm) from the walls or fixed air-conditioning equipment. It is to this region that ventilation air must be supplied. This concept is defined in order to clarify the difference between moving air through the ventilation system ductwork and actually getting it to where the occupants breathe.

The ability of the ventilation system to deliver outdoor air to the breathing zone of the space can be described by two factors: zone air distribution effectiveness, and system ventilation efficiency as applied to multiple space recirculating systems.

- *Zone Air Distribution Effectiveness*: Concerns have long been expressed about inefficiencies in the mixing of ventilation air within rooms and the possibility that ventilation air was not getting to the breathing zone of the space. Several terms have been used to describe this performance, including Zone Air Distribution Effectiveness (used in the current Standard), Ventilation Effectiveness (used in *Standard 62-2001*), and Air Change Effectiveness (used in ASHRAE *Standard 129-1997 [RA 02]* and most research projects). These terms have slightly different definitions but essentially measure the same effect: the ability of the system to deliver air from the supply air outlet to the breathing zone of the space. There has been a significant amount of research on ventilation effectiveness in the lab and in the field.[47] In addition, ASHRAE has issued a standard test method (ASHRAE *Standard 129-1997 [RA 02]*) for measuring air change effectiveness. The table of default values for Zone Air Distribution Effectiveness in *Standard 62.1* is based on this research as well as engineering judgment for applications where research is less complete. The research has shown without exception that spaces supplied with air cooler than the room air have an air change effectiveness near one (E_z~1) regardless of the design of the air distribution system. This includes overhead supply and return systems even when serving spaces partitioned into cubicles. The reason is that the cool air is denser than the room air and naturally falls while heat sources in the room (people, PCs) cause plumes of warm air that rise up toward the ceiling. The combination causes air to naturally mix. Poor zone air distribution effectiveness (E_z) results mostly from warm air supply systems, as discussed later in the Chapter under"Zone Calculations (§ 6.2.2)."

47. Faulkner, D. et al. "Ventilation Efficiencies of Desk-Mounted Task/Ambient Conditioning Systems" *Indoor Air* 9 no. 4 (1999): 273–281. Faulkner D. et al. "Indoor Airflow and Pollutant Removal in a Room with Floor-Based Task Ventilation" *Building and Environment* 30 no. 3 (1995): 323–332. Fisk, W.J. et al. "Air Change Effectiveness and Pollutant Removal Efficiency During Adverse Conditions" *Indoor Air* 7 no. 1 (1997): 55–63. Fisk, W.J. et al. "Air Exchange Effectiveness in Office Buildings" *International Symposium on Room Air Convection and Ventilation Effectiveness* (1992): 213–223. Fisk, W.J. et al. "Air Change Effectiveness of Conventional and Task Ventilation for Offices" ASHRAE *IAQ Healthy Buildings, Postconference Proceedings* (1991): 30–34. Offerman, F.J. "Ventilation Effectiveness and ADPI Measurements of a Forced Air Heating System" ASHRAE *Transactions* 94 (1988): 694–704. Persily et al. "Air Change Effectiveness Measurements in Two Modern Office Buildings" *Indoor Air* 4 no. 1 (1994): 40–55. Persily et al. "Field Measurements of Ventilation and Ventilation Effectiveness in an Office/Library Building" *Indoor Air* 3 (1991): 229–246. Sandberg, M. "Ventilation Efficiency as a Guide to Design" ASHRAE *Transactions* 89 no. 2B (1983): 455–477

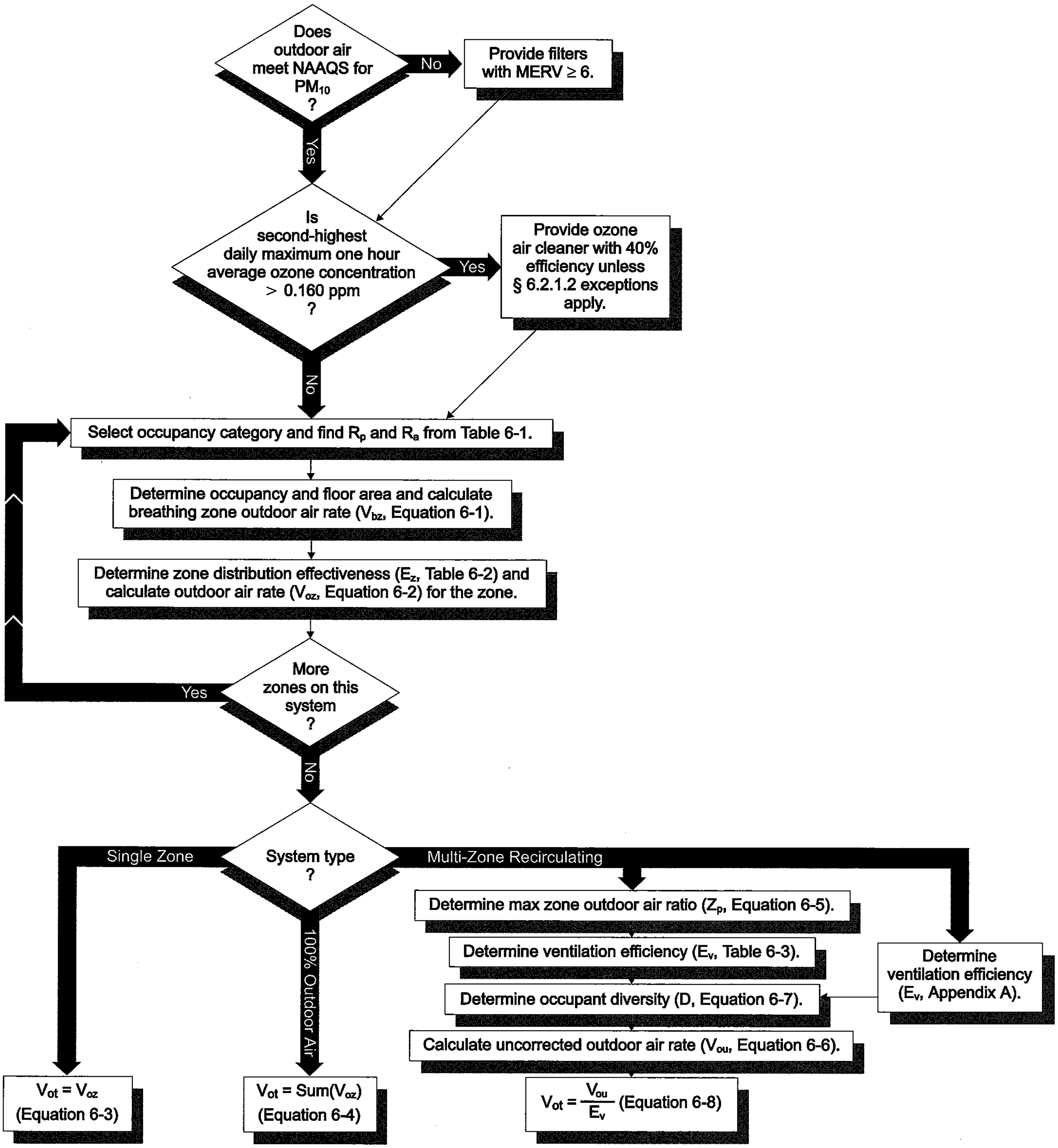


Figure 6-B—Ventilation Rate Procedure Flow Chart

- *System Ventilation Efficiency for Multiple Zone Recirculating Systems*: Systems that serve multiple spaces and that recirculate air from one or more of these spaces have an inherent inefficiency if the percentage of outdoor air required is not the same for each space. This is because the percentage of outdoor air in the supply air is the same for all spaces, so spaces that require a high ratio of outdoor air to supply air will be under-ventilated if outdoor air rates at the air handling unit are not increased. Adjustment for this effect was first introduced in the 1989 version of the Standard. Equation 6-1 (sometimes called the "Multiple Spaces Equation") in that Standard was derived for single path supply air systems, such as central variable air volume or constant volume systems with terminal reheat. The current Standard uses the same approach for single path systems, but the equation has been rearranged to use the term System Ventilation Efficiency. Because many designers considered the Multiple Spaces Equation too complex, it has been simplified into a default table of System Ventilation Efficiency values. The concept has also been expanded[48] in Appendix A of the current Standard to allow multiple recirculation paths to be taken into account, improving the System Ventilation Efficiency of systems such as dual fan/dual duct systems and systems with fan-powered terminal units.

VRP Summary

The VRP requires three basic steps, summarized below and shown graphically in Figure 6-B. Each step will be described in detail in the following sections.

0. Determine if air cleaning is required:
   a) For particulate matter,
   b) For ozone,
   c) For other contaminants (documentation only).
1. For each ventilation zone, calculate minimum zone outdoor air rate required at supply air outlets, V_{oz}.
   a) Select occupant category in Table 6-1 and determine occupant and building rate requirements, R_p and R_a, from Table 6-1.
   b) Estimate the number of occupants in the zone, P_z.
   c) Calculate the zone net occupied floor area, A_z.
   d) Calculate the outdoor air required in the breathing zone, V_{bz}, from Equation 6-1.
   e) Determine the zone air distribution effectiveness, E_z, from Table 6-2.
   f) Calculate the minimum zone outdoor air rate required at the supply air outlets, V_{oz}, from Equation 6-2.
2. For each ventilation system (air handler), determine system outdoor air rate required at the system outdoor air intake, V_{ot}.
   a) For single zone systems calculate system outdoor air rate, V_{ot}, from Equation 6-3.
   b) For 100% outdoor air systems calculate system outdoor air rate, V_{ot}, from Equation 6-4.
   c) For multiple zone recirculating systems:
      1) Select either the simplified Table 6-3 approach or the more complex Appendix A approach:
         a) For Table 6-3 approach:
            i. Find the largest ratio of zone outdoor air rate to zone primary air rate for each zone served by the system, Z_p, from Equation 6-5.
            ii. Determine system ventilation efficiency, E_v, from Table 6-3.
         b) For Appendix A approach use the equations and procedures in Appendix A to determine E_v.
      2) Determine the occupant diversity, D, from Equation 6-7.
      3) Calculate the uncorrected outdoor air rate, V_{ou}, from Equation 6-6.
      4) Calculate system outdoor air rate, V_{ot}, from Equation 6-8.

Outdoor Air Treatment (§ 6.2.1)

If the outdoor air quality has been judged to be unacceptable in accordance with § 4.1, each ventilation system must comply with the following sections as applicable for the control of particulate matter (PM_{10}), ozone, or other outdoor contaminants that exceed the national standards. Occupied spaces will be subject to reduced air quality if unacceptable outdoor air is introduced into the occupied spaces without having first been cleaned.

Air for enclosed parking garages, warehouses, storage rooms, janitor's closets, trash rooms, recycling areas, and

48. Warden, D. "Outdoor Air: Calculation and Delivery" *ASHRAE Journal* 37 no. 6 (1995): 54–63

shipping/receiving/distribution areas are exempt from the air cleaning requirements described in this section.

Particulate Matter (§ 6.2.1.1)

When the building is located in an area where the national standard for PM_{10} is exceeded, particulate filters or air cleaning devices shall be provided to clean the air prior to its introduction to occupied spaces. Particulate matter filters or air cleaners shall have a Minimum Efficiency Reporting Value (MERV) of 6 or higher when rated in accordance with ASHRAE *Standard 52.2-1999.*

Conventional wisdom has held that because essentially every building HVAC system already has particulate filters (or other particulate air cleaners), they should already be able to address the large majority of particulate contamination issues. These filters have traditionally had as their primary function the protection of mechanical equipment and not building occupants. This section addresses the additional requirement for air cleaning in nonattainment areas for particulate matter (PM_{10}).

Particles with an aerodynamic diameter less than or equal to a nominal 10 micrometers (PM_{10}) are the standard on which national compliance is based.

Example 6-A—New PM_{10} Requirement

Q

Previous versions of *Standard 62.1* suggested but did not require cleaning for outdoor air. Why is there now a requirement for the control of PM_{10}?

A

As of November 2004, the EPA identified 58 areas in 57 counties in 18 states as having air quality that violates the current federal air standard for PM_{10}. These areas encompass a total population of almost 30 million people or more than 10% of the population.* Some of the sources of these coarser particles are smoke, dirt/dust from factories, farming, roads, mold, spores, and pollen. These smaller particles are likely responsible for most of the adverse health effects of particulate matter because of their ability to reach the thoracic or lower regions of the respiratory tract.

Based on studies of human populations exposed to high concentrations of particles (sometimes in the presence of SO_2), there are major effects of concern for human health. These include breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense systems against foreign materials, damage to lung tissue, carcinogenesis, and premature death. Individuals with chronic obstructive pulmonary or cardiovascular disease or influenza, asthmatics, the elderly, and children appear to be most sensitive to particulate matter. Particulate matter also soils and damages materials, and is a major cause of visibility impairment in the United States.

The Standard already requires the use of minimum MERV 6 particulate filters or air cleaning devices upstream of cooling coils or other wetted surfaces in § 5.9. This removal technology has reached a level of maturity such that its application for the control of PM_{10} does not present an undue economic burden on building owners/operators.

** Particulate Matter Nonattainment Area Summary, U.S. EPA, Washington, D.C., http://www.epa.gov/air/oaqps/greenbk/pindex.html. The Particle Pollution Report: Current Understanding of Air Quality and Emissions through 2003, U.S. EPA, Washington, D.C., http://www.epa.gov/airtrends/pm.html.*

Ozone (§ 6.2.1.2)

This section requires air cleaning for ozone in regions when the second-highest daily maximum one-hour average monitored ozone levels exceed 0.160 ppm (313 μg/m^3) and this data can be found on the EPA website.

Air-cleaning devices for ozone must have a minimum volumetric ozone removal efficiency of 40% when installed, operated, and maintained in accordance with manufacturer recommendations. The authority having jurisdiction must approve these devices. Such devices must be operated whenever outdoor ozone levels are expected to exceed 0.160-ppm (3.13 mg/m^3). That would typically be during the warm weather months.[49]

Previous versions of the Standard required outdoor air assessment, and recommended outdoor air cleaning for contaminants of concern, but did not require air cleaning. As of August 2004, the EPA identified part or all of 474 counties in 31 states and the District of Columbia as having air quality that exceeds the current 8-hour federal air standard for ozone (commonly called smog). These areas encompass a total population of almost 160 million people or more than 54% of the population. This Standard still references the older one-hour ozone standard that reduces the number of states with nonattainment areas to 24 and the number of counties to 216. These areas, however, still have a total population of over 108 million people that represents more than 36% of the general U.S. population.[50] Ozone is the one criteria pollutant that has experienced a continuous increase in the number of areas designated as nonattainment.

Mandatory air cleaning for ozone is appropriate because of the large number of people living in nonattainment areas, and the negative impact that ozone has on indoor air quality and occupant well being. Reducing the ozone concentration and its oxidation byproducts indoors may have a beneficial health effect as well as reduce irritation and discomfort.

Note that buildings with air change rates of 1.5 air changes per hour or less are exempt from the ozone air cleaning requirement, since even very high outdoor ozone concentrations will be diluted with recirculated air when air change rate is low. Air cleaning for ozone is not required if controls reduce intake airflow to 1.5 air changes or less during periods of high ozone levels, provided the short term condition ventilation requirements in § 6.2.6.2 are met. It is also not required for buildings located in ozone nonattainment areas wherein the second-highest daily maximum reported one-hour average concentration in outdoor air is 0.160 ppm (3.13 mg/m^3) or less. Finally, there is no requirement for ozone control when outdoor air is heated by direct-fired, makeup air units.

Other Outdoor Contaminants (§ 6.2.1.3)

If the building is located in an area where the national standard is exceeded for one or more contaminants not specifically addressed in § 6.2.1design documents must include any design assumptions and/or calculations related to the impact on indoor air quality . This requirement is specific to contaminants other than PM_{10} and ozone, however, other potential contaminants of concern identified in § 4.2 may also be considered.

If any other outdoor contaminants are considered under this section, direct control using air cleaning is not specifically required. However, an investigation into its practicality, effectiveness, and economic viability may be reasonable.

49. Green Book Nonattainment Areas for Criteria Pollutants-Ozone Monitoring Season By State, U.S. EPA, Washington, D.C., http://www.epa.gov/oar/oaqps/greenbk/o3season.html.
50. Green Book Nonattainment Areas for Criteria Pollutants-8-Hour Ozone Area Summary, U.S. EPA, Washington, D.C., http://www.epa.gov/oar/oaqps/greenbk/gnsum.html, or U.S. Census Bureau, United States Department of Commerce, Washington, D.C., http://www.census.gov/index.html.

Example 6-B—Air Cleaning for Ozone

Q

A building is located in a region where the second-highest daily maximum one-hour average monitored ozone levels exceed 0.160 ppm (313 $\mu g/m^3$). How might the owner achieve the required minimum volumetric ozone removal efficiency of 40% for compliance with § 6.2.1.2?

A

Assuming that none of the exceptions to § 6.2.1.2 apply to this application, air cleaning for ozone may be used for compliance. An air cleaning system for ozone would be located in the HVAC system so as to treat the outdoor air prior to it being delivered into the occupied space(s), generally downstream of the particulate filters section. Air cleaners employing a nominal minimum 1 in. (25 mm) bed of activated carbon can provide the required level of protection over an extended period of time.* Pleated media filters employing a carbon-loaded non-woven fiber matrix† may also meet the air cleaning requirement.‡ Filters that employ an activated carbon powder or slurry, or those utilizing adhesives to attach the carbon to a fiber or foam matrix should be used with caution, since they may have neither an acceptable removal efficiency nor service life.||

The presence of submicron dust or high levels of humidity (>70%) can render activated carbon much less effective for ozone removal.** Optimum air cleaner performance may require the use of higher efficiency particulate filters (MERV 13 or higher) upstream of the carbon filters or placement of the carbon filters downstream of the cooling coils and/or in the mixed airstream.

* *Weschler, C. J., et al. "Ozone-removal efficiencies of activated carbon filters after more than three years of continuous service," ASHRAE* Transactions *100, Part 2 (1994): 1121–1129. Shields, H. C. et al. "Ozone removal by charcoal filters after continuous extensive use (5 to 8 years)," Proceedings of the 8th International Conference on Indoor Quality and Climate,* Indoor Air *4 (Construction Research Communications, Ltd. London 1999): 1072–1077. Muller, C.O., "Gaseous Contaminant Control Strategies at the Hague," In Proceedings of the Air & Waste Management Association 87th Annual Meeting & Exhibition, (June 1994). Havermans, J., et al., "The effects of air purification at the National Archives on the quality of durable storage of their paper based collection," In Proceedings of 6th Indoor Air Quality 2004 Meeting, Padova, Italy (Nov. 10–12, 2004).*

† *Middlebrooks, M.C. and Muller, C., "Application and Evaluation of a New Dry-scrubbing Chemical Filtration Media," In Proceedings of the Air & Waste Management Association 94th Annual Meeting and Exhibition, June 24-28, 2001, Orlando, FL.*

‡ *Gundel, L.A., et al. "A pilot study of energy efficient air cleaning for ozone," Lawrence Berkeley National Laboratory, Paper LBNL-51836 (2002).*

|| *Muller, C.O., "Developments in Measurement and Control of Airborne Molecular Contaminants" In Proceedings of Semicon Taiwan (Sep. 17–19, 2001).*

** *This surface oxidation that occurs on or near the external surface of the carbon granule can result in physical degradation of the carbon over time. This can manifest itself in the form of brittleness, increased dusting, reduced media volume, and bypass around the media. Further breakdown of the media can lead to a reduced surface area (external and internal) available for reaction and/or adsorption, which in turn results in a decreased efficiency for control of ozone. It is for this reason that replacing the media at least every 1½–2 years when used for ozone control alone is recommended. This interval may be shorter depending on the ozone concentration. Higher ozone concentrations would tend to break down the media quicker than lower concentrations. Periodic checks of the system should allow the continued viability of the media to be determined.*

Zone Calculations (§ 6.2.2)

The first step in the VRP is to determine the outdoor air required at the supply air outlets to each ventilation zone. A ventilation zone is defined as one or more occupiable spaces that have:

- Similar occupancy category (meaning that occupant and building ventilation rates, R_p, and R_a, are similar);
- Similar occupant density (number of people per unit floor area);
- Similar zone air distribution effectiveness (Table 6-2);
- Similar zone primary airflow per unit floor area. The primary airflow is the air supplied to the space from the air handler that is ventilating the space, including both outdoor air and recirculated air. In general, this means that each space in the ventilation zone should have similar thermal loads.

The term "similar" is not defined in the Standard. Most designers (and air balancers) are likely to agree, however, that values within about 10% of each other would be considered similar.

A"ventilation zone" is not the same as an "HVAC zone" (also called a "thermal zone"). An HVAC zone, per ASHRAE *Standard 90.1*, is defined as "a space or group of spaces within a building with heating and cooling requirements that are sufficiently similar so that desired conditions (e.g., temperature) can be maintained throughout using a single sensor (e.g., thermostat or temperature sensor)." However, a well-designed thermal zone will generally qualify as a ventilation zone. See Example 6-G.

Determine Occupant and Building Rate Requirements (R_p and R_a)

Table 6-1 includes a list of about 65 occupancy types (categories). Select the occupant category that matches the type of the room for which ventilation rates are being calculated. If the occupancy type is not listed, find a type that has similar occupancy activity levels and activities and similar building contaminant sources.

Once a category is selected, find the associated occupant (R_p) and building rate requirements (R_a), from the table.

Estimate the Number of Occupants in the Zone (P_z)

With the possible exception of fixed-seat auditoriums, the number of people that may occupy a ventilation zone cannot be known precisely during the design phase. Zone population must be estimated by the design engineer, just as the design engineer must estimate the number of occupants for cooling load calculations. Here are some information resources that can be used, listed roughly in order of accuracy:

- *Program*: The architect or owner generally prepares a program indicating the building's intended use. The number of expected occupants (e.g. employees) is often listed. In some cases, the program may list the number on a room-by-room basis (e.g. students per classroom), but more often only the overall number expected in the suite or building are known. In that case, the program number can be used as an estimate of overall system population (P_s) for

Example 6-C—Building Code Occupancy Estimates

Q

The local building code includes occupant densities to estimate the number of occupants for exiting purposes. Must ventilation rates be based on these estimates of the number of occupants?

A

No. Building code occupant densities are for use in the design of exits, corridors, and similar fire and life safety issues. They generally overestimate the actual number of occupants for ventilation design purposes by a factor of two or more. If the number of occupants is unknown (i.e., cannot be determined from the program, furniture plan, or other reliable resources), *Standard 62.1* requires that the default values from Table 6-1 be used.

Example 6-D—Planning for Future Revisions

Q

A school is being designed using the default classroom occupant densities from Table 6-1. However, some existing schools in the district have become overenrolled and in some cases more students have been crowded into classrooms than initially anticipated, increasing occupant density above the default density. Must the ventilation design be based on this possibility?

A

No, the design zone population can be based on expected occupant density, not on a future possibility. Howeverm even though it is not required, anticipating future needs may still be a good idea. It is common for designers to include safety factors in HVAC designs, in part to handle unexpected revisions and space usages that increase loads. If overcrowding of the classrooms is a likely possibility, designing ventilation and HVAC systems for the added loads can obviate the need for expensive future retrofits. Care must be taken not to be too conservative. Oversizing some HVAC systems can reduce energy efficiency and may result in high space humidity levels. See the discussion of "Dehumidification Systems (§ 5.10)" beginning on page 5-20.

multiple zone ventilation systems while other resources listed below can be used for room-by-room occupant estimates.

- *Furniture plans*: The number of chairs shown on furniture plans is a good source of occupant count for individual spaces.
- *Industry data*: Facility and building owner associations conduct surveys among their members to provide benchmark data of facility usage and performance to their membership. Occupant density is often one piece of information collected. These occupancy densities are reasonable values to use for diversified occupancy density for speculative buildings for which no program information is available. However, these data are averaged over large facilities and are therefore not generally appropriate for individual room occupancy estimates.
- *Table 6-1 default occupant densities*: The default occupant densities listed in Table 6-1 are based on past experience and judgment. The Standard requires that if the number of occupants is not known (i.e., if none of the above information is available) then the Table 6-1 default densities must be used to calculate the number of occupants in a given space. However, these values are not mandatory when better information is available.

The peak population value determined from the above references may be used as the design value for P_z. Alternatively, time-averaged population determined as described in § 6.2.6.2, Example 6-S, Example 6-T, and Example 6-W may be used to determine P_z.

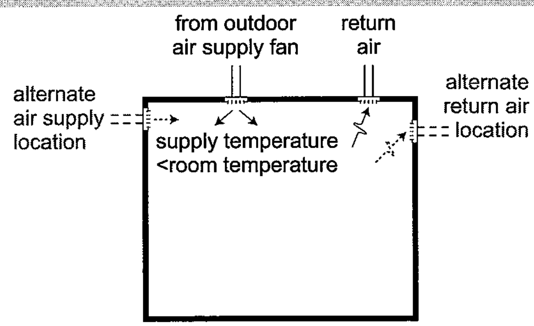
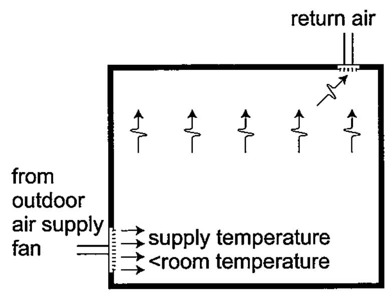
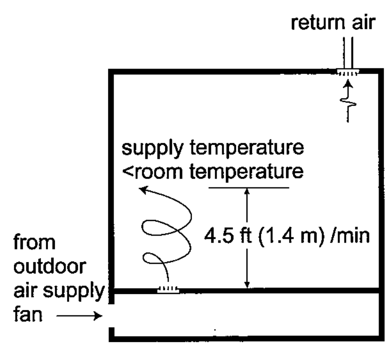
Calculate the Net Occupiable Floor Area (A_z)

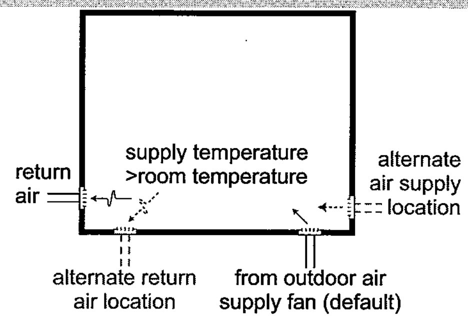
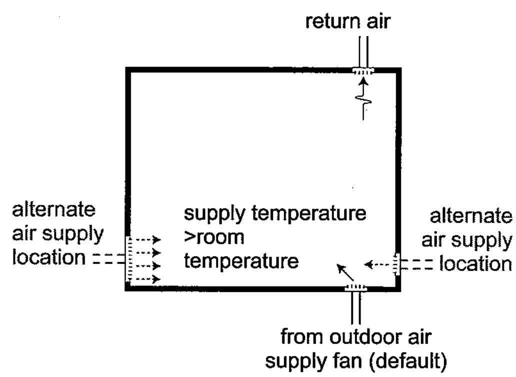
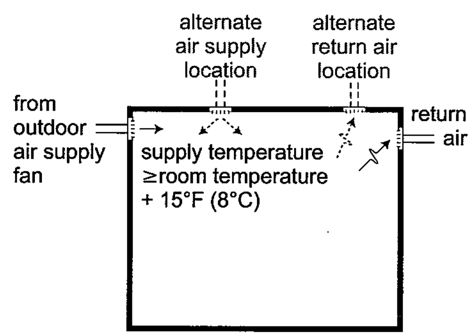
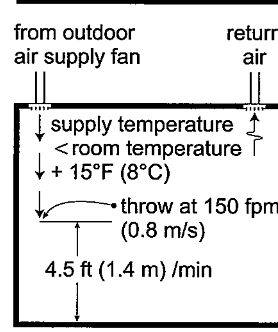
The net occupiable floor area is defined in detail in § 3. It excludes permanently-enclosed, inaccessible, and unoccupiable areas; but space for furnishings and other non-permanent elements cannot be excluded. For instance, the space required for storage racks in a warehouse or food display racks in a grocery store are included in the occupiable floor area.

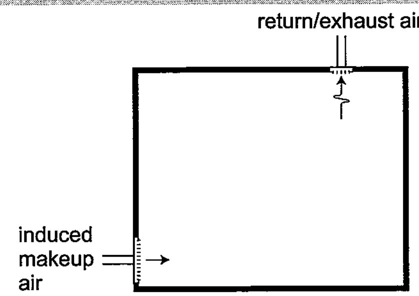
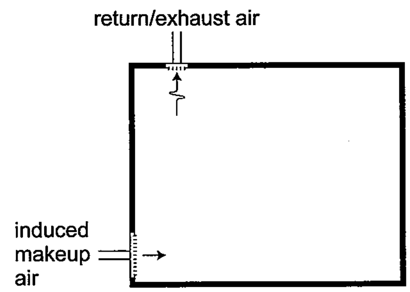
Calculate the Outdoor Air Required in the Breathing Zone (V_{bz})

Equation 6-1 in the Standard, reprinted as Equation 6-B above, is used to calculate the ventilation rate required in the breathing zone of the space. (See Figure 6-A and discussion of breathing zone in "Ventilation Efficiency" beginning on page 6-7.)

Table 6-B—Zone Air Distribution Effectiveness

Mode	Description	Supply Air Conditions	E_z	Schematic
COOLING	Ceiling supply of cool air and ceiling return	Supply air temperature is cooler than room air.	1.0	
	Thermal displacement	Supply air temperature is cooler than room air and delivered at a low velocity to achieve unidirectional flow and thermal stratification.	1.2	
	Underfloor air distribution	Supply air temperature is cooler than room air and delivered at 150 fpm so that the supply air jet reaches at least 4.5 ft above the floor.	1.0	

Mode	Description	Supply Air Conditions	E_z	Schematic
HEATING	Floor supply and return	Supply air temperature is warmer than room air.	1.0	
	Floor supply of warm air and ceiling return	Supply air temperature is warmer than room air.	0.7	
	Ceiling supply of warm air and ceiling return	Supply air temperature is more than 15°F warmer than room air.	0.8	
	Ceiling supply of warm air and ceiling return	Supply air temperature is less than 15°F warmer than room air, provided 150 fpm supply air jet reaches to within 4.5 ft of the floor.	1.0	

Mode	Description	Supply Air Conditions	E_z	Schematic
INDUCED VENTILATION	Makeup air	Makeup air is drawn in on the opposite side of the room from the exhaust and/or return.	0.8	
	Makeup air	Makeup air is drawn in near the exhaust and/or return.	0.5	

Determine the Zone Air Distribution Effectiveness (E_Z)

Table 6-2 (reprinted here as Table 6-B, with schematics added to demonstrate the typical application arrangement) is used to estimate the zone air distribution effectiveness based on the configuration and design of the air distribution system and supply air temperatures. With most HVAC systems, supply air temperatures will vary as loads in the space vary. The supply air temperature used in determining E_z for the zone calculation must be that which can be expected to occur when the space is occupied and which results in the lowest value of E_Z. Table 6-2 covers air distribution configurations for most HVAC applications. For those configurations not covered, or as an alternative to using the values in Table 6-2, E_Z may be determined in accordance with ASHRAE *Standard 129-1997 (RA 02)* for all air distribution configurations except unidirectional flow. This is typically done using a mock-up of the air distribution system in a test laboratory.

Calculate the Minimum Zone Outdoor Air Rate Required at the Supply Air Outlets (V_{OZ})

The minimum outdoor air required at the air outlets (usually the diffusers, but may include transfer grilles and doorways in some zones) supplying air to the zone is calculated using Equation 6-2, reprinted as:

6-C

$$V_{oz} = \frac{V_{bz}}{E_z}$$

If the ventilation system is a 100% outdoor air supply system (that is, it supplies outdoor air for ventilation directly to each ventilation zone), V_{OZ} would be the design supply air rate at the air outlet (e.g. diffuser) supplying the space. For systems that supply a combination of outdoor air and recirculated air to spaces in order to provide heating and cooling capability as well as ventilation, the design supply air rate to the zone is usually determined from space heating and cooling loads and must be larger than V_{OZ} to compensate for recirculated air. How much larger is a function of the system type (single zone or multiple zone) and is discussed further below.

Example 6-E—Zone Air Distribution Effectiveness During Morning Warm-up

Q

A ventilation system is designed so that the 150 fpm supply jet reaches to 4 ft above the floor with less than 15°F supply to room air temperature difference during steady-state heating conditions, but during morning warm-up, the temperature difference rises to 25°F. Does this large temperature system mean the zone ventilation effectiveness, E_Z, must be assumed to be 0.8?

A

No, provided the warm-up cycle occurs before the space is occupied, as is generally the case. (Typically the outdoor air intakes are closed during warm-up so E_Z is not relevant.)

Example 6-F—Hotel Room Ventilation with Corridor Makeup

Q

A hotel room is 250 ft^2 with a 50 ft^2 bathroom. The bathroom is exhausted with an exhaust fan that runs continuously. Makeup for the exhaust comes from a pressurized corridor, which is supplied with 100% outdoor air, through the hotel room door that is located adjacent to the bathroom. The room is assumed to have two occupants. What are the ventilation requirements for this room?

A

First calculate the breathing zone airflow rate for the hotel room using the design occupancy, floor area, and ventilation rates from Table 6-1:

$$\begin{aligned} V_{bz} &= R_p P_z + R_a A_z \\ &= 5*2+0.06*250 \\ &= 25\text{cfm} \end{aligned}$$

Next determine the zone air distribution effectiveness from Table 6-2. The last row in this table was specifically provided to address this design. The makeup air from the corridor will substantially short-circuit the space so the air distribution effectiveness is 0.5.

Next, calculate the minimum zone outdoor airflow (V_{OZ}) rate:

$$\begin{aligned} V_{oz} &= \frac{V_{bz}}{E_z} \\ &= \frac{25}{0.5} \\ &= 50\text{cfm} \end{aligned}$$

To provide this zone outdoor airflow rate using the toilet exhaust, the toilet exhaust rate must be at least 50 cfm. This rate would need to be greater if the corridor contained both outdoor air and recirculated air, rather than 100% outdoor air as assumed in this example. Per Table 6-4, the exhaust rate would only have to be 25 cfm for continuous fan operation to meet § 6.2.8, but the larger rate is required in this case for the fan to also provide space ventilation. The exhaust fan must run whenever the space is expected to be occupied so an exhaust fan manually controlled by a wall switch would not comply.

System Calculations

Once the zone calculations are complete, the overall system outdoor air intake rate (V_{ot}) may be calculated. For single zone, 100%-outdoor-air systems, and, typically, multiple zone systems (see below), the zone calculations are made for each zone served by the ventilation system. This is especially true for small systems and if the calculations are done using a computer program as part of standard heating and cooling load calculations. For large multiple zone recirculating systems, however, it may not be necessary to do the system-related calculations for each zone. There will typically be critical zones that drive the overall system outdoor air rate so zone outdoor airflow (V_{oz}) need only be calculated for those zones. (See Example 6-K and Appendix A of the Standard.)

The system ventilation efficiency (E_v), and the resulting outdoor air intake flow (V_{ot}), can be determined using the equations outlined in Appendix A of the Standard for all system types. But for ease of use, the equations have been simplified for common system applications. These follow.

Single Zone Systems

For systems that serve a single ventilation zone, the system outdoor air rate is simply equal to the zone outdoor air rate.

$$V_{ot} = V_{oz} \tag{6-D}$$

100% Outdoor Air Systems:

For systems that supply 100% outdoor air to each zone, the system outdoor air intake flow rate is equal to the sum of the zone outdoor air airflow rate for all zones served by the system. See Equation 6-4 in the Standard, reprinted here as:

$$V_{ot} = \sum_{\text{all zones}} V_{oz} \tag{6-E}$$

Multiple Zone Recirculating Systems

Multiple zone recirculating systems are systems that supply primary air to more than one ventilation zone and that recirculate air from one or more of the ventilation zones served. As noted above, this can lead to ventilation inefficiencies when zones have widely different ratios of outdoor air required for ventilation to supply air required for thermal loads. Variable air volume (VAV) systems are the most common example of multiple zone recirculating systems in most parts of the U.S.

- DETERMINE SYSTEM VENTILATION EFFICIENCY (E_V): The first step with multiple zone systems is to determine the system ventilation efficiency. This is done using one of two methods: the simplified Table 6-3 approach or the more complex Appendix A approach. The former is much simpler and can be done with minimal calculations. On the other hand, the Appendix A approach can result in lower outdoor air rates, particularly for systems with multiple recirculation paths such as dual-fan/dual-duct and systems with fan-powered terminals.

Example 6-G—Single Zone Definition

Q

A single zone air conditioning unit supplies several interior offices plus adjacent corridor and storage rooms. Is this considered a single zone system that would fall under § 6.2.3?

A

No, perhaps practically but not technically. The term "zone" as used in *Standard 62.1* may not be the same as an HVAC zone. A zone as defined in § 3 requires that each space within the zone have similar occupant and building outdoor air rates, similar occupant density, and similar zone primary airflow rates. Corridors and storage rooms are not similar to the office spaces in these respects. So technically the AC unit serving these rooms must be considered a multiple zone recirculating system with outdoor air rates calculated in accordance with § 6.2.5. However, from a practical perspective, because the supply air rates and outdoor air rates to the corridor and storage room are both low, the system outdoor air rate calculated per § 6.2.3 and § 6.2.5 would be very similar.

Table 6-3 Approach: Table 6-3 was developed from the equations in Appendix A assuming a single path air distribution system and typical operating parameters. Because it ignores secondary recirculation paths and because assumptions in the calculations were largely conservative, the ventilation efficiency determined using Table 6-3 are usually (but not always) lower than those calculated using the more precise equations in Appendix A of the Standard. For systems with high outdoor air percentages (higher than 15%) and systems with multiple recirculation paths, Table 6-3 will result in significantly lower ventilation efficiency than the Appendix A approach.

To use the table, first find the largest ratio of zone outdoor air rate to zone primary air rate for each zone served by the system, Z_p. Z_p is defined in Equation 6-5, reprinted here as:

$$Z_p = \frac{V_{oz}}{V_{pz}} \qquad \text{6-F}$$

While the simplest way to find the maximum Z_p for the system is to calculate the value for all zones and choose the highest, it is not always necessary to do that, as discussed above and in Example 6-K. For VAV systems, the largest ratio Z_p occurs when the primary airflow to a zone is at its minimum expected value.

If the highest value of Z_p is greater than 0.55, Table 6-3 cannot be used and the Appendix A approach must be used. If the highest Z_p value is less

Example 6-H—Meeting Rooom Ventilation With Single Zone Unit

Q

A 2000 ft^2 meeting/conference room with a design occupancy of 100 people is served by a single zone unit with heating and cooling capability. The system supplies and returns air from the ceiling through perforated grilles. What are the ventilation requirements for this system?

A

First, calculate the breathing zone outdoor air rate, V_{bz}, using the occupant and building area rates from Table 6-1 for conference/meeting rooms:

$$\begin{aligned} V_{bz} &= R_p P_z + R_a A_z \\ &= 5 * 100 + 0.06 * 2000 \\ &= 620 \text{ cfm} \end{aligned}$$

Next, determine the zone air distribution effectiveness from Table 6-2. The system supplies warm air from the ceiling with ceiling return so either the 3rd or 4th rows of the Table apply. To comply with the 4th row (E_z=1.0) the supply air temperature during heating operation must be less than 8°C (15°F) above space temperature and the diffusers must be able to maintain a 0.8 m/s (150 fpm) throw within 1.4 m (4.5 ft) of floor level. If the air is warmer or the throw is shorter, then the 3rd row applies (E_z=0.8). Since perforated diffusers are generally not able to deliver warm air with sufficient vertical throw, the 3rd row applies in this case and E_z=0.8. Hence, the zone ventilation rate, V_{oz}, is:

$$\begin{aligned} V_{oz} &= \frac{V_{bz}}{E_z} \\ &= \frac{620}{0.8} \\ &= 775 \text{ cfm} \end{aligned}$$

For single zone systems, the system outdoor air intake rate is simply equal to the zone outdoor air rate, so:

$$\begin{aligned} V_{ot} &= V_{bz} \\ &= 775 \text{ cfm} \end{aligned}$$

than or equal to 0.55, system ventilation efficiency, E_V, is determined from Table 6-3. Interpolation is allowed (see Example 6-I).

Appendix A Approach: The equations in Appendix A of the Standard were originally developed by Warden in 1995[51] to allow systems with multiple recirculation paths to get credit for the dilution of contaminants in one zone due to air transferred from adjacent overventilated zones. Figure 6-C shows a system with series fan-powered mixing boxes serving exterior zones and cooling-only VAV boxes serving an interior zone. If the interior zone was supplied with a higher rate of outdoor air than required to meets its ventilation needs, return air from this zone is not fully saturated with contaminants and thus can be used to ventilate other zones. This is done in two ways. First, the air can be drawn into the fan-powered boxes from the return air plenum. Second, the air can return all the way back to the air handler and be recirculated from there.

Both recirculation paths are accounted for in the Appendix A equations. The recirculation path through the fan-powered boxes improves overall system mixing and reduces outdoor air intake flow rates required at the air handler and it allows a reduction in minimum airflow setpoints at the zone level compared to a single path system (such as VAV with reheat).

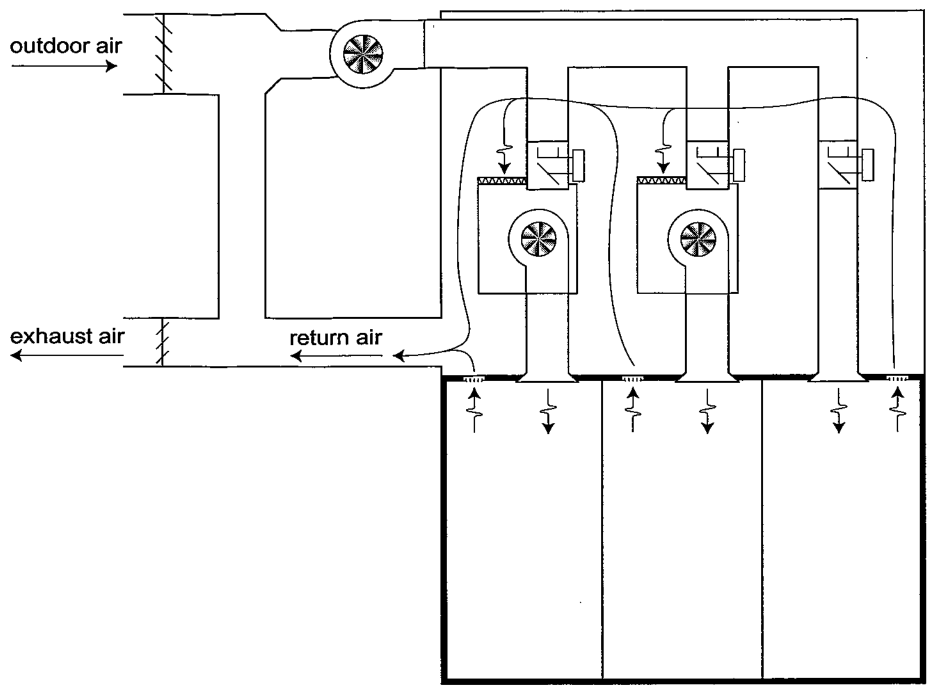


Figure 6-C—System With Multiple Recirculation Paths

While equations in Appendix A can be solved by hand, use of a spreadsheet will save time and reduce errors. A spreadsheet called 62MZCalc designed for this purpose is included on the CD that accompanied this Manual. It may be used for all system types, including single zone systems and 100% outdoor air systems, but it is primarily intended for multiple zone systems, and in particular those with multiple recirculation paths.

Each of the input variables used in Appendix A is explained in the 62MZCalc spreadsheet, Directions tab.

- Determine the Occupant Diversity (D): In considering multiple zone systems design, it is reasonable to assume that people are not in every space at their design occupancy rate at the same time. For instance, in an office building, if everyone is in their office or cubicle, the conference room and break room are likely to be occupied at below the design occupancy level. In schools, if students

51. Warden, D. "Outdoor Air: Calculation and Delivery" *ASHRAE Journal* 37 no. 6 (1995): 54–63

are all in the classroom, the multipurpose room is likely to be empty or only sparsely occupied. The larger the system, the more likely this diversity will occur and the smaller the diversity factor.

The diversity factor is determined from Equation 6-7, reprinted here as:

6-G

$$D = \frac{P_s}{\sum_{allzones} P_z}$$

Values of system population P_s can often be estimated from the program requirements as discussed previously in the VRP Summary section.

- CALCULATE THE UNCORRECTED OUTDOOR AIR RATE (V_{ou}): The "uncorrected" outdoor air intake rate is the minimum outdoor air required by all zones in the system before adjusting for system ventilation efficiency. It is the sum of the zone minimum breathing zone outdoor airflow rates, V_{bz}, adjusted for occupant diversity. It is calculated from Equation 6-6, reprinted here as:

6-H

$$V_{ou} = D \sum_{allzones} R_p P_z + \sum_{allzones} R_a A_z$$

- CALCULATE SYSTEM OUTDOOR AIR RATE (V_{ot}): Finally, the design outdoor air intake flow rate for the ventilation system, V_{ot}, is calculated from Equation 6-8, reprinted here as:

6-I

$$V_{ot} = \frac{V_{ou}}{E_v}$$

Example 6-I—Using Interpolation in Table 6-3

Q

The critical zone in a multiple zone system has a primary outdoor air fraction Z_p of 0.2. What is the system efficiency if the Table 6-3 method is used?

A

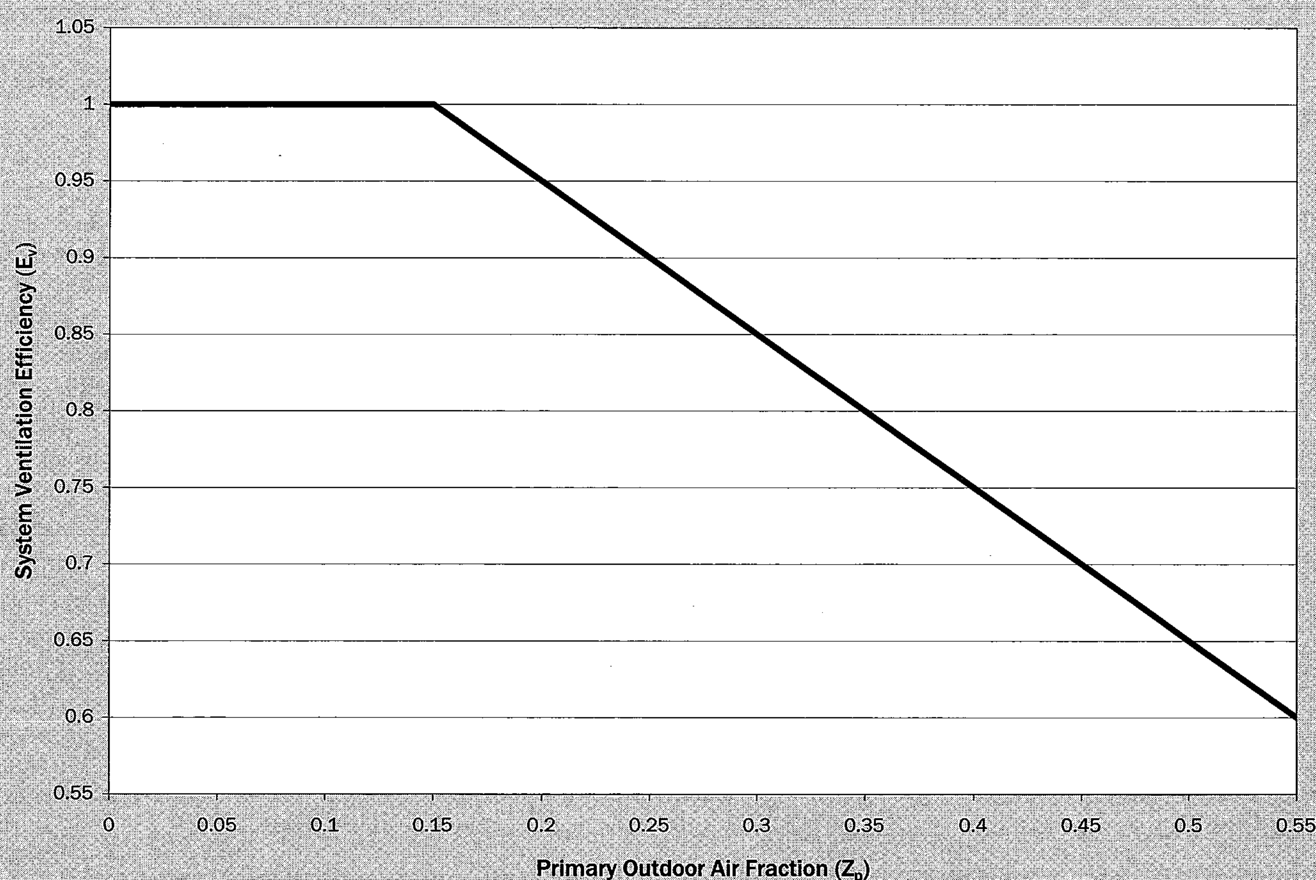
Since Z_p is less than 0.25, an E_v of 0.9 could be used per Table 6-3. However, the Standard allows linear interpolation when Z_p is greater than 0.15 (E_v=100%) and less than 0.55 (E_v=0.6), so E_v at Z_p=0.2 would be:

$$E_v(Z) = \frac{(Z - Z_1)(E_{v1} - E_{v2})}{(Z_1 - Z_2)} + E_{v1}$$

$$= \frac{(0.2 - 0.15)(1.0 - 0.9)}{(0.15 - 0.25)} + 1$$

$$= 0.95$$

This is shown diagrammatically in the figure below:



Example 6-J—Minimum Supply Air to Zones Served by Multiple Zone Recirculating Systems

Q

A ventilation system supplies 20% outdoor air and 80% return air to multiple ventilation zones. If a zone requires 100 cfm of outdoor air (V_{oz}=100 cfm), must the design supply airflow rate to the zone be equal to or greater than 100 cfm divided by 0.20 or 500 cfm?

A

No. Because air is recirculated from other zones, the return air may include unused outdoor air. For instance, the return air from any zone that requires less than 20% outdoor air will not be saturated with contaminants and thus the return air may be used to ventilate other zones. This is the basis of the default values in Table 6-3 and the equations in Appendix A. These equations (which are included in the 62MZCalc spreadsheet provided with this Manual) must be used to determine minimum supply air rates to ventilation zones.

Example 6-K—Finding Critical Zones in Multiple Zone Recirculating Systems

Q

Section 6.2.2 notes that zone calculations need not be done for all zones in multiple zone systems. How does the designer pick which zones need to be analyzed?

A

With both approaches to multiple zone systems (either Table 6-3 or Appendix A), it is possible to calculate outdoor air rates without having to perform system-related calculations for each zone. This is because the system outdoor air intake flow rate is determined by just one zone (or a group of identical zones) called the "critical zone." The critical zone is simply defined as the one that results in the highest system outdoor air rate. For single-path systems (on which Table 6-3 is based), the critical zone is the one with the highest value of Z_p, which is the ratio of zone outdoor airflow rate to primary airflow rate. For systems with multiple recirculation paths, the critical zone is the one with the lowest zone ventilation efficiency E_{vz}, as defined in Appendix A of the Standard. The most straightforward way to determine the critical zone is to calculate Z_p (or E_{vz}) for every zone and find the one with the highest Z_p (or lowest E_{vz}) value. This can be easily done if the calculations are being made by a computer program, but may be time consuming if done by hand or using the 62MZCalc spreadsheet. Guidance for selecting critical zones is provided under "Selecting Zones for Calculation" in Appendix A. Here are some additional guidelines (see also Example 6-L):

- Cooling Condition: For single path systems, the zones most likely to be critical are those with low cooling loads and high occupancy loads. For example, in office buildings, interior conference rooms are very often the critical zone. Exterior conference rooms with north exposures or shaded glass are also likely candidates. Zones with high envelope cooling loads (e.g. south and west zones) seldom are critical due to their high supply air rates. Zones with low occupant density, such as corridors, are also seldom critical zones.
- Heating Condition: For single path systems, the critical zones are generally perimeter zones with low airflow rates, such as north zones. For VAV systems, look for exterior zones that have low minimum primary supply air rates.

Designers can gain experience by analyzing all zones until they get a feel for the zones that tend to be critical. On later projects, their experience will allow them to reduce the number of zones analyzed to only those most likely to be critical.

Example 6-L—Applying the Appendix A Method to VAV Systems

Q

Variable air volume (VAV) systems can operate over a wide range of airflow rates depending on cooling and heating loads. At the same time occupancy also varies. Given the infinite number of operating points possible, how can Appendix A of the Standard be practically applied to VAV systems?

A

While VAV systems have an infinite number of operating points, the designer only needs to be concerned with the condition that results in the highest system outdoor air intake flow rate. Those conditions tend to occur at one of two conditions:

- *Design cooling condition with the critical zone at its minimum expected airflow rate*: This condition is often critical because the percentage of outdoor air needed for the system is at its smallest while the critical zone Z_p or Z_d value is at its highest. At this condition, the system has a low efficiency because the return air contains the highest percentage of unused outdoor air, some of which is exhausted from the building without being used for dilution ventilation. Using the 62MZCalc spreadsheet, set the system variables to their design conditions and set the zones to the lowest airflow rates that can be expected to occur when the space is occupied. This is typically the minimum airflow setpoint on the zone VAV box, but it could be higher if the zone cooling load when it is fully occupied under system design cooling conditions would result in a higher airflow rate for temperature control. (See also Example 6-N.)
- *Design heating condition*: This condition can be critical since zones are typically at their minimum airflow rates and zone air distribution effectiveness can be low (e.g. 80%). Using the 62MZCalc spreadsheet, set the system and zone variables to the conditions they operate at when the system is on a design heating day at peak occupancy at steady-state. Perimeter zones would be at their design heating conditions (e.g., primary airflow rate at the minimum airflow setpoint and with fans on for fan-powered boxes) while interior zones would be at the lowest airflow rates that can be expected to occur when the space is occupied.

For VAV systems, considerable judgment is required on the part of the designer in determining system ventilation efficiency, particularly when the Appendix A approach is used. For example, assumptions must be made regarding airflow rates to critical zones and to the system as a whole at part-load conditions. The resulting E_z and V_{ot} values can vary considerably depending on these assumptions. Some may feel that designers should not have this flexibility, but consider that designers have similar flexibility with respect to almost all other aspects of the system design. It is not unusual, for instance, for one designer to size a cooling system 25% to 50% higher than another designer due to more conservative design assumptions. The same range can occur with ventilation rates.

Example 6-M—Impact of Zones with Very High Z_p Values

Q

A large variable air volume system includes an interior conference room that has a high occupant load but a low overall cooling load. The Z_p value for the room is very high, causing the system ventilation efficiency to fall below 50%. This one zone is thus doubling the ventilation rate for the entire system. Can this be right?

A

Yes, but there are design options to avoid the problem. For instance, use transfer air and the Appendix A approach. Transfer air can dilute the bioeffluents in the conference room provided air in adjacent rooms or the return air plenum is not saturated with bioeffluents. Perhaps the simplest transfer air solution is to use a series fan-powered mixing box to supply the room with the fan sized larger than the primary airflow rate. The exact fan size is determined using 62MZCalc as required to improve zone ventilation efficiency (E_{vz}) to a value similar to that of other zones.

Example 6-N—Minimum Primary Airflow Setpoints on VAV Boxes, Single Duct Systems

Q

For single-path variable air volume systems, must the minimum primary airflow setpoint be set to at least V_{oz}?

A

Strictly speaking, no, but in most cases it must be substantially larger than V_{oz}. The Standard does not prescribe how minimum ventilation rates must be provided, simply that they must be provided whenever the space is occupied under any expected operating condition (§ 6.2.6.1). Setting minimum primary airflow setpoints above V_{oz} ensures that § 6.2.6.1 will be met under all conditions and thus is the easiest and most reliable way to comply. However, it is technically possible to set lower minimum airflow rates if calculations can show that when the space is occupied the required minimum rates will be provided by other means (e.g. via temperature controls).

If energy conservation and concerns about overcooling in interior spaces are the reasons for wanting low minimum primary airflow rates, time averaging of zone population can be used to reduce V_{oz} values. See "Time Averaging (§ 6.2.6.2)" beginning on page 6-33.

Note minimum primary airflow setpoints may need to be substantially above V_{oz} to avoid very low ventilation system efficiencies and high outdoor air rates. See Example 6-P.

Example 6-O—Minimum Primary Airflow Setpoints on VAV Boxes, Dual-Duct, and Fan-Powered Systems

Q

For a variable air volume (VAV) system with multiple supply air paths (such as dual-fan/dual-duct systems and systems with series or parallel fan-powered terminals) must the minimum primary airflow setpoint be set to at least V_{oz}?

A

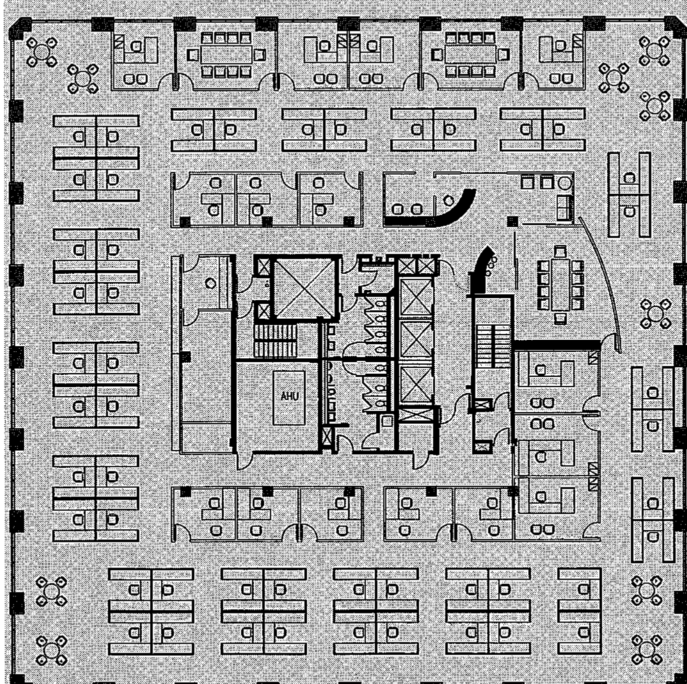
No. The overall outdoor airflow rate to the zone must equal or exceed V_{oz}, but this air need not originate solely from the primary air handler (the one with the outdoor air intake). Because of the transfer air these systems provide to the zone, Appendix A and the 62MZCalc spreadsheet can be used to show that the primary airflow may be reduced below V_{oz} while still meeting dilution requirements. In fact, the minimum primary rate can be reduced to zero provided the local transfer air contains sufficient outdoor air due to overventilation of other zones. See Example 6-Q.

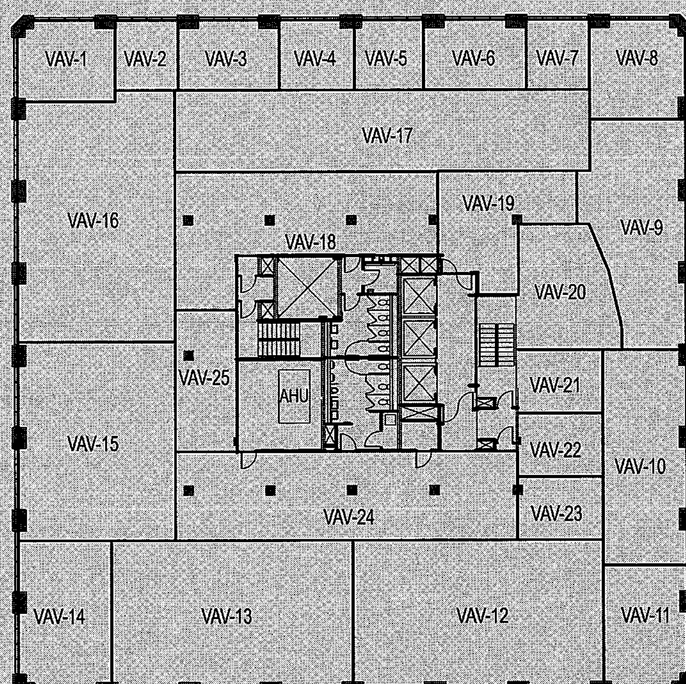
Example 6-P—Ventilation Rate Calculation for a Typical VAV System, Using the Table 6-3 Method

Q

The figure on the left (directly below) shows the partition and furniture plan for a 15,080 net ft^2 office floor. The floor is served by a single VAV air handling unit that receives pre-conditioned outdoor air from a centralized air handling unit, which serves several floors.

The figure on the right (directly below) shows HVAC zoning for the floor. VAV zones are proposed to be cooling-only VAV boxes in interior spaces and VAV with hot water reheat for exterior spaces.





The firm occupying the floor has sixty-three employees. What is the design outdoor air requirement for the system using the Table 6-3 approach?

A

For this example, we will analyze those zones likely to be critical. In Example 6-Q the same system is analyzed with all zones served by the system, using the 62MZCalc spreadsheet.

First find the uncorrected outdoor air rate. The peak number of people served by the system is estimated to be the sixty-three employees, plus ten guests, for a total of seventy-three people. All ventilation zones served by the system (office, conference room, reception) have the same R_p and R_a values (5 cfm/p and 0.06 cfm/ft^2 respectively). Equation 6-H can therefore be written as follows.

$$\begin{aligned} V_{ou} &= D\sum_{allzones} R_p P_z + \sum_{allzones} R_a A_z \\ &= P_s R_p + R_a \sum_{allzones} A_z \\ &= 73*5+0.06*15{,}080 \\ &= 1270 \end{aligned}$$

Next determine the highest Z_p value. Per Example 6-K, only those zones likely to be critical need be considered. In this example, these include the north conference rooms (VAV-3 and -6) and the main conference room (VAV-20), both of which are zones with relatively high occupancy and low airflow rates. (Example 6-Q confirms that these zones are the most critical.) The following table shows the design data for these zones.

	NAME	NORTH CONFERENCE	INTERIOR CONFERENCE ROOM
	Zone Tag	VAV-3,-6	VAV-20
	Space Type	Conference	Conference
	Area (ft^2)	267	443
	Number of People	10	10
	Design Airflow (cfm)	265	325
	Zone Outdoor Airflow (V_{bz}, cfm)	66	77
Cooling Condition	Zone Air Distribution Effectiveness	1.0	1.0
Cooling Condition	Outdoor Air Rate Required at Supply Outlets (V_{oz})	66	77
Cooling Condition	Airflow Rate at Condition Analyzed (fully occupied, low sensible load)	239	225
Cooling Condition	Outdoor Air to Primary Air Ratio (Z_p)	0.28	0.34
Heating Condition	Zone Air Distribution Effectiveness	0.8	1.0
Heating Condition	Outdoor Air Rate Required at Supply Air Outlets (V_{oz})	83	77
Heating Condition	Airflow Rate at Condition Analyzed (fully occupied, design heating load)	151	225
Heating Condition	Outdoor Air to Primary Air Ratio (Z_p)	0.55	0.34

Occupancy is based on the furniture plans. Both zones are analyzed at the design cooling condition (when the system and zones are at peak airflow) and at design heating conditions (all zones in heating mode). The actual airflow rates are based on the following:

- *Cooling*: Calculate airflow rates to the critical zones under the assumption that the room is fully occupied but that all other loads are the lowest that can be reasonably expected. For instance, for these conference rooms, the lowest load condition would be when the lights are off for a slide presentation.
- *Heating*: Zones would be in the full heating mode allowed by the zone controls. For most systems, the primary airflow rate would be at the minimum airflow setpoint to the zone.

The previous table shows the airflow rates and Z_p values for both of these conditions. In the peak cooling condition, the interior conference room is the most critical, with a Z_p value of 0.34. In the heating condition, the interior conference room is unchanged but the north conference room airflow rate is reduced to the minimum airflow rate. Initially, this was set to 30% of the zone design airflow rate, but the Z value was so high (greater than 0.55) that the Table 6-3 approach could not be used. The north conference room zone airflow minimum had to be raised to 57% of its zone maximum so that its Z_p value dropped to 0.55. At this value, the ventilation system efficiency is 0.60, per Table 6-3. Therefore, the system outdoor air intake flow rate is:

$$\begin{aligned} V_{ot} &= \frac{V_{ou}}{E_v} \\ &= \frac{1270}{0.6} \\ &= 2117 \end{aligned}$$

This equates to 0.14 cfm/ft^2.

Example 6-Q—Ventilation Rate Calculation for a Typical VAV System using the Appendix A Method

Q

The system for the building described in Example 6-P is revised to include series fan-powered VAV boxes in each zone, both interior and perimeter. What is the design outdoor air requirement for the system, using the Appendix A method?

A

This system could be analyzed using either Table 6-3 or Appendix A, but the latter method includes the effect of the local recirculation provided by the fan-powered boxes, which improves system ventilation effectiveness.

The example 62MZCalc spreadsheet included on the CD provided with this Manual shows the analysis of this option. All zones are included in the analysis, although only the potentially critical zones need be included in real applications. In this example, the use of series fan-powered VAV boxes reduces the supply air temperature so that (with proper diffuser selection), the air change effectiveness in the heating mode is 1.0 (see the fourth row of Table 6-2). Airflow rates in the cooling mode were determined from load calculations. Design interior zone airflow rates were oversized to allow for supply air temperature reset in the heating mode, so airflow rates are reduced at the peak cooling condition when supply air temperatures are at design conditions. The screenshots below show the spreadsheet results for the cooling and heating design conditions respectively. Only the critical zones are shown for brevity. Intermediate results (such as V_{oz}, Z_p, or Z_d, V_{ou}) are also calculated in the spreadsheet but are not included in this screenshot, again for reasons of brevity. See the Definitions tab of the 62MZCalc spreadsheet for an explanation of each variable.

Building:	**Typical Office Building**					
System Tag/Name:	**AHU-1**					
Operating Condition Description:	**Design cooling**					
Units (select from pull-down list)	**IP**					
Inputs for System	**Name**	**Units**		**System**		
Floor area served by system	As	sf		15,080		
System population (including diversity)	Ps	P		73		
Design primary supply fan airflow rate	Vpsd	cfm		14,000		
Average outdoor airflow rate per unit area for the system	Ras	cfm/sf		0.06		
Average outdoor airflow rate per person for the system	Rps	cfm/p		5.0		
Inputs for Potentially Critical Zones						
Zone Name **Show Values per Zone**	*Zone title turns purple italic for critical zone(s)*				**North Conference Room**	***Interior Conference room***
Zone Tag					**VAV-3**	***VAV-20***
Space type		Select from pull-down list			**Conference/ meeting**	**Conference/ meeting**
Floor Area of zone	Az	sf			267	443
Design population of zone	Pz	P	(default value listed; may be overridden)		10	10
Design discharge airflow to zone (total primary plus local recirculated	Vdzd	cfm			265	325
Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A			ITU	ITU
Local recirc.air fraction representative of ave system return air	Er				0.50	0.50
Inputs for Operating Condition Analyzed						
Percent of total design airflow rate at conditioned analyzed	Ds	%		100%	100%	100%
Air distribution type at conditioned analyzed		Select from pull-down list	**Show codes for Ez**		CS	CS
Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
Primary air fraction of supply air at conditioned analyzed	Ep				0.90	0.69
Results						
System Ventilation Efficiency	Ev			**0.80**		
Outdoor air intake airflow rate required at condition analyzed	Vot	cfm		**1596**		
Outdoor air intake rate per unit floor area	Vot/As	cfm/sf		**0.11**		
Outdoor air intake rate per person served by system (including diver	Vot/Ps	cfm/p		**21.9**		
Outdoor air intake rate as a % of design primary supply air	Vot/Vpsd	%		**11%**		
Uncorrected outdoor air intake airflow rate	Vou	cfm		**1270**		

Building:		**Typical Office Building**				
System Tag/Name:		**AHU-1**				
Operating Condition Description:		**Design heating**				
Units (select from pull-down list)		**IP**				
Inputs for System		**Name**	**Units**		**System**		
	Floor area served by system	As	sf		15,080		
	System population (including diversity)	Ps	P		73		
	Design primary supply fan airflow rate	Vpsd	cfm		14,000		
	Average outdoor airflow rate per unit area for the system	Ras	cfm/sf		0.06		
	Average outdoor airflow rate per person for the system	Rps	cfm/p		5.0		
Inputs for Potentially Critical Zones							
	Zone Name **Show Values per Zone**	*Zone title turns purple italic for critical zone(s)*				*North Conference Room*	**Interior Conference room**
	Zone Tag					*VAV-3*	**VAV-20**
	Space type		Select from pull-down list			**Office space**	**Office space**
	Floor Area of zone	Az	sf			267	443
	Design population of zone	Pz	P	(default value listed; may be overridden)		10	10
	Design discharge airflow to zone (total primary plus local recirculated)	Vdzd	cfm			265	325
	Induction Terminal Unit, Dual Fan Dual Duct or Transfer Fan?		Select from pull-down list or leave blank if N/A			ITU	ITU
	Local recirc.air fraction representative of ave system return air	Er				0.50	0.50
Inputs for Operating Condition Analyzed							
	Percent of total design airflow rate at conditioned analyzed	Ds	%		19%	100%	100%
	Air distribution type at conditioned analyzed		Select from pull-down list	**Show codes for Ez**		CS	CS
	Zone air distribution effectiveness at conditioned analyzed	Ez				1.00	1.00
	Primary air fraction of supply air at conditioned analyzed	Ep				0.15	0.55
Results							
	System Ventilation Efficiency	Ev			**0.69**		
	Outdoor air intake airflow rate required at condition analyzed	Vot	cfm		**1831**		
	Outdoor air intake rate per unit floor area	Vot/As	cfm/sf		**0.12**		
	Outdoor air intake rate per person served by system (including diversity	Vot/Ps	cfm/p		**25.1**		
	Outdoor air intake rate as a % of design primary supply air	Vot/Vpsd	%		**13%**		
	Uncorrected outdoor air intake airflow rate	Vou	cfm		**1270**		

The spreadsheet shows that using fan-powered VAV boxes can either allow a reduction in minimum zone primary airflow rates (even all the way to zero in many zones) or a reduction in outdoor airflow rates. The heating condition tends to dominate when minimum primary airflow rates are very low or zero. In most climates, these low minimum airflow rates require the use of a heating coil at the air handling unit or outdoor air intake to maintain supply air temperatures since the percentage of outdoor air will be very high in the heating mode. In this example, the primary airflow rate drops to 19% of design, almost 60% of which is outdoor air, during the peak heating condition.

The balance in first costs and energy costs between lowering minimum rates and lowering design outdoor air intake flow rates depends on the climate and energy rates. In general, in mild and cold climates, reducing minimum primary airflow rates will likely be the most cost-effective. In hot/humid and very cold climates, reducing design outdoor air intake flow rates will likely be the most cost-effective.

In the example, minimum primary airflow rates in exterior zones were reduced to zero in all but the north perimeter conference rooms and offices (the critical zones) which were reduced to 15%. The resulting system ventilation efficiency is 0.69, resulting in an outdoor air intake flow rate of 1854 cfm. This is somewhat less than the system in Example 6-P, but with much lower reheat and central fan energy due to the low minimum primary airflow setpoints—offset by the fan energy used by the fan-powered boxes.

(Note that care must be taken not to reduce minimum airflow rates so low that the primary air handling system airflow rate drops below the required outdoor air rate. If all zones served by the system are entered into the spreadsheet, the spreadsheet will calculate the total primary airflow rate to the zones and provide a warning if this airflow rate is below the required outdoor airflow rate.) With 30% minimum primary airflow rates on all exterior zones, ventilation system effectiveness rises to 0.71 resulting in an outdoor air intake flow rate of 1794 cfm, only a slight decrease in design outdoor airflow rate but a significant increase in reheat and fan energy. Increasing minimum primary airflow rates only in critical zones improves performance even more—system outdoor airflow rates are reduced, reducing outdoor air conditioning costs, while low minimum primary airflow rates at non-critical zones reduce fan energy and reheat energy losses. The 62MZCalc spreadsheet is a powerful tool that can be used to optimize this energy balance.

** The software is updated periodically and the screen images shown in this example may not be entirely consistent with the latest software.*

Designing for Varying Operating Conditions (§ 6.2.6)

Variable Load Conditions (§ 6.2.6.1)

Section 6.2.6.1 requires that ventilation systems be capable of delivering the minimum outdoor air rate to the breathing zone of each space when the space is occupied, over the entire range of normal operating conditions. This means that the system must be designed for the "worst case" operating condition, the one that results in the highest outdoor air intake flow rate. This is primarily an issue for VAV systems (see Example 6-N and Example 6-O), but can also affect constant volume systems. For example, if the zone air distribution effectiveness is lower for normal heating operation, the outdoor air rate must be calculated based on this reduced effectiveness.

For VAV systems that can operate under a wide range of operating conditions, the system must be designed to provide the minimum outdoor air rates under all reasonably anticipated operating conditions. This may require that outdoor air intake flow rates be calculated under various load conditions and the highest rate selected (see Example 6-L).

Time Averaging (§ 6.2.6.2)

The VRP outdoor air rate equations are based upon steady-state conditions, meaning that the rates are those required to maintain desired contaminant concentrations assuming source strengths and ventilation system operation and efficiency are constant for a long enough time to reach relatively steady conditions in the space. But because these factors may change over time, few spaces ever reach steady-state conditions. Hence the Standard allows (but does not require) averaging of ventilation design parameters over time. The averaging time window is equal to three times what the space time constant would be without any ventilation rate reductions for time averaging. This is the time required to reach about 95% of steady-state conditions and is expressed in Equation 6-9 in the Standard, reprinted here as:

$$T = \frac{3v}{V_{bz}} \qquad \text{6-J}$$

where

v is the space volume and
V_{bz} is the breathing zone outdoor air rate, in consistent units.
(T is in minutes when V_{bz} is in cfm and v is in ft^3.)

The larger the ventilation rate on a unit area or volume basis, the shorter the averaging window and the less impact time averaging will have on the averaged parameter. Spaces with higher ceilings will have longer averaging windows than the same space with a lower ceiling.

Examples of acceptable uses of time averaging include:

- Zone population (P_z) may be averaged over time (T). Table 6-C shows typical averaging windows for example occupancy types using default occupant density and typical ceiling heights listed. As indicated, typical classroom averaging windows will be on the order of one hour. Since classes tend to run about that same length of time, time averaging occupancy in classrooms will have little or no effect on P_z. The same is true of restaurants, conference rooms, and retail sales areas which have averaging times that are short relative to the typical peak occupancy time (i.e., the peak occupancy time can be expected to occur for a period at least as long as the averaging window). However, lobby/pre-function spaces and offices have relatively long averaging windows. Example 6-S, Example 6-T,

Table 6-C—Typical Averaging Times

OCCUPANCY CATEGORY	OCCUPANT DENSITY #/1000 ft	CEILING HEIGHT ft	AVERAGING TIME (T) minutes	hours
Classrooms (age 9 plus)	35	10	64	1.1
Restaurant dining rooms	70	9	38	0.6
Conference/meeting	50	9	87	1.5
Lobbies/pre-function	30	15	160	2.6
Office space	5	9	320	5.3
Sales	15	12	160	2.6

and Example 6-W show how time averaging might be applied to these two occupancy types.

Note that when demand-controlled ventilation (DCV) is used to match ventilation capacity to the current ventilation load (see Appendix and the next section "Dynamic Reset (§ 6.2.7)" beginning on page 6-39), time averaging to reduce zone population for design purposes is not allowed. Design calculations must be based on peak, not average, zone population when DCV controls are used. This is because the control system will reduce ventilation during off-peak occupancy conditions, not allowing the system to overventilate during these periods to make up for under-ventilating at peak conditions.

- The outdoor airflow supplied to the breathing zone may be averaged over time (T), allowing temporary reductions in outdoor air supply rate (see Example 6-U) or intermittent supply fan operation (see Example 6-V). This applies primarily to single zone systems.
- The outdoor airflow intake rate at the air handler may be averaged over time (T), allowing intermittent closure of the outdoor air intake.

Example 6-R—Speculative Buildings

Q

A new speculative office building is being built with the HVAC system, including variable air volume air handlers and chilled water and hot water plants, provided with the "shell & core." Tenant requirements are not known during the shell & core design. Given that zone ventilation efficiency determines system efficiency in multiple zone recirculating systems, how can the outdoor air system be sized when tenant requirements are unknown?

A

The issue is really no different than how heating, cooling, and air handling systems are sized for speculative buildings when tenant interior loads from occupants, office equipment, and lighting are not known: reasonable assumptions must be made in the shell & core design. In this case, assumptions with respect to occupant density and system ventilation efficiency must be made. Occupant density assumptions must also be made for cooling load calculation purposes and the same value can be used for outdoor air system sizing. System ventilation efficiency assumptions can be based on similar past projects and examples of similar buildings with similar HVAC systems such as Example 6-P and Example 6-Q. Shell & core design assumptions for outdoor air system sizing must balance first costs with future flexibility. Conservative assumptions will increase shell & core first costs but will assure that most or all future tenant ventilation needs can be met without having to upgrade shell & core systems, the cost of which can be substantial. Future tenant designs can often be designed to meet the outdoor air constraints of the shell & core design through the use of transfer air (see Example 6-M) and by increasing the minimum primary air rates to critical zones. This can be done by using 62MZCalc and iterating on zone minimum primary airflow or transfer airflow rates (or using Microsoft Excel™'s "Goal Seek" command) in order to keep ventilation system outdoor air rates at or below the shell & core outdoor air rate designed for the system.

Example 6-S—Time Averaging Zone Population, Large Open Office

Q

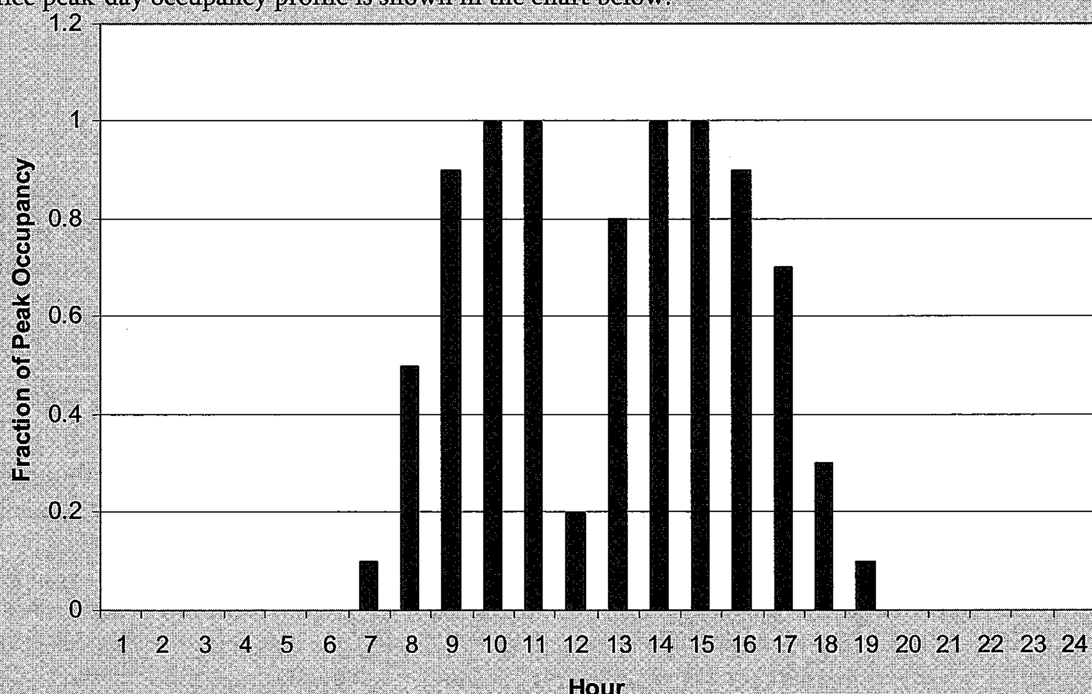
What is the design occupancy (P_Z) of a 2000 ft^2 office with a nine foot ceiling and 20 workstations?

A

The design occupancy could be assumed to be simply 20. In other words, the Standard does not require that the designer account for the occupancy variation over time. If time averaging is desired, the designer must both calculate the averaging time window and develop a reasonable occupancy profile for the space. The averaging time period is:

$$T = \frac{3v}{V_{bz}}$$
$$= \frac{3*2000*9}{20*5+2000*0.06}$$
$$= 245 \text{ minutes}$$
$$\approx 4 \text{ hours}$$

A typical office peak-day occupancy profile is shown in the chart below.



The time-weighted average population fraction is the largest consecutive total fraction over the averaging time (T). In this case, this occurs from 1 PM and 5 PM (hours 13–16 in the chart above). During this period the average is (0.8+1+1+0.9)/4 ˜0.9.

So the design occupancy is 0.9 * 20 = 18 occupants.

Example 6-T—Time Averaging Zone Population, Private Office

Q

A private corner office is 230 ft^2 with a nine foot ceiling. Furniture plans show a workstation with two guest chairs. What is the design occupancy?

A

The averaging window is:

$$
\begin{aligned}
T &= \frac{3v}{V_{bz}} \\
&= \frac{3*230*9}{3*5+230*0.06} \\
&= 215 \text{ minutes} \\
&= 3.6 \text{ hours}
\end{aligned}
$$

The guest chairs are most likely going to be occupied for a short period of time relative to the averaging time. If we assume two guests are present for about 1/3 of the averaging time, the design occupancy would be 1 + 2 * 1/3 = 1.7 occupants.

Example 6-U—Time Averaging with VAV Changeover Systems

Q

A variable air volume (VAV) changeover system (also called a variable volume and temperature system) uses a single zone packaged gas/electric unit to serve multiple zones each of which has a single-path VAV box. At times the zones are in differing modes (some require heating and some require cooling) or have widely varying loads (some require near maximum cooling while others require very little cooling). To avoid overheating, overcooling, and the need for and energy waste of reheat at the zone level, minimum airflow setpoints on zone VAV boxes are proposed to be zero (full shut-off). Does this design meet *Standard 62.1*?

A

Yes, but very complex controls may be required. Zone airflow can be shut off to zones provided the average outdoor airflow rate over averaging time (T) meets or exceeds the zone minimum outdoor airflow rate (V_{oz}). To ensure this happens, the control system would have to be designed to first determine the amount of outdoor air (not supply air) supplied to the space (the multiple zone equations in Appendix A of the Standard can be used for this) and integrate this amount over time with special logic that would cause the system to at times overventilate the zone (increasing airflow rates to the zone and/or increasing outdoor air rates at the system) so that the running average outdoor air intake flow (V_{ot}) is maintained. Commercial versions of this control system do not commonly include this logic and it would be difficult to implement in a fully programmable control system. However, the Standard could be met by using pressure-independent VAV boxes with minimum airflow rates set as per any VAV system. Overheating and overcooling problems can be addressed by including reheat at each zone or by only grouping zones onto the AC unit that are likely to be in similar modes (e.g. only interior zones or only perimeter zones).

Example 6-V—Time-Averaging Intermittent Supply Fan Operation

Q

A simple single zone AC unit supplies cooling to a building located in a humid climate. Humidity is better controlled if the unit is allowed to cycle on calls for cooling (rather than running continuously) to avoid the intake of humid, unconditioned outdoor air. Is this allowed by *Standard 62.1*?

A

Yes, but probably not in a manner that will address the humidity problem. To meet *Standard 62.1* with cycling, the design of the system and controls must ensure that the average outdoor airflow rate over the averaging time (T) meets or exceeds the system minimum outdoor air intake flow rate (V_{ot}) if it were provided continuously. This leads to three problems.

- First, the outdoor air rate to the AC unit must be higher than V_{ot} to overventilate the space when the fan is on, making up for the time it is off.
- Second, control logic may be needed to force the unit to run even when cooling is not required to ensure that V_{ot} is maintained over the averaging window. For example, let's say the averaging time is two hours and that the outdoor air rate was designed to be 50% greater than the continuous (without averaging) rate. The control system could then be designed so that if the unit had cycled off for x minutes, it would be forced to run at least three times as long (3x minutes) before it is allowed to cycle off again; and if x=30 minutes, the system would be forced on even if no cooling is required to ensure the average of two hours is met. When forced on in this way, the system will be supplying humid, unconditioned outdoor air at a rate that is even higher than the required continuous outdoor air rate.
- Third, since the outdoor air rate is higher, the cooling capacity of the unit must be higher due to the higher outdoor air load. For simple single zone AC units (particularly direct expansion systems), increased cooling capacity often means increased fan size and increased supply airflow, which means increased supply air temperature at any given load and higher space humidity.

Thus, while it is possible for the system to cycle and still meet § 6, doing so will most likely not improve humidity control (and may make it worse), and the system may not meet the humidity requirements of § 5.10.1.

Example 6-W—Time Averaging Zone Population, Pre-Function Space

Q

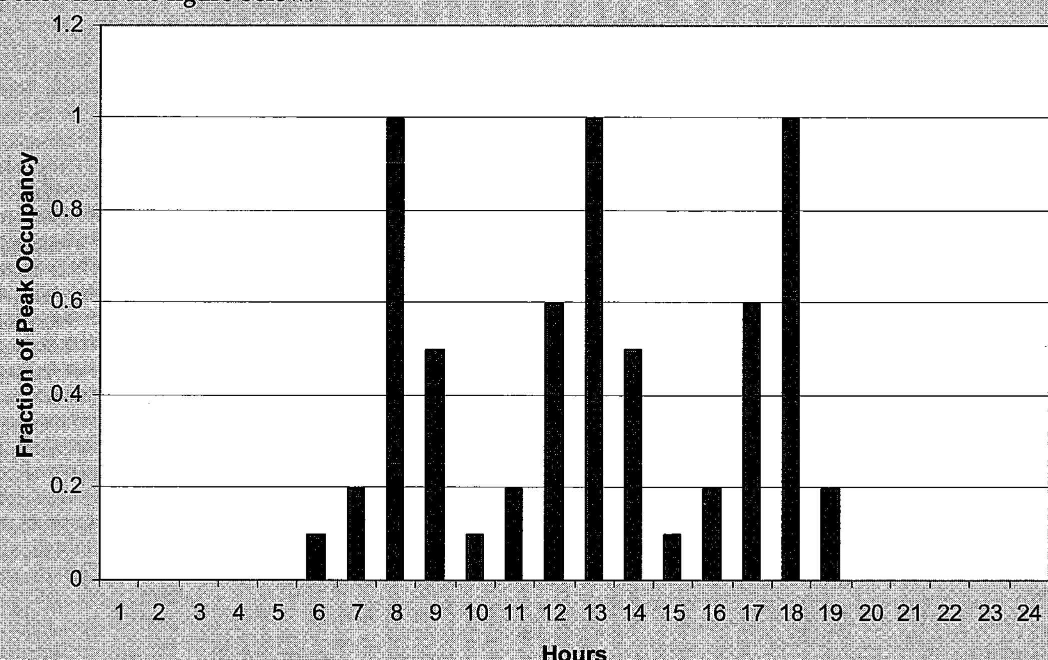
What is the design occupancy (P_z) of a 5000 ft^2 pre-function space to convention meeting rooms with a 15 foot ceiling?

A

Using the default value in Table 6-1 for occupancy density, the peak number of occupants is estimated to be 30/1000 * 5000 = 150 people. The averaging time period is then:

$$
\begin{aligned}
T &= \frac{3v}{V_{bz}} \\
&= \frac{3*5000*15}{150*7.5+5000*0.06} \\
&= 160 \text{ minutes} \\
&= 2.6 \text{ hours}
\end{aligned}
$$

Assume that the design day is a series of meetings or seminars in the morning and afternoon. The occupancy profile is estimated as shown in the figure below:



The time-weighted average population fraction is the largest consecutive total fraction over the averaging time (T). In this case, with the window rounded up to 3 hours, this occurs from noon to 2 PM (hours 12–14 in the chart above). During this period the average is (0.6+1+0.5)/3 ~0.7. So the design occupancy is 0.7 * 150 = 105 occupants.

Dynamic Reset (§ 6.2.7)

The ventilation system minimum outdoor air intake flow rate determined using the VRP is a peak rate based on worst-case operating conditions. The HVAC equipment must be selected for this worst-case rate but these conditions may occur only for very short periods of time, if at all. The Standard therefore allows outdoor air supply rates at both the space level (V_{oz}) and system level (V_{ot}) to be reduced from design setpoints as operating conditions change. Resetting ventilation airflow setpoints is called dynamic reset or demand-controlled ventilation (DCV). Operating parameters that can be sensed or measured and used to reset outdoor air rates include occupancy, air distribution efficiency, and economizer operation with VAV systems.

Occupancy

The number of people occupying a space can be estimated by (but not limited to) the following.

- *Expected occupancy based on time-of-day*: This is perhaps the most common example of occupancy-based outdoor air control—most HVAC systems include time based scheduling to operate ventilation systems based on an assumed occupancy schedule. More sophisticated systems also shut off ventilation during other unoccupied modes such as warm-up and setback.
- *Occupancy sensors*: These sensors, commonly used for lighting control, can also be used to assure design ventilation is supplied when people are present and shut off ventilation or reduce minimum airflow setpoints (on VAV systems) when spaces are unoccupied.
- *Carbon dioxide (CO_2) concentration*: The use of CO_2 sensors in controlling ventilation is addressed in the Appendix of this Manual.

Air Distribution Efficiency

Examples include:

- For systems whose zone or total outdoor air rate were determined based on the low air distribution efficiency that occurs when the system is in heating mode, when air tends to short-circuit into the return bypassing the breathing zone (see Table 6-2), the outdoor air rate can be reduced when the system is supplying air that is colder than space temperatures.
- For multiple space systems, the equations in Appendix A can be solved dynamically based on zone and system supply airflow rates and outdoor air requirements to reset either or both zone minimum airflow setpoints (VAV systems) and outdoor airflow rates. This approach can also respond to scheduled or sensed changes in occupancy (see previous discussion of occupancy).

Economizer Operation With VAV Systems

When a ventilation system has an outdoor air economizer, outdoor air rates can be more than five times the design minimum outdoor air rate during mild and cool weather. During these periods, minimum primary airflow rate setpoints at VAV boxes can be reset downward since the primary air is richer in outdoor air content, possibly reducing fan energy and reheat energy.

The strategies just listed are examples only. The Standard allows for the reset of outdoor air rates based on any parameter used in the VRP to determine rates, provided the parameter can be sensed directly or indirectly.

Exhaust Ventilation (§ 6.2.8)

Table 6-4 in the Standard lists occupancy categories that are required to be ventilated by exhausting air at the minimum rates shown, to the outdoors. These spaces are expected to have contaminants not generally found in adjacent occupied spaces. Hence the air supplied to the space to make up for (replace) the air exhausted may be any combination of outdoor air, recirculated air, and transfer air—all of which are expected to have low or zero concentration of the pollutants generated in the listed spaces. For example, the exhaust from a toilet room can draw air from either the outdoors, adjacent spaces, or from a return air duct or plenum. Because all of these sources of makeup air have essentially zero concentration of toilet-room odors, they are equally good at diluting odors in the toilet room. If the rate of air exhausted from these spaces exceeds the outdoor air supplied to adjacent spaces, the outdoor air rate to the adjacent spaces will generally be increased to ensure the net building pressure is not negative. Maintaining a positive net pressure is required for some systems per § 5.10.2.

Ventilation in Smoking Areas (§ 6.2.9)

The Standard requires that when using the VRP, the rate of outdoor air ventilation or air cleaning for smoking areas must be greater than similar non-smoking areas, but it does not say how much more ventilation or air cleaning should be provided. The Standard acknowledges that specific ventilation or air cleaning requirements for environmental tobacco smoke (ETS) cannot be established until cognizant authorities determine the concentration of ETS that achieves an acceptable level of risk to occupants. ETS has many adverse health effects, in addition to being a known carcinogen. The heart-disease-related death and disease rate from ETS is even greater than that related to cancer. No level of acceptability for ETS is under development by any cognizant authority in the U.S. as of the time of this writing.

The Standard does not allow air from smoking areas to be recirculated or transferred to non-smoking areas, regardless how much it is diluted by outdoor air or cleaned. The air delivered to smoking areas can be cleaned and/or diluted and recirculated back to smoking areas, but it may not be recirculated or transferred to non-smoking areas.

When providing one of the required measures (increasing ventilation rates or additional air cleaning), designers may wish to evaluate alternative measures to improve the cost-effectiveness of ETS removal in smoking areas, such as:

- Recovering energy from exhaust air (provided that no cross-contaminated air is supplied to a non-smoking area);
- Sensing levels of ETS and modulating outdoor air in response; and/or
- Using displacement or directional ventilation.

Example 6-X—Five More Cubic Feet Per Minute For Smoking Area

Q

If a system serving a smoking area is delivering 20 cfm/person to the space and 15 cfm/person is required for a comparable non-smoking area, does it meet the requirements of § 6.2.9?

A

Yes, because the Standard only requires that smoking areas shall have more ventilation and/or air cleaning than comparable non-smoking areas. However, a small increase in ventilation rates alone is not likely to result in acceptable air quality.

Example 6-Y—Higher MERV, Same Ventilation Rate

Q

If a MERV 6 filter is required per § 5.9 or § 6.2.1.1 and a system serving a smoking area has a MERV 7 filter at the same ventilation rate as a comparable non-smoking area, does it meet the requirements of § 6.2.9?

A

Yes, because again the Standard only requires that smoking areas shall have more ventilation and/or air cleaning than comparable non-smoking areas. However, an incremental increase in particulate filtration efficiency is not likely to provide acceptable air quality.

Indoor Air Quality Procedure (§ 6.3)

The Indoor Air Quality Procedure (IAQP) may be used as an alternative to the Ventilation Rate Procedure (VRP). While the VRP is a prescriptive procedure that determines minimum outdoor air ventilation rates for typical applications, the IAQP is a performance-based design approach that focuses on controlling the concentrations of contaminants to certain levels and maintaining a specified percentage of occupant satisfaction. The VRP is an indirect solution to achieving acceptable IAQ. The IAQP is a more direct approach to the goal, but it requires very different methods, knowledge, evaluations, decisions, and documentation than those of the VRP.

While the VRP allows (and in some cases requires) that recirculated air be cleaned, the specified outdoor air ventilation rates may not be reduced. On the other hand, the IAQP allows any method to be used to achieve the target (or maximum) concentrations of contaminants, including source control, air cleaning, or dilution of indoor contaminants with outside air.

The performance of the HVAC system in maintaining good air quality is based upon two requirements:

- Maintaining concentrations of specific contaminants below target concentration limits, and
- Achieving a design target level of perceived indoor air quality acceptability.

Sometimes meeting the target concentrations will result in perceived acceptability and sometimes not. For instance, the human nose is very sensitive to odors that may or may not be addressed by the contaminant concentration targets. On the other hand, meeting only the perceived acceptability targets is not sufficient since some contaminants cannot be sensed until harmful levels are reached (for instance radon and carbon monoxide).

The IAQ Procedure requires the building and its ventilation system to be designed to achieve both objective and subjective criteria. The IAQP allows ventilation air to be reduced below rates that would have been required by the VRP, if it can be reliably demonstrated that the resulting air quality meets the required criteria described in § 6.3.1.

The IAQP may allow for a more cost-effective solution to providing good air quality since all design strategies may be considered and compared, including:

- Dilution ventilation and the commensurate added energy costs of conditioning greater volumes of outdoor air;
- Controlling contaminants at the source by specifying low-emissions carpets, wall coverings, paints, adhesives and furnishings;
- Air cleaning strategies; and
- Evaluation of occupant satisfaction based on perceived air quality in similar buildings or through post-occupancy evaluation.

Many of these strategies involve added construction and maintenance costs but can have the benefit of conditioning less outdoor air. They can also result in higher levels of perceived acceptability by building occupants. The IAQP may also be used to achieve better air quality than the VRP (lower contaminant levels and/or higher perceived acceptability) with or without increasing first cost or maintenance cost.

Compliance Requirements (§ 6.3.1)

Designing for compliance using the IAQ Procedure requires four steps:

- Identifying contaminants of concern (COC);
- Determining acceptable concentrations of these contaminants;
- Specifying the perceived indoor air quality criteria; and
- Applying an acceptable design approach to achieve the performance criteria.

These steps are described in greater detail in the following subsections.

Contaminant Sources (§ 6.3.1.1)

The Standard requires that the COC that will be used for design purposes be identified. For each contaminant, both indoor and outdoor sources shall be identified, and the strength of each source shall be determined.

Establishing the contaminants of concern for a specific application is a somewhat subjective task, since hundreds of contaminants are known to be harmful to human occupants and/or to affect perceived acceptability. For instance, does one choose those contaminants present in the highest concentration—even though they represent a very low odor or irritation risk?[52] Or does one look for and choose those known to present IAQ concerns, even though these contaminants may represent a very small portion of the total contaminant load?[53]

Identification of the COC produced by indoor sources may come from previous experience with a particular building type or occupancy pattern, or may involve an investigation into the use of the spaces served by the HVAC system being designed. Identifying the COC may also result from an evaluation of building materials,[54] wall and floor coverings, finishes, and furnishings in each space. Specific contaminant sources produced by personnel or by activities in the space (cooking, printing operations, etc.) might also be considered in the choice of COC. Choosing the indoor COC may require collaboration among the HVAC system designer, building owner/operator, and the authority having jurisdiction. Looking at the most common contaminants, the most abundant contaminants, or the most problematic may all potentially be valid approaches to choosing the COC.

Identification and selection of the COC may also be influenced by whether the application involves new construction, renovation, or simple retrofit. For new construction and renovation applications, there may be less data on which to base the selection of COC, especially if experience with the building type is limited. Immediately after construction, there may be contaminant sources present that will recede over time. The design team may choose to consider these temporary sources. While post-construction verification of the COC list or the source strengths or the resulting concentrations may be valuable for the design team, it is not required by the Standard.

One method used for determining COC in new construction/renovation applications is a review of the available published literature on buildings of similar construction, size, and uses. There are many research, field, and practitioner studies available for office environments, schools, and medical facilities—but fewer for other building types. One of the more commonly studied building types (e.g., an office building) may serve as a base model with further specific or expected contaminant source types or increased emission rates added to the base.[55] For retrofit applications[56] involving only the selection and installation of ventilation system enhancements (such as improved air cleaning), the same COC selection process can be used. Alternatively, since the building already exists, COC selection may be determined by direct and/or indirect contaminant monitoring techniques and may be combined with assessment of occupant-perceived acceptability.

Of course, such monitoring costs money, takes time and requires appropriate techniques and protocols. COC may already have been identified in § 4 and the outdoor air quality may have been determined to be unacceptable. Indoor source strength from outdoor contaminants is a function of outdoor concentration and ventilation rate. Site-specific sources could include diesel generator exhaust, bus stops, helicopter pads, or other combustion engine processes. Other potential sources of odors and irritants

52. Individual VOCs may be COC in the application of the IAQ Procedure. Concentrations of concern range from less than 1 part per billion (ppb) for some very toxic compounds or for compounds having very low odor thresholds up to concentrations several orders of magnitude higher. Not all compounds can be identified, and toxicological data are incomplete for many compounds.

53. "ASHRAE 62-89 Analysis, Part 3: Indoor Air Quality Procedure" *Trane Engineers Newsletter* 22 no. 2.

54. Alevantis, L. "Building Material Emissions Study" submitted to the California Integrated Management Board through the Public Health Institute, available at: http://www.ciwmb.ca.gov/greenbuilding/Specs/Section01350/METStudy.htm, California Department of Health Services (2003)

55. Womble, S.E., et al. "Developing Baseline Information on Buildings and Indoor Air Quality (BASE '94): Part I—Study Design, Building Selection, and Building Descriptions" Presented at Healthy Buildings (Sep. 1995), Table 3: 6. Brightman, H.S., et al. "Baseline Information on Indoor Air Quality in Large Buildings (BASE '95)" Table I. Copies of both resources available through: Indoor Air Division, Office of Radiation and Indoor Air, U.S. Environmental Protection Agency, Washington, DC 20460 USA.

56. Modifying existing buildings for new uses or renovating existing building and using the IAQ Procedure to avoid having to upgrade the HVAC system to meet higher ventilation requirements.

could be landfills and industrial processes. There are guidance documents available from the EPA for a number of industry types that describe common pollutants and sources.[57]

In addition to or in the absence of site-specific outdoor air COC, designs may consider the criteria pollutants listed in the NAAQS.

Source strengths must be determined for all specified COC. For indoor contaminants, source strengths are most often represented as generation rates (mass emitted over time). For new construction applications, building studies may be used as a source of information on contaminant generation rates for both people and materials. Manufacturers of construction materials and building products may be able to provide information on the contaminant generation rates for specific products.[58]

Outdoor air source strengths are typically represented as a volumetric concentration (ppbv, g/m^3). For the criteria pollutants, the AIRS Database can be used unless site-specific information is available for these contaminants. For other contaminants (depending on the source(s) identified), one may be able to review an emission inventory on file with the local fire department, emergency management agency, air quality board,[59] and/or the EPA. Air monitoring data may also be available for the source or direct monitoring may be required.

Contaminant Concentration (§ 6.3.1.2)
The Standard requires that, for each contaminant of concern, a target concentration limit be specified along with the corresponding exposure period. An appropriate reference to a cognizant authority must be specified for each contaminant concentration. A cognizant authority is defined as either of the following:

- An agency or organization in possession of both the expertise and jurisdiction to establish and regulate concentration limits for airborne contaminants.
- An organization that is recognized as authoritative and whose scope includes the establishment of guidelines, limit values, or concentrations levels for airborne contaminants.

Appendix B of the Standard lists some contaminant concentration guidelines pertinent to indoor environments that may be relevant to a specific application.

Contaminant concentrations listed in Appendix B may be specified for design purposes, but sometimes appropriate target concentration limits will be those related to odor and/or irritation thresholds—especially where the design is intended to attain specific levels of perceived indoor air quality. Studies of irritation and odors related to IAQ can be reviewed to develop target concentration limits that may be lower than the Appendix B levels.[60]

Perceived Indoor Air Quality (§ 6.3.1.3)
The Standard's definition of acceptable indoor air quality reads: "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." The latter perceived air quality criterion must also be used for compliance with the IAQ Procedure. For the purposes of the IAQ Procedure, acceptable perceived indoor air quality excludes dissatisfaction related to thermal comfort, noise and vibration, lighting, and psychological stressors. Although these stressors may cross over to influence occupant perception of air acceptability, they are beyond the scope of the Standard.

57. "Industrial Processes" U. S. EPA, Washington, D.C., http://www.epa.gov/ebtpages/induindustrialprocesses.html
58. "Indoor Emissions of Formaldehyde and Toluene Diisocyanate," California Air Resources Board, 1997, http://www.arb.ca.gov/research/resnotes/notes/97-9.htm. Persily, A. K., et al, "Transient Analysis of VOC Concentrations for Estimating Emission Rates," In *Proceedings of Indoor Air, 9th International Conference on Indoor Air Quality and Climate* 2 (June 30-July 5, 2002, Monterey, CA): 189-194. Yu, C. and Crump, D. "VOC emissions from building products—Sources, testing and emission data," *BRE Digest* 464 Part 1 (Building Research Establishment Ltd. 2002)
59. California Air Resources Board (CARB), Air Quality, Emissions, and Modeling, http://www.arb.ca.gov/html/aqe&m.htm
60. 3M 2004 Respirator Selection Guide. ASTM, 1978, Compilation of Odor and Taste Threshold Values Data—2nd Edition. Cometto-Muñiz, J.E., et al. "Detection of single and mixed VOCs by smell and by sensory irritation" *Indoor Air* (2004) (in press).

The criteria to achieve the design level of acceptability must be specified in terms of the percentage of building occupants and/or visitors expressing satisfaction with perceived indoor air quality. A minimum design level of 80% acceptability is consistent with the Standard's definition of acceptable IAQ. However, other targets of acceptability may be determined based on the conditions of a specific building. For example, there may be some applications where a lower satisfaction criterion would be appropriate, such as an office area in a manufacturing facility. A higher percentage could also be a goal, but would be more difficult to achieve. Obviously, specifying the percentage of acceptability is dependent upon the specific application and may be somewhat subjective, like identifying the COC.

One method of gauging perceived air quality, if required after construction, is through the use of subjective evaluations in the completed building. Panels of observers have been used to perform these evaluations of indoor air quality in buildings and an acceptable approach to subjective evaluation is presented in Appendix B of the Standard.

Design Approaches (§ 6.3.1.4)

The fourth step in the IAQP is to apply the data collected in the previous steps by using one of four design approaches. The four methods are: mass balance analysis; those having proved successful in similar buildings; those validated by contaminant monitoring and subjective occupant evaluations; and application of one of these three approaches to specific contaminants and the use of the VRP to address the general aspects of indoor air quality.

- *Mass balance analysis* is the most commonly used method. This involves taking the information generated from § 6.3.1.1 and § 6.3.1.2 and performing a mass balance analysis of the spaces served by the HVAC system to show that the target concentration limits for all COC are not exceeded. Equations for performing a steady-state mass balance analysis on single zone systems are provided in Appendix D of the Standard. However, these equations may not be appropriate for a system serving multiple zones. For multizone systems, software modeling tools such as CONTAM[61] may be utilized to perform the mass balance analysis. Section 6.3.1.3 requires that a goal be set for occupant acceptability, and this goal may be estimated using the mass balance analysis method.
- *Design approaches that have proved successful in similar buildings* is the second method. The key word here is "similar" and while not required, this similarity can be tied to the definition of a zone. A zone is defined in § 3 as, "a collection of occupied spaces of the same occupancy category, occupant density, and air distribution effectiveness."
- *Contaminant monitoring and occupant surveys* is the third option given. Validation of acceptable IAQ through contaminant monitoring and subjective occupant evaluations or surveys must be performed at some time after all construction is complete. While the Standard does not specify exactly when such monitoring and evaluation must be done, a typical design approach would be to do so when the building is being normally occupied and operated. Construction and building material related contaminants are likely to be somewhat higher immediately after completion. The USGBC's LEED rating program gives credit for indoor air quality sampling prior to occupancy. While the design approach may consider this, the Standard does not require that the IAQP address these short-term increases. Many building studies have discussed the time it takes for initial higher building emission rates to decrease and these data can aid in deciding when to begin monitoring and evaluations that address steady-state conditions. Contaminant monitoring involves selecting the appropriate monitoring equipment based on the COC of indoor and outdoor origin, the time and duration of the monitoring period and how soon after the building has been normally occupied that the monitoring will commence. Compliance with this design approach requires subjective occupant

61. This program can be downloaded at no charge from the *NIST Multizone Modeling Website*: http://www.bfrl.nist.gov/IAQanalysis/index.htm or http://www.bfrl.nist.gov/IAQanalysis/CONTAMWdesc.htm.

evaluation. Appendix B of the Standard presents one approach for these evaluations. The evaluations may be done during or in the same general time period as contaminant monitoring, but not before the building is completed. Similar timing considerations to those discussed above about contaminant monitoring also apply to occupant evaluation.

- *Combination of methods with the VRP* is the fourth design approach given. Application of one of the three preceding approaches to specific contaminants and the use of the VRP to address the general aspects of indoor air quality would most likely be used when specific contaminants are anticipated or expected that are not typical or not covered by the VRP occupancy categories. In this situation, the VRP is used to determine the design ventilation rate of the space and the IAQ Procedure is used to address the specific contaminants through source control, supplemental ventilation, exhaust at the source, air cleaning, or some other means. This design approach will never result in outdoor air quantities lower than what is required by the VRP.

Documentation (§ 6.3.2)

The Standard requires that the IAQP be documented. The following information must be included in the documentation.

- The design approach used to control the contaminants of concern and the background or justification for using the approach;
- The contaminants of concern used in the design process;
- The sources and source strengths of the contaminants of concern found both indoors and outdoors;
- The target concentration limits and exposure periods for the COC, and the reference to cognizant authorities that justify said limits;
- If the design is based on an approach that has proved successful for similar buildings, the documentation must include the basis for concluding that the design approach was successful in the other buildings and the basis for concluding that the other buildings are substantially similar to the proposed design;
- If contaminant monitoring and occupant evaluation are to be used to demonstrate compliance, then the monitoring and evaluation plans must also be included in the documentation.

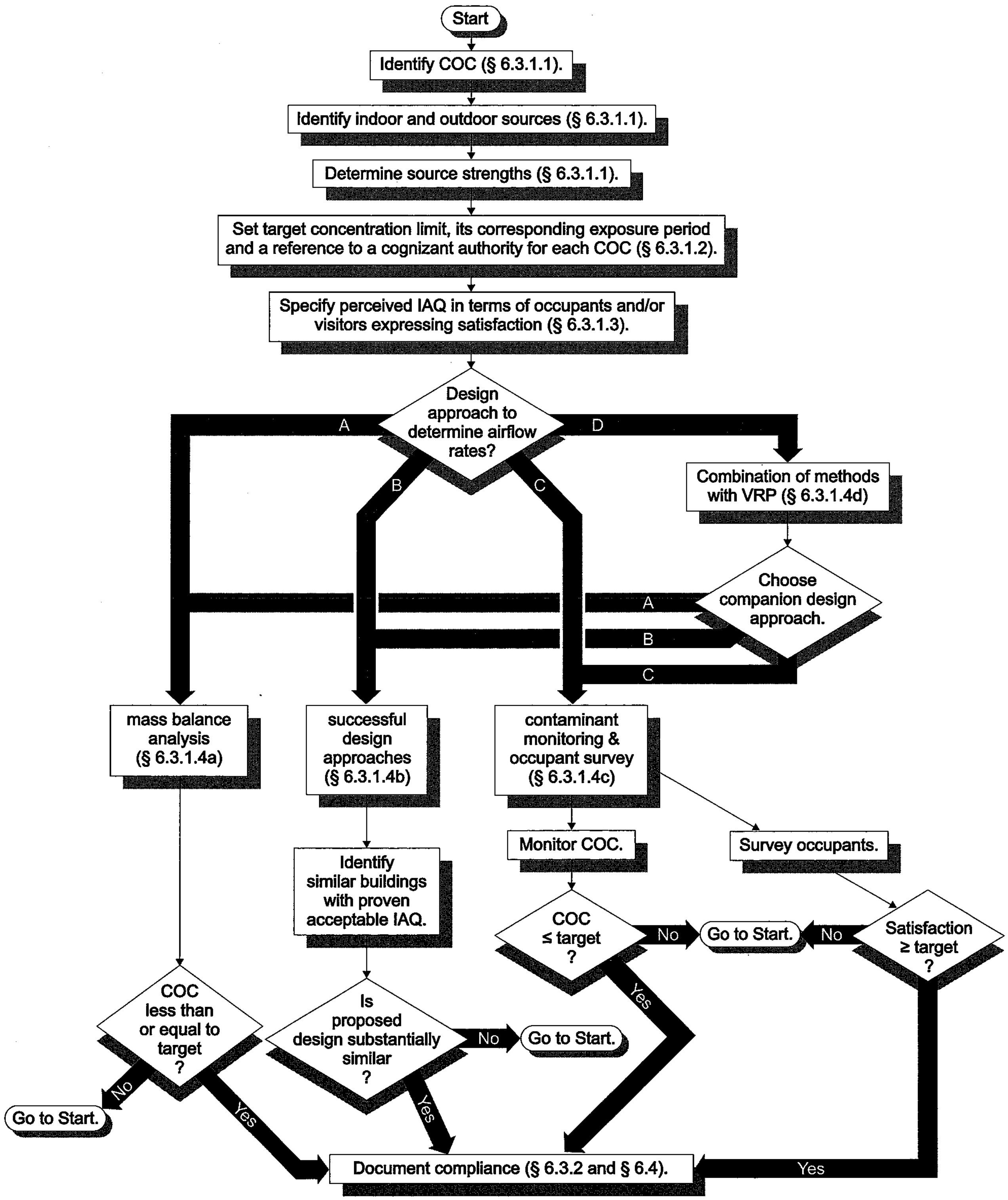


Figure 6-D—IAQ Procedure Flow Chart

Example 6-Z—IAQ Procedure, Single Zone System

Q

Can you provide an example of how the IAQ Procedure can be applied to a single zone space such as a lecture hall?

A

The IAQ Procedure may be a good choice for this application given the following set of design considerations: new construction, a desired outdoor air intake rate of 5 cfm/person, perceived IAQ acceptability of 80% of occupants, an air handler with constant outdoor and supply airflows, a filter (air cleaner) location in the supply (mixed) airstream (location B in Figure D.1 in the Standard), and a supply airflow of 20,000 cfm.* The following table shows specific zone summary information.

Area	Volume	No. Of People	Supply Air, Cooling and Heating	Supply Location	Return Location	Zone Air Distribution Effectiveness†
12,790 ft^2	260,000 ft^3	600	20,000 cfm	ceiling	ceiling	0.8

Given these design criteria, the outdoor air intake flow (V_{ot}) required under § 6.2.3 of the VRP would be 6,584 cfm. This compares to 3,000 cfm using the IAQ Procedure.

For this example, the contaminants of concern in the outdoor air were carbon monoxide, nitrogen dioxide, ozone, and sulfur dioxide. Concentration values to be used for the mass balance analysis are shown below.

2^{nd} Max 8-hr Value for CO	NO_2 Annual Mean Value	4^{th} Max 8-hr Value for O_3	SO_2 Annual Mean Value
2.2 ppm	0.014 ppm	0.084 ppm	0.002 ppm

For indoor contaminants, both the contaminants of concern must be chosen as well as the generation rates of these contaminants from occupants, materials, and processes. Acetone, ammonia, hydrogen sulfide, methyl alcohol, and phenol were chosen to be indicators of human activities. The contaminants from building materials and processes were selected to be formaldehyde and total volatile organic compounds (TVOC). Each of these contaminants chosen are representative compounds in indoor and outdoor air and there is much data in the public domain from which concentrations and generation rates could be obtained (see references below). TVOC was chosen due to the fact that many of the published building studies include this as an air quality indicator—sometimes as the sole indicator of air quality.‡ For this application, no particulate contaminants of concern were chosen.

GENERATION RATES OF BIOEFFLUENTS FROM OCCUPANTS (Wang, 1975)
& OUTDOOR AIR CONCENTRATIONS (ASTDR, 1990, 1994, 1998, 1999)

Contaminant	Generation Rate, in mg/(min*person)	Concentration in Outdoor Air
Acetone	0.0352	0.007 ppm
Ammonia	0.0224	0.005 ppm
Hydrogen Sulfide	0.0019	0.00033 ppm
Methyl Alcohol	0.0517	negligible
Phenol	0.0066	0.000091 ppm

** The choice of the outdoor air intake rates to use with the IAQ Procedure can be based on a simple reduction of those prescribed by the VRP (i.e., 25%, 50%, 75%, etc.); based on some fixed value necessary to recover exhaust air volumes and maintain pressure differentials in the space (building); or based on economic considerations due to estimated HVAC system capital and/or operational savings possible by a reduction in heating and cooling requirements.*

† Referred to as "Air Change Effectiveness" in Appendix D of the Standard.

‡ For this example, the COC were chosen using the best available information and based upon agreement between the HVAC system designer, the building owner/operator, and the authority having jurisdiction. This could include published building studies and general IAQ studies, review of IAQ standards and guidelines, etc.

GENERATION RATES FROM BUILDING MATERIALS AND PROCESS (Offerman, 1993)
& OUTDOOR AIR CONCENTRATIONS (Brightman, 1995; Girman, 1995; Womble, 1995)

Contaminant	Net Emission Rates (ug/m^3-h)	Concentration in Outdoor Air
TVOC (as carbon)	303	0.0685 mg/m^3
Formaldehyde	21	0.0068 mg/m^3

STANDARDS AND GUIDELINES FOR COMMON INDOOR AIR CONTAMINANTS
Target levels used in this example are shown in italics.

Compound	MW	ppm	mg/m^3	Time	Description
Acetone	58.08	*2.95*	*7*	*24 hrs*	*Newill, 1977*
		62	147	Immediate	Threshold-ED_{50} (ASHRAE, 2001)
		500	1188	8 hrs	TLV-TWA (ACGIH, 2003)
		2.40	5.9	1 hr	Alberta Environment, 2004
Ammonia	17.03	*0.72*	*0.5*	*Yr*	*VDI, 1974*
		17	11.8	Immediate	Threshold-ED_{50} (ASHRAE, 2001)
		25	17	8 hrs	TLV-TWA (ACGIH, 2003)
		2.0	1.4	1 hr	Alberta Environment, 2004
Carbon Monoxide	28.01	*9*	*10*	*8 hrs*	*NAAQS (EPA, 2003)*
		9	*10*	*8 hrs*	*ASHRAE 62 (ASHRAE, 1981)*
		25	29	8 hrs	TLV-TWA (ACGIH, 2003)
Formaldehyde	30.03	0.1	0.12	long term	Canadian Exposure Guidelines (ASHRAE, 2003)
		0.3	0.4	Ceiling	TLV-TWA (ACGIH, 2003)
		0.75	0.92	8 hrs	PEL-TWA (OSHA, 2002)
		0.027	*0.033*	*8 hrs*	*Cal-EPA, OEHHA, 1999*
Hydrogen sulfide	34.08	*0.03*	*0.042*	*24 hrs*	*CARB, 2003*
		10	14	8 hrs	TLV-TWA (ACGIH, 2003)
Methyl alcohol	32.04	*1.14*	*1.5*	*24 hrs*	*Newill, 1977*
		2.0	2.6	1 hr	Alberta Environment, 2004
		160	209	Immediate	Threshold-ED_{50} (ASHRAE, 2001)
		200	262	8 hrs	TLV-TWA (ACGIH, 2003)
Nitrogen Dioxide	46.01	*0.053*	*0.1*	*Yr*	*NAAQS (EPA, 2003)*
		3	6	8 hrs	TLV-TWA (ACGIH, 2003)
Ozone	48	*0.080*	*0.157*	*8 hrs*	*NAAQS (EPA, 2003)*
		0.120	0.235	1 hr	ASHRAE 62 (ASHRAE, 2001)
		0.2	0.39	<2 hrs	TLV-TWA (ACGIH, 2003)
Phenol	94.01	*0.03*	*0.1*	*24 hrs*	*Newill, 1977*
		0.025	0.10	1 hr	Alberta Environment, 2004
		0.06	0.231	Immediate	Threshold-ED_{50} (ASHRAE, 2001)
		5	19	8 hrs	TLV-TWA (ACGIH, 2003)
Sulfur Dioxide	64.07	*0.03*	*0.08*	*Yr*	*NAAQS (EPA, 2003)*
		2	5	8 hrs	TLV-TWA (ACGIH, 2003)
		2.7	7.07	Immediate	Threshold-ED_{50} (ASHRAE, 2001)
TVOC	100	*0.24*	*1.0*	*–*	*Target Level (Tucker, 1988)*
		0.32	0.05–1.30	–	Nordic Standard (Etkin, 1996)
		0.73	3	–	Discomfort Range (Etkin, 1996)
		1.22	5	Immediate	Action Level (EPA, 1989)

The following mass-balance equation (from Appendix D of the Standard) determines the space contaminant (C_s) concentration for this particular system configuration. Using the information for formaldehyde as an example, the calculations are as follows.

$$C_s = \frac{N + eV_o(1-E_f)C_o}{e(V_o + RV_rE_f)}$$

where:

N	*= generation rate of formaldehyde = V * [0.021 mg/(m³*hr)**]*
	[V=260,000 ft³ (7,362 m³)]
	*= (7,362 m³)(0.021 mg/[m³*hr])*
	= 154.6 mg/hr
e	*= air change effectiveness = 0.8*
V_o	*= volumetric flow of outdoor air = 3,000 cfm (5,097 m³/hr)*
E_f	*= air cleaning efficiency = 0.25 ††*
C_o	*= concentration of formaldehyde in outdoor air = 0.0068 mg/m³*
RV_r	*= volumetric flow of recirculated air = 17,000 cfm (28,883 m³/hr)*
C_s	*= space concentration of formaldehyde = 0.0178 mg/m³*

Target concentration limit for formaldehyde = 0.033 mg/m^3 (see STANDARDS AND GUIDELINES)

% Target= [(C_S / Target)](100%)

= [(0.0178 mg/m^3) / (0.033 mg/m^3)]×(100%)

= 53.9%

This confirms that outdoor air intake rate of 5 cfm/person is sufficient to provide a space concentration of formaldehyde that would be below the established target concentration limit. The results of repeating this calculation for the mass balance analysis for all of the contaminants of concern used in this example are shown in the following table.

SPACE (ZONE) CONTAMINANT CONCENTRATION RESULTS FOR ALL CONTAMINANTS OF CONCERN

Contaminant	Units	Concentration Value	Target Concentration Limit	% Target
Acetone	[mg/m³]	0.134	7	2%
Ammonia	[mg/m³]	0.202	0.5	40%
Carbon monoxide	[ppm]	2.2	9	24%
Formaldehyde	[mg/m³]	0.0178	0.12	15%
Hydrogen sulfide	[mg/m³]	0.00708	0.04	18%
Methyl alcohol	[mg/m³]	0.189	1.5	13%
Nitrogen dioxide	[ppm]	0.00434	0.053	8%
Ozone	[ppm]	0.0261	0.08	33%
Phenol	[mg/m³]	0.0242	0.1	24%
Sulfur dioxide	[ppm]	0.000621	0.03	2%

For all of the contaminants used in this example, using an outdoor air intake rate of 5 cfm/person will provide a C_s value of 55% or less of the COC target concentration limits shown above. This model will therefore comply with the requirements of the IAQ Procedure.

** *Offerman, F.J. et al. "Indoor Emission Rates Before and After a Building Bake-Out."* Operating and Maintaining Buildings for Health, Comfort, and Productivity *Proceedings IAQ 94. (Philadelphia: ASHRAE Nov. 1993): 157-163.*

†† *This is a conservative estimate of filter efficiency based on manufacturer's test data as well as data from NIST studies. Howard-Reed, C., et al, "Measurement and Simulation of the Indoor Air Quality Impact of Gaseous Air Cleaners in a Test House"* Indoor Air *(July, 2002) Proceedings: 9th International Conference on Indoor Air Quality and Climate (Monterey, CA). Howard-Reed, C., et al, "Predicting the Performance of Gaseous Air Cleaners: Measurements and Model Simulations from a Residential-Scale Pilot Study" NISTIR 7114 (NIST 2004). The air cleaning efficiency (E_f) will most likely be different for each COC and in fact may require more than one type of filter or filter medium for best effectiveness. Because of this, it might be advisable to use a conservative value for E_f based on the lowest reported efficiency for each of the COC. Documentation as to the method(s) used to determine air cleaning efficiencies and the E_f for each individual COC should be available for review by all parties.*

Example 6-AA—IAQ Procedure, Multizone Systems

Q

A retail store is being built in San Antonio, Texas and will have the following space types: corridors, fitting rooms, and sales areas. How might the IAQ Procedure be applied for this application?

A

This is an example of a multizone system. Of the four design approaches presented in § 6.3.1.4, the mass balance analysis is most frequently used and will be used for this example. Although the equations from Appendix D of the Standard could be used here, the recirculation of air between zones is not easily accounted for. For multizone systems, software tools such as CONTAM can be utilized to perform the mass balance analysis.

For the purposes of this User's Manual, this example will use the same indoor and outdoor contaminants, air change effectiveness, and air cleaning efficiency data as in Example 6-Z. Please note, however, that each application of the IAQ Procedure will require a separate determination of contaminant sources and concentrations as well the appropriate design approach to use. The additional information necessary to perform the mass balance analysis for this example is provided below.

AIR HANDLER DESCRIPTION

Supply Airflow Type	Outdoor Airflow Type	Filtration Location	Supply Air (cfm)	Outdoor Air (cfm)	
				VRP	IAQP*
Constant	Constant	Supply	14,080	6,860	1,900

** The desired limit was 1,900 cfm, this results in an outdoor airflow rate at the intake of 7 cfm/person based on total occupancy.*

ZONE INFORMATION

Zone #	Room Type	Area (ft²)	Volume (ft³)	People	Supply Air (cfm)	Supply Location	Return Location	Zone Air Distribution Effectiveness
1	Corridor	305	3,355	0	300	Ceiling	Ceiling	0.8
2	Fitting	480	4,320	5	690	Ceiling	Ceiling	0.8
3	Fitting	542	4,878	5	930	Ceiling	Ceiling	0.8
4	Sales 1	6,040	66,440	60	3,360	Ceiling	Ceiling	0.8
5	Sales 2	1,628	17,908	16	840	Ceiling	Ceiling	0.8
6	Sales 3	9,828	108,108	98	3,980	Ceiling	Ceiling	0.8
7	Sales 4	8,786	96,646	88	3,980	Ceiling	Ceiling	0.8

The CONTAM software has been used with the information provided above to calculate the space/zone concentrations based on outdoor air of 7 cfm/person at the outdoor air intake, i.e., 7 cfm/person multiplied by total occupancy. The results are displayed in the following table as a percent of the target concentration limit for each contaminant. The outdoor air contaminants and concentrations were obtained from the AIRS database for monitoring station nearest the site.* All calculations were carried out at steady state.

** For more information about the AIRS Database, visit: http://www.epa.gov/airs/ or http://www.epa.gov/air/data/. For more general information about the EPA's outdoor air quality monitoring programs, visit: http://www.epa.gov/oar/oaqps/montring.html, http://www.epa.gov/oar/oaqps/qa/monprog.html, or http://www.epa.gov/ttn/amtic/.*

RESULTING ZONE CONTAMINANT CONCENTRATIONS
in the form of Percent of Target Concentration Limit

	Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Zone 7
Acetone	1	1	1	1	1	1	1
Ammonia	26	27	27	29	29	30	30
Carbon monoxide	71	71	71	71	71	71	71
Formaldehyde	23	21	21	26	27	30	28
Hydrogen sulfide	8	9	9	12	12	13	12
Methyl alcohol	6	7	6	8	8	9	9
Nitrogen dioxide	4	4	4	4	4	4	4
Ozone	34	34	34	34	34	34	34
Phenol	11	13	12	16	16	18	17
Sulfur dioxide	6	6	6	6	6	6	6
TVOC	30	28	27	35	36	39	38

As in Example 6-Z, all of the contaminants of concern are less than the target concentration limits when using a mass balance analysis design approach (§ 6.3.1.4a). Therefore, using a total system outdoor airflow of 7 cfm per person based on total occupancy (1900 cfm) would comply with the Standard using the stated design criteria and the IAQ Procedure.

Design Documentation Procedures (§ 6.4)

Design criteria and assumptions must be documented and should be made available for operation of the system within a reasonable time after installation. This includes documentation of the findings of the outdoor air quality investigation (§ 4.3), the ventilation air distribution design (§ 5.2.3), the justification for classification of air from any location not listed in Tables 6-1, 5-2, or 5-3 (§ 5.17.4), and the IAQ Procedure design documentation (§ 6.3.2).

7. Construction & System Start-up

General

Section 7 contains requirements for two phases of activity: construction and system start-up.

Construction Phase (§ 7.1)

The requirements of § 7.1 apply when any of the following takes place:

- A new building is constructed;
- An addition to an existing building is built;
- Alterations are made to an existing building.

However, not all the requirements are applicable to each of the three circumstances listed above, as will be seen in the following sections.

Filters (§ 7.1.2)

Sometimes, the HVAC system is ready for operation while construction activities are still ongoing. It may be necessary to run the HVAC system to prevent pipe freezing, or if the building is closed in, for the benefit of the construction crew. Since construction activities such as drywall sanding create large amounts of dust, filters can clog quickly, resulting in a temptation to run a system without filters. Section 7.1.2 requires that systems designed to have particle filters not be operated without them in place. As a practical matter, this should generally be coordinated with the trade responsible for the system and the proper filters should be provided.

Note that § 7.1.2 does not require that the same filters specified for normal occupancy be used during construction. Although not prohibited by the Standard, use of the newly installed HVAC system for temporary heating/cooling can have a negative impact on the overall duct system regardless of the filtration used and may pose problems with the future operation and maintenance of the equipment. Equipment manufacturers who become aware that newly installed equipment is used for these purposes may accelerate the commencement and/or termination of the warranty period.

Nevertheless, if the unit is used during construction and if a high level of particulate filtration has been specified for normal occupancy, it may make sense to provide a lower level during construction so that the filters last longer. Furthermore § 7.1.2 does not require that gaseous air cleaners be in place or in operation during construction. Occupational safety personnel responsible for the construction crew should be involved in any decisions about the level of filtration required, since more stringent workplace criteria than *Standard 62.1* may apply.

Protection of Materials (§ 7.1.3)

Section 7.1.3 requires that building materials be protected from rain and other sources of moisture both at the construction site and in transit, but only when recommended by the manufacturer.

Building materials made of organic matter (such as wood, paper, or glue) or those that collect organic matter (such as leaves, insects, and grass clippings) that are left exposed outdoors and allowed to get wet can be sites for microbial growth. This can happen either before or after they are brought into the building. More inert materials, such as structural steel and plastic pipe, can be left exposed with no ill effects on indoor air.

A second requirement of § 7.1.3 relates to the presence of visible microbial growth, regardless of manufacturer's recommendations. Porous materials exhibiting visible microbial growth must not be installed. Non-porous materials, such as sheet metal, with visible microbial growth must be decontaminated. Methods for such decontamination can be found in other reference materials.[62]

62. See, for example, "Mold Remediation in Schools and Commercial Buildings," U.S. EPA, March 2001.

Example 7-A—Temporary Filter During Construction

Q

An air handler specification calls for a 4 in. (100 mm) thick extended media particulate filter with a MERV-15 rating (per ASHRAE *Standard 52.2*) and a charcoal-impregnated post-filter for gaseous phase contaminants. The contractor has proposed to run the unit with a temporary construction filter that consists only of a 1 in. (25 mm) thick polyester filter during construction. Does this meet the requirement of § 7.1.2?

A

Yes. Since the air handler is designed to be run with a filter, it must be run with a filter during construction. It need not be the same filter as the one used for normal occupancy. The temporary construction filter described meets the minimum requirement, even though it's unlikely to filter the quantities of dust generated during construction.

Protection of Occupied Areas (§ 7.1.4)

Many, but not all, construction activities create contaminants that can impact nearby occupied areas. Such contaminants can be particulate matter from activities such as sanding and gaseous-phase contaminants from activities such as painting.

When such activities take place, *and* the construction activities require a building permit, § 7.1.4 requires that steps be taken to prevent the migration of contaminants to the occupied areas.

Many day-to-day operational activities in a building involve the same activities as construction projects, but to a small degree and do not require a building permit. Examples include touch-up painting and cutting drywall to install an electrical junction box.

When a building permit is required *and* the construction entails sanding, cutting, grinding or other activities that generate significant amounts of airborne particles *or* the construction entails procedures that generate significant amounts of gaseous contaminants, then the protective measures must be taken.

The measures themselves are not prescribed, rather, examples are given. Sample protective measures include:

- Sealing the construction area using temporary walls or plastic sheathing;
- Exhausting the construction area; and
- Pressurizing contiguous occupied areas.

A combination of these methods may be used. If exhaust to the outdoors cannot easily be achieved, then high efficiency filtration might be used to make the air suitable for recirculation. Another option is to perform the construction activities during hours when other spaces in the building are not occupied. Spaces that are not adjacent may also require protection, for example if they share a common ventilation system or are connected by a chase or shaft to the construction area.

Very often other aspects of construction, such as noise, dirt, movement of materials and use of elevators by crews, can be intrusive and annoying to building occupants. These can aggravate the potential air quality effects and therefore might be included in an overall protection plan.

Air Duct System Construction (§ 7.1.5)

Section 7.1.5 requires that air ducts be constructed in accordance with applicable industry standards, as noted below.

- Flexible ducts must be constructed in accordance with certain referenced sections of SMACNA *HVAC Duct Construction Standards*, 2nd edition, 1995.
- Sheet metal casings and plenums must be constructed in accordance with certain referenced sections of SMACNA *HVAC Duct Construction Standards*, 2nd Edition, 1995.

- Fibrous glass ducts (duct board) must be constructed in accordance with all sections of SMACNA *Fibrous Glass Duct Construction Standards*, 6th edition.
- All duct systems must be constructed in accordance with National Fire Protection Association *Standards for the Installation of Air-Conditioning and Ventilating Systems*, NFPA No. 90A (generally for buildings over 25,000 ft^3/700 m^3 in volume or combustible construction over three stories), and *Installation of Warm Air Heating and Air-Conditioning Systems*, NFPA No. 90B (generally for buildings under 25,000 ft^3/700 m^3 in volume).

See the NFPA Standards themselves for more detail on which buildings each applies to. Both of them contain requirements for equipment and other components that are not strictly part of the duct system and are therefore not invoked by § 7.1.5.

Example 7-B—Protective Measures for Non-Permit Job

Q

The entrance lobby of a hotel is being repainted and light fixtures are being replaced. No building permit is required, but the electrician must secure a trade permit. What measures must be taken to protect occupants of the building?

A

Since the construction does not require a building permit, no measures are required by *Standard 62.1*. However, protective measures may be prudent.

System Start-Up Phase (§ 7.2)

Application (§ 7.2.1)

Section 7.2 has stricter requirements for the start-up of new systems and lesser requirements for those that undergo more limited alterations. These requirements are specifically described in the body of the Standard and in the following sections.

New Air Handler

Only the installation of a new air handling system triggers all the requirements of § 7.2. The new air handler may be in a new building, an existing one or an addition. The requirements, further described in subsequent sections, consist of all of the following:

- Air balancing;
- Testing of drain pans;
- Cleanliness;
- Testing of outdoor air dampers; and
- System documentation.

Limited Alterations

Certain alterations short of replacing the air handler trigger only the air balancing requirement of § 7.2.2. These limited alterations include:

- Reduction in supply or outdoor airflow; or
- Alterations to air distribution systems affecting more than 25% of the floor area served by the systems.

Air Balancing (§ 7.2.2)

Section 7.2.2 requires testing and balancing of the outdoor airflow at the intake and the balancing of airflow to each ventilation zone (see § 6) in the system. Testing and balancing procedures are normally performed on a ventilation system at start-up for multiple purposes, including:

- Verification that equipment such as fans and controls are installed and functioning properly;
- Energy conservation;
- Thermal comfort;
- Protection of equipment from excessive flows and pressures; and
- Ventilation and air distribution.

Section 7.2.2 contains minimal balancing requirements to meet the last goal only. All it requires is to verify conformance with the total outdoor airflow and space supply airflow requirements.

Any balancing method is acceptable if it is equivalent to the SMACNA or ASHRAE publications referenced in the Standard.[63] There are two other major organizations in the U.S. that certify balancing technicians and methods and publish methodology guides.[64] Many balancing procedures will follow one of these two guides, which are both acceptable for meeting the Standard.[65]

Balancing procedures are also required for systems that undergo limited alterations that involve reductions in airflow or air distribution modifications that exceed the 25% of floor area criterion as described previously.

Testing of Drain Pans (§ 7.2.3)

Section 7.2.3 requires verification that drain pans drain for new air handlers, using one of two methods: field-testing or proper installation per factory certification.

Stagnant water in a drain pan should be avoided. It can be a site for biological contamination, since organic matter is present. Furthermore, during off-periods, the water temperature may increase, creating conditions ideal for the growth of microorganisms. Growth can occur even in relatively cold water.

Field-testing may be performed for any drain pan, including those that are manufactured, but it is the only acceptable method for those that are field-erected (not manufactured). The details of the field test method are not specified, but it must demonstrate that the pan drains under normal operating

63. *Standard 111* (ASHRAE 1988). *Practices for Measurement, Testing, Adjusting, and Balancing of Building Environmental Systems* and *HVAC Systems—Testing, Adjusting & Balancing* SMACNA, (Chantilly, VA: 2002). The latter includes material very similar to the NEBB publication and additional background information. Neither ASHRAE nor SMACNA certify balancing technicians.

64. *Procedural Standards for Testing Adjusting and Balancing of Environmental Systems* 6th ed. (NEBB, Gaithersburg, MD, 1998). *National Standards for Total System Balance* 6th ed. (AABC Washington, D.C. 2002). Testing, Adjusting and Balancing Bureau (TABB) visit www.tabbcertified.org for additional information.

65. Balancing procedures that follow any of these guides are acceptable for meeting the Standard.

Example 7-E—System Upgrade

Q

A system upgrade project consists only of an air handler being replaced with one of identical size and configuration. Must the air distribution system be recalculated and reworked?

A

No, the air distribution can remain as is, except for air balancing and testing. Nothing in § 7 requires recalculation of the ventilation air (see § 8.1.3 for changes that can trigger a reevaluation). However, the newly installed air handler triggers the requirements of § 7.2. Therefore, the air handler must undergo air balancing, drain pan testing, cleanliness, damper testing, and meet cleanliness and system documentation criteria, in accordance with § 7.2.2 through § 7.2.6. If documentation of airflow and damper operation are no longer available for the existing distribution system, then the system may need to be evaluated and the missing documentation created to complete the required tasks. Similarly, if the means to balance airflows are not present, they may need to be installed to perform the required balancing.

conditions. In other words, the fan must be operating and the coil dehumidifying.

Factory testing can be employed if it meets all of the following criteria:

- It is used for factory-installed drain pans;
- The pan is certified by the manufacturer for proper drainage; and
- It has been installed as recommended.

The Standard presumes that the manufacturer's recommendation includes a tolerance for level installation of the manufactured unit to preserve the drainability of the pan.

Use of either of these test methods does not exempt the manufactured or the field-erected pan from the requirements of § 5.11 for slope, location of the drain connection, P-trap, etcetera.

Cleanliness (§ 7.2.4)

Dirt or debris left in a ventilation air distribution system can clog coils, filters, turning vanes, diffusers, fan wheels, and other important system components. It can also be entrained in the air of the occupied space. Therefore, § 7.2.4 requires that ventilation air distribution systems be clean of dirt and debris.

Testing of Outdoor Air Dampers (§ 7.2.5)

Section 7.2.5 requires that each ventilation system be tested to verify that the outdoor air damper(s) operates properly and in accordance with the system design prior to occupancy.

The automatic outdoor air damper is one of the most essential elements of a mechanical ventilation system. Many control sequences specify dampers to close when a system is off and open when the system is turned on. More sophisticated designs call for automatic dynamic adjustment of the damper. No matter how good the duct system, controls, and design intentions, if the outdoor air damper does not do what it should, then the occupied spaces will not be properly ventilated.

System Documentation (§ 7.2.6)

Standard 62.1 covers activities for acceptable indoor air quality throughout the life of the building:

- Pre-design observations in § 4;
- System and design requirements in § 4, § 5 and § 6;
- Construction and start-up activities in § 7; and
- Operation and maintenance requirements in § 8.

To execute the ventilation plan for the life of the building, a strategy is necessary. Due to the limitations of institutional memory, this strategy must be documented as required in § 7.2.6 and maintained as required in § 8.

Normally, the engineer of record will prepare a portion of the documentation and the mechanical contractor or equipment/system manufacturer will prepare the remainder. However, the Standard does not specify who prepares it. It does require that the documentation be provided to the building owner or his/her designee and retained within the building. The documentation may be in paper copy or electronic form, so long as it is made available to the building operations personnel.

Many specifications call for an operating and maintenance manual, project record documents, balancing reports, and other data. Operating and maintenance manuals often contain a great deal of useful information, but may not meet the specific requirements of *Standard 62.1.* Many contractors take manufacturer's submittals and insert them into sections of a loose-leaf binder. This is inadequate. To provide the required content, collaboration between the designer and installer is likely to be necessary.

Table 7-A describes the specific content requirements, grouped into two categories. The left column lists those that are often common practice to include in turnover documents. The middle column describes requirements that go beyond documents that many turnover packages include. The right column contains other comments concerning the required documentation.

These documents must be maintained on site as required by § 8.

Example 7-F—Duct Cleaning Prior to System Start-Up

Q

Does § 7.2.4 require that ducts be cleaned prior to start-up of any new or altered system?

A

No. Section 7.2.4 is not a requirement for universal duct cleaning prior to starting up a system. If the system was installed clean and debris was not left in it, then no action is required at all. Whatever dirt or debris is there must be removed. The degree of cleanliness and selection of appropriate methods is left to the user of the Standard.

Table 7-A—Required Documents Compared to Common Contract Closeout Practice

Common Practice For Contract Closeout*	Additional *Standard 62.1* Requirements	Comments
Basic data relating to the operation and maintenance of ventilation systems and equipment as installed	Not merely equipment submittals, but actual operating and maintenance procedure manuals or instructions must be included, not just for individual components, but for the system as a whole.	This may require the designer to prepare the system operating procedures.
HVAC controls information consisting of diagrams, schematics and control sequence narratives	Controls maintenance and/or calibration information	The controls vendor and/or designer might provide the maintenance or cailbration information.
An air balance report documenting the work performed for § 7.2.2	None	A standard complete report will document much more than required.
Construction drawings of record and final design drawings	Control drawings are required. These may be included in the diagrams listed above.	
	Design criteria and assumptions for the ventilation design—in order to be useful, this would normally include all the calculations required by § 6.2 if the ventilation rate procedure is used. If the design is based on the IAQ Procedure (§ 6.3), then additional assumptions related to contaminant sources and concentrations must be included.	This will likely require that the designer document assumptions in a form that can be easily transferred.

** According the Construction Specifications Institute Master Format (see csinet.org and masterspec.com), general requirements for documents to be turned over at contract closeout are covered in Division 1 and may be in Sections titled, "Closeout Procedures," "Operation and Maintenance Data," and "Project Record Documents." Specific requirements for mechanical systems appear in Division 15, for instance in a section that may be titled "Testing, Adjusting and Balancing." Sections such as "HVAC Commissioning Requirements" and "Demonstration and Training" may appear in either division and may contain applicable requirements.*

8. Operations & Maintenance

General (§ 8.1)

Standard 62.1-2004 includes requirements for operation and maintenance (O&M), first introduced in *Standard 62-2001.* Effective operation and thorough maintenance of a building and its systems over their lifetimes affect indoor air quality at least as much as proper design and construction. It is essential that equipment operate correctly; potential sources of moisture and other contaminants are managed; and appropriate quantities and qualities of outdoor air are distributed to spaces even as their uses change, buildings are remodeled, and equipment is upgraded.

Operation refers to the day-to-day activities of turning systems on and off, observing equipment function, as well as responding to occupants and changes in physical plant conditions. Maintenance refers to a set of recurring activities that keep the building and its systems running well. Some corrective and curative actions are also required in this section, as described further in the following paragraphs.

Building alterations and change-of-use are also included in § 8.1 because they fit under a broader understanding of activities that occur during the life of the building.

The success of O&M hinges on teamwork. The foundation for good process (such as an O&M Manual and physical access to equipment) must be put in place by the team that designed and constructed the building. Once the building is complete, a building owner or operator typically manages the process going forward. Facility managers and their staff, who spend a great deal of time on site, often carry out operational activities. Technicians, who may spend less time at a particular facility, typically moving between several facilities, often carry out maintenance activities. Many of the requirements of § 8.1 also will require the services of qualified system designers, installers, and testing specialists. Although the Standard has various O&M requirements, it does not and may not dictate who carries them out.

There are many reasons for performing O&M, such as thermal comfort, energy efficiency, and equipment life. *Standard 62.1* singles out only those requirements that are essential for acceptable indoor air quality and may be appropriate as "code minima." Therefore, checking sensors used for minimum outdoor airflow is required, while checking room thermostats is not.

A strong maintenance management program will include much more than the minimum required by the Standard (see Chapter 38 of the 2003 ASHRAE *Handbook—HVAC Applications* and other industry documents).[66]

Application (§ 8.1.1)

Only those buildings and their ventilation systems and components constructed or renovated after the adoption of this section on November 16, 2001 are required to comply with § 8. This is because the documents, service clearances, means to balance, and other system characteristics may not exist to enable the O&M procedures to take place in accordance with the Standard. However, the principles and specific practices may be applied to all buildings.

Operation & Maintenance (§ 8.1.2)

Section 8.1.2 specifies that the building be operated in accordance with the rest of the Standard. The bulk of *Standard 62.1* (§ 1 through § 7) discusses design and installation requirements. For instance, § 6.2.6.1, Variable Load Conditions, requires that systems be designed to be capable of providing the required ventilation rates in the breathing zone whenever the zones served by the system are occupied. Section 8.2.1 requires that this capability be maintained and used.

On the most basic level, this means that the system must be turned on and the outdoor air dampers opened when the zones are occupied. It also means that diffusers in an occupied space may not be closed and that system adjustments may not be made if these actions would reduce the airflow below the minimum determined in the other sections. Specific

66. "Preventive Maintenance and Building Operation Efficiency" *BOMA International* 2003, www.boma.org

Example 8-A—Milestone Dates

Q

Construction of a school was completed in August 2002, based on a permit applied for on March 15, 2001, and plans approved in July 1999. Nothing has been renovated since then. What does *Standard 62.1-2004* require for operation and maintenance?

A

Nothing. There are no requirements for operation and maintenance since the permit was applied for on March 15, 2001, which is prior to November 16, 2001, and no renovation has been done since then. Notice that three separate dates have been provided in the question: permit application, plan approval, and construction completion. For the purposes of this example, though it is not mentioned in the Standard, we assume that the authority having jurisdiction recognizes the significant date is the permit application date, which is typical for most jurisdictions. Check with the jurisdiction or other authority responsible for compliance with codes and standards for different applicability or adoption dates.

Even though there are no requirements, an operations and maintenance plan is a good idea for any building and the principles in § 8 can be applied on a voluntary basis.

Example 8-B—Reevaluation of Ventilation System, No Change in Use or Occupancy

Q

In July 2003, an entire office building was vacated in order to paint, reroof, as well as upgrade lobbies and elevators. After the work was completed, the building was reoccupied as office space with the same density. The conference room, enclosed offices, open plan offices, and all other spaces are in identical locations. Is a reevaluation of the ventilation system design required?

A

No. Since there has been no change in building use or occupancy category, the alterations are not considered significant enough to warrant a reevaluation. There is no change in occupant density nor any other changes inconsistent with design assumption. However, see § 7 for required protection of occupied areas.

procedures that exist are given in the O&M Manual. Section 8.1.2 does not require systems to be redesigned every time a minor repair or change to the building is made. Specific events that trigger partial or full redesign are discussed in the following section (§ 8.1.3).

Building Alterations or Change of Use (§ 8.1.3)

Section 8.1.3 requires that the entity operating the building have some knowledge of design assumptions. This is because ventilation system design, operation, and maintenance must be reevaluated if any of the following occurs:

- Change in building use;
- Change in occupancy category;
- Significant building alteration;
- Significant changes in occupant density;
- Other changes inconsistent with design assumptions.

Operations and Maintenance Manual (§ 8.2)

This section requires that an operations and maintenance manual be maintained at a centrally accessible location for the life of the ventilation system or components. The manual must contain the following as a minimum:

- Operation and maintenance procedures;
- Final design drawings;
- Current operation and maintenance schedules;
- Maintenance requirements and frequencies.

The O&M manual required by the Standard may be different from what is often called for in engineers' construction specifications as well as that which is often turned over by installing contractors.

This O&M manual is contained in the documentation that § 7.2.6 requires to be provided to the building owner or its designee. It is permitted to be in electronic form.

The O&M manual is required to be updated as necessary. Thus it is a living document, to be modified by the building operator as changes are made to physical features of the building and systems, operating procedures and schedules. Some of this modification will require skilled assistance by design engineers or specialty contractors, such as changes to system air distribution or to control system components.

The maintenance activities must include the thirteen specific items listed in Table 8-1, but may contain more. Table 8-1 gives default frequencies for seven of the thirteen activities, but these frequencies may be increased or decreased for a specific project and documented in the O&M manual.

The installer, engineer, or manufacturer may list tasks and frequencies in the O&M manual that is turned over to the building operator at system installation; but the operator is permitted to adjust these frequencies, so long as a record of this adjustment is kept in the current copy of the O&M manual.

Ventilation System Operation (§ 8.3)

Section 8.3 requires that the ventilation systems be operated in a manner consistent with the O&M manual. Thus, the operation procedures, schedules, and maintenance activities in the manual are requirements of the Standard for the particular building for which they were written.

Example 8-C—Reevaluation of Ventilation System, Change in Occupancy and Design Assumption

Q

In July 2004, walls were installed to carve a new 120 ft^2 (11 m^2) enclosed office out of a formerly open plan office area. The new office does not have a supply air diffuser. Another office area was converted to a conference room. The original building was constructed in November 2002. Is a reevaluation of the ventilation system design required?

A

Yes. Since both a change in occupancy category (the conference room) and a change inconsistent with design assumptions (the room with no supply diffuser) occurred, a reevaluation is required. This reevaluation will likely conclude that additional supply air must be provided to the conference room and supply air extended to the new enclosed office. The reevaluation may be confined to the areas that receive more or less air and need not extend to the entire building. If the conference room and new office comprise more than 25% of the floor area served by the system, then § 7.2.1 triggers the need for rebalancing in accordance with § 7.2.2. It is possible that the amount of minimum outdoor air may need to be increased in accordance with § 6.

Example 8-D—Reevaluation of Ventilation System, Change in Occupied Schedule

Q

The occupied schedule for an auditorium is lengthened in a school that was constructed in August 2001. Is a reevaluation of the ventilation system design required?

A

Yes. However, keep in mind that reevaluation does not necessarily mean redesign. For instance, the reevaluation might be limited to equipment schedules and may result in an earlier start time and later stop time for the auditorium's air handler.

In certain cases, skilled reevaluation will be required. For instance, in this example, skilled analysis of the time averaging may be required.

Example 8-E—Complete Recalculation

Q

An entire office building is remodeled with new partitions, new space uses, and different occupant densities. Is a complete recalculation of the ventilation air quantities required?

A

Yes. This recalculation may trigger the need for duct, outdoor air intake, and cooling capacity design changes. Or it may trigger a mere readjustment of the outdoor air damper. Alternatively, it may demonstrate that the old air distribution complies without any changes at all, for instance if the system is modular and occupant densities and categories decrease the requirements.

Example 8-F—Reevaluation of Ventilation System, Change in Seating Patterns

Q

Some tables in the large dining area of a restaurant were moved together to accommodate large parties. The numbers of seats in the private dining areas are continually changed, but the number never exceeds the original design assumption. Is a reevaluation of the ventilation system design required?

A

No, regardless of when the building was constructed. The Standard requires reevaluation of ventilation systems when significant changes in occupant density or other changes inconsistent with system design assumptions are made.

It is reasonable to conclude that slight relocations of the same number of occupants or a reduction in the density that was part of the design assumptions are not significant enough to warrant reevaluation.

Ventilation System Maintenance (§ 8.4)

Standard 62.1 gives tasks and frequencies for maintenance that impact indoor air quality. Thirteen specific ventilation system components, building features, and air quality impacts are covered by § 8.4. They are:

- Filters and air cleaning devices;
- Outdoor air dampers;
- Humidifiers;
- Dehumidification coils;
- Drain pans;
- Outdoor air intake louvers;
- Sensors;
- Outdoor airflow verification;
- Cooling towers;
- Equipment/component accessibility;
- Floor drains;
- Visible microbial contamination;
- Water intrusion.

These same items are summarized in Table 8-B (Table 8-1 in the Standard). The O&M manual is allowed to supersede those frequencies and activities detailed in the Standard. However, the latter would prevail in the absence of specific information in the O&M manual.

Individual Requirements (§ 8.4.1)

There are a number of individual elements of the ventilation system that are essential to the process of removing contaminants from the air, bringing in the correct amounts of outdoor air, distributing outdoor air, as well as controlling moisture and other sources of contaminants. Proper maintenance is the key to acceptable indoor air quality and is required for compliance with the Standard. The following list itemizes the individual maintenance requirements.

- *Filters and air cleaning devices* require periodic checks, renewal, and/or cleaning as well as other maintenance for them to perform the contaminant removal for which they are intended. This is true whether they are flat panel particulate filters, bag type particulate filters, electrostatic precipitators, or gas-phase air cleaners. All filters and air cleaning devices must be replaced or maintained as specified by the O&M manual.
- *Outdoor air dampers* must be inspected once every three months or else remotely monitored to verify that they are functioning in accordance with the O&M Manual. Outdoor air dampers are the manual and automatic means to adjust the amount of outdoor air that enters a mechanical ventilation system. Manual dampers are generally adjusted once at system start-up, as part of testing and balancing. Automatic dampers respond to signals from the control system. (See Figure 5-B.)

- *Humidifiers*, when they are installed, must be cleaned and maintained to limit fouling (deposition of solid material that may or may not be organic) and microbial growth. In addition, a regular inspection schedule should be set and adhered to (once every three months, or as specified in the O&M Manual). Humidifiers add moisture to the airstream. They are not required, since the Standard no longer includes a minimum humidity requirement. However, they are sometimes installed, especially in computer rooms, some hospitals, and in locations where a work process requires it. Humidifiers are known to be a potential source of biological contamination, but proper maintenance and cleaning can reduce this possibility.
- *Dehumidification coils* must be visually inspected on a regular basis, especially during the cooling season (once a year or as specified in the O&M Manual). In addition, they must be cleaned when fouling or microbial growth is observed. Dehumidification coils (most often serving the dual function of cooling coils) are intended to be wet, since they take water vapor from the air and condense it into free water (also called condensate). While the coils themselves are made of metal, organic solids collect on them, and conditions of moisture and temperature favorable to biological growth are likely to occur. Anti-microbial treatments for dehumidification coils exist, but are not required by the Standard. Please note that such treatments can introduce contaminants into the airstream at the same time that they reduce biological activity.
- *Drain pans* must be kept clean to prevent contamination of the air. Another important reason for keeping drain pans clean is so that the condensate pipe does not become clogged, causing an uncontrolled water overflow into the air handler and/or the occupied space. Water from the dehumidification coil and/or the drain pan will wet adjacent surfaces. Sometimes this is intended (such as on the metal support frame of the drain pan) and other times it is not (such as the sound lining downstream of the pan). Section 8.4.1.5 requires that such wetting be investigated, cleaned up as necessary, and the cause of any unintended wetting rectified. Rectification methods are not specified by the Standard, but they may include measures such as enlargement of the drain pan, reduction in air volume, installation of mist/moisture eliminator panels or smoothing of the velocity profile using air baffles. Drain pans collect the moisture that the dehumidification coils remove from the system airstream. The pan is generally connected to a condensate drain pipe that conducts the water, usually to a sewer system. Some packaged air conditioners conduct the water to the outdoor refrigerant condenser, where it evaporates into the outdoor air.
- *Outdoor air intake louvers* must have the ability to control moisture entry and be equipped with bird screens. Section 8.4.1.6 requires that they be visually inspected for cleanliness and integrity and that they be cleaned as needed, including the removal of visible debris or biological material. It also requires the repair of any physical damage to louvers, screens, or mist eliminators that impairs the ability to prevent contaminant entry. Outdoor air intake louvers are openings in the building wall that allow the introduction of outdoor air. Usually they have fixed position vanes, except for special products that serve the dual function of outdoor air damper (see previous bullet).
- *Sensors* whose primary function is dynamic minimum outdoor air control, such as flow stations at an air handler and those used for demand-controlled ventilation (CO_2 sensors, people counters) are required to have their accuracy verified. Recalibration is required for a sensor that fails the accuracy specified in the O&M manual.
- *Outdoor airflow verification* must be performed for all ventilation systems where the supply air quantity is 2000 cfm (1000 L/s) or greater. Many systems have so-called outdoor air economizers, which bring in excess outdoor air for free cooling when outdoor air temperatures are moderate enough to permit it. The verification should not be done in this excess outdoor air mode; instead it is required to be performed when the system is in minimum outdoor air mode. If the measured minimum outdoor airflow rate is less than that specified in the O&M manual (+/- 10% tolerance) then it must either be adjusted to the

specified rate, or evaluated to determine if the measured rate is in compliance with the Standard. This latter case may occur if the system was designed for more people than the occupied space now contains. Such reevaluation for multizone or other complex systems will likely require skilled analysis.

- *Cooling towers* must be treated to limit the growth of microbiological contaminants, including *Legionella sp.* Table 5-1 also requires certain separation distances from outdoor air intakes. Cooling towers are potential sources of biological contamination due to their operating temperature range, which is often around 100°F (38°C) and their location outdoors where ample biological material is available. Some biological growth, such as *Legionella sp.*, is infectious to people and death or serious harm can result.
- *Equipment/component accessibility* is required. Section 8.4.1.10 requires that the space provided for routine maintenance and inspection around ventilation equipment be kept clear. Section 5.14 requires that equipment be installed with sufficient working space. Without access, many of the tasks described in this bulleted list could not be completed.
- *Floor drains* located in air plenums or rooms that serve as plenums must be maintained to prevent the introduction of contaminants into the airstream. This could occur, for instance, if the floor drains are connected to sanitary sewer systems. Such a drain should have a P-trap, to prevent the entry of sewer gas by providing a water seal. However, if the trap is too shallow, the pressure in the air plenum can empty it. If the drain rarely conducts water, the trap may dry by evaporation. This problem can be addressed by the use of an automatic trap primer.

Microbial Contamination (§ 8.4.2)

Visible microbial contamination must be investigated and rectified. Such microbial contamination is usually associated with odors and occupant discomfort that may include physiological symptoms.

Water Intrusion (§ 8.4.3)

Any water intrusion must be investigated and rectified. Water is not supposed to intrude or accumulate in ventilation system components such as ducts, plenums, and air handlers. Should this occur, biological activity may develop, resulting in the contamination of the indoor environment. Water in dehumidification coils or drain pans (which are supposed to be wet) is not considered an intrusion. But a puddle found in the return section of an air handler (where water is not supposed to be) must be investigated and rectified. Fixing the leak or stopping the source of the water constitute means of rectification.

Table 8-A—Minimum Maintenance Activity and Frequency (Table 8-1 in the Standard)

ITEM	ACTIVITY	MINIMUM FREQUENCY
Filters and air cleaning devices	Maintain according to O&M Manual.	According to O&M Manual
Outdoor air dampers and actuators	Visually inspect or remotely monitor for proper function.	Every three months, or in accordance with O&M Manual
Humidifiers	Clean and maintain to limit fouling and microbial growth.	Every three months of use, or in accordance with O&M Manual
Dehumidification coils	Visually inspect for cleanliness and microbial growth, and clean when fouling is observed.	Regularly when it is likely that dehumidification occurs, but no less than once per year or as specified in the O&M Manual
Drain pans and other adjacent surfaces subject to wetting	Visually inspect for cleanliness and microbial growth, and clean when fouling is observed.	Once per year during cooling season or as specified in the O&M Manual
Outdoor air intake louvers, bird screens, mist eliminators, and adjacent areas	Visually inspect for cleanliness and integrity, and clean when necessary.	Every six months or as specified in the O&M Manual
Sensors used for dynamic minimum outdoor air control	Verify accuracy and recalibrate or replace as necessary.	Every six months or periodically in accordance with O&M Manual
Air handling systems except for units under 2000 cfm (1000 L/s)	Measure minimum quantity of outdoor air. If measured minimum airflow rates are less than 90% of the minimum outdoor air rate in the O&M Manual, they must be adjusted or modified to bring them above 90%, or must be evaluated to determine if the measured rates are in conformance with this Standard.	Once every five years
Cooling towers	Treat to limit the growth of microbiological contaminants.	In accordance with O&M Manual or treatment system provider
Floor drains located in plenums or rooms that serve as air plenums	Maintain to prevent transport of contaminants from the floor drain to the plenum.	Periodically according to the O&M Manual
Equipment/component accessibility	Keep the space provided around the ventilation equipment for routine maintenance and inspection clear.	
Visible microbial contamination	Investigate and rectify.	
Water intrusion or accumulation	Investigate and rectify.	

Example 8-G—Compliant Water Treatment Programs

Q

What are examples of a water treatment programs compliant with § 8.4.1.9?

A

Any treatment of the water to limit growth of microbiological contaminants is compliant.

Slug dosing at relatively high concentrations of broad-spectrum biocides at regular intervals is usually the preferred method for cooling towers.* "Broad-spectrum" means having the capability of controlling a wide range of conditions. The water treatment vendor recommends the concentration. It is common to use two broad-spectrum biocides in an alternating fashion so that each one is used once per week during the cooling season. In this way, an organism that is not susceptible to one of the biocides will be controlled by the other. It is possible to dose the cooling tower directly into its lower basin, using manual chemical handling procedures. To reduce handling by maintenance personnel, the dosage and timing can be automated using feed pumps.

There are tablet products intended for smaller cooling towers that can be inserted into the cooling tower once every few weeks. Ozone treatment programs are also available to limit microbial growth.

*Cooling Water Treatment Manual, *3rd ed., National Association of Corrosion Engineers, TPC Publication 1, (1990): 20.*

Example 8-H—Investigation and Rectification of Visible Microbial Growth

Q

What are examples of investigation and rectification of visible microbial contamination that is compliant with § 8.4.2?

A

Any response that includes both investigation and rectification is compliant.

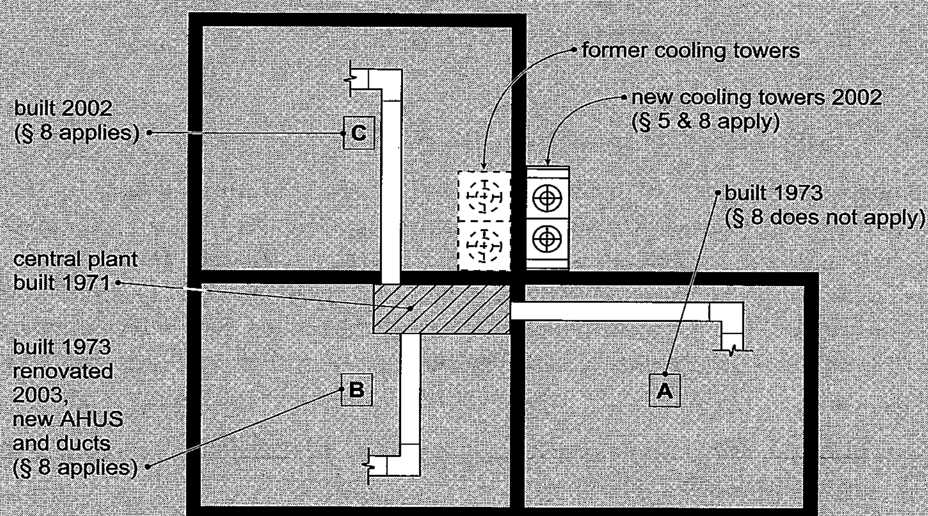
Examples of some responses include the following:

- Any of the procedures described in Section 7 "Mitigating IAQ Problems," Problems 5, 8, 9, and 15 of EPA's *Building Air Quality, A Guide for Building Owners and Facility Managers*, see http://www.epa.gov/iaq/largebldgs/baqtoc.html;
- Any of the techniques described in EPA's *Mold Remediation in Schools and Commercial Buildings*, see http://www.epa.gov/iaq/molds/mold_remediation.html; and

New York City's "Guidelines on Assessment and Remediation of Fungi in Indoor Environments," see http://www.ci.nyc.ny.us/html/doh/html/epi/moldrpt1.html.

Example 8-I—Wings Constructed in Different Years

Q



The Health and Life Sciences (HLS) building wings A and B of a State College were constructed in 1973. Wing C was constructed in 2002 and the wing B renovation, which took place in 2003 included new air handlers and new supply air distribution ducts. The 1971 central plant, located in wing B, serves all of the wings. Since wing C was built in the location of the old cooling towers, they were replaced in a new location adjacent to wing C at the time of its construction. The College uses the same maintenance schedule, plan storage system, and O&M procedures for all areas of all of its buildings. How does § 8 apply to the HLS building?

A

Section 8 of *Standard 62.1-2004* applies in full to wings B & C since they were constructed or renovated after November 16, 2001. Even though building alterations and change-of-use may occur in wing A, § 8 requirements do not apply. However, building codes and application of previous versions of *Standard 62.1* may have requirements that are beyond the scope of this Manual.

The O&M Manual (§ 8.2), operation procedures (§ 8.3), and maintenance procedures (§ 8.4) for wings B & C must be compliant, so if the college desires consistent procedures in all areas, it may voluntarily use these same compliant procedures for wing A. Strictly speaking, the Standard requires that visible microbial contamination be investigated and rectified only if it occurs in wings B & C, but for reasons of consistency and best practice, the College may also elect to comply in wing A.

Since the cooling tower is located in the newly constructed wing C and since its replacement in a new location amounts to a building component renovation, it must be installed with the clearances required in § 5 and must have water treatment compliant with § 8.4.1.9.

A. Appendix
CO_2-Based Demand Controlled Ventilation

Overview

This appendix describes how carbon dioxide (CO_2) concentration may be used to control the occupant component of the ventilation rate. The approaches described may be used to dynamically control ventilation in compliance with § 6.2.7.

CO_2 is a bioeffluent generated by people at a rate determined by their size, age, fitness, and activity level. At the same time people are generating CO_2, they are also producing odorous bioeffluents. These odorous bioeffluents are generated proportionally to the rate of CO_2 production, although diet and personal hygiene also play a role. Nevertheless, CO_2 concentration is a fairly dependable indicator of the concentration of the odorous bioeffluents that the occupant component of the breathing zone ventilation rate attempts to control. Hence, we can use CO_2 concentration to dynamically adjust the occupant component of the ventilation rate to reduce outdoor air intake rates when zones are not occupied at their design occupancy. This is commonly called CO_2-based demand-controlled ventilation (DCV). CO_2-based DCV should not be used where there are significant indoor sources of CO_2 other than people, such as direct-fired combustion devices, dry ice, compressed CO_2, etc., since it could result in excessive ventilation.

CO_2-based DCV is an energy conservation measure; its purpose is to reduce outdoor air rates and the energy required to condition the outdoor air when spaces are not occupied at design densities. While CO_2-based DCV can be used in all occupancy categories for which there is an occupant component to the ventilation rate required in Table 6-1, it is most cost effective in those occupancies that have a high design occupancy density but which are not occupied at that density consistently. Examples include ballrooms, conference/meeting rooms, and lecture halls.

Fundamentals

This section describes the science behind the CO_2 control strategies described later in this Chapter.

Figure A-A shows airflow rates and CO_2 concentrations for a single zone ventilation system.

The zone is assumed to be pressurized and thus exfiltrating the outdoor air supplied. The exfiltrated air is assumed to have a CO_2 concentration equal to the room air concentration since space leakage is likely to occur at windows and doors which are located within the breathing zone. Using a control volume around the room and balancing CO_2:

$$\dot{N} + V_{pz}C_s - (V_{pz} - V'_{ot})C_{RA} - V'_{ot}C_R = v\frac{\partial C_R}{\partial t} \quad \text{A-A}$$

where

V_{pz} is the primary supply flow rate to the zone,
V'_{ot} is the outdoor air rate at the air handler V'_{ot} is equal to the design outdoor air rate V_{ot} when the zone is at full occupancy),
v is the zone volume,
C_s is the concentration of CO_2 in the supply air,
C_R is the concentration of CO_2 in the room at breathing level,
C_{RA} is the concentration of CO_2 in the return air, and
$\dot{N}$ is the generation rate of CO_2 in the zone.

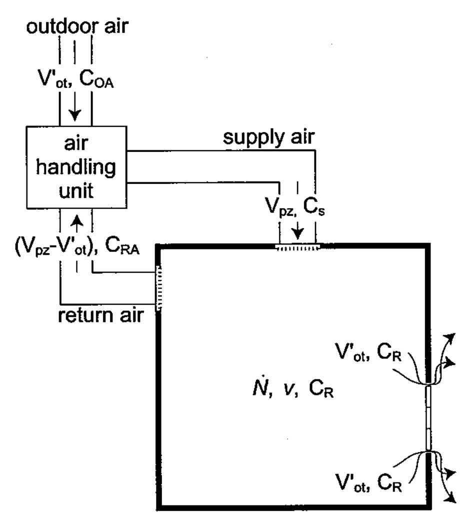


Figure A-A—Single Zone CO_2 Concentrations

Assuming steady-state (this assumption is justified subsequently), the equation simplifies to:

A-B

$$\dot{N} = V_{pz}(C_{RA} - C_s) + V'_{ot}(C_R - C_{RA})$$

At the air handler, mass balance equations yield:

A-C

$$V'_{ot}(C_{RA} - C_{OA}) = V_{pz}(C_{RA} - C_s)$$

Combining these two equations yields:

A-D

$$\dot{N} = V'_{ot}(C_R - C_{OA})$$

For single zone systems, the system outdoor air rate can be converted to the breathing zone outdoor air rate:

A-E

$$V_{ot} = V_{oz} = \frac{V_{bz}}{E_z}$$

The outdoor air rate in the breathing zone, V_{bz}, is calculated from Equation 6-B. V_{ot} in Equation A-E becomes V'_{ot} when the occupancy is at other than design conditions.

If people are the only sources of CO_2 in the zone, then the source strength of CO_2 is:

A-F

$$\dot{N} = k\,m\,P_z$$

where
k is the generation rate of CO_2, which averages about 0.0084 cfm/met/person over the general adult population,
m is the activity level of the people in the zone (in met), and
P_z is the number of people in the zone.

Chapter 8 of the ASHRAE *Handbook—Fundamentals*, contains typical met levels for a variety of activities. Some of these values are reproduced in Table A-A.

Table A-A—Typical Met Levels for Various Activities

ACTIVITY	MET
Seated, quiet	1.0
Reading and writing, seated	1.0
Typing	1.1
Filing, seated	1.2
Filing, standing	1.4
Walking, at 0.89 m/s	2.0
House cleaning	2.0–3.4
Exercise	3.0–4.0

Combining the last three equations and Equation 6-B, the outdoor air intake rate as a function of CO_2 concentration (V'_{ot}) can be determined as:

A-G

$$V'_{ot} = \frac{R_a A_z}{E_z - \dfrac{R_p (C_R - C_{OA})}{k\,m}}$$

With typical adult CO_2 generation rates and the units of concentration in parts per million, this equation can be written:

A-H

$$V'_{ot} = \frac{R_a A_z}{E_z - \dfrac{R_p (C_R - C_{OA})}{8400\,m}}$$

Equation A-H can be used to determine the CO_2 concentration that will occur in the breathing zone at design occupancy and minimum outdoor air rate under steady-state conditions:

A-I

$$V_{ot} = \frac{R_p P_z + R_a A_z}{E_z} = \frac{R_a A_z}{E_z - \dfrac{R_p (C_R - C_{OA})}{8400\,m}}$$

Table A-B—Steady State CO_2 Concentrations at 400 ppm Ambient

Occupancy Category	Activity level (met)	Steady State CO_2 Concentration (ppm)
Classrooms (age 9 plus)	1	1025
Restaurant dining rooms	1.4	1570
Conference/meeting	1	1755
Lobbies/prefunction	1.5	1725
Office space	1.2	990
Sales	1.5	1210

Solving for room CO_2 concentration we get:

$$C_R = C_{OA} + \frac{8400 E_z m}{R_p + R_a A_z / P_z} \qquad \text{A-J}$$

Table A-B shows steady-state CO_2 concentrations for several common occupancy types calculated using Equation A-J assuming default occupant density, estimates of activity levels, E_z equal to 1.0, and an ambient CO_2 concentration of 400 ppm.

For offices, the CO_2 concentration is about the same as what was recommended in previous versions of *Standard 62* (about 525 ppm above ambient or 925 ppm at 400 ppm ambient). Concentrations for the other occupancy types listed, which are all densely occupied zones, are significantly higher than prior recommendations. This is due to the less conservative "code intended" philosophy used to determined ventilation rates.

Steady-State Assumption

Both Equation A-H and Equation 6-B from which it was derived are based on an assumption of steady-state conditions. In the non-steady-state conditions typical of most real-world applications, CO_2 concentration will generally lag behind changes in the actual number of occupants in the zone and changes in ventilation airflow rates. However, using Equation A-H to control outdoor air rates is still valid because the rate of generation of CO_2 by occupants should be nearly proportional to the rate of bioeffluent generation; both are generated at a rate that is in proportion to the number of people and their activity level. It is bioeffluent (odor) concentration we are trying to control, and if the source strengths of CO_2 and bioeffluents are proportional, CO_2 concentration may be used as an indicator of bioeffluent concentration. Thus the steady-state assumption in Equation A-H is made not because the actual system is at steady-state but because the ventilation rate equation, Equation 6-B, is based on steady-state conditions. This steady-state relationship is simply being used to establish the relationship between CO_2 (odor) concentration and airflow setpoint in Equation A-H. Therefore, while the rate of air supplied using Equation A-H will not exactly track the source strength of bioeffluents due to transient effects, it should maintain an acceptable bioeffluent concentration. In practice, acceptable performance will also hinge on the ability of the control system to sense CO_2 concentrations and adjust ventilation rates according to the equation.

Dynamic Reset of Outdoor Air Intake

Constant Volume Systems with Airflow Measurement

For single zone systems with outdoor airflow measuring and control devices, Equation A-H can be used to dynamically reset outdoor air intake rate, V'_{ot}. The control system (e.g. a direct digital control system) would have to be capable of using Equation A-H to dynamically calculate the required outdoor air rate setpoint and then modulate dampers (or provide some other means) to adjust the outdoor air rate to the new setpoint.

The variables in Equation A-H can be determined as follows.

Zone Breathing Level Parameters (R_p, P_z, R_a, A_z)

Breathing level ventilation parameters are determined as described in Chapter 6's "VRP Summary," with one exception: the number of occupants (P_z) cannot be reduced using the time averaging technique described in the "Time Averaging (§ 6.2.6.2)" section of Chapter 6. This is necessary since the control system will reduce ventilation during off-peak occupancy conditions, rather than allowing the system to overventilate during these periods to make up for underventilating at peak conditions, as would be the case if average population were used to determine the breathing zone ventilation rate.

Zone Air Distribution Effectiveness (E_z)

E_z is determined from Table 6-2 and may be adjusted dynamically in some cases. For instance, if the system uses overhead supply and return, E_z could be 0.8 when the unit is heating, and 1.0 when the unit is cooling.

Activity Level

Activity level is estimated from Table A-A. The lower the estimate, the more conservative the resulting outdoor air rates will be.

Indoor Concentration

Indoor concentrations of CO_2 are measured with a CO_2 sensor located within the breathing zone of the zone (usually located adjacent to the zone thermostat). Typical sensors are of the infrared type with accuracies on the order of ±75 ppm. Many commonly used commercial sensors are factory calibrated and guaranteed not to require recalibration for as long as five years.

Outdoor CO_2 Concentration

Outdoor CO_2 concentration is commonly determined in one of two ways.

- *Conservatively assumed constant value typical of the area where the intake is located*: Outdoor air CO_2 concentration remains fairly constant unless the intake is located near roads where vehicle exhaust can raise levels during traffic conditions. But even where such spikes can occur, assuming a typical background (non-traffic affected) concentration (e.g. 400 ppm) will still be effective even if it results in somewhat higher outdoor air rates when spikes occur. Assuming a typical value is of course a very reliable approach since there are no sensors to get out of calibration.
- *Dynamic measurement using a CO_2 sensor located outdoors, typically a duct-mounted type located in the outdoor air intake plenum or duct*: While arguably the most accurate approach since it results in actual differential CO_2 concentration measurement, this approach can also be the least accurate and reliable due to sensor inaccuracy. For example, one sensor could read low while the other reads high, creating a doubly inaccurate differential reading. On the other hand, in areas where outdoor CO_2 concentration varies considerably (e.g. from 400 ppm to 600 ppm due to local automobile traffic), using an outdoor CO_2 sensor can improve energy savings even with sensor inaccuracy. The accuracy of differential CO_2 concentration measurement can be improved by using a single CO_2 sensor with a sampling pump, sequenced valves, and tubes piped to the zone and to the outdoors—but first costs will be higher.

Constant Volume Systems Without Airflow Measurement

In the previous application, DCV was implemented by solving Equation A-H dynamically for the outdoor air intake airflow setpoint and adjusting dampers to maintain this setpoint. This requires a sophisticated control system (such as a DDC system) to make the setpoint calculation and an airflow measuring device (such as a pitot array) to measure outdoor airflow, neither of which are commonly found on typical single zone HVAC systems such as packaged air conditioners. DCV could be implemented with prior versions of *Standard 62* using only a CO_2 sensor and controller in the zone and a standard outdoor air economizer (mixing damper) assembly. Unfortunately, there is no precise way to do this with the current Standard due to the addition of the occupant and building components in Equation 6-A, which complicates the mathematics, since the effective ventilation rate per person and the CO_2 concentration both vary with population. But a relatively simple approach to DCV is still possible, described as follows:

- *Step 1*: Calculate the required V_{ot} ($=V_{oz}$) at design occupancy using Equations 6-B and 6-C.
- *Step 2*: Use the same equations to calculate the outdoor air rate with no occupants (P_z=0). Call this value V_{at} (the area building based component adjusted for distribution effectiveness).
- *Step 3*: Use Equation A-J to determine the steady-state CO_2 concentration when the zone is fully occupied and at its design outdoor airflow rate, V_{ot}. See examples in Table A-B. Call this value CO_{2max}.
- *Step 4*: Provide a CO_2 sensor/controller that is adjusted to send a maximum output signal when the room CO_2 is at the CO_{2max} and a minimum output signal when the room CO_2 is at the ambient conditions (e.g. 400 ppm).
- *Step 5*: Adjust the outdoor air damper so that at the maximum controller output signal the system delivers design outdoor air rate V_{ot}. This is generally done by or in conjunction with the test & balance contractor.
- *Step 6*: Adjust the outdoor air damper so that at the minimum controller output signal the system delivers the building area outdoor air rate V_{at}. Again, this is generally done by or in conjunction with the test & balance contractor.

In this way, the minimum outdoor air intake rate varies from the building area rate (V_{at}) to the design rate (V_{ot}) as the CO_2 concentration varies from ambient to the steady-state maximum rate CO_{2max}. Note that this control adjusts the minimum outdoor air rate setpoint. The economizer controller can override DCV to provide additional outdoor air to reduce cooling energy usage when weather and load conditions are favorable.

The design for a packaged single zone AC unit is shown in Figure A-B. A CO_2 sensor provides an analog signal proportional to CO_2 concentration. It is wired to a signal converter (transducer) that scales the output and converts it to be compatible with the damper actuator. For instance, the damper actuator may operate using a variable resistance signal with a potentiometer to maintain a minimum damper position when the AC unit is on. The signal converter replaces the potentiometer—the CO_2 DCV controls will maintain minimum outdoor air rates instead. The signal converter is adjusted to send a resistance that provides V_{at} (as measured at the AC unit outdoor air intake by the test & balance contractor) when the CO_2 sensor output corresponds to ambient CO_2 concentration and to a resistance that provides V_{ot} when the CO_2 sensor output corresponds to CO_{2max}.

Multiple Zone Systems

There are several strategies that might be used for DCV in multiple zone recirculating systems such as VAV systems. Here is one option for single path and multiple path VAV systems:

- *Step 1*: Use Equations 6-1, 6-2, and 6-5 through 6-8, as appropriate, along with Table 6-3 or Appendix A (of the Standard) approach to determine the system minimum outdoor air rate V_{ot}.
- *Step 2*: Use the same equations as Step 1 to calculate the ventilation system outdoor air rate with no occupants (P_z=0) in any zone that has a CO_2 sensor (DCV zones). Call this ventilation rate $V_{ot\text{-}min}$. Zones without CO_2 sensors (non-DCV zones) are assumed to be occupied at the design population. System-wide diversity (D) can be accounted for but only among non-DCV zones, i.e., in Equation 6-7, P_s is the population served by the system assuming all

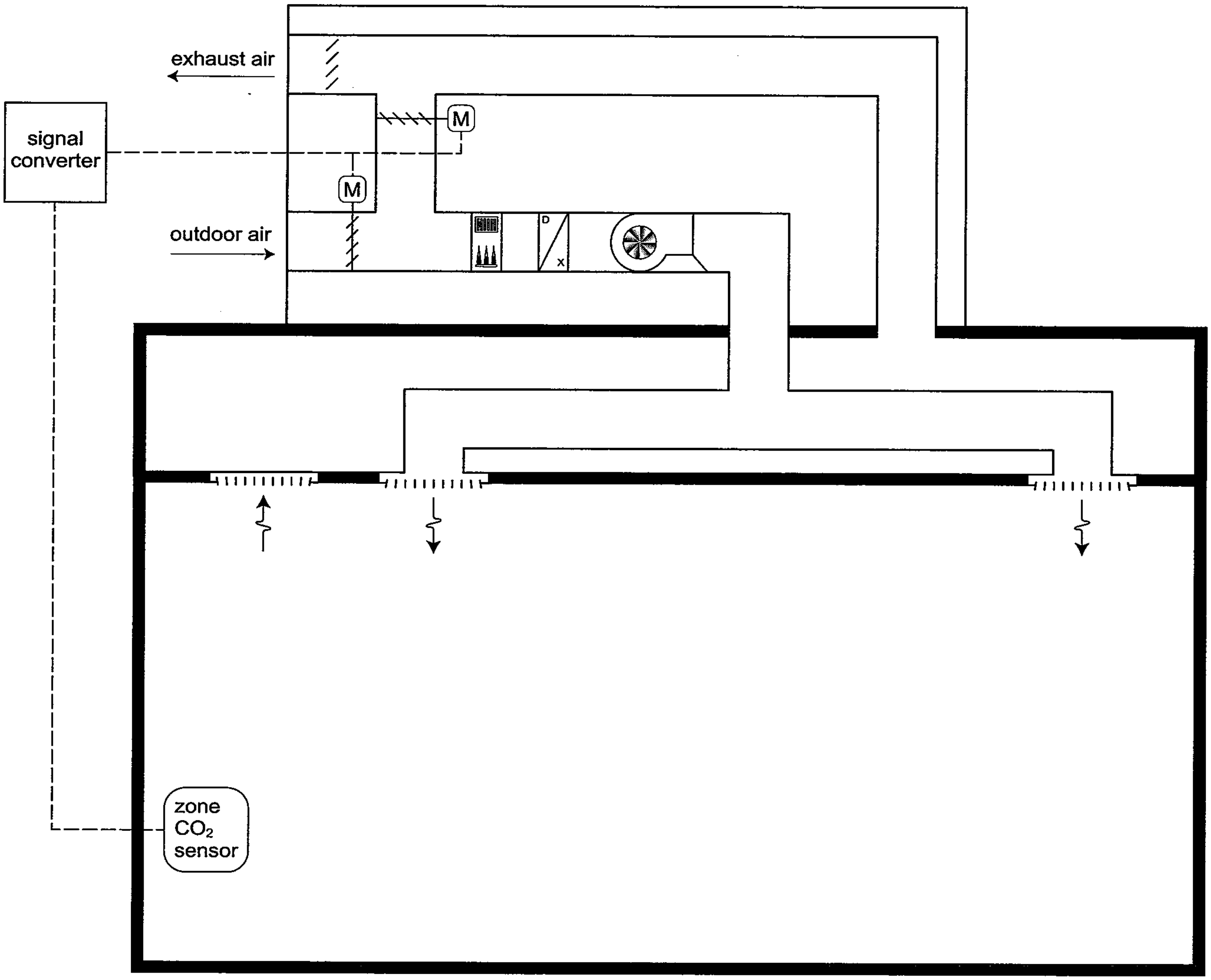


Figure A-B—CO_2 DCV For Packaged Air-Conditioning Unit

DCV zones are unoccupied, and the sum of zone populations (P_z) is taken only over non-DCV zones.

- *Step 3*: Use Equation A-J to determine the steady-state CO_2 concentration in each DCV zone when the zone is fully occupied and ventilated at its design outdoor airflow rate, V_{oz}. See examples in Table A-B. Call this value $C_{R\text{-}max}$.

- *Step 4*: Determine the minimum primary airflow setpoint for each DCV zone using either the Table 6.3 or Appendix A (of the Standard) calculation methods (description follows). Call this value $V_{pz\text{-}min}$. The minimum primary airflow rate is the lowest rate possible without causing the zone to increase the required system outdoor airflow rate above V_{ot}, as determined in Step 1.

For the Table 6.3 approach, the minimum airflow rate for each zone would be equal to the zone minimum airflow rate V_{oz} divided by the Max (Z_p) value used to select the system efficiency in Table 6.3 in Step 1.

For the Appendix A (of the Standard) approach using the 62MZCalc spreadsheet, either iterate or use Excel™'s "Goal Seek" function to find the lowest primary airflow rate to each zone that does not make the zone critical, i.e., the lowest rate possible while keeping system outdoor air rate and efficiency constant at the design rates determined in Step 1.

- *Step 5*: The ratio of actual measured zone CO_2 concentration C_R to the maximum concentration $C_{R\text{-}max}$ (both relative to ambient CO_2 concentration) is calculated by the control system dynamically. A digital control system will generally be required. For an assumed 400 ppm ambient concentration, the following equation is used:

A-K

$$\%CO_2 = \frac{C_R - 400}{C_{R-max} - 400}$$

- *Step 6*: The $\%CO_2$ value is used to reset the zone minimum primary airflow rate and system outdoor air rate as shown in Figures A-C and A-D. Figure A-C shows that $\%CO_2$ values from 0 to 50% are used to reset the zone minimum airflow rate V_{pz} from $V_{pz\text{-}min}$ to the zone maximum primary airflow rate (generally determined by the cooling load), V_{pzd}. Note that $V_{pz\text{-}min}$ may need to be higher than the minimum required for ventilation determined here due to other system limitations, such velocity sensor low limits and to prevent dumping in single path VAV systems.

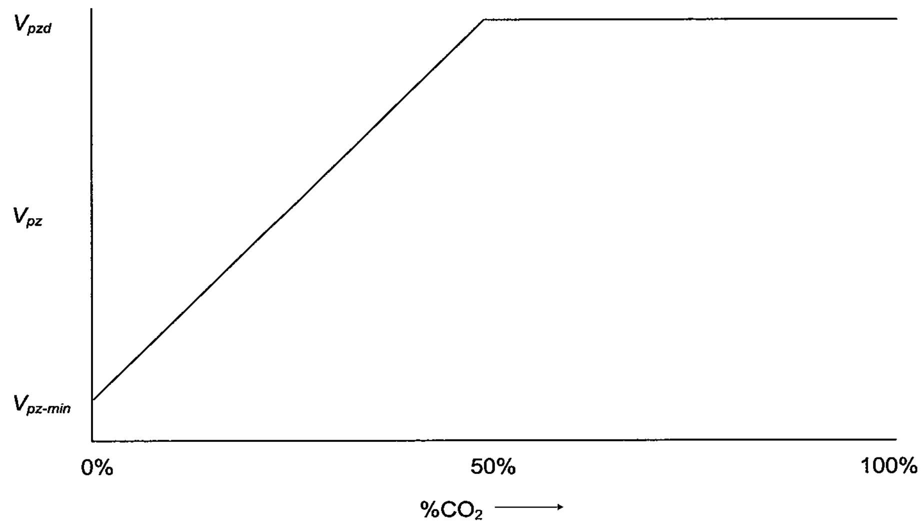


Figure A-C—Zone Minimum Primary Airflow Setpoint Reset From CO_2

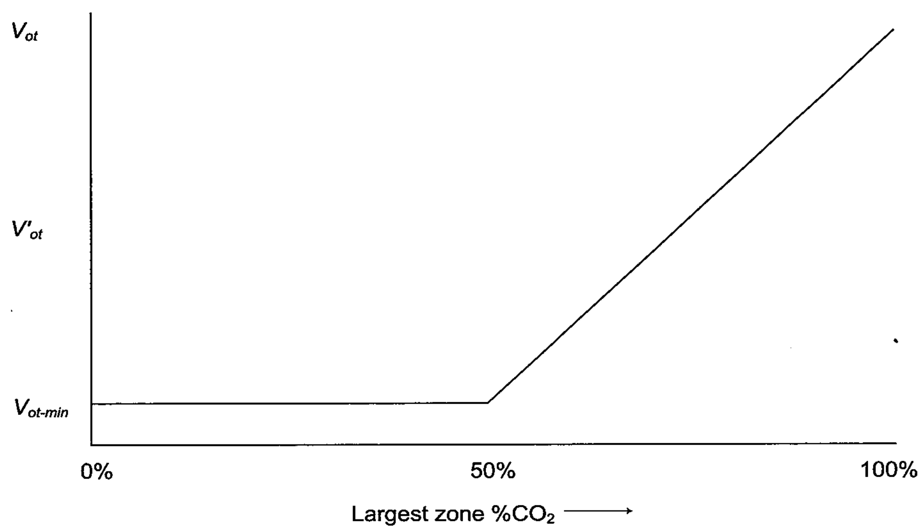


Figure A-D—Primary System Outdoor Air Setpoint Reset From CO_2

- *Step 7*: At the system level, the outdoor air rate V'_{ot} is reset from $V_{ot\text{-}min}$ to V_{ot} as the largest $\%CO_2$ value of all zones served by the system varies from 50% to 100%, as shown in Figure A-D. An outdoor air control system at the system level must adjust dampers, outdoor air fan speed, etc. to adjust the outdoor air rate to maintain the reset outdoor airflow setpoint V'_{ot}.

With this approach, when the zones served by the system are fully unoccupied and zone CO_2 concentrations are at ambient levels, the system will supply only the building area component of the ventilation rate and zone minimum airflow setpoints will be at their lowest values. As CO_2 concentration rises in any DCV zone, the minimum primary airflow in the zone rises until it reaches the maximum zone primary airflow rate. If the CO_2 concentration continues to rise, the outdoor airflow setpoint at the system is increased from the minimum building area component rate to the design outdoor airflow rate.

Note that raising the zone minimum airflow rate up to the zone maximum rate in this way will require that some form of reheat be used or zones will be overcooled. Reheat coil capacity must be sized for the zone maximum airflow rate, not the minimum airflow rate as is typically the case. But in most climates and energy rate structures, this added energy cost will be more than offset by the reduced air conditioning costs allowed by the lower outdoor air rates back at the air handling unit. This is particularly true when the air handler has an outdoor air economizer because the second half of the reset (50% to 100%) where the air handler minimum outdoor air intake is increased (see Figure A-D) will only occur when the economizer is disabled in either very cold or warm weather. Under these conditions, the energy cost increase to condition additional outdoor air will almost surely be greater than the added energy cost of additional zone reheat. Note also that ASHRAE *Standard 90.1* allows increasing zone reheat energy in this way if the overall energy usage is reduced.[67] Alternative, perhaps more sophisticated, control logic may be required for some system designs to optimize energy usage while still maintaining minimum outdoor air rates in all zones.

67. Exception (a), 5 of Section 6.5.2.1, ASHRAE *Standard 90.1-2004*

Example A-A—Occupancy Sensor DCV

Q

Occupancy sensors have been provided on a project to shut off lights when people are not present. Can they be used to control ventilation?

A

Yes. Section 5.4 and § 6.2.6.1 require ventilation to be provided only when zones are occupied. In this example, the lighting occupancy sensors could be interlocked with the controls for the VAV box serving the zone, allowing minimum airflow setpoints to be set to zero whenever the occupancy sensor indicates the zone is unoccupied. The air handler minimum outdoor air intake V_{ot} could also be reduced, but the increased complexity of adding this dynamic V_{ot} recalculation may not be justified by the energy cost savings.

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