Chapter 4

Ventilation and Indoor Air Quality

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Instructions

Read the material of Chapter 4. Re-read the parts of the chapter that are emphasized in the summary and learn highlighted definitions.

Objectives of Chapter 4

Chapter 4 deals with the reasons for ventilating buildings and how ventilation rates are chosen for specific situations. After studying the chapter, you should be able to:

List, and give examples of the four types of indoor air contaminants
Describe the three methods of maintaining indoor air quality
Understand the criteria for filter selection
Understand the main concepts of *ASHRAE Standard 62.1-2004* ventilation rate procedure and how it differs from *ASHRAE Standard 62.1-2001.*

4.1 Introduction

In Chapter 3, we covered two factors that affect comfort and activity: temperature and humidity. In this chapter, we will be discussing an additional factor: Indoor Air Quality (IAQ). The maintenance of indoor air quality

(IAQ) is one of the major objectives of air-conditioning systems because IAQ problems are a significant threat to health and productivity.

Those who study indoor air quality consider the makeup of indoor air, and how it affects the health, activities, and comfort of those who occupy the space. The primary factors that influence and degrade IAQ are particles, gases, and vapors in the air. Maintenance of good indoor air quality is a significant issue to both the HVAC design engineer and to those who maintain the system subsequent to its design and installation.

To deal properly with the issues of IAQ, it is important to be aware of

The various types of pollutants and contaminants, their sources, and their effects on health.

The factors that influence pollutant and contaminant levels in buildings
- The sources of pollutants.
- The ways pollutants can be absorbed and re-emitted into the building spaces.

Ways of maintaining good IAQ by
- Controlling the source of pollutants within the space.
- Using filters to prevent pollutants and contaminants from entering the space.
- Diluting the pollutants and contaminants within the space.

ASHRAE has two ANSI approved standards on ventilation:

ANSI/*ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality*[1] (Standard 62.1-2004) which deals with ventilation in "all indoor or enclosed spaces that people may occupy."

ASHRAE/ANSI Standard 62.2-2004, Ventilation and Acceptable Indoor Air Quality in Low Rise Residential Buildings[2] (Standard 62.2) which deals, in detail, with residential ventilation.

The scope of Standard 62.1-2004 deals with all indoor or enclosed spaces that people may occupy, including "Release of moisture in residential kitchens and bathrooms," while Standard 62.2 deals with "mechanical and natural ventilation systems and the building envelope intended to provide acceptable indoor air quality in low-rise residential buildings."

Like other ASHRAE standards, these are consensus documents, produced by a volunteer committee of people who are knowledgeable in the field. The standards have been publicly reviewed and are continuously re-assessed. They have force of law only when adopted by a regulatory agency, but are generally recognized as being the standard of minimum practice.

4.2 Air Pollutants and Contaminants

Air pollutants and contaminants are unwanted airborne constituents that may reduce the acceptability of air. The number and variety of contaminants in the air are enormous. Some contaminants are brought into the conditioned space from outside, and some are generated within the space itself. *Figure 4-1* lists some of the most common indoor air contaminants and their most common sources.

Contaminants	Major Source
Particles (particulates)	Dust (generated inside and outside), smoking, cooking
Allergens (a substance that can cause an allergic reaction)	Molds, pets, many other sources
Bacteria and Viruses	People, moisture, pets
Carbon Dioxide (CO_2)	Occupants breathing, combustion
Odoriferous chemicals	People, cooking, molds, chemicals, smoking
Volatile Organic Compounds (VOCs)	Construction materials, furnishings, cleaning products
Tobacco Smoke	Smoking
Carbon Monoxide (CO)	Incomplete and/or faulty combustion, smoking
Radon (Rn)	Radioactive decay of radium in the soil
Formaldehyde (HCHO)	Construction materials, furniture, smoking
Oxides of Nitrogen	Combustion, smoking
Sulfur Dioxide	Combustion
Ozone	Photocopiers, electrostatic air cleaners

Figure 4-1 Common Air Contaminants

4.3 Indoor Air Quality Effects on Health and Comfort

It is important to distinguish between the various contaminants in terms of their health effects. The HVAC designer and building operator may take different approaches to contaminants that can be detrimental to health and those that are merely annoying. Although it is the annoying aspects that will draw immediate attention from the occupants, it is the health-affecting contaminants that are of the utmost short and long-term importance. It is useful to think of contaminants in terms of the following classes of effect:

Fatal in the short-term
Carcinogenic (cancer causing substances)
Health threatening
Annoying, with an impact on productivity and sense of well-being.

Fatal in the Short-Term

At times, contaminants are found in buildings in concentrations that can cause death. These include airborne chemical substances, such as carbon monoxide, or disease-causing bacteria and other biological contaminants.

Carbon monoxide, a colorless and odorless gas, is produced during incomplete combustion. It is attributed as the cause of many deaths each year. One source of carbon monoxide is a malfunctioning combustion appliance, such as a furnace, water heater, or stove. Another possible source of carbon monoxide is the exhaust that results from operating a combustion engine or motor vehicle in an enclosed space.

Certain disease-causing bacteria can be present in the air in the building. These include contagious diseases, such as tuberculosis, exhaled by people who are infected with the disease. The tubercle bacillus is very small and tend to stay afloat in the air. Exposure can be minimized by isolating affected individuals, and by using special ventilation methods.

A third group of contaminants are disease-causing bacteria that are generated by physical activity or equipment. One, which is particularly dangerous for people with a weak immune system, is legionella. Legionella is the bacteria that causes Legionnaire's Disease. Legionella multiplies very rapidly in warm, impure water. If this water is then splashed or sprayed into the air, the legionella bacteria become airborne and can be inhaled into a person's lungs. Once in the lungs, the bacteria pass through the lung wall and into the body. The resultant flu-like disease is often fatal.

The source of a legionella outbreak can often be traced to a particular location, such as a cooling tower or a domestic hot water system. Where we know the source and the mechanism of transfer of disease to the individual, we call it a "building-related illness."

The pollutants that are fatal in the short-term are often unnoticeable except as a result of their health effects.

Carcinogens

Carcinogens are among the most significant contaminants because of their potential to cause cancer in the long-term. The risk of cancer increases with level and time of exposure to the substance. The exposure may be unnoticeable and not have any immediately apparent impact in the short-term. However, in the long-term, even low levels of exposure may lead to severe, irreversible health problems.

Environmental tobacco smoke (ETS) has been one of the major concerns in maintaining good indoor air quality. Concern has been heightened by increased evidence of its role in lung and heart disease. Most tobacco-related deaths occur among the smokers themselves, but tobacco smoke in the indoor air can also cause cancer in non-smokers. The smoke also causes physical irritation, annoyance, and dirt on all exposed surfaces.

Another carcinogen of concern in some places is the gas radon. Radon is a naturally occurring radioactive gas that results from the decay of radium in the soil. This radioactive gas leaks into buildings where it can be inhaled and potentially cause cancer. In places where radon is an issue, it can be controlled by venting the crawlspace, sealing all cracks, or by pressurizing the interior so as to minimize radon entry.

Health Threatening

Many indoor air contaminants (such as allergens, volatile organic compounds, bacteria, viruses, mold spores, ozone, and particulates) can be physically irritating or health threatening, although they are not usually fatal. Among the most common symptoms is the irritation of delicate tissues such as the eyes, skin, or mucous membranes. Many contaminants cause cold-like symptoms that are often mistaken as the effects of a viral infection.

In some buildings, a significant proportion of the occupants may experience symptoms. If the symptoms disappear when the occupants have left the building, one can surmise that something in the building is causing the symptoms. If 20% or more of the occupants experience the symptoms *only* when they are in the building, then they are considered to be suffering from "sick building syndrome."

Annoying, with an Impact on Productivity and Sense of Well-Being

Although not health threatening, many odoriferous chemicals are annoying and may be distracting enough to affect productivity without threatening health. These include body odors, some chemicals, the smells of spoiling food, and some molds that do not have more serious effects. In high enough concentrations, some contaminants have physical effects that are gradual and subtle enough not to be immediately noticed.

4.4 Controlling Indoor Air Quality

Maintaining acceptable IAQ depends on the judicious use of three methods:

1. Source control
2. Filtration
3. Dilution.

IAQ Control Method 1: Source Control

The most important method of maintaining acceptable indoor air quality is by controlling sources of contaminants and pollutants. Sources can be controlled by restricting their access to the space, either by design or by appropriate maintenance procedures, and by exhausting pollutants that are generated within the space. Avoiding the use of volatile solvents and banning smoking are two simple indoor examples.

Another example of source control is found in a new requirement in *Standard 62.1-2004* where it states that water for humidifiers "shall originate directly from a potable source or from a source with equal or better water quality." In the past, steam from the steam heating system was often used for humidification of buildings. This steam was frequently treated with anti-corrosion additives that would not be acceptable in potable water. Now, this steam is not an acceptable source for direct humidification.

When designing the air intake system, one should always deliberately reduce the likelihood of pollutants coming in from outside. Methods include locating intakes:

Away from the ground, where dust blows by
Away from loading docks, where there are higher concentrations of pollutants from vehicles
Away from outlets on the roof that vent things, such as toilets, furnaces, drains, and fume hoods.

One common source of indoor pollution is mold. The spores and dead particles of mold adversely affect many people. To prevent mold, keep the building fabric and contents reasonably dry. As a general rule, maintain the relative humidity below 60% to prevent mold growth. This is a challenge in a hot, humid climate with air-conditioned buildings where the outside air contains so much moisture. For example, a new prestigious hotel in Hawaii had to be closed within a year of opening, due to mold in over 400 bedrooms. Remedial costs will exceed $US10 million.

One source of mold, that is often neglected, is the drain pan beneath a cooling coil. The coil collects moisture and, being wet, some dirt out of the air. Ideally, this moisture and dirt drips down into the tray and drains away. Unfortunately, (and frequently), if the tray has a slope-to-drain ratio that is less than the required 10 mm per meter, a layer of sludge can form in the tray and grow mold. If the coil is not used for cooling for a while, the tray dries out and the crust of dried sludge can breakup and get carried through the system into the occupied spaces. Regular cleaning of the tray is required to minimize the problem.

If the pollution is from a specific source indoors, then direct exhaust can be used to control the pollutants. For example: the hood over a cooking range pulls fumes directly from the stove and exhausts them; exhausting the fumes from large photocopiers avoids contaminating the surrounding office space; and the laboratory fume cabinet draws chemical fumes directly to outside. When designing any direct exhaust system, one should attempt to collect the pollutant before it mixes with much room air. This reduces the required exhaust air volume and hence reduces the amount of conditioned air required to make up for the exhaust.

The design of exhaust systems for a large variety of situations is very clearly explained and accompanied with explanatory diagrams in *Industrial Ventilation*,[3] published by the American Conference of Governmental Industrial Hygienists.

IAQ Control Method 2: Filtration

Filtration is the removal of contaminants from the air. Both particulate (particles of all sizes) and gaseous contaminants can be removed, but since gaseous filtration is a rather specialized subject, we will not discuss it in this course.

Particulate filters work by having the particles trapped by, or adhere to, the filter medium. The actual performance of a filter depends on several factors, including particle size, air velocity through the filter medium, filter material and density, and dirt buildup on the filter. The main operating characteristics used to distinguish between filters are:

- Efficiency in removing dust particles of varying sizes
- Resistance to airflow
- Dust-holding capacity (weight per filter)

Choosing a filter is a matter of balancing requirements against initial purchase cost, operating cost, and effectiveness. In general, both the initial cost and the operating cost of the filter will be affected by the size of the particles that need to be filtered out, and the required efficiency of the filter: the smaller the particle size and the greater the efficiency required, the more expensive the filter costs.

Figure 4-2 shows a sample of particles and their range of size.

Information on filter performance is usually based on a standard. For the HVAC industry, ASHRAE has produced two standards. The first was *ASHRAE Standard 52.1-1992, Gravimetric and Dust Spot Procedures for Testing Air Cleaning*

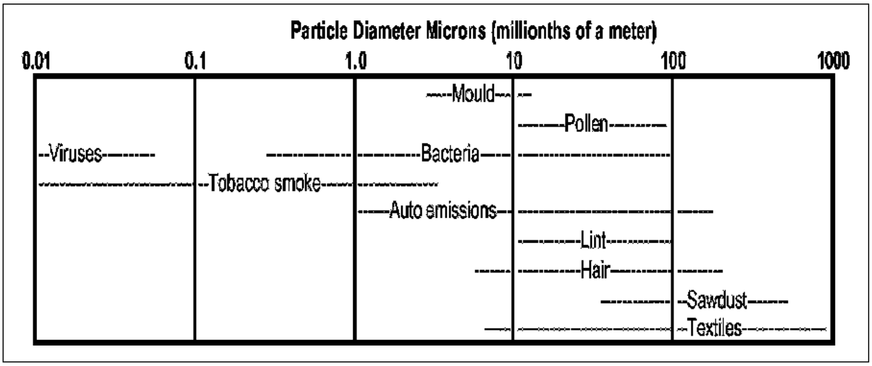

Figure 4-2 Particle Diameter, Microns (millionths of a meter)

Devices used in General Ventilation for Removing Particulate Matter[4] (Standard 52.1). Testing a filter to Standard 52.1 produces an "ASHRAE atmospheric dust spot efficiency" and an "ASHRAE arrestance." The "dust spot" efficiency is a measure of how well the filter removes the finer particles that cause staining, and the "arrestance" is a measure of the weight of dust that is collected before the resistance of the filter rises excessively. Unfortunately, the dust spot efficiency does not give much information about filter performance for different particle sizes and does not differentiate among less efficient filters.

As a result, a new standard was introduced, *ASHRAE Standard 52.2-1999, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size*.[5] It is based on using a particle counter to count the number of particles in twelve different size fractions. This data is used to classify a filter into one of 20 "Minimum Efficiency Reporting Values" called MERV. The least efficient filter is MERV 1, and the most efficient is MERV 20. *Figure 4-3* shows typical filters with their range of performance and typical applications.

There are numerous types of filters, made with a variety of filter media. The simplest, cheapest, and generally least effective, is the panel filter. The panel filter, commonly used in residential systems, is a pad of filter media across the air stream. The pad can be aluminum mesh, to provide a robust washable unit,

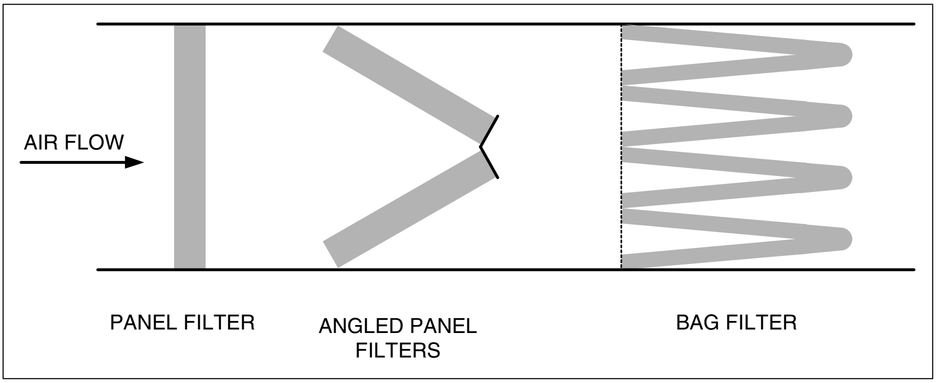

Figure 4-3 Basic Filter Media Filter Arrangements

typically having a MERV rating 1 to 3. The media may be a bonded fiberglass cloth with a MERV rating up to 4. There are many other constructions that are designed to satisfy the market at an affordable price.

The performance of the panel filter can be improved by mounting panel filters at an angle to the air stream to form an extended surface. For the same air velocity through the duct, the filter area is increased and the velocity through the media is decreased to improve performance.

The filtering performance and dust holding capacity can be further improved by pleating the media. Variations of pleated media filters cover the MERV range from 5 to 8.

To achieve a higher dust holding capacity, the media can be reinforced and formed into bags of up to approximately 1 meter deep. The bags are kept inflated by the flow of air through them during system operation.

These arrangements are shown in *Figure 4-3*.

Two of the factors that influence filter performance are the filter media and the air velocity through the media. Some filters have graded media with a coarse first layer to collect most of the large particles, and then one or more finer layers to catch progressively smaller particles. As a result of the grading, the final fine layer does not get quickly clogged with large particles. Pleated and bag filters extend the surface of the filter. This reduces the velocity of the air through the fabric and greatly increases the collection area for the particles, resulting in a much higher dust-holding capacity.

For ventilation systems, filters with a MERV above 8 are almost always provided with a pre-filter of MERV 4 or less to catch the large particles, lint and insects. It is more economical to remove the large particles with a course filter and prolong the life of the better filter.

Electronic filters can be used as an alternative to the media filters discussed above. In an electronic filter, the air passes through an array of wires. The wires are maintained at a high voltage, which generates an electrical charge on the dust particles. The air then passes on between a set of flat plates that alternate between high voltage and low voltage. The charged dust particles are attracted to the plates and adhere to them. These filters can be very efficient but they require cleaning very frequently to maintain their performance. Larger systems often include automatic wash systems to maintain the performance.

Filter characteristics

Let us return to the three main filter characteristics:

Efficiency in removing dust particles of varying sizes
Resistance to airflow
Dust-holding capacity.

Efficiency in removing dust particles of varying sizes is influenced by how clean the space is required to be, and whether any particular particles are an issue. One might choose a MERV 5 to 8 filter in an ordinary office building, but a MERV 11 to 13 filter in a prestige office complex. The higher MERV filters cost more to install and to operate but they reduce dirt in the building and so they save on cleaning and redecorating costs.

When it comes to medical facilities, MERV 14 to 16 filters will remove most bacteria and can be used for most patient spaces. For removal of all bacteria and viruses, a MERV 17, called a *HEPA filter,* is the standard filter. HEPA filters have an efficiency of 99.7% against 0.3 micron particles.

Standard 52.2 Minimum Efficiency Reporting Value (MERV)	Approximate Standard 52.1 Results		Application Guidelines		
	Dust Spot Efficiency	Arrestance	Typical Controlled Contaminant	Typical Applications and Limitations	Typical Air Cleaner/Filter Type
20	n/a	n/a	**Larger than 0.3 μm particles** Virus All combustion smoke Sea salt Radon progeny	Cleanrooms Pharmaceutical manufacturing Orthopedic surgery	HEPA/ULPA filters ranging from 99.97% efficiency on 0.3 mm particles to 99.999% efficiency on 0.1–0.2 mm particles
19	n/a	n/a			
18	n/a	n/a			
17	n/a	n/a			
16	n\a	n/a	**0.3–1.0 μm Particle size, and all over 1 μm** All bacteria Most tobacco smoke Sneeze nuclei	Hospital inpatient care General surgery Superior commercial buildings	**Bag filters** Nonsupported (flexible) microfine fiberglass or synthetic media 305 to 914 mm deep, 6 to 12 pockets **Box filters** Rigid style cartridge filters 152 to 305 mm deep may use lofted (air laid) or paper (wet laid) media
15	>95%	n/a			
14	90–95%	>98%			
13	80–90%	>98%			
12	70–75%	>95%	**1.0–3.0 μm Particle size, and all over 3.0 μm** Legionella Auto emissions Welding fumes	Hospital laboratories Better commercial buildings Superior residential	
11	60–65%	>95%			
10	50–55%	>95%			
9	40–45%	>90%			
8	30–35%	>90%	**3.0–10.0 μm Particle size, and all over 10 μm** Mold Spores Cement dust	Commercial buildings Better residential Industrial workplaces	**Pleated filters** Disposable extended surface, 25 to 127 mm thick with cotton-polyester blend media, cardboard frame **Cartridge filters** Graded density viscous coated cube or pocket filters, synthetic media **Throwaway** Disposable synthetic media panel filters
7	25–30%	>90%			
6	<20%	85–90%			
5	<20%	80–85%			
4	<20%	75–80%	**>10.0 μm Particle size.** Pollen Dust mites Sanding dust Textile fibers	Minimum filtration Residential Window air conditioners	**Throwaway** Disposable fiberglass or synthetic panel filters **Washable** Aluminum mesh, latex coated animal hair, or foam rubber panels **Electrostatic** Self charging (passive) woven polycarbonate panel filter
3	<20%	70–75%			
2	<20%	65–70%			
1	<20%	<65%			

Figure 4-4 Filter Test Performance and Applications (extracted from ASHRAE *Standard 52.2-1999*, p. 39)

Resistance to airflow directly affects the fan horsepower required to drive the air through the filter. Many less expensive, pre-packaged systems do not have fans that are capable of developing the pressure to drive air through the dense filter material of the higher MERV rated filters. Typically, most domestic systems will handle the pressure drop of a MERV 5 or 6 filter, but not higher.

Dust-holding capacity influences the filter life between replacements. A pleated filter with MERV 7 or 8 may be all that is required, but a bag filter with MERV 9 or 10 can have a much higher dust holding capacity. The bag filter could, therefore, be a better choice in a very dirty environment or where there is a high cost to shut down the system and change the filters.

IAQ Control Method 3: Dilution

In most places the outside air is relatively free of pollutants, other than large dust particles, birds, and insects. When this air is brought into a space, through a screen and filter to remove the coarse contaminants, it can be used to dilute any contaminants in the space. We also need a small supply of outside air to provide us with oxygen to breathe and to dilute the carbon dioxide we exhale.

Dilution ventilation is the standard method of controlling general pollutants in buildings and the methods and quantities required are detailed in *Standard 62.1-2004*, which is the subject of the next section.

4.5 ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality

ANSI/ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality[1] was published in 1971, 1981, and again fully revised in 1989. The complete revisions made it easy to reference in Building Codes. Designers could refer to the edition stipulated, and there was no question about the reference. The policy was changed for this standard in 1997, to align with the ANSI "continuous maintenance" process. Under continuous maintenance, the Standard is updated a bit at a time and is not required to be a consistent, whole document. The information in this section is based on the 2004 printed edition.

Standard 62.1-2004 applies to "all indoor or enclosed spaces that people may occupy" with the provision that additional requirements may be necessary for laboratory, industrial, and other spaces. As noted at the beginning of this chapter in the introduction, residential ventilation is specifically covered in *ASHRAE Standard 62.2-2004, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings*. You should also note that many local authorities have more demanding and specific requirements for residential ventilation than the ASHRAE standards. For industrial occupancies, refer to *Industrial Ventilation*, published by the American Conference of Governmental Industrial Hygienists.

The first section of *Standard 62.1-2004* states

> "The purpose of this standard is to specify minimum ventilation rates and indoor air quality that will be acceptable to human occupants and are intended to minimize the potential for adverse health effects."

Note that this is a minimum standard, that it is aimed at providing "acceptable indoor air quality" which is defined as:

> "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 Standard defines two types of requirements to maintain indoor air quality: requirements to limit contamination; and requirements to provide ventilation to dilute and remove contaminants. The requirements to limit contamination also include several system and building design requirements to minimize moisture problems that typically lead to mold problems including:

Requirements for filtering
Separation distance between outside air inlets and contaminated exhausts
Rules about recirculation of air between zones that have different contamination levels

Requirements for maintenance and operation
Requirements for design and maintenance documentation.

Standard 62.1-2004 requires that "Air from smoking areas shall not be recirculated or transferred to no-smoking areas." Also smoking areas "shall have more ventilation and/or air cleaning than comparable no-smoking areas." However no specific recommendations are included for smoking areas.

There are two approaches to providing ventilation for the occupants to breathe and to dilute the inevitable pollutants:

i. "The *Indoor Air Quality Procedure*" Acceptable air quality is achieved within the space by controlling known and specifiable contaminants to acceptable limits. The application of the Indoor Air Quality Procedure allows the use of particulate and gaseous filters to assist in maintaining acceptable indoor air quality. The complexity of the procedure is beyond this course and will not be discussed.
ii. "The *Ventilation Rate Procedure*" Acceptable air quality is achieved by providing ventilation air of the specified quality and quantity.

The *Ventilation Rate Procedure* is based on providing an adequate supply of acceptable outdoor air to dilute and remove contaminants in the space to provide acceptable IAQ. Acceptable outdoor air must have pollution levels within national standards.

The basic required outside air for ventilation is based on a rate, L/s, per person, plus a rate per square meter, $\mathrm{L/s \cdot m^2}$. This basic requirement is then adjusted to allow for the ventilation effectiveness in each space and the effectiveness of the system. Let us briefly go through those steps. An excerpt of the base ventilation data from Table 6-1 in *Standard 62.1-2004* is shown in *Figure 4-5*.

Look at the first occupancy category, the hotel bedroom. The requirement here is for 2.5 L/s· person per person and $0.3\,\mathrm{L/s \cdot m^2}$. Based on the default occupancy density of 10 persons per $100\,\mathrm{m^2}$ the combined outdoor rate per $100\,\mathrm{m^2}$ is

$$10\ \text{people} \cdot 2.5\,\mathrm{L/s} \cdot \text{person} + 100\,\mathrm{m^2} \cdot 0.3\,\mathrm{L/s \cdot m^2} = 25\,\mathrm{L/s} + 30\,\mathrm{L/s} = 55\,\mathrm{L/s}$$

The default combined outdoor air rate is thus 55 L/s for 10 people occupying $100\,\mathrm{m^2}$. Divided by the default population of 10 persons we get 5.5 L/s for the base requirement per person.

Now look at the last hotel category, multi-purpose assembly. The rate per person, 2.5 L/s, and rate per $\mathrm{m^2}$, 0.3 L/s, are the same. What is different is the default occupancy density of 120 persons/$100\,\mathrm{m^2}$. With the much higher occupancy density the ventilation for the space is much less significant and therefore the combined outdoor air rate per person is halved to 2.75 L/s, shown rounded up to 2.8 L/s in the table.

These default outdoor air rates must then be adjusted to allow for the proportion of ventilation air that actually circulates through the breathing zone. If we suppose that only 90% of the outdoor air enters the breathing zone, and the other 10% circulates above the breathing zone and is exhausted, then only the 90% of outside air is being used effectively. Therefore, the proportion of air that actually circulates into the breathing zone is called **zone air distribution effectiveness**. In the example, the zone air distribution effectiveness would be

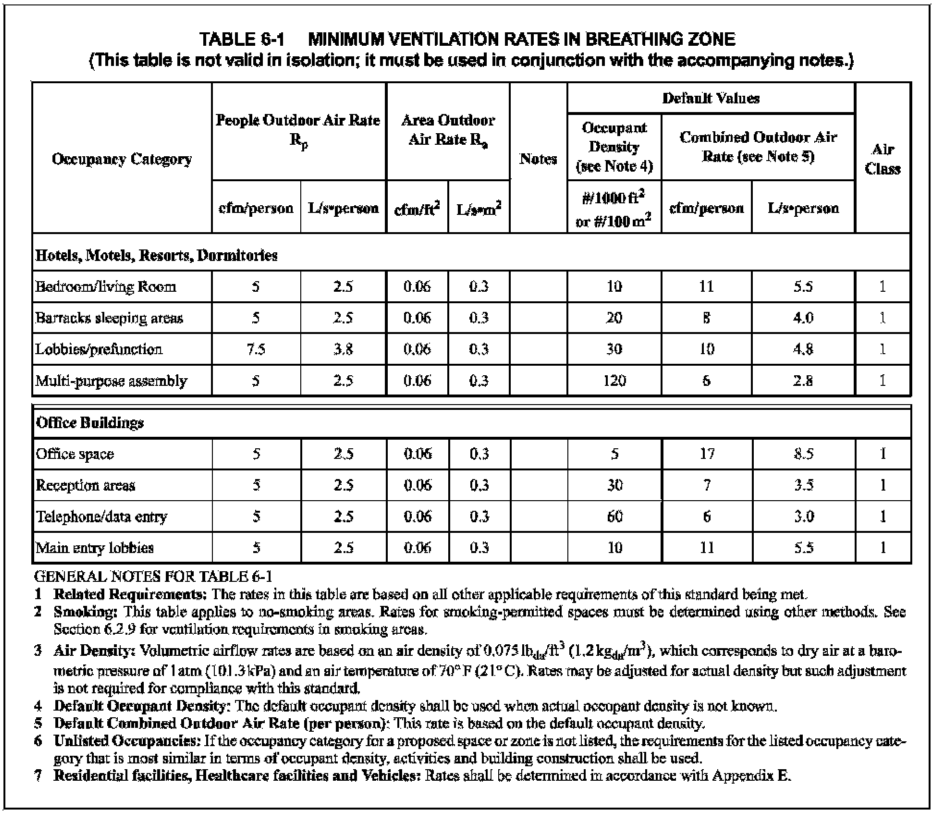

TABLE 6-1 MINIMUM VENTILATION RATES IN BREATHING ZONE
(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate R_p		Area Outdoor Air Rate R_a		Notes	Default Values			Air Class
						Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
	cfm/person	L/s•person	cfm/ft^2	L/s•m^2		#/1000 ft^2 or #/100 m^2	cfm/person	L/s•person	
Hotels, Motels, Resorts, Dormitories									
Bedroom/living Room	5	2.5	0.06	0.3		10	11	5.5	1
Barracks sleeping areas	5	2.5	0.06	0.3		20	8	4.0	1
Lobbies/prefunction	7.5	3.8	0.06	0.3		30	10	4.8	1
Multi-purpose assembly	5	2.5	0.06	0.3		120	6	2.8	1
Office Buildings									
Office space	5	2.5	0.06	0.3		5	17	8.5	1
Reception areas	5	2.5	0.06	0.3		30	7	3.5	1
Telephone/data entry	5	2.5	0.06	0.3		60	6	3.0	1
Main entry lobbies	5	2.5	0.06	0.3		10	11	5.5	1

GENERAL NOTES FOR TABLE 6-1

1 **Related Requirements:** The rates in this table are based on all other applicable requirements of this standard being met.
2 **Smoking:** This table applies to no-smoking areas. Rates for smoking-permitted spaces must be determined using other methods. See Section 6.2.9 for ventilation requirements in smoking areas.
3 **Air Density:** Volumetric airflow rates are based on an air density of 0.075 lb_{da}/ft^3 (1.2 kg_{da}/m^3), which corresponds to dry air at a barometric pressure of 1 atm (101.3 kPa) and an air temperature of 70° F (21° C). Rates may be adjusted for actual density but such adjustment is not required for compliance with this standard.
4 **Default Occupant Density:** The default occupant density shall be used when actual occupant density is not known.
5 **Default Combined Outdoor Air Rate (per person):** This rate is based on the default occupant density.
6 **Unlisted Occupancies:** If the occupancy category for a proposed space or zone is not listed, the requirements for the listed occupancy category that is most similar in terms of occupant density, activities and building construction shall be used.
7 **Residential facilities, Healthcare facilities and Vehicles:** Rates shall be determined in accordance with Appendix E.

Figure 4-5 Parts of Table 6-1, *ASHRAE Standard 62.1-2004*

0.9. The **breathing zone** is defined as between 75 and 1800 mm from the floor and 600 mm from walls or air-conditioning equipment.

Let us consider a space with the ventilation air being provided from a ceiling outlet. *Standard 62.1-2004* gives the zone air distribution effectiveness for cool air supplied at ceiling level as "1." To obtain the corrected ventilation rate, we divide the base rate by the zone air distribution effectiveness. In this case, default outdoor air rate divided by a zone air distribution effectiveness of "1" means the default rate is unchanged.

Now let us suppose that the same system is used for heating in the winter. In this example, the maximum design supply temperature is 35 °C and space design temperature is 22 °C. The supply air temperature is

$$35\,°\mathrm{C} - 22\,°\mathrm{C} = 13\,°\mathrm{C}$$

above the temperature of the space. According to *Standard 62.1-2004*, "For warm air over 8 °C above space temperature supplied at ceiling level and ceiling return, the zone air distribution effectiveness is 0.8." In this example, with the default rate divided by 0.8, we obtain the corrected required ventilation, $1/0.8 = 1.25$. This means that the outside air requirement has increased by 25%, compared to the cooling-only situation. If this system runs all year, then the ventilation should be designed for the higher winter requirement.

Thus far, we have used the Standard's Table 6-1 (see *Figure 4-5*) rates to obtain base ventilation rates and then corrected those to recognize zone air distribution effectiveness within the space. Now we must consider the effectiveness of the system.

If the system supplies just one zone or 100% outside air to several zones, the calculated rate is used. However, if the system serves multiple zones with a mixture of outside air and recirculated return air, we may have to make a system adjustment to allow for differing proportions of outside air going to different zones.

For example, an office building might require 15% outside air to the offices, but 25% to the one conference room. If the system provides only 15%, then the conference room will be under-ventilated. However, 25% for the conference room will provide much more than the required ventilation to the rest of the offices. *Standard 62.1-2004* includes a simple calculation to obtain a rate between 15% and 25% that provides adequate outside air for all the zones.

Further adjustments can be made to allow for variable occupancy and for short interruptions in system operation. Just one example of this type of adjustment can occur in churches with high ceilings. If the services are of limited duration, say under an hour and a half, and the volume of the zone is large per person, then the outside air ventilation rate can be based on an average population over a calculated period. This may substantially reduce the required flow of outside air.

This discussion has all been based on *Standard 62.1-2004*. In many jurisdictions, earlier versions of the standard will remain the legal requirement for many years. If this is the case in your jurisdiction, it is important to know that previous versions of the Standard generally calculated the required ventilation based on L/s-per-person and took no separate account of the size of the zone. The simpler requirement facilitated a simple method of adjusting ventilation rates to meet actual occupancy needs in densely occupied spaces. The following section describes how carbon dioxide can be used to determine ventilation requirements in these situations.

The Use of Carbon Dioxide to Control Ventilation Rate

All versions of the Standard allow for reduced ventilation when the population density is known to be lower. For example, the ventilation for a movie theatre must be sized for full occupancy, although the theatre may often be less than half-full. In these "less-than-full" times it would save energy if we could reduce the ventilation rate to match the actual population. In the versions of *Standard 62* that preceded 2004, the ventilation rates were based on L/s per person. As a result, the ventilation could be adjusted based on the number of people present.

Conveniently for the purposes of measurement, people inhale air that contains oxygen and exhale a little less oxygen and some carbon dioxide. The amount of carbon dioxide, CO_2, that is exhaled is proportional to a person's activity: more CO_2 is exhaled the more active the person. This exhaled CO_2 can be measured and used to assess the number of people present.

In our movie theatre, the people (assume adults) are all seated and the metabolic rate is about 1.2 met. At 1.2 met, the average CO_2 exhaled by adults is 0.0052 L/s. At the same time as the people are exhaling CO_2, the ventilation air is bringing in outside air with a low level of CO_2, as indicated in *Figure 4-6*.

Figure 4-6 Addition of Carbon Dioxide in an Occupied Space

This process can be expressed in the formula:

$$VC_{space} = N + VC_{outside} \tag{4-1}$$

where V = volume of outside air, L/s, entering the space
$C_{outside}$ = concentration, m^3/m^3, of CO_2 in outside air
N = volume of CO_2 produced by a person, L/m
C_{space} = concentration, m^3/m^3, of CO_2 in exhaust air

For the movie theatre example (the same as the hotel assembly-room) the required ventilation rate is 7.5 L/s per person. Inserting the values for V and N produces:

$$
\begin{aligned}
&VC_{space} = N + VC_{outside}\\
&7.5\,\mathrm{L/s} \cdot C_{space} = 0.0052\,\mathrm{L/s} + 7.5\,\mathrm{L/s} \cdot C_{outside}\\
&7.5\,\mathrm{L/s} \cdot C_{space} - 7.5\,\mathrm{L/s} \cdot C_{outside} = 0.0052\,\mathrm{L/s}\\
&(7.5\,\mathrm{L/s} \cdot C_{space} - 7.5\,\mathrm{L/s} \cdot C_{outside})/7.5\,\mathrm{L/s} = 0.0052\,\mathrm{L/s}/7.5\,\mathrm{L/s}\\
&C_{outside} - C_{space} = 0.0052/7.5\ (m^3/m^3)\\
&C_{outside} - C_{space} = 0.000693\ (m^3/m^3)
\end{aligned}
$$

This is about 700 parts per million of CO_2 in the exhaust air.

Note that this calculation is based on the ventilation for one person and the CO_2 produced by one person. The result is the same, regardless of how many people are in the space, since everything is proportional.

The outside CO_2 is typically in the range of 350 to 400 parts per million, ppm, so the incoming CO_2 level is raised by the CO_2 from the occupants:

$$350 + 700 = 1050\,\mathrm{ppm}.$$

In polluted cities, the CO_2 level might be much higher at, say, 650 ppm, in which case the inside level will be

$$650 + 700 = 1350\,\mathrm{ppm}$$

for the same ventilation rate.

In our theatre, we can install a CO_2 sensor to measure the CO_2 level, and connect it to a controller to open the outside air dampers to maintain the CO_2 level at no higher than 1000 ppm. In this way the outside air provided matches the requirements of the people present. If the outside CO_2 concentration is above 300 ppm, then our controller, set at 1000 ppm, will cause over-ventilation rather than under-ventilation.

In this process CO_2 is used as a **surrogate** indicator for the number of people present.

The use of CO_2 control works really well in a densely populated space served by a dedicated system. It works poorly in a building with a very variable and low population.

This calculation assumes a perfect world. As we all know, this is a false assumption. The main assumptions are:

Perfect mixing. Mixing is usually quite good but some ventilation air may not reach the occupied space.

Steady state. It will take from 15 minutes to several hours for the CO_2 concentration to become really steady. The length of time depends on the volume of space per person. In densely populated spaces, steady state can be reached quite quickly, but in low population density areas, it can take hours.

An even distribution of people in the space. If people are clumped together then the level will be higher in their area and lower in the less densely occupied parts of the space.

This simple use of carbon dioxide as a surrogate cannot be used under the requirements of *Standard 62.1-2004*, due to the $L/s \cdot m^2$ ventilation requirement for the space. More sophisticated methods are possible for use under the requirements of *Standard 62.1-2004*, but they are beyond the scope of this course.

The Next Step

Having introduced the ideas of air-conditioning zones in Chapter 2, thermal comfort in Chapter 3, and indoor air quality and ventilation rates in this chapter, we will go on in Chapter 5 to consider why air conditioning zones are required, how to choose zones, and how they can be controlled.

Summary

Chapter 4 deals with the reasons for ventilating buildings, how ventilation rates are chosen for specific situations, and the how to determine and maintain good indoor air quality, IAQ.

4.1 Introduction

The maintenance of good indoor air quality (IAQ) is one of the major objectives of air-conditioning systems, because IAQ problems are a significant threat to health and productivity. The primary factors that influence and degrade IAQ are particles, gases, and vapors in the air.

4.2 Air Pollutants and Contaminants

Air pollutants and contaminants are unwanted airborne constituents that may reduce the acceptability of air. Some contaminants are brought into the conditioned space from outside, and some are generated within the space itself.

4.3 Indoor Air Quality Effects on Health and Comfort

Contaminants can be classified based on their effects: fatal in the short-term, carcinogenic (cancer causing substances), health threatening, and annoying, with an impact on productivity and sense of well-being.

4.4 Controlling Indoor Air Quality

Maintaining acceptable IAQ depends on the judicious use of three methods: source control, filtration, and dilution. This section also included a more detailed discussion on source control, and on filtration.

4.5 ASHRAE *Standard 62, Ventilation for Acceptable Indoor Air Quality*

ANSI/ASHRAE Standard 62, Ventilation for Acceptable Indoor Air Quality[1] was published in 1971, 1981, and again fully revised in 1989. The complete revisions made it easy to reference in Building Codes. In many jurisdictions, earlier versions of the standard will remain the legal requirement for many years.

Since 1997, to align with the ANSI "continuous maintenance" process, the Standard is updated a bit at a time and is not required to be a consistent, whole document. Standard 62.1-2004 applies to "all indoor or enclosed spaces that people may occupy" with the provision that additional requirements may be necessary for laboratory, industrial, and other spaces.

We introduced the idea of the ventilation rate procedure, and the formula

$$\mathrm{VC}_{\mathrm{space}} = \mathrm{N} + \mathrm{VC}_{\mathrm{outside}}$$

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