RP-1663

Residential INDOOR AIR QUALITY Guide

Best Practices for Home Design, Construction, Operation, and Maintenance





Expert Guidance on Indoor Air Quality in Single-Family and Multifamily Housing for

- Designers
- Builders
- Property Managers
- Homeowners, Buyers, and Renters

Residential Indoor Air Quality Guide

Best Practices for Home Design, Construction, Operation, and Maintenance

This is an ASHRAE Guide developed under ASHRAE's Research Project procedures and is not a consensus document. This document is an application manual that provides voluntary recommendations for consideration in achieving improved indoor air quality.

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Preface

Dwellings come in a variety of sizes, shapes, and configurations and are expected to provide shelter and comfort, fulfill a variety of functional requirements, meet applicable codes and standards, and fit into the local environment and community. People spend most of their time indoors, and much of that is at home. At the same time, occupants continue to perform more and more activities, such as work and exercise, in their homes.

Indoor air quality (IAQ) is typically addressed through compliance with building codes, which in turn are based on industry consensus standards, such as ANSI/ASHRAE Standard 62.2 (ASHRAE 2016b). Such codes and standards provide minimum requirements that do not fully address all the IAQ issues that contribute to human health and comfort in the dwelling.

Although builders and the general public might recognize the importance of IAQ, they often do not appreciate the impact of routine decisions on IAQ. In addition, they might assume that achieving good IAQ is very costly and requires novel or even risky technical solutions. In other cases, they might seek a "silver bullet" device, test, or one-time activity to improve their dwelling's IAQ, sometimes at significant cost, with limited success. The manufacturers and sellers of products for cleaning the air might make questionable claims based on little or no evidence, and their products might therefore not achieve the desired result.

Information is available on how to achieve good IAQ without requiring excessive expenses or practices that are beyond the capabilities of residents, builders, and construction and maintenance tradespeople. This guide was written by some of the most experienced individuals in residential IAQ and presents best practices for design, construction, maintenance, and operation of dwellings to maximize IAQ that have proven to be successful. It provides information and tools that residents, home designers, and builders can use to integrate IAQ into dwellings while addressing budget constraints and other functional requirements.

The IAQ field is too broad to cover everything in one book, so the authors and ASHRAE's Project Monitoring Subcommittee selected those topics that they believe could have the biggest impact. In many cases, the guide provides only a brief summary of an issue and refers readers to other sources for more details. In other cases, when other good references on a subject are not readily available, the authors cover a topic in greater detail. IAQ knowledge is incomplete and growing constantly, and this document presents the best available information in the authors' judgement to allow informed decision making.

The guide addresses residential dwelling units covered by ASHRAE Standard 62.2 (ASHRAE 2016b) and was written for the following audiences:

- Homeowners and renters who might choose a dwelling and/or its custom features or work with designers to build a dwelling from scratch and who can choose materials, products, and activities that improve or at least do not reduce IAQ

- Architects, home designers, and builders who can apply the recommended practices during design, construction, and renovation

- Developers of multifamily building (e.g., duplex, rowhouse, or low- or high-rise apartment or condominium) projects and other decision makers who direct the work of the above professionals

- Home energy raters and commissioning authorities who determine whether design elements, construction observation, functional testing, and the finished dwelling meet IAQ-related goals and requirements

- Organizations with sustainable building rating programs and/or that conduct training for these programs

- Indoor environmental professionals who seek a broader understanding of residential building practice in order to better serve their clients' concerns about their home IAQ

- Multifamily building managers and operators who need to understand the IAQ implications of existing heating, ventilation, and cooling (HVAC) systems (the components in a dwelling that that heat, cool, ventilate, and/or dehumidify it) and operations and maintenance practices

Message to Developers and Builders

Some have questioned the movement to make dwellings tighter and the resulting need to provide whole-dwelling ventilation, usually using mechanical means. This guide does not revisit this subject because such features are now required by consensus standards and construction codes.

IAQ is one of many issues that building owners and developers must address to meet their needs and those of the dwelling occupants. Although occupants do sometimes complain about poor IAQ, IAQ is not always their top concern. So why should developers and builders worry about IAQ when they have so much else to think about?

- Better IAQ leads to more satisfied residents, better referrals, and fewer complaints. The general public often has incomplete knowledge about IAQ. Buyers and renters depend on professionals to deliver high-quality dwelling units and sound advice.

- IAQ problems that get out of hand can be quite costly by distracting developers and builders from other business goals, requiring expensive building or mechanical system repairs, incurring legal costs, and resulting in bad publicity. Although extreme IAQ problems are rare, they do occur, and the consequences can be dramatic. Less severe problems are more common and can affect occupancy and/or rent levels. They can also lead to expenses for more minor legal disputes or repairs.

- Many of the measures that are used to achieve good IAQ also contribute to durability of the building.

Educating occupants is also important. If they understand the importance of not smoking or burning candles indoors, using the kitchen range hood if they have one, and closing windows when outdoor air quality is poor, they are more likely to make positive IAQ-related choices.

This guide presents a wealth of practical information on how to design and construct dwellings that have good IAQ without large financial investments or use of untested technologies. Although the guide is full of information on design and construction approaches to control moisture, reduce contaminant entry, and provide effective ventilation, probably the

most important message for the owner and developer is to incorporate IAQ at the start of the development and design processes. Doing so will make efforts to provide good IAQ at a low or even no added cost easier and more effective.

By the time a dwelling's basic layout (schematic design) is complete, many opportunities to achieve good IAQ have been foreclosed, which can easily result in unintended consequences or expensive and inadequate "force fitting" of solutions. When IAQ, energy efficiency, and other project objectives are considered together at the initial design phases, design elements for each objective can be mutually reinforcing rather than at odds with one another.

Message to Homeowners, Renters and Other Residents

Opportunities to achieve better indoor air quality at all the stages of occupancy occur in the following situations:

- When choosing features of the dwelling design or construction
- When choosing a dwelling to acquire or rent
- When renovating, retrofitting, or painting a dwelling
- When purchasing appliances, equipment, and furnishings
- When choosing activities to perform inside the dwelling
- When purchasing and using cleaning, pest control, maintenance, and personal care products
- During daily activities, such as bathing and cooking

Homes built to current codes and standards or that are retrofitted for energy purposes are much tighter (have lower air and energy leakage) than in the past. Yet they require outdoor air to dilute contaminants produced by people and their activities as well as by the building and its fixtures and furnishings. Because these new homes cannot depend on natural leakage, they have mechanical ventilation systems for this purpose. These systems need to be operated as designed, and operation of local exhaust (kitchen and bath) fans is particularly important in tight homes.

It is essential to avoid smoking indoors, limit the burning of candles and incense, and use the kitchen range hood. Windows need to be closed when outdoor air quality is poor, and consideration should be given to opening them when outdoor air quality and temperature are good.

This guide presents a wealth of other practical information on how to live in a home to achieve good IAQ without large financial investments or use of untested technologies. Probably the most important message for the home occupant is to incorporate thinking about

IAQ into all the other activities that make the home comfortable. There is no “silver bullet” device, test, or one-time activity to improve a dwelling’s IAQ, despite claims of manufacturers and sellers of products and services. However, a variety of small actions will improve IAQ at a low or even no added cost.

Special IAQ Considerations for Low-Income Housing

Builders, owners, and designers need to be aware of special IAQ concerns related to low-income housing and to take steps to reduce the risks associated with them.

Socioeconomic disparities related to indoor exposure to particulate matter (discussed in Strategy 7.2) are large (Adamkeiwicz et al. 2010). Many building and occupancy characteristics associated with greater particulate matter exposure are more pronounced in lower-income housing. These features include greater building age, peeling paint, heavy street traffic nearby, factories and industrial buildings nearby, uncomfortable temperatures, small floor area, high occupant density, and visible cracks in the building enclosure (roofs, ceilings, above-grade and below-grade walls, windows, and floors that separate the indoors from outdoors).

Indoor smoking adds significantly to indoor particulate matter in units in which smoking occurs and in adjacent multifamily units, including those occupied by nonsmokers. The risk of poor IAQ can disproportionately affect housing and multifamily dwellings occupied by elderly and low-income populations. A best practice is therefore to ban or at least discourage smoking in multifamily dwellings (HUD 2018).

Furthermore, residents of these buildings often have limited choice in where they live and less empowerment to demand repairs, and they might be affected by the decisions of other people who live in the same unit. In addition, occupants with limited financial resources or access to transportation need to be able to buy replacement filters locally and inexpensively because ordering products online might be expensive and difficult to accomplish without a credit card (Singer 2016). If management does not change filters, it should make it easy for residents to obtain them.

There are actions everyone can take to improve the air quality in homes, whether one’s responsibility is to design, build, buy, rent, operate, clean or simply occupy a dwelling.

Keeping homes clean, dry, and ventilated is often not complicated, but it takes continued effort. This includes exercising care with products brought into the home, avoiding moisture problems and correcting them promptly if they appear, providing ventilation with outside air, and good air filtration.

The authors hope that you, the reader, find this Guide informative, helpful, and interesting and that it helps lead to health and vitality through homes that have clean and comfortable air to breathe.

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Deborah Berlyne, Ph.D., joined the project as technical editor and helped make the guide much clearer and more coherent, with editorial assistance from Hannah Bachman. The authors sought input from other experts, too numerous to mention, to capture the latest and best thinking on their topics, and they appreciate those contributions. The authors extend their personal thanks and appreciation to this group for the extraordinary effort they poured into this guide and the passion they displayed about providing quality indoor environments.

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Abbreviations and Acronyms

ACCA	=	Air Conditioning Contractors of America
ACH50	=	air changes per hour at 50 Pascals
AHAM	=	American Home Appliance Manufacturers
AHU	=	Air Handling Unit
ANSI	=	American National Standards Institute
ASTM	=	ASTM International (formerly the American Society for Testing and Materials)
BPI	=	Building Performance Institute
Bq/m^3	=	Becquerels per cubic meter
CADR	=	clean air delivery rate
CFA	=	conditioned floor area
CFM	=	cubic feet per minute
DALY	=	disability-adjusted life year
EPA	=	U.S. Environmental Protection Agency
ERV	=	energy recovery ventilator
HEPA	=	high-efficiency particulate air
HRV	=	heat recovery ventilator
HVAC	=	heating, ventilating, and air conditioning
IAQ	=	indoor air quality
ICC	=	International Code Council
IMC	=	International Mechanical Code
in. w.g.	=	inches, water gauge
IP	=	inch-pound
IRC	=	International Residential Code
LEED	=	Leadership in Energy and Environmental Design
MERV	=	Minimum Efficiency Reporting Value
NFPA	=	National Fire Protection Association
NIST	=	National Institute of Standards and Technology
OSB	=	oriented strand board
Pa	=	Pascals
pCi/L	=	picocuries per liter
PM	=	particulate matter
PM2.5	=	particulate matter with a diameter of 2.5 μm or less
RESNET	=	Residential Energy Services Network
RH	=	relative humidity
SI	=	International System of Units
SVOC	=	semivolatile organic compound
TVOC	=	total volatile organic compound
UFP	=	ultrafine particles
VOC	=	volatile organic compound

Definitions

Air pressure: Force delivered by air molecules bumping into a surface. Air moves from areas of low to areas of high pressure, which drives the movement of contaminants.

Air sealing: Sealing of gaps, cracks, and holes in a surface or building enclosure against the flow of air in the dwelling walls, ducts, or air-handling units. See definition of “air-handling unit.”

Air-handling system: Assembly of components, including the air-handling unit and attached ductwork, that deliver conditioned air to a dwelling. See definition of “air-handling unit.”

Air-handling unit (AHU): Equipment containing a fan or blower that draws air in; passes it through components that heat, cool, and/or dehumidify it; and blows it out.

Backdraft: Potentially dangerous condition that occurs when negative pressure causes combustion products to be drawn back from a natural draft venting system into the occupied portions of a dwelling. See definitions of “air pressure” and “natural draft venting system.”

Bathroom: Any room containing a bathtub, shower, spa, or similar source of moisture.

Building enclosure (or building envelope): Roofs, ceilings, above-grade and below-grade walls, windows, and floors that separate the indoors from outdoors.

Chase (e.g., duct or plumbing chase): Vertical shaft among floors of a multistory building that accommodate ducts, wires, or plumbing.

Combustion appliance: One that burns fuel (e.g., natural gas, propane, or kerosene) to heat a dwelling or produce hot water.

Commissioning: Quality control process of determining whether heating, ventilation, and air conditioning systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner’s requirements; can also be applied to building enclosures. See definition of “building enclosure.”

Compartmentalization: Sealing of each dwelling unit in a multifamily building so that they are separated from each other, utility chases, and common areas. See definitions of “multifamily buildings” and “chase.”

Conditioned air: Air that has been treated to control its temperature, relative humidity, and/or purity. See definition of “relative humidity.”

Conditioned space: Parts of the dwelling that are intentionally heated and/or cooled to achieve occupant comfort.

Cubic feet per minute (CFM): Measure of airflow rate by volume. The comparable unit in the International System (SI) is the liter per second (l/s). 10 CFM is approximately equivalent to 5 l/s.

Dwelling unit: A single unit providing complete, independent living facilities for one or more persons, including permanent provisions for living, sleeping, eating, cooking, and sanitation.

Energy recovery ventilator (ERV): Device that transfers both sensible and latent heat between the incoming air that ventilates a dwelling and the outgoing exhaust air so that when it is cold and dry outside, the incoming air is warmed and humidified, and when it is hot and humid outside, the incoming air is cooled and dehumidified. See definitions of “heat recovery ventilator,” “latent heat,” and “sensible heat.”

Exfiltration: Uncontrolled outward leakage of air through cracks and interstices in any building element and around windows and doors.

Exhaust air (or exhaust): Air removed from a dwelling using a fan. See definition of "exhaust-only system" under "ventilation system."

Grade (e.g., above-grade or below-grade): Level of the ground surface outside a dwelling.

Heat recovery ventilator (HRV): Device that transfers sensible heat between the incoming air that ventilates a dwelling and the outgoing exhaust air so that the incoming air is warmed in winter or cooled in summer, with no transfer of latent heat. See definitions of "energy recovery ventilator," "latent heat," and "sensible heat."

Heating, ventilation, and air conditioning (HVAC) systems: All components in a dwelling that heat, cool, ventilate, and/or dehumidify it.

Infiltration: Uncontrolled inward leakage of air through cracks and interstices in any building element and around windows and doors.

Intake: Location where air is pulled into a fan or duct system. For example, the outdoor air intake for a dwelling is the outdoor location where air is pulled into its ventilation system.

Latent heat: Heat added to or removed from air that causes humidity to be added to or removed from the air but does not change the air temperature.

Local exhaust system (or local exhaust): System that removes indoor air in a location where levels of indoor air contaminants or moisture are expected to be high, such as a kitchen hood used to remove cooking contaminants or a bathroom fan that removes odors and moisture.

Mechanical ventilation: Active process of ventilating a dwelling unit using powered equipment, such as motor-driven fan and blowers.

Minimum efficiency reporting value (MERV): Scaled rating of the effectiveness of air filters in removing particulate matter (PM):

- *Low-efficiency filters (MERV 6 and under):* Low filtration efficiency, can remove some coarse particles, but has little impact on fine particles.
- *Medium-efficiency filters (MERV 8-12):* Widely available and can remove fine particles from the air without significant cost, energy use, or system considerations.
- *Higher-efficiency filters (MERV 13 and up):* Increasingly able to remove fine particles and ultrafine particles.

See definition of "particulate matter."

Minisplit: Small, low-capacity heat pump or air conditioner, often in or close to the living space it serves. The indoor units are often ductless and serve a single room, but some can accommodate a small amount of ductwork and serve a few closely grouped rooms.

Multifamily buildings (or dwellings): Residential buildings containing units built one on top of another and those built side-by-side which do not have a ground-to-roof wall and/or have common facilities (i.e., attic, basement, heating plant, plumbing, etc.) Includes duplexes, some rowhouses, and low- and high-rise apartments and condominiums.

Definitions

Natural draft venting system: Venting system that relies on a draft produced by the difference in the density of gases inside a chimney or vent and the density of air outside the chimney or vent to convey combustion products outside.

Oriented strand board (OSB): Engineered wood product formed by the addition of adhesives and compression of layers of wood strands or flakes in specific orientations; widely used as a sheathing material in residential construction.

Particulate matter (PM): Mixture of solid particles (typically organic and inorganic particles, including dust, pollen, soot, and smoke) and liquid droplets suspended in air; often subgrouped by size because different-sized particles have different health effects and filtration requirements. For example, PM2.5 refers to all PM with a diameter of 2.5 □m and smaller.

Permeance (or vapor permeance, measured in perms): Rate of water vapor that passes through a given area of solid building material driven by a difference in water vapor pressure rather than air pressure. The lower the permeance (or "perm rating") of a material, the less water vapor can pass through it. See definition of "air pressure."

Plenum: Cavity in a building that is part of an air-handling system. See definition of "air-handling system."

Point source: Source of pollution that can be attributed to a specific physical location.

Relative humidity (RH): Amount of water vapor in air expressed as a percentage of the maximum possible amount of water vapor that could be present at a given temperature.

Remodeling: Process of making changes to the construction of a dwelling and/or building systems.

Retrofit: Modification of existing equipment, systems, or buildings to improve performance, update operations, and/or improve energy performance.

Return (or air return or return grille): Location from which air is drawn into an air-handling system.

Semivolatile organic compounds (SVOCs): Subgroup of volatile organic compounds that evaporate at higher temperatures than other volatile organic compounds. See definition of "volatile organic compounds."

Sensible heat: Heat added to or removed from air that raises or lowers the air temperature without causing condensation or evaporation.

Stack effect: Movement of air driven by buoyancy and resulting from temperature differences.

Supply air: Conditioned air delivered to the dwelling by its air-handling system. See definition of "air-handling system."

Thermal comfort: Thermal conditions deemed acceptable by an occupant or group of occupants.

Thermal conditioning: Process of heating, cooling, and/or dehumidifying a dwelling to achieve human comfort and durability of the dwelling.

Thermal enclosure: Enclosure that is insulated and air sealed to reduce the flow of heat between the inside and outside.

Toilet room: Any room containing a toilet.

Total volatile organic compounds (TVOCs): Total concentration of volatile organic compounds in an air sample; a measurement that groups together a wide range of chemical compounds into a single measurement, rather than singling out individual compounds. See definition of “volatile organic compounds.”

Ventilation system: Assembly of fan or fans, ductwork, controls, passive building features and other components that work together to introduce outdoor air into a dwelling to dilute indoor contaminants. In this document, the terms ventilation system, whole-dwelling ventilation system and dwelling-unit ventilation are used interchangeably.

- *Balanced ventilation system:* System that mechanically supplies outdoor air and exhausts indoor air such that the total supply and exhaust quantities are approximately equal to each other.

- *Exhaust-only ventilation system:* System that exhausts air from the home without mechanical (fan-driven) outdoor air intake. Exhaust is done by one or more fans, which usually also serve as bathroom or kitchen fans. A small negative air pressure causes an equal amount of outdoor air to leak into the dwelling through the enclosure. See definitions of “air pressure” and “building enclosure.”

- *Supply-only ventilation system:* System that supplies outdoor air to the home whether or not the home’s exhaust fans are operating. A small positive air pressure causes an equal amount of indoor air to leak to the outside through the enclosure. See definitions of “air pressure” and “building enclosure.”

- *Natural ventilation system:* System that ventilates as a result of only natural forces, such as wind pressure or differences in air density.

Ventilation: Process of supplying outdoor air to or removing indoor air from a dwelling by natural or mechanical means to dilute indoor contaminants. Such air might or might not have been conditioned.

Volatile organic compounds (VOCs): Organic chemicals that can evaporate at normal indoor temperature and air pressure. See definition of “air pressure.”

Weatherization: Process of retrofitting an existing dwelling to make it more energy efficient. See definition of “retrofit.”

Zoning: Control strategy that allows different parts of the dwelling to be conditioned using separate thermostats. One purpose of zoning is to maintain thermal comfort in locations that have different rates of heat gain or loss (e.g., because they are on different floors). See definition of “thermal comfort.”

IAQ is one of many factors that make a dwelling healthy, comfortable, and functional. When IAQ is good, it is nearly invisible; when IAQ is poor, it can have a negative effect on the health of children and adults. With good IAQ, builders retain an unblemished reputation and rental housing occupancy rates remain strong.

The High Cost of Poor IAQ

Poor IAQ in a new dwelling or professionally managed multifamily housing can require the developers, designers, and managers to devote considerable resources to addressing resident complaints, making major repairs, engaging in expensive legal actions, and, in extreme cases, relocating residents.

The costs of poor IAQ can include legal fees and damages. IAQ has direct effects on health, comfort, and the ability to do normal activities. Well-established, serious health impacts of poor IAQ include circulatory and lung disease from exposure to secondhand smoke, Legionnaires' disease from legionella bacteria in the air, lung cancer from radon exposure, and death from acute carbon monoxide poisoning (from, for example, a backdrafting combustion appliance). More widespread health effects include increased rates of allergy and asthma from exposure to indoor pollutants (particularly those associated with dampness and biological growth), colds and other infectious diseases from microbes transmitted through the air, and cardiovascular risks related to particulate matter exposure. These more widespread effects have the potential to affect large numbers of people and are associated with significant costs in the form of health care expenses, sick leave, and lost productivity at work and school.

Despite these significant effects, many dwelling design and construction decisions are made without an understanding of the potentially serious consequences of poor IAQ or consideration of the well-established body of knowledge on how to avoid IAQ problems. Although controlling indoor contaminants, providing adequate ventilation, and achieving thermal comfort (thermal conditions deemed acceptable by an occupant or group of occupants) has been part of the construction and use of dwellings for centuries, awareness of and concerns about IAQ have increased in recent decades, as severe IAQ problems have received media coverage. But in most cases, IAQ is still not a high priority for dwelling design or management compared with function, cost, living space, aesthetics, location, and accessibility.

Given the very real benefits of good IAQ and the potentially serious consequences of poor IAQ, residents, builders, designers, contractors, and building managers can all benefit from an increased focus on achieving good IAQ in dwellings. This guide can enhance all parties' ability to design, construct, and operate buildings with good IAQ using proven strategies without significant expense.

What is Good IAQ?

This guide is intended to help move beyond current practice to provide good IAQ in dwellings. A dwelling with good IAQ provides air in occupied rooms that contains no known or expected contaminants at concentrations likely to be harmful, does not create conditions likely to be associated with health or comfort complaints, and results in satisfaction of most occupants. Good IAQ requires consideration of both indoor air pollution levels and thermal environmental parameters. However, the limits of existing knowledge about the health and comfort effects of specific contaminants and contaminant mixtures, addition of unstudied chemicals to manufactured products, and variations in human susceptibility make it impossible to develop a single IAQ metric that can provide a summary measure of IAQ in dwellings.

Therefore, in this guide, good IAQ results from:

- Diligent compliance with both the letter and intent of building codes and ASHRAE Standard 62.2 (ASHRAE 2016b)
- Technically sound and well-executed efforts to meet or exceed these minimum requirements
- Application of IAQ-sensitive practices in design and construction
- Efforts by the occupants to avoid generating contaminants indoors, and efforts by building operators, managers and occupants to utilize systems designed to remove these contaminants when they occur.

Adherence to today's minimum standards (i.e., building codes and ASHRAE Standard 62.2) is essential to achieve acceptable IAQ, yet current practice does not always result in a dwelling that meets these standards. Furthermore, codes and standards do not cover operation and maintenance practices well or help residents, builders, and designers achieve better-than-acceptable IAQ. These factors are the primary motivations for the development of this guide.

Importance of Considering IAQ in the Design and Construction Process

Although ample information and experience is available on achieving good IAQ in newly built dwellings, good IAQ is not automatic because it requires a level of awareness and commitment, including an effort to make IAQ part of the design from the very beginning, that is not typical of most dwelling building and renovation projects. The three primary reasons to include IAQ considerations in the earliest stages of project planning are to avoid problems when IAQ is treated as an afterthought, to allow consideration of alternative design concepts that require decisions early in the design process, and because it is more cost effective to do this early in the design process

Incorporating IAQ at the very beginning of the conceptual design process—on par with function, aesthetics, and energy use—enables the design team to consider high-performance design concepts that can support good IAQ, energy efficiency, and other important design goals, and make informed decisions that will affect the project throughout the construction

and occupancy phases. The issues owners and residents need to consider and decisions they must make include their expectations for IAQ, contaminant sources in or near the dwelling, activities expected to occur in the dwelling and contaminants that might be associated with them, and resident characteristics (e.g., age range, health status, and how they heat, cool, and ventilate the dwelling). If these considerations are not addressed until after the building layout has been determined and the ventilation system is designed, it will be difficult to meet the needs of the dwelling and its occupants.

Examples of decisions made in the early phases of design that can promote good IAQ include:

- Mechanical systems that provide outdoor air ventilation independently of heating and cooling
- High-efficiency air cleaning strategies
- Selection of low-emitting materials based on sound technical consideration of options
- Opportunities for natural ventilation

Decisions made in the early phases that can lead to poor IAQ include the following:

- Site selection, building orientation, and surface grading that can lead to moisture problems
- Poor location of outdoor air intakes (locations where air is pulled into a fan or duct system) that introduces unwanted contaminants into the building
- Inadequate space for mechanical equipment, limiting the types of systems that can be selected, making it more difficult to filter and distribute air
- Limited access for inspection and maintenance, which can result in IAQ problems going undiscovered and unaddressed
- Use of materials that can lead to high levels of volatile organic compound emissions

Making a commitment to good IAQ at the beginning of a project and maintaining that focus throughout the design and construction will result in a dwelling that more successfully achieves its design goals and the desired level of performance throughout its lifespan.

Sometimes, even if intentions to achieve a high-quality dwelling with good IAQ are high, things can go wrong. Here are a few problems that can be avoided by addressing their root causes.

Lack of Quality Control

Although a good design is critical to good IAQ, neglecting to install and test the HVAC system and building enclosure so that they operate as designed often compromises IAQ. Therefore, a key factor in achieving good IAQ is a serious commitment to the comprehensive commissioning (quality control process of determining whether heating, ventilation, and air conditioning systems are designed, installed, functionally tested, and capable of being operated and maintained according to the owner's requirements; can also be applied to building enclosures) of HVAC and ventilation systems and assemblies that are critical to good IAQ. This commitment must start in the design phase and continue well into occupancy.

Moisture in the Enclosure

Many notable cases of IAQ problems have been associated with excessive levels of moisture. These problems can be very difficult to fix without major renovation efforts and costs. Moisture problems arise for a variety of reasons, including leaks where a roof meets a wall and in roofs and windows, designs that respond inappropriately to ambient moisture (e.g., low-permeability wall coverings in hot and humid climates), and poor air pressure control. These problems are largely avoidable but require an understanding of building moisture movement and attention to detail in enclosure design and construction and in mechanical ventilation system (system that actively ventilates a dwelling unit using powered equipment, such as motor-driven fan and blowers) selection, installation, and operation.

Poor Outdoor Air Quality

The traditional way to promote IAQ is through outdoor air ventilation, which can dilute indoor contaminants but is only effective when the outdoor air is cleaner than the indoor air. In many locations and for many contaminants, this is not the case, and insufficiently treated ventilation air can make IAQ worse. Outdoor air quality is poor when outdoor contaminant levels and local contaminant sources (e.g., motor vehicle exhaust from nearby roads and contaminants generated by activities in adjacent buildings) are high. Whether to increase outdoor air ventilation rates above minimum requirements depends upon the potential effects of outdoor air quality.

ASHRAE Standard 62.2 (ASHRAE 2016b) does not require an assessment of outdoor air quality in a dwelling's vicinity. Given the key role of outdoor air ventilation in IAQ control, this guide covers outdoor air quality and air-cleaning alternatives.

Moisture and Dirt in Ventilation Systems

Dirt accumulation in ventilation systems combined with poor water management can lead to biological growth in the airstream and serious IAQ problems. These conditions generally result from inadequate particle filtration, poor filter maintenance, pooling of cooling coil condensate, or other moisture sources. ASHRAE Standard 62.2 (ASHRAE 2016b) has some requirements related to dirt and moisture management in ventilation systems. This guide addresses the topic in Strategy 4.1.

Indoor Contaminant Sources

Normal building materials and furnishings release many contaminants, especially when these materials are new, as do materials and substances brought into the dwelling once it is occupied. Unusual, unexpected, or atypically high contaminant emissions from indoor sources are associated with many IAQ problems, and this guide addresses material selection, cleaning, and other indoor sources.

IAQ problems can also result from improper equipment operation, inadequate exhaust ventilation (removal of air from a dwelling using a fan), and use of inappropriate materials for activities in the dwelling. This guide contains information on how to decrease the likelihood of such problems.

Inadequate Ventilation Rates

Although building codes and standards have addressed outdoor air ventilation for decades, many dwellings are poorly ventilated, which increases the likelihood of poor IAQ. The many potential causes of inadequate ventilation include lack of compliance with applicable codes and standards, installation or maintenance problems that prevent delivery of the target ventilation rate, or incorrect use of the installed systems by occupants. Also, even when system-level outdoor air intake rates are adequate, poor air distribution can under-ventilate some portions of the dwelling. ASHRAE Standard 62.2 (ASHRAE 2016b) covers the determination of target ventilation rates, and this guide offers additional advice to help address these issues.

Ineffective Filtration and Air Cleaning

Filtration and air cleaning are effective ways to control many indoor air pollutants, particularly those associated with poor outdoor air quality. Air filtration or air cleaning, therefore, is an important adjunct to outdoor air ventilation. This guide provides information on filtration and air-cleaning alternatives that, when properly implemented and maintained, can both improve IAQ and reduce energy use.

What is Covered in This Guide

This guide addresses the design and construction of dwelling units, including single-family homes and horizontally- (duplexes, triplexes, and row houses) and vertically-attached multifamily housing, and it is not restricted by building sizes or HVAC system type. These dwelling unit distinctions are covered by ASHRAE Standard 62.2 and are the focus of most of the recommendations in this guide.

What is Not Covered in This Guide

This guide does not cover spaces in residential buildings that are outside the dwelling unit, such as mailrooms, lobbies, corridors, exercise rooms, natatoriums, offices, or storage and equipment rooms. For guidance on these other types of spaces, see the Indoor Air Quality Guide (ASHRAE 2009) and ASHRAE Standard 62.1 (ASHRAE 2016b). Furthermore, this guide does not address multiple chemical sensitivity, although improved IAQ will benefit people with this condition.

Many of the recommendations of this guide can make dwellings more resilient in extraordinary incidents, either natural (e.g., earthquakes, fires, and floods) or intentional (e.g., terrorist attacks). This is not the primary focus of this guide and it certainly does not guarantee safety or good IAQ in these circumstances. Information planning for such events in building designs is available from several sources, including the Federal Emergency Management Agency and the National Fire Protection Association.

The housing and shelters for homeless people are often substandard in many ways, including IAQ, even in developed nations like the United States. This guide does not cover the challenges society faces in dealing with this major problem that affects public health, shortens lifespans, reduces productivity, and increases health care costs.

This guide does not cover ventilation for smoking and recommends against smoking indoors or any location outdoors where smoke could enter a dwelling. Any level of secondhand smoke (also known as environmental tobacco smoke) is incompatible with good IAQ based on the health risks and the inability of engineering controls to adequately control those risks.

This guide does not provide a metric, or method for quantifying, what good IAQ is, because there are no comprehensive consensus methods to measure or evaluate IAQ in any indoor environment. Health data are limited, at best, on dwelling features that enhance health and well-being across large populations, except for environmental tobacco smoke exposure. The authors long for a day when such tools exist and dwellings can have automatic protective features similar to those for preventing vehicle collisions and protecting drivers and passengers in modern automobiles.

This Guide focuses on IAQ and not the broader category of Indoor Environmental Quality (IEQ), except in limited cases. IEQ is generally understood to include not just air contaminants, but temperature comfort (which is covered in Strategy 8.3), acoustic comfort, and visual comfort (lighting and glare). Many also include ergonomics, daylight and views, and aesthetics.

The information in this guide addresses the IAQ problems that have been occurring in dwellings for several decades based on the authors' experience in investigating, resolving, and preventing these problems. Based on the known causes of the IAQ problems discussed in this introduction, this guide is organized into eight sections that address each of eight objectives for improving IAQ:

- Objective 1 – Acquire, Design, Construct, and Operate to Achieve Good IAQ
- Objective 2 – Manage Moisture
- Objective 3 – Limit Entry of Outdoor Contaminants
- Objective 4 – Control Contaminants Related to Mechanical Systems
- Objective 5 – Limit Contaminants from Indoor Sources
- Objective 6 – Minimize Exposure to Unavoidable Contaminants
- Objective 7 – Use Ventilation and Filtration to Reduce Contaminant Concentrations
- Objective 8 – Energy, Comfort, and Interactions

Each section offers details on several strategies to help achieve each objective.

What to Expect in Each Section of this Guide

Objectives and strategies. The overview section at the beginning of each objective explains why the objective is important for good IAQ. Each overview is followed by descriptions of the strategies that can be used to achieve that objective and provides a visual depiction of these strategies.

Sidebars. Sidebars are interspersed throughout the guide to define terms, address specific topics, or offer examples.

Bibliography. All sources cited in this guide are listed in the bibliography.

Appendix. Case studies describing different ventilation system and filtration options are included in Appendix A. They provide insights into system selection and integration, advantages and disadvantages of each, and guidance for practical implementation.

Objective 1



ACQUIRE, DESIGN, CONSTRUCT, AND OPERATE A DWELLING TO ACHIEVE GOOD IAQ

Many important choices made at the beginning—when a dwelling is designed, built, renovated, bought, or rented—influence the potential to reliably achieve good IAQ. Residents and those who operate and maintain the dwelling subsequently make other critical choices that also influence IAQ. Without good quality control during construction, even the most sophisticated design and IAQ technologies might not deliver the desired results. The quality control processes described in this objective can help even simple designs avoid IAQ problems and provide a good indoor environment.

This section describes how these choices affect IAQ and how to make decisions that are most likely to have a positive effect. The Objective 1 strategies are as follows:

Strategy 1.1 Build, Buy, or Rent a Dwelling with Good IAQ identifies important issues to consider when selecting, building, or renovating a dwelling. Many IAQ problems occur when building elements are designed by different people working in isolation from one another. This strategy therefore includes approaches to integrate design across disciplines while minimizing the cost of achieving good IAQ and other performance goals.

Strategy 1.2 Select Heating, Ventilation, and Air Conditioning (HVAC) Systems to Manage the Energy Effects of Ventilation explains how the type of HVAC system selected can constrain options for achieving good IAQ by limiting ventilation (process of supplying outdoor air to or removing indoor air from a dwelling by natural or mechanical means to dilute indoor contaminants), filtration, and space humidity control capability. HVAC system choice can also have a major impact on the energy consumed by ventilation.

Strategy 1.3 Schedule and Manage Construction and Renovations to Facilitate Good IAQ highlights the importance of construction processes to IAQ. A project schedule that is too compressed or improperly sequenced can jeopardize IAQ. Likewise, failure to manage contaminants, humidity, or water during construction can threaten occupant health in dwellings undergoing renovation and long-term IAQ in new dwellings.

Strategy 1.4 Observe, Verify, and Test Dwelling Construction provides guidance on quality control for IAQ, including establishment of IAQ requirements and construction observation, verification, and testing. This strategy also covers the need for a full commissioning process for multifamily buildings.

Strategy 1.5 Effectively Operate and Maintain the Dwelling to Maximize IAQ explains the responsibilities of residents and, if applicable, professional property managers to operate and maintain the dwelling so as to maximize IAQ. This strategy also covers actions for homeowners to take or avoid for preventing IAQ degradation.

Objective 1



ACQUIRE, DESIGN, CONSTRUCT, AND OPERATE A DWELLING TO ACHIEVE GOOD IAQ

Other important strategies for acquiring, designing, constructing, and operating a dwelling to achieve good IAQ are discussed in the following sections:

- Strategy 2.2 – Control Indoor Humidity
- Strategy 3.6 – Control Entry of Contaminants from Unoccupied Spaces
- Strategy 4.1 – Control Moisture and Dirt in AHUs
- Strategy 6.2 – Provide Local Capture and Exhaust for Point Sources of Contaminants
- Strategy 7.1 – Implement Appropriate Outdoor Air Ventilation Strategies and Quantities
- Strategy 7.2 – Provide Particle Filtration and Air Cleaning

The example below shows how the strategies in Objective 1 work together and with strategies elsewhere in this guide as part of a process for creating good IAQ.

An exhaust hood over the kitchen range and oven can remove particles and gases released during cooking (Strategy 6.2). The performance of a range hood depends on its height above the cooking surface, depth, and width as well as its provision of sufficient exhaust air to capture the plume of contaminants from the stove. The hood design (Strategy 1.1) must address all these factors. Changes can be made to the HVAC system design to accommodate an unusually large flow hood (Strategy 1.2). The contractor must install the hood far enough from the stovetop and not make any small mistakes that reduce airflow (Strategies 1.3 and 1.4). Common mistakes are forgetting to remove the tape that holds the backdraft damper closed during shipping or using a screw to secure the duct to the damper fitting that is too long and prevents the damper from opening. At the completion of the construction, the flow rate of the hood should be tested to demonstrate that it is working properly (Strategy 1.4). Of course, the cook must turn the exhaust hood fan on to reap the benefit of the care taken to plan and install the hood (Strategy 1.5).

Strategy 1.1 Build, Buy, or Rent a Dwelling with Good IAQ



Introduction

Anyone renting, buying, or building a dwelling should select one that has met the requirements of one of the label programs that includes IAQ requirements. Examples of these programs are the Environmental Protection Agency's (EPA's) ENERGY STAR and Indoor airPLUS, Leadership in Energy and Environmental Design (LEED) for Homes of the U.S. Green Building Council, and National Green Building Standard of the International Code Council and ASHRAE. None of the programs addresses all IAQ features, but they are a good place to start. Your local builder may have options meeting a state or local green building code or program.

To promote good IAQ when renting or buying a dwelling:

- Choose a dwelling that has an EPA ENERGY STAR Indoor airPLUS label or a Standard 62.2 compliant ventilation system.
- Have the home inspected; include indoor environmental problems (e.g., biological growth and moisture problems, indoor pests, odors, bath and kitchen exhaust fans, and nearby sources of air pollution) in the inspection list.

To promote good IAQ when building a new dwelling:

- Ask the builder or architect for the EPA ENERGY STAR Indoor airPLUS label.
- Determine whether the building enclosure and HVAC recommendations in this guide have been implemented.

Buying or Renting an Existing Dwelling

Those buying or renting an existing dwelling should look for the following signs of existing problems:

- Moisture:
  - Identify biological growth, stains, peeling paint, or musty odors indoors, including locations such as the ceiling in the level below the roof, window sills, and cabinets under sinks in the kitchen and bathrooms (any room containing a bathtub, shower, spa, or similar source of moisture).
  - Examine the outside for puddles or low spots near foundations as well as damaged flashing, siding, gutters, or roofing. Make sure that grading slopes away from the dwelling to allow water to move away from the foundation and that gutters direct water to a sloping grade (level of ground surface outside) away from the dwelling.
  - Check for signs of moisture or past moisture intrusion in basements and crawlspaces, such as rusty metal (e.g., hangers or heads of flooring nails) in crawlspaces.
- Pests:
  - Check for signs of rodents, cockroaches, or bats in cabinets, stoves, closets, attics, basements, and crawlspaces.
- Odors:
  - In a multifamily building, check the common corridors for odors (a potential sign of an air quality problem) because they are likely to enter the living spaces.
- Ventilation equipment:
  - Make sure that the kitchen and bath exhausts are present and operational, quiet enough to use, and vented to the outdoors. If they are not vented properly, determine whether they could be vented to the outdoors.

- Check whether the dwelling has a whole-dwelling mechanical ventilation system (assembly of fan or fans, ductwork, controls, and other components that work together to introduce outdoor air into a dwelling to dilute indoor contaminants). It might be integrated into the central HVAC system or be a standalone system. If the dwelling does not have a whole-dwelling mechanical ventilation system, determine whether installing such as system is feasible and practical.

- Entryways:
  - Make sure that the entryway has room for a good track-off mat and for residents to remove boots and change into indoor shoes. In a multifamily building this should already be in use.

- Outdoor air pollution:
  - Check whether the dwelling is next to a busy highway or industry with noticeable emissions.

Special Considerations for Buyers of an Existing Dwelling

Common practice standards for home inspectors (e.g., those of the International Association of Certified Home Inspectors and the American Society of Home Inspectors) exclude IAQ and combustion equipment (which burns fuel, such as natural gas, propane, or kerosene to heat a dwelling or produce hot water). It might be necessary to search widely to find a home inspector with specific expertise in indoor air issues, though most have experience evaluating the installation of key building components that affect IAQ (such as insulation or ductwork) and performing tests such as those outlined in Strategy 1.4. Home inspectors with additional credentials, such as Home Energy Rating System (HERS) raters or those with a Building Performance Institute (BPI) credential, often have more specialized skills. The home inspection should include a radon test.

Special Considerations for Renters

Finding rental properties with no-smoking policies has become much easier. If the building has a professional property manager, that individual should answer these questions:

- Have you implemented other IAQ policies in your operation and maintenance programs?

- Was the building designed and constructed to provide good IAQ as part of a high-performance or labeling program?

- What ventilation systems have been installed?

- How is the indoor air filtered?

In addition to the programs listed at the beginning of this section, ENERGY STAR Multifamily High Rise Program guidelines can be applied to taller buildings (ENERGY STAR 2017b).

Table 1.1-A Sample IAQ Checklist for Renting an Apartment

Table 1.1-A provides a sample checklist that renters might use to select an apartment with good IAQ. Renters assign points to indicate the extent to which the apartment has each feature so that they can compare the scores of several apartments. They can assign partial points for partial implementation of a feature or when they are not sure whether the apartment has the feature.

IAQ Features	Max Points	Points Achieved
No unusual odors or known pollution outside and no highway next to the building	2	
No standing water outside	2	
Track-off mats at main entryway	2	
Nonsmoking building	3	
Radon test result below 2.7 pCi/L (100 Bq/m3) (important for apartments on ground, first, second, and third floors)	3	
Designed and constructed to Indoor airPLUS, ENERGY STAR, National Green Building, or LEED for Homes standards	3	
Free of lead and asbestos or these have been encapsulated according to the landlord	3	
No unusual odors in apartment or corridors, including from neighbors' cooking	3	
Mats at the main building entrance and room for mats and a place to leave shoes by unit entrance	1	
Exhaust system covering top of range with a draft that can be felt	2	
Range hood vented to outside and not back into the kitchen	3	
Exhaust fan in each full bathroom strong enough to hold toilet paper against the surface of the inlet	3	
No water stains, peeling paint, or moldy smell, including under sinks	3	
No signs of pests in kitchen cabinets, closets, or other concealed places, and landlord uses integrated pest management and has sealed pest entry points	3	
Windows that can be opened easily	2	
Outside ventilation air ducted directly into apartment	2	
No garage under the living space	2	
HVAC filter with 2 in. (50 mm) thick slot accessible (assign 1 point if the slot is 1 in. (25 mm) thick) or landlord uses a filter with a Minimum Efficiency Reporting Value (MERV) of 13 or higher (assign 1 point if the MERV is at least 8)	2	
Solid cleanable surfaces throughout (assign fewer points for extensive carpets, fabrics, and upholstery), and carpets meet the Carpet and Rug Institute's Green Label Plus or similar standards	3	
Thermostat in the apartment that responds to adjustment	3	
Kitchen and bathroom cabinets, if new, have a seal indicating certification by the Kitchen Cabinet Manufacturers Association Environmental Stewardship Program	1	
Labels on plywood, medium-density fiberboard, oriented strand board, and particle board, if new, indicating compliance with California Air Resources Board requirements or that they meet a low-emissions standard	2	
Total score:	53	

Table 1.1-A Sample IAQ Checklist for Renting an Apartment

Strategy 1.1 Build, Buy, or Rent a Dwelling with Good IAQ



Special Considerations for those Purchasing a New Dwelling

IAQ features need to be fully integrated into the design of the building enclosure, HVAC equipment, layout of the building and landscape, and selection of materials.

A person buying or designing a new dwelling should work with a builder, architect, or engineer to implement the strategies in this guide. Many of them can be completed even if the purchaser is buying a unit in a multifamily building.

It is a good idea to sign a contract with a verifier with one of the label programs mentioned at the beginning of this strategy. A third party should test the dwelling and verify that it meets the program's specifications. Most builders do not have the specialized equipment needed for this testing and verification, and a project can always benefit from an additional set of eyes. Ideally, this verifier should be involved throughout the construction process. Consideration should be given to adding IAQ features in this guide that are missing from the selected program.

The design of a custom dwelling needs to take into consideration the needs of the new owners. For example, if one of the occupants has asthma or allergies, care can be taken to avoid known asthma triggers and allergens and to control moisture during construction and in the operation and maintenance of the dwelling. If an occupant is sensitive to odors or chemical emissions, building materials, finishes, and furnishings with lower emissions can be used. The National Institute of Standards and Technology (NIST) has a specification that can provide guidance (NIST 2015). To address particular needs, a team member (e.g., architect, contractor, or consultant) should have experience and training in designing and/or installing enhanced IAQ features for buildings.

One of the best ways to achieve a house design that addresses IAQ protection is to ask an independent party to review the design. Residential construction design is rarely reviewed by an IAQ consultant. However, some performance programs—such as ENERGY STAR, Indoor airPLUS (which requires ENERGY STAR labeling), and LEED for Homes—include design reviews, typically by a Home Energy Rating System (HERS) rater. Similarly, Passive House Institute US (PHIUS) certification requires verification by PHIUS+ Raters and Verifiers.

By the time occupants move into a new dwelling, developers, architects, engineers, building contractors, and code officials have been involved in designing and building the dwelling. The contractor might have employed subcontractors to excavate, build, and waterproof the foundation; frame and sheath the house; install the roofing and siding, air seal (sealing of gaps, cracks, and holes in a surface or building enclosure against the flow of air in the dwelling walls, ducts, or air-handling unit), insulate, install plumbing and HVAC equipment, install cabinets in the kitchen and bathrooms, hang gypsum board; hang doors; lay the flooring; and paint and varnish the interior finishes. One should never assume that these individuals will have communicated with each other about indoor air quality.

Strategy 1.1 Build, Buy, or Rent a Dwelling with Good IAQ



Integrated design brings several professionals with different areas of expertise together early on so that specific features are included and coordinated among team members and that desired outcomes are achieved. The most important IAQ features that need to be integrated into the design are as follows:

- A building enclosure designed to:
  - Be airtight and well insulated
  - Prevent condensation, rain leaks, and below-grade water leaks
  - Prevent pipe freezing and plumbing leaks

- HVAC systems that:
  - Are located inside the thermal enclosure (enclosure that is insulated and air sealed to reduce the flow of heat between the inside and outside)
  - Implement a whole-house mechanical ventilation strategy that meets the guidelines in Strategy 7.1
  - Keep the indoor temperature in the desired comfort range
  - Keep indoor humidity levels below 65% relative humidity (RH; amount of water vapor in air expressed as a percentage of the maximum possible amount of water vapor that could be present at that temperature) during the cooling season by sizing cooling equipment correctly, or by providing supplemental dehumidification where needed
  - Implement a whole-house filtering strategy that meets the guidelines in Strategy 7.2

- Fan-powered local exhaust systems (systems that remove indoor air in a location where level of indoor air contaminants or moisture are expected to be high, such as a kitchen hood that is used to remove cooking contaminants or a bathroom fan that removes odors and moisture) that truly exhaust to the outside.

For guidance on selecting the HVAC system, see Strategy 1.2 below.

After Move-In

Some IAQ improvements are easy to add, regardless of whether the person has bought or rented a new or existing dwelling. For example, the occupant can install a portable air cleaner or a basement dehumidifier and take it with them if they move. See Strategy 1.5 for other ways the occupant can maximize the IAQ in the dwelling.

Strategy 1.2 Select Heating, Ventilation, and Air Conditioning (HVAC) Systems to Manage the Energy Effects of Ventilation



Introduction

Selection of the heating system, air conditioning system, or both for a dwelling is usually driven by cost, available fuels, and the local climate. The choice sets in motion a cascade of decisions that affect IAQ, creating opportunities and challenges for meeting IAQ goals. This section is for designers and builders, although it can also provide guidance to potential buyers and occupants.

Key criteria to consider when designing an HVAC system:

- Thermal comfort
- Humidity
- Noise
- Cost
- Maintenance
- Integration with filtration and ventilation air
- Impact on building pressure relationships
- Transfer of contaminants from unconditioned spaces through ductwork

Although people often talk about the HVAC system, dwellings sometimes have multiple systems that perform these functions, and some dwellings do not have a system that provides one of these functions.

The function of heating and cooling systems in dwellings is to maintain conditions that are thermally comfortable for the occupants. Dehumidification is an important additional function of cooling systems. Ventilation systems enhance IAQ by introducing outdoor air to dilute and remove contaminants, and they might or might not be integrated into the heating and cooling system.

In addition to making sure that an HVAC system has basic features — heating, cooling, dehumidification and ventilation with outdoor air — those choosing an HVAC system should consider several secondary features, including the system's energy efficiency, potential for affordable installation and operation, ease of maintenance, and contribution to good IAQ. Although IAQ is important for human comfort, it goes beyond what the occupants perceive because they are unlikely to be aware of many very harmful indoor air pollutants, such as carbon monoxide, nitrogen dioxide, and radon.

There is no "one size fits all" approach to selecting HVAC systems to support good IAQ. Each system that might be chosen influences the options available to the designer to address IAQ. Designers who consider IAQ when choosing an HVAC system can exploit the benefits of each system while taking steps to prevent problems. Regardless of the system chosen, designers need to include methods to dilute contaminants using outdoor air (Strategy 7.1) and filter air (Strategy 7.2). They also need to be aware of how the HVAC system's design might influence building pressurization and durability. The case studies in Appendix A show several system combinations that achieve these goals using different combinations of methods.

Air-Handling System and Conditioned Air

Air-handling system: Assembly of components, including the air-handling unit and attached ductwork, that deliver to a dwelling conditioned air.

Conditioned air: Air that has been treated to control its temperature, relative humidity, and/or purity.

Central Air-Handling Systems

Perhaps the most consequential choice for the dwelling's design is whether to use a central air-handling system. Central air-handling systems have a centralized fan that delivers heated or cooled air to the conditioned spaces of the dwelling through a system of ducts. Possible methods of heating or cooling the air for these systems include forced-air furnaces, heat pumps, air conditioners, and ground-source

heat pumps. Central air handling systems are common because they are often economical, have less equipment to maintain than more distributed systems, and offer the most options to integrate heating and cooling into a single system.

A central air-handling system provides several opportunities for integration with systems that support IAQ. Outdoor ventilation air (Strategy 7.1) and filters (Strategy 7.2) can be integrated into the air-handling system. This type of system provides more options for designers, who can sometimes simplify the system in ways that reduce installation, maintenance, and replacement costs. Also, the mixing of indoor air when these systems are used can prevent contaminant "hot spots" from reducing IAQ in certain rooms.

However, integrating a filter or outdoor air ventilation strategy into the central air-handling system is not always the best choice. The impact of system runtime must be considered. Allowing the system to turn on only when heating and cooling are needed (as is typical in most dwellings) reduces the effectiveness of the filter and the quantity of ventilation air in mild weather. Because filtration and ventilation are needed in all weather conditions, a controller must be added to achieve minimum run time of the air-handler (AHU; equipment with a fan or blower that draws air in one side, passes it through components that heat, cool, and/or alter its humidity, and blows it out the other side) when demand for heating and cooling is insufficient to support these functions. In addition, the AHU fan is typically large and consumes more energy than the smaller fans typically used for standalone outside air ventilation or filtration. The designer should consider ways to reduce this energy impact (such as those presented in Strategies 7.1, 7.2, and 8.1) while maintaining good IAQ.

The duct system provides a pathway through which several problems can arise. If leaky ducts are outside the conditioned space, they can introduce contaminants from attics, garages, or crawlspaces (Strategy 3.6). They can also alter the pressure balance in the dwelling, creating combustion safety problems (Strategy 6.1), reducing energy efficiency, or increasing contaminant transfer from adjacent spaces (Strategy 6.3). Locating the ducts inside the enclosure of the dwelling, testing the ducts for leakage, and sealing them if necessary can prevent or at least reduce these problems. Because the AHU is an important part of the duct system, it should be inside the thermal enclosure and included in airtightness testing and air sealing.

When air conditioning is added to existing dwellings with ducts that previously carried hot air only, complete insulation and a vapor retarder are particularly important (Strategy 4.2). In climate zones 1, 2, 3, and 4 (Figure 1.2-A), the addition of air conditioning usually requires replacing the ducts because larger airflow volumes are typically needed.

Nonducted HVAC Systems

A wide variety of system options are available for thermal conditioning (process of heating, cooling, and/or dehumidifying a dwelling to achieve human comfort and durability) without a central ducted system, including: radiant floor heating, baseboard or radiator heating, ductless minisplits (small, low-capacity heat pump or air conditioner, often in or close to the living space; shown in Figures 1.2-B and 1.2-C), and self-contained through-the-wall air conditioners and heat pumps. These systems are common in small dwellings, apartments, and larger dwellings that lack air conditioning.

Figure 1.2-A 2017 North American Climate Zones

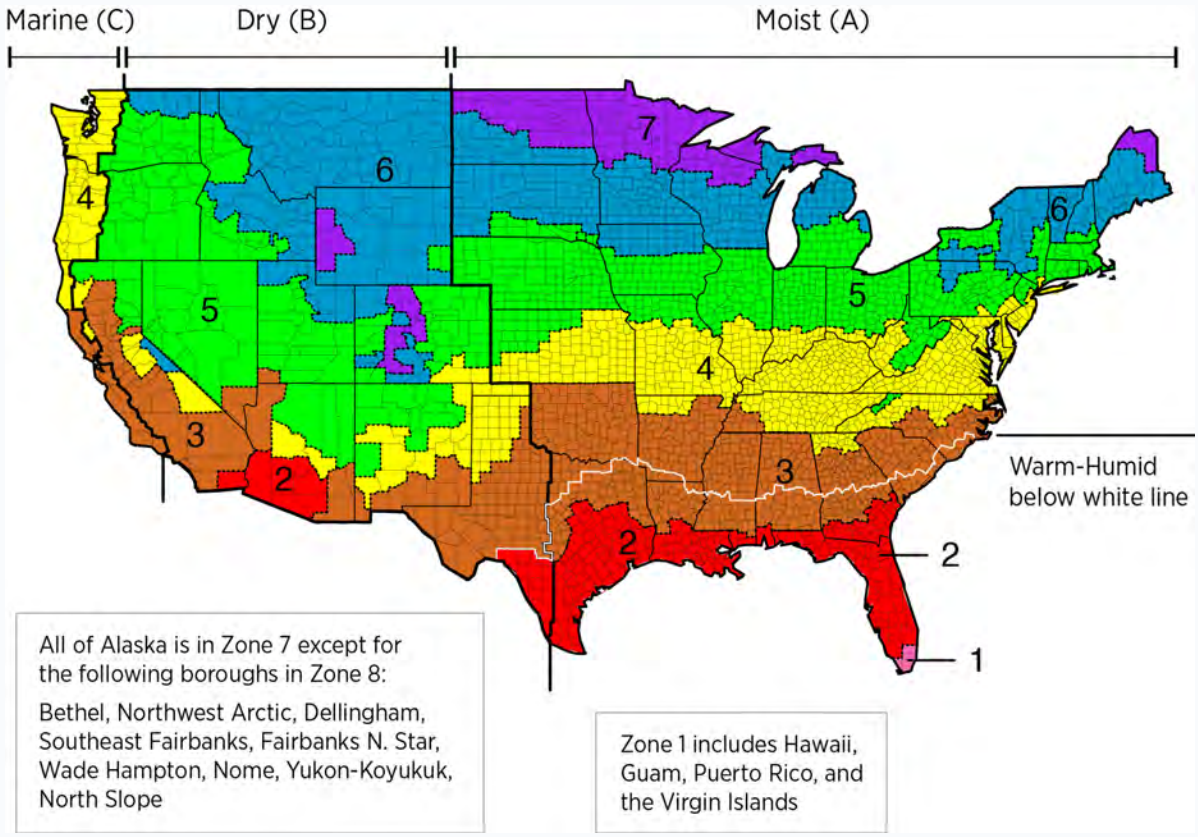


Figure 1.2-A 2017 North American Climate Zones
Map courtesy ASHRAE (2017e).

When a nonducted system is used, no central duct system is available to filter or deliver outside ventilation air, and the indoor air cannot be easily mixed. These issues do not mean that the dwelling cannot have very good systems to achieve good IAQ, but the available options are limited. The case studies in Appendix A include some options for ventilation and filtration that do not require a ducted HVAC system.

Filtration options (Strategy 7.2) for nonducted systems are limited. Standalone filter units take