2020 WHITE PAPER

WHAT WE BREATHE, WHAT WE FEEL:

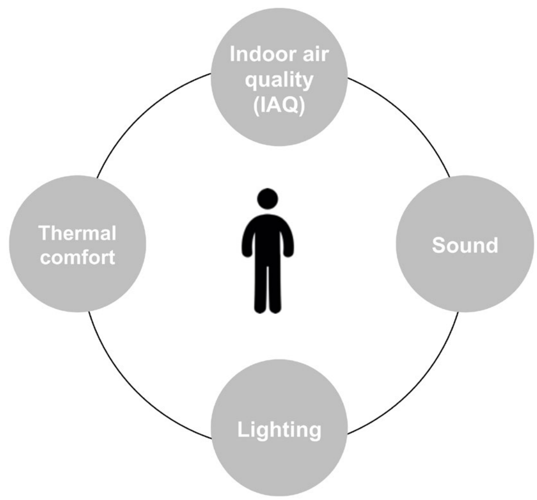
DESIGNING HOMES FOR OPTIMAL IEQ

INTRODUCTION

Typical homeowners may understand the value of indoor air quality (IAQ), but will leave contributing technical features, like structural design, kilowatt hours, heating and cooling loads, and blower-door testing to the professionals. Builders can start with IAQ when educating homeowners on "high-performance" versus "code-built homes, but homeowners may find indoor environmental quality (IEQ) more impactful. IEQ describes how well the indoor environment promotes occupant comfort and health. Most people spend about 90 percent of their time indoors, making the value of IEQ readily apparent. According to a 2019 study by the Joint Center for Housing Studies at Harvard University and the Farnsworth Group, 30 percent of all US households had concerns about potential health hazards in their homes when surveyed in 2018.

The components of IEQ include thermal comfort, indoor air quality (IAQ), sound and lighting. IEQ requirements vary per occupant and household due to individual health needs and levels of sensitivity to sound, light, color and temperature. This White Paper focuses on controlling the indoor environment for thermal comfort and IAQ as related to HVAC design.

COMPONENTS OF IEQ



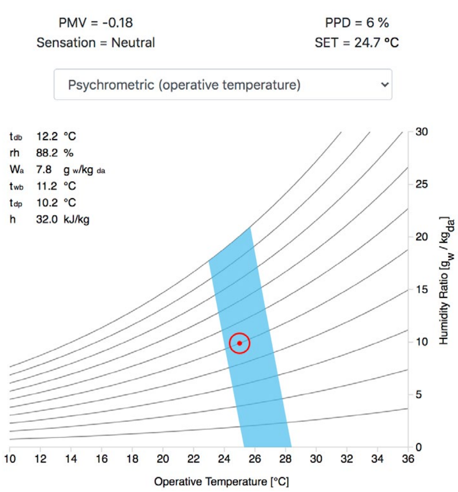
THERMAL COMFORT

Comfort is a subjective experience that can be affected by variables including the occupant's age, level of physical activity and where they were raised. ASHRAE Standard 55 and the Predictive Mean Vote (PMV) concept uses five factors to help builders design comfortable environments specific to occupants: **operative temperature, air speed, relative humidity, metabolic rate and occupant clothing**. Software like the Thermal Comfort Tool developed by the Center for the Built Environment (CBE) can help clarify requirements. The blue band in the image below shows where most people in the scenario described by the inputs are likely to feel comfortable.

INDOOR AIR QUALITY

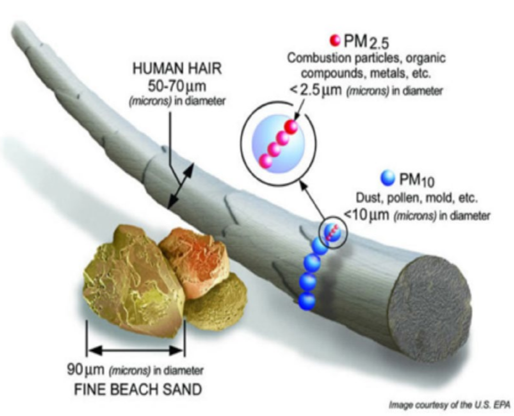
IAQ is particular to occupants but less subjective than comfort and is contingent on keeping pollutants from endangering occupant health. Contaminants of concern include particulate matter 2.5 (PM 2.5), acrolein, formaldehyde and volatile organic compounds (VOCs). PM 2.5, for example, can contribute to asthma, sinus congestion, coughing, skin rashes, brain plaque and cognitive issues, including headaches and sleep disturbances. Source control is the foundation of IAQ. In designing healthy homes, builders should avoid building products that off-gas formaldehyde and VOCs, consider all-electric appliances like induction cooktops to reduce indoor carbon dioxide pollution and limit the infiltration of outdoor pollutants.

THERMAL COMFORT TOOL



Source: Center for the Built Environment

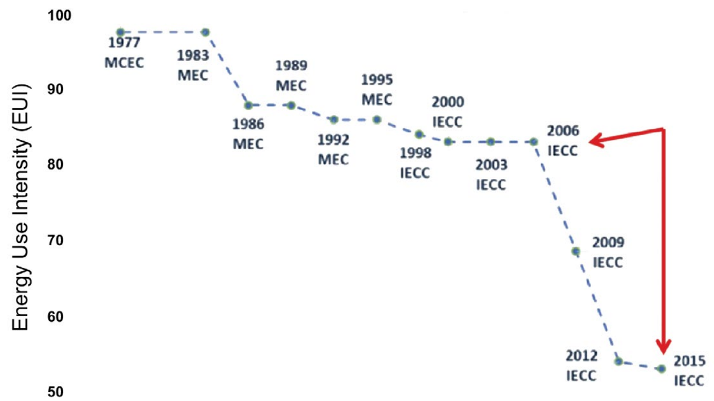
PARTICLE SIZES RELATIVE TO HUMAN HAIR



START WITH THE ENVELOPE

The healthy and comfortable home with optimal IEQ can be considered a **single system consisting of interdependent parts and sub-systems.** Builders and mechanical system designers give careful consideration to how components perform in relation to each other and other variables, including the local climate, altitude, solar orientation and individual occupant requirements. Code requirements for tighter envelopes, improved windows, increased insulation values and more-efficient appliances have reduced energy use intensity (EUI) since the 1970s, but also provide the foundation for better thermal comfort and IAQ.

RESIDENTIAL CODE STRINGENCY



EUI reductions as the International Energy Conservation Code (IECC) became stricter compared to the Model Energy Code (MEC) and Model Conservation Energy Code (MCEC) of the past

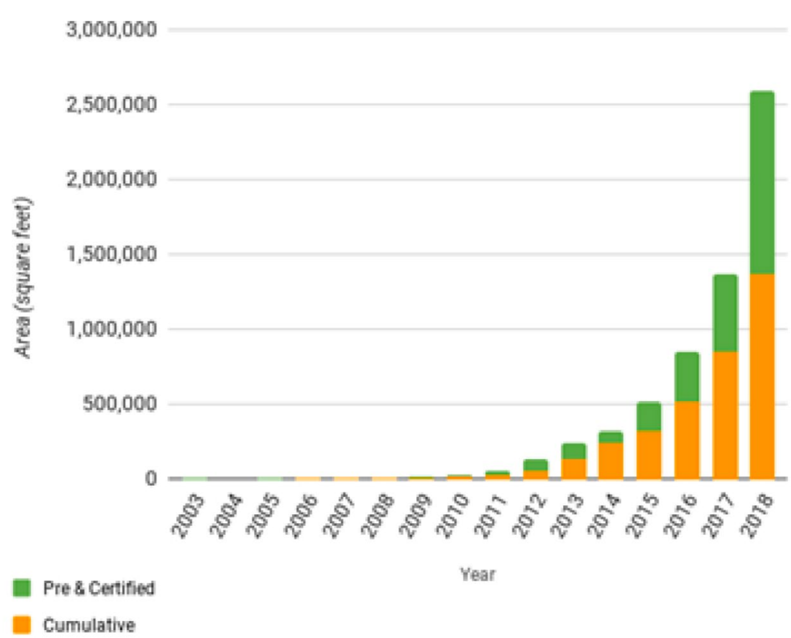
IAQ AND HOMEOWNER SATISFACTION

- Interest in healthy homes is greatest among millennials and families with children
- 3 of 4 households with healthy housing concerns prioritized IAQ
- More than one-third of surveyed homeowners had completed upgrades to improve IAQ or have plans to do so
- 68 percent of builders said addressing IAQ improved customer satisfaction

Source: **Healthy Home Remodeling: Consumer Trends and Contractor Preparedness**

Better indoor environmental control is made possible by higher construction standards due to stricter residential codes. High-performance construction methods like net-zero and programs like passive house exceed code and offer increased IEQ control. For example, instead of uncontrolled air infiltration and air leakage, which increases sensible loads and may introduce pollutants, healthy homes have low ACH50 values and introduce fresh air through dedicated ventilation systems. Code-built homes typically have air tightness between 4-6 ACH50, while healthy and comfortable homes built to passive house standards, for example, have an ACH50 of 0.6 or less. Greater control of the indoor environment through high-performance construction enables builders to customize IEQ for occupants. In more controlled environments, mechanical designs for heating, cooling and ventilation systems are more likely to promote occupant comfort and health as intended.

PHIUS+ CERTIFIED & PRE-CERTIFIED SQUARE FOOTAGE



As of 2018, PHIUS+ Certified and Pre-Certified projects total more than 2.5 million square feet across 2,300 units. Source: **Passive House Institute US**

CONTROL THERMAL ENERGY FLOW

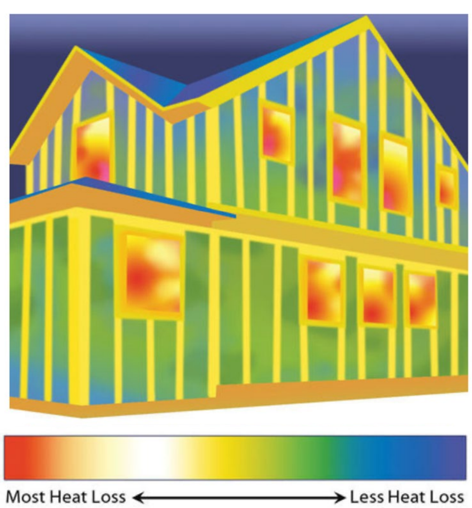
The IEQ controls strategy, including construction methods and mechanical design, should account for how nature seeks balance. This holds true for air pressure, moisture and heat. Air flows from spaces with higher air pressure to spaces with lower air pressure. Moisture naturally moves from places of higher moisture concentration to drier places. The direction of flow is always from a place of higher concentration to a place of less concentration. Additionally, whenever there is a temperature difference between objects or spaces, heat energy moves from warmer objects to colder objects as described by the Second Law of Thermodynamics.

THERMAL BRIDGING

A thermal bridge, also known as thermal bypass, is an area or component of an object which has higher thermal conductivity than the surrounding materials, creating a path of least resistance for heat transfer. In home construction, the bleeding of heat energy happens through low-grade windows, walls, roofs and floors. When designing high-performance homes for maximum efficiency, health and comfort, builders use techniques to eliminate thermal bridging such as continuous insulation and windows with low U-values to reduce heat loss in the winter and limit heat gain in the summer.

The home in the image below is in heating season with warmth on the inside and cold outdoors. The yellow parts of the frame are thermal bridges. Thermal bridges reduce energy efficiency and create health and comfort challenges. When the components of a building assembly are made colder than the air in those spaces, there is the potential for condensation. This can reduce the durability of the building and create potential health hazards like mold.

HOME WITH THERMAL BRIDGES

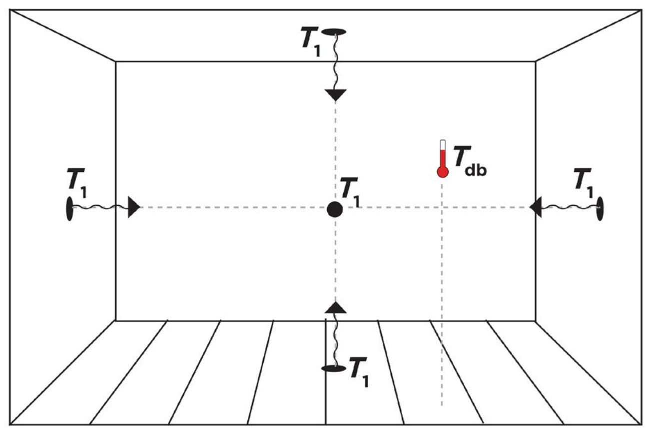


Source: BuildingGreen, Inc.

MEAN RADIANT TEMPERATURE

Even if the heating and cooling system maintains the air temperature set point, occupants will still feel uncomfortable if designs don't account for humidity, air velocity, air stratification and the mean radiant temperature (MRT), which is the average temperature of surfaces around an occupant. The radiative heat transfer caused by thermal bridges can lower the temperature of interior surfaces, which adds complexity to the challenge of addressing MRT when designing mechanical systems for comfort.

CONTINUOUS HEAT TRANSFER



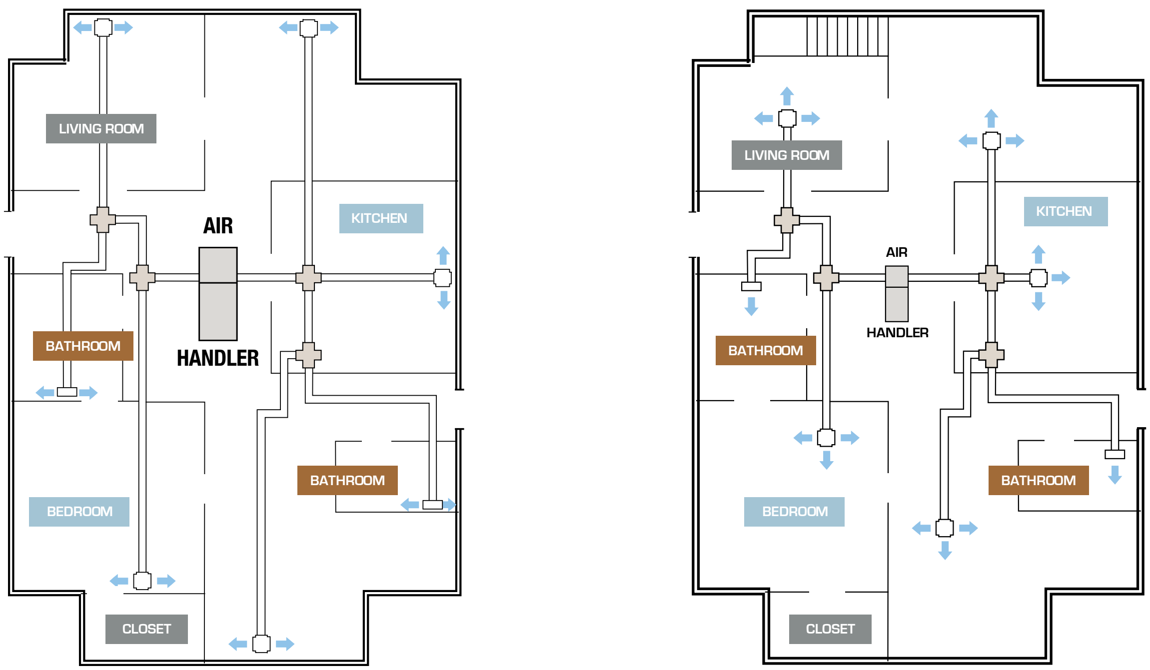
COMPACT DUCT DESIGN

Builders can further improve performance by applying a heat pump system with a compact duct design instead of a large, complicated, conventional duct design. During heating season, thermal energy is lost as conventional systems push conditioned air through long duct runs in unconditioned spaces. This heat loss through ducts can result in comfort issues not to mention poor energy performance. Similarly, in cooling season, long duct runs can result in hot air pushed from hot ducts.

In compact designs, duct runs are shorter and more centralized with ducts running to interior walls and blowing toward exterior walls. With shorter duct runs, and less opportunity for energy loss, builders can install smaller indoor units with quieter fans. Ductless indoor units for heat pump systems, such as **recessed ceiling cassettes** or **wall-mounts**, don't require ducts. Ducted **air handlers**, which might replace an old gas furnace in a retrofit, and **horizontal-ducted units**, which are about the size of a suitcase, are compact so builders can more easily fit all HVAC equipment and ductwork within the envelope.

CONVENTIONAL VERSUS COMPACT DUCT DESIGN

CONVENTIONAL DUCT DESIGN | COMPACT DUCT DESIGN



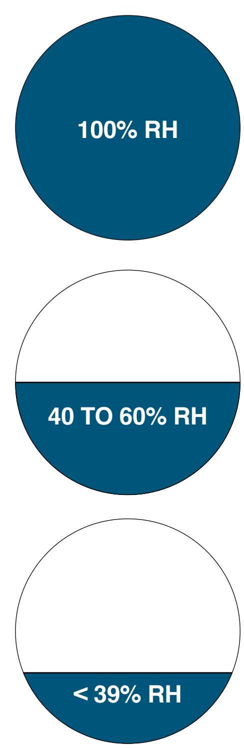
HUMIDITY CONTROL

Humidity control is required in all climates when builders design for health and comfort. The human body tries to maintain an internal temperature of around 98.6° F. The amount of moisture in the air affects the body's ability to regulate its temperature. Shivering helps a person raise their temperature, while sweating helps a person cool down. Too much humidity makes it difficult for sweat to evaporate and transfer thermal energy from the body. This is why a person might feel cooler in a dry space that has a higher air temperature than a more humid space.

Relative humidity (RH) is the ratio between moisture in a volume of air versus the amount of moisture it could hold at a given temperature and pressure. An RH between 40 and 60 percent, at dry bulb temperatures ranging from 68°-75° F, will allow most people to regulate their interior temperatures comfortably. **Some studies suggest that maintaining a 40 to 60 RH range can also support occupant health**. An RH less than 40 percent can result in dry mucosa, which increases the occupant's susceptibility to respiratory issues.

Humidity control requires attention to the envelope and mechanical system design. Eliminating thermal bridging by insulating surfaces such as windows and ductwork, enables a home to better handle an RH of 40 percent without condensation and mold issues. In some cases, depending on variables like the heat pump's sensible heat factor (SHF), the climate and occupant behavior, builders may apply dehumidifiers to achieve optimal humidity levels. Highly-efficient heating and cooling systems like variable-capacity heat pumps lower sensible loads but don't always address latent loads.

RELATIVE HUMIDITY



MAINTAIN SET POINTS WITH HEAT PUMPS

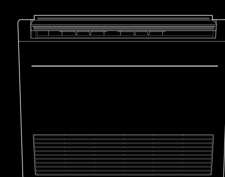
A heat pump uses the natural movement of thermal energy from hotter objects to colder objects to heat or cool the home's zones. In heating mode, the outdoor unit expands refrigerant gas to make it colder than the ambient air. This enables the unit to extract thermal energy from the outdoor air and transfer it via refrigerant lines to the indoor unit that conditions the zone. Using this method, a heat pump can provide more energy for heating than it consumes in electricity. The coefficient of performance (COP) for some heat pumps can be greater than 3 at 5° F. Even at low ambient temperatures, modern, all-electric heat pumps can be up to three-times more efficient than conventional electrical-resistance systems that can reach a COP of 1. In cooling mode, this process is reversed with thermal energy transferred away from the zone and indoor unit.

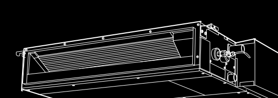
Variable-capacity heat pumps adjust refrigerant flow and fan speeds to match heating and cooling loads. The outdoor unit's compressor adjusts its speed to maintain the set point of each zone. In a well-insulated, air-tight, controlled indoor environment, with low sensible loads, these systems, when properly sized, can maintain zone set points and can ramp up capacity to provide comfort when **ASHRAE** design temperatures occur. Proper HVAC design for variable-capacity systems requires room-by-room load calculations and consideration for system capacity ranges. Each system has a minimum and maximum capacity published in the manufacturer's technical literature and builders need to ensure the range fits the home's loads. To limit the risks of oversizing and undersizing, **Manual J®**, **Manual S®**, **Manual D®** and **Manual T®** are mandatory. Load calculations should be revisited during retrofits if the homeowner has improved the home's insulation, added a new room or wants a ductless mini-split to serve a previously unconditioned space like an attic. Improper load calculations and duct designs commonly cause performance issues.

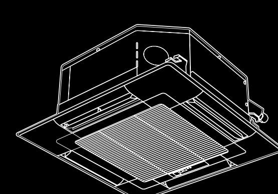
Comfort is subjective and heat pump systems with individually-controlled indoor units for each zone create opportunities to customize comfort for specific occupants and activities (e.g., cooking, exercise, sleep). Using multiple independent units and compact duct runs, rather than a large central system, gives the builder more flexibility to design according to occupant preferences. Indoor unit selection depends on aesthetic preferences, comfort needs and the application. If the cost of changing ductwork in an existing house is prohibitive, ductless indoor units may be the solution. In a new, two-story home, the builder might install a ducted unit for each zone.

DIVERSE EQUIPMENT OPTIONS

- Heat pump systems can be **single-zone**, with one outdoor unit and one air handler, or **multi-zone**, with up to 8 indoor units connected to a single outdoor unit
- Indoor units include ductless options like **wall-mounts** and **ceiling cassettes** as well as ducted options such as **air handlers** and **horizontal-ducted units**







AIR SPEED AND MOVEMENT

Air distribution, speed and stratification affect how occupants experience a zone's temperature. If the home's air is stratified, with cold air at the bottom and hot air at the top, homeowners may be uncomfortable. As discussed earlier, heat is always flowing. Also, volumes of air naturally seek to equalize pressures, with air flowing from high pressure to low pressure. In most variable-speed heat pump systems, fans run continuously to distribute air and reduce stratification. Continuous movement eliminates the need to blow air at high velocities. Sensors monitor temperatures as the air passes through indoor unit coils, so the system can move the fan at the best rate for optimizing comfort. When selecting systems, the project team should review manufacturer literature to understand air throw from units and how the units meet requirements derived from **Manual T** air movement calculations.

HEAT PUMPS AND SOUND CONTROL

The sound control component of IEQ includes minimizing operational noise from mechanical systems. Indoor units and outdoor units operate at sufficiently low decibels to limit the risk of hearing damage and help create more tranquil environments for occupants. When builders install outdoor units on patios or in developments with small setbacks, the ability to operate at a decibel level similar to a normal conversation is a significant benefit. Occupants can enjoy outdoor spaces without disruptions, and builders can be confident the equipment will more than satisfy noise regulations for outdoor units in **cities like Seattle**.

INTEGRATE CONTAMINANT CONTROL METHODS

WIth low energy cost fans, ducted mini-splits with high efficacy filters can help reduce airborne contaminants like PM 2.5 and animal dander by filtering the air that passes through indoor unit coils. Mid- and high-static ducted mini-splits can be used in combination with properly designed duct systems to accommodate higher-efficiency filters. But to fully realize strategies for contaminant control, builders integrate and coordinate dedicated equipment for filtration, dilution and elimination with controls provided by heat pump manufacturers.

SOUND LEVELS AND HEARING DAMAGE

2 minutes at 110 dB(A) can potentially damage hearing
Fireworks: 140-160 dB(A)
Ambulance: 110-129 dB(A)

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Fireworks: 140-160 dB(A)
Ambulance: 110-129 dB(A)

8 hours at 85 dB(A) can damage hearing
Lawnmower: 80-100 dB(A)

Sounds are generally safe at 70 dB(A) and below
Normal conversation: 60-70 dB(A)
Outdoor unit: 60 dB(A)
Whisper: 30 dB(A)
Indoor unit: 22 dB(A)

Source: National Institute on Deafness and Other Communication Disorders.

MERV AND PARTICLE SIZES

MERV Rating	Average Particle Size Efficiency in Micrometers
1-4	3.0 - 10.0 less than 20%
6	3.0 - 10.0 49.9%
8	3.0 - 10.0 84.9%
10	1.0 - 3.0 50% - 64.9%, 3.0 - 10.0 85% or greater
12	1.0 - 3.0 80% - 89.9%, 3.0 - 10.0 90% or greater
14	0.3 - 1.0 75% - 84%, 1.0 - 3.0 90% or greater
16	0.3 - 1.0 75% or greater

Source: EPA

WHOLE-HOME FILTRATION

MERV stands for Minimum Efficiency Reporting Value and uses a scale of 1-20 to describe how effectively a filter can capture particles of a given size. For example, MERV 8 indicates the filter can capture particles larger than 3 micrometers. A MERV rating of 13 to 16 means the filter can capture particles bigger than 0.3 micrometers. A High-Efficiency Particulate Air Filter (HEPA) has capabilities in the range of MERV 17 to 20 and can be expected to remove 99.97% of airborne particles as small as

0.3 micrometers. When considering the level of filtration required for the health of particular occupants, builders should consider the impact of the static pressure drops associated with increases in the efficacy and depth of pleated filters. The duct design and **Manual D** calculations must account for pressure drops which cause air to move more slowly. Depending on the application, a larger space may be needed to accommodate a larger filter or larger return duct to slow the velocity of the air.

Homes with multiple zones may have a mix of indoor unit styles, including ductless and ducted units. A ducted indoor unit may provide MERV 13 performance or higher depending on the available static pressure. If the homeowner's IEQ requirements mean higher filtration levels are needed, builders can install a complementary system purpose-built for whole-home filtration. Air-filtration systems use MERV 13, MERV 16 or HEPA filters. In addition to reducing contaminants for better IAQ, these filtration systems move air between zones, enhancing occupant comfort by improving mixing and reducing air stratification.

ELIMINATION AND DILUTION

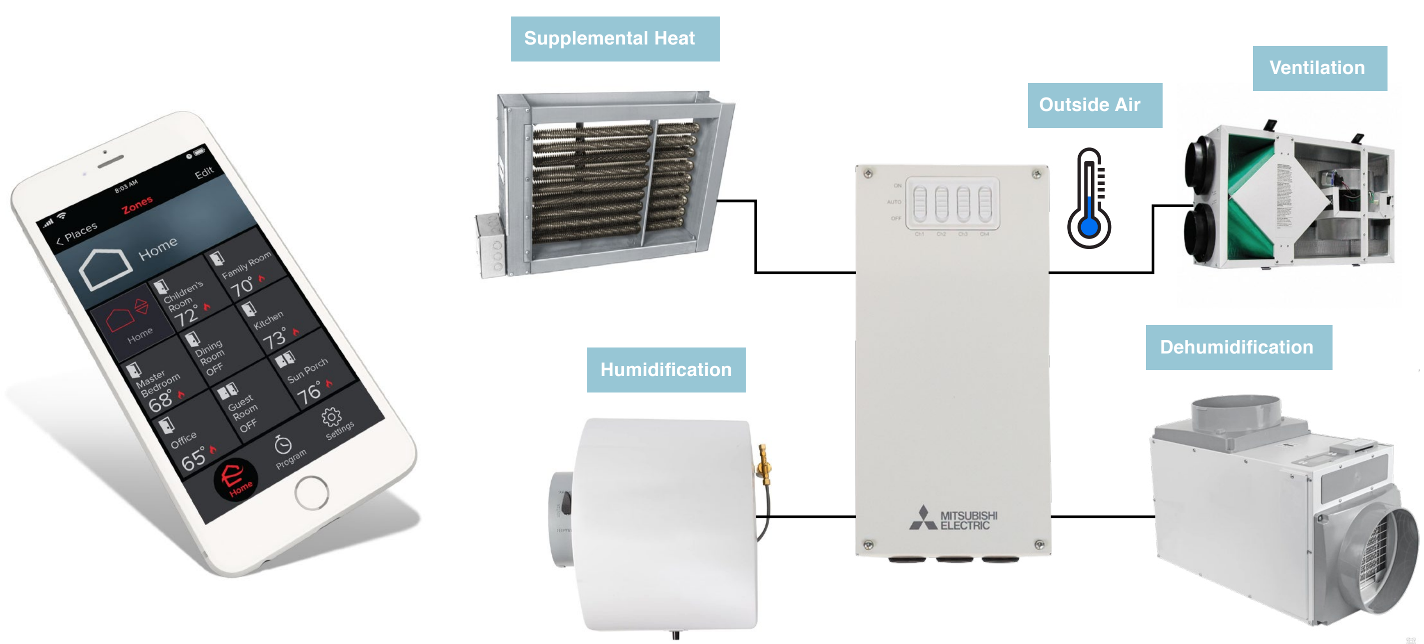
For pollutant control at source points like cooktops and bathrooms, builders will install exhaust fans to remove particulates from the home. Dedicated exhaust fans over cooktops are are ideally under 400 CFM. Higher airflows require makeup air by most codes and can cause depressurization in airtight homes.

To address pollutants that can't be eliminated or filtered, healthy and comfortable homes use high-performance ventilation systems to introduce fresh outdoor air. An energy recovery ventilator (ERV) or heat recovery ventilator (HRV) provides conditioned ventilation air to dilute pollutants and remove stale air without significantly increasing heating or cooling loads. Humidity-balanced, conditioned fresh air may be directed to the air handler or ducted directly to zones served by ductless units.

CONTROLS AND INTEGRATION

Through the integration of systems for heating, cooling, ventilation, filtration and humidity control, builders enable homeowners to obtain information and control IEQ equipment with minimal effort. For today's homeowners, controls must offer intuitive interfaces and options for control through mobile devices and integration with digital assistants and third-party thermostats. Ease of use is the goal of any controls solution, so builders will want to consider systems that incorporate sensors for automated changeover to supplemental heating sources and demand-based control based on occupancy, humidity and the presence of pollutants like VOCs or carbon dioxide.

INTEGRATED EQUIPMENT



CONCLUSION

The trend toward healthy and comfortable homes reorients high-performance construction toward the essential purpose of shelter. Homes have always served as a means to control environmental conditions to improve their suitability for human beings. With modern construction methods, mechanical systems, knowledge of human physiology and help from immutable physical laws, builders can produce homes purpose-built for occupant comfort and health. For further discussion of IEQ, consider watching our webinar with *Fine Homebuilding.*

Source: Andrea Calo