U.S. DEPARTMENT OF
ENERGY

Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Healthy Indoor Air Quality: A Guide To Understanding Pollutants In Extreme Cold Climates

IECC Climate Zones 6 and Above

Extreme cold climates require special measures to mitigate impacts of interior and exterior source pollutants. *Illustration by Joshua Bauer, NREL.*

Pollutants concentrate in extreme cold climates homes that tend to be more airtight and have poor ventilation (Johnson et al. 2002 and Singleton et al. 2017).

What Does It Mean To Have Healthy Indoor Air Quality

A healthy indoor environment means that the air you breathe inside your home is free of large concentrations of pollutants. This is not as simple as it sounds; the indoor air in a house can be two to five times more polluted than the air outside (U.S. EPA 2021). Knowing where major pollutants come from and potential mitigations can help home occupants control and improve their indoor air quality (IAQ).

There are many reasons why the IAQ in a home can be outside a healthy range. Sometimes particulates, odor, and gases can come from outside and be trapped indoors, such as smoke from a wildfire. Other sources can originate inside the home, such as particulates and oil vapors from cooking and chemical vapors released by furniture and cleaning supplies.

Avoiding materials that introduce pollutants should be the primary strategy for healthy IAQ. However, even with the best avoidance practices, pollutants still enter homes. Ventilation, diluting indoor air with outside air, is the most common method for removing pollutants.

ASHRAE Standard 62.2 2019 specifies the importance of dwelling unit ventilation, and it defines volumetric air flow requirements based on floor area and number of bedrooms. However, if done improperly, ventilation can introduce pollutants from unwanted spaces, like garages and crawlspaces. Untempered outside air can also cause discomfort by lowering temperature and humidity within the home.

In some cases, filtration supplements ventilation and can potentially reduce the energy demands of a ventilation-only system while also maintaining humidity and temperature by reducing the amount of air exchange required to keep pollutants within a healthy range.

Methods for Improving IAQ

Source Control: Avoiding activities and materials that introduce pollutants is the most important method for maintaining healthy IAQ. Smoking, burning candles, and heavy chemical cleaners and air fresheners can introduce pollutants into the house that should be avoided.

Ventilation: Ventilation can be passive or mechanical. Passive ventilation is typically accomplished through open windows and doors. In cold climates this is not an option in the winter. Mechanical ventilation uses fans to exchange air in the home. Exhaust ventilation, using bathroom fans and range hoods, is the most common form of home ventilation. This type of ventilation is unbalanced, however, and can create cold drafts in the winter, which leads to less healthy IAQ if occupants turn off the system (Kotol 2021). Positive pressure ventilation is discouraged in cold climates, as it can force interior moisture into wall cavities if the building envelope is compromised.

Heat or energy recovery ventilation (HRV or ERV) systems are another approach to ventilating homes. These balanced ventilation systems are more commonly built into new homes as it can be difficult to retrofit a fully ducted system into an existing home. Even though these systems can recover exhausting heat energy, they still introduce colder air into the house (especially in the coldest climates on the coldest days).

Filtration: Filtration means forcing air through a filter medium that traps pollutants, mainly particles. Specialized air filters also exist that can remove certain gases from the air. Filtration systems can be stand-alone or can operate in tandem with existing heating/ventilation systems. Filtration systems must be operated and maintained properly

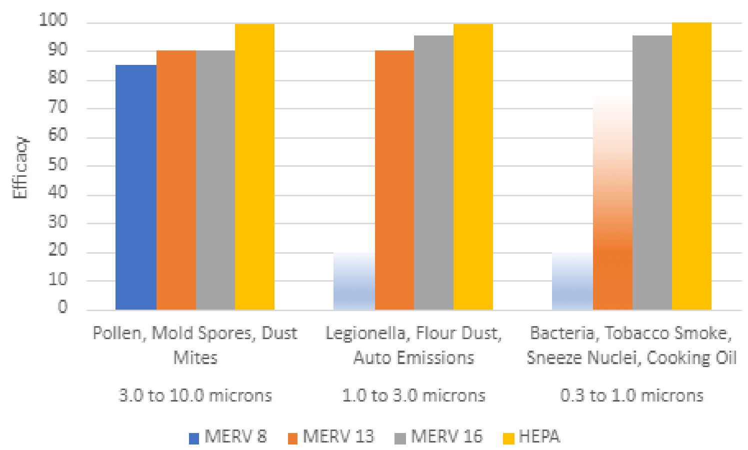

Figure 1. Filter rating comparison. Efficacy describes the specified efficiency at removing specific sized particles. Gradients signify that the filter can reach up to the top point, but may or may not reach it.

in order to be effective at removing particulates from the air. Filters only work if air is circulated through them; for filters incorporated into furnace heating systems, that is about 20% of the time (Harriman, Stephens, and Brennan 2019). Portable air filters or air cleaners can be helpful in removing pollutants if they are the correct size for the space and can remove particles of all sizes suspended in air, even the particles as small as 0.1 to 1 microns (U.S. EPA 2020).

Air filters are rated based on the size of particles they can remove and how efficient they are at removing the particles (ASHRAE 2017). A Minimum Efficiency Reporting Value (MERV) rating is most common in heating and ventilation systems. The larger the MERV rating, the better the filter will be at trapping the particles. MERV 8 is most typical for larger dust particles (10 microns or larger, PM_{10}); MERV 13 will remove 90% of fine particles that are 2.5 microns or smaller in diameter ($PM_{2.5}$). High Efficiency Particulate Air (HEPA) filters are another option. HEPA filters are considered 99.97% effective at removing particulates with a 0.3 micron diameter. Figure 1 provides a summary of MERV and HEPA filter efficacy (ASHRAE 2017). Changing the filter efficacy in an existing system can affect the airflow of the fan and should be evaluated before making filter changes.

Table 1. Annual Energy Cost Associated With Ventilation

Air Leakage	Ventilation Option	Air Leakage/Ventilation Heating Costs* (Alaska)	Air Leakage/Ventilation Heating Costs* (Northern U.S.)
Leaky 5 ACH50	Natural 85-90 CFM	$370	$389
	Exhaust 92-93 CFM	$477	$369
Average 4 ACH50	Natural 65-69 CFM	$402	$289
	Exhaust 92-96 CFM	$458	$454
	HRV 90-94 CFM	$423	$321
Tight 1 ACH50	Exhaust 92 CFM	$459	$369
	HRV 93-94 CFM	$199	$157

** Based on 2021 average cost of heating for Alaska ("Alaska – SEDS – EIA" n.d.)*

Portable air cleaners are electric units that are designed to provide clean air to a space (typically sized for a room) by pulling air into the device and passing it through filters or some form of pollutant capture device. The clean air delivery rate (CADR) is a measure of the air cleaner's delivery of "clean" air, usually measured in cubic feet per minute (CFM). The higher the CADR, the more effective the air cleaner; cleaners must be sized for their location (California Air Resources Board 2022). Studies of air cleaners find significant (50%) reduction in indoor particulate pollutants (as small as $PM_{2.5}$); however, there is less decisive information on the effectiveness of air cleaners for other pollutants (U.S. EPA 2018a).

Monitoring and Other Methods: Tracking the quality of air by using monitoring devices that detect when IAQ is out of range is a good way to keep an eye on certain pollutants that may cause harm and to develop a mitigation strategy. There are several multi-pollutant IAQ meters on the market. When looking for one, make sure that it meters the pollutants of concern and that it has reasonable accuracy in metering (http://www.aqmd.gov/aq-spec/evaluations and Wang et al. 2020 offers some accuracy test data for $PM_{2.5}$).

There are other potential air cleaning methods that are not covered in this document, such as ultraviolet germicidal irradiation and electrostatic precipitators, but they tend to be large and inappropriate for residential buildings (U.S. EPA 2018a). Additionally, some of these types of systems can produce local ozone, which is a dangerous pollutant that should be avoided in homes (U.S. EPA 2018a).

Energy Costs

Maintaining healthy IAQ has certain associated energy costs, especially during the winter. Ventilation replaces the warm indoor air with cold outside air roughly once every 3 hours if the system is sized and used appropriately; this can lead to a significant heating energy demand. An HRV or ERV

Table 2. Common Indoor Pollutants

Pollutant	Sources	Health Effects	Mitigation Strategies
Carbon monoxide (CO) is an odorless, colorless, and toxic gas	• Fuel-burning heaters, propane cook stoves, vehicles, and wood-burning stoves (any device that has incomplete combustion)	• Headache • Nausea • Death	**Avoidance, CO detection, and proper maintenance of combustion appliances** • Combustion devices need to be properly installed, vented, and maintained • All homes should have CO detectors that are properly maintained and tested regularly
Particulates ($PM_{2.5}$ and PM_{10}) — small particles that can be inhaled deep into the lungs and can enter the bloodstream	• Road dust stirred up from dirt roads is an example of PM_{10} • $PM_{2.5}$ is created through cooking and combustion; wildfires create dangerous $PM_{2.5}$ conditions outside • Woodstoves, fireplaces, gas ranges, smoking, and burning candles are inside sources of $PM_{2.5}$ • Smoking tobacco introduces particulates • Hair and dander from pets • Pollen	• Asthma • Eye, nose and throat irritation • Allergies • Aggravation of respiratory illness $PM_{2.5}$ can also cause • Heart attacks • Aggravated heart and lung disease	**Avoidance, ventilation, and filtration** • Avoid smoking and burning incense or candles inside • Using the range hood when cooking is very important to controlling PM • Diluting the particulates in the air with clean outside air is the most common mitigation for particulatev matter • Filtration is effective at removing particulate matter from inside air if filters with appropriate ratings are utilized (e.g., MERV 13 for $PM_{2.5}$) and are maintained and operated properly If outside air quality is poor, filtration can help
Carbon dioxide, mold spores	• Overcrowding and/or underventilation can cause excess carbon dioxide	• Reduced cognitive function • Asthma • Respiratory infection	**Ventilation** • Carbon dioxide is lowered by increasing ventilation
Mold spores	• Overcrowding and/or underventilation can cause levels of moisture which can cause mold growth • Bulk water from weather, the ground, or pipes can be a significant source of mold	• Asthma • Respiratory infection	**Ventilation and dehumidification** • Humidity is lowered by increasing ventilation • Bathroom fans and kitchen range hoods are critical to lowering humidity build-up • Dehumidifiers can also be effective in high humidity scenarios • Eliminate bulk water problems by repairing leaks Any mold that develops needs to be physically removed with cleaning
Volatile organic compounds (VOCs)	• Cooking, especially at high temperatures, emits VOCs • Furniture and cabinetry often continuously emit VOCs and may continue emitting for many years • Many cleaning supplies emit VOCs during use • Tobacco smoke contains many VOCs	• Asthma • Respiratory infections • Skin, eyes, nose irritation • Cancers • Nervous system problems • Nausea • Fatigue	**Avoidance, ventilation, and filtration** • Avoiding activities that introduce VOCs inside the home as much as possible will lessen exposure • Spot ventilation via kitchen range hood when cooking lessens VOCs from cooking • Whole-house ventilation is important to dilute concentrations of VOCs in a home • Activated carbon filters can help remove VOCs from the air, although there are no standards of effectiveness • More information on VOCs is available at: https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality
Viruses	• Transmitted from person to person • Travel on respiratory droplets exhaled during breathing	• Sickness (e.g., SARS-CoV-2, chickenpox, and influenza) and sometimes death	**Ventilation and filtration (HEPA)** • Ventilation dilutes airborne virus concentration • Filtration in-line with a heating system can decrease risk of airborne infection by up to 50% relative to no filtration system (Azimi and Stephens 2013) • Portable air cleaners that filter very small particles (HEPA) can be effective in removing viruses from the air
Radon — a radioactive gas that occurs naturally	• Radon exists naturally within soils, rocks, and water • Radon is present in nearly all soils, and any home has the potential to have elevated levels of radon • It can travel into a home through the cracks and openings in floors and walls	• The leading cause of lung cancer in non-smokers	**Ventilation and foundation depressurization** • Testing is necessary to know if your house has a radon problem • Whole-house ventilation can reduce radon concentration • Sub-slab exhaust systems are long-term radon mitigation solutions • The EPA provides radon mitigation strategies for buildings: https://www.epa.gov/radon/radon-standards-practice

can lower the demand by recovering some heat from the exhausting air.

Table 1 presents basic ventilation energy cost information from an energy model of a 2,000 ft^2 home with varying ventilation strategies located in cold climates like Alaska and northern Minnesota. The minimum required ventilation air for this house is 90 CFM (ANSI/ASHRAE Standard 62.2-2019, 2019). The leaky house barely reaches 90 CFM naturally in Alaska; it requires ventilation to meet the minimum ventilation in the warmer location. For the average house, natural ventilation is too low to meet the minimum required for healthy air. The natural, exhaust, and HRV ventilation option effects shown describe passive, exhaust fan, and heat recovery methods, respectively.

Air tightening of the home envelope can save significant energy costs, but adding ventilation as the home gets tighter is imperative to maintaining healthy IAQ. The heating costs shown in Table 1 represent what is lost from the house due to all air transfer, including passive, exhaust, and HRV/ERV means as shown. It is important to note that a tighter envelope with mechanical ventilation costs less money than a very leaky house with natural ventilation.

In some cases when high outdoor pollution levels or adverse weather limit the possibility of increasing ventilation rates, air filtration might be an option to help improve IAQ (U.S. EPA 2018b). In extreme cold weather, portable air filters could potentially lower high energy costs, but ventilation will always be necessary because commonly available air filters do not address all pollutants such as gaseous pollutants like carbon monoxide, carbon dioxide, nitrogen dioxide, ozone, etc.

Pollutant Types

The air inside a home can accumulate pollutants at a higher concentration than the outside air (U.S. EPA 2021). They can be seriously harmful when confined into high concentrations inside the home. Pollutants in indoor air can be highly variable in types and concentrations and are very dependent on occupant behavior and building characteristics. Table 2 highlights some pollutants of concern in a home.

Key Takeaways

The indoor home environment can become unhealthy without occupants even being aware of it. Most indoor pollution mitigation strategies require occupant knowledge and participation to employ avoidance, detection, and removal strategies. Automated or manual mechanical ventilation systems rely on occupant understanding so that they are properly maintained and not disabled. Filtration will not work if the system is not utilized regularly and maintained.

In cold climates, the cost of air leakage through the building envelope can be up to 35% of the whole-house heating load. A tight building envelope coupled with balanced mechanical ventilation can lower that percentage to 12% if heat recovery is part of the ventilation system. However, even with heat recovery, ventilation air can be perceptively cold for the occupant where it is introduced into the living space; this cold, uncomfortable air means that properly sized ventilation systems may be turned off or not engaged by the occupants. An auxiliary filtration system, in-line with existing ducts or a stand-alone room filter, can help improve IAQ when cold exterior temperatures cause the ventilation to be turned off or cut back. Filtration cannot replace ventilation entirely, because pollutants like VOCs, carbon dioxide, excess moisture, and radon require ventilation or other mitigation methods.

The best method for improved IAQ is an educated home occupant who is actively working to maintain a healthy indoor environment. ■

References

"Alaska - SEDS - U.S. Energy Information Administration (EIA)." n.d. Accessed January 6, 2022. https://www.eia.gov/state/seds/data.php?incfile=/state/seds/sep_prices/tx/pr_tx_AK.html&sid=AK.

ASHRAE. 2017. "Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size ANSI/ASHRAE Standard 52.2-2017." 52.2-2017.

ASHRAE. 2019. "Ventilation and Acceptable Indoor Air Quality in Residential Buildings. ANSI/ASHRAE Standard 62.2-2910.".

Azimi, Parham, and Brent Stephens. 2013. "HVAC Filtration for Controlling Infectious Airborne Disease Transmission in Indoor Environments: Predicting Risk Reductions and Operational Costs." *Building and Environment* 70 (December): 150–60. https://doi.org/10.1016/j.buildenv.2013.08.025.

California Air Resources Board. 2022. "Air Cleaning Devices for the Home." 2022. https://ww2.arb.ca.gov/resources/fact-sheets/air-cleaning-devices-home.

Harriman, Lew, Brent Stephens, and Terry Brennan. 2019. "New Guidance for Residential Air Cleaners." *ASHRAE Journal* 61 (9): 8.

Johnson, R., Schmid, J., and Seifiert, R. 2002. "Assessment of indoor air quality in interior Alaskan homes." Journal of Cold Regions Engineering, 16(4), 218-229.

Kotol, Martin. 2021. "Current Ventilation Strategies in Greenlandic Dwellings." *Journal of Building Engineering* 39 (July): 102283. https://doi.org/10.1016/j.jobe.2021.102283.

Sherman, Max. 2015. "How ASHRAE Set the Rates for Residential Ventilation." *ASHRAE Journal* 57 (July): 20–23.

Singleton, R., et al. 2017. "Housing characteristics and indoor air quality in households of Alaska Native children with chronic lung conditions." Indoor Air, 27, 478–486. doi:10.1111/ina.12315

U.S. EPA. 2018a. "Guide to Air Cleaners in the Home, 2nd Edition." Overviews and Factsheets. https://www.epa.gov/indoor-air-quality-iaq/air-cleaners-and-air-filters-home.

———. 2018b. "Residential Air Cleaners - A Technical Summary." EPA-402-F-09-004. https://www.epa.gov/sites/production/files/2018-07/documents/residential_air_cleaners_-_a_technical_summary_3rd_edition.pdf.

———. 2020. "Air Cleaners, HVAC Filters, and Coronavirus (COVID-19)." Collections and Lists. June 18, 2020. https://www.epa.gov/coronavirus/air-cleaners-hvac-filters-and-coronavirus-covid-19.

———. 2021. "Volatile Organic Compounds' Impact on Indoor Air Quality." Overviews and Factsheets. 2021. https://www.epa.gov/indoor-air-quality-iaq/volatile-organic-compounds-impact-indoor-air-quality.

Wang, Zhiqiang, William W. Delp, and Brett C. Singer. 2020. "Performance of Low-Cost Indoor Air Quality Monitors for PM2.5 and PM10 from Residential Sources." Building and Environment 171: 106654. https://doi.org/10.1016/j.buildenv.2020.106654.

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

For more information, visit: energy.gov/eere/buildings/building-america

DOE/GO-102022-5733 • September 2022

Produced for the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, by the National Renewable Energy Laboratory (NREL).