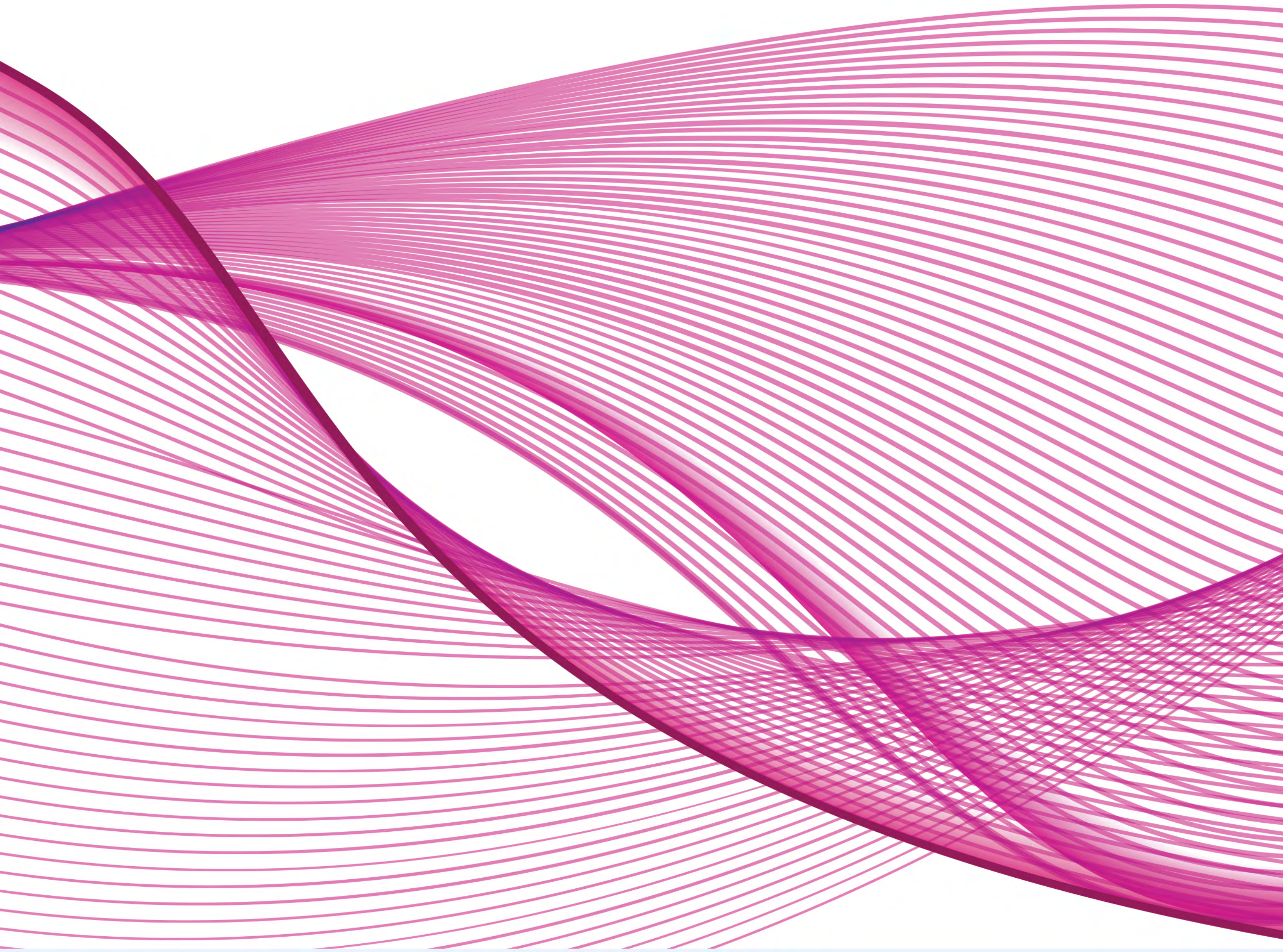
Ventilation System Guidelines



Ontario Society of Professional Engineers Special Topics in Indoor Air Quality Report: Ventilation System Guidelines

Published:
July 2025

www.ospe.on.ca

ONTARIO SOCIETY OF PROFESSIONAL ENGINEERS

Acknowledgements

This report was developed through the collaborative efforts of dedicated members of Ontario's engineering community. OSPE gratefully acknowledges the contributions of the following individuals:

Contributors

Stephane Bilodeau, Ph.D., P.Eng.
David Elfstrom, P.Eng., CEM, CMVP
Sandra Dedesko, PhD, P.Eng.
Joseph Fox, P.Eng.
Linda Gowman, Ph.D., P.Eng.
Amy Katz, CHI, ROH
Victor Leung, MD, FRCPC
Marianne Levitsky, Ph.D., CIH, ROH
Amy Li, Ph.D., P.Eng.
Ted Mao, P.Eng.
Petre Moga, Mech. Eng.
Duncan Phillips, Ph.D., P.Eng.
Hans Schleibinger, Ph.D.
James Andrew Smith, Ph.D., P.Eng.
Tomer Zarhi, P.Eng, HFDP
Yash Vyas, MASc, BASc

Table of Contents

Introduction

Ventilation refers to the process of moving air in and out of a space. Clean air is supplied to dilute indoor pollutants, while stale air is exhausted. Ventilation also contributes to thermal comfort and overall indoor environmental quality. Adequate ventilation rates are essential for occupant well-being and are defined by various codes, standards, and guidelines.

Building ventilation consists of two key components:

- **Ventilation Rate:** The amount and quality of outdoor air supplied into a space, which determines the maximum possible dilution of contaminants.
- **Air Distribution:** The airflow patterns within a space that deliver external air efficiently and remove airborne pollutants. These patterns may involve mixing or unidirectional flow.

Ventilation only improves air quality when the air supplied is cleaner than the indoor air. For example, outdoor air pollution caused by wildfires or smog can negatively impact **Indoor Air Quality (IAQ)**. When outdoor fine particulate matter exceeds national guidelines, filtration is required before introducing outdoor air into occupied spaces. Many commonly used HVAC filters are ineffective against fine particulate matter.[1]

Office buildings and schools should aim for an outdoor airflow rate 30% above the minimum requirements. When heat recovery is used, an increase of up to 100% above the minimum outdoor airflow rate can be considered. Any increased ventilation rates should be combined with MERV-13 filtration of outdoor air at a minimum.

For air distribution, the use of fans is recommended to improve airflow and air distribution in mixing ventilation systems. Avoid use in spaces with directional airflow and avoid creating direct currents between people.

Modes of transportation, including buses, subways, trains, and airplanes, should achieve a minimum of twelve **Air Changes per Hour (ACH)** in occupied spaces through a combination of ventilation, filtration, or **Ultraviolet Germicidal Irradiation (UVGI)**.[2]

Types of Ventilation Systems

Adequate ventilation involves delivering cleaner, external air to each part of the space in an efficient manner and efficient removal of airborne pollutants from each part of the space.

Choosing the appropriate ventilation method for your building depends on several factors, including the building type, the building's layout, the number of occupants, the activities conducted within the space, and the time frame these activities are done in.

Understanding the number of occupants and their schedules helps tailor the building's design, including the ventilation system, to meet their needs effectively. Local climate considerations, such as temperature and humidity, are also primary determinants; therefore, building design should include

[1] In Canada is 8.8 µg/m3 maximum average annual exposure and 27 µg/m3 maximum average daily exposure.
[2] J. Mathews, "Rail Passengers Association | Washington, DC - How Safe is Amtrak as Delta Spreads?" Rail Passengers Association. Accessed: Feb. 21, 2024. [Online]. Available: https://www.railpassengers.org/happening-now/news/blog/how-safe-is-amtrak-as-delta-spreads/

heating and cooling strategies to account for these variables.

Indoor humidity levels must also be managed to prevent issues like mould, which can affect air quality. Additionally, it is important to consider the operational and capital costs to ensure the long-term financial sustainability of the ventilation system. Compliance with local building codes and standards, including energy efficiency requirements, is also crucial. Regular maintenance is essential for the optimal functioning of ventilation systems, so choosing systems that are easy to maintain and have clear maintenance schedules is advised. Finally, integrating air quality monitoring systems allows for continuous, real-time assessment of indoor air quality, enhancing both air quality and occupant comfort.

Mechanical ventilation uses fans to move air into and out of rooms. These fans may be in the room or external to the room and use a network of ducts to blow air into rooms and/or extract stale air. There are different ways of introducing air into the room, which result in different airflow patterns. These have various advantages and disadvantages. Many buildings have a mixture of natural and mechanical ventilation.

Natural Ventilation

Natural ventilation is defined as ventilation provided by thermal or diffusion effects through doors, windows, or other intentional openings in the building.[3] Air supply through natural ventilation can be categorized into two categories:

- **Controlled Natural Ventilation:** Uses operable windows and designed openings to regulate airflow as needed.
- **Uncontrolled Ventilation (Infiltration):** Occurs when air leaks into buildings through gaps in the structure, often supplemented by general exhaust fans. Air entering through infiltration is unfiltered and unconditioned, carrying potential outdoor pollutants.

Natural ventilation has many advantages, including:

- Reduced energy consumption.
- Increased outdoor airflow under favorable conditions.
- Enhanced connection to outdoor environments (biophilic response).

However, natural ventilation is not always reliable due to changing outdoor conditions and potential air pollution concerns. Additionally, older buildings relying solely on natural ventilation often fail to meet modern ventilation requirements.[4]

When wind strikes a building, it induces a positive pressure on the windward face and a negative pressure on the leeward face. This drives the air to flow through windward openings into the building to the low-pressure openings at the leeward face. It is possible to estimate the wind pressures for

[3] World Health Organization, "Natural ventilation for infection control in health care settings." Accessed: Mar. 13, 2024. [Online]. Available: https://www.who.int/publications/i/item/9789241547857

[4] M. H. Sherman and C. R. Wanyu, "Building Air Tightness: Research and Practice," Building Ventilation: The State of the Art. Accessed: Feb. 21, 2024. [Online]. Available: https://books.google.ca/books?hl=en&lr=&id=0aCOAwAAQBA-J&oi=fnd&pg=PA137&dq=Uncontrolled+ventilation,+also+called+infiltration,+is+when+air+leaks+into+buildings+and+can-not+be+stopped+when+air+leakage+is+not+desired&ots=98LEbgnDow&sig=Ks9aXBSRwPgl4UPW-wOKitgWTHg#v=onep-age&q&f=false

simple buildings.[5]

However, in single-sided ventilation scenarios (where openings exist only on one side of a room), the fluctuating wind component is the primary driver. Temperature differences between indoor and outdoor air may also result in bi-directional airflow. Over time, air leakage around doors and other penetrations may affect ventilation effectiveness. Importantly, opening a window does not guarantee sufficient air exchange to meet ventilation requirements.

To estimate wind-driven ventilation rates in a room with two opposite openings (e.g., a window and a door), the following formulas can be used:

Air Changes Per Hour (ACH):
ACH = 0.65 × wind speed (m/s) × smallest opening area (m^2) × 3600 (s/h) / room volume (m^3)

or calculated as **Ventilation Rate** (L/s):
Ventilation rate = 0.65 × wind speed (m/s) × smallest opening area (m^2) × 1000 L/m^3[6]

Table 1 provides estimates of the air changes per hour and ventilation rate due to wind alone at a wind speed of 1 m/s, assuming a ward of length 7 m, width 6 m, and height 3 m, with a window measuring 1.5 m × 2 m and a door measuring 1 m × 2 m (the smallest opening).

Table 1: Estimated ACH and ventilation rates due to wind.

Openings	Air changes per hour (ACH)	Ventilation Rate (l/s)
Open window (100%) + open door	37	1300
Open window (50%) + open door	28	975
Open window (100%) + closed door	4.2	150

Natural ventilation relies on two primary forces:

1. Wind-driven flow through envelope openings such as windows, doors, solar chimneys, wind towers, and trickle ventilators.
2. Stack effect caused by indoor-outdoor air density differences.

Building ventilation performance depends on climate, structural design, and occupant behaviour. Window replacements intended for energy efficiency can sometimes reduce infiltration, restricting the originally intended natural ventilation. Additionally, replacing operable windows with fixed ones can eliminate a building's ability to ventilate naturally.[7]

Improving natural ventilation involves ensuring that operable windows are functional and used effectively. However, ASHRAE advises against excessive reliance on open windows if it compromises

[5] J. Atkinson, Y. Chartier, C. L. Pessoa-Silva, P. Jensen, Y. Li, and W.-H. Seto, "Natural Ventilation for Infection Control in Health-Care Settings," 2009, Accessed: Feb. 21, 2024. [Online]. Available: https://www.ncbi.nlm.nih.gov/books/NBK143277/
[6] JSTOR, "Ventilation from Severe Acute Respiratory Infections Treatment Centre: Practical manual to set up and manage a SARI treatment centre and a SARI screening facility in health care facilities." Accessed: Feb. 22, 2024. [Online]. Available: https://www.jstor.org/stable/resrep27997.10?seq=2
[7] *Window Design Strategies to Conserve Energy*. 1977.

occupant comfort, as defined in **ASHRAE Standard 55-2020**. In many cases, buildings designed solely for natural ventilation fail to meet modern minimum IAQ requirements.[8]

Mechanical Ventilation

Mechanical ventilation uses fans, dampers, and duct systems to regulate airflow. Unlike natural ventilation, mechanical systems filter and condition incoming air, providing consistent ventilation. These systems can supply outdoor air through air handling units or local unit ventilators, ensuring appropriate air exchange and climate control.

Mechanical ventilation systems often incorporate recirculated air to moderate temperature extremes, preventing heating or cooling coils from freezing in cold conditions. These systems also use filters to limit dust accumulation and maintain indoor air quality. Temperature control is achieved through heating coils, burners, or cooling coils, with humidity regulated by humidifiers or cooling dehumidification. Heat recovery systems can improve energy efficiency by reducing waste from exhausted air.

Key Considerations for Mechanical Ventilation

- Proper air distribution is necessary for effective contaminant removal.
- Ventilation rates should be adjusted for room modifications (e.g., partition walls).
- Many mechanical systems recirculate air, requiring high-efficiency filtration.

Types of Mechanical Ventilation Systems

▶ **Constant Volume**

Constant volume systems supply a fixed amount of airflow to all spaces. The supplied air can be used for ventilation alone or combined with heating and cooling.

▶ **Ventilation Only**

If zones have independent means of temperature control through systems like radiant heating, the tempered air supplied is for ventilation purposes. The outdoor air can also be used for free cooling to allow extra supplied air when the outdoor air is below the space temperature and cooling is required. This is also known as economizer mode.[9]

Systems with recirculated air can present an opportunity to improve ventilation by either increasing the amount of outdoor air supplied or by replacing the recirculated air with a heat recovery system and exhausting the air instead.[10]

Systems that are solely responsible for ventilation without recirculated air present no opportunities for

[8] ASHRAE, "ANSI/ASHRAE Standard 55 – Thermal Environmental Conditions for Human Occupancy." Accessed: Aug. 20, 2024. [Online]. Available: https://www.ashrae.org/technical-resources/bookstore/standard-55-thermal-environmental-conditions-for-human-occupancy

[9] M. H. Kim, J. Y. Park, M. K. Sung, A. S. Choi, and J. W. Jeong, "Annual operating energy savings of liquid desiccant and evaporative-cooling-assisted 100% outdoor air system," *Energy Build*, vol. 76, pp. 538–550, Jun. 2014, doi: 10.1016/J.ENBUILD.2014.03.006.

[10] Homeowner Protection Office, "Heat Recovery Ventilation Guide for Houses," 2015, *Homeowner Protection Office*.

increasing the amount of outdoor air supplied to the spaces.[11]

▶ Ventilation and Climate Control

Mechanical ventilation systems can be designed to manage both air exchange and climate control through various configurations:

- **Multizone, Hot/Cold Deck Systems:** These air handling units contain separate heating and cooling ducts. Dampers regulate the amount of hot or cold air supplied to different zones, allowing for precise temperature control.
- **Local Heating and Cooling Coils:** Individual coils heat or cool air supplied to specific zones, ensuring localized climate control.[12]
- **Constant Air Supply to Multiple Zones:** Some systems supply a uniform volume and temperature of air across multiple zones. These systems do not account for differences in occupancy, equipment, or shading, which may affect temperature needs.[13]
- **Independent Ventilation Control:** Individual unit ventilators provide localized ventilation and temperature control. These units often struggle with airflow regulation and can be prone to coil freezing due to their small size. Increasing outdoor air percentages in these systems may require additional pressure relief solutions.[14]

▶ Variable Air Volume (VAV) Systems

Variable Air Volume (VAV) systems adjust airflow while maintaining a constant supply temperature. These systems reduce air volume when heating or cooling demands decrease, improving energy efficiency. During heating season, airflow is minimized while temperature control is achieved through reheating or perimeter heating. During cooling season, airflow is adjusted to maintain comfort.[15,16]

Opportunities for IAQ Improvement with VAV Systems

- During heating season, supplying the maximum airflow instead of the minimum can improve IAQ.[17]
- Raising supply air temperature in cooling mode increases airflow, improving ventilation.[18]

---

[11] US EPA, "Heating, Ventilation and Air-Conditioning Systems, Part of Indoor Air Quality Design Tools for Schools | US EPA." Accessed: Feb. 22, 2024. [Online]. Available: https://www.epa.gov/iaq-schools/heating-ventilation-and-air-conditioning-systems-part-indoor-air-quality-design-tools

[12] R. Haines and D. Hittle, "Control Systems for Heating, Ventilating, and Air Conditioning." Accessed: Feb. 22, 2024. [Online]. Available: https://books.google.ca/books?hl=en&lr=&id=jXosn22KHusC&oi=fnd&pg=PA1&dq=Individual+heating+or+cooling+coils+can+control+the+final+temperature+of+the+air+supplied+to+the+zones+for+climate+control+purposes&ots=d7PtnOJPrP&sig=LLYS6MesGU1BvZ3edT1_IuhRV44#v=onepage&q&f=false

[13] S. Zhang, Z. Ai, and Z. Lin, "Novel demand-controlled optimization of constant-air-volume mechanical ventilation for indoor air quality, durability and energy saving," *Appl Energy*, vol. 293, p. 116954, Jul. 2021, doi: 10.1016/J.APENERGY.2021.116954.

[14] Trane Heating & Air Conditioning Engineer's Newsletter, "Managing the Ins and Outs of Commercial Building Pressurization," *Trane Heating & Air Conditioning Engineer's Newsletter*.

[15] T. Zhao, P. Hua, W. Dai, J. Zhang, and L. Ma, "An optimal control method for discrete variable outdoor air volume setpoint determination in variable air volume systems," *Build Environ*, vol. 167, p. 106444, Jan. 2020, doi: 10.1016/J.BUILDENV.2019.106444.

[16] A. Bhatia, "HVAC Design Overview of Variable Air Volume Systems," 2020.

[17] X. Pang, M. A. Piette, and N. Zhou, "Characterizing variations in variable air volume system controls," *Energy Build*, vol. 135, pp. 166–175, Jan. 2017, doi: 10.1016/J.ENBUILD.2016.11.031.

[18] R. Montgomery and R. McDowall, *Fundamentals of HVAC control systems (IP): IP edition hardbound book*. Elsevier, 2009. Accessed: Feb. 23, 2024. [Online]. Available: http://www.sciencedirect.com:5070/book/9780080552330/fundamentals-of-hvac-control-systems

- Enhancements such as MERV-13 filters, increased outdoor air percentages, or in-duct UV treatment can further improve air quality.[19]

When varying the quantity of supplied air to a space, it should always be ensured that the airflow remains between the design minimum and maximum airflows. Supplying less than the minimum can result in insufficient climate control or ventilation. Supplying more than the maximum can lead to poor airflow through the space, depriving other zones of sufficient airflow, excessive noise, or overpressurizing ducts.[20,21]

Variable Air Volume (VAV) boxes: Variable air volume boxes carefully control the airflow to different zones. Individual zones have the airflow measured to ensure that minimum and maximum design airflows are maintained.[22]

Variable Volume Terminal (VVT) systems and Bypass boxes: Variable volume terminal systems, or VVT systems, involve using dampers in each zone to restrict the airflow. These can operate like the VAV systems, but there is poor control over the airflow. Ensuring required ventilation is provided, it must be done by air balancing when the system is initially installed. Due to changes over the life of a system, without proper monitoring of airflow, the air provided to the space does not always accord with the initial design.[23] Because airflow supplied to spaces varies, systems need to be put in place to address this.

The air handling unit can be variable volume and reduce the air supplied to a space. A bypass damper can be placed between the supply and the return ducts. A bypass box can be used, where the excess air is supplied to the ceiling space and recirculated back to the air handling unit.[24]

For cases with bypass dampers and bypass boxes, there are no energy savings to be achieved by restricting airflow to the zones. Improvement of ventilation can be accomplished by supplying the maximum amount of design airflow possible, provided it does not affect the thermal comfort of the zones. The temperature of the air supplied by the air handling unit can be adjusted to minimize thermal comfort impacts while maximizing the ventilation to the zones.[25]

▶ Dedicated Outdoor Air Systems (DOAS)

Dedicated Outdoor Air Systems (DOAS) only provide outdoor air with no recirculated air to the space. They often include heat recovery between the supplied and exhausted air. They can also be used to

[19] A. Capetillo, C. J. Noakes, and A. Sleigh, "Computational fluid dynamics analysis to assess performance variability of ...: EBSCOhost," HVAC&R Research. Accessed: Feb. 21, 2024. [Online]. Available: https://web-p-ebscohost-com.ezproxy.library.dal.ca/ehost/pdfviewer/pdfviewer?vid=0&sid=ee68bb93-0274-4389-9d7d-6c4a9aa4eacc%40redis
[20] D. Mills, "Pneumatic Conveying Design Guide," *Pneumatic Conveying Design Guide*, pp. 1–781, Jan. 2015, doi: 10.1016/C2014-0-02678-0.
[21] P. D. (Peter D. Osborn, *Handbook of energy data and calculations including directory of products and services*. Butterworths, 1985. Accessed: Feb. 23, 2024. [Online]. Available: http://www.sciencedirect.com:5070/book/9780408013277/handbook-of-energy-data-and-calculations
[22] Pacific Northwest National Laboratory, "Variable Air Volume (VAV) Systems Operations and Maintenance." Accessed: Feb. 23, 2024. [Online]. Available: https://www.pnnl.gov/projects/om-best-practices/variable-air-volume-systems
[23] G. Liu and M. Brambley, "Occupancy Based Control Strategy for Variable-Air-Volume (VAV) Terminal Box Systems:," ASHARE. Accessed: Feb. 23, 2024. [Online]. Available: https://web-p-ebscohost-com.ezproxy.library.dal.ca/ehost/pdfviewer/pdfviewer?vid=0&sid=1e1f3089-fc4c-4597-b487-e290dd5087f8%40redis
[24] Braeburn Systems, "Static Pressure Regulating Dampers - Biometric By-Pass Dampers," *Braeburn Systems*.
[25] A. Kusiak, F. Tang, and G. Xu, "Multi-objective optimization of HVAC system with an evolutionary computation algorithm," *Energy*, vol. 36, no. 5, pp. 2440–2449, May 2011, doi: 10.1016/J.ENERGY.2011.01.030.

provide temperature control through variable airflow or individual air temperature control systems. Methods to improve recirculated air are not effective on these systems.[26]

Heat Pumps and Fan Coil Units: Heat pumps and fan coil units often work with a dedicated outdoor air system. The DOAS provides the ventilation while the heat pumps or fan coil units provide the individual zone climate control. The units usually can recirculate air and provide climate control when the DOAS is off.

Airflow: Quite often, supply airflow is initially measured to conform with the design, but over time, this value changes. This can be caused by dust buildup in the ducts, movement of balancing dampers, disconnected ducts, or poor initial balancing. Old buildings were often never balanced properly in the first place. Ensuring the correct quantity of airflow is supplied to the space on an ongoing basis is essential to ensure that proper air quality requirements are met.

Air mixing: For mixing ventilation systems, ineffective air mixing into a room can be a cause of poor air quality. Air supplied at a higher temperature remains buoyant and can travel directly to the return duct instead of mixing into the space.[27] **ASHRAE 62.1** takes this into account and requires a 25% increase in ventilation rate when the supply air exceeds the space temperature by 8 degrees Celsius.[28] Designs usually assume this is not the case, even though it often occurs. There is currently no oversight to ensure this phenomenon is considered in the design process.

Ensuring proper air mixing in a space can be an effective way to improve air quality without requiring additional ventilation. This can be achieved through the following methods:

- Using destratification fans in large rooms.[29]
- Using fans or preferably stand-alone air cleaning units in the space to mix the air.
- Reducing the supply air temperature supplied to the space if the air is supplied by diffusers above the occupants. This reduces short-circuiting caused by the buoyancy of warmer air. Care must be taken not to compromise thermal comfort.
- Moving or ensuring the locations of supply or return ducts are at different heights to force air to travel through the space. Displacement ventilation systems supply air at low heights and extract air at high heights. Mixing air systems, where air is supplied at the ceiling and extracted near the floor, can work similarly.[30]

Hybrid Ventilation

Hybrid ventilation encompasses various definitions within the realm of building ventilation systems, primarily referring to systems that integrate both mechanical and natural ventilation capabilities. There are two main types of hybrid ventilation: one that dynamically switches between mechanical and natural ventilation based on outdoor air conditions, and another that consists of an exhaust-driven

---

[26] ASHRAE, "Design Guide for Dedicated Outdoor Air Systems," ASHARE. Accessed: Feb. 23, 2024. [Online]. Available: https://web-p-ebscohost-com.ezproxy.library.dal.ca/ehost/detail/detail?vid=0&sid=f9aad5a2-0a01-4b5d-9ac3-a72aa96b-45c4%40redis&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#AN=1542524&db=e000xna

[27] C. Zhai et al., "Effect of thermal buoyancy on vortex ring air supply mode," *Build Environ*, vol. 221, p. 109257, Aug. 2022, doi: 10.1016/J.BUILDENV.2022.109257.

[28] ASHRAE, "Standards 62.1 & 62.2." Accessed: Feb. 23, 2024. [Online]. Available: https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2

[29] Z. Zhai and B. Brannon, "Performance Comparison of Destratification Fans for Large Spaces," *Procedia Eng*, vol. 146, pp. 40–46, Jan. 2016, doi: 10.1016/J.PROENG.2016.06.350.

[30] A. Bhatia, "HVAC Design Overview of Variable Air Volume Systems," 2020.

natural ventilation system, where an exhaust fan facilitates consistent airflow by drawing air through the building envelope. Strategies aimed at enhancing natural ventilation efficiency apply to these hybrid systems. Hybrid ventilation may also involve mechanical ventilation setups complemented by operable windows, offering a flexible approach to airflow management within buildings. These diverse interpretations highlight the versatility and adaptability of hybrid ventilation solutions in optimizing indoor air quality and thermal comfort while considering energy efficiency and environmental impact.

Mixing Ventilation

Mixing ventilation systems are the most common form of mechanical ventilation found in buildings. Air is supplied to zones that contain outdoor air with a possible mix of recirculated air. The purpose of these systems is to dilute the concentration of indoor pollutants to acceptable levels. The effectiveness of this system is dependent on the amount of clean air supplied to the space and the efficiency with which the clean air is properly mixed into the space. These systems can be designed with different configurations with great success.[31]

Displacement Ventilation

Displacement ventilation systems are an alternative to mixing ventilation. Air is supplied near the floor level at a temperature below the space temperature and extracted at the ceiling. These systems are not commonly used in Canada. They do not rely on mixing the air, but on creating a steady stream of clean air supplied throughout the space. ASHRAE requires that equipment that causes air mixing in the space, like HEPA filters or pedestal fans, not be used for these systems.[32]

Underfloor Air Distribution

Underfloor Air Distribution (UFAD) systems supply air below the occupants and extract air from the ceiling, creating a stream of air upward in the space. Unlike displacement ventilation, the airflow is not laminar near the floor and can be turbulent even though it does not mix with the rest of the room. Equipment designed to move air from one part of a room to another, like a pedestal fan, is not effective at mixing air in this circumstance. A localized stand-alone HEPA filter can be used to clean air in the vicinity of the occupant, provided the goal is not to move air from one part of the room to another. Stand-alone HEPA filters that discharge air upward can avoid this problem.[33]

Design Considerations

Air Distribution and Mixing

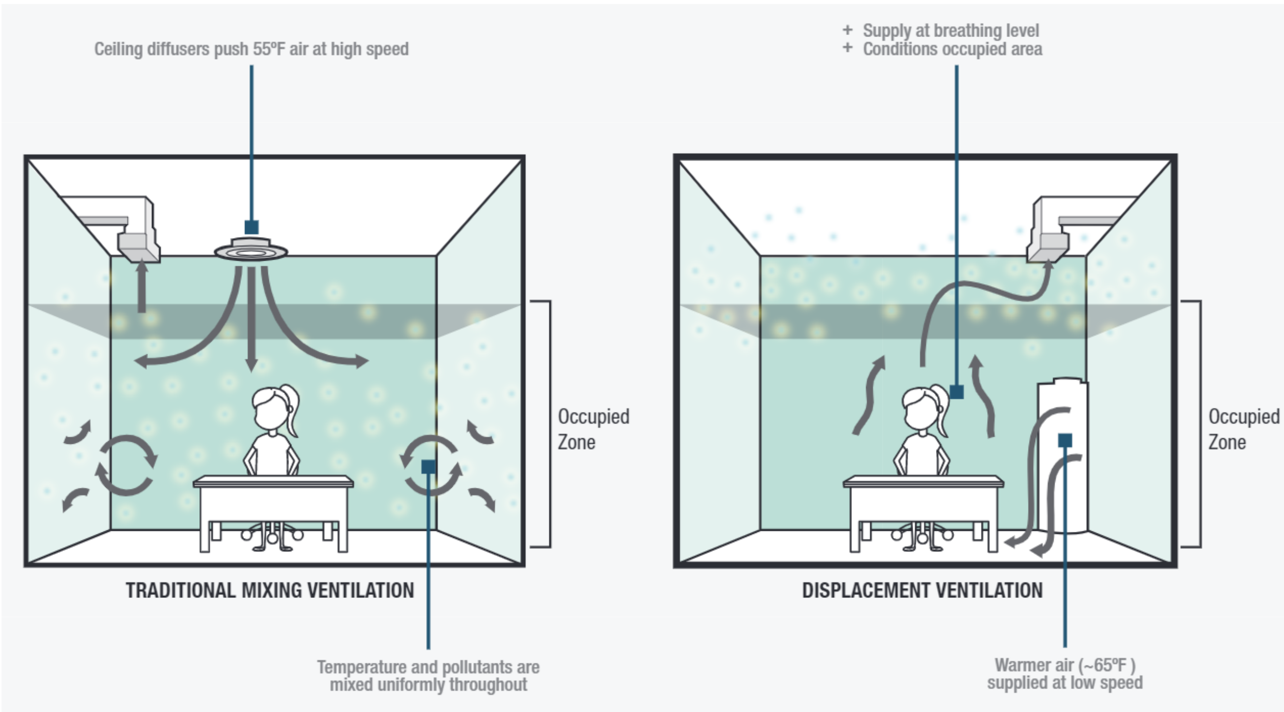
Proper design includes designing air distribution to ensure that air is evenly supplied throughout the

---

[31] D. Müller, "REHVA Guidebook No. 19 - Mixing Ventilation - Guide on Mixing Air Distribution Design," Federation of European Heating, Ventilation and Air Conditioning Association. Accessed: Feb. 21, 2024. [Online]. Available: https://dal.novanet.ca/discovery/fulldisplay?docid=alma9970522736107190&context=L&vid=01NOVA_DAL:DAL&lang=en&search_scope=Everything&adaptor=Local%20Search%20Engine&tab=Everything&query=any,contains,mixing%20ventilation
[32] H. Skistad, Elisabeth. Mundt, and Federation of European Heating and Airconditioning Associations., "Displacement ventilation in non-industrial premises," p. 95.
[33] "UFAD guide : design, construction, and operation of underfloor air distribution systems," *The American Society of Heating, Refrigerating and Air Conditioning Engineers*, p. 323, 2013.

spaces.[34] Poor air distribution will lead to inefficient contaminant removal and poor IAQ. It can also create an uncomfortable indoor environment due to air speeds that are too high or too low, leading to sensations of drafts and/or poor air quality. An example is illustrated in Figure 1 below, which shows displacement ventilation within a school.

Figure 1: Displacement Ventilation (DV) supplies air directly into the occupied portion of the space.[35]



ASHRAE 62.1 (2022) addresses distribution efficiency in mixing ventilation systems and requires varied levels of extra ventilation depending on the system design. Certain systems have poor distribution and would need this to be addressed. Some examples of systems that have poor air distribution include:[36]

- Air supplied from the ceiling at a temperature more than 8° C above the space temperature. This leads to a 20% reduction in efficiency.
- Warm supplied air with low airspeed within 1.4 m of the floor and return. This leads to a 20% reduction in efficiency.
- Air being supplied on one side of the room and returned or exhausted on the other side of the room. This leads to a 20% reduction in efficiency.
- Air being supplied on one side of the room and returned or exhausted on the same side of the room. This leads to a 50% reduction in efficiency.

Displacement ventilation systems can have higher efficiencies in removing pollutants from a space.

[34] Price Industries, "Improve Air Quality in Schools with Displacement Ventilation." Accessed: Aug. 20, 2024. [Online]. Available: https://blog.priceindustries.com/improve-air-quality-in-schools-with-displacement-ventilation
[35] Price Industries, "Improve Air Quality in Schools with Displacement Ventilation." Accessed: Aug. 20, 2024. [Online]. Available: https://blog.priceindustries.com/improve-air-quality-in-schools-with-displacement-ventilation
[36] ASHRAE 62.1-2022. Table 6.4

Underfloor Air Distribution systems can also have higher efficiencies in removing pollutants.

The hazard of a pollutant in the air is related to the inhaled dose, which is in turn related to the concentration of that pollutant in the air. The pollutant concentration is based on the rate the pollutant is generated and the rate it is removed. The higher the removal rate, the lower the concentration will be.

ASHRAE 62.1-2022 guidelines for commercial buildings, ASHRAE 62.2-2022 for residential buildings, and **CSA guideline Z317.2 for healthcare facilities** define the current ventilation standards in Canada. While healthcare ventilation is designed to address the mitigation of airborne diseases, current ASHRAE guidelines for commercial buildings are not.

Metrics for Measuring Ventilation

The effectiveness of ventilation is typically measured by the amount of air exchanged within a given space over a specified period. In any given space, pollutants can be generated by the building itself (e.g., materials, products, ventilation air), activities, or occupants. It is for this reason that **ASHRAE 62.1** determines the ventilation requirements based on both the area and occupancy of the space.

Air changes per hour is a commonly used metric for measuring ventilation in healthcare facilities, as it provides a measure of the airflow per unit volume of the room. ACH represents the number of times the air in a room is replaced with fresh air every hour. This metric has been standardized by organizations like **CSA Z317.2** and **ASHRAE 170**[37,38] which have established guidelines for ventilation in healthcare settings. While ACH is useful for standard-sized rooms with a fixed occupant density, it has limitations when applied to rooms of varying sizes and densities. Increasing room volume, for example, would result in a lower ACH value, but it would not necessarily increase the concentration of airborne pathogens. Additionally, ACH does not account for variations in occupant density, which can significantly affect the risk of transmission of infectious diseases.

Both ACH and person-based metrics have limitations when it comes to determining ventilation requirements. ACH may not provide enough ventilation in spaces with high occupancy density, while a person-based metric may not provide enough ventilation when there are few people in the space. To address these limitations, a combined approach or using the highest number in these scenarios can be more effective. For example, a combined metric of ACH and person-based metrics would be more appropriate when determining ventilation requirements to mitigate pollutants that originate from people, like body odours or infectious bioaerosols. However, it is important to note that infectious bioaerosols only originate from infectious people, and a person-based metric may not assume that everyone is infectious. In situations where there are few people in the room, this could result in a very low ventilation rate, which would be insufficient to reduce the concentration of pollutants to acceptable levels. On the other hand, a very high population could result in overpopulation, which can also be a concern.

[37] American National Standards Institute, "CSA Z317.2-2019 - Special requirements for heating, ventilation, and air-conditioning (HVAC) systems in health care facilities." Accessed: Mar. 13, 2024. [Online]. Available: https://webstore.ansi.org/standards/csa/csaz3172019?gad_source=1&gclid=Cj0KCQjwwMqvBhCtARIsAIXsZpZFmYtdA5dc4SLFiOJYEtbgHdofhZkTP0L3b-fkCTK_QfVZt5O_kBo4aAjMfEALw_wcB

[38] ASHRAE, "Standard 170-2017, Ventilation of Health Care Facilities." Accessed: Mar. 13, 2024. [Online]. Available: https://www.ashrae.org/technical-resources/standards-and-guidelines/standards-addenda/ansi-ashrae-ashe-standard-170-2017-ventilation-of-health-care-facilities

For mitigation of airborne diseases, respiratory aerosols are generated based on the activity, where breathing would produce relatively few aerosols, speaking would produce more, and singing or exercising would produce even more. Spaces with high aerosol generation would require higher ventilation rates to remove those aerosols from the air and maintain an acceptable concentration. Quieter locations and places with less talking, like libraries, would require a lower removal rate than a place with higher aerosol generation, like a gym or nightclub, to achieve the same risk profile.

With these in mind, various agencies have provided varying recommendations. The **World Health Organization (WHO)** recommends 10 litres/sec/person.[39] The **Lancet COVID-19 Commission** released guidelines for 6 ACH as well as conversions to rates per area and per person using assumptions about ceiling height and occupant densities. While ACH is not always a perfect metric, 6 ACH is generally good for most spaces and can serve as a basis for a general recommendation.

Assessing Ventilation Risks

To ensure effective ventilation:

- Commission HVAC systems and verify performance through **Building Management Systems (BMS)**.
- Monitor **CO_2 levels** to assess outdoor air supply adequacy.
- Conduct **air quality testing** for pollutants such as fine particulate matter and formaldehyde.

The **Ontario Occupational Health and Safety Act** mandates HVAC inspections every six months.

Ventilation Improvement Strategies

Enhancing Natural Ventilation

- Open **windows and vents** where possible (fire doors must remain closed).
- Use **fans** to enhance cross-ventilation by drawing air through open windows.
- Install **screens** to prevent debris and insects while maintaining airflow.
- Adjust window use based on seasonal temperature differences.

Improving Mechanical Ventilation

- **Filter outdoor air** before introducing it into occupied spaces, especially in polluted areas.
- Increase **outdoor air intake**, where feasible, while maintaining energy efficiency.
- Upgrade **air filters** to HEPA or MERV-13+ filters for improved pollutant removal.
- Use **ultraviolet germicidal irradiation** to disinfect recirculated air.
- Implement **energy recovery systems** to enhance ventilation without increasing energy costs.

Hybrid systems may require adjustments to prevent pressure imbalances when operable windows are opened.

[39] P. D. Osborn, “Data charts and tables,” *Handbook of Energy Data and Calculations*, pp. 1–67, 1985, doi: 10.1016/B978-0-408-01327-7.50005-1.

Use of Recirculated Air

Recirculated air is often used for heating and cooling, but does not inherently improve IAQ. To mitigate risks:

- Upgrade **air filters** to capture fine particles.
- Install **ultraviolet germicidal irradiation systems** to target airborne microbes.
- Ensure **proper airflow balancing** to prevent pollutant accumulation.

Maintenance Requirements

ASHRAE 62.1-2022 outlines maintenance schedules for ventilation equipment. Regular maintenance ensures systems function optimally and comply with IAQ standards.

If IAQ remains poor despite adjustments, consider:

- **Reducing occupancy limits** in under-ventilated spaces.
- **Upgrading HVAC systems** with expert consultation.

Ventilation Standards Across Canada

Canadian health and safety regulations require employers to maintain IAQ. Key ventilation references include:

- **ASHRAE 62.1** (Commercial Buildings)
- **ASHRAE 62.2** (Residential Buildings)
- **CSA Z317.2** (Healthcare Facilities)

Some provinces, including Newfoundland and British Columbia, require compliance with **ASHRAE 62.1**, mandating **15-20 cfm per occupant** of outdoor air. Other provinces rely on general duty clauses requiring employers to take reasonable precautions for IAQ.

In Ontario, ventilation systems must be inspected at least every six months.

Conclusion

Proper ventilation is essential for maintaining IAQ, reducing health risks, and improving occupant comfort. A **layered approach** combining **source control, ventilation, and filtration** is the most effective strategy for enhancing indoor air environments.

By adhering to established ventilation standards and performing regular system maintenance, workplaces, homes, and public buildings can create safer and healthier indoor spaces.

CONTACT US

Ontario Society of Professional Engineers
5000 Yonge St Suite 701
Toronto, Ontario M2N 7E9
1-866-763-1654

www.ospe.on.ca

ONTARIO
SOCIETY OF
PROFESSIONAL
ENGINEERS