U.S. DEPARTMENT of ENERGY | Federal Energy Management Program

VENTILATION ASSESSMENT AND ACTION GUIDE

Improve Indoor Air Quality and Building Energy Performance

Breathing clean, fresh air indoors isn't just about comfort — it's essential for health, productivity, and overall well-being. Whether managing a school, office, or other shared space, understanding how ventilation works and why it matters can help make smarter decisions about the indoor environment.

This guide, developed by the U.S. Department of Energy's Federal Emergency Management Program (FEMP) explores how to spot signs of poor indoor environmental quality (IEQ), when and how to apply effective ventilation strategies, and how to do it all efficiently. Specifically, it provides information on how to evaluate ventilation levels, best maintenance practices for supporting ventilation, and common improvement measures for inadequately ventilated spaces. There are also best practices for performing upkeep on heating, ventilating, and air-conditioning (HVAC) systems to extend equipment life and reduce costs resulting from system replacement or long-term maintenance.

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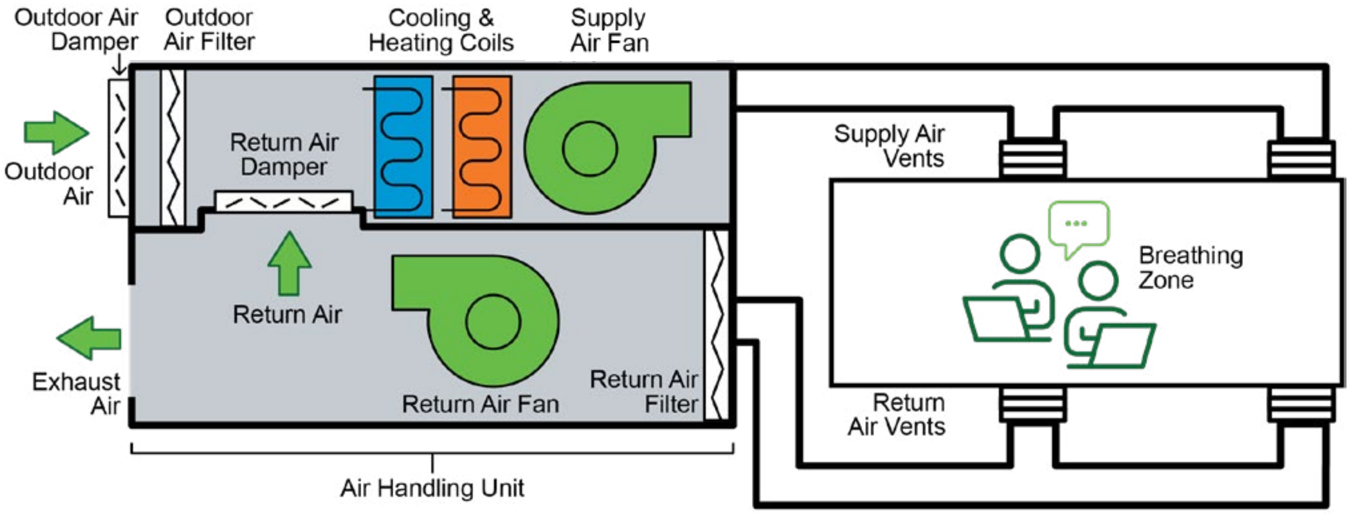

Figure 1 *Diagram of a mechanical ventilation system and components.*

1 - Importance of Ventilation

Ventilation is an important driver for indoor air quality (IAQ). Ventilation removes air contaminants, including particulate matter, volatile organic compounds, and human bio-effluents, from the breathing zone of occupants, assuming the outdoor air is properly filtered of contaminants. Optimizing ventilation is associated with higher quality of life among building occupants as a result of reduced absenteeism, sick building syndrome symptoms, and odor complaints as well as improved task performance (Mendell et al., 2023). Providing high-performance ventilation benefits occupant health and, when achieved in an energy-efficient way, promotes resilience and energy affordability.

Providing sufficient ventilation and reducing building energy use are often seen as competing priorities. This is because outdoor air that is introduced to a building must be conditioned, which requires heating or cooling energy. As a result, building owners and operators may view ventilation as an energy penalty. However, some amount of ventilation should be viewed as a basic building service because it is essential for occupant productivity and health. As an analogy, maintaining indoor temperature within a generally agreed upon comfort band is not considered an energy penalty for a building but rather an expected building service. The generally accepted minimum level of ventilation is discussed in this document.

Mechanical ventilation is provided by a fan (e.g., through an air handling unit [AHU], as seen in *Figure 1*). It can be filtered and supplied to spaces throughout the building. Natural ventilation uses windows to provide outdoor air. This document specifically discusses mechanical ventilation, which is the most common option among commercial buildings.

The Center for Green Schools, in partnership with ASHRAE, developed a series of flyers on air quality topics specifically for schools that is an additional resource for stakeholders interested in this field. This can be found at [*https://www.usgbc.org/resources/school-iaq-fact-sheets-entire-series*](https://www.usgbc.org/resources/school-iaq-fact-sheets-entire-series).

2 - Preventative Maintenance for Ventilation

Making preventative maintenance part of your routine building operation is essential for successful ventilation. Preventative maintenance is a low-cost practice that promotes high-performance building operation, reduces energy waste, and extends building equipment life. Practices that specifically benefit ventilation include the items listed in *Figure 2*.

These activities should be conducted on a quarterly basis to catch and resolve issues proactively. More information on these and other maintenance requirements for ventilation systems can be found in ASHRAE 62.1 Table 8-1.

Preventative Maintenance Checklist for Ventilation

- ☑ Inspect damper, actuators, and linkages for proper operations by cycling fully opened and fully closed.
- ☑ Clean condensate pan with treatment tablets to avoid mold or fungus.
- ☑ Check HVAC belts regularly for signs of wear and replace annually.
- ☑ Wash condenser coils *(dirty coils can use up to 37% more energy.)*

Figure 2 *Important items to include in an operations and maintenance checklist to promote effective ventilation.*

ASHRAE Ventilation Standards

ASHRAE published Standard 62.1-2022: Ventilation and Acceptable Indoor Air Quality, available at ***https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2***, as well as 62.2-2022 for residential buildings, to specify industry-accepted minimum ventilation rates. The standards also provide guidance and maintenance activities for ventilation equipment, filtration, and controls. ASHRAE has another document, Standard 170-2017, available at ***https://www.ashrae.org/technical-resources/standards-and-guidelines/standards-addenda/ansi-ashrae-ashe-standard-170-2017-ventilation-of-health-care-facilities***, that is specifically for health care facilities. Achieving the relevant ventilation rates and procedures specified in these documents should be considered a fundamental building service. Higher ventilation rates can be pursued for improved air quality and additional health benefits, but they should be balanced with the energy required to achieve those benefits. There are other strategies for providing clean air, such as installing portable air filters or germicidal ultraviolet lighting, that use less energy than providing ventilation by conditioning and supplying outdoor air via the HVAC system. Note that these alternative strategies remove some (but not all!) types of contaminants from the air.

For facilities with operations and maintenance (O&M) contracts, it is important to add contract language for maintaining minimum ventilation standards in ASHRAE Standard 62.1 with the most recent revision year. The site personnel in charge of overseeing the contract should familiarize themselves with the components of ASHRAE 62.1 to enforce and track completion of the regular maintenance items with the contractor. FEMP has information on O&M contracts, available at *https://www.pnnl.gov/projects/om-best-practices/contract-challenges-and-improvements*.

3 - Troubleshooting Ventilation Issues

When preventative maintenance activities are regularly conducted, buildings can be assessed to see if the ventilation supplied to each space is sufficient. Some buildings have building automation system (BAS) sensors that can measure and report the ventilation rate, and some buildings have been recently programmed and verified to have minimum ventilation set points to meet target values. For other buildings, underventilation of a space can often be diagnosed by monitoring carbon dioxide (CO_2). In addition, a walkthrough inspection form is helpful to identify possible sources of high CO_2.

More information about assessing ventilation, as well as other IEQ topics, is available at ***https://www.energy.gov/femp/articles/energy-efficiency-and-indoor-environmental-quality-assessment-guide***.

Using CO_2 as an Evaluation Tool

While CO_2 itself is not harmful at the levels typically found in buildings, it is a proxy for ventilation rate and other IAQ pollutants, such as human bio-effluents (Zhang et al., 2017; Azuma et al., 2018). CO_2 levels are usually a useful indicator of ventilation, and they can be measured with low-cost, easy-to-use IAQ loggers. High CO_2 levels suggest that a zone is underventilated or has poor ventilation effectiveness (e.g., poor circulation).

CO_2 data can be used to estimate ventilation rate, but there are some key limitations. When there is a constant occupancy level in a space, the corresponding CO_2 level (referred to as steady-state CO_2) can be used to estimate the rate of ventilation being supplied to the space per person. This method is described by Persily (2022). However, for accurate results, this method should only be used for single-zone spaces. In addition, to compare to ASHRAE standards for minimum outdoor airflow set point, the space should experience an extended period (several hours) at the design occupancy and at the minimum ventilation set point without variation. These limitations make it difficult to confidently estimate the ventilation rate in a field evaluation with CO_2 data.

Even when CO_2 levels cannot be used to accurately estimate ventilation rate, the data can still be used for a high-level evaluation of how well the building flushes out occupancy-related pollutants. CO_2 data is useful for evaluating how well a building flushes out human-generated pollutants. CO_2 data will account for HVAC ventilation as well as dilution between zones, recirculation of unbreathed air, and envelope infiltration. In addition, CO_2 data collected over several weeks will typically capture performance under actual occupancy conditions and ventilation system operation, which has some benefit over evaluating design conditions only.

***Table 1*, on the next page, shows ventilation thresholds and the associated steady-state CO_2 level, which can be used to assess if each space is likely meeting minimum ventilation levels for acceptable air quality.** This table is a summary of ASHRAE minimum ventilation rates converted to CO_2 values with assumptions regarding outdoor CO_2 concentration, occupant age and activity level, occupant density, and floor-to-ceiling height where necessary. The National Institute of Standards and Technology has an online calculator that can be used for similar calculations (National Institute of Standards and Technology, 2019). Because of the limitations mentioned above, there will be some level of uncertainty in how well the CO_2 thresholds correspond to the associated ventilation thresholds in the table, and so the CO_2 values are intended only as a general indicator of acceptable air quality.

METRIC	OFFICES	HOSPITALS	SCHOOLS
Ventilation Rate *(minimum set point)*	>17 cfm per person[1]	>2 ach[2]	>15 cfm per person
Carbon Dioxide *(peak value, outliers removed)*	≤965 ppm[3]	≤580 ppm	≤1,010 ppm *(lower grades)* ≤1,210 ppm *(upper grades)*

Table 1 *Acceptable ventilation rates and corresponding steady-state CO_2 levels that can be used for evaluating offices, hospitals, and schools.*

A CO_2 assessment should span several weeks in each space under the typical occupancy levels for the building. Because the ventilation rate thresholds are for the minimum set point (worst-case scenario), the peak values of CO_2 trend data (also worst-case scenario) should be used for comparison. It is recommended to remove outliers or to use a 15-minute to 30-minute time-based median of the time series data to remove brief spikes in CO_2 that may not be reflective of ventilation rate, such as someone breathing directly on the sensor. It is important that during the CO_2 testing period, the building experiences typical occupancy so that the results reflect realistic conditions.

Leveraging tools to graph CO_2 trend data is helpful for visualizing performance and identifying rooms or spaces that are underventilated. This can be done with a data analysis tool like Excel. Alternatively, many air quality monitors have online dashboards that display interactive graphs with trend data.

Identify rooms that exceed the CO_2 thresholds (*Table 1* above) under typical occupancy for the building. *Figure 3* shows an example of CO_2 trend data across a given week for a sampled office building. Each colored line represents a different room in the building. Several of the rooms regularly exceed the 935 ppm acceptable benchmark for offices at their daily peak values, which, assuming a typical occupancy was achieved at least one day this week, suggests that these rooms may not be effectively flushing out human-generated pollutants and should be flagged for further investigation as to whether they are meeting the corresponding minimum ventilation requirements from ASHRAE 62.1.

Plotting each room individually, or a smaller subset of rooms, can help to more clearly reveal the trends from a specific room or zone. It is recommended to collect data across several weeks to get a representative sample. From the results of IAQ monitoring, the example office building from *Figure 3* above, appears to be a good candidate for implementing strategies to improve ventilation.

1 cfm = cubic feet per minute. ASHRAE 62.1-2022 Ventilation and Acceptable Indoor Air Quality: https://www.ashrae.org/technical-resources/bookstore/standards-62-1-62-2.

2 ach = air changes per hour. ASHRAE 170-2021 Ventilation of Healthcare Facilities: https://www.techstreet.com/ashrae/standards/ashrae-170-2021?product_id=2212971.

3 ppm = parts per million.

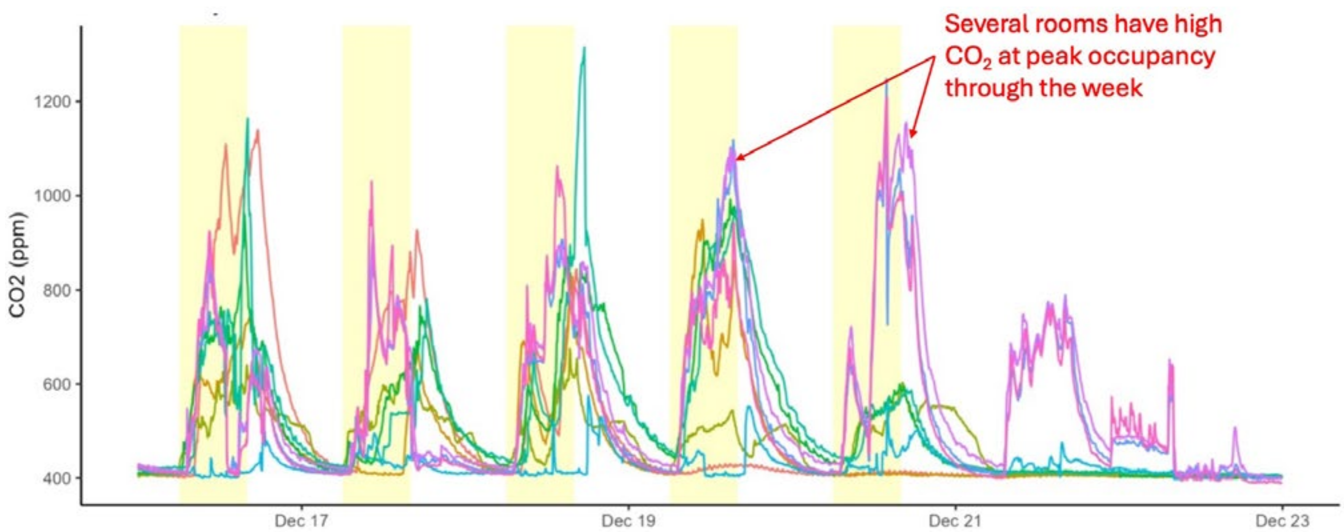

Figure 3 *Example CO_2 trends for one week, with each line representing a different space in a building. Yellow highlighted regions indicate the typical occupancy schedule (8 a.m. to 5 p.m. M–F).*

Using a Walkthrough Inspection Form to Get More Information

Completing a **walkthrough inspection form** can supplement CO_2 data to more accurately diagnose HVAC and ventilation issues, such as stuck-closed dampers, changes in occupancy, supply vent blockage or circulation issues, outdated or dysfunctional BAS software, or too early scheduled HVAC shutdowns or too late startups. For example, identifying that furniture is obstructing supply vents in spaces with high CO_2 levels provides a possible explanation for the results and a clear pathway for remediation. Some items that can be assessed through a data collection form for ventilation include the following:

- Hours of typical occupancy
- Occupant density (number of occupants per floor area)
- Age of air handler units and related HVAC equipment
- Notes on the condition and functionality of air handler equipment, including dampers, actuators, filters, screens, and condensers
- Placement of furniture or other objects in relation to supply air vents
- BAS functionality
- HVAC system setback and startup times
- Existing records of occupant feedback related to air quality

The spatial granularity of each response varies. Some items need to be completed for each space, some need to be completed for each air handler unit, and others only require one response for the whole facility.

4 - Energy and Ventilation Improvement Strategies

There are many possible measures that can be taken to resolve insufficient ventilation in buildings and use ventilation energy more efficiently. *Table 2* summarizes several of the most common and high-impact strategies to improve energy and ventilation. Upfront cost, potential energy savings, and the IAQ benefits are rated for each measure. The cost, savings, and benefits depend significantly on the existing building conditions, so the values provided are generalized. Each measure is discussed in detail in the following sections. This table of measures is not comprehensive.

Identify and Fix Ventilation System Maintenance Issues

Background: One of the most common causes of ventilation issues is easily fixable HVAC component failures. These failures can be identified from a walkthrough inspection of air handlers and supply vents. Issues to look for include the following:

- Dampers are stuck closed (or open) and do not change position when directed to by the BAS
- The HVAC startup and shut-down schedule does not match the current occupancy patterns in the building
- BAS software is out-of-date or does not work well and causes operational issues
- Furniture or other items are blocking supply air vents in a zone and impeding circulation

The solution for each of these problems is to fix those that can be solved with in-house labor (e.g., move furniture or change HVAC schedules) and submit a work order for an HVAC contractor to fix those that cannot be fixed in-house (e.g., upgrade BAS software or replace dampers or actuators). These solutions can sometimes lead to energy savings as well because dysfunctional equipment often leads to poor overall system performance and unnecessary energy use.

When to choose this option: This solution should ideally be implemented as a regular preventative maintenance strategy as part of a building's

IMPROVEMENT MEASURE	COST	ENERGY CONSERVATION	AIR QUALITY
Identify and Fix Ventilation System Maintenance Issues	$		
Test and Balance	$ $		
Demand-Controlled Ventilation	$ $		
Air-Side Economizers	$ $		
Replace or Upgrade Air Handling Units	$ $ $		

Table 2 *Common strategies for improving building ventilation.*

O&M checklist. However, these items can also be completed as reactive maintenance for when a ventilation issue is identified, such as high CO_2 levels in a space or throughout a building. These activities are relatively low effort and low cost compared with other ventilation mitigation strategies, and so it is a good idea to pursue them as a first-pass solution and check to see if zone CO_2 levels improve as a result.

Test and Balance

Background: Testing and balancing the air distribution system is a process that involves hiring a contractor who can verify the HVAC system functionality for the building and, if included in the contract, adjust set points and fan static pressure to improve ventilation as well as improve indoor temperature and humidity control. For the ventilation portion of the procedure, the contractor identifies ways to improve air distribution, such as removing obstructions blocking diffusers, changing the diffuser type or setting (e.g., increasing air velocity), testing and calibrating any issues with controls or sensors, or increasing fan speed for better air circulation. Testing and balancing can also involve ventilation design verification, typically ensuring that the minimum ventilation set points meet at least ASHRAE 62.1 for commercial buildings or ASHRAE 170 for health care facilities. The minimum ventilation rate requirements in ASHRAE 62.1 include calculating the necessary ventilation per occupant, and so testing and balancing should include making updates in response to any changes in building occupancy or space use (for example, converting an open office into meeting rooms) since the previous procedure was performed. ASHRAE 62.1 requires a testing and balancing procedure to be conducted every five years.

When to choose this option: This measure is recommended for all buildings at least every five years as a preventative maintenance measure to ensure effective ventilation and air distribution. It is a good way to verify the ventilation rate and compare it to CO_2 levels from an IAQ assessment. Testing and balancing can also help to solve temperature issues related to HVAC faults. This procedure is beneficial when data from a building walkthrough inspection form indicates that the occupancy level has changed over time, it has been some time since the building was last tested and balanced, or there may be issues with the functionality of air distribution system components from inspection.

Demand-Controlled Ventilation

Background: Demand-controlled ventilation (DCV) is an energy-saving measure that reduces ventilation below the design set point when occupancy is lower than the design occupancy. Many buildings and zones within buildings are not always at design occupancy, and this technique

Figure 4 *Specialist testing the flow rate of a supply vent to verify ventilation effectiveness. Source: Local Energy Audits.*

Testing and Balancing as Part of Commissioning

For existing buildings, testing and balancing can be included in the contract language of an existing building commissioning procedure, which is a more involved building system verification and preventative maintenance process that helps to ensure the reliable and efficient performance of HVAC systems. The procedure is conducted by a contractor and is required to be completed every four years for covered facilities under the Energy Act of 2020. It is important to contract a reputable provider that uses high-quality, calibrated equipment, follows an industry standard or guideline, and can make adjustments to the system to meet the specified ventilation levels.

efficiently provides ventilation when it is needed. For buildings that currently don't have minimum ventilation set points implemented, this measure could improve IAQ as well.

DCV is typically done through modulation of the outdoor air dampers according to feedback from breathing-zone or return-air CO_2 sensors, but it can also be done with a schedule in the BAS based on the observed occupancy of each zone, if there are consistent trends throughout a day or week. For both methods, the settings can be fine-tuned with CO_2 loggers. For BAS-integrated CO_2 sensors, the sensors should be calibrated on a regular basis (as sensor drift commonly occurs over time) and replaced as they become dysfunctional. This measure is relatively low cost but may require added costs for installing programmable outdoor air dampers, if they are not already in place.

When to choose this option: This measure is most beneficial for buildings that have variable occupancy levels within a space throughout the day or week. If there are zones that are sometimes unoccupied or that regularly have low occupancy, this measure could save a lot of energy. If the occupancy level is not very predictable or if it is variable between rooms and spaces (e.g., many conference rooms), DCV operated by CO_2 sensors may be the better option. If the occupancy level is predictable and regular, a programmed schedule may be the better option. It is easiest and most affordable to implement this measure when there is already a well-functioning existing BAS and programmable outdoor air dampers.

DCV is already commonly used in many commercial buildings because it is required under many building codes. For these buildings, it is important to regularly verify the accuracy of the CO_2 sensors and the CO_2 set points. ASHRAE 62.1 recently added an addendum for DCV set points by space type. It is also a good strategy to program the BAS to flag extended periods where the outdoor air damper position is 0 or 100 percent because this is a good indicator that the CO_2 sensors have drifted or that there is another operational issue related to DCV.

Air-Side Economizers

Background: Air-side economizers integrate into AHUs to adjust the quantity of outdoor airflow to optimize space conditioning. Most buildings have an internal heating load that requires HVAC cooling even when the outdoor temperature is lower than room temperature, so cooling with outdoor air instead of with mechanical cooling can save a significant amount of energy. Economizers can also be programmed to run overnight to reduce the anticipated cooling demand on the following day. There are dry-bulb economizers that use outdoor temperature data as the only control input, and there are enthalpy economizers that use both outdoor temperature and humidity as control inputs because HVAC systems must expend energy to remove moisture from outdoor air during cooling. Fixed-enthalpy units are programmed to shut off when the outdoor air enthalpy exceeds a static value, and differential enthalpy units shut off when the outdoor air enthalpy exceeds the return-air enthalpy.

Economizers offer some air quality benefits by providing more ventilation when weather conditions are favorable, especially in shoulder seasons and sometimes in the winter, but they are not consistent or predictable enough to be a solution for poor existing IAQ. Establishing a minimum outdoor airflow set point in accordance with minimum ventilation guidelines is an air quality solution for buildings without existing set points.

When to choose this option: For buildings that do not already use economizers, this solution is most effective in temperate to cool climate zones. Economizers tend to be most effective in dry climates, but they are often used in humid climate zones as well. They also tend to provide greater energy savings in larger buildings.

Economizers are already commonly used in many recently constructed or renovated commercial buildings as a result of building code requirements. For these buildings, it is important to implement minimum outdoor airflow set points, if they do not already exist. It is also important to plan for regular inspection and performance verification (for guidance, see *Table 1* in Pacific Northwest National Laboratory [PNNL], 2021). Many existing economizers do not operate as often as they could, so assessing and reconfiguring controls on a regular basis can reduce energy use in buildings with existing economizers.

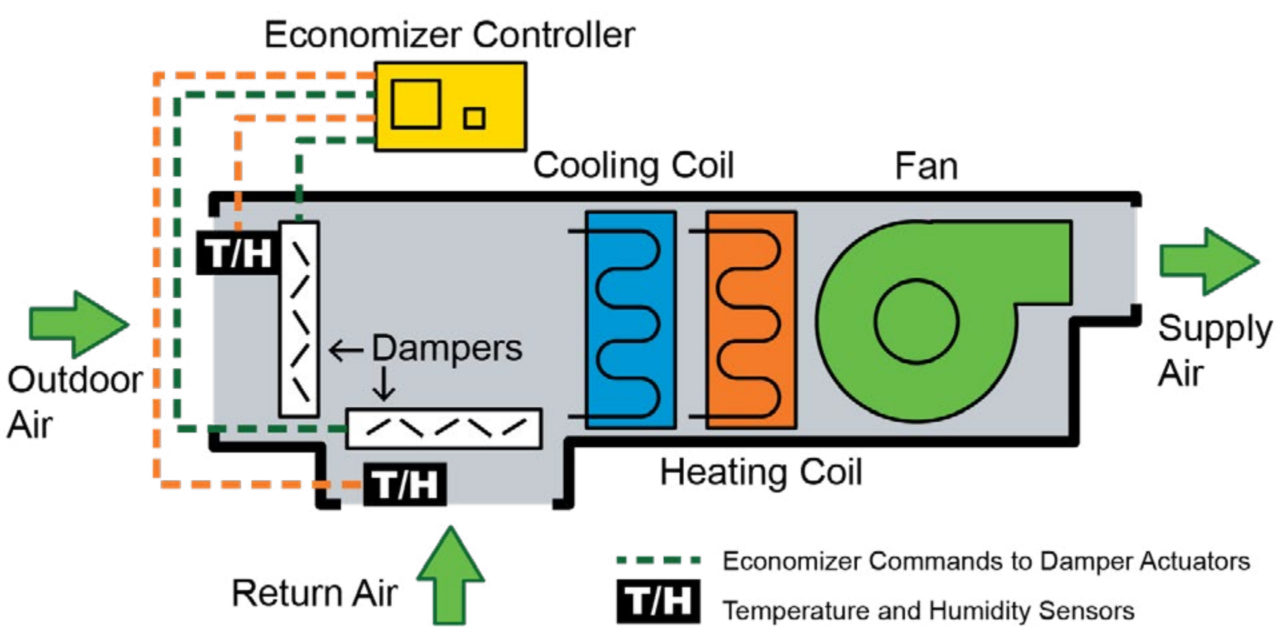

Figure 5 *Diagram of an air-side economizer integrated into an HVAC system.*

Replace or Upgrade Air Handler Units

Background: Depending on the age, state, and quality of existing equipment, replacing or upgrading the AHU could improve the ability of the HVAC system to control air quality and indoor thermal conditions. An aged or failing AHU may no longer be able to meet the ventilation requirements of the building because of a decline in the system's performance or capacity, changes in required load overtime, leaky or undersized ductwork, antiquated designs that do not meet the current ventilation needs or unforeseen challenges, or issues caused by outdated BAS software. Take advantage of the replacement by upgrading with high-performance, energy-efficient equipment.

When to choose this option: This measure is only applicable in a building every 20 to 30 years. This is an applicable measure if there are high CO_2 levels and the AHU(s)—including rooftop units, packaged units, and terminal units—are reaching or have surpassed the end of lifespan or are in poor condition. Replacing the AHUs with high-performance, energy-efficient models involves a high capital cost, but such replacements need to be done at some point, and it is better to do so before the equipment fails than have to suspend building operations because of dysfunctional equipment. Replacements and upgrades can eventually end up being a cost-saving measure, with less maintenance and repairs required for failing, energy-inefficient equipment.

5 - Actionable Takeaways

Preventative maintenance should be prioritized to avoid HVAC faults that could impair ventilation performance. Preventative maintenance means establishing a checklist for your building with the necessary regular inspection activities for each system and a determined frequency. The document found at *https://www.pnnl.gov/projects/om-best-practices/small-building-om-checklist* is a resource that is available for customizing a checklist. All checklist items need to have clear accountability, and corrective actions should be taken for components that need cleaning, repair, or replacement.

IEQ assessments are a valuable tool to diagnose performance and identify strategies for improvement. FEMP's website at *https://www.energy.gov/femp/energy-efficiency-and-indoor-environmental-quality* has numerous resources for conducting this type of assessment, including a short flyer on how to make the most of an IEQ assessment at *https://www.energy.gov/sites/default/files/2024-07/femp-indoor-environmental-quality-assessment.pdf* and the more detailed assessment guide at *https://www.energy.gov/sites/default/files/2024-05/femp-energy-efficiency-indoor-environmental-quality-assessment-guide.pdf*. There are many commercially available devices that can be used to monitor CO_2 trends and other metrics, and walkthrough forms can be used to supplement IEQ data.

Once a measure to improve energy efficiency and IEQ has been identified, it is important to place a work order, especially for the easily implementable options, that clearly describes the retrofit and the value of it. It is also important to continuously follow up on work order requests that get delayed to keep them moving along. The results of an IEQ assessment can be valuable to include in a work order request for demonstrating whether ventilation is currently meeting acceptable conditions, and, if it is not, providing justification for why the work order is necessary.

Acknowledgments

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Kevin Keene *(PNNL)*
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For more information, visit *http://energy.gov/femp*.

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DOE/FEMP-0039 | September 2025