U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Measure Guideline: Passive Vents

David Berger and Robin Neri
Consortium for Advanced Residential Buildings

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15013 Denver West Parkway

Golden, CO 80401

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Prepared by:

David Berger and Robin Neri

Steven Winter Associates, Inc.

Consortium for Advanced Residential Buildings

61 Washington Street

Norwalk, CT 06854

NREL Technical Monitor: Stacey Rothgeb

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The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

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Definitions

ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
CAR	Constant airflow regulator
CARB	Consortium for Advanced Residential Buildings
CFM	Cubic feet per minute
CFM50	Cubic feet per minute flow at a test pressure of 50 Pascals
CFM50/ft^2	CFM at a test pressure of 50 Pascals per square foot of enclosure area
Pa	Pascal

Executive Summary

The U.S. Department of Energy's Building America research team Consortium for Advanced Residential Buildings wrote this measure guideline to address the use of passive vents as a source of outdoor air in multifamily buildings. The challenges associated with implementing passive vents and the factors that affect performance are outlined. A comprehensive design methodology and quantified performance metrics are provided. Two hypothetical design examples are provided to illustrate the process.

This guideline is intended to be useful to designers, decision makers, and contractors who implement passive ventilation strategies. It is also intended to be a resource for those responsible for setting high-performance building program requirements—especially pertaining to ventilation and outdoor air.

A dedicated source of outdoor air ensures good air quality and is an integral part of high-performance buildings. Currently little guidance is available that pertains to the design and installation of passive vents; thus, systems perform poorly. This guideline details the criteria for designing, constructing, and testing passive vent systems to enable them to provide consistent and reliable levels of ventilation air from outdoors.

Progression Summary

Step 1

- **Determine Local Exhaust Ventilation Strategy**
- How does the building designer plan to meet local exhaust ventilation requirements? Continuous or intermittent exhaust?
- **Decision:** If intermittent exhaust is being implemented, passive vents should **not** be used.

Step 2

- **Assess Air Sealing Performance Targets**
- Are the performance targets of the building design ambitious enough to go beyond current energy-efficiency programs such as Leadership in Energy & Environmental Design and ENERGY STAR® to greatly improve compartmentalization between apartment units?
- **Decision:** If the in-unit airtightness target is 0.2 CFM50/ft^2 or less, passive vents could be a viable option.

Step 3

- **Design Air Barriers**
- Use the best practices for effective air sealing for the selected construction type and ensure those are followed, provide buildable continuous unit air barrier details, specify trained and certified contractors and installers.
- Is the building being commissioned from design through construction?
- **Decision:** If the building design and construction process will not receive oversight, passive vents will likely **not** work. The passive design requires specific performance from many building components that can only be achieved with proper oversight.

Step 4

- **Determine Passive Vent Flow Rate**
- Suggestion: Whole-house ventilation per ASHRAE 62.2.-2010 or 2013.

Step 5

- **Calculate Required Vent Area and Exhaust Flow Rate**
- Enter the unit design information into the calculator tool or use the examples provided to determine the total area of passive vent openings required in the unit.
- Continuous local exhaust flow requirements will be determined using this information.
- **Decision:** If exhaust flows are too high, airtightness must be increased or passive vents should **not** be used.

Step 6

- **Design and Position Passive Vents**
- Implement the passive vent area using the passive vent type of choice.
- **Option A:** Use airlets where an additional wall penetration is not an issue or modification of window framing is **not** desirable. Airlets should be placed near the ceiling to minimize uncomfortable drafts.
- **Option B:** Use trickle vents in windows when minimizing wall penetrations.
  - Typically, trickle vents have smaller opening area than airlets, meaning more trickle vents will be necessary.
  - Trickle vents should be installed at the top of the window frame to minimize uncomfortable drafts.

Step 7

- **Commission Passive Vent Design, Construction, and Installation**
- Prior to construction, request samples from the passive vent manufacturer or installer.
- Ensure the passive vents are properly commissioned at each stage in the construction process.
- Ensure the vent location is appropriate in the unit; exact locations where vents are to be located must be specified.
- Installationverify orifice sizes, alignment, and that the airflow path is free from obstructions.
- Verify that operation of moving parts comports with the design specification.

Step 8

- **Test Procedures**
- **Perform Airtightness Testing**
- Perform blower door testing of apartments to confirm air sealing design and implementation.
- Measure pressure across exterior wall to estimate airflow through passive vents.
- Measure exhaust airflow, passive vent airflow, and door leakage.

1 Introduction

Unlike in single-family homes, infiltration cannot and should not be relied upon as a source of outdoor air in multifamily buildings. In an effort to provide a dedicated source of outdoor air for improved indoor air quality, passive vents are being implemented in high-performance new-construction multifamily buildings. However, despite the best intentions, a lack of clear guidance is resulting in poor performance. Insufficient information is available to designers about how these various systems are best applied. Product performance data are based on laboratory tests, and the assumption is that products will perform similarly in the field. Because all ventilation systems are designed to work within a specific operating environment, proper application involves ensuring adequate pressure differentials are established. High-performance building programs have already begun requiring a provision of outdoor air so the need for clear guidelines for implementing passive vents is increasing. Without proper guidance, these systems are not likely to function as designed.

Passive ventilation strategies use engineered passive vents in the exterior envelope to provide makeup air from outside. Exhaust in apartments is provided by either central or in-unit fans that operate continuously. The negative pressure these fans create is meant to draw outdoor air into the apartment through these passive vents—rather than relying on infiltration through the exterior envelope or transfer air from adjacent spaces.

Several common problems with passive ventilation strategies can result in poor-performing systems. One set of problems involves apartment airtightness. A high level of air sealing and compartmentalization—which is not commonly seen in typical construction—is required to create the pressure differential required for passive vents. Although unintentional leakage through the exterior envelope could be considered a source of outdoor air, infiltration is not a reliable source and is not awarded credit in this measure guideline. The airtightness of the apartment door is also important yet seldom tested. Another cause of problems is the exhaust ventilation system. The exhaust fans must be sized appropriately and properly commissioned. Typical problems involve duct leakage and underventilation at the exhaust registers. Also, issues with the passive vents may arise—primarily with proper sizing and installation.

Another challenge in employing passive vents is the required coordination between several contractors and systems. The air barrier, exhaust ventilation, and passive vents are typically the responsibilities of several contractors. The testing and verification of each system are the responsibilities of additional entities.

The continuous local exhaust flow rate needs to exceed the ASHRAE 62.2 level for passive vents to provide a specific flow of outdoor air. This increase in ventilation carries an energy penalty and should be considered when evaluating ventilation strategies.

The following sections describe the various factors that affect the performance of the passive vents and quantify the required level of performance for their successful implementation.

This measure guideline does not advocate for or against passive vents. Rather, it provides a framework for installing them in such a way that their performance can be improved.

The guidance provided by the U.S. Department of Energy's Building America research team Consortium for Advanced Residential Buildings (CARB) in this report should be considered when comparing various supply air strategies. High-performance building programs should also consider these requirements when specifying ventilation strategies.

2 Supplying Outdoor Air

To ensure good indoor air quality, many high-performance building programs require that the units meet the ventilation requirements of ASHRAE 62.2 for whole-house and local exhaust. Whole-house ventilation rates are based on the floor area of the dwelling unit and the number of occupants and are intended to provide a continuous exchange of air. Local exhaust rates, continuous and intermittent, are separately established to adequately remove moisture and contaminants from bathrooms and kitchens. To meet whole-house ventilation requirements, ASHRAE 62.2 accepts a mechanical ventilation system that is supply-only, exhaust-only, or a combination. If exhaust-only, the Standard allows the continuous local exhaust system to serve both purposes, if both rates can be met. It does not require a dedicated source of outdoor air to serve as makeup air to the exhaust system.

Although the Standard does not stipulate a dedicated source of outdoor air, certain building programs have gone beyond the Standard and required one. This measure guideline uses ASHRAE 62.2-2010 whole-house ventilation rates as the target outdoor air rates to be provided by passive vents. Although some air will come from leakage in the exterior envelope, it will vary from building to building and apartment to apartment. Exterior infiltration is unlikely to be quantified through guarded blower boor testing; therefore, this guideline provides a means of establishing the required outdoor air flow rate through the passive vents. Providing outdoor air through passive vents will result in an increase in the ASHRAE 62.2 ventilation rate. Should a different outdoor air flow rate be desired, such as a whole-house ventilation rate from ASHRAE 62.2-2013, the steps and guidance in this report are still relevant, and the calculations can be adjusted accordingly. However, if you are attempting to provide balanced ventilation in which the outdoor air flow rate equals the continuous local exhaust rate, another strategy should be pursued.

3 Measure Implementation

The planning and design of a passive vent system should begin at the earliest stage of the building design process. Unlike other ventilation strategies, passive vents rely heavily on the mechanical exhaust system, the air barrier, and the building envelope to function properly.

3.1 Determine Local Exhaust Ventilation Strategy and Equipment

Passive vents require local exhaust ventilation serving the apartment to function properly. The exhaust system creates a pressure differential between the apartment and outdoors. This pressure differential results in flow through the passive vents. For passive vents to perform consistently and reliably, a continuous exhaust system is needed for each apartment. An intermittent system is not suitable, because it would require excessively large passive vents or additional fan flow, or both. A continuous system can be achieved with either a central system serving numerous apartments or individual exhaust fans for each apartment. For either system, a fan with a direct-drive, electronically commutated motor is suggested. Such a fan can be easily adjusted in the field to increase or decrease exhaust airflow. Although either system is possible, individual systems—either in-line or ceiling exhaust fans—are preferable, because they are easier to balance in the field to meet the target flow for a specific apartment. When selecting the fan capacity, the required flow rate should fall in the middle of the fan curve to provide a degree of adjustability in case the airtightness standards or other metrics are not achieved and exhaust flow needs to be increased to induce the needed airflow through the passive vents. The fans should also be as energy efficient as possible, with a minimum efficiency of 3 CFM/W.

Regardless of the system or fan selected, the ductwork must be sealed to ensure the exhaust is being drawn from apartments and not from interstitial spaces. Duct leakage results in an overall increase in the volume of air exhausted from the building, which carries an energy penalty. For central exhaust risers, similar to testing the duct leakage of forced-air heating and cooling ductwork, the risers should be tested for leakage. A maximum of 5 CFM should be targeted per register for allowable duct leakage when pressure-tested at 50 Pascals.

The central system should employ constant airflow regulators (CARs). The CAR dampers should be specified for the design flow rate and allow for adjustment at the time of commissioning. CAR dampers could also be employed if an individual in-line fan is specified to better control the airflow exhausted from bathrooms and kitchens, but they are essential for an even distribution of airflows in a central system that serves multiple apartments. CAR dampers should be cleaned periodically to prevent the accumulation of dust, which may impede their operation. If dust is a major concern, fixed orifices may be used; however, unlike CARs, fixed orifices do not regulate the flow as the pressure changes across the opening. Also, the ductwork needs to be intact with low leakage. Rooftop or penthouse fans must be adjustable with speed controls or dampers for balancing flows between vertical shafts.

Demand controlled ventilation does not provide a continuous level of ventilation; therefore, the supply flow through the passive vents is unreliable. Passive vents should only be used in conjunction with local continuous exhaust. If demand controlled ventilation is being used, an alternative supply system should be implemented. Again, if balanced ventilation is required where makeup air to match exhaust rates is met solely by outdoor air and not transfer air, an alternative supply system should be implemented.

3.2 Assess Air Sealing Performance Target

At the beginning of the project, the performance targets of the building should be established. Passive vents require a level of air sealing and compartmentalization well beyond code and even beyond some energy-efficiency programs such as Leadership in Energy & Environmental Design and ENERGY STAR®. The team should be prepared to spend additional time and resources to establish well-compartmentalized apartments. At a minimum, the target airtightness should be 0.2 CFM50/ft^2 enclosure; however, 0.1 CFM50/ft^2 is preferable and results in an overall better system design. These targets were empirically determined based on the typical range of exhaust flows and fresh air rates for multifamily dwelling units. For comparison, the ENERGY STAR Multifamily High Rise Program requires 0.3 CFM50/ft^2 enclosure. The enclosure area is defined as the surface area that comprises the boundary of the apartment. This includes floor, ceiling, exterior walls, and demising walls.

If the team does not have experience constructing enclosures to this level of airtightness, or is not prepared to do so, passive vents should not be used to provide outdoor air to apartments. Without a well-compartmentalized apartment, passive vents will not consistently provide adequate outdoor air.

Also, this level of airtightness precludes the use of natural draft combustion appliances in apartments due to the danger of back-drafting or spilling of combustion gases. Passive vents are not a suitable source of combustion air.

3.3 Design Air Barriers

The airtightness of the apartment is a key component in the performance of passive vents. Best practices for effective air sealing should be identified and followed for the specific construction type. The design should provide for a continuous air barrier that covers all surfaces of the apartment. Attention should be given to critical details such as connections and penetrations, as described by Ueno and Lstiburek (2015).

An air barrier consultant should be involved in the design and construction processes. A design review may show more efficient framing or sheathing options that save time and materials and separate units at party walls, duct and plumbing chases, and offsets. The contractors who implement the work must also understand the design needs and the proper methods to complete their work. Also, the sequence of construction must allow completion of the separation layers and sealing of ducts and penetrations before common walls and ceiling cavities are closed.

Periodic compartmentalization testing should be conducted during critical phases of the construction process to ensure the air barrier is implemented correctly and effectively. Conducting an airtightness test only at the completion of construction is insufficient, because remedying air leakage at this point is very difficult and often not feasible. If periodic testing of the air barrier is not part of the construction process, passive ventilation should not be used to provide outdoor air to apartments.

The apartment entry door should be well sealed. The door is part of the apartment air barrier; however, it is not typically tested because the blower door is usually set up in the main entry door. To minimize air leakage around the door, high-quality weather stripping should be used around the frame and a sweep should be installed at the base.

3.4 Determine Passive Vent Flow Rate

The total flow from the passive vents should be determined for each apartment. The hypothetical examples in the following section use the whole-house ventilation rate given by equation 4.1a in the ASHRAE 62.2-2010 Standard, which is:

$$Q_{tot} = 0.01*A_{floor} + 7.5*(N_{br} + 1) \quad (1)$$

Similarly, the equation under the ASHRAE 62.2-2013 Standard is:

$$Q_{tot} = 0.03*A_{floor} + 7.5*(N_{br} + 1) \quad (2)$$

where

Q_{tot} = Whole-building ventilation flow rate (continuous) (CFM)

A_{floor} = Total floor of the apartment (ft^2)

N_{br} = Number of bedrooms (not to be less than 1)

The total flow (Q_{tot}) is the target flow for the passive vents. A continuous local exhaust system is required; the flow rate of that system will be greater than the flow rate from the passive vents and likely greater than the continuous local exhaust requirements of ASHRAE 62.2-2010.

3.5 Calculate Required Passive Vent Area and Exhaust Flow Rate

The area of passive vents required to provide a specific flow is given by the following equation:

$$A_{PV} = \frac{CFM_{PV} * A_{door} + \frac{CFM_{PV} * CFM_{50}}{14}}{CFM_{exhaust} - CFM_{PV}} \quad (3)$$

where

A_{PV} = Total area of the passive vents ($in.^2$)

CFM_{PV} = Total flow from all passive vents (CFM)

A_{door} = Total leakage area of the apartment door ($in.^2$)

CFM_{50} = Total flow from apartment at a test pressure of 50 Pa (CFM)

CFM_{exh} = Total continuous exhaust flow from all registers and fans (CFM)

A derivation of this equation is included in the Appendix.

The following guidance should be used in determining the passive vent area:

- CFM_{PV} represents the total outdoor air flow from all of the passive vents and should be determined using ASHRAE 62.2-2010 or similar guidance.
- A_{door} represents the leakage of the apartment entry door. Table 1 should be used to estimate leakage. A maximum leakage area of 5 in.^{2} should be targeted. The doors should be tested once they are installed. A blower door frame and Duct Blaster can be used for testing by installing it in the frame with the door closed (Figure 1).
- CFM_{50} should be estimated based on reasonable assumptions. An airtightness of 0.1–0.2 CFM50/ft^2 should be used as a guide to determine this value.
- CFM_{exh} is the total continuous exhaust flow from all registers and fans in the apartment. Increasing the value of this parameter decreases the area of passive vent required. This should be adjusted in an iterative fashion to identify a passive vent area that is realistically achievable. Again, the total continuous exhaust flow will likely be higher than the rate specified by ASHRAE 62.2-2010 for the local exhaust requirement (20 CFM in bathrooms and 5 ACH in kitchens). Increasing it even further does incur an energy penalty due to higher fan power, which should be taken into consideration.

Figure 1. Measuring leakage area of entry door

Table 1. Typical Leakage Area between Entry Door and Frame

Condition	Leakage Area (in.^{2})	CFM50
Weather-Stripped with Door Sweep, Good	2	28
Weather-Stripped with Door Sweep, Average	5	71
Weather-Stripped, No Door Sweep	10	142
No Sealing	22	312

This calculation does not take into consideration the effects of wind and weather. These factors are not constant or predictable and thus cannot be accurately incorporated. Excluding these factors results in a slightly conservative approach, which ensures a minimum level of outdoor air is provided.

An energy penalty is also associated with increasing the ventilation rate. The additional air that is being exhausted ultimately comes from outdoors and therefore needs to be conditioned. The energy associated with conditioning this air may be significant and is dependent on the climate, flow rate, and heating and cooling systems.

3.6 Design and Position Passive Vents

The passive vent area determined in the previous step should be incorporated into the building design. To do this, the effective net free area of the passive vents is needed. The two primary passive vent options are trickle vents and airlets. For trickle vents, the manufacturer typically lists the minimum free area in the product specifications. An average value is about 4 in.^{2} per vent. In the case of airlets, the diameter of the vent is not the effective free area because the filter and damper flaps reduce the opening size. The effective net free area for the Airlet 200 is 2.6 in.^{2}. This has been empirically determined through pressure-flow testing. Projects using other make or model airlets should contact the manufacturer for the effective net free area or determine it through pressure-flow tests.

The calculated passive vent area determined in the previous step should be divided by the minimum free area of the trickle vent, or the effective net free area of the airlet, to determine the number of vents needed per apartment. In the case of trickle vents, typically only one vent can be installed per window. Therefore, the number of trickle vents required should not exceed the number of windows in the apartment. If it does, or if the number of airlets is unreasonable, the design should be re-evaluated. The airtightness of the apartment may need to be increased or the exhaust ventilation rate increased, or both.

Another consideration between trickle vents and airlets is the installation requirements. Trickle vents are typically installed in the window frame by the window manufacturer. Consideration should be given to selecting a window manufacturer with experience in installing trickle vents. CARB has tested several buildings in which the trickle vents were not installed as specified and adversely affected the airflow. Airlets are installed in the exterior wall of the building. This requires cutting a continuous opening from the apartment to the outside and results in additional penetrations in the façade. The installation will have greater or lesser complexity depending on the façade system. Aesthetics may also be a concern, because an exterior grille will be located on the façade at each airlet.

3.7 Commission Passive Vent Design, Construction, and Installation

Passive vents must be properly commissioned at each step in the design process. The following conditions should be considered for this process:

- Once a passive vent type has been selected, a sample, installation specifications, and documentation should be requested from the manufacturer.
- For trickle vents, a sample should be sent to the window manufacturer for installation in a window.
- The sample installation should be inspected before any further vents are installed.
- The commissioning agent should ensure the trickle vent is installed as specified.
- The vent should be placed at the top of the window.
- The cover of the vent should be removed and the hole through the window frame should be inspected (Figure 2).

- The number and size of openings through the window frame should be the same on all windows.
- The dimensions of the hole must meet those specified by the trickle vent manufacturer. Common problems include obstructions, holes smaller than those specified, and holes that do not provide a direct connection from one side of the window to the other (Figure 3). The opening does not extend to the outside over the entire length as it should. Secondary holes were drilled in an attempt to address this, but they do not provide the appropriate free area. Corrections must be made until the free area matches the specifications in the design.

Figure 2. Examples of inconsistent trickle vent installation

Figure 3. Cut for trickle vent in window frame (left). Close-up of opening (right)

Airlets must typically be installed near the ceiling in each room. This allows the air drawn through the vent to mix with room air and reduces uncomfortable drafts. The exact locations of all airlets should be clearly shown on the construction drawings. The contractor should not need to determine the placement. CARB has observed several buildings that have installed airlets incorrectly (see Figure 4). The airlet, circled in red, should be installed within 12 in. of the ceiling, not close

Figure 4. Incorrect airlet installation

to the floor as shown. The commissioning agent should ensure the vents are installed with the proper filters, grilles, and regulating flaps.

3.8 Perform Airtightness Testing

Airtightness testing should be performed during critical stages of the construction process to ensure the target airtightness levels are being achieved. Final testing should be conducted at construction completion to verify the airtightness of apartments. If the target airtightness levels are not achieved, additional sealing should be done. If the airtightness cannot be increased, the outdoor air target can possibly still be increased. Equation 2 should be recalculated using actual airtightness. The exhaust flow rate may need to be increased to achieve the desired passive vent flow. Selecting an exhaust fan that is field-adjustable and is sized to accommodate additional flow is critical.

The operating pressure of the apartment should be verified at the completion of construction. The pressure across the exterior apartment wall should be measured under the normal operating condition, which is defined as all windows closed and locked, interior doors open, all continuous exhaust fans running, and all passive vents open. The pressure should match that given by the following equation:

$$P = 0.635 * \left(\frac{CFM_{exh}}{0.82 * \left(A_{door} * \ A_{PV} + \frac{CFM_{50}}{14} \right)} \right)^{1.538} \qquad (4)$$

The derivation of this equation is included in the Appendix. Values for standard conditions have been substituted to simply the calculation.

4 Sample Design Process

This section provides an overview of the passive vent design process for two hypothetical apartments. To facilitate the design process, these equations are part of an Excel-based calculator located on the CARB website.

4.1 One-Bedroom Apartment

The following is an analysis for a hypothetical 750-ft^2, one-bedroom apartment. The physical dimensions of the apartment are in given in Table 2.

Table 2. Dimensions of Hypothetical One-Bedroom Apartment

Length	37.5	ft
Width	20	ft
Height	9	ft
Floor Area	750	ft^2
Enclosure Area	2,535	ft^2
Volume	6,750	ft^3

Equation (3) was rearranged to solve for passive vent flow. The new equation is given as:

$$CFM_{PV} = \frac{A_{PV} * CFM_{exh}}{A_{door} + A_{PV} + \frac{CFM_{50}}{14.02}} \qquad (5)$$

where

CFM_{PV} = Total flow from all passive vents (CFM)

A_{PV} = Total area of the passive vents ($in.^2$)

CFM_{exh} = Total continuous exhaust flow from all fans (CFM)

A_{door} = Total leakage area of the apartment door ($in.^2$)

A_{PV} = Total area of all passive vents ($in.^2$)

CFM_{50} = Total flow from apartment at a test pressure of 50 Pa (CFM)

This equation was used to develop passive vent flow versus area curves for this specific apartment at various apartment airtightness levels. The apartment entry door is assumed to have average weather-stripping and door sweep. The equivalent leakage area around the door is estimated at 5 $in.^2$. Figure 5 shows the flow-area curves for a continuous exhaust rate of 100 CFM; Figure 6 uses a rate of 125 CFM.

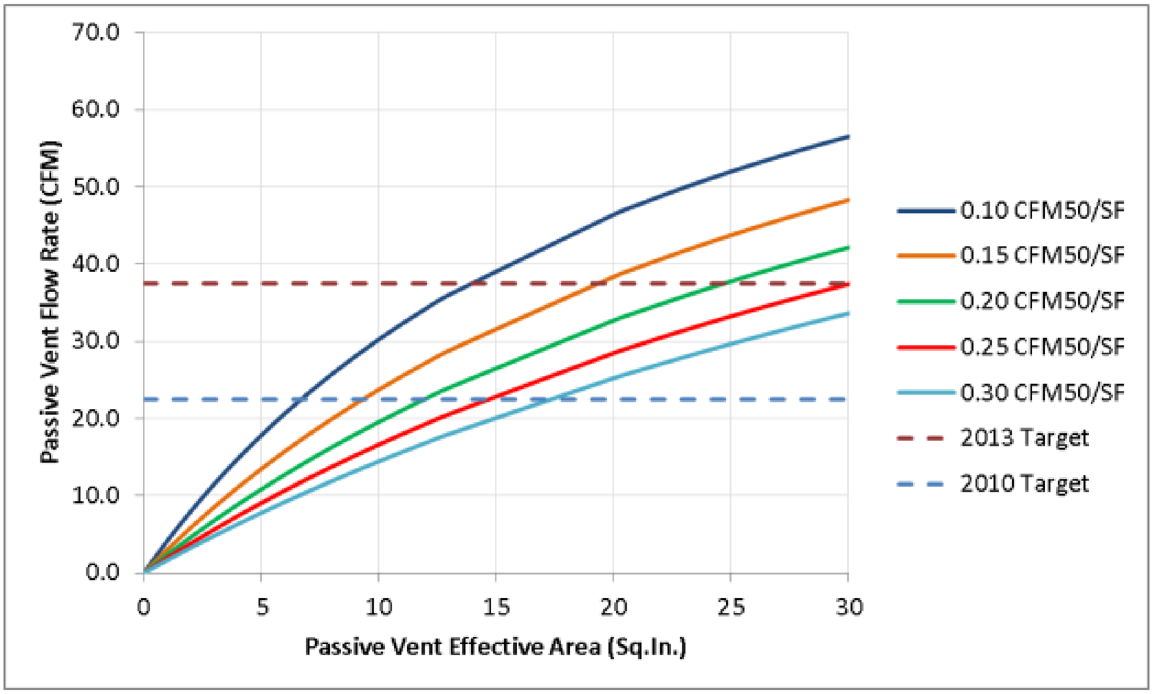

Figure 5. Passive vent flows at various airtightness levels for a one-bedroom apartment with 100 CFM continuous exhaust

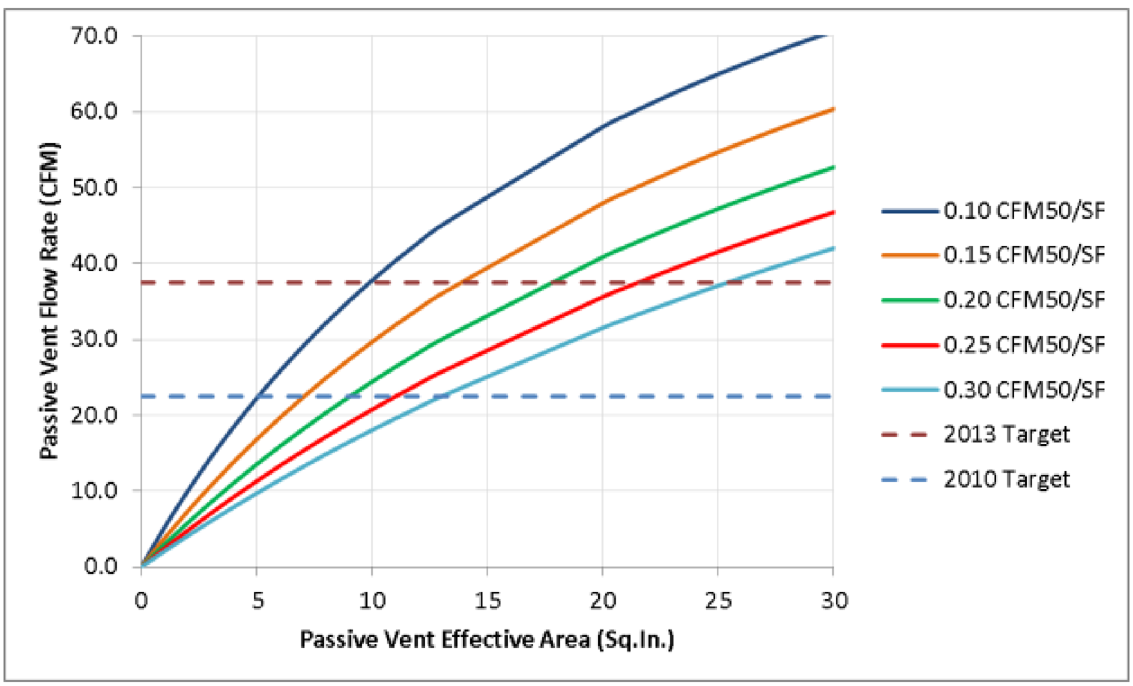

Figure 6. Passive vent flows at various airtightness levels for a one-bedroom apartment with 125 CFM continuous exhaust

For comparison to the required local exhaust rates, in a typical one-bedroom apartment with one bathroom and one kitchen, ASHRAE 62.2-2010 requires 20 CFM continuous in the bathroom and 5 ACH in the kitchen, which for the average apartment kitchen is about 40–60 CFM.

These figures are intended to provide a visual method to the passive vent design process. To determine the passive vent size required to provide a specific flow, a horizontal line should be drawn that intersects the y-axis at the passive vent design flow rate. The dashed horizontal lines represent the ASHRAE 62.2-2010 and 2013 whole-house ventilation rates. A vertical line should be drawn where the horizontal line intersects the curve that corresponds to the apartment airtightness. The intersection of the vertical line and the x-axis gives the required passive vent area in square inches.

As an example, an apartment with 100 CFM continuous exhaust, an airtightness of 0.10 CFM50/ft^2, and a target flow of 22.5 CFM (indicated by the blue dashed line) requires a passive vent area of 6.7 in.^{2}. For reference, the airtightness for this apartment corresponds to approximately 250 CFM50. Assuming a free area of 4 in.^{2} per trickle vent, this corresponds to two trickle vents, which should be appropriate for the number of windows in a typical one-bedroom apartment. If the exhaust rate is increased to 125 CFM, the required area falls to 5.1 in.^{2}. Thus, for a given passive vent flow, increasing apartment airtightness or increasing continuous exhaust rate, or both, result in a reduction in the required passive vent area. However, increasing continuous exhaust does increase overall energy use, because a larger fan is needed.

For example, a 100-CFM in-line exhaust fan that has an efficiency of 3.3 CFM/watt consumes 265 kWh annually. Increasing this to 125 CFM, and assuming the same efficiency, results in 331 kWh annually. Compared to other loads, this is less energy than an ENERGY STAR-certified refrigerator consumes, but is on par with a dishwasher. In addition, the energy penalty associated with heating the additional air due to the higher flow rate in this example is approximately 3,600 kBtu/year. This assumes a heating system efficiency of 80% and 4,500 heating degree days. If natural gas is used for heating and a rate of $1.20/therm is assumed, this results in an additional annual cost of $43 per apartment.

4.2 Two-Bedroom Apartment

The following is an analysis for a hypothetical 900-ft^2, two-bedroom apartment. The physical dimensions of the apartment are in given in Table 3.

Table 3. Dimensions of Hypothetical Two-Bedroom Apartment

Length	25	ft
Width	36	ft
Height	9	ft
Floor area	900	ft^2
Enclosure Area	2,898	ft^2
Volume	8,100	ft^3

Figure 7 and Figure 8 show the passive vent flows versus vent area for this specific apartment at various apartment airtightness levels.

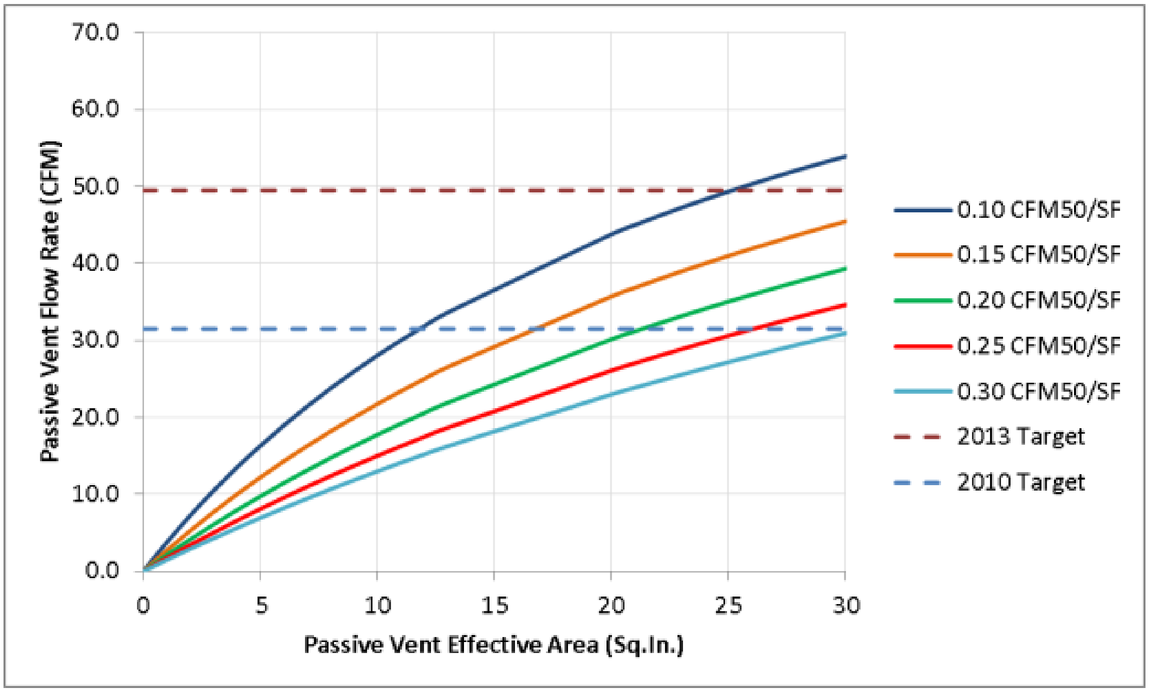

Figure 7. Passive vent flows at various airtightness levels for a two-bedroom apartment with 100 CFM continuous exhaust

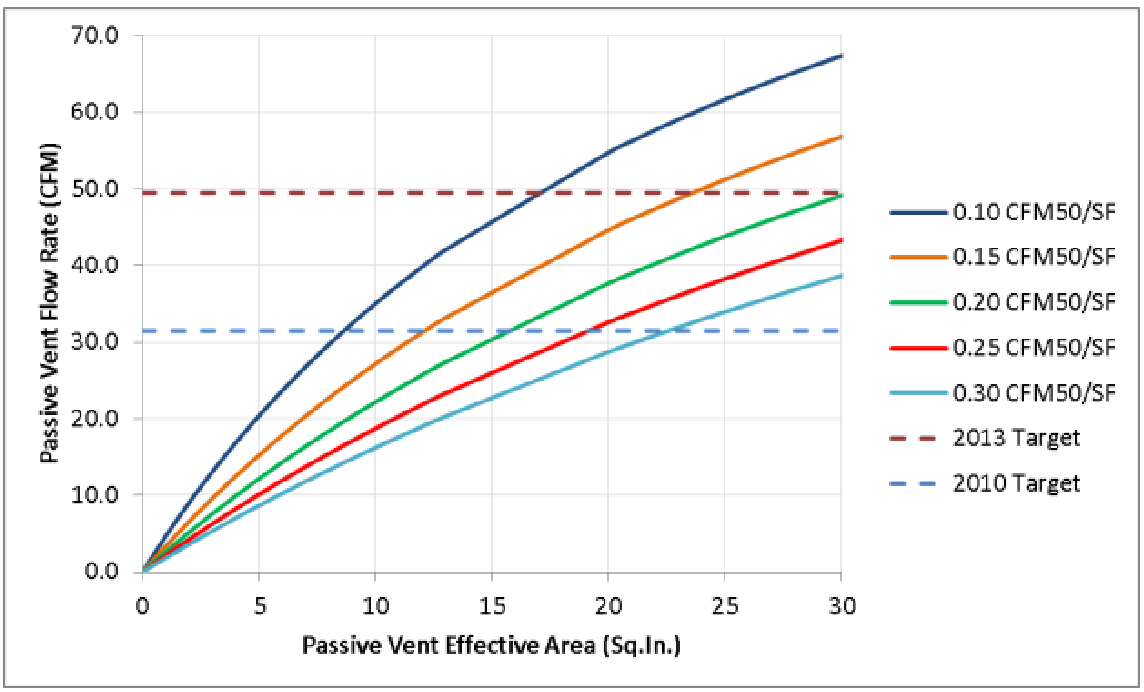

Figure 8. Passive vent flows at various airtightness levels for a two-bedroom apartment with 125 CFM continuous exhaust

To meet the ASHRAE 62.2-2010 whole-house ventilation rate, this apartment with an airtightness of 0.10 CFM50/ft^2 requires 11.8 in.^{2} with 100 CFM of continuous exhaust, or 8.7 in.^{2} with 125 CFM of exhaust. This translates to three trickle vents or four to five airlets.

5 Verification Procedures and Tests

Currently no standard protocols are available for testing passive vents. Thus, energy-efficiency programs that require a source of outdoor air do not require testing of passive vents or verification of airflow. This lack of testing and verification has resulted in numerous installations of passive vents that do not consistently provide design levels of outdoor air.

As stated in previous sections, many building systems affect the operational effectiveness of passive ventilation, so an ongoing and comprehensive commissioning process is necessary for a positive result when construction is completed. The verification procedures and tests outlined in this section should be performed early and often in the design and construction process. The following tests represent a comprehensive process for verifying the installation and performance of passive vents.

5.1 Visual Inspection

1. Assess the installation of the vents:
   A. Is the vent opening in the correct location in the room based on the manufacturer's specifications? Check design drawings and compare to as-built installation.
   B. Does the opening pass through the wall and window frame completely and unobstructed as designed? Measure the size of the free opening through the entire penetration of the wall and window frame Ensure the smallest section of opening through the passive vent complies with the manufacturer's specifications for free area. Correct as needed in the field to ensure free area is as specified.
2. Airlet. Verify that a filter is installed and that flaps can move freely.

5.2 Passive Vent Airflow Test

If a question arises about whether the vent is adequate or whether it will provide the required airflow, a vent airflow test can be performed.

Airflow testing should be conducted on a sample of installed passive vents. The objective of the testing is to verify the pressure-flow relationship of the installed vent.

Passive vent testing involves inducing a pressure difference on either side of the vent and measuring the airflow. One method is to attach a calibrated fan, such as a Duct Blaster, to a capture box with an orifice plate (see Figure 9). The fan is used to induce a pressure. The speed of the fan is varied and the pressures across the passive vent and across the orifice plate are recorded. Typically, the flow through the passive vent is lower than the Duct Blaster fan can measure directly; therefore, the pressure across the orifice plate is used to determine the flow with the following equation:

$$Q = 0.8202 * A_{orifice} * \left(\frac{2 * \Delta P}{\gamma}\right)^{0.65} \quad (6)$$

where:

Q	=	Airflow (CFM)
$A_{orifice}$	=	Area of orifice opening (in.^{2})
ΔP	=	Differential pressure across orifice (Pa)
γ	=	density of air (kg/m^3)

This equation is a simplification of the orifice equation with substitutions for typical conditions.

Figure 9. Testing device for passive vents

5.3 Short-Term Pressure Monitoring

Knowing the pressure-flow relationship from the previous test, the normal operating pressure is needed to determine if the desired flow from passive vents is being achieved. Create the normal operating conditions of the apartment when the vents would be operating—entry door closed, all interior doors open, windows closed and locked, passive vents open, all continuous exhaust fans operating. Measure the pressure across the passive vents under these operating conditions by using a manometer and running the tubing outside through a window, passive vent, or some other opening. Use a metal tube so as not to pinch the tubing if squeezing through tight spaces.

5.4 Apartment Airtightness Test

The goal of airtightness testing is to quantify the compartmentalization of an apartment and compare it to the intended design airtightness.

- **Method 1.** Conduct a blower door test of the apartment using the entry door. This is the standard method for conducting compartmentalization testing and involves placing the shroud and fan in the entrance door to apply a pressure differential in the apartment and measure airflow through the fan. The measured airtightness should be compared to the design airtightness, CFM_{50}, as used in Equation (2). A weakness of this method is that the air leakage around the door is not recorded, which is a significant omission given that the rest of the apartment is likely to have few leaks as large as the gap between the door and the frame. If this method is used, the entry door leakage should be tested as described in Section 5.5.

- **Method 2.** Conduct airtightness test using Duct Blaster fan in a window. Although this method may be more difficult to set up and execute, its major advantage is that the apartment leakage measurement includes the leakage around the door. Because windows are kept closed during a blower door test, no considerable leakage pathways are omitted when mounting the equipment in the window. If this method is used, A_{door} in Equation (3) should be set to zero and the design airtightness, CFM_{50}, then represents the total leakage from the entire apartment envelope, including the apartment door. The measured airtightness should be compared to this design airtightness.

Performing airtightness testing at different stages of construction enables leakage pathways to be identified before they are inaccessible and remediation is impossible. Testing a mockup unit can also be beneficial before air sealing is conducted on all units.

5.5 Apartment Entry Door Testing

If Method 1 is used to test the apartment airtightness, the apartment entry door should also be tested for leakage for comparison to intended design values. A blower door frame and fan can be used for testing by installing it in the frame with the door closed. This setup is shown in Figure 1. In practice, the apartment airtightness could be tested using Method 1, then the entry door could be closed and the door tested without having to move the blower door frame or fan. The measured leakage should be compared to design values used in Table 1.

5.6 Exhaust Flow Testing

The continuous exhaust flow in apartments should be tested to ensure it matches the design flow. A pressure box, balometer, or powered flow hood should be used to measure the flow at each register. The sum of the airflows from all exhaust registers should be compared to the design exhaust, CFM_{exh}.

5.7 Corridor Supply Flow Testing

Although the supply flow to the corridors is not the intended source of outdoor air being supplied to the apartment, it should be tested to ensure it matches the design flow. At a minimum, testing should confirm that the system is on and providing air to the corridors. Ideally, the flow should be measured at each supply register using a pressure box or powered flow hood.

5.8 Long-Term System Performance

As with any mechanical system, maintenance is required to ensure continued performance. The primary component is the exhaust ventilation system. This should be inspected regularly to confirm the fans and CAR dampers are functioning properly. The passive vents should be inspected at regular intervals to ensure they are clear of debris. In the case of airlets, the filters should be cleaned or changed per the manufacturer’s instructions. The weather stripping and sweep of apartment entry doors should be kept in good repair.

If the components of the passive ventilation system are properly designed, constructed, commissioned, and maintained, the system should provide a reliable source of outdoor air for the life of the building.

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Appendix

Orifice Equation

$$CFM = C_d * A * 1.367 * \left(\frac{2 * \Delta P}{\gamma}\right)^{0.65}$$

Solving for operating pressure of apartment

$$\Delta P = P_{operating} = \frac{\gamma}{2}\left(\frac{CFM_{exhaust}}{C_d * 1.367 * A_{total}}\right)^{\frac{1}{0.65}}$$

$$P_{operating} = \frac{\gamma}{2}\left(\frac{CFM_{exhaust}}{C_d * 1.367 * \left(A_{Door} + A_{PV} + \frac{CFM_{50}}{1.367 * C_d * \left(\frac{2 * 50}{\gamma}\right)^{0.65}}\right)}\right)^{\frac{1}{0.65}}$$

Passive vent flow

$$CFM_{PV} = C_d * A_{PV} * 1.367 * \left(\frac{2 * P_{operating}}{\gamma}\right)^{0.65}$$

Substituting $P_{operating}$ and simplifying

$$CFM_{PV} = \frac{A_{PV} * CFM_{exhaust}}{A_{Door} + A_{PV} + \frac{CFM_{50}}{1.367 * C_d * \left(\frac{2 * 50}{\gamma}\right)^{0.65}}}$$

To find area of passive vent, with C_d=0.6, the above simplifies to:

$$CFM_{PV} = \frac{A_{PV} * CFM_{exhaust}}{A_{Door} + A_{PV} + \frac{CFM_{50}}{14}}$$

Rearranging:

$$A_{PV} = \frac{CFM_{PV} * A_{Door} + \frac{CFM_{PV} * CFM_{50}}{14}}{CFM_{exhaust} - CFM_{PV}}$$

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