Residential Indoor Air Quality Ventilation

2008 California Building Energy Efficiency Standards

New Mandatory Requirements for Indoor Air Quality Ventilation in Low Rise Residential Buildings

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CONTENTS

Purpose

There is recent evidence that ventilation rates in new California homes are lower than had been assumed in the 2005 Standards because infiltration is lower and occupants use windows for ventilation less than had been assumed. Inadequate ventilation rates can contribute to increased concentration of pollutants that threaten the health of occupants. This proposal responds to that threat by specifying a new mandatory requirement that Low Rise Residential Buildings comply with ANSI/ASHRAE Standard 62.2-2004 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Window operation will not be permitted as a means of meeting the whole house ventilation requirements so a mechanical whole house ventilation system will be required.

Overview

Description	This proposal includes the a new mandatory requirement to comply with ASHRAE Standard 62.2-2004 specifies: 1. Mechanical ventilation is required. Window operation is not permitted as a means of meeting the required ventilation. 2. Whole-house Mechanical exhaust, supply or balanced ventilation equal to 1 cfm/100 sq. ft. plus 7.5 cfm *(number of bedrooms +1). 3. If performance approach is not used, the total fan power used to meet this requirement shall not exceed 1.2 W/cfm of required ventilation air. If performance approach is used, total fan power in the standard design is equal to the proposed house but not greater than 1.2 W/cfm of required ventilation air. 4. Control must be provided to allow occupant use and to determine minimum and maximum operating times. 5. Exhaust ventilation (to outside) of at least 50 cfm intermittent or 20 cfm continuous in each bathroom. 6. Exhaust ventilation (to outside) of at least 100 cfm intermittent with a vented range hood or 5 ACH in each kitchen. 7. Air moving equipment must meet requirements for sound of 1 sone for continuous use or 3 sones for intermittent use. 8. Air moving equipment must meet requirements for air flow rating either by ASHRAE 62.2-2004 field verification or using a prescriptive table. 9. MERV 6 (or better) particle filtration must be used for any air handling components with at least 10 ft of ducting. 10. Naturally aspirated combustion equipment may not be used inside the pressure boundary when exhaust flow exceeds specified limits. 11. Clothes dryers must be vented outdoors.

	12. Other requirements involving location of intakes, dampers, ventilation openings etc. The proposal also includes related changes the Residential Alternative Compliance Methods (ACM) manual: 1. Reducing the Specific Leakage Area (SLA) default values by 0.6 to account for reduced air leakage found in recently constructed homes. 2. Removing the current ACM provisions for Indoor Air Quality ventilation using a combination of infiltration and occupant operated windows. 3. Removing the current ACM requirements for mechanical ventilation in homes claiming credit for low Specific Leakage Area (SLA) 4. New ACM definitions and rules for calculating Indoor Air Quality ventilation system energy. 5. Separating the treatment of Infiltration/Ventilation in the ACM into separate sections in the ACM for clarity.
Type of Change	This change adds a mandatory measure and involves related changes to the ACM calculation procedures
Energy Benefits	The proposal requires Indoor Air Quality ventilation and limits the associated energy use.
Non-Energy Benefits	This measure requires a minimum level of ventilation to protect the health of the occupants of California homes.
Environmental Impact	n/a
Technology Measures	ASHRAE 62.2 requires ventilation systems which are rated to ensure they deliver the intended ventilation and are quiet enough to be used routinely by home occupants. Ventilation equipment meeting these requirements is widely available.
Performance Verification	The fan and duct must meet simple prescriptive requirements or air flow must be measured.
Cost Effectiveness	n/a.
Analysis Tools	Mechanical ventilation is already included in the residential ACMs
Relationship to Other Measures	n/a

Methodology

Ventilation with Windows

A survey was conducted to determine occupant use of windows and mechanical ventilation devices; barriers that inhibit their use; satisfaction with indoor air quality (IAQ); and the relationship between these factors[1]. A questionnaire was mailed to a stratified random sample of 4,972 single-family detached homes built in California in 2003, and 1,448 responses were received. A convenience sample of 230 houses known to have mechanical ventilation systems resulted in another 67 completed interviews. Results:

- Many houses are under-ventilated: depending on season, only 10-50% of houses meet the standard recommendation of 0.35 air changes per hour.
- Local exhaust fans are under-utilized. For instance, about 30% of households rarely or never use their bathroom fan.
- More than 95% of households report that indoor air quality is "very" or "somewhat" acceptable," although about 1/3 of households also report dustiness, dry air, or stagnant or humid air.
- Except households where people cook several hours per week, there is no evidence that households with significant indoor pollutant sources get more ventilation.
- Except households containing asthmatics, there is no evidence that health issues motivate ventilation behavior.
- Security and energy saving are the two main reasons people close windows or keep them closed.

Envelope Air Tightness

The envelope leakage area in new homes has been declining since the 2005 default SLA values were established in 1998 based on measurements of houses constructed between 1984 and 1987.[2] The declines are the result of a number of changes including improved components required by the standards such as air tight recessed lighting fixtures, changes in building practices such as the shift to sealed combustion gas fireplaces. Although there have been no comprehensive studies of envelope leakage in California homes since 1990, smaller studies and anecdotal evidence support lower default SLA values. For example Wilson presented data at a CEC workshop from his study of 76 Southern California homes built in 2002 that had an average SLA of 2.8. [3] The PIER study of Residential Construction Quality (RCQ) found average SLAs of 3.2 and 3.5 for 2 groups of homes built in above code incentive programs.[4] Rick Chitwood who carried out the field measurements for the RCQ project recommends an assuming 3.4 to 3.8 SLA for typical new homes.[5]

Applicability of Residential Ventilation Standards in California

McWilliams and Sherman reviewed the literature on residential ventilation, codes, standards and guidelines relevant to residential ventilation[6]. Residential ventilation standards always address local

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1 *Price, P.N. and M.H. Sherman* **"Ventilation Behavior and Household Characteristics in New California Houses,"** April 2006. LBNL-59620. http://epb.lbl.gov/Publications/lbnl-59620.pdf

2 Wilcox, B; Lutz, J. Air Tightness and Air Change Rates in Typical New California Homes," Proceedings of the ACEEE 1990 Summer Study, American Council for an Energy Efficient Economy, Washington, DC, 1990.

3 Wilson, A.L., Bell, J., Hosler, D., Weker, R.A. Infiltration, Blower Door and Air Exchange Measurements in New California Homes. In: IAQ Problems and Engineering Solutions Specialty Conference, Research Triangle Park, NC, AWMA, July 21, 2003.

4 Davis Energy Group. Residential Construction Quality Assessment Project Phase II Final Report, California Energy Commission 400-98-004, 2002.

5 Personal communication, 3/16/2006

6 Sherman, M.H. and J.A. McWilliams "Report on Applicability of Residential Ventilation Standards in California" June 2005, LBNL-58713. http://epb.lbl.gov/Publications/lbnl-58713.pdf

and whole-house ventilation rates and some basic source control requirements, but there are many interactions with building systems that must also be considered.

Analysis and Results

n/a

Recommendations

1. **New Mandatory Requirement.** Add a new section to:

   SUBCHAPTER 7
   LOW-RISE RESIDENTIAL BUILDINGS MANDATORY FEATURES AND DEVICES
   SECTION 150 MANDATORY FEATURES AND DEVICES
   Any new construction in a low-rise residential building shall meet the requirements of this Section.
   ......"

The new section is:

(n) **Ventilation for Indoor Air Quality**

1. All dwelling units shall meet the requirements of ANSI/ASHRAE Standard 62.2-2004 Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Window operation is not a permissible method of providing the Whole Building Ventilation required in Section 4 of that Standard.

2. **Modifications to the Residential ACM Manual.** Make the following modifications to:

- Reducing the Specific Leakage Area (SLA) default values by 0.6 to account for reduced air leakage found in recently constructed homes.
- Remove the current ACM provisions for Indoor Air Quality ventilation using a combination of infiltration and occupant operated windows.
- Removing the current ACM requirements for mechanical ventilation in homes claiming credit for low Specific Leakage Area (SLA)
- New ACM definitions and rules for calculating Indoor Air Quality ventilation system energy. Substantial additional language, not included in this draft, needs to be added to fully describe the ACM modeling rules.
- Separating the treatment of Infiltration/Ventilation in the ACM into separate sections in the ACM for clarity. Substantial additional language, not included in this draft, needs to be added to support this separation.

2.2.13 Infiltration/Ventilation

This listing is only produced when the applicant has used reduced infiltration measures~~ (and mechanical ventilation when necessary)~~ to improve the overall energy efficiency of the Proposed Design~~ while maintaining adequate air quality~~. Reduced infiltration credit may be taken for duct sealing and installation of an air retarder without a blower door test. Otherwise, the use of reduced infiltration requires diagnostic blowerdoor testing by a installer and a certified HERS rater to verify the modeled reduced leakage area~~ and to ensure minimum infiltration/ventilation rates are achieved~~. Relevant information regarding infiltration and ventilation shall be reported in the *Field Verification and Diagnostic Testing* listings on the CF-1R. The listings shall indicate that diagnostic blower door testing shall be performed as specified in ASTM E 779-99, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*. This listings shall also report the target $CFM50_H$ required for the blower door test to achieve the modeled SLA and the minimum $CFM50_H$ (corresponding to an SLA of 1.5) allowed to avoid backdraft problems. This minimum allowed value is considered by the Commission to be “unusually tight” in the requirements of the California Mechanical Code. ~~When the target $CFM50_H$ of the *Proposed Design* is below the value corresponding to an SLA of 3.0, mechanical ventilation with a minimum capacity of 0.047 CFM per square foot of conditioned floor area is required. This requirement for mechanical ventilation and minimum capacity shall be reported in the *Field Verification and Diagnostic Testing* listings of the CF-1R.~~ Also, the *Field Verification and Diagnostic Testing* listings shall state that when the measured $CFM50_H$ is less than the minimum allowed value, corrective action shall be taken to either intentionally increase the infiltration or provide for mechanical supply ventilation adequate to maintain the dwelling unit at a pressure greater than -5 pascals relative to the outside average air pressure with other continuous ventilation fans operating.

When mechanical ventilation is part of the Proposed Design the exhaust and supply fan wattages shall be reported in this listing and the *Field Verification and Diagnostic Testing* listings. ~~Whenever mechanical ventilation is modeled by the user or required by modeling an SLA of 3.0 or less, the mechanical ventilation capacity selected by the user shall be greater than or equal to 0.047 cfm per square foot of conditioned floor area to be modeled by an approved ACM. If the user enters a volumetric capacity that is less than 0.047 cfm/ft^2, the ACM shall indicate an input error to the user and block compliance output.~~

When reduced infiltration or mechanical ventilation is modeled, the *Special Features and Modeling Assumptions* listings shall include a statement that the homeowner’s manual provided by the builder to the homeowner shall include instructions that describe how to use the ~~operable windows or~~ mechanical ventilation to provide for proper ventilation.

INFILTRATION/VENTILATION DETAILS *(Example Listing)*

Blower Door Leakage Target ($CFM50_H$/SLA)	Blower Door Leakage Minimum ($CFM50_H$/SLA)	Vent. Fan CFM (Supply/Exhaust)	Mechanical Vent Fans (Watts) [Supply/Exhaust]
1250/2.9	586/1.5	200/300	*50/75*

- *Blower Door Leakage Target ($CFM50_H$/SLA):* The measured blower door leakage in cfm at 50 pascals of pressurization and its equivalent Specific Leakage Area (SLA) value.
- *Blower Door Leakage Minimum ($CFM50_H$/SLA):* The limit for the blower door leakage test to avoid backdrafting, which corresponds to a Specific Leakage Area (SLA) of 1.5, considered to be “unusually tight” for California Mechanical Code compliance. The ACM shall report in the *Field Verification and Diagnostic Testing* listings that the Commission considers this minimum CFM and the corresponding SLA of 1.5 or less to be “unusually tight” per the Uniform Mechanical Code. In the sample listing given above a 1600 square foot house and the SLA lower limit of 1.5 is used to determine the *Blower Door Leakage Minimum* shown.
- *Vent. (Ventilation) Fans (CFM):[Supply/Exhaust]* The total volumetric capacity of supply fans and exhaust fans listed separately, separated by a slash (or reported in separate columns). The balanced portion of mechanical ventilation is the smaller of these two numbers while the

unbalanced portion is the difference between these two numbers. These values are reported in cubic feet per minute.

- *Mechanical Vent. (Ventilation) Fans (Watts) [Supply/Exhaust]:* The total power consumption of the supply ventilation fans and the total power consumption of the exhaust ventilation fans in watts.

Use of an air retarding wrap shall be reported in the Special Features and Diagnostic Testing listings.

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2.2.23 Field Verification and Diagnostic Testing

This listing shall **stand out and command the attention** of anyone reviewing this form to emphasize the importance of Field Verification and Diagnostic Testing of these features and the aspects of these features that were modeled to achieve compliance.

Specific features that require diagnostic testing to assure proper installation require field testing and verification by a certified home energy rater (HERS rater) under the supervision of a CEC- approved HERS provider, and shall be listed in this section.

All items in the *Field Verification and Diagnostic Testing* listings shall also report that the installer and HERS rater shall both provide the appropriate CF-6R and CF-4R documentation, respectively, for proper installation, testing, and test results for the features that require verification by a HERS rater. The installer shall document and sign the CF-6R to verify compliance with design and installation specifications. The HERS rater shall document and sign the CF-4R to confirm the use of proper testing procedures and protocol, to report test results, and to report field verification of installation consistent with the design specifications needed to achieve these special compliance efficiency credits.

~~The ACM shall ask the user if there are vented combustion appliances inside the conditioned space that draw air for combustion from the conditioned space prior to accepting any entry for reduced infiltration or mechanical ventilation. Cooking appliances, refrigerators and domestic clothes dryers are excluded from this requirement. If appliances other than cooking appliances, refrigerators and domestic clothes dryers are present and use conditioned air for combustion, the ACM shall instruct the user that reduced infiltration shall not be modeled when these devices are part of the Proposed Design and block data entries and ACM modeling of reduced infiltration and mechanical ventilation. When the user indicates that such devices are present or when the user models reduced infiltration or mechanical ventilation, the ACM shall report in the *Special Features and Modeling Assumptions* listings that reduced infiltration and/or mechanical ventilation are prohibited from being modeled when vented combustion appliances, not excluded above, are inside conditioned space.~~

~~When a *Proposed Design* is modeled with a reduced target infiltration ($CFM50_H$) that corresponds to an SLA less than 3.0, mechanical ventilation is required and shall be reported in the *Field Verification and Diagnostic Testing* listings.~~

FIELD VERIFICATION AND DIAGNOSTIC TESTING

This house is using reduced duct leakage to comply and shall have diagnostic site testing of duct leakage performed by a certified HERS rater under the supervision of a CEC-approved HERS provider. The results of the diagnostic testing shall be reported on a CF-6R form and list the target and measured CFM duct leakage at 25 pascals.		
This house has tight construction with reduced infiltration and a target blower door test range between 586 and 1250 CFM at 50 pascals. The blower door test shall be performed using the ASTM *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization*, ASTM E 779-99.		
This house is using an HVAC system with all ducts and the air handler located within the conditioned space. This results in a higher distribution efficiency rating due to elimination of conduction losses (losses due to leakage are not changed) and shall be visually confirmed by a certified HERS rater under the supervision of a CEC-approved HERS provider. This verification shall be reported on a CF-6R form.		
WARNING: If this house tests below 586 CFM at 50 pascals, the house shall either be provided with a ventilation opening that will increase the tested infiltration to at least 586 CFM at 50 pascals (SLA = 1.5) OR mechanical supply ventilation shall be provided that can maintain the house at a pressure of at least -5 pascals relative the outside average air pressure while other continuous ventilation fans are operating. Note also that the Commission considers an SLA≤1.5 to be "unusually tight" per the California Mechanical Code.		
~~WARNING - Houses modeled with reduced infiltration are prohibited from having vented combustion appliances other than cooking appliances, refrigerators and domestic clothes dryers that use indoor air for combustion inside conditioned space.~~		

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3.5 Infiltration/Ventilation

The intentional or unintentional replacement of conditioned indoor air by unconditioned outdoor air creates heat gains or heat losses for a conditioned building. This exchange of indoor and outdoor air occurs for all buildings to a greater or lesser extent. Mechanical ventilation gives a certain degree of control of the rate of this exchange and depending on the balancing of the ventilation may create building pressurization.

Proposed Design. As a default, ACMs shall not require the user to enter any values related to infiltration ~~or mechanical ventilation for air quality~~ and shall set the infiltration level to be the same as the standard design. Specific data on infiltration may be entered if the building will be diagnostically tested during building construction or if a qualifying air-retarding wrap is specified.

Air Retarding Wrap. An air retarding wrap can qualify for a default reduction in Specific Leakage Area (SLA) of 0.50 without confirmation by diagnostic testing. The air retarding wrap shall be tested and labeled by the manufacturer to comply with ASTM E1677-95, *Standard Specification for an Air Retarder (AR) Material or system for Low-Rise Framed Building Walls* and have a minimum perm rating of 10. The air-retarding wrap shall be installed per the manufacturer's specifications that shall be provided to comply with ASTM E1677-95 (2000). The air retarding wrap specifications listed above shall also be reported in the *Special Features and Modeling Assumptions* listings when an air retarder is modeled by the ACM.

Reduced Infiltration due to Duct Sealing. The default infiltration (no diagnostic testing and measurement of infiltration) credit for reduced duct leakage is also an SLA reduction of 0.50. The ACM shall automatically apply this credit when the *Proposed Design* has sealed and tested ducts. The use of this SLA reduction credit for Low-leakage HVAC ducts shall be listed in the *Special Features and Modeling Assumptions* listings of the CF-1R.

Diagnostic Testing for Reduced Infiltration. Neither of the above credits shall be taken if the user chooses a diagnostic testing target for reduced infiltration. When the user chooses diagnostic testing for reduced infiltration, the diagnostic testing shall be performed using fan pressurization of the building in accordance with ASTM E 779-1987 (Reapproved 1992), *Standard Test Method for*

Determining Air Leakage Rate by Fan Pressurization and the equipment used for this test shall meet the instrumentation specifications found in ACM RF. The specifications for diagnostic testing and the target values specified above shall be reported in the *Field Verification and Diagnostic Testing* listings on the CF-1R.

If the user specifies they will be using diagnostic testing during construction, ~~for either~~ reduced infiltration ~~or reduced infiltration with mechanical ventilation,~~ the ACM shall require the user to enter a target value for measured $CFM50_H$ or the SLA corresponding to the target $CFM50_H$~~, and, if mechanical ventilation is to be used, the wattage and cfm of the ventilation supply and exhaust fans. Note that when the *Proposed Design* target value for reduced infiltration falls below a value corresponding to an SLA of 3.0, mechanical ventilation is required and this requirement shall be reported as described in Chapter 2. Whenever mechanical ventilation is modeled (required or not), the volumetric capacity modeled shall be at least 0.047 cfm/ft² of conditioned floor area. This minimum capacity is needed to provide adequate ventilation for indoor air quality. If the user attempts to model total mechanical volumetric capacity (balanced + unbalanced) less than 0.047 cfm/ft², then the ACM shall indicate an input error and automatically block compliance output.~~

Tested infiltration below a value corresponding to an SLA of 1.5 is not allowed unless mechanical *supply* ventilation is installed adequate to maintain the residence at a pressure greater than -5 pascals relative to the outside average air pressure with other continuous ventilation fans operating.

Standard Design. The *Standard Design* ~~does not use mechanical ventilation and~~ assumes infiltration corresponding to a Specific Leakage Area (SLA) of ~~4.9~~ 3.8 for ducted HVAC systems and an SLA of ~~3.8~~ 3.2 for non-ducted HVAC systems. See Chapter 4 for more detailed information.

…

4.5 Infiltration and Natural Ventilation

4.5.1 Infiltration/Ventilation

The reference method uses the effective leakage area method for calculating infiltration in conditioned zones. Calculations shall use Shielding Class 4 as defined in the 2001 *ASHRAE Handbook of Fundamentals*.

Default Specific Leakage Area. The default specific leakage area (SLA) is ~~4.9~~ 3.8 for designs with ducted HVAC systems and ~~3.8~~ 3.2 for non-ducted HVAC systems. The default is always used for the *Standard Design*. The *Proposed Design* may use an alternate value, but only with diagnostic testing. The specific leakage area (SLA) is the ratio of the effective leakage area to floor area in consistent units. The value is then increased by 10,000 to make the number more manageable. If the effective leakage area (ELA) is known in inches, then the SLA may be calculated with Equation R4-1.

Equation R4-1

$$SLA = \left(\frac{ELA}{CFA}\right)\left(\frac{ft^2}{144in^2}\right)(10000) = \left(\frac{ELA}{CFA}\right)69.444$$

where

ELA = Effective leakage area in square inches

CFA = Conditioned floor area (ft^2)

SLA = Specific leakage area (unitless)

~~**Minimum Outside Air**. For both the *Standard Design* and the *Proposed Design*, ACMs shall assume that occupants will open the windows if the air becomes stagnant. When natural ventilation, infiltration, and mechanical ventilation fall below a threshold value of 0.35 air changes per hour (ACH) , the occupants are assumed to open the windows at the beginning of the next hour sufficient to provide a combination of infiltration and ventilation equal to 0.35 ACH for an eight foot high ceiling. The windows are assumed to remain partially open to provide a minimum of 0.35 ACH as long as the previous hour's infiltration and mechanical ventilation rate is below the threshold.~~

Effective Leakage Area (ELA) Method. The Effective Leakage Area (ELA) method of calculating infiltration for conditioned zones is documented below and in Chapter 26 of the 2001 ASHRAE Handbook of Fundamentals. The ELA for the *Standard Design* and for the default values for the *Proposed Design* (if diagnostic tests are not used), is calculated from Equation R4-1. The energy load on the conditioned space from infiltration heat gains or losses are calculated as follows.

Equation R4-2
$$CFM_{infil} = ELA \times \sqrt{A \times \Delta T_2 + B \times V^2}$$

Equation R4-3
$$CFM_{infil+unbalfan} = \sqrt{CFM_{infil}^2 + MECH_{unbal}^2}$$

Equation R4-4
$$CFM_{infil+totfan} = CFM_{infil+unbalfan} + MECH_{bal}$$

The volumetric airflow (cfm) due to natural ventilation is derived from the natural ventilation cooling for the hour:

Equation R4-5
$$CFM_{natv} = \frac{Q_{natv}}{1.08 \times \Delta T_1}$$

The total ventilation and infiltration (in cfm) ~~including indoor air quality window operation~~ is:

Equation R4-6
$$CFM_{total} = CFM_{natv} + CFM_{infil+totfan}$$

~~The value of CFM_{iaq} depends on the sum of CFM_{natv} and $CFM_{infil+totfan}$ from the previous time step: When~~

~~Equation R4-7~~
$$CFM_{natv} + CFM_{infil+totfan} < \frac{(AFT \times CFA)}{7.5}$$

~~then~~

~~Equation R4-8~~
$$CFM_{iaq} = \frac{(0.35 \times CFA)}{7.5}$$

~~otherwise~~

~~Equation R4-9~~
$$CFM_{iaq} = 0.000$$

~~where~~

~~CFA = the total conditioned floor area of the residence~~
~~AFT = 0.18 for Climate Zones 2 through 15 inclusive, and;~~
~~AFT = 0.25 for Climate Zones 1 and 16.~~
~~When the windows are opened they provide an overall ventilation rate equal to 0.35 air changes per hour for a residence of the same floor area but with eight foot high ceilings. CFM_{iaq} simulates the opening of windows to achieve an acceptable indoor air quality by the occupants when ventilation and infiltration from other sources does not provide an adequate quantity of outdoor air to dilute pollutants and refresh the indoor air.~~
The energy load on the conditioned space from all infiltration and ventilation heat gains or losses is calculated as follows:

Equation R4-10

$$Q_{total} = 1.08 \times CFM_{total} \times \Delta T_1$$

where
Q_{total} = Energy from ventilation and infiltration for current hour (Btu)
CFM_{infil} = Infiltration in cubic feet per minute (cfm)
$CFM_{infil+unbalfan}$ = combined infiltration and unbalanced mechanical ventilation in cubic feet per minute (cfm)
$CFM_{infil+totfan}$ = infiltration plus the balanced and unbalanced mechanical ventilation in cubic feet per minute (cfm)
$MECH_{bal}$ = the balanced mechanical ventilation in cfm. This value is the smaller of the total supply fan cfm and the total exhaust fan cfm.
$MECH_{unbal}$ = the unbalanced mechanical ventilation in cfm. This value is derived from the absolute value of the difference between the total supply fan cfm and the total exhaust fan cfm.
1.08 = conversion factor in (Btu-min)/(hr-ft^3-°F)
ΔT_1 = difference between indoor and outdoor temperature for current hour (°F)
~~ΔT_2 = difference between indoor and outdoor temperature for previous hour (°F)~~
A = stack coefficient, (cfm^2/in^4/ F)
B = wind coefficient, (cfm^2/in^4/mph^2)
V = average wind speed for current hour (mph)
ELA = effective leakage area (in^2), measured or calculated using Equation R4-11.
The stack (A) and wind (B) coefficients to be used are shown in Table R4-1.

Table R4-1 – Infiltration Coefficients

Coefficient	*One Floor*	*Two Floors*	*Three Floors*
A (stack)	0.0156	0.0313	0.0471
B (wind) (Shielding Class 4)	0.0039	0.0051	0.0060

The ELA is calculated from the SLA as follows:

Equation R4-11

$$ELA = CFA \times SLA \times \left(\frac{144\,in^2}{1ft^2}\right) \times \left(\frac{1}{10{,}000}\right)$$

where
CFA = conditioned floor area (ft^2)

SLA = specific leakage area (ft^2/ft^2)
ELA = effective leakage area (in^2)
Alternatively, ELA and SLA may be determined from blower door measurements:

Equation R4-12
$$ELA = 0.055 \times CFM50_H$$

where

$CFM50_H$ = the measured airflow in cubic feet per minute at 50 pascals for the dwelling with air distribution registers unsealed.

Substituting Equation R4-12 into Equation R4-1 gives the relationship of the measured airflow rate to SLA:

Equation R4-13
$$SLA = 3.819 \times \frac{CFM50_H}{CFA}$$

Reduced Infiltration. ACM users may take credit for reduced infiltration ~~(with mechanical ventilation when it is required)~~ for low-rise, single-family dwellings when verified by on-site diagnostic testing. ~~While credit is offered for reduced infiltration, the model also assumes that dwelling occupants will open windows when natural ventilation and infiltration do not provide a minimum of 0.35 ACH.~~
~~Both r~~Reduced ELA/SLA ~~and ventilation fans are conditions which~~ requires field verification or diagnostic testing and shall be reported in the *Field Verification and Diagnostic Testing* listings on the Certificate of Compliance.

Material for Compliance Manuals

Not developed at this time.

Bibliography and Other Research

Appendix

Relevant Requirements of ANSI/ASHRAE Standard 62.2-2004
Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings

3. DEFINITIONS

acceptable indoor air quality**:** air toward which a substantial majority of occupants express no dissatisfaction with respect to odor and sensory irritation and in which there are not likely to be contaminants at concentrations that are known to pose a health risk.

air cleaning**:** the use of equipment that removes particulate, microbial, or gaseous contaminants (including odors) from air.

air, exhaust**:** air discharged from any space to the outside by an exhaust system.

air, indoor**:** air in an occupiable space.

air, outdoor**:** air from outside the building taken into a ventilation system or air from outside the building that enters a space through infiltration or natural ventilation openings.

air, transfer**:** air moved from one occupiable space to another, usually through doorways or grilles.

air, ventilation**:** outdoor air delivered to a space that is intended to dilute airborne contaminants.

air change rate**:** airflow in volume units per hour divided by the volume of the space on which the air change rate is based in identical units (normally expressed in air changes per hour).

balanced system**:** one or more fans that supply outdoor air and exhaust building air at substantially equal rates.

bathroom**:** any room containing a bathtub, a shower, a spa, or a similar source of moisture.

climate, hot, humid**:** climate in which the wet-bulb temperature is 67°F (19°C) or higher for 3500 hours or more, or 73°F(23°C) or higher for 1750 hours or more, during the warmest six consecutive months of a year that is typical for that geographic area (see Section 8.1).

climate, very cold**:** climates that have more than 9000 annual heating degree-days base 65°F-day (5000 annual heating degree-days base 18°C-day). (See Section 8.1.)

conditioned space**:** the part of a building that is capable of being thermally conditioned for the comfort of occupants.

contaminant**:** a constituent of air that may reduce acceptability of that air.

exhaust system**:** one or more fans that remove air from the building, causing outdoor air to enter by ventilation inlets or normal leakage paths through the building envelope.

exhaust flow, net**:** flow through exhaust system minus the compensating outdoor airflow through any supply system that is interlocked to the exhaust system.

habitable space**:** building space intended for continual human occupancy. Such space generally includes areas used for living, sleeping, dining, and cooking but does not generally include bathrooms, toilets, hallways, storage areas, closets, or utility rooms.

heating degree-day**:** the difference in temperature between the outdoor mean temperature over a 24-hour period and a given base temperature of a building space. That is, for heating degree-day base 65°F (18°C)**,** for any one day, when the mean temperature is less than 65°F (18°C), there are as many heating degree-days as degrees Fahrenheit (Celsius) temperature difference between the mean temperature for the day and 65°F (18°C). Annual heating degree-days are the sum of the heating degree-days over a calendar year.

high-polluting events**:** isolated and occupant-controllable events that release pollutants in excess quantities. Typical cooking, bathing, and laundry activities are not considered high-polluting events.

infiltration**:** uncontrolled inward leakage of air through cracks and interstices in any building element and around windows and doors of a building.

kitchen**:** any room containing cooking appliances.

mechanical cooling**:** reducing the temperature of a fluid by using vapor compression, absorption, desiccant dehumidification combined with evaporative cooling, or other energy-driven thermodynamic means. Indirect or direct evaporative cooling alone is not considered mechanical cooling.

mechanical ventilation**:** the active process of supplying or removing air to or from an indoor space by powered equipment such as motor-driven fans and blowers but not by devices such as wind-driven turbine ventilators and mechanically operated windows.

natural ventilation**:** ventilation occurring as a result of only natural forces such as wind pressure or differences in air density, through intentional openings such as open windows and doors.

occupiable space: any enclosed space inside the pressure boundary and intended for human activities, including, but not limited to, all habitable spaces, toilets, closets, halls, storage and utility areas, and laundry areas.

pressure boundary: primary air enclosure boundary separating indoor and outdoor air. For example, a volume that has more leakage to the outside than to the conditioned space would be considered outside the pressure boundary.

readily accessible: capable of being quickly and easily reached for operation, maintenance, and inspection.

source: an indoor object, person, or activity from which indoor air contaminants are released; or a route of entry of contaminants from outdoors or sub-building soil.

supply system: one or more fans that supply outdoor air to the building, causing indoor air to leave by normal leakage paths through the building envelope.

system: equipment and other components that collectively perform a specific function, such as mechanical cooling or ventilation.

toilet: space containing a toilet, water closet, urinal, or similar sanitary service.

utility: laundry, lavatory, or other utility room containing sinks or washing equipment.

ventilation: the process of supplying outdoor air to or removing indoor air from a dwelling by natural or mechanical means. Such air may or may not have been conditioned.

4. WHOLE BUILDING VENTILATION

4.1 Ventilation Rate

A mechanical exhaust system, supply system, or combination thereof shall be installed for each dwelling unit to provide whole-building ventilation with outdoor air each hour at no less than the rate specified in Table 4.1a and Table 4.1b or, equivalently, Equations 4.1a and 4.1b, based on the floor area of the conditioned space and number of bedrooms.

$$Q_{fan} = 0.01A_{floor} + 7.5(N_{br} + 1) \qquad (4.1a)$$

where

Q_{fan} = fan flow rate in cubic feet per minute (cfm),
A_{floor} = floor area in square feet (ft^2),
N_{br} = number of bedrooms; not to be less than one.

$$Q_{fan} = 0.05A_{floor} + 3.5(N_{br} + 1) \qquad (4.1b)$$

where

Q_{fan} = fan flow rate in liters per second (L/s),
A_{floor} = floor area in square meters (m^2),
N_{br} = number of bedrooms; not to be less than one.

Exception to Section 4.1: Whole-building mechanical systems are not required provided that at least one of the following conditions is met—

(a) the building is in a climate that has less than 4500°F-day (2500°C-day) infiltration degree-days as defined by *ANSI/ASHRAE Standard 119-1988 (RA94)*, *Air-Leakage Performance for Detached Single-Family Residential Buildings*[1] (see Table 8.2.),

(b) the building has no central air conditioning and is in a climate having less than 500 heating °F-day base 65°F (280°C-day base 18°C), or
(c) the building is thermally conditioned for human occupancy for less than 876 hours per year—and if the authority having jurisdiction determines that window operation is a locally permissible method of providing ventilation.

TABLE 4.1a (I-P)
Ventilation Air Requirements, cfm

	Bedrooms				
Floor Area (ft^2)	**0-1**	**2-3**	**4-5**	**6-7**	**>7**
<1500	30	45	60	75	90
1501-3000	45	60	75	90	105
3001-4500	60	75	90	105	120
4501-6000	75	90	105	120	135
6001-7500	90	105	120	135	150
>7500	105	120	135	150	165

TABLE 4.1b (SI)
Ventilation Air Requirements, L/s

	Bedrooms				
Floor Area (m^2)	**0-1**	**2-3**	**4-5**	**6-7**	**>7**
<139	14	21	28	35	42
139.1-279	21	28	35	42	50
279.1-418	28	35	42	50	57
418.1-557	35	42	50	57	64
557.1-697	42	50	57	64	71
>697	50	57	64	71	78

4.1.1 Different Occupant Density. Tables 4.1a and 4.1b and Equation 4.1 assume two persons in a studio or one-bedroom dwelling unit and an additional person for each additional bedroom. Where higher occupant densities are known, the rate shall be increased by 7.5 cfm (3.5 L/s) for each additional person. When approved by the authority having jurisdiction, lower occupant densities may be used.

4.1.2 Alternative Ventilation. Other methods may be used to provide the required ventilation rates (of Table 4.1) when approved by a licensed design professional.

4.1.3 Infiltration Credit. Section 4.1 includes a default credit for ventilation provided by infiltration of 2 cfm/100 ft^2 (10 L/s per 100 m^2) of occupiable floor space. For buildings built prior to the application of this standard, when excess infiltration has been measured using *ANSI/ASHRAE Standard 136-1993 (RA 2001), A Method of Determining Air Change Rates in Detached Dwellings,*[2] the rates in Section 4.1 may be decreased by half of the excess of the rate calculated from Standard 136 that is above the default rate.

4.2 System Type

The whole-house ventilation system shall consist of one or more supply or exhaust fans and associated ducts and controls. Local exhaust fans shall be permitted to be part of a mechanical exhaust system. Outdoor air ducts connected to the return side of an air handler shall be permitted as supply ventilation if manufacturers' requirements for return air temperature are met. See Appendix B for guidance on selection of methods.

4.3 Control and Operation

The "fan on" switch on a heating or air-conditioning system shall be permitted as an operational control for systems introducing ventilation air through a duct to the return side of an HVAC system. Readily accessible override control must be provided to the occupant. Local exhaust fan switches and "fan on" switches shall be permitted as override controls. Controls, including the "fan-on" switch of a conditioning system, must be appropriately labeled.

Exception to Section 4.3: An intermittently operating, whole-house mechanical ventilation system may be used if the ventilation rate is adjusted according to the exception to Section 4.4. The system must be designed so that it can operate automatically based on a timer. The intermittent mechanical ventilation system must operate at least one hour out of every twelve.

4.4 Delivered Ventilation

The delivered ventilation rate shall be calculated as the larger of the total supply or total exhaust and shall be no less than specified in Section 4.1 during each hour of operation.

Exception to Section 4.4: The effective ventilation rate of an intermittent system is the combination of its delivered capacity, its daily fractional on-time, and the ventilation effectiveness from Table 4.2.

$$Q_f = Q_r/(\varepsilon f) \qquad (4.2)$$

where

Q_f = fan flow rate,
Q_r = ventilation air requirement (from Table 4.1a or Table 4.1b),
ε = ventilation effectiveness (from Table 4.2),
f = fractional on time.

If the system runs at least once every three hours, 1.0 can be used as the ventilation effectiveness. (See Appendix B for an example of this calculation.)

4.5 Restrictions on System Type

Use of certain ventilation strategies is restricted in specific climates as follows.

4.5.1 Hot, Humid Climates. In hot, humid climates, whole-house mechanical net exhaust flow shall not exceed 7.5 cfm per 100 ft^2 (35 L/s per 100 m^2). (See Section 8.1 for a listing of hot, humid U.S. climates.)

TABLE 4.2
Ventilation Effectiveness for Intermittent Fans

Daily Fractional On-Time, f	Ventilation Effectiveness, ε
f ≤35%	0.33
35% ≤f < 60%	0.50
60% ≤f< 80%	0.75
80% ≤f	1.0

4.5.2 Very Cold Climates. Mechanical supply systems exceeding 7.5 cfm per 100 ft^2 (35 L/s per 100 m^2) shall not be used in very cold climates.

Exception to Sections 4.5.1 and 4.5.2: These ventilation strategies are not restricted if the authority having jurisdiction approves the envelope design as being moisture resistant.

5. LOCAL EXHAUST

5.1 Local Mechanical Exhaust

A local mechanical exhaust system shall be installed in each kitchen and bathroom. Each local ventilation system shall be either one of the following two:

1. an intermittent mechanical exhaust system meeting the requirements of Section 5.2,
2. a continuous mechanical exhaust system meeting the requirements of Section 5.3.

Exception to 5.1: *Alternative Ventilation*. Other design methods may be used to provide the required exhaust rates when approved by a licensed design professional.

5.2 Intermittent Local Exhaust

An intermittently operating, local mechanical exhaust system shall be designed to be operated as needed by the occupant.

5.2.1 Control and Operation. Control devices such as, but not limited to, the following are permissible provided they do not impede occupant control: shut-off timers, occupancy sensors, multiple-speed fans, combined switching, indoor air-quality sensors, etc.

5.2.2 Ventilation Rate. The minimum airflow rating shall be at least the amount indicated in Table 5.1.

5.3 Continuous Mechanical Exhaust

A continuously operating mechanical exhaust system shall be installed to operate without occupant intervention. The system may be part of a balanced mechanical system. See Appendix B for guidance on selection of methods.

5.3.1 Control and Operation. The system shall be designed to operate during all occupiable hours. Readily accessible override control must be provided to the occupant.

5.3.2 Ventilation Rate. The minimum delivered ventilation shall be at least the amount indicated in Table 5.2 during each hour of operation.

TABLE 5.1 Intermittent Local Ventilation Exhaust Airflow Rates

Application	Airflow	Notes
Kitchen	100 cfm (50 L/s)	Vented range hood (including appliance-range hood combinations) required if exhaust fan flow rate is less than 5 kitchen air changes per hour.
Bathroom	50 cfm (25 L/s)	

TABLE 5.2
Continuous Local Ventilation Exhaust Airflow Rates

Application	Airflow	Notes
Kitchen	5 air changes per hour	Based on kitchen volume
Bathroom	20 cfm (10 L/s)	

6. OTHER REQUIREMENTS

6.1 Transfer Air
Dwelling units shall be designed and constructed to provide ventilation air directly from the outdoors and not as transfer air from adjacent dwelling units or other spaces, such as garages, unconditioned crawl spaces, or unconditioned attics. Measures shall be taken to prevent air movement across envelope components separating attached, adjacent dwelling units, and between dwelling units and other spaces, both vertically and horizontally. Measures shall include sealing of common envelope components, pressure management, and use of airtight recessed lighting fixtures.

6.2 Instructions and Labeling
Information on the ventilation design and/or ventilation systems installed, instructions on their proper operation to meet the requirements of this standard, and instructions detailing any required maintenance (similar to that provided for HVAC systems) shall be provided to the owner and the occupant of the dwelling unit. Controls shall be labeled as to their function (unless that function is obvious, such as toilet exhaust fan switches). See Appendix A for information on instructions and labeling.

6.3 Clothes Dryers
Clothes dryers shall be exhausted directly to the outdoors.

6.4 Combustion and Solid-Fuel Burning Appliances
Combustion and solid-fuel burning appliances must be provided with adequate combustion and ventilation air and vented in accordance with manufacturer's installation instructions, *NFPA 54-2002/ANSI Z223.1-2002, National Fuel Gas Code,*[3] *NFPA 31-2001, Standard for the Installation of Oil-Burning Equipment,* [4] or *NFPA 211-2000, Standard for Chimneys, Fireplaces, Vents, and Solid-Fuel Burning Appliances,*[5] or other equivalent code acceptable to the building official.
Where atmospherically vented combustion appliances or solid-fuel burning appliances are located inside the pressure boundary, the total net exhaust flow of the two largest exhaust fans (not including a summer cooling fan intended to be operated only when windows or other air inlets are open) shall not exceed 15 cfm/100 ft² (75 Lps/100 m²) of occupiable space when in operation at full capacity. If the designed total net flow exceeds this

limit, the net exhaust flow must be reduced by reducing the exhaust flow or providing compensating outdoor airflow. Atmospherically vented combustion appliances do not include direct-vent appliances.

6.5 Garages
When an occupiable space adjoins a garage, the design must prevent migration of contaminants to the adjoining occupiable space. Doors between garages and occupiable spaces shall be gasketed or made substantially airtight with weather stripping. HVAC systems that include air handlers or return ducts located in garages shall have total air leakage of no more than 6% of total fan flow when measured at 0.1 in. w.c. (25 Pa), using California Title 24 (2001)[6] or equivalent.

6.6 Ventilation Opening Area
Spaces shall have ventilation openings as listed below. Such openings shall meet the requirements of Section 6.8.

Exception: Spaces that meet the local ventilation requirements set for bathrooms in Section 5.

6.6.1 Habitable Spaces. Each habitable space shall be provided with ventilation openings with an openable area not less than 4% of the floor area nor less than 5 ft^2 (0.5 m^2).

6.6.2 Toilets and Utility Rooms. Toilets and utility rooms shall be provided with ventilation openings with an openable area not less than 4% of the room floor area nor less than 1.5 ft^2 (0.15 m^2).

Exceptions: (1) Utility rooms with a dryer exhaust duct; (2) toilet compartments in bathrooms.

6.7 Minimum Filtration
Mechanical systems that supply air to an occupiable space through ductwork exceeding 10 ft (3 m) in length and through a thermal conditioning component, except evaporative coolers, shall be provided with a filter having a designated minimum efficiency of MERV 6, or better, when tested in accordance with *ANSI/ASHRAE Standard 52.2-1999, Method of Testing General Ventilation Air-Cleaning Devices for Removal Efficiency by Particle Size.*[7] The system shall be designed such that all recirculated and mechanically supplied outdoor air is filtered before passing through the thermal conditioning components. The filter shall be located and installed in such a manner as to facilitate access and regular service by the owner. The filter shall be selected and sized to operate at a clean pressure drop no greater than 0.1 in. w.c. (25 Pa) unless the equipment is designed or selected to accommodate any additional pressure drop imposed by the filter selection
[i.e., greater than 0.1 in. w.c. (25 Pa)].

6.8 Air Inlets
Air inlets that are part of the ventilation design shall be located a minimum of 10 ft (3 m) from known sources of contamination such as a stack, vent, exhaust hood, or vehicle exhaust. The intake shall be placed so that entering air is not obstructed by snow, plantings, or other material. Forced air inlets shall be provided with rodent/insect screen [mesh not larger than 1/2 in. (13 mm)].

TABLE 7.1 Prescriptive Duct Sizing

Duct Type	**Flex Duct**				**Smooth Duct**			
Fan Rating CFM @ 0.25 in. wg (L/s @ 62.5 Pa)	50 (25)	80 (40)	100 (50)	125 (65)	50 (25)	80 (40)	100 (50)	125 (65)
Diameter in. (mm)	**Maximum Length** ft. (m)							

3 (75)	X	X	X	X	5(2)	X	X	X
4 (100)	70(27)	3(1)	X	X	105(35)	35(12)	5(2)	X
5 (125)	NL	70(27)	35(12)	20(7)	NL	135(45)	85(28)	55(18)
6 (150)	NL	NL	125(42)	95(32)	NL	NL	NL	145(48)
7 (175) and above	NL	NL	NL	NL	NL	NL	NL	NL

This table assumes no elbows. Deduct 15 feet (5 m) of allowable duct length for each elbow.
NL = no limit on duct length of this size.
X = not allowed, any length of duct of this size with assumed turns and fitting will exceed the rated pressure drop.

Exceptions to Section 6.8:
(a) Ventilation openings in the wall may be as close as a stretched-string distance of 3 ft (1 m) from sources of contamination exiting through the roof or dryer exhausts.
(b) No minimum separation distance shall be required between windows and local exhaust outlets in kitchens and bathrooms.
(c) Vent terminations covered by and meeting the requirements of the National Fuel Gas Code (*NFPA 54-2002/ANSI Z223.1-2002, National Fuel Gas Code*[3]) or equivalent.

6.8.1 Ventilation Openings. Operable windows, skylights, through-the-wall inlets, window air inlets, or similar devices shall be readily accessible to occupants. Where openings are covered with louvers or otherwise obstructed, openable area shall be based on the free unobstructed area through the opening.

7. AIR-MOVING EQUIPMENT

All air-moving equipment used to comply with this standard shall meet the following criteria:

7.1 Selection and Installation

Ventilation devices and equipment shall be selected using tested and certified ratings of performance, such as those provided by the Home Ventilating Institute Division of Air Movement and Control Association International (airflow testing in accordance with *ANSI/ASHRAE Standard 51-1999/AMCA 210-99, Laboratory Methods of Testing Fans for Aerodynamic Performance Rating*,[8] sound testing in accordance with *AMCA 300-96, Reverberant Room Method for Sound Testing of Fans*,[9] and product certification procedure in accordance with HVI 920-01, *Product Performance Certification Procedure*[10]) or other widely recognized testing and certification organizations. Installations of systems or equipment shall be carried out in accordance with manufacturers' design requirements and installation instructions.

7.2 Sound Ratings for Fans

Ventilation fans shall be rated for sound at no less than the minimum airflow rate required by this standard, as noted below.

7.2.1 Continuous Ventilation Fans. These fans shall be rated for sound at a maximum of 1.0 sone.

7.2.2 Intermittent Fans. These fans shall be rated for sound at a maximum of 3 sone, unless their maximum rated airflow exceeds 400 cfm (200 L/s).

Exception to Section 7.2: HVAC air handlers and remote-mounted fans need not meet sound requirements. To be considered for this exception, a remote-mounted fan must be mounted outside the habitable spaces, bathrooms, toilets, and hallways, and there must be at least 4 ft (1 m) of ductwork between the fan and the intake grille.

7.3 Airflow Rating

The airflows required by this standard refer to the delivered airflow of the system as installed and tested using a flow hood, flow grid, or other airflow measuring device. Alternatively, the airflow rating at a pressure of 0.25 in. w.c. (62.5 Pa) may be used, provided the duct sizing meets the prescriptive requirements of Table 7.1 or manufacturer's design criteria.

7.4 Multi-Branch Exhaust Ducting

If more than one of the exhaust fans in a dwelling unit share a common exhaust duct, each fan shall be equipped with a back-draft damper to prevent the recirculation of exhaust air from one room to another through the exhaust ducting system. Exhaust fans in separate dwelling units shall not share a common exhaust duct. Exhaust outlets from more than one dwelling unit may be served by a single exhaust fan downstream of all the exhaust inlets, if the fan is designed and intended to run continuously or if each outlet is equipped with a back-draft damper to prevent cross-contamination when the fan is not running.