Building Codes and Indoor Air Quality

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Note: This report presents the findings, recommendations and views of its author and not necessarily those of the U.S. Environmental Protection Agency.

Forward

The following is the charge provided as the basis for this paper

> *Background: Some states have already updated their building codes to foster improved energy efficiency of residences and other buildings and there is increasing pressure for others to do so. Conservation-minded building codes have the potential to reduce naturally occurring air exchange for buildings by tightening the envelope and reducing pressurization of unconditioned spaces (e.g. duct sealing). Indoor moisture, altered airflows, lowered air exchange all have the potential for increasing occupant risk of exposures to indoor generated contaminants.*
>
> *Report topic: Provide a comprehensive listing of energy-related building codes—including model "green housing" codes—across the US to identify how these address the issues of ventilation, air exchange and indoor air pollution.*

Building Energy Codes and Indoor Air Quality

Abstract

There is significant political and institutional momentum toward energy conservation in buildings which has led to building codes devoted solely to energy conservation, and resulted in the tightening of building envelopes and reduced air infiltration and leakage. With air exchange significantly reduced, there is little room for error in protecting indoor air quality, other than providing more sophisticated and more tightly calibrated and coordinated systems. With evidence that windows are seldom or almost never used in some homes (Offerman 2009), and reduced infiltration air, the building community is gradually turning to whole house mechanical ventilation to provide sufficient outdoor air to dilute and remove indoor-generated pollutants. The speed with which that is happening may be slower and more uneven than needed to prevent many homes from becoming under-ventilated from tighter building envelopes, and there are issues with whole house ventilation (type of system, continuous or intermittent operation, occupant controls) that have not been fully resolved. With respect to backdrafting of combustion appliances, attention needs to be focused on power venting and sealed combustion design of these appliances, where EPA's Indoor airPLUS program, and the U.S. Green Buildings Council's Leadership for Energy and Environmental Design (USGBC LEED) program currently have more robust provisions than the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) residential ventilation standard or the current building codes.

While ASHRAE and others are gradually including provisions in standards to resolve these indoor air quality concerns, the institutional issues and pressures that are associated with code development, adoption, enforcement and implementation, and ultimately lead to inclusion of solutions in actual practice, are likely to keep indoor air protection in a process of perpetual "catch up" because the institutional processes for energy conservation have a lot of momentum and political support, something that is not present for indoor air quality.

Background on Model Building Codes

Historically in the U.S. three model code groups were used in most parts of the country. The Southeastern states used the codes of the Southern Building Code Congress International (SBCCI), the West Coast used the codes of the International Conference of Building Officials (ICBO), the states in the East Coast used the codes of the Building Officials Code Administrators International (BOCA), and the Midwestern states used both the BOCA and the ICBO codes. However, in 1994, the three major code groups joined forces to form the International Code Council (ICC) to develop codes that would have no regional limitations. In 2000, ICC had completed the International Codes series that now replaces the three predecessor codes.

Energy Legislation and Building Energy Codes

Climate change, dependence on foreign oil, and a dwindling supply of fossil fuels has fostered significant pressure toward greater energy conservation and the development of alternative energy sources. Since buildings account for 40 percent of the energy consumption in the United States, much of the energy conservation activities are directed toward reducing the energy use in buildings.

Congress recently enacted legislation to reduce the energy use in buildings through building code modifications. Section 304 of the Energy Policy and Conservation Act (EPCA, Public Law 94-163), as modified by the Energy Policy Act of 1992 (EPAct 1992) establishes roles and requirements for the Department of Energy (DOE) and the states to reduce the use of energy in buildings through the building code process[1]. The legislation and the codes distinguish between residential and commercial buildings. Residential refers to low rise residential of 3 stories or less. All others are considered commercial, and include office, industrial, warehouse, school, religious, dormitories, and high-rise residential buildings.

Residential buildings

The International Energy Conservation Code® (IECC)[2] forms the primary basis for energy code improvements in the residential sector. DOE issues a determination about whether the latest version of this code will improve energy efficiency. However, States have some flexibility. If DOE determines that the new version improves energy efficiency, each state is required to certify, within 2 years, that it has reviewed its residential building energy code regarding energy efficiency and has made a decision as to whether it is appropriate for that state to revise its own code accordingly. DOE provides technical assistance and incentive funding to states to improve and implement state residential building energy codes or to otherwise promote the design and construction of energy efficient residential buildings.

Commercial buildings

The ANSI/ASHRAE/IESNA Standard 90.1, "Energy Standard for Buildings Except Low-Rise Residential Buildings", current version is Standard 90.1-2007 (ASHRAE 2007), forms the primary basis for energy code improvements in commercial buildings. With each new edition of this standard, DOE issues a determination about whether the new edition will improve energy efficiency in commercial buildings. DOE has one year to publish the determination after the newest edition of the code is approved, and results are published in the Federal Register. States have less flexibility for commercial buildings than they do for residential buildings. If DOE finds that the newest version of Standard 90.1 is more energy efficient than the previous version, states are required by the Energy Policy Act to certify that their building energy codes are at least as stringent as the new Standard within two years, or justify why they can not comply. DOE must provide technical assistance and incentive funding to states to review, update and implement their codes. Time extensions with good faith effort are allowed.

Model Energy Codes

While the IECC is the primarily residential energy code it does not cover other issues. It has a commercial section that allows the use of ASHRAE 90.1 for compliance. The International Residential Code (IRC) is also used by some states, but it has a much larger focus than energy. The National Fire Protection Association (NFPA) has commercial and residential energy codes based on ASHRAE Standards 90.1 and 90.2 respectively. Some states, (e.g. Florida and California) have developed and adopted their own energy codes. Table 1 lists the model energy codes used by states in decreasing order of their frequency of use.

[1] See http://www.energycodes.gov/status/all_about_determinations.stm.
[2] Formerly the Model Energy Code (MEC)

Table 1. Energy Codes in Order of Frequency of Adoption by States

Commercial[1]	Residential
ASHRAE 90.1	IECC (MEC)
IECC[2]	IRC
NFPA 5000[3]	NFPA 5000[3]
	ASHRAE 90.2

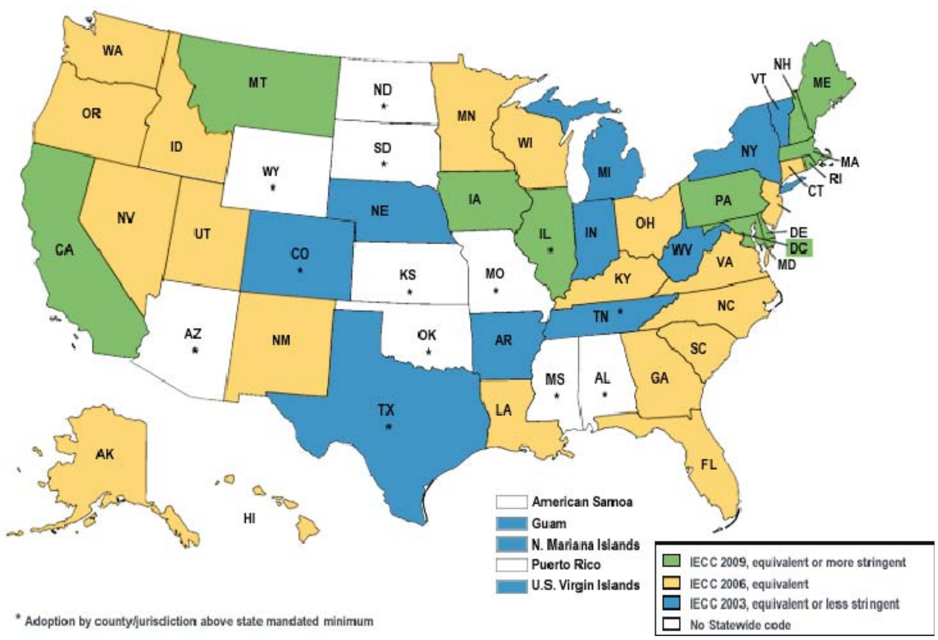
[1]Commercial codes often include high-rise residential; see individual codes for definitions.
[2]The IECC allows the use of ASHRAE 90.1.
[3]NFPA 5000 is based on ASHRAE 90.1 and 90.2.
Source: Whole Building Design Guide, National Institute of Building Sciences http://www.wbdg.org/resources/energycodes.php

Status of Energy Code Adoption by States and Their Implementation

The following represents the status of code adoption by States for the residential and commercial sectors.

Status of Residential Energy Codes

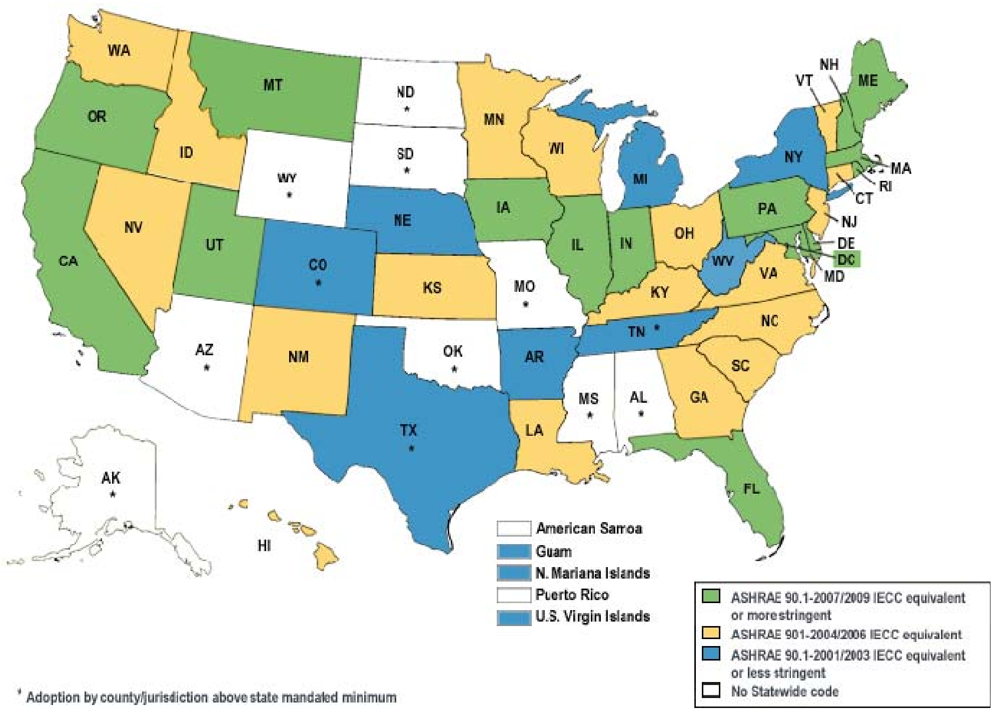
As of July 1, 2010



Source: Department of Energy, Building Energy Code Project (BECP)
http://www.energycodes.gov/states/maps/residentialStatus.stm

Status of Commercial Energy Codes

As of July 20, 2010



Source: Department of Energy, Building Energy Code Project (BECP)
http://www.energycodes.gov/states/maps/commercialStatus.stm

Relationships between energy use and indoor air quality

How energy is conserved through building practices can have profound importance to the health of occupants because the majority of building energy goes to conditioning the air that occupants breathe. Buildings in the past had high air change rates that ensured that the pollutants generated indoors were constantly diluted with outdoor air. However, except when outdoor climate conditions are complementary to what is desired indoors, such air changes require energy to condition the air for health and comfort indoors. This energy burden can be significant during outdoor temperature and humidity extremes.

In general, the primary ways of conserving energy in buildings involves: (1) improving the energy efficiency of equipment and appliances and reducing their unnecessary use, and (2) improving the thermal performance of the building envelope and reducing air change rates to minimize the energy used to condition the indoor air. This latter function-- reducing air change rates—puts energy conservation in conflict with providing adequate indoor air quality if it provides insufficient outdoor air to dilute indoor-generated contaminants, or insufficiently replace air exhausted by exhaust fans, clothes dryers and combustion equipment. This is of concern in all buildings, but especially in homes where adequate ventilation has traditionally relied on infiltration or occupant use of windows.

Because building codes are a primary institutional mechanism for establishing and enforcing standards for building construction, building codes are important for reducing energy use and preserving indoor air quality. However, building codes themselves are not perfect mechanisms. The more important question relates not just to what's written in the codes, but how buildings are actually built. It is equally important, therefore, to consider the extent to which codes are implemented and enforced, as well as the interests, motivations, and responses of builders and contractors in the field. While these issues can only be touched upon in this paper, they are subjects of important inquiry.

Provisions in Energy Codes Affecting Indoor Air Quality

Minimum ventilation or air change rate requirements, including passive ventilation (e.g. through windows or infiltration) plus provisions for exhaust of known sources of contaminants, are the principal mechanism that building codes use to address indoor air quality concerns. Furthermore, building codes often address moisture control, which is an important consideration for indoor air quality. Energy codes typically focus exclusively on energy conservation[3], while provisions in other codes are relied on to protect indoor air quality. Therefore, in this paper, the main energy codes are examined in light of other building codes for residential and commercial construction. The International Residential Code (IRC) for residences, and the International Mechanical Code (IMC) for commercial buildings specifically include provisions for ventilation and related issues and are commonly used by states and communities, and are included. In addition, ASHRAE Standard 62.1 for commercial buildings, and ASHRAE Standard 62.2 for residential buildings are consensus standards and represent the standard of practice for the building industry with respect to ventilation and indoor air quality. Provisions of these standards most often form the basis for ventilation requirements in building codes, and therefore, these standards are also included.

Tables 2a and 2b lists key issues in the building codes that affect indoor quality in residential and commercial buildings respectively, along with provisions of ASHRAE Standards 62.2 (for residential buildings) and 62.1 (for commercial buildings). For brevity, provisions listed for the IMC are limited only to those specifying outdoor air ventilation rates and not to other related issues.

[3] The term energy conservation rather than energy efficiency is purposely chosen here because the term "efficiency" implies that building objectives are being met with the minimum energy. However, the term conservation has no such implication concerning the objectives. The objectives of a building are essentially to provide healthy, safe, comfortable and productive environments for people, and the issues of concern in this paper in part deal with whether these objectives are being compromised in the attempt to conserve energy.

Table 2a: Residential Building Code Provisions Affecting Indoor Air Quality

Issue	International Energy Conservation Code (IECC 2009)	International Residential Code (IRC 2006)	ASHRAE Standard 62.2-2010
Envelope tightness (infiltration)	- Minimum insulation factors by climate zone for all elements of the thermal envelope, including fenestrations. - Air sealing of thermal envelope to limit air infiltration. - Blower door test (7 ACH_{50}) or visual inspection options.	- Minimum insulation factors by climate zone for all elements of the thermal envelope, including fenestrations. - Air sealing of thermal envelope to limit air infiltration. - Total envelope performance calculated from summation of individual requirements is option.	- Allows some infiltration to be counted as ventilation air. See "Ventilation and ventilation distribution" section of this table, and Note (a) regarding infiltration.
Combustion appliances	- New wood-burning fireplaces shall have gasketed doors and outdoor combustion air.	- Factory built or masonry fireplaces shall have exterior supply of combustion air, with requirements for exterior air ducts and outlets to ensure uninterrupted flow. - Combustion air for fuel-burning appliances may be obtained from infiltration for spaces of 50 ft^3/ Btu/h. - In buildings of unusually tight construction, combustion air shall be obtained from outside the sealed thermal envelope.	- Does not address unvented combustion space heaters.
Venting and exhausts	No requirements.	- The air removed by every mechanical exhaust system shall be discharged to the outdoors. - Air shall not be exhausted into an attic (except whole house ventilation), soffit, ridge vent or crawl space. - Clothes dryers must be vented to the outside except condensing dryers. - Range hoods shall exhaust to the outside (not to attic or crawl space) except for ductless ranges when natural or mechanical ventilation is supplied. - Operable glazing or mechanical exhaust (continuous or intermittent at prescribed rates) [d] required for kitchen and bath.	- Exhaust required in each kitchen and bathroom. May be continuous or intermittent (occupant controlled) with prescribed rates.[e] - Clothes dryers must be vented to the outside, or condensing dryers plumbed to a drain. - Limits the capacity of a home's two largest exhaust fans to a net total exhaust flow of 15 cfm/100 ft^2 when atmospherically-vented fuel burning appliances are located inside the pressure boundary, beyond which "compensating outdoor air" must be provided (excludes direct vented appliances).

Issue	International Energy Conservation Code (IECC 2009)	International Residential Code (IRC 2006)	ASHRAE Standard 62.2-2010
Duct leakage or location. Limit of air migration from contaminated areas	Duct insulation and sealing required to specified limits to reduce leakage.	- Mechanical and gravity outdoor air intake openings shall be located a minimum of 10 feet from any hazardous or noxious contaminant (e.g., vents, chimneys, plumbing vents, streets, alleys, parking lots and loading docks, except bathroom or kitchen vents), or 2 feet below the source. - Outdoor air inlets shall be covered with screens of specified mesh size.	- Measures required to minimize air movement between dwellings, or into dwelling from garages, unconditioned crawl spaces or unconditioned attics. - Garages required to be sealed. - No supply air to or return air from garage. - Ducts outside pressure boundary sealed to no more than 6% leakage. - Spaces meeting exhaust requirements of bathrooms are exempted from above provisions. - Air inlets must be at least 10 feet (with exceptions) from known contaminant sources and protected from snow, with rodents and insect screens. - Multiple exhausts sharing same exhaust duct shall each have a backdraft damper to prevent recirculation of exhaust air.
Ventilation and ventilation distribution	Requires gravity dampers for outdoor air (OA) vents that close when ventilation system is off.	- Natural ventilation shall be through windows, doors, louvers or other approved openings to the outdoor air with ready access to and controllable by the building occupants. - Openable area shall be at least 4% of the floor area, or mechanically ventilated with system capable of producing 0.35 ACH in the room, or whole-house mechanical ventilation capable of supplying 15 cfm per occupant.[c] - In HVAC systems, mixing outdoor air with return air is allowed. - Return air must not be from identified contaminated spaces (e.g. bathroom).	- Whole house ventilation (or equivalent) system is required at minimum cfm defined as $Cfm = 0.01(A_{sf}) + 7.5\ (N_{br} + 1)$[a] - Exception allowed if there is no mechanical cooling and in IECC 2004 climate zones 1& 2; or if air is thermally conditioned for less than 876 hrs/year, of if local authority deems windows to provide adequate ventilation. - Automatic intermittent operation allowed. Required to operate at least 1 time per day and at least 10% of time at flow rates calculated by prescribed formula to be equivalent

Issue	International Energy Conservation Code (IECC 2009)	International Residential Code (IRC 2006)	ASHRAE Standard 62.2-2010
		- Supply and return air flow must be approximately equal.	to continuous required whole house ventilation. - Each habitable space must have ventilation air openings with an openable area of at least 4% of floor area and be at least 5ft^2. - The whole-house mechanical net exhaust flow is not to exceed 7.5 cfm per 100 ft^2 in hot, humid climates. Also, mechanical supply systems exceeding 7.5 cfm per 100 ft^2 are not to be used in very cold climates.[b]
Occupant controls/ease of use	- At least one thermostat required for each separate heating and cooling system. - Programmable thermostat required where the primary heating system is a forced-air furnace.	No requirements.	-Occupant override controls required, such as on/off switch to HVAC or exhaust fan. -Controls must be labeled for occupant, with information and instructions on proper operation and maintenance provided to owner and occupant. -All ventilation openings, including windows, must be accessible. - Fan noise is limited
Filtration	No requirements.	No requirements.	HVAC filters must be at least MERV 6 rating
Reference Standards	ASHRAE Standard 62.2 not referenced	ASHRAE Standard 62.2 not referenced	

Notes for Table 2a:

[a] Incorporates infiltration of 0.02cfm/ft^2); if infiltration is measured and is more than that, may reduce the required outdoor air by half the excess. If measured infiltration is less, no increase in outdoor air is required. Assumes two persons for studio or one-bedroom residence, and one person per added bedroom. For higher occupancies, add 7.5 cfm per added occupant.

[b] Intended to control condensation in the building envelope.

[c] Computed as 2 occupants for the first bedroom and 1 for each additional bedroom.

[d] Flow rate for intermittent = 100 cfm (kitchen),50 cfm (bathroom); for continuous = 25 cfm (kitchen), 20 cfm (bathroom).

[e] Flow rate for intermittent = 100 cfm (kitchen),50 cfm (bathroom); for continuous = 5 ach (kitchen, based on kitchen volume), 20 cfm (bathroom).

Table 2b: Commercial Building Code Provisions Affecting Indoor Air Quality

Issue	ASHRAE Standard 90.1- 2007	International Energy Conservation Code (IEC C-2009). Section 503 for commercial buildings	International Mechanical Code (IMC-2009)[a]	ASHRAE Standard 62.1-2010
Envelope tightness (infiltration)	- Minimum thermal performance factors (e.g. R-rated insulation, U rated and SHGC windows, air leakage limitations for fenestrations) by climate zone for all elements of the thermal envelope. - Air sealing of thermal envelope to limit air infiltration. - Vestibules separating outdoor from conditioned spaces required. - Loading dock sealing requirements.	- Minimum thermal performance factors (e.g. R-rated insulation, U rated windows) by climate zone for all elements of the thermal envelope. - Air sealing of thermal envelope to limit air infiltration. - Motorized dampers required on outdoor air (OA) supply and exhaust ducts (with exceptions) to limit leakage when system not being used.		Requires weather barrier, vapor barrier, and sealing of all penetrations.
Combustion appliances				- Captured contaminants from non combustion appliances must be discharged outside. - Combustion appliances includes unvented with "adequate removal of combustion products"[b] but if vented, must be discharged outside.
Venting and exhausts	Motorized dampers required on stair and shaft vents, and on outdoor air supply and exhaust gravity hoods, vents, and ventilators, to control leakage.			Minimum exhaust rates are provided for multiple occupancy / building use categories.
Duct leakage, or location. Limit of air migration from contaminated areas	All HVAC supply and return ducts and plenums must be insulated except in conditioned spaces (and other exemptions). - Ducts and plenums shall be sealed to prescribed leakage limits.	- Duct and plenum insulation required (with exemptions) when located outside the conditioned space (R-6) or outside (R-8).	- Offices, waiting rooms, ticket booths and similar uses connecting public garages shall be maintained at a positive pressure.	- Exhaust ducts must be sealed or negatively pressurized. - Buildings with attached garages require vestibule, garage under negative relative pressure, and otherwise minimize entrainment of garage contaminants.

Issue	ASHRAE Standard 90.1- 2007	International Energy Conservation Code (IEC C-2009). Section 503 for commercial buildings	International Mechanical Code (IMC-2009)[a]	ASHRAE Standard 62.1-2010
		- All ducts, air handlers and filter boxes must be sealed. - Separate sealing requirements for low, medium, and high pressure ducts. - HVAC must be balanced prior to occupancy.		- Air classifications by degree of contamination are used with rules limiting the transfer of contaminated air into spaces with cleaner air. - Environmental tobacco smoke (ETS) free areas must be positively pressurized relative to ETS areas.
HVAC	- Demand control ventilation required for large high occupancy areas (spaces: >500ft^2 with > 40 people/1000ft^2). - Airside economizer (with capacity for 100% OA) or water side economizers required (with exceptions), and must be integrated with the cooling system - Required to have relief excess OA capability to avoid over-pressurization. - Exhaust air energy recovery with $\geq$50% recovery effectiveness required for systems with supply air >5000 cfm and minimum OA $\geq$70% of supply air.	- Ventilation required as per IMC. Mechanical systems must be capable of reducing outdoor air to minimum required. - Demand control ventilation (DCV) required for spaces larger than 500 ft^2 and with occupant load of 40 people per 1000 ft^2 of floor area. - Airside economizers required (with exceptions) with capacity for 100% outdoor air and relief of excess outdoor air to prevent over-pressurization, and relief outlet located to avoid recirculation. - No over-sizing of HVAC allowed. - Energy recovery* required (with exceptions) for fan systems having supply air capacity of 5,000 cfm or more and minimum of 70%	- OA intake openings shall be located a minimum of 10 feet from lot lines or contaminant sources, or 3 feet below sources. - Variable air volume air shall be designed to maintain the minimum required OA flow rate over the entire range of supply air operating rates.	- OA intakes located at prescribed distances from known contaminant sources. - Ventilation designed to provide minimum required outdoor air flow during all load conditions (specifically including VAV with fixed outdoor dampers at minimum flow) - AHU mounted outdoors requires rain and snow entrainment systems and bird screens. - Systems with dehumidification required to have capacity for indoor RH of 65% or less under specified conditions. - System must ensure that OA intake exceeds maximum exhaust whenever dehumidifying.[c] - Drain pan: Specified slope and otherwise designed for free flow of condensate. - Specific requirements for access to HVAC for inspection and maintenance.

Issue	ASHRAE Standard 90.1- 2007	International Energy Conservation Code (IEC C-2009). Section 503 for commercial buildings	International Mechanical Code (IMC-2009)[a]	ASHRAE Standard 62.1-2010
		outside air. Required minimum recovered enthalpy of 50% of outdoor air -return air difference at design conditions. - VAV required (with exceptions) for complex multizone systems with capacity to reduce outdoor air supply to defined minimums, including minimum required by IMC.		
Ventilation		Must meet provisions of the IMC for commercial buildings.	**Natural ventilation** - The minimum openable area to the outdoors shall be 4 percent of the floor area being ventilated. When openable area is provided through adjoining rooms, the openable area must be $\geq$8% of floor area of the interior room, and not less than 25 unobstructed feet away - OA intake openings shall be located a minimum of 10 feet from lot lines or contaminant sources, or 3 feet below sources. **Mechanical ventilation** Flow rate requirements follow ASHRAE Standard 62.1 ventilation rate procedure, based on cfm per person plus cfm per ft^2 for	- OA ventilation may be supplied mechanically using a Ventilation Rate Procedure or an IAQ Procedure, or with natural ventilation with mechanical backup as needed. - Outdoor air not meeting EPA standards to be treated to prescribed levels for PM_{10}, $PM_{2.5}$, and ozone. **Ventilation Rate Procedure** - OA must be delivered to occupants' breathing zone at prescribed rates for all occupied spaces, during all hours of occupancy, and at full or part load conditions. Rates vary by type of occupancy, and include a rate per unit area and a rate per person for each space. E.g. Classroom (age 5+) = 10 cfm/p +0.12 cfm/ft^2

Issue	ASHRAE Standard 90.1- 2007	International Energy Conservation Code (IEC C-2009). Section 503 for commercial buildings	International Mechanical Code (IMC-2009)[a]	ASHRAE Standard 62.1-2010
			most spaces. An IAQ procedure is also allowed. - For residences, a minimum ventilation rate of 0.35 ACH but not less than 15 cfm/person where occupant density based upon 2 persons for first bedroom and 1 person for each additional bedroom.	Office = 5 cfm/p +0.06 cfm/ft2 - OA delivery to spaces is adjusted for breathing zone at prescribed rates. - OA rates may be reset as conditions change: variable occupancy (demand control ventilation), variable ventilation effectiveness, and use of economizer. **IAQ Procedure** **-** For each contaminant of concern, a concentration limit and exposure period provided by a cognizant authority, and a satisfactory perceived air quality shall be used to establish the required OA ventilation rate. - The OA ventilation rate shall be at least the highest needed to control any contaminant of concern. **Natural Ventilation** - Natural ventilation openings must be at prescribed maximum distances (based on ceiling height)from occupied space. - Opening size must be a minimum of 4% of floor area. - Openings must be accessible and open during occupancy.
Controls/ease of use	Thermostat controls must prevent reheating or recooling.	- Manuals must be provided for equipment capacities; operation and maintenance;		**Operation and maintenance** Minimum operation and maintenance procedures are

Issue	ASHRAE Standard 90.1- 2007	International Energy Conservation Code (IEC C-2009). Section 503 for commercial buildings	International Mechanical Code (IMC-2009)[a]	ASHRAE Standard 62.1-2010
		system controls, calibration, sequences and programming; and written narrative of operational intent. - Thermostatic controls required for each zone with dead band range of 5°F or more. - Thermostatic setback controls required to maintain zone down to 55°F or up to 85°F.		specified to ensure that systems continue to operate as intended.
Filtration				Minimum of MERV 6 rated filters are required.
Other	Optional compliance of non mandatory prescriptive provisions is allowed in which prescribed energy simulation of building meets or exceeds prescribed standard building.			**IAQ During Construction** - Procedures required to protect materials and HVAC from contamination and mold, and to otherwise protect IAQ.
Referenced standards	ASHRAE Standard 62.1 not referenced	ASHRAE Standard 62.1 not referenced	ASHRAE Standard 62.1 is referenced	

Notes for Table 2b:

[a] In this table, only provisions for outdoor air ventilation or air change rates are included for this code.

[b] Potential problem with transferring return air VOC contaminants to the supply air stream.

[c] This reduces potential for infiltration of humid outdoor air.

Model Residential "Green" Building Standards

There are several national green building standards for homes. These include EPA's Energy Star/Indoor airPLUS program, DOE's Builders Challenge program, USGBC's LEED for Homes program, NAHB's National Green Building Program™, and MASCO's Environments for Living® program. Because many of these programs partner to share certification, they have a lot in common. In this paper, the EPA, DOE, and USGBC's programs are chosen for further analysis. All of these programs cover both energy efficiency and indoor air issues.

EPA Indoor airPLUS, DOE Builders Challenge, and USGBC LEED for Homes

EPA Indoor airPLUS is designed to provide an indoor air quality certification label to Energy Star-rated homes, and with respect to indoor air, Indoor airPLUS may be considered one of the best industry practices because its specifications are more robust, and many of its requirements are considered options in other programs. For example, recommended provisions in DOE's Builders Challenge for isolating attached garages, whole house ventilation, and low VOC emissions are requirements in Indoor airPLUS program which also includes provisions for radon not covered in DOE's Builders Challenge.

The complete specifications for EPA Indoor airPLUS are provided in the Appendix to this paper, and can be accessed at http://www.epa.gov/indoorairplus/construction_specifications.html.

Specifications for DOE's Builders Challenge are summarized in Table 3 below and can be accessed at http://www1.eere.energy.gov/buildings/challenge/pdfs/bcqc_version_1_3_060408.pdf

Table 3: DOE's Builders Challenge Program: Summary of Key Specifications for energy and indoor air
5. **Space Conditioning Design – *Required*** Right-size space conditioning system for heating/cooling loads based on ACCA Manual J Version 8 or comparable load sizing analysis. The maximum over-sizing limit for cooling equipment is 15%, with the exception of heat pumps in Climate Zones 5 - 8 where the maximum over-sizing limit is 25%. 11. **Whole Building Mechanical Ventilation I - *Required*** Design and install a mechanical system(s) to provide outside air to the indoor environment through either exhaust, supply, or balanced ventilation. Equip outside air intakes for ventilation with filters and shutoff dampers. (Also see QC Provision: Whole Building Mechanical Ventilation II – which is a recommended measure). 12. **Kitchen Ventilation – *Required*** Provide mechanical kitchen ventilation with an exhaust fan(s) that can provide at least 100 cfm intermittent or airflow equivalent to 5 air changes per hour based on the kitchen volume (continuous use). Fans are vented to exhaust kitchen air to outdoors. Refer to ASHRAE 62.2-2007 for information on providing for adequate combustion air for combustion appliances. 13. **Bathroom Ventilation – *Required*** Include mechanical ventilation for all bathrooms with a bathtub, shower, spa, or similar source of moisture with an exhaust fan(s) that can provide at least 50 cfm (intermittent use) or 20 cfm (continuous use), or provide the room a window with an openable area of at least 4% of the floor area and no smaller than 1.5 square feet. All bathroom fans are vented to outdoors.

14. **Clothes Dryer Venting – *Required***
Clothes dryer vented directly to the outdoors. Condensing dryers are exempt.

15. **Duct Leakage – *Required***
Duct leakage to outdoors is less than 5% of conditioned floor area when measured at 25 Pascal using duct pressurization methods. OR
All duct work is located within the conditioned envelope (meaning the air barrier and thermal barrier) of the house, AND total duct leakage is less than 10% of conditioned floor area when measured at 25 Pascals.

16. **Air Barrier and Insulation Integrity - *Required***
Complete the ENERGY STAR Thermal Bypass Inspection Checklist for the home.

17. **Filtration - *Required***
Equip the central air handler(s) with a MERV 8 filter or higher.

18. **Combustion Safety - *Required***
Fossil fuel-fired furnaces or water heaters installed in conditioned spaces must be sealed combustion, direct vented, or power-vented units.

19. **Carbon Monoxide - *Required***
For homes with combustion appliance(s) or an attached garage, install at least one carbon monoxide (CO) alarm in a central location outside of each separate sleeping area in the immediate vicinity of the bedrooms. They must be hard-wired with a battery back-up function.

21. **Garage Exhaust Ventilation – *Recommended***
Ventilate attached garages with a 100 cfm (ducted) or 80 cfm (un-ducted) exhaust fan, venting to outdoors and designed for continuous operation. Alternatively, automatic fan controls may be installed that activate the fan whenever garage is occupied, and for at least1 hour after garage is vacated.

22. **Air Handler Location - *Required***
Central air handler(s) is isolated from the garage by a thermal barrier and an air barrier.

23. **Building Envelope Moisture Management – Field Verification - *Required***
Flashing details, foundation details, vapor barrier selection, and water drainage space details are installed per construction plans and specifications.

24. **Energy Star Equipment - *Recommended***
For equipment included in the sale of the home, use ENERGY STAR qualified appliances and equipment (including HVAC systems).

25. **Whole Building Mechanical Ventilation II - *Recommended***
Install a whole building mechanical ventilation system complying with the requirements of ASHRAE 62.2-2007. Whole building ventilation systems may consist of an exhaust system, supply system, or balanced system, and must be capable of providing the outside air rates specified in Standard 62.2-2007. Refer to Section 6.4 of ASHRAE 62.2-2007 “Combustion and Solid-Fuel Burning Appliances” for information on providing for adequate combustion air for combustion appliances. (Also see QC Provision: Whole Building Mechanical Ventilation I – which is a required measure). Include mechanical plans which include systems for whole building mechanical ventilation in project records.

26. **Pressure Balancing - *Recommended***
All rooms in the conditioned space of the home do not exceed +/- 3 Pascals pressure difference relative to the central (open) areas of the home, when interior doors are closed and the central air handler is operating. Powder rooms and laundry rooms are exempt.
OR
Return ducts or transfer grilles are installed in every room with a door to which conditioned air is supplied, except for bathrooms, closets, pantries, and laundry rooms.

27. **Low VOC Interior Coatings - *Recommended***
Paints, coatings, and primers applied to interior walls and ceilings have VOC levels of no more than 50 g/L (flats) or 150 g/L (non-flats). (reference LEED for Homes MR Credit 2.2) Keep specifications in project record.

28. **Low VOC Adhesives - *Recommended***
Adhesives comply with the following maximum limits for VOCs: Carpet pad adhesives: 50 g/L (excluding water); Indoor carpet adhesives: 50 g/L (excluding water); Wood flooring adhesives: 100 g/L (excluding water); Subflooring adhesives: 50 g/L (excluding water); Multi-purpose construction adhesives: 70 g/L (excluding water),(reference LEED for Homes MR Credit 2.2)

29. **Low Emission Cabinets - *Recommended***
Kitchen and bath vanity cabinets are in accordance with one of the following.
(1) Installed kitchen and bath vanity cabinets comply with the Kitchen Cabinet Manufacturers Association Environmental Stewardship Program 01-06
(2) Installed kitchen and bath vanity cabinets are in accordance with the CARB standard for urea formaldehyde emissions in composite wood
(3) Installed kitchen and bath vanity cabinets contain no added urea formaldehyde or comply with GREENGUARD testing protocol and emission standards (ASTM D 6670) or equivalent. (reference National Green Building Standard 901.10)

A potent force in the green building area is the USGBC LEED certification program, which has a mix of prerequisites and optional provisions in which points or credits are earned toward achieving a certification in a large number of environmental categories. Many federal agencies and state and local governments encourage or require buildings to meet these standards.

LEED for Homes has two optional paths toward certification in the Indoor Environmental Quality category. These paths toward satisfying the indoor environmental quality requirements and earning additional credits are outlined in Table 4. The full standards can be accessed at http://www.usgbc.org/ShowFile.aspx?DocumentID=3638 .

Table 4: Summary of Indoor Environmental Quality Provisions in LEED for Homes*

Path 1	Max Points	Path 2**	Max Points
(Required for this path) Energy Star w Indoor airPLUS	13	**2 Combustion venting** (Required)No unvented appliance, CO monitor on each floor, doors on fireplaces &wood stoves, sealed or power vented exhaust on water heaters -Specific enhanced combustion venting measures with backdraft testing	2
4.2 Enhanced OA Ventilation -Whole house ventilation in mild climates exempted by ASHRAE 62, or with ERV	2	**3 Moisture control** -Install dehumidification equipment	1
5.2 Enhanced local exhaust -ASHRAE 62 exhaust requirements with added controls such as occupant sensor, timer, humidistat control or continuous operation.	1	**4 Outdoor air ventilation** (Required) Whole house ventilation as per ASHRAE 62.2-2007 -Enhanced OA ventilation as in 4.2 -Third party testing of OA flow rate	3

Path 1	Max Points	Path 2**	Max Points
5.3 Third party testing -Third party testing of exhaust flow rate	1	**5 Local exhaust** -(Required) Meet ASHRAE 62.1-2007 requirements. All exhaust to the outdoors, and Energy Star fans. -Enhanced local exhaust as in 5.2 -Third party testing of exhaust flow as in 5.3	2
7.2/7.3 Better/Best filters -Better filters = MERV 10 -Best filters = MERV 13	2	**6 Distribution systems** -(Required) Conduct room by room load calculations and install ducts accordingly -Provide adequate return air to rooms with jump ducts, transfer grills or multiple returns, and ensure prescribed size of opening of grills or maximum pressure differentials between rooms and adjoining spaces. -Equivalent calculations for unducted systems -Third party testing of supply air flow.	3
8.2 Indoor contaminant control **-** Contaminant control during construction by sealing of vents, walk-off mats or shoe removal provisions, or central vacuum	2	**7 Air filtering** (Required)Good filters = MERV 8 -Better filters = MERV 10 -Best filters = MERV 13	2
		8 Indoor contaminant control -Contaminant control during construction as in 8.2 -Preoccupancy flush.	4
		9 Radon -(Required)Radon resistant new construction(RRNC) in high risk areas -RRNC in medium risk areas	1
		10 Vehicle emission protection (Required) No HVAC in garage -Tightly seal surfaces between garage and indoor spaces, and/or have a detached or no garage	3
Note: In addition to the provisions above under the Indoor Environmental Quality (EQ) category, there are provisions under the Materials and Resources (MR) category with some limited emission requirements for building materials and VOC content limits for paints and coatings.			

*The numbers preceding each provision correspond to the numerical credit designation in the Indoor Environmental Quality (EQ) category of LEED for Homes.

**A total of 6 points are required for this path from the listed categories, each of which includes a requirement if any points in that category are to be achieved.

Tightening of the Building Envelope in Homes

Sealing of building envelopes in all buildings is gradually advancing, but it is of particular concern in homes because homes have not traditionally been required to have mechanical ventilation. Residential buildings are therefore the focus in this paper.

There are two indoor air quality related concerns with tightening the building envelope:

(1) a tight home may not provide sufficient outdoor air ventilation to dilute indoor-generated contaminants, and

(2) a tight home may be incapable of providing make up air for exhaust fans, a clothes dryer and vented combustion equipment. The negative pressure in the home caused by these appliances can draw exhaust gasses back into the home (backdrafting), and also force air through the building envelope and create moisture/mold problems as humid air condenses within the building envelope.

Building codes have traditionally relied on infiltration plus the provision for windows, and relied on ASHRAE Standard 62, which, in previous versions and in some current codes, required an air change rate of 0.35 ACH but not less than 15 cfm per person (ASHRAE Standard 62-1989). But this is not directly measured, and, even if it were, it is highly dependent on climatic conditions outdoors, the size of the building, and other factors, so the actual rate has always been uncertain.

As the building envelope is increasingly tightened, eventually, infiltration rates in homes become low enough that alternative means of ventilation become necessary for indoor air. This issue was seriously addressed during the implementation of weatherization programs in the early 1990s. Specific building tightness limits (BTLs) were developed as target levels needed to achieve the ASHRAE 62-1989 infiltration rates for different climate zones (Tsongas, 1993). Additional Depressurization Tightness Limits (DTL) were also developed to ensure against backdrafting. Instrument manufacturers such as Texas Instruments developed program applications that would automatically estimate the BTL and DTL for a given home. Essentially, the BTL and DTL were lower limits below which the air tightness of the home should not go without compensating ventilation.

The limits were based on blower door measurements or could be estimated. Blower door tests are very useful as they provide an accurate measurement of building tightness. However, a good deal of accuracy is lost when estimating the average annual air leakage for any given home, and, the use of an annual average leaves a wide margin of variability at different outdoor conditions and occupant activities. This means that tightening a home to the point where mechanical ventilation is required, and calibrating the ventilation system to ensure that the average annual ventilation rate is adequate, but not excessive, is a precarious venture.

General issues of concern

Provisions for whole house ventilation with intermittent operation

Evidence suggests that it may be folly to rely on occupants to open windows to provide needed ventilation. Offerman (2009) found that in California, because of concerns for safety, noise, dust and odors, many homeowners never or seldom open their windows. Offerman (2009) also found that, except for heat recovery ventilators which are usually on continuously, whole house ventilation systems that cycle on and off with the home's central heating, ventilating, and air conditioning (HVAC) system are not effective at diluting indoor contaminants, and recommends that such systems have a separate switch and timer to cycle the system on automatically to provide adequate ventilation irrespective of the thermal air conditioning requirements. This would suggest that many buildings currently built to tight envelope specifications, but without whole house ventilation which is not required in IRC 2006, or with whole house ventilation that cycles on and off with the HVAC, are most likely under-ventilated. ASHRAE Standard 62.2-2010 requires whole house ventilation based on floor area and occupancy. But the adequacy of these systems is hard to judge, given the variability in envelope leakage rates from day to day based on the weather, and the ability of the occupant to control the cycling of the ventilation in these systems.

Whole house ventilation can be exhaust, supply, or balanced design. The exhaust design depressurizes the home and exacerbates problems associated with infiltration of hot humid air in warm climates and with backdrafting, while supply based systems pressurize homes and causes similar problems in cold climates. These issues are addressed in ASHRAE Standard 62.2-2010. Balanced systems avoid these problems but are more expensive.

There are many reasons why occupants would want to discontinue the whole house ventilation during some portions of the day. Poor outdoor air quality during some parts of the day, for example, could warrant shutting down the system during that period. But the principal driving force for shutting off mechanical ventilation is generally to reduce energy use, especially during peak demand (and sometimes peak pricing). Discontinuing mechanical ventilation during peak demand (and peak pricing), reduces the economic (and personal) cost of energy generation and use. From this perspective, it is rational to allow the intermittent use of the whole house ventilation system. However, it is a precarious balance to provide for intermittent use and ensure that indoor contaminants will be at acceptable levels when the system is not in use. Further, it is perhaps a leap of faith that, with provisions for occupant control, to assume that tight homes will be adequately ventilated.

Sufficient make up air for combustion equipment

ASHRAE standard 62.2-2010 limits the capacity of a home's two largest exhaust fans to a net total exhaust flow of 15 cfm/100 ft^2 when atmospherically-vented fuel burning appliances are located inside the pressure boundary, beyond which "compensating outdoor air" must be provided. ASHRAE is not specific as to how that compensating air is to be supplied. Since it does not take much negative pressure in a home to cause backdrafting, and since ASHRAE only requires compensating air based on the two largest exhaust systems, some uncertainty remains as to the backdrafting potential in some homes. Whole-house exhaust ventilation and other exhaust systems have the potential to cause significant depressurization. Also, ASHRAE also does not address unvented space heaters.

One might, therefore, look toward the green building programs for more protective measures. EPA's Indoor airPLUS program does not allow unvented space heaters and requires oil-fired furnaces/boilers to be power vented or direct vented, and gas-fired furnaces/boilers to be direct vented (Climate Zones 1-3 exempted), plus additional energy efficiency and emissions requirements for fireplaces and space heating equipment. The LEED program credit (EQ2) for Combustion Appliances has similar provisions including requirements for closed combustion with direct powered exhaust for space and water heaters in all climates, and does not allow unvented combustion appliances including decorative logs. How these requirements apply, however, depends in part on what LEED categories the user chooses to comply with to gain sufficient credit for certification. Nevertheless, when such protections are instituted, provisions for whole house ventilation are less likely to cause significant backdrafting of flue gasses.

From Standards and Codes to Actual Practice

General overview

As building envelopes are tightened and the "excess outdoor air" is eliminated to save energy, there is little room for error. Degradations in indoor air quality becomes much more sensitive to and dependent on even small changes in climate, building practices, mechanical ventilation system, emissions of contaminants from appliances and materials, and occupant behavior. As a result, more sophisticated analysis (e.g. of building air leakage rates) is required and must be matched to specific design features and performance of other systems (e.g. whole house ventilation (exhaust, supply, or balanced systems) and design outdoor air rates, kitchen and bath and clothes dryer exhausts, combustion flue gas exhaust systems) which all must be "calibrated" to operate in all seasons, and in all climates, to provide healthy, comfortable, and productive indoor environments. No longer can old "rules of thumb" be relied upon to provide good indoor air quality because there is no longer the same room for error.

Fortunately, it appears from looking at current building code developments, that enough is known and appreciated about indoor air quality in the building community to avoid the kinds of pervasive gross errors that were made after the oil embargo in the 1970's when energy conservation led to significant indoor air quality problems. Nevertheless, this movement toward more tightly calibrated building systems creates significant pressures on existing institutions to adapt. This adaptation will necessarily be colored by the continued political and institutional momentum toward energy conservation when compared to indoor air quality. Energy conservation is backed by significant political and institutional frameworks, funding, legislation, and overall public involvement with large constituencies. This is not nearly the case with indoor air. This imbalance, therefore, increases the vulnerability of indoor air quality in buildings to changes made in buildings to save energy.

For example, how is indoor air quality currently balanced against energy conservation in building design and development? In a word, attempts are being made to minimize energy use under constraints of providing "minimally acceptable" indoor air. In other words, indoor air quality is being squeezed to its "minimally acceptable level" while energy conservation has become the objective to maximize.[4] Given the uncertainties as to what is minimally acceptable for indoor air, the health, comfort, and productivity of occupants is placed in an increasingly precarious situation.

As energy conservation measures progress, there are a number of reasons to be concerned that houses will inevitably get built to inadequate indoor air quality specifications. These reasons include the following: (a) climatic change will alter local climate conditions upon which building specifications are based; (b) it takes time to adapt to emerging issues, and when adaptations are made, pressures for cost containment plus uncertainties and differences of opinion leads to compromises in codes; (c) increased sophistication in specifications will require that code administration become more sophisticated and precise because there is less room for error, and enforcement will have to become more rigorous; and (d) the public, which must operate and maintain the systems on which indoor air quality depends, need to understand them, maintain them, and use them even when that means using more energy and increasing their operational cost.

Because room for error is becoming so narrowed for protecting indoor air, each of these issues has magnified potential to negatively impact indoor air. These issues are briefly discussed below.

Potential problems caused by a changing climate

The issue here is that building design is climate dependent. As climate conditions change, existing housing built to a previous standard may experience serious indoor air problems, because either the building envelope or provisions for ventilation, or both, may prove to be inadequate. For example, if colder and dryer climates become hotter and more humid, exhaust ventilation systems will present more mold problems as humid air is drawn into an inadequately protected building envelope. That is, what once was adequate for the original climate becomes inadequate because of climate change. Also, it will take time for local communities to adapt to the changes in climate, so that even new construction could be perpetually behind the curve. Thus, adapting to continuous change may require new institutional, more "forward looking" framework, and a willingness to invest in increased envelope protection and greater adaptability of systems (e.g. balanced ventilation systems tend to be more adaptable, but also cost more). **The seriousness of this problem will depend on the speed with which climate changes relative to the speed with which local communities are able to adapt.**

Potential problems caused by delayed response in codes

It takes several years between the time a model code is issued, and the time states and local communities update their codes. For example, almost all the state and local codes currently in use follow the model codes issued in 2006. And when a code is updated, it reflects the final resolution of issues that may have surfaced several years before. Further, some of the options and exceptions and compromises embedded in the codes reflect uncertainty and controversy about the most appropriate solutions. Codes also incorporate standards developed independently, such as ASHRAE Standards 62.1 and 62.2, so there is a time delay and adjustments in the process of adopting new standards into building codes. Indoor air problems are becoming more vulnerable during this adjustment period than they have been in the past.

[4] Offerman (2009) makes a similar case. He concludes from his study that indoor air quality and energy conservation can be entirely compatible objectives, but for this to happen "homes need to be, first and foremost, built to provide healthy environments, while striving for energy efficiency and sustainability."

Thus, as tightening of building envelopes continues, ventilation requirements may have to play catch up, and homes in the interim will likely be under-ventilated. As described previously, this is probably already happening.

Potential problems caused by inadequate code administration and enforcement

Building design and construction is highly localized, both because building practices must respond to climate and topography, and because buildings themselves help define and reflect the character of local communities. Local governments, therefore, assume responsibility for zoning, building permits, and code administration and enforcement, and thus often have the last say in determining what the code provisions will be for its community, and how they will be administered and enforced. At the local level, this can be greatly influenced by the local community of builders, the local political climate, budget, and the availability of resources.

It is difficult to quantitatively assess how well codes are implemented and enforced by local communities. One indication of this stems from evaluations of these functions at the community level as a way of managing risks, particularly risk of losses from natural disasters. One company that provides these evaluation services has published the results from the evaluations it has performed throughout the country. The company, ISO, uses its Building Code Effectiveness Grading Schedule (BCEGS®) to perform this function[5]. Communities get rated on a 10 point scale with 1 representing exemplary administration and enforcement of the code, and 10 representing little or no quality administration and enforcement. According to data provided by ISO from their evaluations, about 60% received a 4 or better (good), while almost 20% received a 7 or worse (not good), while the remaining 20% scored a 5 or 6 (just OK). This means that a large number of communities have room for significant improvement in their code development and enforcement. Looking at local communities within individual states reveals similar disparities, even among states with very strong state code development.

What this demonstrates is that practices at the local level are the ultimate determinant of how buildings are actually built, and there is considerable room at the local level for different interpretations and enforcement priorities of individual code provisions. As described earlier, there is powerful legislation "mandating" the adoption of energy codes. These codes themselves do not cover issues other than energy. In fact, the IECC does not even mention indoor air quality or ventilation except to ensure that air leakage is minimal. In addition, these energy codes are receiving a lot of attention, and through legislative mandate, the Department of Energy has an extensive program of technical assistance and grants to assist in their development. Further, utilities provide substantive technical support to local communities.

In all of these efforts, improved energy conservation often appears to be the sole objective. As a result, one would expect that when it comes to the balancing energy and indoor air quality, builders and code enforcement officials will be leaning heavily on the energy side. This issue becomes increasingly important for indoor air quality, because as energy practices become more stringent, there is much greater probability for poor indoor air quality if building practices and code enforcement leans too heavily on the side of energy conservation even if a reasoned balance is achieved in the code itself.

[5] See http://www.isomitigation.com/bcegs/1000/bcegs1001.html

Potential problems caused by lack of an educated public

The indoor climate is much more satisfying to occupants when they can control it, which is why "occupant controls" are so important. However, the general public is not very knowledgeable about the role they play in protecting the indoor air quality in their home. What does that mean when mechanical ventilation is increasingly relied on for adequate indoor air quality? These systems must be maintained and used properly if they are to function as needed. If they are noisy, or are not easily maintained, they probably won't be used, which is why ASHRAE 62.2 also has provisions to deal with these issues. Further, the media is filled with messages from utility companies and contractors about better insulation and tighter windows to stop air and energy leaks. Unvented gas fireplaces are heaters are advertised, for example, using words like "Don't let all that heated air go up the chimney. It's like throwing money away". These messages can easily dominate the public's perception about ventilation. Thus, even when mechanical ventilation is required, some people may not use it, and even if it is required to be "continuous," some will likely just shut it off. A strong public education campaign may be needed, and it would be best done in conjunction with education about energy conservation so the public can more clearly understand the need for balancing these two objectives. Use of heat (energy) recovery systems in most climates, where appropriate, may be a useful alternative to ensure that outdoor air ventilation is on most of the time without wasting energy.

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Appendix

Indoor airPLUS Construction Specifications

(Excludes table of contents, definitions, and references.
See http://www.epa.gov/indoorairplus/pdfs/construction_specifications.pdf for complete document.)

These specifications were developed by the U.S. Environmental Protection Agency (EPA) to recognize new homes equipped with a comprehensive set of Indoor Air Quality (IAQ) features. They were developed with significant input from stakeholders, based on best available science and information about risks associated with IAQ problems, and balanced with practical issues of cost, builder production process compatibility, and verifiability. Although these measures were designed to help improve IAQ in new homes compared with homes built to minimum code, they alone cannot prevent all IAQ problems. Occupant behavior is also important. For example, smoking indoors would negatively affect IAQ and the performance of the specified Indoor airPLUS measures.

1. Moisture Control

Note: ENERGY STAR Thermal Bypass Checklist (TBC) requirements are an integral part of the Indoor airPLUS moisture control strategy. TBC requirements improve the control of air and thermal flows through building assemblies, which is critical to controlling water vapor migration and condensation. Since TBC compliance and verification are required for ENERGY STAR qualification, TBC requirements are not re-stated in the Indoor airPLUS Construction Specifications.

Water-Managed Site and Foundation

1.1 Provide site and foundation drainage as follows:

- Slope patio slabs, walks and driveways a minimum of 1/4 in. per ft. away from house, tamp back-fill to prevent settling, AND slope the final grade away from the foundation at a rate of 1/2 in. per ft. over a minimum distance of 10 ft. Where setbacks limit space to less than 10 ft., provide swales or drains designed to carry water away from the foundation. Back-fill tamping is not required if proper drainage can be achieved using non-settling compact soils, as determined by a certified hydrologist, soil scientist, or engineer.
- Install protected drain tile at the footings of basement and crawlspace walls, level or sloped to discharge to outside grade (daylight) or to a sump pump. The top of each drain tile pipe must always be below the bottom of the concrete slab or crawlspace floor. Each pipe shall be surrounded with at least 6 inches of 1/2 to 3/4 in. washed or clean gravel. The gravel layer shall be fully wrapped with fabric cloth to prevent fouling of the drain tile. If a drain tile discharges to daylight and radon-resistant features are required (see Specification 2.1), install a check valve at the drain tile outfall.
- Install a drain or sump in basement and crawlspace floors, discharging to daylight at least 10 ft. outside the foundation or into an approved sewer system. Floor drains are not required for slab-on-grade foundations.

1.2 Install capillary breaks as follows:

Beneath concrete slabs, including basement floors:

- Install a 4 in. layer of 1/2 in. diameter or greater clean aggregate, covered with 6 mil (or thicker) polyethylene sheeting, overlapped 6 to 12 in. at the seams, and in direct contact with the concrete slab above; OR
- Install a 4 in. uniform layer of sand, overlain with a layer or strips of geotextile drainage matting installed according to the manufacturer's instructions, and covered with polyethylene sheeting overlapped 6 to 12 in. at the seams.

Crawlspace floors:

- Cover crawlspace floors with a concrete slab over 6 mil (or thicker) polyethylene sheeting overlapped 6 to 12 in. at the seams; OR
- Cover crawlspace floors with 6 mil polyethylene (10 mil recommended) sheeting, overlapped 6 to 12

in. and sealed or taped at the seams and penetrations. The sheeting shall be attached to walls and piers with adhesive and furring strips.

Exceptions:

- In areas of free-draining soils — identified as Group 1 by a certified hydrologist, soil scientist, or engineer through a site visit — a gravel layer or geotextile matting is not required under concrete slabs.
- Polyethylene sheeting is not required in Dry (B) climates, as defined by IECC Figure 301.1, unless the sheeting is required for radon resistance (see Specification 2.1).

1.3 Damp-proof or waterproof exterior surfaces of below-grade foundation walls as follows:

- Poured concrete, concrete masonry, and insulated concrete forms (ICFs) shall be finished with a damp-proof coating; AND
- Wood-framed walls shall be finished with trowel-on mastic and polyethylene, or with other waterproofing demonstrated to be equivalent.

Exceptions: Houses without below-grade walls.

1.4 Insulate and condition basements and crawlspaces as follows:

- Insulate crawlspace and basement perimeter walls according to IRC Table N1102.1 or IECC Table 402.1.1 (also see Specification 1.12); AND
- Seal crawlspace and basement perimeter walls to prevent outside air infiltration; AND
- Provide conditioned air at a rate not less than 1 cfm per 50 s.f. of horizontal floor area. If radon-resistant features are required (see Specification 2.1), do not install exhaust ventilation, as described in IRC section R408.3.2.1.

Exceptions:

- Homes built in areas designated as flood zones (conditioned crawlspaces are not recommended for use in flood zones).
- Raised pier foundation with no walls.
- Dry climates, as defined by IECC Figure 301.1.
- Marine climates, as defined by IECC Figure 301.1, if no air handler or return ducts are installed in the crawlspace.

Note: In each of the preceding exceptions, floors above unconditioned spaces shall be insulated to the IECC-specified R-value and sealed to prevent air infiltration.

Water-Managed Wall Assemblies

1.5 Install a continuous drainage plane behind exterior wall cladding, AND install flashing or an equivalent drainage system at the bottom of exterior walls to direct water away from the drainage plane and foundation. Drainage plane material shall overlap flashing and shall be fully sealed at all penetrations. Any of the following systems meet this requirement:

- Monolithic weather-resistant barriers (i.e., house wrap), shingled at horizontal joints and sealed or taped at all joints; OR
- Weather-resistant sheathings (e.g., faced rigid insulation), fully taped at all “butt” joints; OR
- Lapped shingle-style building paper or felt.

Note: Include weep holes for masonry veneer and weep screed for stucco cladding systems, according to the manufacturer’s specifications.

1.6 Fully flash all window and door openings, including pan flashing at sills, side flashing that extends over pan flashing, and top flashing that extends over side flashing.

Water-Managed Roof Assemblies

1.7 **Direct roof water away from the house using gutters and downspouts that empty into lateral piping that deposits water on a sloping finish grade a minimum of 5 ft. from the foundation.** Roofs designed without gutters are acceptable if they are designed to deposit rainwater to a grade-level rock bed with waterproof liner and drain pipe that deposits water on a sloping finish grade, as specified above. When lot space limits or prevents required grading, direct roof water to an underground catchment system (not connected to the foundation drain system) that deposits water a minimum of 10 ft. from the foundation. Rainwater-harvesting systems may be used to meet this requirement when they are designed to properly drain overflow, meeting discharge-distance requirements above.

Exception: Dry climates, as shown in IECC Figure 301.1.

1.8 **Fully flash roof/wall intersections and all roof penetrations.** Install step flashing at all roof/wall intersections, except metal and rubber membrane roofs, where continuous flashing should be installed. "Kick-out" flashing shall be installed at the low end of roof/wall intersections to direct water away from walls, windows, and doors below. In all cases, flashing shall extend at least 4 in. on the wall surface above the roof deck and shall be integrated with the drainage plane above (shingle style) to direct water onto and not behind flashing. In addition, intersecting wall siding should terminate a minimum of 1 in. above the roof, or higher according to the manufacturer's recommendations.

1.9 **Install self-sealing bituminous membrane or the equivalent at all valleys and roof decking penetrations for durability at potential failure points.**

Exception: Dry climates, as shown in IECC Figure 301.1.

1.10 **In colder climates (IECC Climate Zones 5 and higher), install self-sealing bituminous membrane or the equivalent ("ice flashing") over the sheathing at eaves to provide protection from ice dams.** The ice flashing shall extend up the roof plane from the eave to a point at least 2 ft. inside the vertical plane of the exterior wall.

Exception: Climate Zones 1 to 4, as shown in IECC Figure 301.1.

Interior Water Management

1.11 **Install moisture-resistant materials and moisture-protective systems in vulnerable areas. For example:**

- Install water-resistant hard-surface flooring in kitchens, bathrooms, entryways, laundry areas, and utility rooms. Do not install wall-to-wall carpet adjacent to toilets and bathing fixtures (i.e., tubs and showers).
- Install moisture-resistant backing material (i.e., cement board or the equivalent, but not paper-faced wall board) behind tub and shower enclosures.
- Install all condensate discharge according to IRC section M1411.3.
- Insulate piping installed in exterior walls.

1.12 **Do not install continuous vapor barriers on the interior side of exterior walls that have high condensation potential (e.g., below-grade exterior walls in most climates and above-grade exterior walls in warm-humid climates).** For the purpose of this specification, vapor barriers are materials that have a perm rating of 0.1 or less (see manufacturer's product specifications or 2005 ASHRAE Handbook of Fundamentals, Chapter 25, Tables 7A and 7B).

1.13 **Do not install building materials that have visible signs of water damage or mold.** In addition, interior walls shall not be enclosed (e.g., with drywall) if either the framing members or insulation has a high moisture content. For wet-applied insulation, follow the manufacturer's drying recommendations.

Advisory: Lumber should not exceed 18% moisture content.

2. Radon Control

2.1 **Homes built in EPA Radon Zone 1** (see www.epa.gov/radon/zonemap.html) **shall be constructed with approved radon-resistant features according to EPA's "Building Radon Out"; NFPA 5000, Chapter 49; IRC, Appendix F; CABO, Appendix F; or ASTM E1465.** The following requirements shall be verified:

- Capillary break installed according to Specification 1.2; AND
- A 3 or 4 in. diameter gas-tight vertical vent pipe, clearly labeled "Radon Pipe" or "Radon System," connected to an open T-fitting in the aggregate layer (or connected to geotextile drainage matting according to the manufacturer's instructions) beneath the polyethylene sheeting, extending up through the conditioned spaces and terminating a minimum of 12 in. above the roof opening. For crawlspaces, install at least 5 ft. of horizontal perforated drain tile on either side of the T-fitting, attached to the vertical radon vent pipe beneath the sheeting and running parallel to the long dimension of the house; AND
- Radon fan installed in the attic (i.e., an active system) OR an electrical receptacle installed in an accessible attic location near the radon vent pipe (i.e., a passive system) to facilitate future fan installation if needed; AND
- Foundation air sealing with polyurethane caulk or the equivalent at all slab openings, penetrations, and control or expansion joints. Sump covers also shall be air sealed (e.g., mechanically attached with full gasket seal or equivalent.)

Exception: The Indoor airPLUS Construction Specifications recommend, but do not require, radon-resistant features for homes built in EPA Radon Zones 2 and 3 unless required by local building codes (see Advisory 1).

Advisories:

1. Elevated levels of radon have been found in homes built in all three zones on EPA's Map of Radon Zones. Consult your state's radon coordinator for current information about radon in your area. Go to www.epa.gov/radon/whereyoulive.html and click on your state for contact information.
2. If soil or groundwater contamination is suspected on or near the building site (e.g., former industrial sites), volatile contaminants or breakdown products may pose an IAQ risk through soil gas intrusion. In such cases, EPA recommends radon-resistant features consistent with Specification 2.1, which can prevent the intrusion of soil vapor into a house. See the EPA Vapor Intrusion Primer or ASTM E2600 for more information, or consult your state or tribal Brownfield voluntary cleanup program or environmental regulatory agency for information on the risks of vapor intrusion in your area.

2.2 Provide two radon test kits designed for 48-hour exposures for the buyers of homes in EPA Radon Zones 1 and 2, including test kit instructions and EPA guidance on follow-up actions to be taken in response to the test results.

Advisory: The U.S. Surgeon General and EPA recommend that all homes (including homes built in Radon Zone 3) be tested for radon. Refer interested buyers to www.epa.gov/radon for more information.

3. Pest Barriers

3.1 **Minimize pathways for pest entry by sealing penetrations and joints in and between the foundation and exterior wall assemblies with blocking materials, foam, and polyurethane caulk or the equivalent.** Sump pit covers shall be air sealed (e.g., mechanically attached with full gasket seal or the equivalent).

Advisories:

1. Additional precautions should be taken in areas of "Heavy" termite infestation probability (as identified by IRC Figure 301.2[6]) as follows:

- Foundation walls should be solid concrete or masonry with a top course of solid block, bond beam, or concrete-filled block; AND
- Interior concrete slabs should be constructed with 6 x 6 in. welded wire fabric or the equivalent, and concrete walls should be constructed with reinforcing rods to reduce cracking; AND
- Sill plates should be made of preservative-treated wood.

2. The following additional precautions should be taken in areas of “Very Heavy” termite infestation probability (as identified by IRC Figure 301.2[6]) i.e., Alabama, Florida, Georgia, Louisiana, Mississippi, South Carolina, and parts of California and Texas:

   Below-grade:

   - Foam plastic insulation should not be installed on the exterior face of below-grade foundation walls or under slabs.

   Above-grade:

   - Foam plastic insulation installed on the exterior of above-grade foundation walls should be kept a minimum of 6 in. above the final grade and any landscape bedding materials, and should be covered with moisture-resistant, pest-proof material (e.g., fiber cement board or galvanized insect screen at the bottom-edge of openings).
   - Foam plastic insulation applied to the interior side of conditioned crawlspace walls should be kept a minimum of 3 in. below the sill plate.

3.2 Provide corrosion-proof rodent/bird screens (e.g., copper or stainless steel mesh) for all building openings that cannot be fully sealed and caulked (e.g., ventilation system intake/exhaust outlets and attic vent openings). This requirement does not apply to clothes dryer vents.

4. HVAC Systems

Heating and Cooling Equipment

4.1 Heating and cooling design loads shall be determined for each room according to ACCA Man J, ASHRAE Handbooks, or equivalent software. Heating and cooling equipment shall be properly sized and selected to meet the design loads and accommodation must be made for pressure drop from specified filter (see Specification 4.7). This requirement shall be met by an ENERGY STAR HVAC QI Certificate (where available) OR verification of all the following:

- Documentation of design load calculations (i.e., load calculation worksheet or software report), AND
- System design documentation (i.e., sizing calculations and equipment performance information), AND
- Verification that outdoor and indoor coils match in accordance with the AHRI Directory of Certified Product Performance. For more information, see www.ahridirectory.org

4.2 Duct system(s) shall be designed according to ACCA Man D, ASHRAE Handbooks, or equivalent software AND installed to be substantially airtight, properly balanced, and protected from construction debris. This requirement shall be met by an ENERGY STAR HVAC QI Certificate (where available) OR verification of all the following prescriptive requirements, OR the Performance Test Alternative below:

- Design verified by appropriate documentation (i.e., duct-sizing worksheet or annotated layout), AND
- Duct system verified to meet the following additional requirements:
  - Seams in the HVAC cabinet, plenum, and adjacent ductwork shall be sealed with mastic systems, tape that meets the applicable requirements of UL 181A or UL 181B, or gasket systems.
  - Building cavities shall not be used as part of the forced air supply or return systems.

- Duct openings shall either be covered during construction or vacuumed out thoroughly prior to installing registers, grilles, and diffusers (see Specification 7.1)

Performance Test Alternative:

- Room-by-room airflows balanced and verified within +/-20% of calculated room airflows to meet design loads (see Specification 4.1), except for baths, closets, and pantries, AND
- Duct system TOTAL leakage test no greater than 6 cfm per 100 s.f. of floor area (or 9% design fan flow), measured at 25 Pa, with duct boots and air handler in place, according to ASTM E1554, ASHRAE 152, or other RESNET-approved method.

4.3 No air-handling equipment or ductwork shall be located in garages.

Note: Ducts and equipment may be located in framing spaces or building cavities adjacent to garage walls or ceilings if they are separated from the garage space with a continuous air barrier (see ENERGY STAR Thermal Bypass Checklist Guide).

4.4 Room pressure differentials shall be minimized by installing transfer grilles or jump ducts for any closed room that does not have a dedicated return, except for baths, kitchens, closets, pantries, and laundry rooms. The opening size shall be 1 square in. capacity (grille area) per cfm of supply (including free area undercut below door as part of the area).

Performance Test Alternative: Measured pressure differential no greater than 3 Pa (0.012 in. w.c.) between closed rooms and adjacent spaces that have a return.

Ventilation

4.5 Provide mechanical whole-house ventilation meeting all ASHRAE 62.2 requirements. The following requirements shall be visually verified:

- Whole house mechanical ventilation system & controls shall be installed to deliver the prescribed outdoor air ventilation rate (ASHRAE 62.2 section 4), including ventilation restrictions in ASHRAE 62.2 section 4.5 (e.g., not greater than 7.5 cfm/100 s.f. in “Warm-Humid” climates as defined by IECC Figure 301.1); AND
- Transfer air (i.e., air from adjacent dwelling units or other spaces such as garages, crawlspaces, or attics) shall not be used to meet ventilation requirements (ASHRAE 62.2 section 6.1); AND
- Outdoor air inlets shall be located a minimum of 10 ft. from contaminant sources (ASHRAE 62.2 section 6.8); AND
- Airflow shall be tested to meet rated fan airflow (at 0.25 in. w.c.) OR verify duct(s) sized according to the requirements of ASHRAE 62.2 Table 7.1 and the manufacturer’s design criteria (ASHRAE 62.2 section 7.3).

Note: Outdoor air ducts connected to the return side of an air handler shall be permitted as supply ventilation only if the manufacturers’ requirements for return air temperature are met (e.g., most manufacturers recommend a minimum of 60^{o} F air flow across furnace heat exchangers).

4.6 Provide local exhaust ventilation to the outdoors for known pollutant sources, as follows:

- Provide local mechanical exhaust ventilation to the outdoors in each bathroom and kitchen, meeting ASHRAE 62.2 section 5 requirements. In addition, all bathroom ventilation fans shall be ENERGY STAR qualified unless multiple bathrooms are exhausted with a multi-port fan.
- Conventional clothes dryers shall be vented to the outdoors. Electric condensing dryers are not vented and shall be plumbed to a drain according to the manufacturer’s instructions.
- If a central vacuum system is installed, the system shall be vented outdoors at least 10 ft. from the ventilation system air inlets (see Specification 4.5), or the power/filtration unit shall be installed in the garage according to the manufacturer’s instructions.

Air Cleaning and Filtration

4.7 Central forced-air HVAC systems shall include a filtration system meeting the following requirements:

- HVAC filters shall be rated MERV 8 or higher according to ASHRAE 52.2 (at approximately 295 fpm).
- There shall be no visible bypass between the filter and the filter rack.
  The filter access panel shall include gasket material or comparable sealing mechanism to prevent air leakage, and it shall fit snugly against the exposed edge of the installed filter when closed to prevent bypass.
- No air-cleaning equipment designed to produce ozone (i.e., ozone generators) shall be installed.

Advisory: Filters perform best when the filter rack design includes the following features, which are also included in some manufacturers' filter media boxes:

- Flexible, air-tight (e.g., closed-cell foam) gasket material on the surface that contacts the air-leaving (downstream) side of the filter, AND
- Friction fit or spring clips installed on the upstream side of the filter to hold it firmly in place.

Dehumidification

4.8 In "Warm-Humid" climates as defined by IECC Figure 301.1 (i.e., Climate Zone 1 and portions of Zones 2 and 3A below the white line), equipment shall be installed with sufficient latent capacity to maintain indoor relative humidity (RH) at or below 60%. This requirement shall be met by either:

- Additional dehumidification system(s), OR
- A central HVAC system equipped with additional controls to operate in dehumidification mode.

Exception: Climate Zones 4-8, 3B, 3C, and the portions of 3A and 2B above the white line as shown by IECC Figure 301.1.

Advisory: Although not required to meet this specification, independent dehumidification is recommended in Climate Zones 4A and 3A above the white line as shown in IECC Figure 301.1.

5. Combustion Pollutant Control

Combustion Source Controls

5.1 For combustion space-heating and water-heating equipment located in conditioned spaces:

- Gas-fired furnaces/boilers shall be direct vented, except in Climate Zones 1-3 as shown in IECC Figure 301.1.
- Oil-fired furnaces/boilers shall be power vented or direct vented, except in Climate Zones 1-3 as shown in IECC Figure 301.1.
- Combustion water heaters shall be power vented or direct vented.
- No unvented combustion space-heating appliances shall be permitted.

Exception: Houses with no combustion heating equipment located in conditioned spaces.

Note: Unfinished basements and crawlspaces (except raised pier foundations with no walls) and attached garages that are air-sealed to the outside and intended for use as work space or living space, are considered "conditioned spaces" for the purpose of this requirement.

5.2 Fireplaces and other fuel-burning space-heating appliances located in conditioned spaces shall be vented to the outdoors and supplied with adequate combustion and ventilation air according to the manufacturers' installation instructions, AND they shall meet the following energy efficiency and emissions standards and restrictions:

- Masonry fireplaces are not permitted, with the exception of “masonry heaters” as defined by ASTM E1602 and section 2112.1 of the International Building Code (i.e., fireplaces engineered to store and release substantial portions of heat generated from a rapid burn).
- Factory-built, wood-burning fireplaces shall meet the certification requirements of UL 127 and emission limits found in the EPA Standard for New Residential Wood Heaters.Natural gas and propane fireplaces shall be power vented or direct vented, as defined by NFPA 54, section 3.3.108, have a permanently affixed glass front or gasketed door, and comply with ANSI Z21.88/CSA 2.33.
- Wood stove and fireplace inserts as defined in section 3.8 of UL 1482 shall meet the certification requirements of that standard, and they shall meet the emission requirements of the EPA Standards for New Residential Wood Heaters and WAC 173-433-100 (3).
- Pellet stoves shall meet the requirements of ASTM E1509.
  Decorative gas logs as defined in K.1.11 of NFPA 54 (National Fuel Gas Code) are not permitted.
- Unvented combustion space-heating appliances are not permitted.

Advisory: To minimize the potential for spillage or back-drafting, fireplaces and fuel-burning appliances located in conditioned spaces should be installed in compliance with ASHRAE 62.2 (section 6.4) or by conducting a Worst Case Depressurization Combustion Air Zone (CAZ) Test according to an established protocol.

5.3 All homes equipped with combustion appliance(s) or an attached garage shall have a carbon monoxide (CO) alarm installed in a central location in the immediate vicinity of each separate sleeping zone (e.g., in a hallway adjacent to bedrooms.) The alarm(s) shall be hard-wired with a battery back-up function and placed according to NFPA 720. The alarms shall be certified by either CSA 6.19-01 or UL 2034.

5.4 Reduce exposure to environmental tobacco smoke (ETS) in multi-family buildings by:

- Prohibiting smoking in indoor common areas, specified explicitly in building rental/lease agreements or condo/co-op association covenants and restrictions, AND
- Locating designated outdoor smoking areas a minimum of 25 ft. from entries, outdoor air intakes, and operable windows, AND
- Minimizing uncontrolled pathways for ETS transfer between individual dwelling units by sealing penetrations in the walls, ceilings, and floors of dwelling units, sealing vertical chases adjacent to dwelling units, and applying weather stripping to all doors in dwelling units leading to common hallways.

Attached Garage Isolation

5.5 Attached garages shall be isolated from conditioned spaces as follows:

- Common walls and ceilings between attached garages and living spaces shall be visually inspected to ensure they are air-sealed before insulation is installed.
- All connecting doors between living spaces and attached garages shall include an automatic closer, and they shall be installed with gasket material or be made substantially air-tight with weather stripping.

5.6 Attached garages shall include an exhaust fan, with a minimum installed capacity of 70 cfm, rated for continuous operation, and installed to vent directly outdoors. If automatic fan controls are installed, they shall activate the fan whenever the garage is occupied and for at least 1 hour after the garage has been vacated.

Advisory: ENERGY STAR qualified fans are highly recommended.

6. Low-Emission Materials

Note: The evaluation, certification, and labeling of products for indoor VOC emissions is complex and evolving. EPA has not established threshold levels for indoor VOC emissions from any of the product categories addressed in these specifications. The third-party programs referenced in these specifications include U.S. programs that are designed to reduce indoor human exposure to individual VOCs of potential concern for human health effects, compared to similar products not certified as low-VOC or no-VOC. EPA will consider modifying these specifications to include additional third-party programs as appropriate.

6.1 Structural plywood, oriented strand board (OSB), and composite wood products (i.e., hardwood plywood, particleboard, medium density fiberboard [MDF], and cabinetry made with these products) shall be third-party certified for compliance with industry and federal standards, as follows:

- Structural plywood and OSB shall be certified compliant with PS1 or PS2, as appropriate, and shall be made with moisture-resistant adhesives as indicated by "Exposure 1" or "Exterior" on the American Plywood Association (APA) trademark.
- Hardwood plywood shall be certified compliant with the formaldehyde emissions requirements of ANSI/HPVA HP-1-2004 and U.S. HUD Title 24, Part 3280, OR certified compliant with CA Title 17.
- Particleboard and MDF shall be certified compliant with the formaldehyde emissions requirements of ANSI A208.1 and A208.2, respectively, and U.S. HUD Title 24, Part 3280, OR certified compliant with EPPS CPA 3-08 by the CPA Grademark certification program, OR certified compliant with CA Title 17.
- Cabinetry shall be made with component materials that are certified to comply with all the appropriate standards above OR shall be registered brands or produced in registered plants certified under KCMA's Environmental Stewardship Certification Program (ESP 01-06).

Note: In California, composite wood products shall be certified compliant with CA Title 17 as appropriate.

6.2 Interior paints and finishes, including 90% or more of such products applied to interior surfaces of homes, shall be certified low-VOC or no-VOC by one of the following:

- Green Seal Standard GS-11, OR
- Greenguard Certification for Paints and Coatings, OR
- Scientific Certification Systems (SCS) Standard EC-10.2-2007, Indoor Advantage Gold, OR
- Master Painters Institute (MPI) Green Performance Standards GPS-1 or GPS-2, OR
- A third-party low-emitting product list based on CA Section 01350, e.g., the CHPS List at www.chps.net/dev/Drupal/node/381

6.3 Carpets and carpet adhesives shall be labeled with, or otherwise documented as meeting, the Carpet & Rug Institute (CRI) Green Label Plus or Green Label testing program criteria. Carpet cushion (i.e., padding) shall similarly be certified to meet the CRI Green Label testing program criteria.

7. Home Commissioning

7.1 HVAC systems and ductwork shall be verified to be dry and clean and installed according to their design as documented by an ENERGY STAR HVAC QI Certificate (where available) OR as follows:

- Inspect ductwork before installing registers, grilles, and diffusers to verify it is dry and substantially free of dust or debris, and that there are no disconnects or visible air gaps between boots and framed openings. If duct openings were not covered during construction, thoroughly vacuum out each opening prior to installing registers, grilles, and diffusers.
- Inspect air-handling equipment and verify that heat exchangers/coils are free of dust caused by construction activities (e.g., drywall, floor sanding) AND the filter is new, clean and meets specified MERV rating (see Specification 4.7). After installation of registers, grilles, and diffusers, verify detectable airflow from each supply outlet.
- Verify the HVAC contractor has documented measured airflow or pressure drop across the cooling coil or heat exchanger within +/- 15% of system design airflow, or the manufacturer-specified operating range, tested according to ASTM E1554, ASHRAE 152, or an equivalent method.
- Verify the HVAC contractor has documented the installation and testing of proper refrigerant charge. This requirement may be met by any of the following methods according to ACCA 5 QI-2007:
    - Superheat method test measurement within 5% of the manufacturer-recommended charge, OR
    - Subcooling method test measurement within 3% of the manufacturer-recommended charge, OR
    - Other equivalent method/tolerance approved by the equipment manufacturer.

Note: If weather conditions do not meet required test conditions, verify that the builder or contractor has arranged for future testing.

7.2 Verify that the home has been ventilated with outside air at the highest rate practical during and shortly after installing products that are known sources of contaminants (e.g., cabinets, carpet padding, and painting) and during the period between finishing and occupancy, meeting ventilation requirements for outdoor air flow and humidity control (see Specifications 4.5 and 4.8). If whole house ventilation cannot be scheduled prior to occupancy, advise the buyer to operate the ventilation system at the highest rate it can provide during the first few months of occupancy, meeting the above requirements.

7.3 Provide for buyers a completed checklist and other required documentation about the IAQ features of their home, including:

- A copy of the Indoor airPLUS verification checklist or other written documentation indicating compliance with all required measures from the Indoor airPLUS construction specifications, signed by an official representative of the builder, AND
- HVAC, duct, and ventilation system design documentation (i.e., airflow requirements) or performance test results (i.e., measured cfm) required by Specifications 4.1, 4.2, and 4.5, respectively, and a description of the ventilation system (i.e., system type, components, and controls), AND
- Operations and maintenance instruction manuals for all installed equipment and systems addressed by Indoor airPLUS requirements, including HVAC systems and accessories, combustion appliances, and radon system literature and test kit instructions.