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Trend in the US ventilation market and drivers for change

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1 Introduction

This paper discusses current key changes in the ventilation market in the United States. The US ventilation industry is driven primarily by codes and standards. Codes are regulations with the force of law. There are no national codes relating to ventilation in the United States as such regulations are left up to the individual states—most of whom have empowered more local authorities. These local codes evolve over history and are influence by model codes (such as those from the International Code Council) as well as by appropriate standards.

Standards are created by professional or technical groups to represent appropriate practice. They do not have the force of law by themselves. For ventilation and related standards the key body is the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), who puts out a series of standards.

1.1 Background on Ventilation Standards IN the US

By the 1880s, the general consensus was that proper ventilation required 30 cfm/person and 22 states had this value prescribed by law by 1925 (Janssen 1999). After the turn of the century, research was beginning to question the need for such high rates. With improvements in sanitation and hygiene reducing the need for ventilation to control contagion, the rationale for ventilation began to shift towards odor and comfort. Yaglou's research in the early 20th century used room-sized chambers and calculated how much airflow would be needed to keep people comfortable. This research served as the basis for American ventilation standards.

Janssen (1994) reports how the consensus ventilation rate dropped over the next half century, principally based on the odor acceptability work of Yaglou and others. ASHRAE's first ventilation standard, 62-1973, reflected this philosophy and typically recommended 10 cfm/person (varying by space type). The subsequent revisions to the standard were marred by controversy as different rationales were applied [see Stanke (1999) and Janssen (1999)].

Before 1996 the only way ASHRAE standards addressed residential ventilation was as a small part of its broader ventilation standard, standard 62. In 1996, ASHRAE recognized that there was a need to have a separate standard for residential ventilation and formed a committee to do just that. Seven years later, ASHRAE approved Standard 62.2-2003. As a standard intended for use in regulation, 62.2 was crafted to describe the minimum requirements necessary to provide minimally acceptable indoor air quality for typical situations. The standard is a trade-off between dilution ventilation and source control and attempts to be as flexible as the consensus process allows.

The main body of Standard 62-2001 and earlier was devoted to non-residential buildings. The current version of this standard is 62.1-2007. The current version of the residential standard is 62.2-2007described below.

1.2 Traditional Ventilation and Air Tightness

Historically dwellings in the United States had little in the way of designed ventilation. While sometimes local exhaust fans may be required, often operable windows are assumed to meet the requirement. Similarly codes required ventilation but that could be assumed to be supplied through operable windows and air leakage. Thus very little of the existing stock of US dwellings have designed whole-house ventilation.

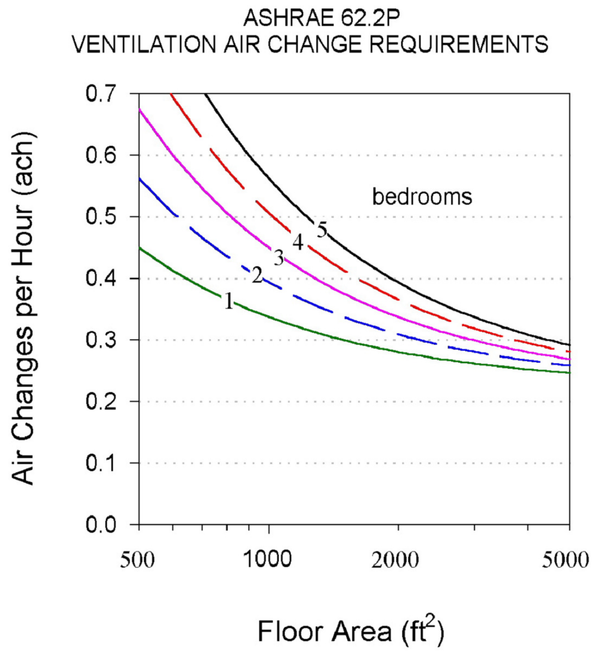
Traditionally this system worked to provide acceptable indoor air quality principally because the building envelope was leaky. Sherman and McWilliams (2007) have analyzed approximately 100,000 residential air tightness measurements to create a model of the current building stock. That data implies that they annual effective air change rate of a typical dwelling is on the order of 1 air change per hour. This rate is roughly 3 times the rate required by Standard 62 and indicates energy savings opportunities.

By contrast most non-residential buildings have designed mechanical ventilation. Because most commercial spaces are heated and cooled using air systems, mechanical ventilation is an easy approach. What data exists on air tightness of non-domestic buildings indicates their envelopes are just as leaky. Because of the unbalanced nature of their mechanical systems, the leakage matters little for net ventilation or energy. Such leakage, however, may be critically important for durability or moisture management.

2 Overview of 62.2

In developing this standard ASHRAE recognized that there were many different kinds of houses, many different climates, and many different styles of constructions. To accommodate these differences, the major requirements were designed with several alternate paths to allow users flexibility. Some requirements are performance based, with specific prescriptive alternatives. The standard recognizes that there are several different ways to achieve a specified ventilation rate and allows both mechanical and natural methods.

There are three sets of primary requirements in the standard and a host of secondary ones. The three primary sets involve whole-house ventilation, local exhaust, and source control. Whole-house ventilation (below) is intended to dilute the unavoidable contaminant emissions from people, from materials and from background processes. Local exhaust is



intended to remove contaminants from those specific rooms (e.g. kitchens) whose intended functions necessarily produce airborne contaminants. Other source control measures are included to deal with those sources that can reasonably be anticipated and dealt with.

The secondary requirements focus on properties of specific items that are needed to achieve the primary objectives of the standard. Examples of this include sound and flow ratings for fans and labeling requirements. Some of the secondary requirements as well as the guidance in the appendices help keep the design of the building as a system from failing because ventilation systems were installed. For example, ventilation systems that excessively push moist air into the building envelope can lead to material damage unless the design of the envelope is moisture tolerant.

The first thing people tend to look at in a ventilation standard are the ventilation rates, specifically the whole-house rates. From 1989 onwards, the whole-house rate in Standard 62 was set at 0.35 air changes per hour, but no less than 15 cfm/person (7.5 l/s/person). The default number of people was assumed to be two for the first bedroom plus one for every additional bedroom.

In 62.2 the committee decided to make the target ventilation rate the sum of the ventilation rates necessary to dilute background sources plus sources attributable to occupancy. To find the total amount of outside air needed one needs to add 3 cfm/100 sq. ft. (15 l/s/100 sq. m.) to the 7.5 cfm required per person (3.5 l/s/person). Thus the air change rate requirement will vary by the size of the house and the occupancy.

For larger houses the 62.2 value comes out smaller than the 0.35 ACH of 62-2001, but for small houses the 62.2-2003 rates are higher.

2.1 Mechanical Ventilation

With some exceptions 62.2-2007 requires that a fan be used to provide whole-house ventilation. To size the fan we can start with the values in the figure above, but the standard allows credit to be taken for infiltration (including natural ventilation). The standard has a default infiltration credit (of 2 cfm/100 sq. ft. [10 l/s/100 sq. m.]) that can be used in lieu of an air tightness measurement.

The standard allows intermittent whole-house mechanical ventilation to be used as an option to continuous ventilation. The size of the fan can be calculated from the fractional run time with a formula given in the standard. For designs in which the total cycle time is over three hours, the fan size must be further increased to account for the poor efficiency associated with running the fan only rarely (i.e. an infrequently operated fan needs to push through a larger total air volume than a continuously operating one to control the same pollutant). The fan must run at least one hour out of every twelve.

The standard allows approaches in which air is drawn into the house through the forced air system, provided that there is a timer or other mechanism to assure a minimum amount of ventilation each day and such that some minimum cycle time can be estimated. Such systems currently exist in the market.

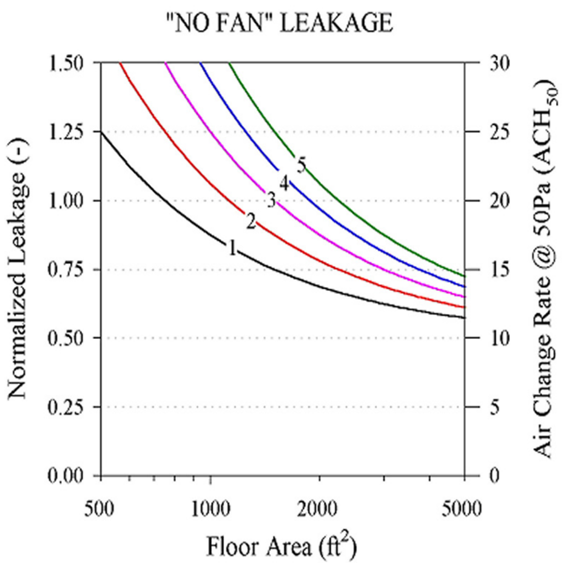
2.2 Natural Ventilation

There is also a requirement that each room have the capacity for additional ventilation. A dwelling that has 4% of the floor area as operable openings would meet this requirement, provided the openings do not present a hazard when used to provide ventilation. Such hazards need to be evaluated locally, but could include proximity to local sources of air or noise pollution (e.g. a freeway, an airport, industrial sites, etc.). Security and operability may be other reasons to exclude this as an option. In lieu of a window (e.g. for completely interior habitable spaces), a local mechanical ventilation system may be provided.

2.3 Infiltration

The default infiltration credit corresponds to a rather tight new house compared to the stock. Unlike standard, 62-2001, 62.2-2003 does not allow any additional credit to be taken for infiltration, unless it can be demonstrated—and it can only be demonstrated in an existing home. A larger infiltration credit can be used if the air leakage is greater than the default, as demonstrated by ASHRAE Standard 136.

For example, the figure below shows minimum leakage rates for an existing house, in a mild climate to be meet requirements without any mechanical ventilation. The figure is labeled both in the Normalized Leakage parameter of Standard 119 and the more common Air Changes at 50 Pa.



Extra infiltration credit for new construction is not currently allowed in 62.2 because from a practical standpoint, it may be unreasonable to design a new house with the intent of making it leaky. The discomfort, energy impacts, and possible moisture problems of intentionally leaky houses make it an unattractive alternative.

Research has shown, however, that older houses in the U.S. are often quite leaky [Sherman & Matson, 1997] and are quite likely to meet the requirements of this standard on infiltration alone. Their estimate of the average air tightness of the stock is approximately an ACH_{50} of 24. Those wishing to apply 62.2 to existing houses in the context of Home Energy Rating Systems or utility programs can make good use of the infiltration credit for measured air tightness to reduce or eliminate the requirements for additional whole-house mechanical ventilation.

2.4 Other Requirements

The standard is more than just whole-house rates. It also contains requirements to control local pollution either by direct source control or by local exhaust. It contains requirements to assure that any systems intended to meet the ventilation requirements can and do deliver ventilation without in themselves causing additional problems.

2.5 Local Exhaust:

Houses are designed to have certain activities in certain rooms. Kitchens, bathrooms, lavatories, laundries, utility rooms and toilets are all built to accommodate specific functions. These functions produce pollutants such as moisture, odors, volatile organic compounds, particles or combustion by-products. The purpose of local exhaust requirements is to control the concentration of these pollutants in the room on which they were emitted and to minimize the spread of the pollutants into other parts of the house. Local exhaust ventilation is source control for the sources of pollution that are expected in certain rooms. The standard requires mechanical exhaust in some of these rooms.

Unlike the whole-house rates, which are most effective when they are operated continuously, source control through exhaust is best operated when the source of pollution is active. The basic rates in the standard are for intermittently operated exhaust fans. For kitchens the basic rate is 100 cfm (50 l/s) and for bathrooms the rate is 50 cfm. (25 l/s) .

Continuous local exhaust is allowed as an alternative to give the designer the flexibility of making the local exhaust part of a larger ventilation system (e.g. a continuous, whole-house ventilation system). The rate in bathrooms is 20 cfm (10 l/s). Because of the concern about migration of pollutants out of the kitchen, continuous kitchen ventilation cannot be used unless the exhaust rate is at least five kitchen air changes per hour. For larger kitchens this value will be bigger than the 100 cfm (50 l/s) required for intermittent operation, but for small kitchens such as those found in many apartments, this requirement may allow central exhaust systems to be used.

62-2001 allowed operable windows as a substitute for exhaust ventilation requirement. 62.2 requires natural ventilation in all habitable spaces (that do not have local ventilation), but does not allow natural ventilation to meet the local ventilation requirement in bathrooms. This is because of the low pollutant removal efficiency of operable windows (e.g. a window could just as easily allow moisture to blow into the rest of the house as out of the bathroom).

Laundries can meet the requirement using their dryer vent; toilet compartments can meet the local exhaust requirement through a connected bathroom. There are no local exhaust requirements for other rooms having unvented combustion equipment, lavatories, garages, home offices or hobby or utility rooms.

2.6 Ventilation System Requirements

The ventilation system, whether it be natural or mechanical has to meet some basic requirements:

Capacity and Distribution. Because there will sometimes be activities which produce pollutants in excess of that handled by the basic ventilation rates, the standard requires that each room have either a window or meet the local exhaust requirements for bathrooms These kinds of activities might include cleaning, smoking, parties, painting, etc. The requirement would usually be met by the code-required amount of window area. There is no explicit requirement, however, for air distribution.

Flow Rating. To make sure that the fan actually delivers the amount of air intended, the standard requires either that the air flow rate be measured in the field or that certain prescriptive requirements be met. These prescriptive requirements deal with the size and length of ducting as well as the fan manufacture's ratings.

2.7 Source Control

While many of the potential sources of pollution are beyond the control of a standard such as 62.2, there are various measures that can reasonably be taken to reduce pollutant sources at the design stage and thus reduce the need for excessive ventilation. Indeed, for some sources, ventilation increases pollutant level. This section summarizes some of the source control measures in the standard.

Outdoor Air. Outdoor air can be a source of pollution. The ventilation rates in the standard assume that the outdoor air is relatively clean and able, therefore, to improve indoor air quality by diluting indoor pollutants. When outdoor air quality excursions are foreseeable (e.g. excessive ozone) the standard requires that the occupants be able to reduce whole-house ventilation rates. In humid climates the moisture that outdoor air can contain should be considered as a contaminant and suitable source control measurements should be undertaken to mitigate any undesirable impacts (e.g. mold).

Ventilation Inlets. Even if regional outdoor air is of good quality, pollution in the building's microclimate can be of poor quality. The standard requires that there be adequate separation between inlets and exhausts or other known sources of pollution.

Garages. Attached workspaces and garages can be a source of significant pollution. Carbon monoxide is of particular concern when combustion (e.g. from cars) is taking place. The standard requires than any air handling equipment placed in these spaces be sealed to prevent entrainment of these contaminants.

Clothes Dryers. 62.2 requires that clothes dryers be vented directly outdoors both to minimize moisture and laundry pollutions. Laundry rooms which are intended to have clothes dryers (i.e. with installed vents) are exempt from requirements for exhaust fans or windows.

2.8 Moisture Migration

If moisture is forced into building cavities or the building envelope and where it is able to condense, molds and other microbiological contamination can become a threat to indoor air quality and material serviceability. The standard restricts the use of some ventilation methods (at excessive rates) in some applications, (e.g. supply ventilation in very cold climates) that would contribute to this effect unless the building envelope has been designed to accept it. The primary purpose of 62.2 is to provide ventilation to dilute indoor contaminants. This can, if not handled properly, cause or exacerbate moisture problems. The system, the envelope and the climate must all be properly considered in the design in order to keep that from happening.

2.9 Combustion Appliances

Keeping combustion appliances from becoming indoor pollutant sources is a concern of the standard. Vented combustion appliances can become a problem if there is any significant spillage or backdrafting. 62.2 is not a standard about combustion safety, but indoor combustion sources can be a significant source of pollution and the requirements of 62.2 could have adverse impacts on those sources. The standard mostly considers the impact that envelope tightness and/or ventilation systems could have on the operation of a combustion appliance. Backdrafting is not always a ventilation issue. Excessive exhaust ventilation, however, can cause backdrafting.

To minimize the potential for backdrafting the standard forbids naturally aspirated combustion appliances in the conditioned if the total of the largest two uncompensated exhaust appliances exceed about 1 air change per hour of ventilation (not counting any summer cooling fans). Many new houses would be exempt from these considerations either because all their vented combustion appliances are outside the pressure boundary or are direct-vent or because their two biggest exhaust appliances fall below the limit.

Unvented combustion sources such as indoor barbeques, vent-free heaters, cigarettes, decorative gas appliances, or candles can be the cause of high-polluting events and are presumed to be under the control of the occupants. Occupants are presumed to know when such sources are important and to take appropriate action - such as opening windows - when necessary. Despite the fact that they are known sources of contaminants, unvented combustion space heaters are explicitly excluded in the scope of the standard.

3 Current Trends

Because of increasing concerns about comfort, IAQ and most importantly energy, the traditional dwelling is changing and new construction is substantially different from traditional construction. These changes impact the design and performance of new dwellings and also have represented opportunities for the ventilation industry to provide new products.

3.1 Air Tightness

Air tightness in new homes is substantially improved over the stock Sherman and Matson (2002) have documented this trend. Voluntary programs such as the Department of Energy's Building America program have air tightness specifications. The general trend in air tightening, however, is almost a by-product of the improved construction that comes from having additional insulation, sheer support, better windows, etc.

New US homes are not particularly tight compared with European levels, but there is a qualitative difference current new construction and the existing stock. Whereas the existing stock was sufficiently leaky to provide ventilation, new construction would be substantially under-ventilated most of the time from infiltration alone. This trend in air tightness requires consideration be given to meeting minimum ventilation standards through other means

3.2 Window Opening

The traditional assumption had been that people open their windows and use natural ventilation to supplement. While that assumption may once have been true it no longer appears to be true.

Price and Sherman (2006) have shown that occupants in relatively new homes do not use their windows to meet minimum ventilation requirements even in the mildest climates. cooling, but generally there are more reasons to keep windows closed than open.

Only about 20% of those surveyed operated their windows in a way that provided significant ventilation throughout the year. The survey found that occupants are concerned with noise, dirt, security, draught and privacy. These issues would tend to override window opening needs except for occasional needs to mitigate odors or provide ventilative cooling.

3.3 Codes, Standards and Programs

Standard 62.2-2007 is the current version of that standard. Since its passage many institutions have considered or are adopting it for their regulatory or voluntary programs. ASHRAE is, for example, actively pursuing adoption of the requirements of 62.2 into the model codes used in North America.

Several localities have adopted 62.2 are part of their regulation either state-wide or locally. Various states like Washington and Minnesota have ventilation codes already and are considering adaptations for 62.2. States in the Northeast of the US such as Maine are adopting 62.2, but the biggest impact will be felt from California. The State of California has adopted 62.2 as part of the energy code and new homes built in 2009 and beyond must have mechanical ventilation systems.

Voluntary programs also use 62.2 either as a requirement or a guideline. Department of Energy's Building America program and Weatherization program are all sensitive to the requirements for minimum ventilation from the ASHRAE Standard. The clearest and most wide-spread programmatic use of 62.2 in the is category is the Indoor Air Package http://www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_iap of the US Environmental Protection Agency.

A growing sustainability movement spearheaded by the US Green Building Council has led to the LEED rating systems. The LEED rating for homes, http://www.usgbc.org/DisplayPage.aspx?CMSPageID=147, requires that Standard 62.2 be met and encourages users to go beyond minimum requirements. Similarly the draft ASHRAE Standard for non-residential sustainability (189P) will require that Standard 62.1-2007 be met.

The trend for use of 62.2 and the desire to meet minimum ventilation in homes is increasing. This will undoubtedly greatly increase over the next several years.

3.4 Ventilation Systems

Residential ventilation systems have only a small penetration but are expected to increase substantially for the reasons indicated above. Manufacturers are selling products specifically tailored to meet 62.2. All the major manufacturers list their products through the Home Ventilating Institute http://www.hvi.org which provides information and guidance to users, consumers, installers, designers, etc.

There are three major types of equipment being used for compliance: supply, exhaust and balanced.

While fully ducted supply systems can be used, they are rarely done in the US. The most common supply systems are ones linked to the very common forced air systems in US houses. That is, a duct is typically run to the return plenum of the air handling system and this brings in outdoor air when the central system operates and distributes it to the dwelling. Exhaust is passive. Suitable controls are installed to make sure that there is not too much or too little air. In energy efficient homes where the air handling system may be too small, this system may be combined with an exhaust system.

The most common system used is a simple continuous exhaust system. Typically a properly sized exhaust fan will run continuously in a master bathroom. In some installations there may be a central fan with multiple pick-ups or several fans may be connected logically together. Because US houses are typically not very tight, the supply air enters passively, that is no special inlets are installed, thus making this system relatively inexpensive.

In more severe climates balanced systems with heat recovery ventilation (HRV) or energy recovery ventilation (ERV) may be installed. The most typical installation is in a new energy efficient home and integrated into the air handling system to provide distribution. Stand alone units (e.g. through the wall) may also be used.

The systems above are discussed only briefly. Russell et al (2005) have done an extensive review of residential ventilation technologies for the US situation.

3.5 Changes in Standards

ASHRAE Standard 62.2 is always under development. There are several key issues currently being discussed in the committee. Any of these changes could lead to modification in the version of the standard scheduled to be released in 2010.

One key issue is the issue of rates. Currently 62.2's ventilation rate is substantially below national standards in other countries. There are those who seek to raise it based on contaminant measurements. There are those that seek to lower it because of concerns in hot, humid climates. There are those who seek to change the role that air leakage plays in calculating the rates. All these issues are currently in discussions.

Another key issue is the efficacy of different system types with particular emphasis on distribution effects. That is, should system that actively distribute air to each zone be treated as having a different efficiency as those that do not. Should systems that exhaust air from a small number of points be treated differently than those that do not. Because of the potential to integrate ventilation systems with the air handling systems of US homes, this issue can in theory make a significant difference. Research has been underway to determine what if any "credit" should be given to different systems.

ASHRAE Standard 62.2 does not specifically address energy or humidity control issues. The committee is currently discussing how best to address those important concerns.

Unlike the 62.2 (the residential standard), 62.1 (the non-residential standard) is not changing so dynamically. There are issues related to specific occupancies and to the general topic of smoking, but the standard itself is relatively stable.

4 Current Activities

A workshop on Barriers to the Implementation of Energy Efficient Residential Ventilation (Sherman 2008) was recently held in Washington DC, and included researchers, builders, policy makers, and industry representatives.
http://epb.lbl.gov/publications/lbnl-41E.pdf
contains the full summary but the conclusions from that workshop are as follows:

- Builders need simple, preferably single, solutions that are easily implementable
- More research is needed on the ventilation science, looking at minimum requirements, contaminants of concern (including humidity), regional issues and exposure. Much of the data justifying higher ventilation rates have come from Scandinavian countries. This may not be applicable to hot-humid climates where high vent rates can cause high humidities and dust mites and mold and other IAQ problems. What is the right vent rate that optimizes energy usage, eliminates moisture problems and keeps VOCs to acceptable levels?
- 3rd party labels or ratings should be developed/expanded to facilitate evaluation and implementation of energy efficient strategies
- Risk assessment and IAQ analyses should be done evaluating moisture as a pollutant. This could be extended to other outdoor air contaminants as well.
- To address barriers and other key issues mentioned discussed in the workshop, several areas of work relating to ASHRAE Standard 62.2 (or similar codes and standards) were identified as needing further development:
  - Trade-offs between minimum ventilation rate and air distribution systems
  - Role of infiltration
  - Minimum rates
  - Role of air cleaning/filtration
  - Material emission reduction (e.g. low emission furnishings)
  - Regional requirements
  - Alternative compliance mechanisms including "the IAQ method" of 62.1
  - Differences between new and existing homes
- A significant recommendation of the group was the need for a study to determine the relationship between contaminant levels, ventilation rates and house properties. Such a study would be large in scope and likely involve several institutions so that energy, indoor air quality, cost and sustainability concerns could be properly addressed.
- Another recommendation was to look at moisture as a special kind of contaminant. Moisture is special because a) for hot humid climates is both indoor and outdoor, b) it can be a comfort problem when too high or too low, c) it is not itself a contaminant but can enable contamination when it allows materials to become too damp, d) it has a special kind of "air cleaning" in the form of AC operation and/or dehumidification.

The workshop provided an excellent venue to exchange information regarding the implementation of energy efficient residential ventilation. The net outcome was felt to be positive and worth repeating. It was generally felt that any future such workshop would benefit from more input from the indoor air quality community.

5 Conclusions

The residential ventilation market is changing rapidly in the United States. Dwellings are going from having no designed core requirements. That standard has only been active for about 4 years and so has not yet been fully adopted. The standard itself is evolving to meet the societal needs.

The market for residential ventilation products is adapting to meet the evolving needs of the market. New products are coming out frequently and presumably more are in development. The only product specifications currently required involve airflow and (in some cases) acoustic performance. The market will take many years to mature.

By contrast the market for non-residential ventilation is reasonably mature. There are trends specific to hot, humid climates or special occupancies. No radical changes, however, are expected in standards or technologies, in genera

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The Air Infiltration and Ventilation Centre provides technical support in air infiltration and ventilation research and application. The aim is to promote the understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in the design of new buildings and the improvement of the existing building stock.