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Report on Applicability of Residential Ventilation Standards in California

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Disclaimer

Preliminary report on applicability of residential ventilation standards in California

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EXECUTIVE SUMMARY

The California Energy Commission is considering updating its requirements for residential ventilation in the next round of its energy code, known as "Title 24." This report contains recommendations for potential changes to the code. These recommendations must be further developed into specific wording before they can be formally considered.

Residential ventilation standards always address local and whole-house ventilation rates and some basic source control requirements, but there are many interactions with building systems that must also be considered. McKone and Sherman [8] laid out a set of additional issues that should be addressed before any specific changes to the code should be made. Those key issues included the following:

- Adventitious Air Flow
- Air Distribution
- Filtration and Air Cleaning
- Occupant Acceptability and Control
- Outdoor Air
- Peak Demand
- Unusual Sources and High-Polluting Events
- Window Operation

McWilliams and Sherman [9] reviewed the literature on residential ventilation and in particular these key issues. They also reviewed codes, standards and guidelines relevant to residential ventilation. That literature serves as the technical basis for this report.

In this report we applied the information in the literature to key issues above and to the specific concerns of California in order to develop a series of recommendations. Through this process we developed the following recommendations:

IAQ-Related Requirements

- ASHRAE Standard 62.2-2004 [1] should be adopted by reference except where overridden by any of the other recommendations in this report. (These requirements are summarized in the Overview of ASHRAE Standard 62.2 section.)

- Air leakage and window operation shall be deemed to provide the default infiltration of 62.2 and also meet the window opening requirements of the standard, but may not be used to otherwise meet the whole-building ventilation or local exhaust provisions of the standard. (For details see the sections on Use of Windows and Infiltration and Its Impact on Sizing).

- The mechanical ventilation rates of Section 4.1 of the standard shall be increased by 25 cfm. (For details see the section on Intermittent Ventilation and Its Impact on Sizing which indicates the benefits of this strategy on Peak Demand and when there is poor Outdoor Air quality.)

- When ducts pass through buffer zones (e.g. a garage, attic or crawlspace) the total leakage shall be limited to 5% of the air handler flow. (For details see the section on Duct Leakage.)

Energy-Related Requirements

- SLA=4 shall be the default value for use in energy calculations, but measured air tightness may be used if known. Current restrictions on tightness below SLA=1.5 shall be removed. (For details see the sections on Infiltration and Its Impact on Sizing and Combustion)

- Designs with suitable control systems (e.g. a programmable timer) may take energy credit for shutting off the ventilation system up to 4 hours per day. (For details see the section on Intermittent Ventilation and Its Impact on Sizing relative to its impact on Peak Demand and Occupant Acceptability and Control.)

R&D Needs

- A broad based field study to determine envelope and duct air leakage of current new construction and how commonly used mechanical ventilation systems perform with such leakage. (Discussed in the sections on Infiltration and Its Impact on Sizing, and Duct Leakage)

- A study to determine how contaminants are transported from garages and other buffer zones and to determine if Carbon Monoxide alarms are necessary.

(Discussed in the section on Duct Leakage and Unusual Sources and High-Polluting Events.)

- Evaluation of the need to have air distribution systems in California homes in order to provide acceptable indoor air quality. (Discussed in the section on Air Distribution and Filtration and Air Cleaning.)

- Development and testing that would allow additional ventilation credit to be given to economizers, direct evaporative coolers and other systems that provide ventilative cooling. (Discussed in the section on Intermittent Ventilation and Its Impact on Sizing and Window Operation.)

The rationale of and background for these recommendations is discussed further in the full text of this report.

In completing this work, there were issues that were investigated, but for which existing requirements in either Title 24 or ASHRAE 62.2 were found adequate. No additional changes were needed relating to any of the following:

- High Polluting Events: The exclusions of 62.2 point out that these requirements are not intended to protect against all hazards and that the occupants have the responsibility to protect themselves when engaging in high-pullulating activities

- Particle Filtration: While enhanced particle filtration would of value to some, the basic (MERV 6) requirement is sufficient for a minimum standard.

- Indoor Air Cleaning: The ability to clean air of contaminants in order to lower minimum ventilation rates requires further research.

- Outdoor Air Cleaning: Although treating outdoor air would benefit those in areas with poor local or regional outdoor air quality, it is beyond the scope of an energy code.

This report contains recommendations for potential changes to the code. These recommendations must be evaluated and then further developed into specific wording before they can be formally considered.

Keywords: Ventilation, Air Exchange Rate, Indoor Air Quality, Ventilation Standards

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NOMENCLATURE

ALA	American Lung Association
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
EEBA	Energy and Environmental Building Association
EPA	Environmental Protection Agency
EPA IAQ	Energy Protection Agency Indoor Air Quality Specifications
HDD	Heating Degree Days
HVAC	heating, ventilating, and air conditioning
IRC	International Residential Code
IECC	International Energy Efficiency Code
MERV	Minimum Efficiency Reporting Value
NL	Normalized Leakage
SLA	Specific Leakage Area
SVOC	semi-volatile organic compound
Title 24	2005 Building Energy Efficiency Standards for Residential and Non-Residential buildings
VOC	volatile organic compound

INTRODUCTION

Because of the effects it has on health, comfort, and serviceability, indoor air quality in our homes is becoming of increasing concern to many people. According to the American Lung Association a number of factors within our *homes* have been increasingly recognized as threats to our respiratory health. The Environmental Protection Agency lists poor indoor air quality as the fourth largest environmental threat to our country. Asthma is the leading serious chronic illness of children in the U.S. Construction defect litigation and damage are on the increase in new houses and some of this increase is related to indoor air quality problems such as moisture. Residential ventilation can address many of these indoor air quality problems.

Traditionally residential ventilation was not a major concern because policy makers believed that between operable windows and envelope leakage, people were getting enough outdoor air. In the three decades since the first oil shock, houses have become much more energy efficient. At the same time, the types of materials used in furniture, appliances, and building materials in houses have changed. People have also become more environmentally conscious not only about the resources they were consuming but about the environment in which they lived.

All of these factors have contributed to an increasing level of public concern about residential indoor air quality and ventilation. Where once there was little concern about the residential indoor environment, there is now a desire to define levels of acceptability and performance. Because states and other jurisdictions have a responsibility to protect the health and safety of their populace, more and more of them are considering changes to their codes and regulations.

Ventilation can be an energy consuming activity that provides acceptable indoor air quality. There is no fixed "right" amount of ventilation in the same sense that there is no fixed "right" size of furnace or air conditioner for all houses and climates. To find the minimum requirements for thermal conditioning, one must determine the thermal load and the desired thermal conditions to be met. Similarly, to determine how much ventilation is necessary, one must look at the sources and emissions of concern to indoor air quality (e.g. moisture levels and pollutant loads) and the desired level of indoor air quality. Based on these two factors, the choice of a ventilation level must be made by trading off various costs (e.g., energy costs, first cost, risks) with the benefits associated with the building service (e.g., health and comfort).

The problems of determining appropriate minimum ventilation rates are much more complex than those confronted in efforts such as determining thermal insulation levels. Thermal loads are well studied and can be robustly estimated from internal gains and weather conditions. In contrast, pollutant sources tend to be highly variable among different households and are quite dynamic. Thermal comfort can be predicted quite reliably from just a few environmental parameters (e.g., temperature, air speed, humidity.)

whereas acceptable indoor air quality depends on a number of environmental and exposure parameters, many without established value ranges or acceptability criteria.

Because of the complexities of IAQ, ventilation standards and guidelines have followed a much more subjective route than thermal standards and guidelines. Extant ventilation requirements are based on evaluations of what has or has not worked and thus incorporate the experience of experts in the field.

When determining regulatory requirements in a particular area, the authority having jurisdiction must make judgments even if there is not consensus on some items, but it should always do so based on the best available information. The purpose of this report is to bring forth the best available information on residential ventilation requirements and to see how they would apply in a regulatory environment, with particular emphasis on California.

CALIFORNIA ENERGY AND VENTILATION CONCERNS

California's Energy Code, known as Title 24 (Part 6), focuses on cost-effective ways to minimize the energy-related impacts of providing building services such as thermal conditioning, lighting and water heating. Ventilation is an energy consuming activity and considered an energy end-use. Providing acceptable indoor air quality is the building service provided by ventilation.

The purpose of ventilation is to provide acceptable indoor air quality and to enhance durability of systems and materials. This report is part of a project to provide input to the California Energy Commission and its efforts to update the State's energy code: 2005 Building Energy Efficiency Standards for Residential and Non-Residential buildings (referred to as Title 24). We examine the relationship of ventilation to health by using ASHRAE/ANSI 62.2-2004 [1] and examining how this differs from current Title 24 requirements and other relevant codes. A key factor for this project is the effect that any changes to the ventilation requirements in Title 24 have on energy use algorithms and compliance tools already in use by the California building industry. Addressing this issue requires interactions with software developers who provide compliance tools for the California Building Energy Efficiency Standards.

The building ventilation requirements in the current Title 24 standard are primarily engineering based and, as a result, technical feasibility is likely to remain a key driver for these standards. Therefore this project will focus on existing ventilation strategies and technologies.

The engineering issues related to providing acceptable indoor air quality without large energy penalties that will be examined in this project are:

- The usability of occupant control, particularly window opening
- Distribution and mixing of fresh air throughout a house

- The role of unusual sources and/or source control
- The role of air cleaning and particle filtration
- Effects of poor outdoor air quality (e.g., particulates near busy roads or in rural communities)

The current version of Title 24 has ventilation requirements that go beyond what most states require. Other states including Florida, Minnesota and Washington have also adopted minimum ventilation requirements. Other countries, such as Canada, France, Sweden, the United Kingdom and Denmark have specific ventilation requirements. In order to evaluate changes to Title 24, it is important to look at what other codes have specified, as well as what are considered best professional practice (ASHRAE 62.2).

The objective of this report is to review and analyze the current version of appropriate codes, ASHRAE standard 62.2-2004 and similar documents as input to the development of an optimal set of requirements for use in the 2008 California Building Energy Efficiency Standards.

APPROACH

In this report we examine relevant codes and the most authoritative standards and guidelines to determine what aspects ought to be considered in developing a modern set of residential ventilation regulations. As a prelude to this report, McWilliams and Sherman [9] have done an extensive literature review of residential ventilation standards and related issues, and will serve as the technical reference for many of the issues discussed below.

The International Residential Code, 2003 [6] is the model code that many jurisdictions use and that represents a valid point of comparison. Current California requirements (in Title 24) exceed those in the IRC. The most authoritative document, however, is ANSI/ASHRAE Standard 62.2-2004 [1], which is the only consensus standard on the topic of residential ventilation. What makes it particularly relevant is that ASHRAE intends this standard to be used in regulatory documents and has focused it on minimum requirements just as health and safety regulations focus on the minimum levels required to achieve health and safety in a building.

Although ASHRAE Standard 62.2 may be the standard of care for the HVAC profession, it is not necessarily right for all jurisdictions. A given region may focus on different issues than did 62.2 or may have unique or special circumstances not adequately addressed. A given jurisdiction may decide it desires a different level of protection than that offered by the standard. Thus, while 62.2 may be a touchstone for developing regulatory options it is not necessarily the final answer.

In the following sections we will investigate the issues that must be addressed in developing residential ventilation code requirements by looking at what extant codes and standards are or are not currently doing and comparing it to existing research. We will both look at the requirements of 62.2 and examine issues that are addressed by 62.2.

The required minimum ventilation rate is both the first and last thing one should think about when setting minimum requirements. It is the first thing because that is what people normally think a ventilation standard should be all about. But, ventilation is not an end in itself; rather it is a means to provide acceptable indoor air quality. As such, before one can determine the correct ventilation rate one needs to have considered the sources and contaminants of concern and the acceptable exposure to those sources for the population of interest.

The state of knowledge today does not allow an unambiguous determination of either the full impact of all sources or the susceptibility of occupants, and so it is impossible to scientifically define proper ventilation rates. Nevertheless, we know that there are sources and we know that under-ventilated homes have caused and can cause problems; so it is incumbent upon those charged with protecting the public welfare to use the best information available.

In the sections below, we provide a brief overview of some of the key reference documents. Major features are included but some individual aspects will not be listed.

Overview of ASHRAE Standard 62.2

In developing this standard ASHRAE recognized that there were many different kinds of houses, many different climates, and many different construction methods. 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 main primary sets of 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 is intended to dilute the unavoidable contaminant emissions from people, from materials and from background processes. Local exhaust is intended to remove contaminants from specific rooms in which sources are expected to be produced by design (primarily kitchens and bathrooms). 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 main 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.

ASHRAE Standard 62.2 [1] has requirements for whole-house ventilation, local exhaust ventilation, source control and system requirements. In brief they can be summarized as follows:

The whole-house ventilation rate is 3 cfm/100 sq. ft. plus 7.5 cfm/person. It is assumed that 2 cfm/100 sq. ft. can be supplied through infiltration. For most of the country the difference must be supplied by mechanical ventilation, but for most of California operable windows may be used.

Local mechanical exhaust is required in kitchens and bathrooms. Kitchens must have the capacity to exhaust at least 100 cfm through a range hood or provide 5 kitchen air changes per hour. Bathrooms must have the capacity to exhaust 50 cfm or have 20 cfm of exhaust continuously.

For source control: dryers must be vented to outdoors; naturally aspirated combustion appliances may not be inside under some conditions; filtration is required on air handling systems; leaky ductwork is not permitted in garages.

Air moving equipment must be rated and certified to meet its intended use and meet certain noise and airflow specifications.

Overview of Ventilation Requirement in the IRC/IECC

The International Residential Code (IRC) and the International Energy Conservation Code (IECC) are related in the same way as many of the codes in that ventilation is regulated by the building code, and addressed only briefly in the energy code. The IECC only mentions ventilation in one instance where it states that a ventilation system must have a shutoff control to reduce ventilation when it is not required, and that all air intakes and exhausts must be equipped with dampers.

Compliance with the energy code can be met by modeling the building energy use or through meeting a set of prescriptive regulations. When energy modeling is used, the default value for building shell air-tightness is defined in the IECC by a normalized leakage of 0.57, the same value that is used as a default in RESNET energy modeling. (For single-story houses a normalized leakage of 0.57 is equivalent to a Specific Leakage Area of 5.7.)

The IRC has similar requirements to ASHRAE Standard 62.2. The requirement is phrased somewhat differently, with openable windows being the primary way of supplying ventilation. The IRC requires that ventilation be provided by a minimum openable area in each room of no less than 4% of the floor area, or a mechanical ventilation system that can supply 0.35 air changes per hour to the space. The ventilation requirement can alternatively be met by a mechanical whole house ventilation system that provides 15 cfm/person where the number of people equals the number of bedrooms plus one.

As in ASHRAE Standard 62.2, local exhaust is required in the bathroom and kitchen. Kitchen fans must have the capacity to exhaust 100 cfm, or they must exhaust 25 cfm continuously. Bathrooms must have the capacity to exhaust 50 cfm or have 20 cfm of exhaust continuously.

Source control is also regulated, although less stringently than in the ASHRAE standard. Dryers must be ducted to outside, and combustion appliances must have adequate combustion air. If a combustion appliance takes air from inside the building then the room containing the appliance must be of a certain volume: 50 cu ft per 1000 BTUH input of the appliance. If the envelope is "unusually tight" then combustion air must be obtained from outside. "Unusually tight" construction is defined only by the fact that "infiltration air is not adequate for combustion" under the previously defined volume required for a particular sized combustion appliance.

Overview of Residential Ventilation Requirements in Title 24

Mechanical ventilation is required by Title 24 only if the building has a Specific Leakage Area (SLA) less than 3.0, which corresponds (in typical California climates) to approximately 0.26 air changes per hour that would be provided by infiltration in such a house. Of course, the actual ventilation provided by infiltration would vary with seasonal temperature differences and local wind conditions. When mechanical ventilation is specified, Title 24 requires that a whole house ventilation system be installed with the capacity to provide 0.047 cfm/square foot.

If the SLA is less than 1.5, Title 24 states that supply ventilation must be provided with enough capacity to maintain a house pressure greater than -5 Pascals relative to outside when the other exhaust fans are running. This is to avoid potential backdraft problems with combustion appliances, particularly fireplaces and also to provide some protection in case of future installation of combustion appliances. The standard also requires an air inlet and glass doors for fireplaces, wood, pellet and gas stoves.

When performing energy calculations, Title 24 also assumes that windows will be opened by the occupants whenever the ventilation rate drops below 0.35 air changes per hour. This ventilation rate trigger can be from infiltration or mechanical ventilation.

Ventilation appears in Title 24 not only as a minimum ventilation requirement but also in the form of ventilative cooling. The latter is in the form of natural ventilation, whereby Title 24 assumes that under certain circumstances occupants will open their windows to provide free cooling. This ventilative cooling servers both purposes of reducing air conditioning and, incidentally, of exhausting indoor contaminants.

Overview of Residential Ventilation HERS/RESNET

The RESNET modeling does not assume mechanical ventilation. It models mechanical ventilation in the reference house only if it is specified in the rated house.

The reference house has an assumed normalized leakage (NL) of 0.57. A weather factor (w, specified in ASHRAE Standard 136) is used to translate the leakage area into an air change rate, which is used to calculate an infiltrative load. This is added to the other loads in energy use calculations.

Natural ventilation is assumed in both the reference and the rated house when it would reduce the annual energy needed for cooling.

Verification of building shell air tightness and duct tightness is required by diagnostic test in accordance with nationally accepted pressurization test standards or observation. When observation is used, the minimum normalized leakage (NL) is 0.67 for the building shell, and a range of duct efficiencies may be specified, from 0.70 for ducts located in unconditioned space with visible air leakage pathways to 0.85 for ducts located in conditioned space without visible air leakage pathways.

Overview of EPA IAQ Specifications

EPA's "Indoor Air Package" is a voluntary approach that adds an indoor air quality (IAQ) label to a house that is already *Energy Star* qualified. It requires that the ventilation standards of ASHRAE Standard 62.2 be met, and goes quite a bit further in a variety of source control measures:

The "Indoor Air Package" includes extensive moisture control provisions, which vary by foundation type, to keep rain and ground moisture out of the living space. In addition, outside air with a relative humidity of greater than 60% cannot be supplied in a "warm humid" climate and outside air must be tempered to 60° F in "cold" climates. The label also contains ground-level provisions to minimize radon entry. The standard requires low-emitting materials and practices to minimize volatile organic compounds (VOC) commonly present in new construction materials (carpets, paint, cabinetry.). Isolation of the garage and combustion equipment is required to minimize indoor exposure to chemicals commonly stored in the garage and products of combustion. The installation of a CO alarm is also required for additional safety. The garage must also have 100 cfm of continuous exhaust.

Enhanced particle filtration is provided by the requirement of a MERV 8 filter installed with no filter bypass. A neoprene gasket must be installed on one side of the filter rack to bring the filter into contact with the rack.

Improved duct design and air handler placement are required to reduce leakage of conditioned air and entrainment of polluted air. The maximum allowable HVAC duct leakage is 3 cfm/100sq ft of floor area at 25 Pascals. HVAC ducts are not allowed in the garage; building cavity ducts are not allowed; and a transfer grille is required to allow air movement in and out of each room when the doors are closed except in bathrooms, kitchens and laundry rooms.

Air-sealing is required between the attic and conditioned space, including a provision that recessed light fixtures must be air tight, complying with the Washington State Standard.

This one of the few standards that contains commissioning specifications. If requires a final inspection of the ductwork to ensure that it is free of debris, that there are no disconnects and that air is flowing well. The building must be ventilated at the highest rate possible between the time the building is finished and occupancy. Refrigerant charge must be verified by a certified testing method, and all houses in high radon areas must be supplied with a radon test kit. A homeowner's manual must also be provided with documentation for special equipment, maintenance instructions, and HVAC load calculations.

KEY ISSUES

In scoping the R&D necessary to develop new requirements for residential ventilation in California, McKone and Sherman [8] have identified several key issues that require further consideration.

Adventitious Air Flow

Generally a ventilation standard determines how much whole-house ventilation is necessary to meet health and comfort, but it may not tell us where that ventilation comes from. Ventilation can come from mechanical and passive systems or envelope airflow either intentionally or unintentionally. *Adventitious Air Flow* refers to all forms of unintentional or incidental airflow that can contribute to the total ventilation.

In order to size any designed ventilation system, it is important to know the amount of adventitious airflow that would occur without a designed system. In principle some of this can be measured, but in practice a ventilation requirement usually makes some reasonable assumption about the relative magnitude of this ventilation.

Infiltration

Infiltration is weather-induced (i.e. wind and stack induced) airflow through leaks and cracks in the building envelope. The building stock has traditionally been relatively leaky such that building scientists estimate that the average house has over one air change per hour due to infiltration. This high value satisfies the ventilation requirements of virtually all ventilation standards and guidelines, so most existing houses may not need any additional ventilation system.

New construction on the other hand is quite different. New construction typically is a factor of 3-4 tighter than the existing stock. This impact has something to do with aging, of course, but may also be due to the fact that insulation, caulking and sheathing levels have increased. In any case, at this tightness level many houses are unlikely to receive sufficient ventilation from infiltration. To save energy, however, it is important to determine how much "credit" to give for infiltration. This calculation can avoid over sizing the designed ventilation system for overall dilution. Conversely, realistically large amounts of infiltration credit could effectively cause poor indoor air quality.

While measured data have been collected and analyzed for the existing housing stock and new construction in the US as a whole, there has been little specific study for California construction in several years. Data from the complimentary characterization project will help in this regard. Additional analyses of existing datasets should provide a reasonable estimate of what is happening in current California construction until such time as a California-specific study is undertaken.

The amount of ventilation measurement data available will likely always be limited due to the expense of collecting it. Furthermore, datasets of convenience often have hidden biases because they are collected for purposes other than random infiltration sampling. Another way of estimating infiltration credit is to examine default values that may be included in codes and standards.

Currently, California Title 24 provides several air tightness values using the metric of Specific Leakage. The default value is 4.9, which is used in calculating infiltration energy load in the absence of a blower door test. A low leakage design house is defined as one with SLA less than 3.0. Such a house must have a mechanical ventilation system with a minimum capacity of 0.047 cfm per square foot of conditioned space. An unusually tight house is one with Specific Leakage area less than 1.5, and this type of house must have continuous mechanical supply ventilation to maintain the residence at a pressure of greater than -5 Pa relative to outside. These values were thought to be appropriate in 1998.

ASHRAE Standard 62.2 has a default infiltration value of 0.02 cfm per square foot. Although this number is expressed in terms different from Title 24, it is generally more conservative (i.e. tighter) than what is specified in Title 24. Both documents allow a measured value to be used when it is available in place of default values. This diagnostic approach is an important feature that should be preserved in any new code.

The ASHRAE default is structured as airflow and therefore cannot be simply converted to an air tightness level such as SLA. If one needed it for some reason, the equivalent SLA would vary by weather conditions throughout the year. In mild periods quite large opening (e.g. windows) might be required to actually provide enough area to meet the ASHRAE default limit. Even if a single SLA for the year were used to provide the same average default, it would vary by climate. The SLA limits in Title 24 are principally about energy requirements not ventilation requirements.

Most current codes and standards do not provide explicit infiltration defaults. Some standards focus on mechanical ventilation systems and how they should be sized. The bodies that created these standards may have assumed some implicit values for infiltration, but, based on what is provided in the standards, it is not clear what value was assumed.

There are, however, some data sources of relevance for California. Wilcox (1990) studied California houses of the 1980s and showed them to have an SLA in the range typically of 4-5—which was the source of the default in earlier versions of Title 24. Sherman and Matson [14] demonstrated that nationally there is a trend to much tighter construction in new construction—which was considered in the development of the default level in Standard 62.2. Wilson, Bell, Hosler and Weker [16] have done a quite recent study in Southern California that shows the existing houses to be roughly as tight as Wilcox's [15] new houses of the 1980s and that new houses are about twice as tight. This data also suggests that the infiltration rate of these houses is similar to that assumed as the default in 62.2.

Use of modeling tools such as the LBNL infiltration model or ASHRAE Handbook of Fundaments must be used to incorporate infiltration with designed ventilation systems in any simulation or evaluation.

Duct leakage

Research has demonstrated that duct leakage in California can easily triple the natural infiltration rate. In fact it is quite likely that in the new houses built in the last 15 years, duct leakage was the dominant source of ventilation because of leaky ducts and relatively tight building envelopes.

While duct leakage can, in principle, provide an important source of ventilation, it is highly energy inefficient and it is always better from a cost standpoint to reduce it. For these reasons, no ventilation code or standard we could find allows explicit credit for airflows induced by duct leakage. However, duct leakage (when the system is off) may be counted as part of the air leakage of the envelope.

It is important to recognize that duct leakage in return ducts could serve to reduce indoor air quality. When return ducts or air handlers are in attics, crawlspaces or garages, they can be a source of contaminants rather than providing effective dilution ventilation. These types of buffer zones can often have chemical or biological contaminants that should not be transferred into areas occupied by residents. Also important, supply leakage can depressurize the living space, pulling those pollutants through leakage paths from the buffer zones.

A relatively new test method exists, ASTM E1554-03,[1] [2] to separately determine the supply and return leakage to outside and the house envelope leakage. This measurement technique, however, is not yet very common in California, so from a practical standpoint it may be necessary to recast requirements in terms of the total duct leakage measurement that has been in use in previous versions of Title 24.

Reducing duct leakage for ducts outside the conditioned space is thus a source reduction action. Reducing duct leakage is also a quite significant energy savings measure, which suggests that reducing duct leakage should have a high priority.

Flues, stacks, vents, & chimneys

There are a variety of intentional penetrations in a typical house that are used to exhaust contaminants of one form or another. When these components are in operation, they provide desirable source control measures, but when they are not in operation they can provide an unintended source of extra ventilation. Combustion appliances and local ventilation systems are the most common reasons for such penetrations.

This extra ventilation is not normally accounted for in the existing codes and standards. At best this type of ventilation is implicitly lumped into the infiltration number. Because most of these penetrations are relatively large openings and in vertical shafts, their ventilation contribution is not accounted for adequately in existing codes and standards. However,

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[1] ASTM Standard E1554-03 defines a duct air tightness test method that incidentally provides envelope air leakage.

there are modeling tools and existing studies [17, 18] that examine the ventilation and energy impact of these penetrations.

Improved modeling of such shafts should be given consideration in the future to better account for wind, stack and tightness interactions. This is important not only to better understand their performance as part of contaminant exhaust systems, but also because passive, whole-house ventilation systems have shown promise in the context of sustainability.

It must be noted that many of the penetrations that provide inadvertent ventilation can also become pollutant sources by processes such as back drafting, if the system is not configured properly. This effect must be considered as part of source control evaluation.

Many codes require makeup air to reduce negative pressure caused by exhaust fans or testing for spillage. The American Lung Association (ALA) Health house simply states to "reduce the depressurization of the building." ASHRAE Standard 62.2 states that the net flow, at full capacity, of the largest two exhaust fans cannot be greater than 15 cfm/100 ft^2 of occupiable space. In most houses the two largest exhaust devices are likely to be the clothes dryer and the kitchen exhaust. Minimally compliant houses above 2000 sq. ft. would not likely have to worry about this requirement, but small houses or houses with large kitchen exhaust may.

If this condition is not met, compensating airflow must be provided, or maximum flow reduced. Compensating supply fans are often integral to commercial kitchen hoods, but are not typically found in residential products. A separate supply fan could, however, be interlocked to the kitchen exhaust—thereby achieving the same objective. Standard 62.2-2003 also allowed the option of having atmospherically vented combustion appliances inside the conditioned space tested for spillage. The current version (62.2-2004), however, removed that compliance path.

Title 24 requires that glass doors and an air inlet be provided for each fireplace and each wood, pellet or gas stove. The Minnesota code [10] limits "excessive depressurization" except when all appliances are sealed combustion and the three biggest exhaust fans have a combined flow less than 425 cfm. There are four prescriptive paths or a performance test to show compliance. The Canadian code [4, 11] requires make up air for exhaust flow greater than 150 cfm if there is a chimney vented oil or gas appliance in the house. The Energy Protection Agency Indoor Air Quality Specifications (EPA IAQ) [5] standard goes even farther to require a direct vent or power vented water heater. It also requires a direct vent furnace if the house is located in a climate with more than 4000 Heating Degree Days (HDD).

Air Distribution

Almost all ventilation standards and guidelines have provisions for local ventilation to remove contaminants from rooms known to have specific sources. In houses, kitchen and bath fans are often required for source control. However, many standards including ASHRAE or Title 24 assume that contaminants and ventilation air are evenly distributed throughout the house. As a result, they treat the house as a single zone and thus only set single-zone ventilation requirements. To the extent that there is an air distribution system that keeps the air mixed, this is appropriate.

On the other hand, some standards, such as those in Europe, typically require minimum ventilation rates for each habitable room. Belgium and Switzerland require ventilation in bedrooms, Denmark, Germany and Italy require ventilation in living rooms, and Finland, Sweden, the Netherlands and the UK require ventilation in both bedrooms and living rooms. Canada requires that fresh air be distributed throughout the dwelling[2]. This divergence is undoubtedly due to the difference in the housing stock and air distribution systems between the two cultures. California has typically had leaky houses with forced air distribution systems, while Europeans have tended towards tighter houses with hydronic distribution systems.

As space energy demands in houses continue to decrease due to improved thermal envelopes, the circulation of ventilation air in a forced-air system will also decrease. Energy losses from thermal distribution systems can be significantly reduced by the use of hydronic systems. It is possible that the use of these systems will increase over the next few years.

An important aspect of air distribution is fully determining the air flow pathways. Supplying air to a room, for example, can result in that room becoming over-pressurized and other parts of the house being under-pressurized and net flow rates reduced. These pressures can exacerbate infiltration losses or lead to poor operation of vents or chimneys. For these reasons some specifications call for return pathways using transfer grilles or "jump ducts".

We believe that it is important to define what constitutes a minimally-acceptable air distribution system. This information will assure that indoor air quality will not be compromised as trends toward alternate heating (and cooling) systems develop.

Filtration and Air Cleaning

Whole-house ventilation reduces exposures to dispersed indoor contaminants by diluting them with outdoor air. Another method to reduce exposure is to extract contaminants from the air with filtration or air cleaning. Doing so can, in principle, reduce the requirements for dilution ventilation and thereby save energy and operating costs. When contaminants of concern can be identified it is often vastly more efficient to remove them than to dilute them.

Since such strategies are pollutant specific, it is important to understand the contaminants of concern before attempting to remove them. Furthermore, for such strategies to succeed

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[2] Residential Mechanical Ventilation Systems, CAN/CSA-F326, requires 10 cfm (5 l/s) for each room except the master bedroom and basement which require 20 cfm (10 l/s), however the National Building Code only specifies that the fresh air be distributed. Compliance in Canada can be met by satisfying either of these codes.

often requires more care and/or maintenance and the cost of these actions must be included in trade-off assessments.

An air cleaning or filtration system can be developed for almost any pollutant of concern. But in terms of what is most practical, the current literature lists particulate matter and ozone as pollutants for which filtration is readily available. When airborne organic compounds are an issue, air cleaning can become quite expensive and more cost effective alternatives must be considered.

The proposed EPA IAQ standard requires filtration for IAQ reasons. A MERV 8 filter must be installed with no filter bypass. This is ensured with a neoprene gasket installed on one side of filter rack to bring the filter into contact with the rack.

As contaminants of concern are identified, it may be possible to develop trade-off mechanisms between air cleaning, source control and dilution ventilation. This approach, however, requires more research before it could be implemented in regulation. The practical aspects of installation and operation must also be given due consideration.

Particle filtration and HVAC Systems

Although filtration and air cleaning are alternatives to dilution ventilation for known sources, no current residential ventilation standard has such a mechanism at minimum rates, although some may allow it for special purposes. In contrast, ASHRAE 62.2 does specify filtration as a mechanism for keeping the HVAC system from becoming a source.

When dust and dirt build up on components of HVAC systems, those components can become contaminant sources. In climates that require cooling, water collected in the HVAC system can combine with organic materials in the dust and dirt, allowing mold growth that is disseminated by the HVAC system.

This so-called "wet coil" problem has been more severe in humid climates than in California. As sensible loads are reduced through better building envelopes, however, latent loads will represent a larger fraction and wet-coil operation will be more common.

Another source of contaminants from HVAC particulates comes from certain semi-volatile organic compounds (SVOCs) that are produced in the residence but condense and re-volatilize in the HVAC systems. SVOCs are compounds that do not completely volatilize at room temperatures, but have a sufficiently high vapor pressure to volatilize to some extent into room air. Incomplete combustion processes (e.g., fireplaces, cooking, "candle soot".) can be important sources of SVOCs, which can exist as particles or stick to particles and evaporate slowly over a long time. Furthermore, because they tend to increase their re-emission rates when their corresponding air concentration is lowered, many SVOCs are somewhat resistant to dilution ventilation. An optimum mechanism for dealing with these types of contaminants is to filter them out of the air (and periodically remove the dirty filter).

An added factor, which is important for energy consumption but not for IAQ, is that particles can build up and eventually reduce the efficiency of evaporator coils. This effect will have the impact of reducing the system efficiency and capacity over time. Reasonable filtration has been shown to double the life of indoor coils.

ASHRAE 62.2 requires a MERV 6 filter to protect HVAC systems. This is a low-to-intermediate filtration level that was not intended to address human health protection, but will be good at protecting coils and other HVAC components. Particle filtration to reduce human exposure generally requires higher-efficiency filters and continuous operation at very high air flows to be effective, but such a system could have substantial energy penalties unless additional requirements were placed on distribution systems and air handler efficiency.

Occupant Acceptability and Control

The purpose of residential ventilation is to provide acceptable indoor air quality for the building occupants. Not only must the occupants find the indoor air acceptable, they must find the systems that they have to interact with acceptable. Thus it is important to consider a wide variety of occupant-related issues when developing minimum requirements.

One example of such an issue is noise. Ventilation and air distribution systems can generate noise. Canadian surveys have shown that occupants who are bothered by noise will find ways to disable the ventilation system. It is, therefore, important that fans and other components not generate excessive noise. ASHRAE 62.2 sets sound limits for both continuous and intermittent fans at 1 sone and 3 sones respectively except for fans with flow greater than 400 cfm[3]. The state of Washington sets a limit of 1.5 sones at 1 inch of water for ventilation fans that are within 4 feet of the interior grille. Similarly, the state of Minnesota has a limit of 1 sone for surface mounted fans.

Similarly, annoyed occupants are likely to disable ventilation systems that create drafts or other thermal discomfort. Literature from the Pacific Northwest and other climates demonstrate that people would rather have insufficient ventilation than have cold air blow on them. Systems that are inherently uncomfortable should be avoided.

Research demonstrates that occupants feel more comfortable when they have control over their environment. It is important that occupants have some level of control of their ventilation systems. They must have the ability to disable it for service or emergencies; they must have the ability to increase ventilation for events such as parties, cleaning, or hobby activities when they know they will need extra dilution. But because occupants are, in general, not trained to sense IAQ and ventilation needs, ventilation systems must be able to run simply, automatically and unobtrusively.

[3] This exception allows large flow kitchen range hood fans that would otherwise be prohibited due to noise.

Sensitive populations

Building standards are typically designed to specify minimum requirements and to address the needs of a majority of occupants. It must be recognized, however, that there are special populations who have greater sensitivities to some contaminants (e.g., allergies, compromised immune systems, airway disease) and will, therefore, experience discomfort with contaminant levels that elicit no response in most people.

While it may not be appropriate to design new standards to protect the most sensitive populations, it is appropriate to encourage the development of systems that such populations can upgrade to meet their needs and to determine the extra protection from contaminants appropriate for such populations. Therefore, it is important that the impact of various choices on sensitive populations, and their needs, be assessed during the development of these requirements.

Outdoor Air

In designing residential ventilation systems to dilute indoor contaminants, designers usually assume that the outdoor air itself is of acceptable quality and contains low levels of contaminants of concern. Unfortunately, in many California regions, outdoor air quality can be poor during some parts of the year, e.g., high particulate concentrations in rural communities.

Some ventilation system designs can provide various forms of protection for short-term outdoor contamination incidents. Ozone, for example, is highly reactive and can be reduced simply by pulling air through the building envelope instead of through large openings such as windows. This is what happens when exhaust fans provide primary ventilation. If filtration is part of the HVAC system, then supply ventilation systems can help remove particles (e.g., pollen, dust, anthrax)

Occupant-controlled ventilation systems and tight envelopes can allow a house to float through a few hours of bad outdoor air, whether it is from burning, pesticide spraying, or accidental or intentional release of toxic substances.

Enthalpy vs. Temperature

The outdoor air supplied by ventilation must be conditioned for human comfort. The associated energy requirement depends on whether we are considering only the sensible load (i.e. the temperature) or also the latent load (i.e. the humidity). In principle a house could require humidification or dehumidification in winter or summer—resulting in different energy impacts.

In the winter dehumidification produces free heat which would reduce heating demand. Conversely, humidification requires energy either directly (i.e. by heating water) or indirectly by cooling the air and increasing heating demand. Neither of these issues is particularly important in new California construction.

Dehumidification is often required in hot, humid climates in the summer, but for most of California the dehumidification that happens as part of normal air conditioning operation is more than enough. In fact, for much of California summer indoor conditions are sufficiently dry that energy could be saved using direct evaporative cooling techniques. Re-evaporation from cooling coils is considered a problem in hot, humid climates, but actually saves energy in dry climates suggesting that certain short-cycling control strategies may have value in California.

When doing energy calculations the impact of infiltration and ventilation will depend on whether or not costs and benefits of latent impacts are considered, which in turn depends on the system being used. For example, ventilation air with a dry-bulb temperature above the cooling set-point, but a wet-bulb temperature below it would be a load on the air conditioner if no evaporation occurs. That same air could be a negative load on the air conditioner if full enthalpy control is considered by the use of some evaporative technique.

Peak Demand

The phrase "All energy is equal, but some energy is more equal than others," describes a recent change made to Title 24 to place time-dependent valuation (TDV) on energy use. The philosophy of TDV is that the cost to supply energy during peak periods is higher and therefore more valuable to save. Valuing the energy more correctly should make energy demand more uniform by increasing the value and cost of energy consumed during peak-use periods.

The energy cost of ventilation is not constant because it depends not only on the ventilation rate, but also on the difference between indoor and outdoor air. Ventilation energy cost can be quite high during the peak-demand weather conditions (heat of summer and cold of winter). But during mild conditions when ventilation supplies free cooling, its cost is low and can even be negative.

If ventilation rates remain constant throughout the year, little could be done to respond to these cost variations. But health studies indicate that it is possible to reduce pollutant exposures without specifying a *constant* ventilation rate. For many pollutants it is not the instantaneous concentration that is of significance, but an occupant's cumulative exposure to that pollutant. To the extent that we can understand how time-varying concentrations contribute to overall exposure and health risk, we can allow the flexibility in ventilation technology to minimize energy impacts under the TDV scenario. A strategy that has higher ventilation rates when the TDV is low and lower rates when it is high could, in principle, be designed to provide the same or lower cumulative exposure limits at lower energy impact than a system with a constant ventilation rate. As discussed above, though, it can be problematic to ventilate when the outdoor air is, itself polluted.

Outdoor ozone is a key outdoor pollutant in many areas of California. Because of temperature, sunlight and hydrocarbon production patterns, ozone concentration is highly time dependent with highest levels typically appearing in late afternoon—in rough coincidence to peak electricity demand. Thus an intermittent ventilation strategy that responds to summer TDV patterns would offer additional benefits in those areas with high outdoor ozone concentrations. With the recent adoption of a new standard for ozone exposure levels by the California Air Resources Board[4], this benefit could extend to a significant portion of California's population.

Unusual Sources and High-Polluting Events

As a code, Title 24 specifies a minimum level of ventilation. Users are free to go beyond that level, but may not go below it. In a practical sense this situation requires that one identify both those hazards for which the code provides protection and those for which it does not.

From a residential ventilation perspective, one must determine whether the control of a particular contaminant source has been included in the ventilation design. Often this is done implicitly, for example, by using existing requirements as a basis for ventilation requirements. However, it must be made clear what protections are provided regardless of whether protection results implicitly or explicitly from ventilation requirements.

During the development of ASHRAE 62.2, for example, the project committee specifically excluded certain categories of sources from consideration. That does not mean that the standard does not give some protection from those sources, but that the required ventilation rates and other requirements were not designed to do so. In developing requirements for California it will be important to determine which contaminants are excluded.

ASHRAE 62.2 defines a class of sources called "high-polluting events" as "isolated and occupant-controllable events that release pollutants in excess quantities." It goes on to say that acceptable IAQ may not be provided in the presence of high-polluting events even though the standard has been met. It similarly excludes (i.e. does not address) unvented space heaters, but for political rather than technical reasons.

Unvented combustion of all types (cooking, candles, smoking, heating) can be the most problematic of "excluded" sources, but other occupant activities such as refinishing furniture, cleaning, pest removal, and office work must be considered as "unusual" sources.

Window Operation

Some organizations, such as the National Association of Home Builders, contend that ventilation standards are not needed because windows can reliably supply any needed whole-house dilution of indoor contaminants.

It is probably true that windows *could* supply that ventilation, but there are many reasons why occupants do not choose to open their windows:

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[4] http://www.arb.ca.gov/research/aaqs/ozone-rs/ozone-rs.htm

- Draft and thermal discomfort
- Noise, outdoor contaminants and insects.
- Security and safety
- Energy costs
- Access and difficulty of operation

Nevertheless, it must be acknowledged that people do tend to open their windows if they perceive an indoor air quality problem. But occupants can readily perceive only a limited number of indoor air quality problems. For example, bad odor is often a good indicator of bad IAQ, but lack of odor is not an indicator of good IAQ.

Currently the IRC, ASHRAE 62.2 and Title 24 allow window operation as an acceptable means to ventilate most California houses. But it must be noted that many in the air-quality research community have questioned this assumption and it is topic of on-going research being carried out by the California Air Resources Board.

CRITERIA FOR REGULATION

The purpose of this section is to discuss the criteria needed to build a consistent residential ventilation regulation within the California context and to suggest preliminary recommendations for consideration in developing the 2008 version of Title 24.

In some cases the recommendations are based on consensus standards or are completely or partially derivable from the literature. In many cases, however, the recommendations are the judgment of the authors—based on the literature and our expertise.

Standard of Care in Code Development

When developing or revising a regulation, it is always best to start with an existing document and modify it to suit the particular needs of a specific jurisdiction and function. This document becomes the starting point for the standard of care. Then one needs only to justify modifications to that standard based on those particular needs identified by the specific function or jurisdiction.

A review of the existing appropriate documents to determine the standard of care is thus the first step in revising Title 24's residential ventilation requirements. The first document that should be considered in revising any regulation is the previous version of that regulation—i.e. the 2005 version of Title 24 should be examined as to whether or not it should be used as the basis of the 2008 version. The existing language should always be used as a start when only minor modifications are needed to the regulation.

Model codes are another kind of document that could be considered for the standard of care because they have been created with broad input to reflect broad applicability. The requirements in the IRC, for example, apply in most States. Model codes often represent the lowest common denominator in regulations and are often good choices when looking for similarity with other jurisdictions or when first applying regulation in a particular area. When model codes are insufficient, codes from other jurisdictions should also be considered.

When appropriate and authoritative standards exist, such as consensus standards certified by the American National Standards Institute (ANSI), they may be used as the standard of care. ANSI/ASHRAE Standard 62.2 is the only such standard that is appropriate.

Voluntary guidelines can serve as the standard of care when a higher degree of protection is desired than that provided by existing codes and/or ANSI standards. Independent and/or industry organizations such as the Energy Efficient Builder's Association have produced guidelines, but the Indoor Air Package from the Energy Star program of EPA is the most relevant and authoritative voluntary guideline.

Recommendations for California

We recommend that ASHRAE Standard 62.2-2004 be adopted as a mandatory requirement for all new houses. California strives to be a leader on energy and environmental issues; and Title 24 reflects that. California requirements already exceed that of the model codes and the codes of most jurisdictions in the country.

ANSI/ASHRAE Standard 62.2 is a code-intended consensus standard that is more suitable to the needs of California than any of the model codes and has some major improvements compared to the current version of Title 24. Other states are considering adopting it. Furthermore as a standard from a professional society it represents that standard of care that HVAC professionals are expected to adhere to. As a code-intended document, 62.2 was designed as a minimum standard; and HVAC professionals have some liability if they do not follow it.

In many aspects the EPA Indoor Air Package could be expected to provide enhanced environmental protection compared to the other options. It was not, however, intended to be applied as code, nor was it put together in a consensus manner and/or validated. While many of its prescriptive recommendations are good advice it is not clear if they are necessary and/or the appropriate and cost-effective ways of achieving acceptable indoor air quality.

Therefore, for the remainder of this document we will assume that ASHRAE Standard 62.2-2004 is the fundamental standard of care being considered. Recommendations for other requirements will be made relative to that standard.

Infiltration and Its Impact on Sizing

Infiltration operates without energy and without intervention, but it is not usually the most energy efficient strategy. The housing stock is and traditionally has been ventilated by infiltration, but often to excess.

Although modern houses have substantially less infiltration, the amount is rarely so small as to be negligible. It is, therefore, important to account for infiltration as both an energy cost and a contributor to minimum ventilation. To overestimate infiltration would lead to under-ventilated houses and an over-prediction of energy consumption. To ignore or under-estimate infiltration would lead to excessive ventilation and excessive energy consumption.

Most codes and model codes oversimplify infiltration either by ignoring it completely or by assuming that infiltration plus window operation will lead to sufficient ventilation without actually quantifying it. Some standards and guidelines use defaults for either infiltration or for the air tightness of the envelope—which then allows infiltration to be calculated from climactic data.

Title 24 is one of the more advanced codes in this respect because it uses air tightness (default or measured) to calculate infiltration and combine it with any mechanical ventilation to see if minimum requirements are met. If they are not met it then assumes that windows would be used to boost total ventilation.

By contrast ASHRAE Standard 62.2 assumes a fixed infiltration rate for all new construction regardless of climate or air tightness. (There is a provision for existing houses to get some credit in 62.2 for measured air tightness, but this does not apply to new construction.) While simple, this assumption can lead to excessive ventilation in looser houses or insufficient ventilation and/or pressure management problems in unusually tight construction.

Recommendations for California

We recommend that the whole-house ventilation rates of 62.2 be followed in California using the default infiltration credit. In other words the mechanical ventilation rate in the base case should be set using the procedure of 62.2 without any adjustment for infiltration or air tightness.

For energy calculation purposes, however, the default SLA should be set using the best available data as has been done for previous versions of Title 24. Specifically we recommend that the base case house be assumed to have an SLA of 4.0.

It is very important that the algorithms used to calculate the energy impacts properly calculate the total ventilation rate and associated energy impact of the envelope leakage and mechanical system combination.

We also recommend that a study be done to determine the actual leakage of new California houses and the impact that would have. The use of an unbalanced ventilation system (i.e. exhaust only) minimizes the impact that envelope leakage plays and the SLA assumption is not critical. If houses are, in fact, substantially tighter than assumed, they could be under-ventilated compared to the intent of 62.2. Similarly if they are substantially leakier than assumed, the actual ventilation and energy costs could be higher.

Duct Leakage

Leaky ductwork can be a major energy loss, but can also cause indoor air quality problems in a variety of ways. Leaky return ducts or plenums can pull in contaminated air from (contaminated) buffer zones such as garages, crawlspaces, and distribute it throughout the house. Also, attics on summer days are much hotter than outside air further increasing the energy cost of leaky returns.

Leaky supply ducts or supply plenums is a lesser problem, but if excessive, could substantially depressurize a house and cause soil gas or air from buffer zones to be pulled into the living space. To a lesser degree, leaky supply ducts could also pressurize a contaminated buffer zone and push polluted air into the living space.

Thousands of new houses are being built in California to meet a voluntary limit of 5% duct leakage (e.g. those participating in the "Environments For Living" program). For a 1200 cfm air handler the 5% limit is 60 cfm or 0.03 cfm/sq. ft. for a 2000 sq. ft. house.

Title 24 currently has a 6% of fan flow prescriptive requirement for total duct leakage, but it is not a mandatory requirement (it can be traded off against other efficiency measures). ASHRAE Standard 62.2 has the same specification as Title 24, but only applies when return ductwork or plenums are in the garage. This specification is 6% of air handler flow.

Standard 62.2 does have a limitation of 0.075 cfm/sq. ft. (floor area) of total net supply and/or exhaust in some climates and a depressurization-related limit of 0.15 cfm/sq. ft. This limitation is for the sum of the two largest pieces of exhaust equipment. These limitations are only relevant for some California houses. If we use the conditions of the example above 0.075 cfm/sq. ft. is roughly 12.5% leakage or 150 cfm.

The EPA Indoor Air package has a tighter specification than Title 24; it does not allow any ductwork or air handlers in garages. The latter requirement is a recognition that the pressure in and around air handlers are the highest in the system and leaks are therefore the most problematic. Eliminating air handlers from the garage greatly reduces the attendant risk, but takes away a builder option.

Most buffer zones including garages can be significant sources of contaminants including pesticides, products of combustion, VOCs, etc. Entrainment due to leakage from return ducts passing through those zones should be minimized. A common approach used to address such health issues is to reduce the exposure to "As Low As Reasonably Achievable" (ALARA).

Recommendations for California

We recommend that the total leakage for ducts passing through buffer zones be limited to 5% of air handler flow as a mandatory measure for all new houses. This value is based on the principle of ALARA and the fact that many new houses in California are routinely being built to the 5% value. This value can be measured using either the existing duct leakage test method or the new ASTM Standard.

Because the new ASTM method potentially allows an easy separation of supply and return leakage, it may be possible in the future to have a more flexible duct leakage requirement that meets or exceeds the one recommended here. We, therefore, recommend that the CEC initiate appropriate research. This research must take into account how supply and return leakage interact with different ventilation systems and contaminant transport. Requirements for indoor air quality concerns would also need to be rationalized with requirements for energy concerns.

Because the ALARA approach is relative to industry practice, it is important to re-evaluate the state of the art on a regular basis to determine if changing the requirement in future is appropriate.

Combustion

Removal of the products of combustion has historically been a key driver for ventilation. Combustion technology has greatly improved, but even the cleanest combustion process produces carbon dioxide, water vapor and ultrafine particles. Less perfect combustion can produce carbon monoxide, soot, and oxides of nitrogen.

Safety and efficiency of combustion appliances are regulated by a host of standards (such as ANSI Z221) and have greatly improved in both efficiency and safety. Nevertheless, appliances that are coupled to the indoor air because they are unvented or use natural draft can still cause problems because they can be reasonably operated at conditions other than the ones envisaged by those standards.

Some jurisdictions (e.g. EPA IAQ [5], Canada [11]) prohibit most unvented combustion appliances. Others allow ones meeting certain standards. California prohibits unvented fireplaces. ASHRAE 62.2 is explicitly silent on their acceptability, but the key issue for any kind of unvented combustion is to sufficiently dilute or remove the products of combustion before they can build up to harmful levels.

Vented combustion appliances are intended to have their products of combustion vented outside. Such venting is an exhaust flow, which interacts with other flows and the building envelope to lower the internal pressure. Low enough internal pressure will inhibit such an appliance from venting correctly and could cause back drafting.

Historically fireplaces and similar features are highly valued by homeowners for aesthetic reasons. Efficiency and safety concerns are traditionally secondary. There are a wide variety of appliance and fuel configurations and current standards include requirements relating to sealed doors and outdoor air intakes.

Standard 62.2 prohibits the use of natural draft appliances inside when the exhaust flow exceeds 0.15 cfm/sq. ft. of floor area, but this limit does not take into account building air tightness nor does it account for duct leakage. EPA's Indoor Air Package prohibits natural draft combustion appliances indoors[5] and requires a carbon monoxide alarm when there are any combustion appliances. Few natural draft appliances are installed in new California houses.

The following specific requirements are from EPA IAQ [3]:

- **Un-vented combustion appliances** (including **Decorative gas logs** as defined in K.1.11 of the National Fuel Gas Code) are not permitted, unless the room they are placed in meets the local exhaust requirements of a kitchen.

- **(Fuel-fired) Furnaces and Water heaters** inside the pressure boundary shall be power vented or direct vented.

- **Masonry fireplaces** are not permitted, with the exception of masonry heaters, as defined by the American Society for Testing and Materials Standard E-1602, and the International Building Code, 2112.1.

- **Factory-built, wood-burning fireplaces** shall meet the certification requirements of Underwriters Laboratory UL-127, "Standard for Factory-Built Fireplaces," and meet the emission limits in U.S. EPA Standard 40 CFR Part 60, subpart AAA, 60.530-539b, "Standards of Performance for New Residential Wood Heaters."

- **Natural gas and propane fireplaces** shall be power vented or direct-vented, as defined by 3.3.108 of the National Fuel Gas Code, have a permanently fixed glass front or gasketed door, and comply with the American National Standards Institute, ANSI/Z21.88/CSA 2.33 Harmonized Standard, "Vented Gas Fireplace Heaters" of the International Code Council's International Fuel Gas Code.

- **Wood stove and fireplace inserts** as defined in Section 3.8 of Underwriters Laboratory UL 1482, "Standard for Safety, Solid-Fuel Type Room Heaters," shall meet the certification requirements of that standard, and meet U.S. EPA Standard 40 CFR Part 60, subpart AAA, 60.530-539b, "Standards of Performance for New Residential Wood Heaters," and Washington State's particulate air containment emission standard, WAC 173-433-100 (3).

- **Pellet stoves** shall meet the requirements of the American Society for Testing and Materials (ASTM) E 1509-04, "Standard Specification for Room Heaters, Pellet Fuel-Burning Type."

- **Carbon monoxide (CO) Alarms** are required to be installed near any sleeping area for all houses with combustion appliances inside the pressure boundary. They shall be placed according to National Fire Protection Association (NFPA) 720, Recommended Practice, "Installation of Household Carbon Monoxide (CO) Warning Equipment," and be hard-wired with a battery back-up function. The

[5] An exception is given for natural draft furnaces if the climate has fewer than 4000 HDD.

alarm devices shall be certified by the Canadian Standards Association, CSA 6.19-01, or Underwriters Laboratory UL 2034.

Recommendations for California

We are not recommending any more stringent requirements on combustion than are included in 62.2-2004. Many of the requirements above are covered either by codes or standard practices in California already and additional requirements beyond what is already contained in Standard 62.2 are not justified at this time.

We recommend that the current prohibition against using exhaust ventilation in houses with an SLA<1.5 be dropped. Standard 62.2 prohibits the use of naturally aspirated combustion equipment inside the pressure boundary if the uncompensated[6] exhaust flow from the two largest exhaust appliances exceeds a specified level. Typically the two largest exhaust devices are the clothes dryer and kitchen exhaust, but that need not always be the case. This requirement serves the same function as the SLA 1.5 level and is more flexible.

We recommend that CEC initiate a study to determine if Carbon Monoxide exposure may be increasing due to changes in building practices. Anecdotal evidence suggests that attached garages and unvented combustion of various sorts could be detrimentally interacting with various construction practices. Various parties have proposed CO Alarm requirements, which should be evaluated.

Air Distribution

We will not consider air mixing within each room because no consensus exists yet on how to reasonably predict this phenomenon. Instead we will limit the discussion to the air supplied to the room.

To assure adequate ventilation to those who may spend much of their time indoors in a small number of rooms, it is important that fresh air be distributed to each room either directly from the ventilation system or by mixing it thoroughly within the space.

In non-residential ventilation standards the indoor environment is usually broken into several zones, and requirements are placed at the zone level. Although there may be modifications due to ventilation efficiency, it is generally assumed air delivered to the zone reaches the occupants equally, regardless of where they are in the zone—i.e. the zone is well mixed.

In North America it is generally assumed that from the point of view of outdoor air delivery, a given house is well mixed also. Thus most residential ventilation requirements are not set per room, but for the whole indoor space. Many European standards, by contrast, have requirements that fresh air be delivered to each habitable room. This

[6] An exhaust fan can be "compensated" if there is an interlocked supply fan that runs with it. This approach, for example, is used with commercial kitchen hoods, but is uncommon in residential construction.

difference is likely attributable to the fact that Europeans do not commonly use forced air systems, which can serve to help distribute air throughout the house.

Codes such as the IRC that rely on window operation have an implicit air distribution requirement because each habitable room must have an operable window and that window is presumed to be part of the ventilation system. Similarly, it is assumed that infiltration is distributed and provides air distribution to most rooms.

ASHRAE 62.2 does not currently have an air distribution requirement, although it is a topic of consideration by the committee.

Houses with forced air systems can get a substantial amount of air distribution from normal operation. Lack of adequate return paths for the air, however, can not only reduce air distribution, but can cause differential pressures that might induce extra contamination, such as from soil gas or, more importantly cause local depressurization that could induce back drafting. It is for this reason the Energy Star Indoor Air package requires transfer grilles or "jump ducts" between zones.

Recommendations for California

We are not recommending air distribution requirements be put into Title 24 at this time, although it may be important for many populations of interest.

While lack of air distribution may soon begin to be an important issue, it may be premature to have requirements for the next code cycle. It is important, however to investigate the issue for consideration in future rulemaking. We therefore recommend that suitable R&D be initiated in the air of air distribution:

An approach that could be easily met by houses with forced distribution systems would be to have each room connected to the ventilation system by having one of features:

- A supply register connected to the central air handler or a dedicated supply ventilation system
- A return from the central air handler
- An exhaust opening such as for a bathroom or kitchen fan or central exhaust system including air-to-air heat exchangers
- A passive air inlet designed as part of a central exhaust ventilation system
- An operable window, only if that window is used to meet minimum ventilation requirements.

An open question when central air handlers are used to provide air distribution is the need for transfer grilles or jump ducts. When several hundred cfm need to flow across a door (as is typical), door undercuts will not be sufficient and designed transfer mechanisms should be required. This requirement exists in some programs already.

A related issue concerns running of the air handler (or other distribution mechanism) to actively mix on a regular basis (e.g. 10 minutes out of every 30). This approach assures a more even distribution of both concentrations and temperatures and is currently used in some energy programs.

Intermittent Ventilation and Its Impact on Sizing

Ventilation rates are generally stated in terms of airflow rate per person or airflow rate per floor area, and we generally assume a constant airflow. There are, however, a variety of reasons why one might want to design and operate the ventilation system with variable amounts of ventilation airflow. For example:

- There may be periods of the day when the outdoor air quality is poor (e.g. from smog, pollen, humidity, toxic releases) and one wishes to reduce the amount of outdoor air entering the building;
- Economizer operation can provide more than the minimum ventilation rate (i.e. "over-ventilate" a space) from the point of view of indoor air quality; energy savings can be achieved by lower ventilation rates at other times by taking account of the over ventilation;
- Demand charges, time-dependent valuation or utility peak loads may make it advantageous to reduce ventilation for certain periods of the day; and
- Some HVAC equipment may make cyclic operation more attractive than steady-state operation such as systems that tie ventilation to heating and cooling system operation.

Few codes or standards address the flexibility necessary to allow the designer or occupant to respond effectively to these needs. Some, such as the Washington State code, allow ventilation to run on fixed schedules. Standard 62.2 does have a procedure for accounting for intermittent ventilation, which addresses some, but not all, of these needs.

A recent report by Sherman [1] develops far more flexible and dynamic method of accounting for the efficacy of intermittent ventilation based on first principles. The equations allow the derivation of the efficacy of a particular ventilation approach based on the desired ventilation rate and the ventilation pattern of the system being used. This approach can be applied to any of the needs indicated above as either a design or control function. SSPC 62.2 is considering updating their current method for the new one.

California has large diurnal swings not only in temperature, but in outdoor air quality and utility costs and reliability. Dynamic ventilation approaches can prove quite beneficial. Some of these approaches should be incorporated into the next version of Title 24 while some of them may require additional development.

If the rates from 62.2 were increased by about 20-35% it would correspond to those required by Sherman [13] assuming that the ventilation system is operating for 20 hours on and 4 hours off. The exact value depends on house size, but for a typical house size and number of occupants (and assumptions about infiltration), but a 25 cfm increase covers most cases.

Recommendations for California

We recommend that the mechanical ventilation rate requirement be increased by 25 cfm over that specified by 62.2 in order to allow the occupant to shut-off the ventilation for up to four hours per day on a regular basis and still meet the intent of the standard. This mechanism allows a demand responsive approach to deal with both peak power issues as well as unacceptable outdoor air.

Standard 62.2 requires a control system (e.g. programmable timer) to take credit for intermittent ventilation. We recommend that if such a control exists, any proposed design be allowed to take energy credit for those hour hours in which the ventilation system may be shut down.

We recommend that the CEC initiate research to expand the benefits of intermittent ventilation strategies. When economizers, direct evaporative cooling or natural ventilation are being used to provide free cooling, ventilation is usually far above the continuous rates of 62.2. With a suitable control mechanism this over-ventilation during some periods could allow substantial savings by under-ventilating during others. No such control system has yet been demonstrated, so more research is probably needed before this option can be properly considered in codes.

Use of Windows

In writing a ventilation code one of the most significant decisions to be made is whether or not to allow operable windows to contribute towards meeting minimum ventilation requirements. If they are allowed, it often obviates the need for mechanical systems—thus saving money—but it is not always clear whether and how windows are actually operated.

Title 24, the IRC and most codes in the U.S. allow operable windows to meet ventilation requirements. The Minnesota and Washington codes as well as most European norms require ventilation systems. ASHRAE Standard 62.2 requires mechanical ventilation in most climates, but for much of California it would allow operable windows to meet the requirement.

If operated on a daily basis, windows can easily provide the necessary ventilation rate. The fundamental issue is whether people would, in fact, open them as needed. Noise, pollution, security, draft and physical difficulty are all barriers to regular window operation. Nevertheless many people prefer open windows for a variety of aesthetic reasons and are quite willing to overcome those barriers.

In making the decision, the regulatory authority needs to determine if it is common and reasonable for people to regularly operate their windows when necessary to meet minimum ventilation requirements. This determination will vary by jurisdiction and depend on climate, construction style, occupant expectations and cultural norms.

In order to determine how windows are actually used in California, the California Energy Commission and Air Resources Board have commissioned a survey of new home owners asking about their perceptions of indoor air quality, window opening behavior and other factors.

The study is not yet complete, but preliminary (unpublished) results indicate that while many people operate their windows quite regularly during some parts of the year, there are many people who do not.

Since the purpose of residential ventilation requirements are to protect the health and safety of occupants, requirements are needed to protect more than just a simply majority of people. Thus if any significant minority of occupants do not open their windows, the minimum requirements should be there to protect them and thus require an actual ventilation system.

The studies of occupied California houses by Wilcox [16] and Wilson [35], for example, have also shown that air change rates have dropped over time and are now significantly below recommended rates, also suggesting that significant window opening is not taking place. This supports the need for mechanical ventilation even in mild California climates.

Recommendations for California

We recommend that window opening *not* be considered a permissible means of meeting whole-house ventilation requirements in California. In the context of 62.2 this means that the mild climate exception to section 4.1 cannot be used, but window operation would still be presumed to contribute towards meeting the default infiltration credit and ventilation opening requirements of the standard.

CONCLUSION AND SUMMARY

In the long term, ventilation standards will likely be based on a better understanding of contaminants in the indoor environment and their effects on health. While the current state-of-the-art in IAQ research is not sufficient to provide a truly health-based ventilation standard, current IAQ research is sufficient to improve upon the more traditional engineering-based approaches. By incorporating measures of health protection in the future, ventilation standards can be used to simultaneously reduce ventilation-related costs and improve the indoor environment, with a resulting improvement in Californian's overall quality of life, and the related health care savings and increased economic productivity.

Summary of Recommendations

In this report we have made a series of recommendations to the California Energy Commission. These recommendations can be grouped into those for IAQ-related requirements, those for energy-related requirements and those needed more research.

IAQ-Related Requirements

- ASHRAE Standard 62.2-2004 should be adopted by reference except where overridden by any of the other recommendations in this report. (These requirements are summarized in the Overview of ASHRAE Standard 62.2 section.)

- Air leakage and window operation shall be deemed to provide the default infiltration of 62.2 and also meet the window opening requirements of the standard, but may not be used to meet otherwise meet the whole-building ventilation or local exhaust provisions of the standard. (For details see the sections on Use of Windows and Infiltration and Its Impact on Sizing).

- The mechanical ventilation rates of Section 4.1 of the standard shall be increased by 25 cfm. (For details see the section on Intermittent Ventilation and Its Impact on Sizing which indicates the benefits of this strategy on Peak Demand and when there is poor Outdoor Air quality.)

- When ducts pass through buffer zones (e.g. a garage, attic or crawlspace) the total leakage shall be limited to 5% of the air handler flow. (For details see the section on Duct Leakage.)

Energy-Related Requirements

- SLA=4 shall be the default value for use in energy calculations, but measured air tightness may be used if known. Current restrictions on tightness below SLA=1.5 shall be removed. (For details see the sections on Infiltration and Its Impact on Sizing and Combustion)

- Designs with suitable control systems (e.g. a programmable timer) may take energy credit for shutting off the ventilation system up to 4 hours per day. (For details see the section on Intermittent Ventilation and Its Impact on Sizing relative to its impact on Peak Demand and Occupant Acceptability and Control.)

R&D Needs

- A broad based field study to determine envelope and duct air leakage of current new construction and how commonly used mechanical ventilation systems perform with such leakage. (Discussed in the sections on Infiltration and Its Impact on Sizing, and Duct Leakage)

- A study to determine how contaminants are transported from garages and other buffer zones and to determine if Carbon Monoxide alarms are necessary. (Discussed in the section on Duct Leakage and Unusual Sources and High-Polluting Events.)

- Evaluation of the need to have air distribution systems in California houses in order to provide acceptable indoor air quality. (Discussed in the section on Air Distribution and Filtration and Air Cleaning.)

- Development and testing that would allow additional ventilation credit to be given to economizers, direct evaporative coolers and other systems that provide ventilative cooling. (Discussed in the section on Intermittent Ventilation and Its Impact on Sizing and Window Operation.)

Summary of Non-Recommendations

In the course of this report we investigated other potential recommendations, but concluded that they were not needed. Either ASHRAE Standard 62.2 already addresses them or we did not find any compelling reason to add additional requirements. Some of those non-recommendations are summarized below:

High Polluting Events

In the normal course of use, there are many occupant-controlled events that produce pollutants for a well-defined time in excess of what minimum ventilation requirements can control. Such high-polluting events including cleaning, smoking, painting, entertaining, and hobby activities are usually quite obvious to the occupants. Since Standard 62.2 and building codes require operable windows (or equivalent) in all habitable room, occupants have a way of dealing with these contaminants. There is no reason to set additional requirements.

Particle Filtration

Standard 62.2 requires MERV 6 particle filtration on all air handlers. While such filtration may provide some reduction in direct exposure to the occupants, its primary purpose is to protect the air handling components, whose IAQ and energy performance would degrade otherwise. More stringent particle filtration combined with continuous fan operation would provide an enhanced indoor environment, but we do not feel that such requirements are currently appropriate for a minimum standard.

Indoor Air Cleaning

In theory minimum ventilation rates could be lowered if contaminants of concern were identified and removed from the indoor air by filtration or air cleaning. This kind of approach is sometimes used in industrial occupancies where the contaminants of concern are well known. In residential occupancies contaminants of concern are not well described and the cost and maintenance requirements of air cleaning equipment are beyond what is currently reasonable for regulation.

Outdoor Air Cleaning

Without filtration or air cleaning the indoor air can never be better in quality than the outdoor air in steady state. So when outdoor air quality is poor, no amount of ventilation can provide good indoor air quality. Technologies exist to remove most major outdoor pollutants (e.g. particles ozone,), but they are prohibitively expensive and require maintenance. Furthermore, it is beyond the scope of a building standard to deal with poor outdoor air quality. Standard 62.2 requires that ventilation systems be able to be shut off during periods of poor outdoor air quality. The intermittent ventilation provisions recommended, however, give the user even more flexibility.

When outdoor air is contaminated for short periods of time, such as from a toxic release, the indoor environment can serve as a reservoir of relatively clean air. This "shelter in place" function of a house is a desirable feature, but not one directly related to a residential ventilation code.

REFERENCES

1 ASHRAE Standard 62.2, "Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings," American Society of Heating, Refrigerating and Air Conditioning Engineers, Atlanta, GA, 2004.

2 ASTM E1554-03.. *Standard Test Methods for Determining External Air Leakage of Air Distribution* Systems by Fan Pressurization. Annual Book of ASTM Standards. Vol. 04.11. American Society for Testing and Materials. West Conshohocken, PA. 2003

3 California Energy Commission. 2005. "Title 24, Part 6, of the California Code of Regulations: California's Energy Efficiency Standards for Residential and Nonresidential Buildings." California Energy Commission, Sacramento, CA.

4 CAN /CSA. 1991. "F326-M91 Residential Mechanical Ventilation Systems" Canadian Standards Association, Mississauga, Ontario.

5 EPA. 2005. "Energy Protection Agency Indoor Air Quality Specifications." Energy Protection Agency, Washington, DC.

6 ICC. 2003. "International Residential Code for One and Two-family Dwellings." International Code Council, Country Club Hills, IL.

7 ICC. 2003. "International Energy Conservation Code." International Code Council, Country Club Hills, IL.

8 McKone T.E, Sherman M.H. "Residential Ventilation Standards Scoping Study" LBNL Report #53800, 2003.

9 McWilliams, J., Sherman M., "Review of Literature Related to Residential Ventilation Requirements". LBNL Report # 57236. 2005.

10 Minnesota , State of. 2000. "Minnesota Rules Chapter 7672: Energy Code". Department of Public Service, Minneapolis, MN.

11 NRC. 1995. "National Building Code of Canada 1995." National Research Council Canada, Ottawa, ON.

12 RESNET, "Mortgage Industry National Home Energy Rating Systems Accreditation Standards" Residential Energy Services Network, 2002.

13 Sherman, M. H. "Efficacy of Intermittent Ventilation for Providing Acceptable Indoor Air Quality" (In review at *HVAC&R Research Journal*) Lawrence Berkeley National Laboratory Report #56292, 2004.

14 Sherman, M.H. and Matson, N.E., "Air Tightness of New U.S. Houses: A Preliminary Report ", Lawrence Berkeley National Laboratory, LBNL-48671, 2002

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

16 Wilson, A.L., Bell, J., Hosler, D, Weker, R. "Infiltration, Blower Door and Air Exchange Measurements in New California Houses," Southern California Gas Company. 2005

17 Wilson, D.J., and Walker, I.S., (1992), "Feasibility of Passive Ventilation by Constant Area Vents to Maintain Indoor Air Quality in Houses", Proc. Indoor Air Quality '92, ASHRAE/ACGIH/AIHA Conf., San Francisco, October 1992. ASHRAE, Atlanta, GA.

18 Wilson, D.J, and Walker, I.S., (1991), "Passive Ventilation to Maintain Indoor Air Quality", University of Alberta Dept. of Mech. Eng. Report # 81.