Why We Ventilate Our Houses: An Historical Look

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ABSTRACT

The knowledge of how to ventilate buildings, and how much ventilation is necessary for human health and comfort, has evolved over centuries of trial and error. Humans and animals have developed successful solutions to the problems of regulating temperature and removing air pollutants through the use of ventilation. These solutions include ingenious construction methods, such as engineered passive ventilation (termite mounds and passive stacks), mechanical means (wing-powered, fans), and an evolving effort to identify problems and develop solutions. Ventilation can do more than help prevent building occupants from getting sick; it can provide an improved indoor environment. Codes and standards provide minimum legal requirements for ventilation, but the need for ventilation goes beyond code minima. In this paper we will look at indoor air pollutant sources over time, the evolution of ventilation strategies, current residential ventilation codes and standards (e.g., recently approved ASHRAE Standard 62.2), and briefly discuss ways in which we can go beyond the standards to optimize residential ventilation, reduce indoor air quality problems, and provide corresponding social and economic benefit.

Introduction

The concern about "bad air" and efforts to improve indoor air quality has been around for a millennium. Before there were buildings, humans were ventilating their shelters to improve the quality of their environment. Early humans probably understood that bad air was principally a problem generated in the indoor environment and that bringing in outside air could mitigate these problems. While the built environment has changed substantially over the past 10,000 years, their biology has not; poor indoor air quality creates health risks and can be uncomfortable.

Every HVAC professional knows that good indoor air quality cannot be achieved without proper ventilation. Intuitively most people understand that the purpose of ventilation is to dilute indoor contaminants, and that ventilation can also be used to provide ventilative cooling. For many building types, the ventilation rates are determined by codes, standards or guidelines (e.g., ASHRAE 62). For buildings not covered by these standards, engineers may need to base their designs on what has worked in the past for similar buildings. As buildings and their uses change, or for special situations, designers may need to go beyond these parameters to provide for adequate indoor air quality. Whether working with established codes or starting from fundamentals, an understanding of why we ventilate buildings is required.

To provide an understanding of the important factors to be considered in determining how to ventilate buildings today, this paper will discuss the types of indoor air pollutant sources of importance over time, how buildings have been and are being ventilated, the impact of changing building construction and air tightness on indoor air quality, and how ventilation standards have evolved to provide adequate indoor air quality in homes.

An Historical Perspective

Humans and animals have evolved solutions to either adapt to their existing environments or made changes to improve them. Archeological records and animal research provide several examples of how habitats were built to accommodate ventilation and improve indoor air quality.

Probably the first and still most robust ventilation designs may be credited to the colony builders of the insect world. Bee colonies use wing power to regulate pollutants and airflow in their hives. The tall mounds built by the *Macrotermes natalensis* are highly engineered with a series of conduits and arteries that are continuously modified by the termites to use wind-driven ventilation airflow and thermal mass to maintain thermal comfort (Turner 2000, 2002). In the animal world, mammals that live in underground or animal-made shelters have engineered their shelters in a similar way.

Humans have developed many strategies to manage the indoor environments of their homes. The earliest human-related indoor air quality problem may have been caused by the discovery of fire and the subsequent use of fires inside stone-age dwellings. While the specific pollutant that requires ventilation may have changed over time, it has usually been associated with a particular set of pollutant sources that are causing health or comfort problems. Historically, these sources have been heat, combustion, people and their activities, and the buildings themselves.

Heat. A “pollutant” recognized as a problem in early shelters and dwellings was that of excess heat. Ancient societies and architectural approaches included creative and innovative ways of keeping out, keeping in and getting rid of heat. Ventilative cooling has long been used as a means to remove excess heat from buildings, bring in cooler air (where the outside air was cooler), and move the air fast enough to remove heat, cool the room, the person, and aid the body’s natural cooling mechanisms. Ancient Egyptians developed handheld fans to move air. Some of the earliest buildings of the Minoan period show sophisticated designs for passive ventilative cooling, one of which was through the use of building height and windtowers to induce stack ventilation (Coles and Jackson 1975).

Combustion. One of the earliest reasons to ventilate the indoor environment—and one that is still with us today—is to remove the products of combustion used for heat, light or cooking. Various approaches were developed, from source control to exhaust ventilation to remove smoke from dwellings. In 4000-5000 BC, the Banpo villagers in China incorporated chimneys into their homes (Li and Jones 2000). Early Roman houses had vent holes in the middle of their flat roofs to vent smoke out of the living quarters. The basket weaver’s pit houses found in Mesa Verde National Park, circa 750 AD, use this same approach (Wenger and Wilson 1991). The Anasazi Pueblo Kiva used ventilation shafts and exhaust openings to provide combustion air, ventilation air and exhaust combustion products. (Wenger and Wilson 1991). To control outside airflow and exhaust smoke from indoor cooking fires, teepees could be re-oriented to take advantage of wind-driven ventilation and openings in the teepee walls could be adjusted and opened or closed to optimize air movement and thermal comfort (Laubin et al. 1977).

People and their activities. People’s daily indoor activities can generate a variety of airborne contaminants. The types of activities and contaminants have changed over time. From infrequent bathing (some cultures prized odor as a status symbol) to the inadequate or non-existent waste systems, ancient homes were probably quite odorous. Ancient Egyptians used perfumes to mask odors. While human bio-effluents may be unpleasant, poor hygiene can increase the likelihood of airborne disease transmission. Pollutant and particulate generation can also cause health problems in the indoor environment, as determined early on by the Egyptians – they found that stonecutters working inside had higher rates of respiratory problems than those working out of doors (Lord 1986, Woods 1988).

Building sources. Early living quarters offered a rudimentary level of protection from the elements, roaming creatures and enemies. Caves, overhangs and natural materials (trees, stone, clay and animal skins) were used to build shelters. These shelters often had sturdy doors and small openings to the outside to prevent any unwanted creatures or enemies from entering the shelter. This meant that it was difficult to bring in enough outdoor air to dilute any indoor pollutants and homes were often smoky. Sanitary conditions were often quite poor, providing direct contamination and a growth medium for microorganisms.

An Early Law Benefiting Indoor Air Quality

In 1631, concluding that indoor conditions were causing health problems, King Charles I decreed that the ceilings in houses in England must be ten feet or higher and that windows must be higher than their width to allow for natural ventilation. These improvements were slowly implemented into the British building stock. Implementation was hastened only when the great London fire of 1666 destroyed many of the inadequate houses and made the way for construction of larger, better ventilated houses with chimneys, fireplaces and large windows (NY 1923). This trend towards better air quality, however, was suddenly thwarted and possibly reversed when citizens decided to board up their windows to avoid the chimney and window taxes of the early 1700s.

Early Thermal Comfort and Ventilation Solutions

The Romans (3rd century BC) developed the hypocaust heating system by combining ventilation with combustion. These systems were originally used to heat public baths and then modified to heat larger buildings (Donaldson and Nagengast 1994). The hypocaust was a pre-cursor to the heating and ventilation systems integrated into buildings in the late 1800s. Outside air enters the hypocaust, gains heat from a fire, flows through an under-floor series of channels that lead to other channels in the walls, and is finally vented back outside (Dobson 2002). The systems built in England in the late 1880s used a similar approach, but also supplied outside air to the building. In the House of Commons, outside ventilation air is pulled over steam pipes in a heating chamber and is then ducted into the building. Originally, they used open fires to create a thermal draft (Shaw 1907). Exhaust openings in the upper reaches of the building provide a stack effect to pull air through the building (Donaldson 1984 and Cook 1998). These approaches were later expanded upon by Desagulier's rotary fans in the early 1700s (NY 1923). Electric-powered fans entered the fray in the late 1800s and early 1900s after Faraday's invention of the electric motor in the 1830's and Diehl's development of electric fans (Hansen 2003).

Today's Perspective

A look at past ventilation and indoor air quality issues provides insight into today's issues that might otherwise be overlooked. The more recent energy crisis of the late 1970s led to the need for more efficient use of energy, the development of tighter construction techniques, and reduced ventilation standards. With the exception of overheating control, ventilation has always been about health. Not surprisingly, it is ASHRAE's position (2001) to consider health impacts when specifying equipment and controls for indoor environments.

Today's Sources

Sources, which may have been special cases or non-existent, may be more common today. Source reduction and control has taken care of combustion byproducts (heat and light) and modern sanitation has removed the odors and potential bacterial hazards of human waste. However, as buildings have become tighter, some of the old sources of indoor air pollution that may not have been a problem with higher ventilation rates are how creating problems – such as combustion, bio-effluents, microbiologicals, radon and soil gases, particles, and Volatile Organic Compounds (VOCs).

Combustion. Combustion for cooking, space heating and water heating is still a part of most buildings - but the combustion by-products are usually directly controlled rather than being handled by ventilating the building. Most combustion equipment is either sealed from the building or has venting that, when operating properly, removes the by-products before they mix into the indoor air. Some sources of combustion by-products may still remain – some examples include environmental tobacco smoke, automobile exhaust (e.g., from attached garages), un-vented space heaters, decorative gas appliances and un-vented cooking equipment. Backdrafting, where exhaust gases are pulled back into the house rather than exhausted out the furnace or water heater vent pipe, and malfunctioning equipment can create a source when none previously existed.

Bio-effluents. By the middle of the 20th Century, progress had been made in controlling the sources of poor indoor air quality. Many of the infectious diseases had been eliminated as a major concern by improved sanitation and hygiene as well as advances in the medical field (and a decrease in occupant densities). Source control had been sufficiently successful that the biggest demand left for ventilation was to control the irreducible emissions of human bio-effluents.

Unless infectious, human bio-effluents are not a health hazard, though CO_2 can build up in unventilated spaces and cause headaches, moisture in our breath can raise humidity levels and cause condensation and corrosion, and bio-effluents can produce odors that can be unacceptable. The emission and acceptability of human bio-effluents has been well studied. Since the early 20th century, the general assumption has been that if one ventilates to control human odors, there will be enough ventilation to control the health effects from other contaminants.

Microbiologicals. Historically, biological contamination was caused by poor hygiene and sanitation, and was linked to disease. Improved health care, sanitation and ventilation has reduced disease transmission. Today's biological indoor air quality problems are more concerned with the molds and fungi that can grow on building materials and in systems. Ventilation is not particularly effective at reducing exposures to airborne microbiologicals, but it can be part of maintaining the moisture balance that is critical to retarding or enhancing mold growth. In terms of moisture, ventilation can either be a source-control mechanism or a source, depending on the indoor and outdoor conditions.

Radon and soil gas. Buildings with substantial ground contact can be exposed to contaminants in soil gas through cracks or leaks. Soil gas can contain toxics from pesticides or sewer gas, but the highest profile pollutant in this category is Radon. This radioactive, noble gas can have long-term health impacts at very low concentrations. Pressure control and air tightening are far more effective mechanisms at controlling exposure to soil gas than is ventilation.

Particles. Particles can be generated by combustion, can come from outdoors, or they can be generated from indoor sources such as pets, construction activities, or material degradation. Poor cleanliness can exacerbate airborne particles. Particles may be simple irritants, but also can cause allergic reactions (for example, pet dander) or may contain toxic materials (for example, lead in flaking paint). Ventilation is not particularly effective at reducing particle concentrations, but source control or filtration can be (Sherman and Matson, 2003).

Volatile organic compounds. VOCs are compounds that are a common part of modern life. Such products as paints, stains, varnishes, solvents, pesticides, adhesives, wood preservatives, waxes, polishes, cleansers, lubricants, sealants, dyes, air fresheners, fuels, plastics, copy machines, printers, tobacco products, perfumes, and dry cleaned clothes emit VOCs. Source control for many of these compounds requires changes in production or use of the associated product. While such source control is an on-going effort, modern buildings today are typically filled with a low-level of a broad spectrum of VOCs that must be controlled by ventilation.

If we consider pressure management and exhaust ventilation as forms of source control, then the only category—other than bio-effluents—that must be handled by building ventilation is VOCs. One interesting aspect of this result is that the need for ventilation does not tend to scale directly with the number of people, but rather with the amount of VOC-emitting products in the building. As such, the need for ventilation scales with building size. Modern homes and offices tend to have a relatively low population density and an increasing amount of material that can emit VOCs. As a result it can be more important to ventilate to control VOCs than to control human bio-effluents, especially in low-density spaces.

Determining the VOCs of concern and the associated ventilation requirements requires an examination of the materials and products expected to be present and can vary greatly in different building classes. For example, Sherman and Hodgson (2002) have done such an examination for formaldehyde in homes. Formaldehyde is one of the most common VOCs found indoors and is also one of the most studied. They found that the ventilation required to dilute formaldehyde to acceptable levels was substantially larger than that needed to control human bio-effluents for typical occupancies.

Strategies for Improved Indoor Air Quality

While increasing ventilation rates is often the *first* line of defense, reducing or eliminating the pollutant source has always been recognized as the *best* line of defense. The history of combustion processes changing from open and dirty to sealed and clean combustion is an example of this argument. The current ASHRAE position (2001) follows this trend by stating that source control is the most effective and preferred method of providing good indoor air quality in most cases.

Implicit in this approach is that we have taken sufficient care to reduce emissions of any contaminant below the level of concern. Turning that around, an operational definition of a low-emission source is one that would not expose people to contaminant levels of concern when the ventilation rate is that needed to control human odors.

Ventilation Standards

Tredgold was one of the first to come up with quantitative ventilation recommendations . He based his four cfm/person recommendation primarily on the dilution of carbon dioxide (CO_2) and water generated by people. The estimates used were quite crude, but represented a major step forward by actually making the first quantitative design calculations. Reid recommended ten cfm/person (Janssen 1999). The New York State Commission on Ventilation (NY 1923) and Klaus et al. (1970) both document a steady rise in ventilation recommendations over the next half century as theories are further refined and the need to reduce contagion (mostly tuberculosis) is increased.

By the 1880s, the general consensus in the U.S. was that proper ventilation required 30 cfm/person and 22 states had this value prescribed by law by 1925 (Janssen 1999). After the turn of the century, research was beginning to question the need for such high rates. With improvements in sanitation and hygiene reducing the need for ventilation to control contagion, the rationale for ventilation began to shift towards odor and comfort. Yaglou's research in the early 20th century used room-sized chambers and calculated how much airflow would be needed to keep people comfortable. This research served as the basis for American ventilation standards until the mid-1990s, all of which were based on keeping people comfortable and not on reducing exposure to toxic pollutants.

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

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

Standard 62.2 is applicable to both new and existing homes, including all single-family homes and small multifamily ones. Its major requirements are listed below (Sherman 2004). There are a few other requirements, which are either minor, codify general practice, or are relevant only to specific situations.

- With some exceptions, the standard requires whole-house mechanical ventilation. For a typical house, the required ventilation rate is about 50 cfm, but it increases with house size. The standard allows (and provides guidance for) flexibility in ventilation system selection (e.g., continuous or intermittent; supply or exhaust; with or without heat recovery).
- Mechanical exhaust (i.e., to outdoors) is required in kitchens. The basic requirement is that a user-operable vented range hood must exhaust at least 100 cfm of air. To

accommodate the wide range of kitchen configurations in the market, the standard includes an alternative of 5 kitchen air changes per hour of (continuous or intermittent) exhaust without any requirements regarding location within the kitchen.

- Mechanical exhaust is required in bathrooms, but not in rooms such as toilet rooms, laundry rooms, lavatories, and utility rooms. The basic requirement is for a user-operable fan of at least 50 cfm. A continuously operating exhaust fan of 20 cfm may be used as an alternative.
- The fans or fan systems required to meet the previous requirements must meet specific airflow and noise performance levels.
- Combustion appliances must follow applicable codes. For a narrow set of circumstances, vented combustion equipment must be checked for backdrafting / spillage. Otherwise, there are no requirements specific to combustion equipment, vented or unvented.
- When air handlers or return ducts are in an attached garage, the duct system must be tested to meet air tightness specifications.

Good particle filtration is required upstream of air handling components. (The minimum filtration requirement is easily met, but is better than the fiber filters most commonly used.)

Going Beyond the Standards

HVAC professionals, bound by the ethics of their profession, must consider standards such as 62.2 when dealing with residential ventilation. Best practices, unlike standards, are things to consider and to strive for, but go beyond the minimum standard of care. Current ASHRAE policy is that standards such as 62.2 represent minimum requirements and are not necessarily best practice (Sherman 2004).

ASHRAE has generated a list of the top ten actions that homeowners can take to get good indoor air quality. This list goes beyond the requirements of Standard 62.2 and includes recommendations from ASHRAE's Handbook of Fundamentals and also from the ASHRAE technical committee (TC 5.12: Ventilation Requirements and Infiltration). These recommendations relate to fossil-fuel fired water heaters and furnaces, ventilation fans, location of furnaces and ductwork, fireplace and wood stove venting and air tightness, particle filters in central air handling systems, storage of volatile compounds, outside air provisions, operable windows or additional mechanical ventilation for source control, and restrictions on un-vented combustion sources.

Summary

We ventilate our buildings to provide a healthy indoor environment. The ventilation guidance of the late 20th Century assumed that controlling odors—which are primarily caused by human bio-effluents—would have the desired effect of controlling otherwise unavoidable contaminants as well. Improved source control related to combustion, particulates, moisture, etc. would take care of the rest of the contaminants. These improved source control measures justified the drop in recommended ventilation rates from 30 cfm/person to a third or a half of that.

To a great extent this strategy was successful. As the amount of new products and materials increases in our buildings and as the occupant density of most building goes down, however, it becomes necessary to ventilate for contaminant sources that are related to the building—even when improved source control is used. Failures in source control strategies (e.g., allowing appliance backdrafting, failing to provide bathroom and laundry room exhaust, smoking, improper site drainage, etc.) are often found to be responsible for IAQ problems.

From an energy efficiency standpoint it would be best to keep minimum ventilation requirements as low as possible. Since controlling human bio-effluents is not currently a practical alternative, there is a practical lower limit. To keep minimum requirements at that level requires an understanding and control of the contaminants of concern such as VOCs. If such source control methods are not available, ventilation becomes what it has always been—the control measure of last resort. Over-ventilating during cold weather can cause comfort and possible moisture-related problems as well as un-necessarily increase the amount of energy used to maintain thermal comfort.

Acknowledgements

This work was supported by the Assistant Secretary for Energy Efficiency and Renewable Energy, Office of Building technology, State and Community Programs under U.S. Department of Energy Contract No. DE-AC03-76SF00098.

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