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Effects of Air Infiltration and Ventilation

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Introduction

THIS CHAPTER DISCUSSES THE ROLE OF AIR INFILtration and ventilation in building moisture transport. While water vapor diffusion can be a very important moisture transport mechanism, as discussed in other chapters, bulk air movement via infiltration and ventilation carries far more water vapor into and out of buildings than diffusion, as much as ten times or more under common conditions [1]. Therefore it is important that we understand the phenomena of infiltration and ventilation, and the related building and system features that determine the impacts on moisture transport. This chapter discusses the terminology related to infiltration and ventilation, the driving forces for infiltration, envelope airtightness and its measurement, mechanical ventilation systems, building ventilation requirements and interzone airflows within buildings. Many of these issues are well covered in Chapter 27 Ventilation and Infiltration of the *ASHRAE Fundamentals Handbook* [2], and therefore the material in this chapter reviews that information briefly and focuses on the moisture-specific implications. Other valuable resources for information on infiltration and ventilation include the publications and conference proceedings of the Air Infiltration and Ventilation Centre (AIVC) (*www.aivc.org*), as well as various other ASHRAE publications. In addition, ASTM has held a number of symposia over the years that have resulted in Special Technical Publications (STPs) with a number of useful technical papers [3–5].

Terminology

In discussing the interactions of airflow and moisture transport, it is important to use consistent terminology. However, the relevant terms in the area of building leakage and infiltration are not always used consistently, and therefore several terms are discussed here with reference to Fig. 1. In addition, the AIVC has produced a useful glossary of related terminology that can be consulted for more detailed information [6].

Starting outside the building, *ambient air* refers to the air around a building, which serves as the source of outdoor air (plus water vapor and other airborne substances) brought into a building. *Outdoor air* is the air brought into the building by a ventilation system, which may be impacted by local contaminant sources that do not impact the ambient air. Note that not all buildings have ventilation systems that bring in outdoor air. For example, many low-rise residential buildings in the United States do not have any intentional outdoor air intake, but rather rely on envelope leakage or infiltration for outdoor air. Sometimes outdoor air is referred to as *makeup air*, generally when that air is being used to provide sufficient outdoor air for the proper functioning of exhaust systems and combustion processes. After the outdoor air enters the ventilation system, it is often mixed with *recirculated air*, with the combination referred to as *supply air*. Even if there is no recirculation (so called 100 % outdoor air systems or operating conditions), the ventilation air delivered to the ventilated space is still referred to as *supply air*. Generally, supply air is heated or cooled, humidified or dehumidified, and often filtered. The air pulled back to the system from the ventilated space is referred to as *return air*, some of which is recirculated with the rest exhausted from the building. The air that leaves the building is referred to as *exhaust air* or sometimes *spill air*. Many buildings also have separate exhaust air systems, such as those serving toilets and kitchens. Finally, airflow into and out of the building through leaks in the building envelope is referred to as *infiltration* and *exfiltration*, respectively. As discussed later in this chapter, infiltration is driven by pressure differences across the building envelope caused by indoor-outdoor air temperature differences, wind and the operation of mechanical ventilation equipment and vented combustion devices.

There are other terms of interest relevant to discussions of moisture in buildings that are not depicted in Fig. 1. *Ventilation*, as described in ASHRAE Standard 62.1 [7], is "the process of supplying air to or removing air from a space for the purpose of controlling air contaminant levels, humidity, or temperature within the space." Note that this definition does not refer specifically to outdoor air, which is sometimes a source of confusion. Some people assume that ventilation means outdoor air, while others think of ventilation as supply air, which need not contain any outdoor air at all. Therefore it is a good idea to refer to outdoor air ventilation when discussing outdoor air intake, and supply air or total ventilation when referring to the air delivered primarily for space conditioning. Standard 62.1 defines *mechanical ventilation* as "ventilation provided by mechanically powered equipment such as motor-driven fans and blowers, but not by devices such as wind-driven turbine ventilators and mechanically operated windows" and *natural ventilation* as "ventilation provided by thermal, wind or diffusion effects through doors, windows, or other intentional openings in the building." *Transfer air* refers to airflow from one space to another, which in many cases is done intentionally. For example, bathrooms are ventilated by exhaust, with transfer air from adjoining spaces flowing into the bathrooms, often through grilles in doors, to replace the exhaust air.

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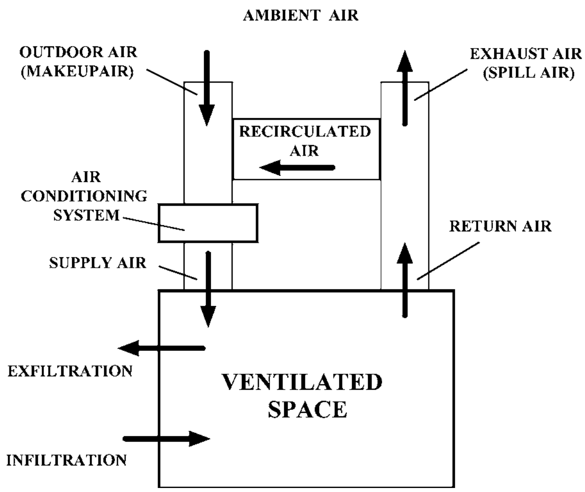

Fig. 1—*Schematic of mechanically ventilated space.*

Another collection of terms is related to the physical porosity or leakiness of the building envelope or its *airtightness*. Often the term *air leakage* is used to refer to this airtightness as a physical attribute of the envelope independent of the weather conditions that lead to airflow through these leaks under normal circumstances. This air leakage or airtightness is measured with a fan pressurization test as described later in this chapter.

The units to describe airflow, infiltration, and ventilation bear some discussion as well. These airflows can be expressed in volumetric airflow units such as L/s, cfm (cubic feet per minute), m^3/s, or m^3/h, but they are also often described in terms of air change rates, which is the volumetric airflow divided by the volume of the space or building of interest. Air change rates are generally expressed in units of air changes per hour or inverse hours, h^{-1}. Some people use ach as a unit for air change rate, but ach is not a proper unit and its use is discouraged. The air change rate of a space or building can be used to describe any of several relevant airflows, total or supply air, mechanical outdoor air intake, infiltration, or total outdoor airflow into a building. In order to avoid confusion it is important to specify which airflow is being discussed when referring to the air change rate of a building or space. Ventilation system airflows are generally referred to in volumetric units, while infiltration rates are almost always presented in air changes per hour or h^{-1}. Ventilation system airflows are sometimes normalized by floor area served, for example commercial building supply airflow rates are often expressed in $L/s \cdot m^2$ or cfm/ft^2.

Infiltration

Infiltration (and exfiltration) through leaks in the building envelope is important to moisture transport for a number of reasons. It is the primary mechanism by which many buildings are ventilated with outdoor air, and by which indoor air leaves the building. The outdoor air change rate determines the indoor moisture level based on indoor moisture generation rates and outdoor conditions, and the indoor moisture level is obviously critical to the potential for condensation and other issues discussed in this book. In addition, infiltration (and exfiltration) carries airborne water vapor into (or out of) the building envelope, where the vapor may encounter temperatures below the dewpoint, leading to condensation. Again as discussed elsewhere in this book, condensation within the envelope can lead to serious problems.

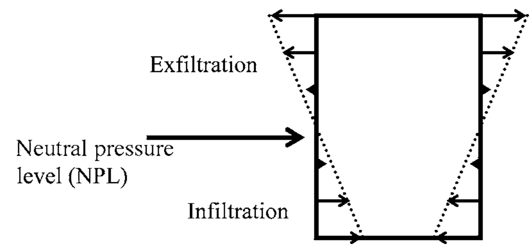

Fig. 2—*Schematic of stack pressures* ($T_{in} > T_{out}$).

Envelope infiltration is driven by pressure differences across openings in the building envelope. This section describes the driving forces for these pressure differences, along with some of the implications for moisture transport, as well as how building leakage is measured. In addition, existing data on building airtightness measurements are summarized for both low-rise residential and commercial buildings.

Driving Forces

The pressure differences that drive infiltration are caused by indoor-outdoor air temperature differences, wind, and the operation of ventilation equipment and vented combustion devices. The physics of these phenomena are well understood and thoroughly discussed in the *ASHRAE Fundamentals Handbook* [2].

When indoor and outdoor air temperatures are different, the resulting indoor-outdoor density difference leads to a change in air pressure with height that is different inside the building than outside. This difference in the air pressure variation with height leads to a pressure difference across the exterior walls, which also varies with height. In the simplest case, with a uniform distribution of leakage over the exterior envelope and no interior obstructions to airflow, indoor-outdoor pressure differences will exist as shown in Fig. 2 under conditions where the indoor air is warmer than outdoors. During such heating conditions, air tends to enter the building through leaks low in the building envelope and then leave or exfiltrate from the higher leaks. This pressure pattern is often referred to as the stack or chimney effect. When the sign of the indoor-outdoor temperature difference is reversed, then the directions of the pressure differences and the airflows are reversed, with air infiltrating high and exfiltrating low. Larger indoor-outdoor temperature differences lead to larger pressure differences. Neglecting internal resistance to airflow, the stack pressure difference at the top and bottom of a building is on the order of 0.02 Pa per m of building height and degree K of indoor-outdoor temperature difference. Therefore for a one-story house (height of 2.5 m) and a 25 K indoor-outdoor temperature difference (cold weather), the stack pressure difference at the top and bottom is about 1.3 Pa. Considering a tall building (20 stories of 4 m each), the stack pressure for this same temperature difference is approximately 40 Pa.

The height at which the pressure difference across the building envelope equals zero is referred to as the neutral pressure level or NPL. The height of the NPL is a function of the vertical distribution of the envelope leakage. If the leakage is uniformly distributed in the vertical extent, then the NPL is one-half the building height. If there is more leakage located high on the envelope, the NPL moves up accordingly. A very high leak, such as a chimney, can raise the neutral pressure plane significantly, even above the roof of the building in extreme circumstances. Operating an exhaust fan also raises the neutral pressure level. The important issue for moisture transport is that outdoor air and the water vapor therein will tend to enter the building at low heights during the heating season and indoor air (at the indoor relative humidity) will flow outwards through the building envelope high in the building. These directional issues are important as the water vapor content of these airstreams interacts with the temperature within the envelope in determining the potential for condensation within the envelope. For example, under heating conditions, the relatively moist indoor air leaving the building at higher points on the wall can encounter cold temperatures in the envelope (particularly when there are insulation defects such as thermal bridges) and condense. In these cases, mold growth may be more likely at these high points, as discussed elsewhere in this manual.

In the more general case of a building with interior partitions such as floors and vertical shafts, and therefore resistance to interior airflow, the stack pressures become somewhat more complicated [8–10]. Generally they will reduce the magnitude of the pressures relative to the idealized case in Fig. 2, but the pattern of infiltration at lower levels under heating conditions remains.

When wind impinges on a building, it tends to cause infiltration on the windward side and exfiltration on the other building sides and the roof. The impact of wind speed and direction on moisture transport will be climate and site specific, depending on the relative consistency of the prevailing wind direction and the exposure of the building. Wind is generally more of an issue in terms of wind-driven rain than infiltration, but wind-induced pressures are a major driving force for infiltration and need to be considered. The wind pressures on the exterior face of a building are a function of the square of the wind speed, as well as the orientation of the face relative to the wind direction and the height on the building. There can also be localized effects, at eaves and corners for example, that can lead to significantly higher or lower wind pressures than the average value over a building wall. Typically at lower wind speed (perhaps 2.5 m/s or less), these exterior wind pressures are on the order of 1 Pa or 2 Pa. At higher wind speeds, for example 10 m/s, wind pressures are on the order of 25 Pa.

When the stack effect and wind act in combination, the pressures add or subtract at each location on the building envelope, resulting in a pressure distribution such as that shown in Fig. 3. This pattern corresponds to a heating situation with the wind blowing from the left-hand side. Note that the neutral pressure is different on the various sides of the building when the wind blows in combination with the stack effect.

The operation of mechanical equipment, ventilation systems, local exhaust fans, and vented combustion appliances also induce indoor-outdoor pressure differences. In the absence of any temperature difference or wind, a net flow into the building will raise the interior pressure above the outdoors at all points on the building envelope. Correspondingly, a net exhaust airflow will lower the interior pressure. When the stack and wind effects exist in combination with these mechanically induced pressure differences, the pressures at each location combine, leading to locally varying and potentially complex pressure patterns. An important impact of these mechanical pressures on moisture relates to climate and whether the building is at a net positive or negative pressure. If the building is positive, the indoor air will exfiltrate out through the building envelope at the interior humidity conditions. Under heating conditions, this can lead to moist indoor air condensing on cold envelope surfaces, even leading to the formation of ice within the wall in colder climates. A host of moisture-related problems can result under these circumstances. On the other hand, a building running negative under cooling conditions will draw moist outdoor air inward through the building envelope where it may encounter cold surfaces and condense. As highlighted elsewhere in this manual, negative building pressures under cooling conditions can lead to some very severe moisture problems, especially if the interior surface of the envelope is relatively impermeable to moisture transport.

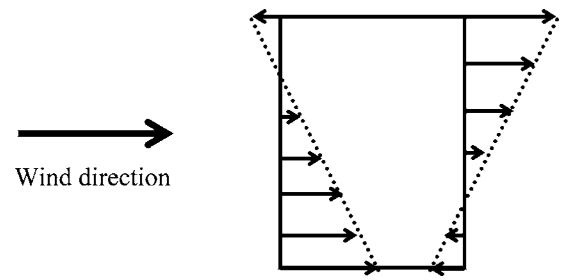

Fig. 3—*Schematic of combined stack and wind pressures.*

Envelope Airtightness

The pressure differences described in the previous section act across openings in the building envelope to cause airflow into and out of buildings. This airflow carries airborne water vapor. Therefore, the airtightness of the building envelope is a critical parameter in discussing and understanding the impacts of infiltration on moisture in buildings. This section discusses envelope airtightness, specifically how it is measured and the range of airtightness values that have been observed in the field.

Measurement

The airtightness of building envelopes is measured using a fan pressurization test in which a fan is used to create a series of pressure differences across the building envelope between the building interior and the outdoors. The airflow rates through the fan that are required to maintain these induced pressured differences are then measured. Elevated pressure differences in the range of 10 Pa to around 75 Pa are used to override weather-induced pressures, such that the test results are independent of weather conditions and provide a measure of the physical airtightness of the exterior envelope of the building.

ASTM Standard E779 [11] is a test method that describes the fan pressurization test procedure in detail, including the specifications of the test equipment and the analysis of the test data. In conducting a fan pressurization test in a commercial building, the building's own air-handling equipment sometimes can be employed to induce the test pressures. A Canadian General Standards Board standard describes the use of a building's air-handling equipment to conduct such a test [12]. In other cases, a large fan can be brought to the building to perform the test. Low-rise residential buildings are often tested with a so-called "blower door" and ASTM Standard E1827 [13] is a test method written specifically for blower doors that employ an orifice approach to measuring the airflow rate.

Fan pressurization test results are generally reported in terms of the airflow rate at some reference pressure difference divided by the building volume, floor area, or envelope surface area. Such normalization accounts for building size in interpreting the test results. In most cases, the pressure and flow data for measurements performed at multiple pressure differences are fitted to a curve of the form:

$$Q = C \cdot \Delta p^n \tag{1}$$

where Q is the airflow rate, Δp is the indoor-outdoor pressure difference, C is referred to as the flow coefficient, and n is the flow exponent. Once the values of C and n have been determined from the test data, the equation can be used to calculate the airflow rate through the building envelope at any given pressure difference.

Using Eq (2) below, the airflow rate at a reference pressure is often used to estimate the effective leakage area of the building, which is the area of an orifice that would result in the same airflow rate at the reference pressure difference.

$$\mathrm{ELA} = 10{,}000 \cdot Q_r(\rho/2\Delta p_r)^{1/2}/C_D \tag{2}$$

where ELA is the effective leakage area in cm^2, Q_r is the airflow rate at the reference pressure difference Δp_r in m^3/s, ρ is the air density in kg/m^3, Δp_r is the reference pressure difference in Pa, and C_D is the discharge coefficient (not to be confused with C in Eq (1)). This equation is often used to calculate the effective leakage area at an indoor-outdoor pressure difference of 4 Pa with a discharge coefficient of 1, but other values of the reference pressure and discharge coefficient are sometimes employed. Values of the effective leakage area are then normalized by the envelope surface area or by the building floor area to account for differences in building size.

In addition to the whole building measurement techniques described above, procedures exist to test the leakage of individual building envelope components such as windows, walls, and doors. ASTM E283 [14] and ASTM E783 [15] are test methods for measuring component air leakage in the laboratory and field, respectively. ASTM E1186 [16] describes several techniques for locating air leakage sites in building envelopes and air barrier systems.

Airtightness Data

The importance of envelope airtightness to residential heating and cooling energy use has long been recognized and, thus, the airtightness of many single-family houses has been measured. Often, these measurements have been made as part of weatherization or other energy efficiency programs. Recently, Sherman and Matson [17] reported on a database of airtightness measurements for over 70,000 U.S. homes. While the average leakage for the whole database is quite high, about 20 air changes per hour at 50 Pa (or ACH50), new U.S. homes appear to be constructed tighter, with the average leakage of over 1,000 conventional new houses built since 1993 about half of that average value. As one might expect, energy efficiency construction programs appear to have a significant impact on house leakage as the average reported for new houses under such programs was half that of conventional new houses, or an ACH50 of 5 h^{-1}. Many homes in Canada and various Nordic countries are often constructed with very tight building envelopes, with several countries having standards or regulations for envelope airtightness [18].

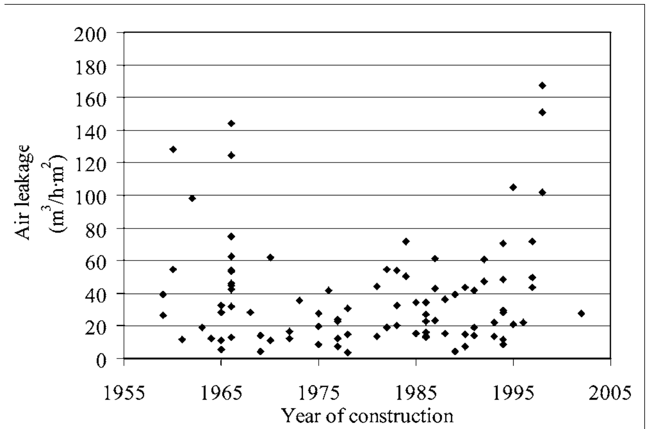

Fig. 4—*Commercial building air leakage (normalized by enclosure area) versus year of construction.*

Many discussions in the popular press and the technical literature still refer to commercial and institutional buildings, and newer buildings in particular, as being airtight. "Tight buildings" are often blamed for a host of indoor air quality problems including high rates of health complaints and more serious illnesses among building occupants. In 1998, Persily published a review of published commercial and institutional building airtightness data that found significant levels of air leakage and debunked the "myth" of the airtight commercial building [19]. More recently, Emmerich and Persily [20] reported on a database of airtightness measurements for 201 commercial and institutional buildings in the United States. The average airtightness for these buildings was found to be 28 m^3/h per m^2 of above grade enclosure surface area at 75 Pa, which is tighter than the average for United States houses but leakier than the average for conventional new United States houses. Unlike the residential airtightness data, the database of U.S. commercial building airtightness shows no indication of a trend toward tightness for newer buildings (see Fig. 4). Although the data show considerable scatter, there are trends indicating taller buildings are tighter on average than shorter buildings and that buildings in colder climates are tighter on average than buildings in warmer climates.

In addition to the whole building airtightness data discussed above, efforts have been made to collect and publish air leakage data for individual components [21]. Data exist for building joints, penetrations, and other leaks. Data also exist for doors and windows; however, those components are generally not significant contributors to total building leakage [22].

Infiltration Measurement and Prediction

Infiltration rates have been measured in many buildings, primarily low-rise residential using tracer gas dilution methods. ASTM Standard E741 [23] describes several tracer gas methods applicable to single zone buildings. These same techniques can be used to determine whole building air change rates in mechanically ventilated buildings, where the test result indicates the combination of infiltration and outdoor air intake. Since infiltration rates are a strong function of weather conditions, varying by a factor of 5 to 1 or even more, it is important to consider those conditions when reporting and interpreting such measurements. And in order to fully understand the infiltration characteristics of a building, many measurements are required under a range of weather conditions. A number of studies of infiltration rates in low-rise residential buildings have been conducted, though they have not involved randomly selected collections of homes [24,25]. Nevertheless, they do provide some indication of variations in infiltration rates as a function of climate and building features such as envelope airtightness.

Models have been developed to predict infiltration rates in buildings as a function of weather conditions, building leakage, and other building features. These range from simple single-zone models that employ a number of assumptions to simplify the calculation process to more complete network airflow analysis models that consider buildings as multizone systems and require more detailed input data [2]. An example of the latter type of program is the CONTAM model [26], which has been widely used to study airflow and indoor air quality in buildings.

Ventilation

Consistent with the definitions in the terminology section, ventilation is considered here to be the purposeful introduction of outdoor air into buildings, which is driven by either natural forces (i.e., natural ventilation), mechanical equipment (i.e., mechanical ventilation), or some combination thereof. While infiltration also introduces outdoor air into buildings, it is not considered to be ventilation per these definitions. The vast majority of residential buildings in the United States rely on infiltration as their primary source of outdoor air, supplemented by use of natural ventilation (e.g., open windows) and mechanical ventilation (e.g., bathroom and kitchen exhaust fans). However, the use of mechanical ventilation as the primary source of outdoor air in single-family houses has been growing in recent years, partially propelled by new ventilation codes and standards. The ventilation picture in United States commercial and institutional buildings is quite different from that in residential buildings, as the dominant practice has long been reliance on mechanical ventilation with infiltration generally considered unwanted and with interest in natural ventilation increasing in recent years.

Natural Ventilation

Natural ventilation's greatest advantage and disadvantage are both derived from the fact that it is driven by natural wind and thermal forces. Since there is no mechanical equipment required, natural ventilation systems typically have lower first costs and no operating cost (not including the costs of heating and cooling the ventilation air). However, since the amount of airflow relies on changing weather conditions, the result can be too little airflow sometimes and too much airflow—causing increased thermal loads—at other times. Many natural ventilation systems also require occupant action (e.g., opening windows or vents) to ensure proper ventilation.

The focus of this discussion of natural ventilation has been on its use as a means of introducing outdoor air for air quality purposes. However, modern buildings with designed natural ventilation often use it as the principal, if not only, source of cooling also. Such natural ventilation systems have significant implications for moisture levels in buildings as those buildings lack the moisture removal provided by mechanical equipment. Therefore, the issue of moisture levels must be considered carefully by the designer if applying natural ventilation to buildings with significant moisture sources or in humid climates.

A recent surge in interest in Europe has led to advanced natural ventilation technology and spurred development of hybrid (or mixed-mode) ventilation systems, which offers the possibility of attaining energy savings in a greater number of buildings through the combination of natural ventilation systems with mechanical equipment. The interested reader can learn more about natural and hybrid ventilation systems from numerous recent publications [27–31].

Mechanical Ventilation

Most U.S. commercial buildings include mechanical systems that supply air made up of a large fraction of recirculated air with a smaller fraction of outdoor air intake. Some mechanical ventilation systems have economizer cycles which provide additional outdoor air for "free cooling" when outdoor temperature or enthalpy conditions fall into an appropriate range. A smaller fraction of U.S. commercial buildings have either 100 % outdoor air systems or dedicated outdoor air systems, which provide conditioned outdoor air without recirculation. With these systems, additional thermal conditioning of the building space is provided by a separate air or water system if needed.

Since residential mechanical ventilation systems are relatively new, at least in the United States, no system can necessarily be called typical. Options include heat or energy recovery ventilators that may be either separate systems or provide supply into a central heating and cooling system, a dampered outdoor air intake connected to the return of a central heating and cooling system, or a whole-house exhaust system with multiple exhaust pick-up locations. These systems are frequently not operated full-time, but have timers to ensure sufficient run-time to meet ventilation needs.

Both residential and commercial buildings also utilize local exhaust systems whose primary purpose is the removal of moisture and odors from spaces such as bathrooms and kitchens. Such systems can be effective at removing moisture from the building before it mixes into the remainder of the building. Typically, local exhaust fans are operated continuously during occupied hours in commercial buildings, but are operated intermittently by occupants in residential buildings. Humidistats are another local exhaust control option and may ensure longer run-times, thus increasing moisture removal.

In addition to directly introducing outdoor air, mechanical systems also have important impacts on building pressures, which may contribute to the infiltration of outdoor air or exfiltration of indoor air through building envelopes. While some of these effects are intentional and expected, such as deliberate provision of greater supply air than return air in an attempt to pressurize a space, just as often such effects may be unintentional through either inappropriate design or lack of thorough testing and balancing. Additionally, even if total supply and return in a building are balanced, individual zones can be pressurized or depressurized due to local supplies and returns, thus resulting in unplanned infiltration or exfiltration.

Similarly, duct leakage can cause unplanned airflows that may result in the introduction of outdoor air from return leaks in humid spaces (e.g., crawl spaces) or through depressurization due to supply leaks outside the building envelope. One study found that residential duct leakage contributed almost 30 % to the total leakage of houses [32].

It is also important to recognize that actual mechanical ventilation system airflows cannot be assumed to equal design flows if such flows are even known. A recent study characterized the ventilation systems serving 100 randomly selected U.S. office buildings [33] including measurement of outdoor airflow rates and comparison to design in the 97 buildings that were mechanically ventilated. The study found that design minimum outdoor air intake values were available for only about half of the mechanical systems. Also, about half of the measured outdoor airflows (under minimum outdoor air intake conditions) were below 10 L/s per person. Under minimum outdoor air intake, about half of the measured outdoor air intake rates were below the requirements in ASHRAE Standard 62-1989 [34], the version of the standard that would have applied at the time they were designed. Similar issues were identified for building exhaust fans as design values were available for 129 of the 159 exhaust fans and the average measured flow in a subset of 41 fans was only 57 % of the design flow.

Outdoor air ventilation rates tend to be higher than might be expected, with a mean value of 49 L/s per person based on the number of occupants and 36 L/s per person based on the number of workstations in the space. Still, 17 % of these measured values (per occupant) are below the 10 L/s per person requirement in ASHRAE Standard 62-1989, and these lower rates occur in 22 of the 97 mechanically ventilated buildings. While these values are high on average relative to the minimum outdoor air requirements in Standard 62, the high outdoor air fractions and the low occupancy relative to the actual number of workstations (and to the default occupancy value in the standard) explains most of the higher values. Adjusting the measured outdoor air ventilation rates to minimum outdoor air conditions and to the occupant density in Standard 62 reduces the mean to 9 L/s per person. Considering only those values that correspond to minimum outdoor air intake, the mean ventilation rate is 14 L/s per person. Adjusting these minimum values for the number of workstations rather than the measured occupancy levels yields a mean of 11 L/s per person, with one-half of these minimum values being below the requirement in ASHRAE Standard 62-1989. In other words, under minimum outdoor air intake, about one-half of the measured outdoor air intake rates are below the requirements in ASHRAE Standard 62-1989 based on the expected occupant levels in the space, and about one-quarter of the rates are below 5 L/s per person, i.e., one-half of the 1989 ASHRAE requirement.

Ventilation Requirements

A number of countries have ventilation requirements in standards or regulations [18]. The most widely recognized ventilation requirements in the United States are ASHRAE Standard 62.1 for commercial buildings and Standard 62.2 for low-rise residential buildings [7,35]. ASHRAE Standard 62.1 has long been adopted by many U.S. codes and provides requirements for ventilation systems and equipment including minimum outdoor airflow rates for spaces including correctional facilities, schools, restaurants, hotels, offices, retail buildings, public assembly spaces, and sports facilities. Standard 62.1 also provides minimum exhaust rates for toilets, commercial kitchens, and other spaces.

ASHRAE Standard 62.2 was first published in 2003 and has not yet been adopted by code in most U.S. jurisdictions. Like Standard 62.1, 62.2 provides requirements for ventilation systems including equipment performance, minimum outdoor airflow rates, and local exhaust rates for kitchens and bathrooms. These latter exhaust requirements are driven primarily by the goal of removing moisture from these spaces.

Interzone Airflows

Consideration of whole building air infiltration and ventilation rates can assist in understanding building moisture issues, but in some cases it is necessary to also consider airflow between buildings zones with potentially different moisture conditions, such as bathrooms, kitchens, and basements. In particular, airflows to and from unconditioned spaces such as crawl spaces, attics, and wall cavities can be more significant due to the generally wider range of temperatures and humidity conditions in these types of spaces. Airflows between these various zones are driven by the same pressures and leakages discussed earlier in the context of whole building leakage, and the same modeling tools such as CONTAM [26] can be used to predict these interzone airflow rates and the associated moisture transport. Tracer gas techniques exist to measure these interzone airflow rates, but they have not been standardized and remain largely in the realm of research. However, it is rarely necessary to measure these airflows to understand the moisture impacts of these spaces in a particular building.

Summary

Infiltration and ventilation airflows can have a major impact on moisture in buildings. They can either be part of the problem or part of the solution, but they cannot be ignored when one is designing, operating, maintaining, or troubleshooting a building. These airflows can directly introduce moist or dry air into a building space, then can create pressures that move moisture into or keep it out of the building envelope, and they can enable or prevent the transport of moist air from one building space to another. In recent decades, the understanding of building airflow fundamentals has improved, measurement methods have been developed and standardized, data have been collected and analyzed, design guidance has been published, and modeling tools have become widely available. There are still unanswered questions and each building still requires consideration of its own unique circumstances, but there is no reason to ignore these effects given the established knowledge.

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