Study Guide for Indoor Air Quality for Inspectors Course

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• read and study offline;
• organize information; and
• prepare for assignments and assessments.

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Learning Objectives

Most of us spend much of our time indoors. The air that we breathe in our homes, in schools, and in offices can put us at risk for health problems. Some pollutants can be chemicals, gases, and living organisms like mold and pests.

Several sources of air pollution are in homes, schools, and offices. Some pollutants cause health problems such as sore eyes, burning in the nose and throat, headaches, or fatigue. Other pollutants cause or worsen allergies, respiratory illnesses (such as asthma), heart disease, cancer and other serious long-term conditions. Sometimes individual pollutants at high concentrations, such as carbon monoxide, cause death.

By attending this session, participants will:

• Learn about the factors affecting Indoor Air Quality (IAQ);
• Understand the role moisture plays in IAQ;
• Learn about moisture movement;
• Learn pollutant remediation techniques; and

The information provided in this course is based on current scientific and technical understanding of the issues presented. Following the advice given will not necessarily provide complete protection in all situations or against all health hazards that may be caused by indoor air pollution.

Acknowledgments

Course content contributors:

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• U.S. Environmental Protection Agency (EPA) Indoor airPLUS Program, Technical Guidelines;
• Oklahoma Department of Commerce, State Energy Office "Best of Building Science" Online Training;
• U.S. Environmental Protection Agency (EPA) Indoor Air Quality http://www.epa.gov/iaq/; and
• The International Association of Certified Home Inspectors (InterNACHI)

Definitions

Air Changes per Hour (ACH): The number of times in one hour that all of the air in a home is replaced by outside air through air leakage and/or ventilation.

Air transport: Movement of moisture vapor by convective air currents.

Building Tightness Limit (BTL): A level of air tightness at which indoor air quality and building integrity may be compromised if the residence is any tighter.

Bulk moisture: Large amounts of water intrusion, for example from wind-driven rain or sub-surface water.

Capillary action: Movement of liquid water across a material as a function of the surface tension of the water and the porosity of the material.

Carbon Dioxide (CO2): One of two main products of complete combustion of a hydrocarbon. (The other is water vapor.)

Carbon Monoxide (CO): Carbon monoxide is a tasteless, odorless, colorless, and poisonous gas that is a by-product of incomplete combustion of fossil fuels. It is usually caused by a lack of air to support combustion or impingement of the flame.

Climate zone: An area with a prevailing climate that distinguishes it from other areas by parameters such as temperature, rainfall, and humidity.

Cubic Feet per Minute (CFM): A measurement of air movement past a certain point or through a certain structure. Used in pressure diagnostics to quantify air leakage.

Diffusion: Movement of water vapor through a material as a function of the driving force across and the porosity of the material.

Dilution: Relying on adequate ventilation to reduce the concentration of pollutants to acceptable levels.

Elimination: Removing the source of the pollution.

Encapsulation: Containing the pollutant so it will not affect air quality.

Indoor Air Quality (IAQ): The quality of indoor air relative to its acceptability for healthful human habitation. Assessing and ameliorating, when necessary, the quality of indoor air is a major concern of the weatherization process. In particular, all by-products of major combustion appliances must be directly evacuated to the outdoors under all operating conditions.

Lawrence Berkeley National Laboratories (LBNL, sometimes referred to as LBL): Member of the national laboratory system supported by DOE though its Office of Science. It conducts unclassified research across a wide range of scientific disciplines.
Minimum Ventilation Guideline (MVG): Process used to emphasize the ventilation needed after a building is tightened to the maximum practical extent.

N-factor: Used to convert readings taken at CFM50 to CFMnatural, the amount of air leakage that occurs naturally. The N-factor depends on climate, building height, and shielding from wind. N ranges from 9.8 to 29.4, but typically averages about 20. A higher N-factor means the blower door is creating more exaggerated conditions. A lower "N" means the blower door reading is closer to the natural leakiness of the home.

Pascals (Pa): Metric standard for measuring pressure differences. 248 pascals equal one inch of water column, approximately the weight of one Post-it note.

Performance standard: Specification of the conditions that will exist when a satisfactory job is performed.

Permeance rating: Number that quantifies the rate of vapor diffusion through a material.

Porosity: Measure of the void spaces in a material, expressed as either a fraction or a percentage of the total volume of material.

Prescriptive standard: Specifies in detail the requirements and test procedures to be followed.

Radon: A radioactive gas present in certain soils that decomposes into radioactive particles. In certain areas, radon compromises IAQ when it enters the home through basements or crawlspaces.

Relative Humidity (RH): The amount of water vapor in the air, expressed as a percentage of the maximum amount that the air could hold at a given temperature.

Savings-to-Investment Ratio (SIR): A calculation that determines the cost-effectiveness of a weatherization measure by dividing the estimated savings over its lifetime by the cost. SIR is computed over the lifetimes of the retrofit measures installed. Investment includes materials, labor, and support costs. Savings is expressed in terms of the net present value of the retail cost of the dwelling's fuel. Under some methodologies, other benefits or investments are included. SIRs of greater than one are counted as cost effective under this DOE WAP method of determining cost-effectiveness.

Zonal Pressure Diagnostics (ZPD): Using a blower door to determine the interconnectivity of various building components, which helps the practitioner locate the pressure boundary and know if the air and thermal barriers are aligned. Also called zonal pressure diagnostics.
Quiz #1

Most of us spend much of our time ____.

- indoors
- outdoors

T/F: Some pollutants can be chemicals, gases, and living organisms like mold and pests.

- True
- False

____ is number of times in one hour that all of the air in a home is replaced by outside air through air leakage and/or ventilation.

- Air Changes per Hour (ACH)
- Cubic Feet per Minute (CFM)
- Air-to-Air Heat Exchanges (AAHE)
- Air Infiltration (AI)

____ is one of two main products of complete combustion of a hydrocarbon. (The other is water vapor.)

- Carbon dioxide
- Carbon trioxide
- Carbon deposits
- Heat dilution

____ is measurement of air movement past a certain point or through a certain structure, and is used in pressure diagnostics to quantify air leakage.

- Cubic feet per minute (CFM)
- Cubic liters per foot
- Air Flow Index (AFI)
- Blower door

The number that quantifies the rate of vapor diffusion through a material is the ____.

- permeance rating
- permanent number
- vapor per foot
- HERS rating

T/F: The amount of water vapor in the air, expressed as a percentage of the maximum amount that the air could hold at a given temperature is the Relative Humidity (RH).
• True
• False

Introduction to Indoor Air Quality (IAQ)

What Causes Indoor Air Problems?

Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes. Inadequate ventilation can increase indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home. High temperature and humidity levels can also increase concentrations of some pollutants.

Pollutant Sources

There are many sources of indoor air pollution in any home. These include combustion sources such as:

- oil, gas, kerosene, coal, wood, and tobacco products;
- building materials and furnishings as diverse as deteriorated, asbestos-containing insulation, wet or damp carpet, and cabinetry or furniture made of certain pressed wood products;
- products for household cleaning and maintenance, personal care, or hobbies;
- central heating and cooling systems and humidification devices; and
- outdoor sources such as radon, pesticides, and outdoor air pollution.

The relative importance of any single source depends on how much of a given pollutant it emits and how hazardous those emissions are. In some cases, factors such as how old the source is and whether it is properly maintained are significant. For example, an improperly adjusted gas stove can emit significantly more carbon monoxide than one that is properly adjusted.

Some sources, such as building materials, furnishings, and household products like air fresheners, release pollutants more or less continuously. Other sources, related to activities carried out in the home, release pollutants intermittently. These include smoking, the use of unvented or malfunctioning stoves, furnaces, or space heaters, the use of solvents in cleaning and hobby activities, the use of paint strippers in redecorating activities, and the use of cleaning products and pesticides in house-keeping. High pollutant concentrations can remain in the air for long periods after some of these activities.

Amount of Ventilation

If too little outdoor air enters a home, pollutants can accumulate to levels that can pose health and comfort problems. Unless they are built with special mechanical means of ventilation, homes that are designed and constructed to minimize the amount of outdoor
air that can "leak" into and out of the home may have higher pollutant levels than other homes. However, because some weather conditions can drastically reduce the amount of outdoor air that enters a home, pollutants can build up even in homes that are normally considered "leaky."

How Does Outdoor Air Enter a House?

Outdoor air enters and leaves a house by: infiltration, natural ventilation, and mechanical ventilation. In a process known as infiltration, outdoor air flows into the house through openings, joints, and cracks in walls, floors, and ceilings, and around windows and doors. In natural ventilation, air moves through opened windows and doors. Air movement associated with infiltration and natural ventilation is caused by air temperature differences between indoors and outdoors and by wind. Finally, there are a number of mechanical ventilation devices, from outdoor-vented fans that intermittently remove air from a single room, such as bathrooms and kitchen, to air handling systems that use fans and duct work to continuously remove indoor air and distribute filtered and conditioned outdoor air to strategic points throughout the house. The rate at which outdoor air replaces indoor air is described as the air exchange rate. When there is little infiltration, natural ventilation, or mechanical ventilation, the air exchange rate is low and pollutant levels can increase.

Indoor Air Pollution and Health

Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later.

Immediate effects

Immediate effects may show up after a single exposure or repeated exposures. These include irritation of the eyes, nose, and throat, headaches, dizziness, and fatigue. Such immediate effects are usually short-term and treatable. Sometimes the treatment is simply eliminating the person’s exposure to the source of the pollution, if it can be identified. Symptoms of some diseases, including asthma, hypersensitivity pneumonitis, and humidifier fever, may also show up soon after exposure to some indoor air pollutants.

The likelihood of immediate reactions to indoor air pollutants depends on several factors. Age and preexisting medical conditions are two important influences. In other cases, whether a person reacts to a pollutant depends on individual sensitivity, which varies tremendously from person to person. Some people can become sensitized to biological pollutants after repeated exposures, and it appears that some people can become sensitized to chemical pollutants as well.

Certain immediate effects are similar to those from colds or other viral diseases, so it is often difficult to determine if the symptoms are a result of exposure to indoor air pollution. For this reason, it is important to pay attention to the time and place symptoms occur. If the symptoms fade or go away when a person is away from home, for example, an effort should be made to identify indoor air sources that may be possible causes. Some effects may be
made worse by an inadequate supply of outdoor air or from the heating, cooling, or humidity conditions prevalent in the home.

**Long-term effects**

Other health effects may show up either years after exposure has occurred or only after long or repeated periods of exposure. These effects, which include some respiratory diseases, heart disease, and cancer, can be severely debilitating or fatal. It is prudent to try to improve the indoor air quality in your home even if symptoms are not noticeable.

While pollutants commonly found in indoor air are responsible for many harmful effects, there is considerable uncertainty about what concentrations or periods of exposure are necessary to produce specific health problems. People also react very differently to exposure to indoor air pollutants. Further research is needed to better understand which health effects occur after exposure to the average pollutant concentrations found in homes and which occurs from the higher concentrations that occur for short periods of time.

**Improving Indoor Air Quality**

**There are three basic strategies to improve indoor air quality:**

1. Source control
2. Improved ventilation, and
3. Air cleaners.

**Source Control**

Usually the most effective way to improve indoor air quality is to eliminate individual sources of pollution or to reduce their emissions. Some sources, like those that contain asbestos, can be sealed or enclosed; others, like gas stoves, can be adjusted to decrease the amount of emissions. In many cases, source control is also a more cost-efficient approach to protecting indoor air quality than increasing ventilation because increasing ventilation can increase energy costs.

**Ventilation Improvements**

For most indoor air quality problems in the home, source control is the most effective solution.

Another approach to lowering the concentrations of indoor air pollutants in your home is to increase the amount of outdoor air coming indoors. Most home heating and cooling systems, including forced air heating systems, do not mechanically bring fresh air into the house. Opening windows and doors, operating window or attic fans, when the weather permits, or running a window air conditioner with the vent control open increases the outdoor ventilation rate. Local bathroom or kitchen fans that exhaust outdoors remove
contaminants directly from the room where the fan is located and also increase the outdoor air ventilation rate.

It is particularly important to take as many of these steps as possible while you are involved in short-term activities that can generate high levels of pollutants — for example, painting, paint stripping, heating with kerosene heaters, cooking, or engaging in maintenance and hobby activities such as welding, soldering, or sanding. You might also choose to do some of these activities outdoors, if you can and if weather permits.

Advanced designs of new homes are starting to feature mechanical systems that bring outdoor air into the home. Some of these designs include energy-efficient heat recovery ventilators (also known as air-to-air heat exchangers).

**Air Cleaners**

There are many types and sizes of air cleaners on the market, ranging from relatively inexpensive table-top models to sophisticated and expensive whole-house systems. Some air cleaners are highly effective at particle removal, while others, including most table-top models, are much less so. Air cleaners are generally not designed to remove gaseous pollutants.

The effectiveness of an air cleaner depends on how well it collects pollutants from indoor air (expressed as a percentage efficiency rate) and how much air it draws through the cleaning or filtering element (expressed in cubic feet per minute). A very efficient collector with a low air-circulation rate will not be effective, nor will a cleaner with a high air-circulation rate but a less efficient collector. The long-term performance of any air cleaner depends on maintaining it according to the manufacturer’s directions.

Another important factor in determining the effectiveness of an air cleaner is the strength of the pollutant source. Table-top air cleaners, in particular, may not remove satisfactory amounts of pollutants from strong nearby sources. People with a sensitivity to particular sources may find that air cleaners are helpful only in conjunction with concerted efforts to remove the source.

Over the past few years, there has been some publicity suggesting that houseplants have been shown to reduce levels of some chemicals in laboratory experiments. There is currently no evidence, however, that a reasonable number of houseplants remove significant quantities of pollutants in homes and offices. Indoor houseplants should not be over-watered because overly damp soil may promote the growth of microorganisms which can affect allergic individuals.

At present, EPA does not recommend using air cleaners to reduce levels of radon and its decay products. The effectiveness of these devices is uncertain because they only partially remove the radon decay products and do not diminish the amount of radon entering the home. EPA plans to do additional research on whether air cleaners are, or could become, a reliable means of reducing the health risk from radon.
IAQ, Moisture and Ventilation

Many pollutants can be confined in a dwelling, including:

- Moisture;
- Stored toxic materials;
- Carbon monoxide;
- Radon; and
- Sewer gas.

While some moisture is necessary, too much moisture causes problems. Energy upgrade contractors often refer to moisture as a “sometimes” pollutant. Let’s learn more about moisture in the next section.

Common Household Sources of Water Vapor

<table>
<thead>
<tr>
<th>Source</th>
<th>Quarts per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction materials first year</td>
<td>40</td>
</tr>
<tr>
<td>Standing water in basement</td>
<td>30</td>
</tr>
<tr>
<td>Damp basement or crawlspace</td>
<td>25</td>
</tr>
<tr>
<td>Greenhouse connected to house</td>
<td>25</td>
</tr>
<tr>
<td>Humidifier - large</td>
<td>20</td>
</tr>
<tr>
<td>Drying 1 cord of firewood</td>
<td>16</td>
</tr>
<tr>
<td>Clothes dryer vented to inside</td>
<td>13</td>
</tr>
<tr>
<td>Respiration - perspiration - 4 people</td>
<td>4.7</td>
</tr>
<tr>
<td>Clothes washing</td>
<td>2.1</td>
</tr>
<tr>
<td>Unvented gas range</td>
<td>1.3</td>
</tr>
<tr>
<td>Cooking without lids</td>
<td>1.0</td>
</tr>
<tr>
<td>Houseplants - average number</td>
<td>0.5</td>
</tr>
<tr>
<td>Dish washing</td>
<td>0.5</td>
</tr>
<tr>
<td>Floor mopping</td>
<td>0.4</td>
</tr>
<tr>
<td>Showering/bathing</td>
<td>0.3</td>
</tr>
</tbody>
</table>

Many seemingly innocent sources create significant water vapor in homes. Note from the table that building materials emit 40 quarts per day of moisture into a home the first year after the home is built. An unvented gas range contributes more to indoor moisture load than showering and bathing.

Try to create a list of common household moisture sources, and then rank them for importance. Take into consideration the following list of moisture sources:

- Running an unvented kerosene or gas fired space heater — each gallon of fuel burned creates about 7.5 pints of water vapor.
- Cooking a gas range without using a ducted range hood — each burner produces between 1 and 2 pints per hour.
- Storing firewood indoors — a cord of green firewood creates about 3.5 pints of water per day.
• Air drying clothes inside — each load of wash creates about 5 pints of water during drying.
• Showering — a 10-minute shower creates about 1 pint of water.
• Cooking without pot lids — about 1/6 pint per person per meal.
• Washing floors — about 4 pints per room.
• Watering plants — all the water is poured into house plants eventually evaporates into the room.
• Pets — pets, and people, create about 1 pint of water per 50 lbs of body weight per day.
• Hand washing dishes, including rinsing — about 1/3 pint per person per meal.
• Faucet aerators — 0.02 pints per minute.

Common Household Moisture Sources

<table>
<thead>
<tr>
<th>Moisture source</th>
<th>Estimated amount (pints)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathing</td>
<td></td>
</tr>
<tr>
<td>tub (excludes towels and spillage)</td>
<td>0.12/standard size bath</td>
</tr>
<tr>
<td>shower (excludes towels and spillage)</td>
<td>0.52/5-minute shower</td>
</tr>
<tr>
<td>Clothes washing (automatic, lid closed, standpipe discharge)</td>
<td>0+/load (usually nil)</td>
</tr>
<tr>
<td>Clothes drying</td>
<td></td>
</tr>
<tr>
<td>vented outdoors</td>
<td>0+/load (usually nil)</td>
</tr>
<tr>
<td>not vented outdoors, or indoor line drying</td>
<td>4.68 to 6.18/load (more if gas dryer)</td>
</tr>
<tr>
<td>Combustion (unvented kerosene space heater)</td>
<td>7.6/gallon of kerosene burned</td>
</tr>
<tr>
<td>Cooking</td>
<td></td>
</tr>
<tr>
<td>breakfast (family of four, average)</td>
<td>0.35 (plus 0.58 if cooking with gas)</td>
</tr>
<tr>
<td>lunch (family of four, average)</td>
<td>0.53 (plus 0.68 if cooking with gas)</td>
</tr>
<tr>
<td>dinner (family of four, average)</td>
<td>1.22 (plus 1.58 if cooking with gas)</td>
</tr>
</tbody>
</table>
simmer at 203°F, 10 minutes, 6-inch pan ..........................................less than 0.01 if covered, 0.13 if uncovered

boil 10 minutes, 6-inch pan .............................................................0.48 if covered, 0.57 if uncovered

Dishwashing

breakfast (family of four, average) .................................................0.21

lunch (family of four, average) ..........................................................0.16

dinner (family of four, average) .......................................................0.68

Firewood storage indoors (cord of green firewood) ......................400 to 800/6 months

Floor mopping ....................................................................................0.03/square foot

Gas range pilot light (each) ..............................................................0.37 or less/day

House plants (five to seven average plants) .......................................0.86 to 0.96/day

Humidifiers ..........................................................................................0 to 120+/day (2.08 average/hour)

Respiration and perspiration (family of four, average) ...............0.44/hour (family of four, average)

Refrigerator defrost ..........................................................................1.03/day (average)

Saunas, steam baths, and whirlpools ..................................................0 to 2.7+/hour

Combustion exhaust gas backdrafting or spillage ......................0 to 6,720+/year

Evaporation from building materials

seasonal ...............................................................................................6.33 to 16.91/average day

new construction ................................................................................10+/average day

Ground moisture migration ..............................................................0 to 105/day

Seasonal high outdoor humidity .....................................................64 to 249+/day

1Minnesota Extension Service, University of Minnesota. Adapted from Home Moisture Problems, by the Minnesota Department of Public Service; and Moisture and Home Energy
Conservation, by the National Center for Appropriate Technology. Prepared with the support of the U.S. Department of Energy.
Quiz #2

T/F: Indoor pollution sources that release gases or particles into the air are the primary cause of indoor air quality problems in homes.

- True
- False

Inadequate ventilation can ____ indoor pollutant levels by not bringing in enough outdoor air to dilute emissions from indoor sources and by not carrying indoor air pollutants out of the home.

- increase
- decrease

An improperly adjusted gas stove can emit significantly ____ carbon monoxide than one that is properly adjusted.

- more
- less

In a process known as____, outdoor air flows into the house through openings, joints, and cracks in walls, floors, and ceilings, and around windows and doors.

- infiltration
- exfiltration
- mobilization
- invitation

T/F: There are three basic strategies to improve indoor air quality: source control, improved ventilation, and air cleaners.

- True
- False

When there is little infiltration, natural ventilation, or mechanical ventilation, the air exchange rate is ____ and pollutant levels can ____.

- low, increase
- high, decrease
- high, increase
- low, decrease

T/F: At present, EPA does not recommend using air cleaners to reduce levels of radon and its decay products.
Running an unvented kerosene or gas fired space heater creates about ____ of water vapor for each gallon of fuel burned.

- 7.5 pints
- 75 pounds
- 3.1 gallons

Cooking a gas range without using a ducted range hood produces between ____ for each burner.

- 1 and 2 pints per hour
- 30 to 40 pints per minute
- 10 to 15 pints per hour

**Moisture**

**Moisture Movement**

To be able to inspect for moisture intrusion and related problems, an inspector should understand the basics of how moisture can move through a house.

**Moisture and water vapor move in and out of a house in three ways:**

- with air currents;
- by diffusion through materials; and
- by heat transfer.
98% of Water Vapor Movement

Of these three, air movement accounts for more than 98% of all water vapor movement in building cavities. Air naturally moves from a high-pressure area to a lower one by the easiest path possible — generally, through any available hole or crack in the building envelope. Moisture transfer by air currents is very fast — in the range of several hundred cubic feet of air per minute. Thus, to control air movement, a house should have any unintended air paths thoroughly and permanently sealed.

The other two driving forces — diffusion through materials, and heat transfer — are much slower processes. Most common building materials slow moisture diffusion to a large degree, although they never stop it completely. Insulation also helps reduce heat transfer or flow.

The laws of physics govern how moist air reacts within various temperature conditions. The study of the properties of moist air is technically referred to as "psychrometrics."

A psychrometric chart is used by professionals to determine at what temperature and moisture concentration water vapor begins to condense. This is called the "dew point." By learning how to determine the dew point, you will better understand how to diagnose moisture problems in a house.

Relative humidity (RH) refers to the amount of moisture contained in a quantity of air compared to the maximum amount of moisture the air could hold at the same temperature. As air warms, its ability to hold water vapor increases; this capacity decreases as air cools.

For example, according to the psychometric chart, air at 68° F (20° C) with 0.216 ounces of water (H2O) per pound of air (14.8g H2O /kg air) has 100% RH. The same air at 59° F (15° C) reaches 100% RH with only 0.156 ounces of water per pound of air (10.7g H2O/kg air). The colder air holds about 72% less of the moisture as the warmer air.

The moisture that the air can no longer hold condenses on the first cold surface it encounters: the dew point. If this surface is within an exterior wall cavity, wet insulation and framing will be the result.

In addition to air movement, one can also control temperature and moisture content. Since insulation reduces heat transfer (or flow), it also moderates the effect of temperature across the building envelope cavity. In most U.S. climates, properly installed vapor
diffusion-retarders can be used to reduce the amount of moisture transfer. Except in deliberately ventilated spaces, such as attics, insulation and vapor diffusion-retarders work together to reduce the opportunity for condensation to form in a house's ceilings, walls and floors.

**Bulk moisture** is large amounts of water intrusion from wind-driven rain and sub-surface water.

**Capillary action** is the movement of liquid water across a material as a function of the surface tension of water and the porosity of the material. Capillary action is what carries water up a tree. It will also wick moisture up through concrete.

**Diffusion** is the movement of water vapor through a material as a function of the driving force across and the porosity of the material.

**Air transport** is the movement of moisture vapor by convective air currents. Air transport is influenced by:

- The stack effect.
- Wind.
- Mechanical equipment, such as fans.
Permeance of Building Materials

Material placed on the warm side of a building surface to retard diffusion of water vapor is called a vapor barrier.

Material intended to retard convection is called an air barrier.

Material which accomplishes both is termed an air/vapor barrier.

A material qualifies as a vapor retarder if its permeance is 1.0 perm or less.

All materials have a permeance rating, a number that quantifies the rate of vapor diffusion through it. Everything — even 6-mil poly — is permeable.

Definitions

Discussions of water vapor, vapor migration, and vapor retarders require clear definitions. This course uses a scale of permeance levels common to building codes and other industry literature (as measured in perms, or gr/hr ft² in Hg):

- vapor retarder is considered having < 1 perm;
- Class I, vapor impermeability is < 0.1 perms (also called a vapor barrier) Polyethylene, metal foils, butyl coating, roof membrane.
- Class II, vapor retarder is semi-impermeable (0.1 to 1 perm); SPF closed cell <2", SPF open cell >2", Polystyrene foam, acrylic/silicone coatings.
- Class III, vapor retarder is semi-permeable (1 to 10 perms); SPF open cell <2", sheetrock, fiberglass; and
- Permeable, vapor permeability is > 10 perms.

Vapor Barriers and Vapor Retarders, Roger V. Morrison, PE, RRC, Deer Ridge Consulting, Inc.


Pollutant Solutions
Pictured: an unvented space heater.

With any pollutant, elimination is preferred, encapsulation is acceptable, and dilution is a last resort.

- **Elimination**: Removing the source of pollution. Examples: (1) Collecting all old paint cans or other old chemicals from the basement and disposing of them at the local municipal waste facility. (2) Installing gutters and downspouts to divert rain runoff away from a basement. (3) Removing the unvented space heater from the home.

- **Encapsulation**: Containing the pollutant so it will not affect air quality. Examples: (1) Air sealing the ceiling over a tuck-under garage to prevent CO from entering the living space. (2) Pouring a concrete floor over a dirt crawl space to contain radon gas. (3) Installing a poly ground cover to contain moisture from the ground.

- **Dilution**: Relying on adequate ventilation to reduce the concentration of pollutants to acceptable levels. Examples: (1) Unvented space heater operating instructions always say to keep windows open while the heater is in use to prevent pollutant buildup. (2) Running a kitchen range hood to exhaust combustion byproducts from a gas range while cooking pulls fresh air in elsewhere, diluting whatever pollutants remain.

An unvented heater can be life-threatening.

A home should not be air sealed or insulated when an unvented combustion appliance is being used as a primary heat source.

**IAQ and Relative Humidity**
Keeping RH below 50% reduces or eliminates many common household problems.

Medical studies show most people—absent a medical condition—are healthiest and most comfortable between 30% and 50% RH.

• Homes should maintain 35% to 45% RH in heating climates.
• In cooling climates, homes should maintain 60% RH.

Homes should stay above 20% and below 50% RH to avoid breakdown of immune systems, mold growth, dust-mite invasions, and viruses.
Quiz #3

T/F: Moisture and water vapor move in and out of a house in three ways: with air currents; by diffusion through materials; and by heat transfer.

- True
- False

Air movement accounts for more than ____% of all water vapor movement in building cavities.

- 98
- 78
- 50
- 0.5

T/F: To control air movement, a house should have any unintended air paths thoroughly and permanently sealed.

- True
- False

As air warms, its ability to hold water vapor ____; this capacity ____ as air cools.

- increases, decreases
- decreases, increases

T/F: A material qualifies as a vapor retarder if its permeance is 1.0 perm or less.

- True
- False

With any pollutant, ____ is preferred, encapsulation is acceptable, and dilution is a last resort.

- elimination
- participation
- emancipation
- intrusion

Homes should stay above ____% and below ____% RH to avoid breakdown of immune systems, mold growth, dust-mite invasions, and viruses.

- 20, 50
- 50, 20
Blower Door

Blower Door Basics

What is a Blower Door?

Inspectors should become familiar with blower doors, as they can be a valuable tool in energy audits. A blower door is a powerful, variable-speed fan that can be temporarily mounted into an exterior door frame to provide controlled air flow for analysis. The way that air flows through a building can have a serious impact on air quality, comfort and energy expenses. The use of a blower door allows air flow through a structure, and the resulting loss of heat can be immediately quantified, providing a way to pinpoint the location of air leaks.

Blower doors were originally developed in the 1970s for use as a research tool. As technology has evolved, allowing for the development of more portable equipment, blower doors have transitioned into use as a valuable field tool, as well. The first portable blower doors weighed as much as 200 pounds and took up quite a bit of space, and were also very expensive. Today, they are much more affordable and are built lighter and smaller. The reduced set-up time allowed by their more compact designs has led to the standard use of blower doors as part of energy audits for measuring air flow.

How It Works

When air pressure and air flow are controlled and measured, they can provide data about how airtight a building is. The three variables involved are pressure, flow and holes or leaks. A change in one of these factors will produce a change in at least one other factor. Since the goal of a blower door test is to locate air leaks in the building envelope, data
regarding air pressure and flow can provide information about the holes, which may otherwise be tough to find.

The blower door utilizes controlled differences in air pressure to collect data. Once installed in an exterior door frame, the air pressure inside a building can be changed in relation to the outside pressure by forcing air into or out of the interior. The difference in pressure forces air through holes or leaks in the building envelope. The pressure and air flow are measured by gauges, which are part of the blower door equipment. By measuring the pressure and air flow in relation to each other, the airtightness of the building envelope can be quantified. The amount of air flow needed to create a change in pressure increases as the airtightness of the building envelope decreases. A well-sealed building requires less air flow to generate a change in pressure.

Finding the Problems

During a blower door test, the interior air pressure needed to be maintained in order to gather useful data is 50 pascals, which is roughly equal to the pressure created when a 20-mph wind hits the building. The blower door equipment has a gauge to indicate when this pressure has been achieved, as well as a gauge to indicate the cubic feet per minute (CFM), which is the standard unit of measure for air flow. Air flow in a well-sealed building will generally be less than 1,500 CFM at 50 pascals. Air flow above 4,000 CFM would be considered leaky. This is valuable data that can be acquired in about half an hour with the use of a blower door.

Since the blower door forces air through cracks and holes, the locations of the leaky spots can be identified. The draft of air entering through the holes can often be felt with the hand. Smoke and infrared imaging can also be employed to locate smaller, more subtle leaks. It is often assumed, especially by homeowners, that poorly sealed windows and doors are the major culprits of air leaks. In reality, leaks in other areas are usually much more significant. The difference in air pressure between the interior and the exterior is greater both at ground level and up high, so leaks in basements and crawlspaces, as well as in attics, are the most important to locate.

When looking for air leaks, check through basement rim joists, holes for plumbing traps under tubs and showers, cracks between finish flooring and baseboards, utility chases, plumbing vent-pipe penetrations, kitchen soffits, fireplace surrounds, recessed can lights,
and cracks between partition top plates and drywall. These are all common places where significant leaks can develop.

**Accounting for Outside Factors**

Wind and temperature can have an effect on the test data. Wind blowing on the outside of the building can add to pressure differences between the interior and exterior. It can also affect the flow rate of the blower fan. It is best not to conduct blower door tests in windy conditions. But if wind is not severe, tests can be conducted at multiple points in the building and then averaged together.

Differences in temperature can create differences in pressure. Accounting for a baseline stack-effect pressure will ensure that the test results are not skewed. The stack-effect pressure is a function of the height of the building and the difference in temperature from the interior to the exterior. A 15-foot tall building with a 50°C-temperature difference between the inside and outside will have a 5-pascal pressure difference from the top of the building to the bottom. Some blower door equipment has a gauge with a built-in baseline feature, so this difference can be easily determined at the outset of the test.

Temperature and barometric pressure affect both air density and viscosity, which is its resistance to flow. Because of this, an adjustment for density is required. Some software packaged with blower door equipment is designed to make these calculations, and if it is not available during the test, the manual supplied with the equipment should have information about making the necessary adjustments and applying it to the results.
Preparation and Safety

In order to ensure accurate results, as well as safe conditions for performing the test, some preparation is necessary before beginning. Any fireplaces or stoves used for heating should not be operating, and all furnaces and pilot lights should be turned off. There should be no open flames anywhere indoors. Ashes in fireplaces or stoves should be removed so they do not get sucked into the building. Dampers should be closed. Every door and window must be closed tightly so that air flowing through them does not affect the test, while all interior doors should be left open.

If there is a basement, it must be determined whether this area is to be considered part of the building envelope for testing purposes. Generally, if there is heat in the basement, even if only because the furnace is located there, it will be considered part of the envelope, and access to it should be left open during the test. Sometimes, the test may be done both ways — with the basement access open and with it closed, and this is quick and simple to accomplish.

Since blower door testing is a standard tool used during an energy audit, it is helpful for inspectors to understand how the test works. Knowing a bit about the outside factors that can influence the results will ensure that the test is performed correctly. Setting up the equipment properly will ensure that testers and occupants are safe, and that the testing and results are accurate.

Outside Air and IAQ

How much outside air do we need for good IAQ?

How do we get it?

- Air change rate(s) are established by ASHRAE, American Society of Heating, Refrigerating and Air-Conditioning Engineers.
- Outside air may be provided by natural air change or by mechanical equipment.
- The amount provided by fans depends on:
  - Fan capacity and efficiency.
  - Restrictions in the exhaust duct system, grilles, dampers, etc.
  - Run time.
• Some amount of exterior air moves through all buildings because of the stack effect and wind.
• The amount provided by natural conditions depends on several factors:

  o Wind strength.
  o Temperature difference, inside to outside.
  o Building height.
  o Building location and exposure.
  o Size, location, and type of holes in the building envelope.

**How is Natural Ventilation Calculated?**

In the mid-1980s, as air sealing techniques improved throughout the United States, practitioners became aware that it is possible to tighten a home so much that IAQ suffers and building degradation occurs.

Knowing that a blower door can accurately quantify hole size led to the logical attempt to relate natural conditions to the blower door CFM\textsubscript{50} number. (If hole size and driver strength are known, CFM is easily calculated.) Initially, the CFM\textsubscript{50} number was simply divided by 20 to arrive at an assumed natural air change rate. While this did produce a house-specific number, researchers quickly realized the number had little relation to reality as the method assumed all houses were exposed to the same conditions and all holes were created equal.

In an article published in the July/August 1986 issue of Home Energy, George Tsongas, professor of Mechanical Engineering at Portland State University in Oregon, produced a chart that quantified stack and wind by assigning a number to geographical location, building exposure, and building height—the famous LBNL n-factor. Using n-factor as a divisor into the building CFM\textsubscript{50} to estimate natural air change soon replaced the original “divide by 20” practice. Professor Tsongas published “Building Tightness Guidelines: When
Is a House Too Tight?” in the March/April 1993 issue of Home Energy that further refined the process by asking practitioners to adjust for smokers, atmospheric combustion appliances, etc.

**BTL, BTLa & MVG**

Building Tightness Limit (BTL), Building Tightness Limit "a" (BTLa) and Minimum Ventilation Guidelines (MVG) are all related and help home energy professionals determine the necessity of adding mechanical ventilation.

**BTL and BTLa**

- The **BTL** uses the **climate zone**, heated square footage of the home, the number of occupants determined by bedrooms plus one with a minimum of five, the height of the building in stories, the degree of exposure to wind, the volume of the house, and the n-factor to produce a threshold CFM\(^{50}\) number. Below this number, a house requires mechanical ventilation to maintain healthy IAQ.
- The **BTLa** uses the same inputs but adds the **CFM\(^{50}\)**, blower door flow exponent, a weather factor, story height, and heated height to not only produce the threshold CFM\(^{50}\) but also estimate natural ACH and the needed amount of mechanical ventilation.

**Minimum Ventilation Guideline (MVG)**

- The **Minimum Ventilation Guideline** process is really the BTLa renamed. The inputs and outputs are the same. The name change moves the emphasis from a tightening threshold to adding the ventilation needed after the building is tightened to the maximum practical extent.
- The MVG number is the required fan CFM.
MVG Theory

The amount of air leakage across any barrier is dependent on the hole size, the hole type, and the pressure differential.

- The concept relies on random types and sizes of holes being randomly distributed over random types of surfaces that are being acted upon by random forces to determine the CFM of natural ventilation. That’s a lot of randomness!
- When used as intended — to determine the average natural CFM over a large number of home-energy-inefficient homes — MVG is reasonably accurate.

Random Hole Type
The blower door can reasonably determine the predominant hole type in the tested surface if a minimum of five pressure tests are performed (i.e., 1 at 10, 20, 30, 40, and 50 Pascals [Pa] pressure difference) and the results plotted on logarithmic paper to establish the slope of the line. We assume a 0.65 slope without doing a five-point test, eliminating any chance for the blower door to determine hole type.

The missing flue plug in the picture is obvious; it is a large diameter hole connected directly to the outdoors through the chimney stack.

**Typically, if we can see holes, they should be blocked or sealed up.**

In the picture above, the ceiling is made of matched pine. Because wood responds to the RH surrounding it, the boards constantly expand and contract, making a permanent air seal between them impossible.

- Not only can we not air seal the cracks, the leakage rate through them changes with the humidity. The total hole in the ceiling will be much greater on dry winter days than it is on humid summer days.
- Proper air sealing leaves mostly linear cracks through multiple surfaces.

**Random Size and Distribution**

All air sealing blocks the big holes in a home — the ones occupants complain about and the ones the blower door locates.

Technology stresses blocking high holes (envelope to attic) to prevent attic condensation.

Economics stress blocking low holes (basement to exterior) because doing so is inexpensive and effective.

Proper air sealing minimizes wind and stack-driven air movement.
What's Left?

After sealing the large holes, what's left are the tiny holes.

- Tiny, deep bore, crack-type holes through multiple layers are left.
- Stopping air-driven heat loss is the goal.
- Air sealing done right eliminates most “randomness.”

Therefore, the assumed MVG natural air change rate may not be valid for a weatherized house (a house that has undergone energy upgrades including adding insulation and air sealing).
Quiz #4

T/F: Air change rate(s) are established by ASHRAE.

- True
- False

T/F: Outside air may be provided by natural air change or by mechanical equipment.

- True
- False

During a blower door test, the interior air pressure needed to be maintained in order to gather useful data is 50 pascals, which is roughly equal to the pressure created when a ____-mph wind hits the building.

- 20
- 5
- 56

Air flow in a well-sealed building will generally be less than ____ CFM at 50 pascals.

- 1,500
- 4,000

44. T/F: The difference in air pressure between the interior and the exterior is greater both at ground level and up high, so leaks in basements and crawlspaces, as well as in attics, are the most important to locate.

- True
- False

T/F: Technology stresses blocking high holes (envelope to attic) to prevent attic condensation.

- True
- False

T/F: Typically, if we can see holes, they should be blocked or sealed up.

- True
- False
ASHRAE 62.1989

ASHRAE 62.1 is an air quality standard meant for large commercial buildings, usually with forced ventilation.

- The standard requires the greater of 15 CFM per person or 0.35 ACH, whichever is higher.
- ASHRAE 62.1 was imposed on small residential buildings because it was the only building ventilation standard available.
- In small buildings (defined as under three stories and having six or fewer units):
  - The person count equals the greater of the number of bedrooms plus one or the actual occupancy. There is a minimum of five persons. (This forces 75 CFM (5 people times 15 CFM) to be the absolute minimum ventilation rate.)
  - IAQ pollutants are to be dealt with at the source.
  - Ventilation may be provided by fans or operable windows.

**Example:** For a 1,150-square-foot, 3-bedroom home with 8’ ceilings, the required CFM will be the greater of the number of bedrooms plus one (with a minimum of five) = 5 x 15 CFM = 75 CFM or 0.35 ACH x (1,150 cu ft x 8’) = 0.35 x 9,200 cu ft = 3,220 CFH/60 minutes = 53.7 CFM.

This home requires 75 CFM.
ASHRAE 62.2-2007

House types clockwise from upper left: cement block single family, mobile home, early 1800s northeastern farmhouse, and a South Western modular house.

ASHRAE 62.2 was originally promulgated in 2004 and revised in 2007.

- It applies to single-family and multifamily residential buildings of three stories or fewer above grade, including manufactured and modular buildings.
- It is a **performance standard**, rather than a **prescriptive standard**, meaning that the actual fan-delivered CFM must be verified by flow testing after installation rather than simply reading the design CFM off the fan unit labels.
- Code requirements:
  - Whole building ventilation: "A mechanical exhaust system, supply system, or combination thereof shall be installed for each dwelling unit to provide whole-building ventilation."
  - Local exhaust fans must be installed in bathrooms and kitchens. The bathroom standard is 50 CFM on demand or 20 CFM continuous.
  - Kitchen standard is 100 CFM on demand or 5 ACH based on kitchen volume. A vented range hood is required if the exhaust fan flow rate is less than 5 kitchen air changes per hour. Continuous fans must be rated at 1 **sone** or less.
    - The **sone** was proposed as a unit of perceived loudness by Stanley Smith Stevens in 1936. In acoustics, loudness is the subjective perception of sound intensity.
    - A **sone** is a subjective measure of loudness. 0 sones is the threshold below which a person cannot hear. Normal talking is about 1 to 4 sones, and the threshold of pain is around 676 sones.
  - Local on-demand fans must be rated at 3 sones or less.
  - Dryers must be vented out of the building.
When the living space adjoins the garage, the design must prevent migration of contaminants. **Zonal pressure diagnostics (ZPD)** will help an energy auditor determine the location and quality of the pressure boundary and ultimately the path that pollutants will take throughout the home.

**ASHRAE 62.2-2007 Table**

![ASRAE 62.2-2007 Table](image)

ASHRAE 62.2-2007 table applies to new construction.

**Download and print this table** for the quizzes and final examination. [ASHRAE 62.2-2007 Table](#)

- Left column = conditioned floor area in square feet.
- Right columns = number of bedrooms.

Read right from Floor Area and down from number of Bedrooms to find the needed ventilation air in CFM.

**Question**: What’s the Minimum Ventilation Air Requirement for a 1,150 sq. ft. 3-bedroom home?

Find the floor area in the left column and the number of bedrooms in the top row. Reading right from the floor area column and down from the number of bedrooms for a 1,150-sq-ft, 3-bedroom home, the Minimum Ventilation Air Requirement would be 45 CFM.

**Answer** is 45 CFM.

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ASHRAE 62.2-2007 Formula

ASHRAE 62.2-2007 formula applies to new and existing construction.

Ventilation air in CFM equals 1% of the conditioned floor area in square feet plus 7.5 times the number of bedrooms plus one.

Will they get a ventilation credit? The fan delivered CFM may be reduced by 0.5 x ((CFM50/n-factor) - 2A/100) if the n-produced CFMnatural estimate is greater than twice the residence area divided by 100.

Example:

1,150-sq-ft, 1,500 CFM\textsuperscript{50}, zone 2, normal exposure, 1.5-story 3-bedroom home.

Ventilation credit? (1,200/16.7) > (2 x 1,150)/100? = 72 > 23? = yes.

Fan CFM = (0.01 x 1,150 sq ft) + (4 x 7.5CFM ) = 11.5 + 30 = 41.5 - [ventilation credit = 0.5 x ((1,200/16.7) - (2A/100)) = 0.5 x (72-23) = 24.5 CFM ventilation credit] = 17 CFM continuous.

What Are the Choices?

Either formula provides code-accepted ventilation rates.
Properly followed, ASHRAE 62.2 practically eliminates moisture problems while keeping air-transported heat loss to the absolute minimum. The air change rate is approximately 50% of that required by ASHRAE 62.1, reducing the client’s heat cost significantly. Only air-to-air heat exchangers retain more conditioned air (at additional installation and operational cost).

If ASHRAE 62.2 can’t be employed, the issue becomes preventing poor IAQ and other moisture-related problems. Fan run time is irrelevant as the assumed natural ventilation rate is unreliable.

What is needed is a way to relate fan operation to high interior humidity only when exterior humidity is low. The best option is client education. For example, an obvious and reliable indicator of excessive moisture in a home is interior fogging or frost build-up on windows. The homeowner could be educated on how to run the fan(s) until observed moisture build-up goes away.

Homeowners should understand about operating fans in the summertime. When exterior humidity is high fans are often counterproductive, particularly for drying basements and crawl spaces.

**Installing Fans**

When a fan is installed, the following concepts shall be the installer’s guide:
• Use units with 1.5 sones or less.
• Seal the fan housing to the ceiling.
• Seal all duct joints.
• Insulate the duct.
• Slope duct to the exterior.
• Run the duct to the gable end if possible.
• If run to the soffit, block any soffit vent openings for 2 feet to either side of the vent hood.
• Don’t go through the roof unless absolutely necessary.

Using ASHRAE 62.1 Installations to 62.2

![Control from Tamarack Technologies Airtrak](image)

The picture above shows a control from Tamarack Technologies Airtrak, which is available from most home energy suppliers.

For energy upgrade contractors, using ASHRAE 62.2:

• Cuts code-required CFM from 15/person, 5-person minimum to 7.5/person actual, no minimum.
• Allows air sealing the home to the greatest extent possible.
• Provides proper ventilation all the time under all conditions.
• Cuts air-driven heat loss to an absolute minimum.
• Requires measuring fan flow, as it’s a performance standard.
• Requires automatic controls.
• Generally has an incremental cost of the fan control switch — air inlets aren’t needed.

**Air-to-Air Heat Exchanger**

An air-to-air heat exchanger is a balanced system where air is pumped in and out in equal amounts. Entering air is passed by exiting air, absorbing (or scrubbing) heat from it.

An air-to-air heat exchanger is generally considered “high-end,” but it may be installed in some client homes.
Summary

Indoor Air Quality (IAQ) depends on the pollutant source strength and the air change rate. Elimination at the source is preferable to confinement, which is preferable to dilution.

Many pollutants are present in the average home:

- Radon;
- Carbon Monoxide (CO);
- Cleaning chemicals;
- Fuels; and
- Moisture.

Typically, excess moisture is the most significant of the common pollutants. The air change rate is a function of inside to outside pressure difference, hole size, and hole location. A higher air change rate equals better IAQ and usually higher space conditioning costs.

ASHRAE 62.1 and 62.2-(2004 or 2007) guidelines are acceptable.

- ASHRAE 62.1 is a large building IAQ standard presently allowed on single-family homes.
- ASHRAE 62.2 is the specific small building IAQ standard.

Quality fans installed and used properly help ensure healthy IAQ.
Quiz #5

T/F: According to ASHRAE 62.2, A mechanical exhaust system, supply system, or combination thereof shall be installed for each dwelling unit to provide whole-building ventilation.

- True
- False

According to ASHRAE 62.2, local exhaust fans must be installed in bathrooms and kitchens. The bathroom standard is ____ CFM on demand or 20 CFM continuous.

- 50
- 20
- 80

According to ASHRAE 62.2, kitchen standard is ____ CFM on demand or 5 ACH based on kitchen volume.

- 100
- 52.5
- 20
- 5

Using the ASHRAE 62.2-2007 table provided as a download in the course, what’s the Minimum Ventilation Air Requirement for a 1,150 sq. ft. 3-bedroom home?

- 45 CFM
- 80 CFM
- -20 CFM
- 30 CFM

T/F: In a air-to-air heat exchanger, entering air is passed by exiting air, absorbing (or scrubbing) heat from it.

- True
- False

T/F: An air-to-air heat exchanger is a balanced system where air is pumped in and out in equal amounts.

- True
- False