

# Building Science 101

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A guide to understanding  
a systems approach to  
building better homes  
and giving customers  
what they want

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## Introduction

Knowledge of building science can help you improve building performance and meet homebuyers' needs in terms of the comfort, durability and energy efficiency of their homes. Modern building science has provided us with very efficient windows, surfaces that reflect heat well, insulation and innovative air sealing products and practices. But it's important to understand the roles of the different components that act as control layers. These innovations won't deliver a high performance structure if they are not used as intended or installed properly and designed to work as a system.

There are two important steps to making building science work for you. The first is to understand the house as a system of three interdependent elements: location, climate, and home construction techniques and materials. The second is to improve the performance of that system through the control of heat, air and moisture flow.

## The House as a System

Designing and building a new house or renovating an existing home to be highly energy-efficient requires careful planning and attention to detail. A whole-house systems approach helps homeowners, architects and builders develop strategies to optimize home performance and energy efficiency.

The "house as a system" approach considers the house as an energy system with interdependent parts, each of which affects the performance of the entire system. It also takes the occupants, site and local climate into consideration. Among things to consider:

- Site conditions
- Local climate
- Air sealing
- Insulation
- Lighting and daylighting
- Space heating, cooling and ventilation
- Water heating
- Windows, doors and skylights
- Appliances and home electronics

Some benefits of using a whole-house systems approach include:

- A healthier and safer indoor environment
- Increased comfort
- Reduced utility and maintenance costs
- Improved building durability
- Reduced noise

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Of course, the climate has an impact on the energy consumption of residential homes and, while building codes and energy efficiency incentives work to provide you with guidelines as to what works in your particular area, it is ultimately up to designers and builders to choose construction methods and building materials that ensure that the home is as energy efficient as possible. As energy efficiency becomes a growing concern, building to your climate zone is an excellent way to ensure that you are providing your buyers with the best options. Keep in mind that building and energy codes are the minimum standard and performance can be increased by going beyond code.

## Controlling the Flow of Moisture, Heat and Air

Controlling the flow of moisture, heat and air within a building is essential to providing a healthy and durable home. Here are the basics of how they each function within a building.

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Liquid flow has the potential to be the most damaging moisture transport mechanism confronted by a building.

### Moisture Flow

Controlling moisture flow in a building has significant impacts on occupant health and safety, comfort, building durability and energy efficiency. Building science is concerned with two main forms of moisture flow: liquid and vapor. Liquid water moves as bulk water and capillary action; water vapor moves through air leakage and diffusion.

Bulk moisture movement (or liquid flow) has the potential to be extremely damaging to buildings. Typically thought of as rain or snow, bulk moisture movement also includes flowing groundwater. Three conditions are required to allow bulk moisture flow into a building:

- A source of water
- A hole in the building envelope
- A driving force (gravity, capillary action, wind, etc.)

In most locations, there will be water present during at least part of the year. The keys to controlling that water are to direct it away from the home and to seal any holes that water might enter.

Directing water away from the home is accomplished by proper grading, drainage, gutters and downspouts. Proper sealing is done by meticulous attention to flashing and caulking details, foundation drainage and sealing door and window installations.

### Capillary Action

Capillary action refers to the ability of water to travel up against the pull of gravity through a porous material. One common example of this action is water “wicking” up through a paper towel. Although not commonly as serious as bulk water movement, capillary forces are both powerful and difficult to detect, since they often work in the dark of a crawlspace, causing significant damage to a building without the occupant’s knowledge.

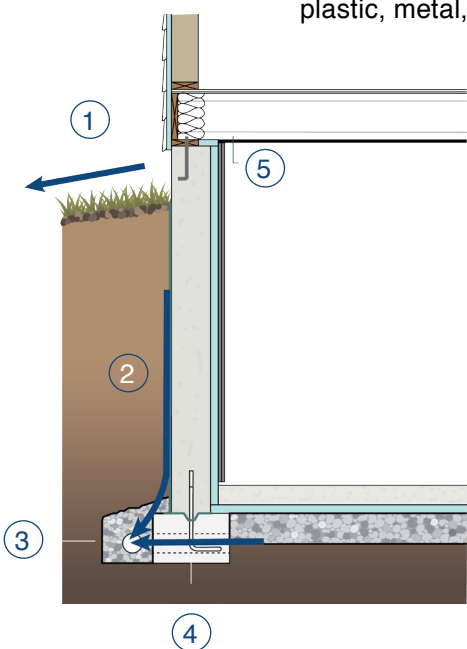
Opposite to what one might expect, capillary action requires small holes or gaps, rather than larger ones.

Opposite to what one might expect, capillary action requires small holes or gaps, rather than larger ones. Large pore sizes, such as those found in some forms of pea gravel and coarse sand, can actually serve to “break” the flow of capillary water. Smaller pores however, such as those found in concrete and brick, provide excellent paths for such wicking action to occur.

Since concrete is commonly used in building foundations, we often see evidence of capillarity in basements and crawlspaces. The concrete footings wick the water up from the ground, where it then travels up the foundation wall. Evidence of capillary action is often seen on many older brick foundations as a white line visible a foot or so above the ground. This white line is caused by a process known as efflorescence, which occurs when water that is drawn up by capillary action evaporates, leaving behind a residue of salts, minerals and other materials left after the water evaporates. Plastic sheeting placed in footing holes prior to pouring concrete can help to prevent groundwater wicking.

Capillary action is also an important issue above-grade. Even two nonporous materials, if placed closely enough together, will provide a channel for capillary action to occur. One common example of this occurs with lapped wood siding. Rain water striking the side of the house will run down the siding to the edge. Capillary forces can then draw the bead of water up and behind the siding, thus wetting the back side of the siding. Obviously, such forms of capillarity can be hard to observe until serious damage has already occurred.

Capillary action can best be controlled by providing a capillary “break” such as plastic, metal, damp-proofing compound or another impermeable material, or by leaving air spaces that are too large for capillarity to occur. For example, installing a “sill seal” between the masonry foundation and any wood structure is essential to protect the wood.



1. The grade is sloped to drain water away from the foundation.
2. Damp proofing limits moisture migration from the soil into the concrete wall.
3. Any water up against the foundation wall will drain down the free, draining backfill and out the perimeter drain at the footing.
4. Capillary break in between footing and foundation wall.
5. Capillary break in between foundation wall and sill plate prevents moisture from migrating from the concrete to the wood structure.

## Air-Transported Moisture

Air-transported moisture (in the form of water vapor being transported by air) can get into or out of buildings. As noted earlier, both uncontrolled pressure sources (such as wind or stack effect) and controlled sources (fans and air handlers) can move significant amounts of moist air through a building's envelope. Leaky ductwork can cause moisture problems by not only increasing the amount of infiltration, but by drawing air in from the humid crawlspace or basement areas. As this humid air travels through a building, the moisture in it may condense on any surface whose temperature is below the dew point.

The amount of condensation that forms is dependent upon several factors: temperature of condensing surfaces, the relative humidity and the speed of the air moving across the condensing surface. Colder surfaces (like windows and poorly-insulated walls) condense moisture more readily; slower-moving air allows more time for condensate to form.

There are several ways to decrease the negative effects of air-transported moisture. The best defense is to keep moist air out of the building through effective sealing against infiltration/exfiltration, sealing the ductwork and pressure-balancing the HVAC system. Proper use of exhaust fans in all bathrooms and kitchens helps to remove moisture-rich indoor air at its source. Preventing cold spots through adequate insulation, heating and air movement removes potential sites for condensation.

## Vapor Diffusion

Even without leaks, small amounts of moisture in the form of water vapor can pass directly through a building's envelope via a process called diffusion. Vapor diffusion from a damp or wet basement or crawlspace into the living space can significantly increase the moisture levels inside a home.

Two things determine the amount of vapor diffusion that occurs in a building: the driving force that pushes it (known as the vapor pressure differential), and the permeability of the material through which the vapor is passing. Most materials (even sheet glass) are unable to completely stop vapor diffusion; thus, calling something a "vapor barrier" is not quite correct since it doesn't stop vapor completely. The current trend in building science is to refer to materials as "vapor retarders," meaning that while they slow down the movement of water vapor, they do not completely halt the process. Materials that significantly slow down the vapor diffusion process are said to have low permeability, or simply "low-perm." Typical building codes classify vapor retarders as:

- **Class I:** Impermeable vapor retarders—rated at 0.1 perms or less. Sheet polyethylene (visqueen) or unperforated aluminum foil (FSK) are Class I vapor retarders.

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Even without leaks, small amounts of moisture in the form of water vapor can pass directly through a building's envelope.

- **Class II:** Semi-impermeable vapor retarders—rated greater than 0.1 perms and less than or equal to 1.0 perms. The kraft facing on batts qualify as a Class II vapor retarder.
- **Class III:** Semi-permeable vapor retarders—rated greater than 1.0 perms and less than or equal to 10 perms. Plywood, OSB, Latex or enamel paints qualify as Class III vapor retarders.

Class 1 vapor retarders are often applied in the crawlspace of a building to prevent ground moisture from evaporating and traveling up into the home. Many building codes require applying 6 mil. polyethylene, a Class 1 vapor retarder, to prevent vapor diffusion from bringing water into the structural assemblies. In cold climates during the heating season, vapor pressure differential drives the vapor from the inside of the building to the outside. In Minnesota, the vapor retarder is generally installed on the interior face of the wall studs. In warmer climates during the cooling season, this vapor drive is from the outside of the building towards the inside—thus, in hot, humid coastal areas like Miami or Houston, vapor retarders are often applied on the outside of buildings. Besides the perm rating of the material, the effectiveness of a vapor retarder is also a function of its surface area. A vapor diffusion retarder that covers 80 percent of a building is said to be “80 percent effective.” It is generally considered more important to have a complete air barrier than a complete vapor retarder, however both are important.

## Effects of Moisture Flow on Occupants

Moisture flow can affect building occupants in different ways, including:

### Health and Safety

Moisture is not often thought of in terms of occupant health and safety. Because of the potential for the accumulation of water to cause bacteria and mold growth, some indoor air quality professionals consider water to be a pollutant.<sup>1</sup> Moisture is the key ingredient for mold and bacteria growth. Not only can these fungi be odorous, unsightly and a cause of wood rot, but they can also cause asthma and allergic reactions in many individuals.

Excess moisture (particularly in the air) also provides a favorable environment for dust mites and cockroaches, serious sources for asthma and allergy problems. Though people don't usually react to the creatures themselves (except to maybe scream and reach for a rolled-up magazine), roach and dust mite droppings can cause asthma and allergic reactions in many people. Another unfortunate side-effect of these creatures' presence is that they often bring about increased use of insecticides. Young children in particular can be extremely susceptible to poisons and can suffer effects such as allergic reactions.

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<sup>1</sup> [https://www.energystar.gov/ia/partners/bldrs\\_lenders\\_raters/downloads/ENERGY\\_STAR\\_V3\\_Building\\_Science.pdf](https://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/ENERGY_STAR_V3_Building_Science.pdf)

## Comfort

Since moisture in the form of water vapor plays such a key role in how we perceive comfort, relative humidity is a primary driving force in determining how to operate building systems. According to [ASHRAE](#)<sup>2</sup>, the comfort zone for buildings in the winter is between 68° and 75° F at a relative humidity of 30 percent to 60 percent. During summer conditions, the comfort range is found between 72° and 78° F at 25 percent to 60 percent relative humidity. It's worth noting that the ranges for comfort and indoor air quality don't always correspond (for example, 60 percent relative humidity in a cold climate is conducive to mold and rot in buildings with typical levels of air sealing and insulation).

## Effects of Moisture Flow on Building Durability

Moisture can be a common cause of building degradation. In fact, much of what we know about applied building science today originates from early work investigating moisture impact on buildings. While the severity of moisture problems varies greatly depending on climate, few regions in North America are free from concerns about moisture in buildings.

Moisture can affect a building's durability on many fronts, from wet crawlspaces to leaking roofs. Moisture-rich air can even become trapped in building structural assemblies, possibly leading to mold growth, rot, or insect infestation. Entire industries have emerged that specialize in combating these various moisture problems.<sup>3</sup>

## Heat Flow

In a typical home, a large portion of all energy consumed is spent on heating and cooling. Air leakage and too little or improperly installed insulation accounts for a large portion of this excessive energy use. A good thermal boundary, which includes insulation, windows and doors, not only reduces energy waste, but also greatly increases an occupant's comfort. It is important to recognize the role of thermal bridging in heat flow. Thermal bridging refers to heat lost through the framing of a building. Various mitigation strategies exist for addressing this form of heat loss which go beyond the scope of this overview, but one thing to remember is that, despite what some claim, your choice of cavity insulation type does not impact thermal bridging.<sup>4</sup>

### The Basics of Heat Flow

- **Conduction:** When two surfaces at different temperatures are in direct contact, heat will flow from the warmer materials to the cooler materials until a balance is reached. The rate at which this heat transfer occurs depends on the temperature difference between the two surfaces and on the thermal resistance (R-value) of the material.
- **Convection:** Warm air naturally rises within a space and colder air falls. These movements of warm and cold air are known as convection currents, which sometimes move in circles called convective loops.

<sup>2</sup> [https://www.ashrae.org/file%20library/doclib/public/2003691613\\_347.pdf](https://www.ashrae.org/file%20library/doclib/public/2003691613_347.pdf)

<sup>3</sup> Energy Star Certified Home Building Science Introduction <https://basc.pnnl.gov/resources/energy-star-qualified-homes-building-science-introduction>

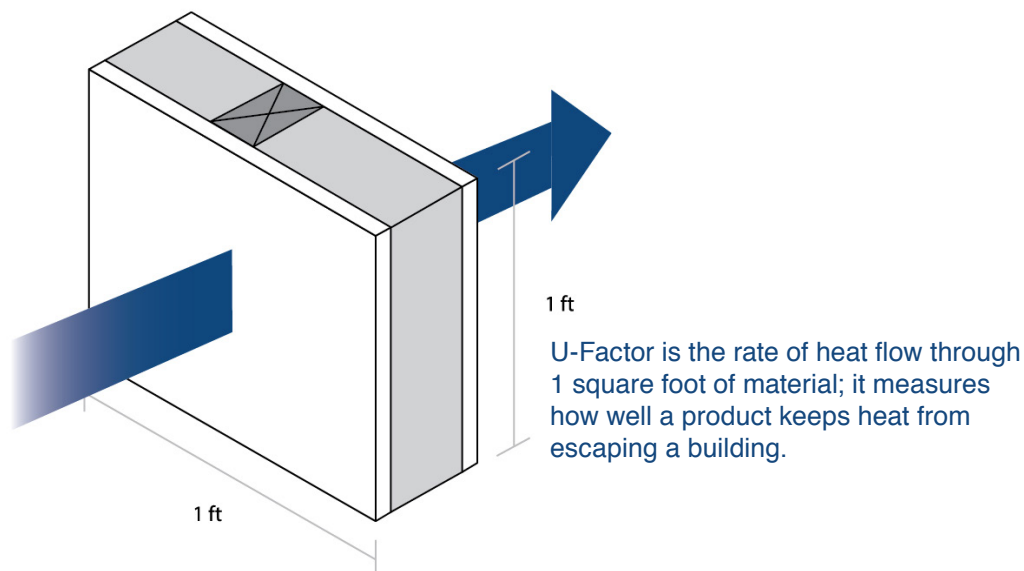
<sup>4</sup> [Building Science Corporation Thermal Metric Report](#)



- **Radiation:** All objects radiate heat, which can travel across an open space and be absorbed by cooler objects. The most common example of this is the sun, which radiates across space to warm the Earth.

## U-Factor

How quickly heat flows through a material is called the material's U-Factor, or heat conductance.



Technically, the U-Factor is the number of BTUs per hour of heat flow for each one degree of temperature difference from one side of the material to the other. U-Factor is the inverse of R-Value with US units of BTU/(h °F ft<sup>2</sup>) and SI units of W/(m<sup>2</sup>K):

$$U = \frac{1}{R} = \frac{\dot{Q}_A}{\Delta T} = \frac{k}{L}$$

## R-Value

The ability of a material to resist heat flow is measured in R-Value. R-Value is the inverse of U-Factor ( $R=1/U$ ). The higher the R-Value, the slower the heat flow through the material. R-Value measurements include the effects of conduction, convection and radiation.

## Insulation

Insulation slows heat transfer by trapping pockets of air. Modern insulation products do an excellent job of preventing heat from passing through a building's walls, ceilings and floors. According to [Building Science Corporation's Thermal Metric Report](#),<sup>5</sup> all insulation types perform essentially the same as long as they are properly air sealed and installed. However, improper installation of insulation greatly reduces its effectiveness.

Improper installation of insulation can greatly reduce its effectiveness.

<sup>5</sup> [Building Science Corporation Thermal Metric Report](#)

## Effects of Heat Flow on Occupants

Heat flow can affect building occupants in different ways, including:

### Health and Safety

As previously noted, mold and mildew growth can occur when moisture-laden air comes into contact with cold surfaces. Proper heat flow within a building helps to prevent such localized cold spots. However, during the summer months, improperly designed cooling vents, leaky ductwork or an oversized system can allow condensation to form. Mold can also grow in the winter when warm, moist air condenses on the cold surfaces, creating liquid water. Poorly designed windows can be an example of this.

### Comfort

Comfort is defined in the [American Society of Heating, Refrigeration and Air-Conditioning Engineers \(ASHRAE\) Handbook of Fundamentals](#) as, “that condition of mind in which satisfaction is expressed with the thermal environment.”

Most people would like to have the highest level of comfort possible at the lowest cost. This is achieved through properly air sealing and insulating buildings.

## Effects of Heat Flow on Building Durability

Water vapor attempts to move from a warm, dry area to cold, moist areas, where it can more readily condense. When such condensation occurs inside walls and other structural assemblies, rotting of wood can occur, as well as mold growth. Unintended heat flow in buildings, even when caused by solar radiation or otherwise normal heating/cooling scenarios, can drive moisture-rich air into the structural assemblies from either inside or outside the building.

When thermal barriers are not properly installed, or air is allowed to pass through insulation, the resulting heat loss or gain can greatly reduce energy efficiency.

This heat loss or gain generally occurs under five different situations:

- Voids within the insulation
- Gaps between the insulation and the adjacent framing members
- Convection of airflow within improperly insulated assemblies
- Air leakage bypassing the thermal boundary
- Highly compressed insulation

## Air Flow

In simplest terms, air needs an opening or hole to flow through and a driving force to move it. The driving force that moves air is a pressure difference. Many different factors control how air flow affects a house. The forces and conditions that allow air to flow into, out of, or within a house include:

- Controlled versus uncontrolled airflow

In order for air to flow into, out of, or within a building enclosure, a hole or path must exist for the air to flow through and there must be a driving force.

- Holes or pathways
- Air pressure
- Effects of air flow

In order for air to flow into, out of or within a building enclosure, two requirements must be met: a hole or path must exist for the air to flow through and there must be a driving force.

Air flows within buildings are either controlled or uncontrolled. In either case, the actual flow of air is determined by several factors, including hole size, resistance to flow, and pressure effects.

### Controlled Versus Uncontrolled Air Flow

*Controlled air flow* is typically generated by a mechanical device and is designed to help ventilate a building and/or distribute conditioned air throughout a building. Ventilation systems, fan spot ventilators, make-up air and heating and air conditioning system flow are typical sources of controlled air flow.

*Uncontrolled air flow* is any non-designed movement of air into, out of or within a building. This can be caused by wind, by force of heated air rising within the building or by malfunctioning fans. Leaks in a building's air distribution system are also uncontrolled air flow.

### Holes and Pathways

In order to have uncontrolled air flow (infiltration) into a building, holes must exist in the building envelope. Reduce the number of unintended holes in the building, and you reduce the amount of uncontrolled air flow. There are two kinds of holes in buildings: unintended holes and designed holes.

Unintended holes allow uncontrolled air leakage and rob a home of its efficiency and healthful environment. Unintended holes in the home are found in the attic, walls, and floors. Any of these holes that connect to unconditioned spaces (*e.g.*, outdoors, garage, crawl spaces...) should be blocked, caulked, gasketed or otherwise sealed. Sometimes these holes are connected to floor, wall or ceiling cavities, or to spaces under bathtubs and stairs, around chimneys, above cabinets, etc. These spaces become pathways for air to move between the interior and exterior of the building. For example, air can leak into the space between the first-floor ceiling and the second-floor floor if the band joist isn't sealed. That air, and any moisture in it, can then flow freely through poorly sealed recessed light fixtures, dropped ceilings over cabinets, etc., and cause serious moisture and comfort problems. Unintended holes should be air-sealed and blocked to control the potential spread of draft, smoke, and fire.

Designed holes are those necessary to allow the proper flow of fresh air supply, such as vents and chimneys. Designed holes include any hole or system that is designed

to have air passing through it in a specific direction. Designed holes should not be blocked, sealed, restricted or have their direction of flow reversed. Examples of such holes include flues and combustion vents, chimneys, make-up fans, exhaust fans, dryer vents, cooktop fans, ventilation systems, central vacuums, windows and doors, and fresh air inlets/outlets. When examining air flow into and out of a building, applied building science addresses three areas of concern: effects on the occupants, effects on the durability and structural integrity of the building, and effects on the energy efficiency of the building.

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Air flow always seeks the path of least resistance.

## Air Pressure

Air always flows from high-pressure area to a low-pressure area, much like water running downhill. Therefore, without an effective barrier, air outside a home at a higher pressure will attempt to enter the home. Similarly, inside air at high pressure with reference to the outside will tend to exit the house.

The nature of air flow always seeks the path of least resistance, with the lowest resistance holes getting more airflow. Generally speaking, for every volume of air that enters a house, an equal volume of air must also exit the building and vice versa. So one cubic foot in equals one cubic foot out.

Both positive and negative pressure zones can exist in the same building at the same time, with a zone of neutral pressure between them. This area between the two pressure zones is known as the neutral pressure plane. Air neither moves in nor out of the house at the neutral plane; on the lower negative pressure side of the plane, air is being drawn into the home and on the positive pressure side, air is being forced out. Since no air moves at the neutral pressure plane<sup>6</sup>, the greatest amounts of air infiltration or exfiltration occur at those points in the house farthest away from the plane.

## Measuring Pressure

One way to measure very small pressures is in units called Pascals. For a frame of reference, there is about one Pascal of pressure exerted by a standard piece of paper lying on a desk. Since a Pascal is a very small amount of pressure, it requires a precise pressure gauge to measure it. These pressure differences are generally measured across boundaries and barriers. For example, measuring the pressure difference across a building exterior wall determines the pressure inside the house with reference to the air pressure outside. One common reason for measuring pressure is to assure that combustion devices are operating properly. Blower door tests measure the airtightness of a building, and pressure measurements are essential for that task.

## Air Pressure Causes

Pressure differences across holes, boundaries, and barriers within a building are caused by one of three forces: wind, heat or fans.

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<sup>6</sup> <https://basc.pnnl.gov/information/building-science-introduction-air-flow>



*Wind* blowing against a building can cause large pressure differences between one side of the building and the other, depending upon both the speed and the direction of the wind. On the windward side of a building, the wind causes a positive pressure outside the building relative to the inside, causing air to enter the building. On the leeward side of a building, the outdoor air has a lower pressure than the air inside of the building and air exits the building through holes and other leak sites.



*Heat* pressure is caused by making hot air buoyant, causing it to naturally rise to the top of a building. This is called stack pressure or stack effect. The magnitude of this pressure depends on the temperature difference between the inside and outside of the building, as well as the height of the building. If the building height or temperature difference doubles, then the stack pressure doubles as well. Generally speaking, the upper regions inside a building are at a positive pressure with reference to the outside, and the lower regions are at a negative pressure with reference to the outside.

*Fans* (particularly exhaust fans and HVAC air handlers) can contribute to pressures changes in several different ways. Leakage in the building envelope or the ducting, or an imbalance in the supply and return ducts can cause these fans to have a drastic effect. While natural forces (wind and stack) produce between one and 10 Pascals of pressure on residential buildings, fans can produce as high as 60 Pascals of pressure. And, the tighter the house, the bigger the pressure difference these three effects can produce. There are several different types of fans in a home system, and each poses different challenges if not designed properly.

Exhaust fans (bathroom, kitchen, and laundry exhaust fans, cooktop fans, dryers, and central vacuum systems, which draw air from the living area of the house and replace it with air drawn in from the outside) can compete with fireplaces, gas-fired water heaters, furnaces, boilers and other combustion devices for the air inside a building. In severe cases naturally vented combustion appliances can experience “backdrafting,” where products of combustions are pulled back into the house, increasing the possibility of carbon monoxide poisoning to the home’s occupants with the increased use of commercial vented hoods with higher flow increases the possibility of this happening.

HVAC fans can exacerbate the effects of leaky ducts. Heating, ventilation, and air conditioning (HVAC) systems that allow air leakage can produce pressure differences across building envelopes. There are two types of duct system leakage: duct leakage to the exterior and duct leakage to the interior of the building. Either can have serious consequences.

- Leakage to the outside of the building from either the supply or the return sides of the system can cause infiltration rates to increase by as much as 300 percent. As noted earlier, every cubic foot of air lost to the outside through

For more information on the effect of duct leakage in buildings, see, “The Sucking and the Blowing—A Lesson in Duct Leakage.”

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[www.energyfanguard.com/blog/building-science-HERS-BPI/bid/76157/The-Sucking-and-the-Blowing-A-Lesson-in-Duct-Leakage](http://www.energyfanguard.com/blog/building-science-HERS-BPI/bid/76157/The-Sucking-and-the-Blowing-A-Lesson-in-Duct-Leakage)

duct leakage must be replaced. Air lost from the ducts must be replaced by outside air drawn in through leaks in the building shell. Unfortunately, most duct leakage occurs when the weather is at its worst—during the peak of summer and winter, when energy efficiency and comfort are in greatest demand. Supply duct leakage to the outdoors can cause a home’s interior to be under negative pressure, which pulls unconditioned air (hot or cold) into the home. Return-side leakage, on the other hand, can cause a positive pressure difference in the building with reference to the outside. On average, such leakage can cause a 10 percent to 20 percent increase in heating and cooling energy use, along with a 20 percent to 50 percent decrease in heating and cooling equipment efficiency.

- Leakage to the interior of a building doesn’t cause large increases in energy use or decreases in equipment efficiency. Supply leakage to an interior portion of a building, such as ducts located between floors, walls, closets, and basements can pressurize a small, localized area, causing the rest of the building to depressurize in response. Similarly, return leakage can depressurize the area where it is located, causing the rest of the building to pressurize. Duct leakage to the inside of a building is more a source of comfort, health and safety than a cause for infiltration. If supply ducts are not delivering conditioned air to the intended area, occupants may adjust the thermostat to the warmer or colder setting than might otherwise be needed, which wastes energy. However, return leakage where combustion appliances are located (basements, equipment rooms, and closets) has been found to cause water heater exhaust spillage, backdrafting, carbon monoxide production, and flame roll-out resulting in fires. The importance of this fact cannot be overstated.

An imbalance of air flow across interior or exterior walls, ceilings, and floors can also cause pressure differences.

### **Air Pressure Caused by Air Flow Imbalance**

An imbalance of air flow across interior or exterior walls, ceilings, and floors can also cause pressure differences. Imbalanced air flow can occur if the supply and return air flows in an area are not equal or if closed interior doors block the supply and return paths.

Unbalanced flow often occurs when a room has more supply air delivered than is removed by the return, allowing the room to pressurize. This can lead to air leaking out through the walls of the room or traveling into the attic or crawlspace. Similarly, if the return flow from a room is larger than the supply flow, the room can depressurize, drawing air in from outside. This can occur, for example, when interior doors are closed in buildings that have central return systems. This HVAC design delivers air to each room, but does not have a return vent in each room. When a door is closed, it becomes a barrier between the return—located in the main body of the house—and the supply air delivered to the closed room. The return attempts to draw this missing air from the rest of the house, depressurizing the main body of the home and possibly causing backdrafting problems with fireplaces, wood stoves, or other combustion appliance.

Likewise, without any local returns, the closed rooms can become pressurized, driving warm, moist, interior air into the walls and ceilings, possibly leading to mold growth and even rot in the structural assemblies.

In both cases, the magnitude of these pressure differences depends on the tightness of the rooms with reference to the main body of the house and to the outside, as well as the amount of air supplied to each room. A common, though not ideal, practice for allowing air to return to the central return is to cut the doors to rooms shorter to allow return air to pass underneath them.

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Improper air flow can have severe effects on the health and safety of the people in the building.

## Effects of Air Flow on Occupants

Improper air flow can have severe effects on the health and safety of the people in the building by promoting mold growth, spreading pollutants, and possibly creating backdrafting of combustion appliances, causing possible carbon dioxide poisoning.

### Combustion

Negative pressure can cause backdrafting and prolonged spillage from fireplaces, gas-fired water heaters, furnaces, boilers or any other device that uses house air for combustion. It can also cause flame roll-out from the bottom of residential water heaters and increased carbon monoxide production in both combustion type water heaters and furnaces.

During the summer months, negative pressures inside the home can draw in warm moist air from outside. When this moist air comes in contact with surfaces that are below the dew-point temperature, condensation can form, providing an excellent breeding ground for mold and mildew, which are known respiratory irritants. The same is true during the winter if the house is pressurized, driving moisture-laden air out of the building and its wall, floor and ceiling assemblies.

### Pollutants

The air in a home often contains many pollutants, such as smoke, pollen, dust mites, animal dander, radon, and fumes from cleaning supplies. Particulate pollutants and volatile organic compounds (VOCs) can be drawn from one area of the home to another by undesigned air flow. Soil gases (such as radon) can be drawn up from the crawlspace or basement in to the building by negative pressures. Combustion devices and fireplaces can backdraft, causing carbon monoxide gases to enter the home.

### Comfort

The actual movement of air within a building can often affect the occupants' comfort. During the winter, movement of cooler air currents is often perceived as unwelcome "drafts." During the summer, however, air movement over exposed skin enhances evaporation, making occupants feel both cooler and dryer. This air movement can be caused by either convection currents or by mechanical means.

## Convection Currents

Air naturally rises when heated and falls when cooled; such movements are known as convection currents. These currents can occur whenever air in a building is heated or cooled in an uncontrolled fashion by improperly insulated surfaces (i.e., poorly insulated walls, single-pane windows). The result is often that the occupants feel drafts and are uncomfortable. All buildings have convection currents to some degree, so the goal is to avoid excessive convection currents when improperly insulated.

Convection currents can also occur within building cavities found in the building.

Examples of this situation are:

- A partially or improperly insulated cavity is tight to the inside of the building but leaky to the exterior. This allows the air inside the cavity to be heated or cooled through its contact to the outside, possibly leading to convection currents.
- A cavity is tight to the interior of the building and to the outdoors, but gaps exist between the insulation and the exterior surfaces of the cavity, allowing convection currents to circulate.
- A cavity is leaky to both the inside and the outside of the building and the air is heated in the cavity. This allows air to leak in to the cavity in either direction where it is heated; it then can develop convection currents.

This worst-case scenario allows direct leakage of outside air to the inside, and vice versa.

## Mechanical Forces

Forced-air heating and cooling equipment is designed to move specific quantities of conditioned air throughout a building. If the air moves too quickly, it can have a noticeable cooling effect on the occupants. This is a cause for discomfort during the winter months, bringing complaints of “drafts,” but can actually increase occupant comfort during the summer. Proper design of HVAC equipment and ducts and proper orientation of the duct registers can help to reduce this effect.

## Effects of Air Flow on Building Durability

Improper air flow can draw in moist air from outside, or force moist interior air out into the walls, ceilings, and other structural assemblies. In either case, this air-transported moisture can have serious effects on the durability of a building.

Condensation occurs as water vapor in the air is changed to liquid. Whether it be interior window sills or hidden structural assemblies, once wood absorbs 30 percent of its weight in water it can begin to rot<sup>7</sup>. The most effective approach to reducing air-transported moisture is to seal the building tightly against air infiltration or exfiltration. This keeps damp outside air outside and allows the building’s ventilation and air-conditioning system to remove excess moisture from the air inside the building.



Unwanted air flow can reduce the energy efficiency of a building, even if the building is tightly sealed to the outside.

## Effects of Air Flow on Energy Efficiency

Unwanted air flow can reduce the energy efficiency of a building, even if the building is tightly sealed to the outside. The following examples demonstrate this effect for both air flow that increases a building's air change rate, and air flow that does not.

### Air Flow that Increases Building Air-Change Rates

When heating and cooling equipment is initially sized for a building, the heat load calculations assume some infiltration rate (uncontrolled air flow). A higher infiltration rate means lower overall energy efficiency for the building. Infiltration rates and subsequent efficiency loss can be affected by both natural and mechanical air movement.

*Natural movement* includes the forces of wind and stack, which cause a certain amount of air infiltration in most buildings. In older buildings an amount of air equal to the entire volume of the house may enter and exit every hour. This is called one air change per hour (ACH). Some newly built homes may have only 0.25 ACH or less. The effect of both wind and stack can be reduced by properly sealing all undesigned holes in the envelope of the building.

*Mechanical movement* from HVAC fans and other mechanically-driven forces can have a much greater effect on a building's air-change rate than natural forces. Research has found duct leakage and imbalance can increase infiltration rates by as much as 300 percent. Mechanical infiltration can also cause air to pass through the thermal boundary of the building. Uncontrolled air infiltration caused by mechanical systems can be controlled by sealing any holes in the air-distribution systems, and properly balancing the air flow and pressure throughout the building.

### Air Flow that Does Not Increase Building Air Change Rates

Convection currents inside some cavities are an example of air flow that can reduce the overall energy efficiency of a building system, even though it does not increase infiltration or air-change rates.

Even cavities that are airtight with respect to the outside can affect the energy efficiency of a building. These normally conditioned spaces (such as hall closets), if open to the interior of the house but not receiving air from the HVAC system, become a potential heat (or cooling) sink. For example, if the interior walls or a dropped ceiling are open to the attic space, then as the air inside these spaces becomes heated; it will rise to fill the attic as well. This expands the volume of the building's conditioned space to include the area in the attic, increasing the building's energy demands and possibly reducing comfort levels as well. The HVAC equipment must then run longer or use more energy to heat or cool space that no one occupies. In such a situation, the building may be tight according to a blower door test but still have higher energy use. The obvious solution to such problems is to ensure that all potential air pathways are sealed tightly against the building's interior as well as exterior.

<sup>7</sup> [https://www.energystar.gov/ia/partners/bldrs\\_lenders\\_raters/downloads/ENERGY\\_STAR\\_V3\\_Building\\_Science.pdf](https://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/ENERGY_STAR_V3_Building_Science.pdf)

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Convection currents inside some cavities are an example of air flow that can reduce the overall energy efficiency of a building system, even though it does not increase infiltration or air-change rates.

### **Thermal Bypass**

Any conditioned air that is able to pass through or around insulation into an unconditioned area lowers the energy efficiency of a building. Such efficiency loss is referred to as thermal bypass. To prevent this type of loss, buildings should be tightly air-sealed and all insulation installed in substantial contact with the adjacent air barrier, allowing no unintentional air spaces.

## **Summary**

Ensuring durable, energy efficient, safe and comfortable homes is easier to do with a basic command of the key elements of building science: that the house is a system, that homes should be constructed using techniques suitable to the location and climate, and that all structures should incorporate methods to control the flows of heat, air and moisture.

## **About Insulation Institute**

The Insulation Institute™ leverage the collective insulation expertise of our organization and our members to empower homeowners and professionals to make informed insulation choices. Our mission is to enable a more comfortable, energy efficient and sustainable future through insulation—and we are constantly working with building professionals, homeowners, government agencies, and public interest, energy and environmental groups to realize that vision.

## **About Energy Vanguard**

Energy Vanguard's mission is to turn houses into high performance homes. Our clients are homeowners, builders, trade contractors, Home Energy Raters, BPI (Building Performance Institute) Building Analysts, manufacturers and governmental bodies. We focus on training, consulting and design and are a RESNET accredited home energy rating ([HERS](#)) provider and a BPI Test Center.