Air leakage in buildings represents from 5% to 40% of the space-conditioning costs. Controlling air leakage is one of the most important functions of weatherization, and often the most difficult.

An air barrier is a building component designed to stop air leakage. The air barrier combined with the insulation defines the thermal boundary.

The main goals of air leakage control are these.

- Save energy.
- Increase comfort.
- Protect insulation's thermal integrity.
- Reduce direct cooling or heating of people and building components by outdoor air.
- Avoid moisture migration into building cavities.

Air sealing may provide these additional benefits.

- Reduce vermin's access to indoors.
- Reduce flow of air pollution from external sources.
- Reduce rainwater leakage.
- Enhance fire safety.

We used to think that existing buildings were relatively airtight, except for seams where building materials joined, especially around windows and doors. In the past, engineers tried to estimate air leakage based on the length and width of cracks between building materials. Estimating crack size wasn't accurate because it neglected major air leaks in hidden locations.

From 1975 to 1985, scientists and technicians developed instruments to evaluate air leakage, including blower doors, infrared scanners, and tracer-gas analysis. With these developments, we now know that the building's hidden air leaks are usually more important than seams between building materials. As a result, technicians found new ways of finding and sealing these hidden air leakage pathways.

Air Leakage Through Construction Materials

Material	CFM_{50}/ 100 ft^2
5/8" oriented-strand board	0.09
1/2" drywall	0.26
4-mil air barrier paper	0.26
1/8" hardboard	0.37
1" EPS (dense)	1.5
(materials below not considered air barriers)	
15# perforated asphalt felt	5.3
Standard concrete block	7.9
1" EPS (light)	170
5/8" tongue & groove boards	300
6" fiberglass batt	490
3" vermiculite	930
1.5" spray-on cellulose	1160

These values represent the approximate air leakage through each square foot of material during a 50-pascal blower-door test.

Based on: "Air Permeance of Building Materials" research report by Canada Mortgage Housing Corporation. Units converted from all-metric by the author.

In the 1990s, Canadian building scientists measured the air permeability of various building materials and joints. They also measured durability of air barriers in very high winds.

Most homes and small multifamily buildings are ventilated by natural air leakage, and this fact informs decisions about whether to seal air leaks and how airtight to make a home. Scientists, engineers, and technicians continue to debate whether air leakage is an acceptable strategy to ventilate homes.

Some recent state building codes now require strong and effective air barriers and mechanical ventilation systems. Canadian builders, architects, and engineers have understood the need for air and vapor barriers for years because of their cold climate and the moisture problems that result from ineffective air and vapor barriers.

This chapter discusses the principles of air leakage, diagnosis of air leaks, construction flaws that allow air leakage, and methods and materials for sealing air leaks.

Air-Sealing Principles

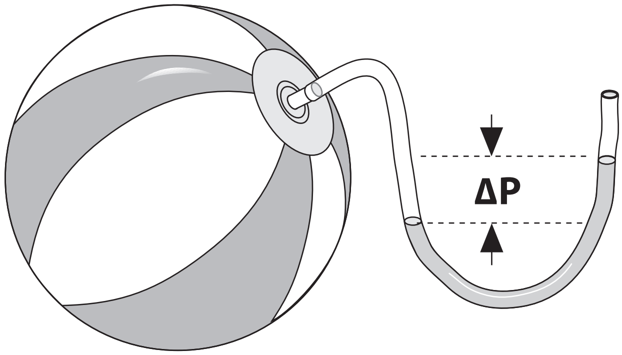
Air leakage from one zone to another requires a hole between the zones and pressure to push air through that hole. The airflow rate through a hole or group of holes depends on two factors: the cross-sectional area of the holes and the difference in pressure (ΔP). Air leaking in is called infiltration, and air leaking out is called exfiltration.

Natural airflows are usually small and variable — too difficult to measure. A blower door's pressure and airflow, however, are steady and measurable. Measuring pressure and airflow with a blower door allows you to estimate the size of holes.

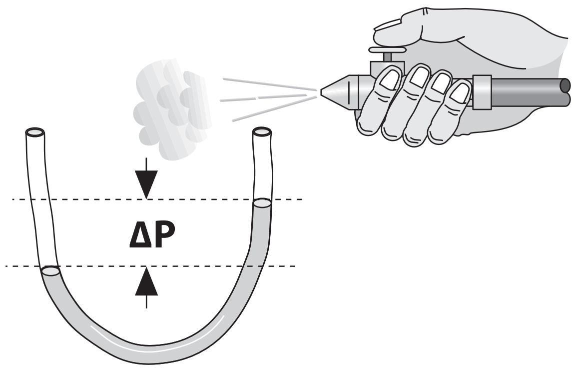
Direct air leakage occurs at windows, doors, and other concentrations of seams, where air leaks directly through the shell. Indirect air leakage enters the building shell in one location, flows through building cavities, and emerges at a different location.

Many indirect air leaks are found in intermediate zones like attics and crawl spaces. One seldom-recognized air-leakage source is airflow through building materials themselves. Concrete block, brick, perforated felt, and most insulation materials have relatively high air permeability and aren't considered air barriers.

Manometer Readings



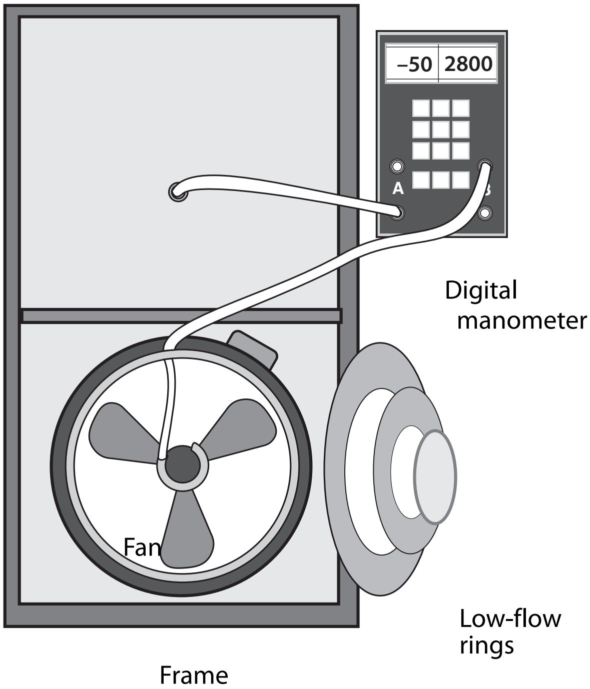
The pressure inside an inflated beach ball is greater than the pressure of the atmosphere. This pressure difference (ΔP) can be measured with a manometer showing how many inches the water level differs in its height. This is the origin of the measurement: inches of water column (IWC).



Air blown across the opening of a liquid manometer creates a vacuum in the tube and a measurable difference in the height of the water level. This ΔP depends on the air velocity and is used to calculate airflow in CFM.

Pressures driving natural air leakage come from wind, exhaust fans, furnace blowers, chimneys, and the stack effect. The stack effect (also called chimney effect) is caused by density differences between warm and cool air masses.

Blower Door



Blower doors create a measurable house pressure and airflow in order to evaluate a building's air leakage.

Chimneys and exhaust fans (including clothes dryers) remove air from the home, creating a slight vacuum, often called depressurization. The wind, furnace blower, and stack effect tend to pressurize some areas of the home and depressurize others.

Beyond air leakage, air can also move around inside building cavities, increasing the rate of heat transmission. Air convects inside building cavities, carrying heat from one surface to another. Air can wash over the insulation's surface, convecting heat away. Or air can convect through an insulation material, reducing its thermal resistance.

Ideally, an effective air barrier surrounds the home on all sides, adjacent to its insulation. An effective air barrier prevents most air leakage and convection. However, most American homes have flawed air barriers that can be significantly improved by diagnosis and air sealing.

Air Pressure and Flow

Air pressure, airflow, and the size of air leaks are directly related to each other. A pressure difference on opposite sides of a hole causes an increase in airflow through the hole. Bigger holes pass more air at the same pressure than smaller ones.

Pressure and airflow can be measured by instruments called manometers. Manometers come in three common types: a transparent tube filled with water; a round gauge with a needle indicating the pressure or flow amount; or a digital manometer, giving a digital readout of pressure.

The air inside an inflated beach ball is denser than the atmosphere outside. Measure this pressure difference by attaching a manometer to the beach ball's valve. The lighter atmosphere presses on one side of the liquid, and the denser beach ball air presses on the other. The distance that the beach ball's denser air moves the water column off level — measured in inches — is a unit of air pressure.

The small air pressure differences caused by wind, blower doors, furnace fans, and chimneys are measured in inches of water column (abbreviated IWC) in the American measurement system. The more common metric unit for small air pressures is the pascal — 249 pascals equal 1.0 IWC.

When talking about pressure differences between two areas, we say that the zone having denser air is pressurized, or is the high-pressure area. The zone with less dense air is depressurized, is under vacuum, or is the low-pressure area.

Another type of manometer is a round gauge with an arc-shaped scale for measuring either pressure (in pascals) or airflow cubic feet per minute (CFM). This gauge has a high pressure tap and a low pressure tap. If the gauge is physically located in the low pressure area — as with typical blower-door testing — its low pressure tap is open to that area (indoors), and a hose is used to expose its high pressure tap to the high pressure area (outdoors).

The digital manometer measures pressure by way of sensors, called pressure transducers. Digital manometers give their readings on a digital screen, and some can measure both house pressure and flow simultaneously.

Airflow is then measured by connecting the manometer's low pressure tap to a hose held parallel to the airflow stream. Air flowing perpendicular to the opening at the hose's end creates vacuum within the hose. This vacuum's strength is directly related to the airflow rate. Manometers convert the pressure they sense to airflow by an airflow scale on the gauge face or by an electronic calculator in the digital manometer.

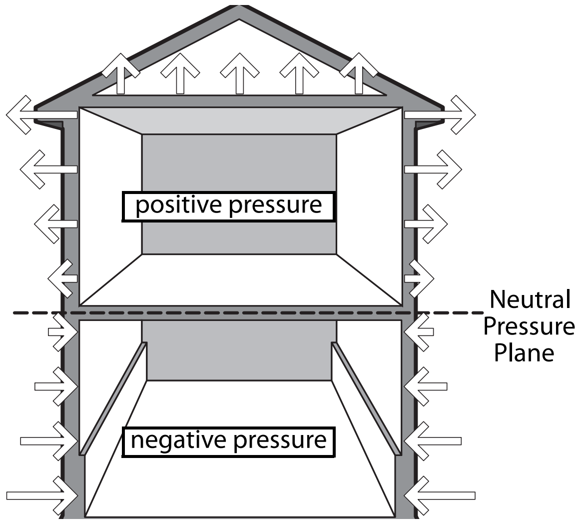
Pressures Driving Air Leakage

Air flowing inside or outside a building creates pressures that affect the building. Buildings aren't equal with respect to their air pressures. Because of differences in pressure, one single-family home may have two to four times the air leakage of another home with the same air leaks. Homes with forced-air distribution systems, fireplaces, and large kitchen exhaust fans have larger pressures than homes without these features. Homes on hilltops in high-wind areas may have twice the air leakage of homes in less windy regions.

This section describes how a building's height, its chimneys, exhaust fans, and furnace blowers, along with the wind, affect its air pressures.

Stack-effect pressure — Cooler air is denser than warmer air, and this density difference creates a pressure that causes air to move. The air inside a home tends to stratify in layers due to density differences. During the heating season, hot air rises to the top and cooler air falls to the bottom. If the home has leaks, warm air leaves through higher openings, and cool air enters through lower openings. This pattern of air leakage is called the stack effect because it resembles airflow in a chimney. During the cooling season the stack effect can reverse causing infiltration higher in the building and exfiltration in the lower.

Stack Effect



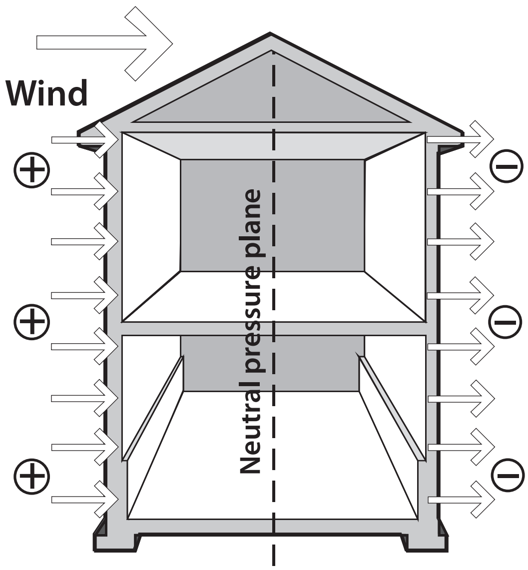
The stack effect is caused by the relative buoyancy of warmer air. Warmer air's upward force exerts an outward pressure. Airflow, through holes in the home's top, creates suction at lower levels, pulling air in. Arrows indicate the direction and intensity of air pressure.

A building's natural pressure difference with the outdoors varies depending on location. Somewhere near the building's midpoint of height is a boundary region, called the neutral pressure plane, which separates the building's negative and positive pressure zones. A hole near the neutral pressure plane allows little or no leakage because there is no indoor/outdoor pressure difference there.

The pressures created by stack effect are greatest at the highest and lowest points in the building. Therefore, a hole in a basement or attic will allow more air infiltration than an equal-sized hole near the neutral pressure plane.

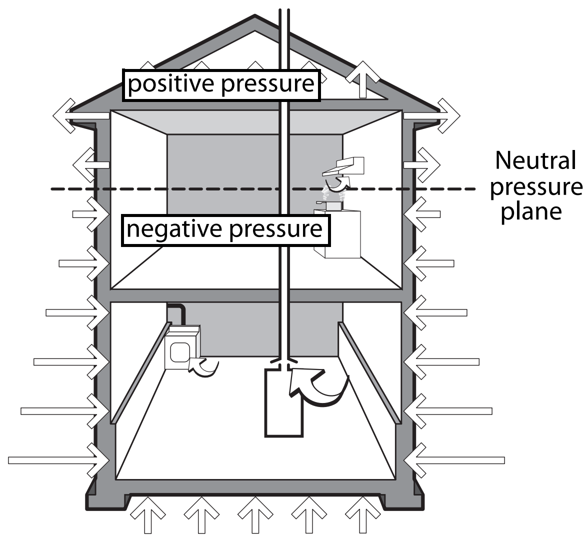
Wind pressure — Wind blowing against a wall creates an area of high pressure, driving outdoor air into the windward side of the home. The wind's force is enhanced or hindered by building and landscaping features that act as dams — porch roofs, overhangs, inside building corners, fences, or vegetation.

Wind Pressure



Wind creates a positive pressure on the windward side of the home and negative pressures on leeward side with reference to the home's interior. Wind pressures push and pull air through holes in the building shell.

Chimney and Exhaust Pressure



The chimney, clothes dryer, and kitchen exhaust fan exhaust air from the home, putting most of the home's volume under negative pressure.

The wind creates a vacuum at wall and roof surfaces parallel to its flow. The leeward side, facing away from the wind, is usually either neutral or depressurized.

The wind's speed is greater the higher from the ground you measure. As building height increases, wind's force against the building increases. Wind speed is affected by trees, fences, neighboring buildings, and hills that block or divert wind. Wind speed varies widely between geographic regions and even within local areas. Strong wind gusts can damage air barriers and permanently increase air-leakage rates.

Chimney and exhaust pressures — Chimneys, exhaust fans, and clothes dryers create a slight vacuum indoors because they exhaust air out of the building. They also move the neutral pressure plane up because more of the building's interior space is under negative pressure. A fan that forces air into the home moves the neutral pressure plane down, putting more of the home under positive pressure.

Replacement air, for air exiting exhaust devices, is called make-up air for exhaust fans or combustion air for combustion appliances. Make-up air and combustion air enter through air leaks, intentional openings, or ducts. Make-up air or combustion air may even come down a chimney if negative pressures become too great — a dangerous situation called backdrafting.

Duct pressure — The furnace blower circulates air through the furnace and its supply and return ducts. Supply registers blow air into a room, pressurizing nearby areas of the room. Return registers suck air out of rooms, depressurizing areas near these registers.

If the ducts are leaking, or return air is restricted, rooms may have high positive or negative pressures. These pressures are often large enough to double or triple the building shell's air leakage, compared to air leakage when the furnace blower is off.