Building Science Introduction - Air Flow

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Many aspects of building design, construction, and operation can affect the health and comfort of the people in the building. This introduction focuses on three particular areas:

- Air Flow
- Heat Flow
- Moisture Flow.

For each of these issues, the introduction explores causes, control measures, and effects on both buildings and occupants. This introduction defines many of the theories behind the ENERGY STAR New Homes requirements.

Air Flow

In simplest terms, air needs an opening or hole to flow through and a driving force to move it. Many different factors control how air flow affects a house. This section examines the forces and conditions that allow air to flow into, out of, or within a building, including:

- Controlled versus uncontrolled airflow
- Causes of air pressure
- Holes and pathways
- Effects of air flow.

In order for air to flow into, out of, or within a building, 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

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

Uncontrolled Air Flow

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

Limiting Factors to Air Flow

Flow Determinants. The amount of air that flows through a hole is limited by three factors:

- Effective hole size
- The magnitude of pressure across the hole
- The amount of time the pressure is present.

Pressure Effects. Air always flows from a 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 always attempt to enter the home. Similarly, inside air at a high pressure with reference to the outside will always attempt to exit the house.

Path of Least Resistance. The nature of air flow always seeks the path of least resistance. Given several choices of openings for entering or exiting a building, the air will move through the largest hole that offers the least resistance.

One Cubic Foot In = One Cubic Foot Out. Generally speaking, for every portion of air that enters a house, an equal amount of air must also exit the building, and vice versa. One example of this rule is the clothes dryer: if a dryer exhausts 200 cubic feet per minute (CFM) of air out of a building, then 200 CFM must enter the building to replace the air exhausted. In such a situation, applied building science asks the question: “Where is this make-up air entering the building, and what are its effects?”

Measuring Pressure

One way to measure very small pressures is in units called Pascals. There is about 1 Pascal of pressure exerted on a piece of bread by a pat of butter. 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's exterior wall determines the pressure inside the house with reference to the air pressure outside. A common reason for measuring pressure is to assure that combustion devices are operating properly.

Air Pressure Causes

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

Wind

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 direction of the wind. On the windward side of a building, the wind causes a positive pressure to build against the outside, causing air to enter the building. On the leeward side of a building, a negative pressure difference develops with reference to the inside of the building, and air exits the building through holes and other leak sites. The effect that wind has on a building depends on four factors:

- The number and size of holes in the building
- Where the holes are located
- The amount of time the wind blows on average (e.g., buildings located in open plains, atop mountains, or near large bodies of water are subjected to wind blowing for longer periods of time than other buildings)
- The amount of shielding present, such as from trees, hills, and other buildings

Heat

Pressure is also caused by the buoyancy of hot air, which naturally attempts to rise to the top of a building. This is called stack pressure. 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 of 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.

Neutral Pressure Plane

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 side of the plane, air is being drawn into the home and on the upper side, air is being forced out. Since no air moves at the neutral pressure plane, the greatest amounts of air infiltration or exfiltration occur at those points in the house farthest away from the plane.

Fans

Fans (particularly exhaust fans and HVAC air handlers) can contribute to pressures changes in several different ways. Under ideal design conditions, neither should have a negative effect on building leakage. Unfortunately, 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 1 and 10 Pascals of pressure on residential buildings, fans can produce as high as 60 Pascals of pressure.

Exhaust Fans

Exhaust fans (bathroom, kitchen, and laundry exhaust fans, cooktop fans, dryers, and central vacuum systems) draw air from the living area of the house. This air must be replaced by air drawn in from the outside. Without proper design, these fans frequently compete with fireplaces, gas-fired water heaters, furnaces, boilers, and other combustion devices for the air inside a building.

HVAC Fans

Heating, ventilation, and air conditioning (HVAC) systems that allow air leakage can produce pressure differences across the shell of buildings. If duct leakage exists, it will be exacerbated by HVAC fans.

There are two types of duct system leakage: duct leakage to the outdoors and duct leakage to the inside of the building. Duct system leakage to the inside or outside of the home, through either the supply or return ducts, can have serious consequences.

Duct Leakage

Duct systems that leak to the outside of the building on both the supply and return sides of the system can cause infiltration rates to increase by as much as 300%. As noted earlier, every cubic foot of air lost to the outside through duct leakage must be replaced. Caught in a vicious cycle, 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-side leakage to the outside can cause a negative pressure difference in the building with reference to outside. 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% to 20% increase in heating and cooling energy use, along with a 20% to 50% decrease in heating and cooling equipment efficiency.

Duct system 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 and health and safety problems than a cause for infiltration.

Return leakage where combustion appliances are located (basements, equipment rooms, and closets) has been found to cause spillage, backdrafting, carbon monoxide production, and flame roll-out resulting in fire. The importance of this fact cannot be overstated.

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 to an area are not equal or if closed interior doors block the supply and return paths.

Imbalanced Supply and Return

Imbalanced 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.

Interior Door Closure

Buildings that have central return systems can experience large pressure differences when certain interior doors are closed. This HVAC design delivers air to each room, but does not have a return 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 any fireplaces, wood stoves, or other combustion appliances.

Likewise, without any local returns, the closed rooms 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.

Holes and Pathways

As explained earlier, in order to have uncontrolled air flow (infiltration) into a building, holes must exist in the building's shell. Reduce the number of holes in the building, and you reduce the amount of uncontrolled air flow. There are only two kinds of holes in buildings: undesigned holes and designed holes. Designed holes, as the name implies, are those necessary to allow the proper flow of air, such as vents and chimneys. Undesigned holes, though, allow uncontrolled air leakage and rob a home of its efficiency and healthy environment.

Undesigned Holes

Undesigned holes in the home are found in the attic, walls, and floors. Any of these holes that connect to the outdoors should be adequately blocked, caulked, gasketed, or otherwise adequately 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 inside and outside 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 it's carrying, can then flow freely through recessed light fixtures, dropped ceilings over cabinets, etc., and cause serious moisture and comfort problems.

Undesigned holes should be air-sealed and blocked to control the potential spread of draft, smoke, and fire.

Designed Holes

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.

Effects of Air Flow

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.

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 water heaters and furnaces.

Moisture/Mold

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 often forms, providing an excellent breeding ground for mildew and other molds, 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.

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) are 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.

Convection currents can also occur within building cavities found in the building. Examples of this situation are:

- A 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, 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 develops 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 forms when air with a high relative humidity (RH) (either indoors or outdoors) comes in contact with surfaces that are below the dew-point temperature. Whether it be interior window sills or hidden structural assemblies, once wood absorbs 30% of its weight in water it
can begin to rot. 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.

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 natural infiltration rate (uncontrolled air flow). A higher infiltration rate means a lower overall efficiency for the building. Infiltration rates and subsequent efficiency loss can be affected by both natural and mechanical air movements.

Natural Air Flow that Increases Building Air-Change Rates. The forces of wind and stack cause a certain amount of air infiltration in most buildings. In older buildings an amount 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 suffer only 0.25 ACH or less. The effect of both wind and stack can be reduced by tightly sealing all undesigned holes in the shell of the building.

Mechanical Air Flow that Increases Building Air-Change Rates. 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%. 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 air-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.

Air Flow in Building Cavities. 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 work overtime to heat or cool space that no one occupies. In such a situation, the building may be very tight according to a blower door test but still have unusually high 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.

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 directly against the adjacent air barrier, allowing no unintentional air spaces.

More Info.

Access to some references may require purchase from the publisher. While we continually update our database, links may have changed since posting. Please contact our webmaster if you find broken links.

References and Resources*

1. **ENERGY STAR Certified Homes Building Science Introduction**
   Author(s): U.S. Environmental Protection Agency
   Organization(s): EPA
   Publication Date: January, 2011
   Document outlining building science principles about air flow, heat flow and moisture flow in homes.

*Publication dates are shown for formal documents. Dates are not shown for non-dated media. Access dates for referenced, non-dated media, such as web sites, are shown in the measure guide text.

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