COOLING (low-energy)

How Cooling is Different than Heating

Cooling is the most variable type of energy consumption in American homes. Two similar homes in the same neighborhood could differ by a factor of 50 for cooling costs. For example, an inefficient home with air conditioning could use $500 worth of electricity in a hot month, while a neighbor in a well-designed home—with no mechanical air conditioning—might spend only $10 per month on electricity to operate room fans and evaporative coolers.

The most effective strategies for improving cooling efficiency are different from the strategies to improve heating efficiency. For example:

- Shade trees and nighttime ventilation will reduce the need for air conditioning, but they won't reduce heating consumption.
- Window glass with a low solar heat gain coefficient (SHGC) will reduce cooling load, but heating efficiency is improved by windows with a low U-factor.
- Low humidity helps reduce cooling energy consumption but not heating consumption.

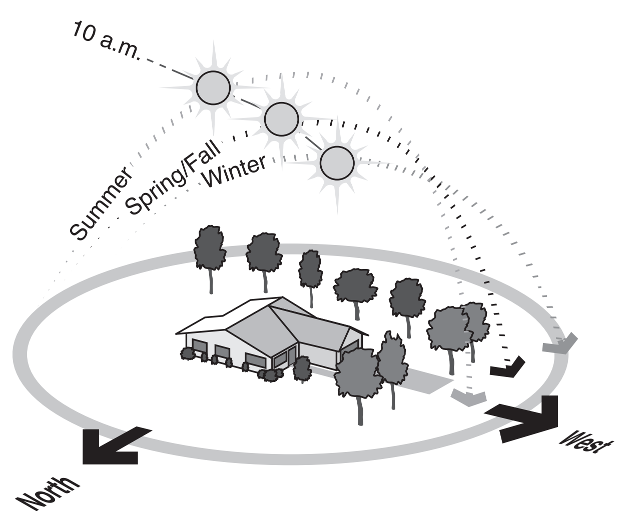
A home's cooling energy consumption depends on its shading, insulation, reflectivity, and the heat-tolerance of its residents. Shading the home, making it as reflective as possible, and using nighttime ventilation can reduce air-conditioning costs or eliminate the need for air conditioning altogether.

Annual Air-Conditioning Energy Use (kWh/yr)

Region & A/C Type	Single Family	Multi-family	Mobile Home
North	**kWh/yr**	**kWh/yr**	**kWh/yr**
Room	200–500	100–300	300–600
Central	900–1400	400–600	1200–1800
South	**kWh/yr**	**kWh/yr**	**kWh/yr**
Room	1100–1500	300–600	1000–1400
Central	3000–4600	1000–1600	2600–3400

From: Lawrence Berkeley National Laboratory, Energy Information Administration, and utility sources. For U.S, households.

Solar Radiation: Winter and Summer



The angle of impact of the sun's rays on the earth changes between seasons. The changes become more extreme farther away from the equator.

Summer Comfort Principles

The combination of air temperature, radiant temperature, humidity, and air movement determine comfort. Air temperature and radiant temperature determine the rate that a human body can lose heat by convection and radiation, which are the body's preferred cooling mechanisms. The relative humidity determines the rate that a human body can reject heat by evaporation of sweat, the body's last-resort cooling system.

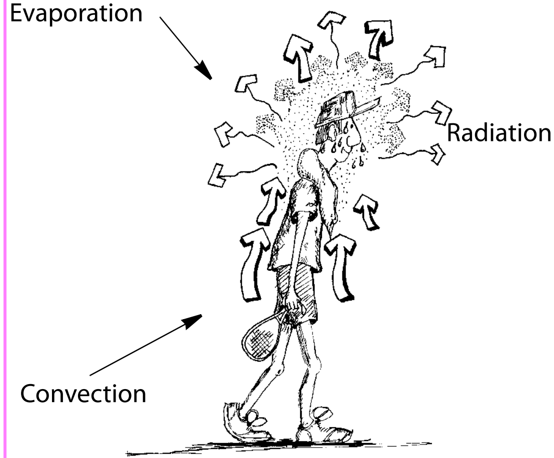
Air temperature and radiant temperature have a combined effect on human comfort. Air temperature is widely recognized as a comfort determinant, but radiant temperature is equally important. Absorbed summer sunlight raises wall and ceiling temperatures, making these surfaces radiant heaters.

Relative humidity is the percent at which air at any temperature is saturated with water vapor. Air at 100% relative humidity is saturated and can hold no more water vapor. Dew point is the temperature at which condensation begins. At 100% relative humidity the dew point is the same as the air temperature. Below 100% relative humidity, the dew point is less than the air temperature.

Humidity affects the choice of a cooling strategy during hot weather. At low relative humidity and low dew point, evaporative cooling and ventilation are effective cooling methods. Ventilation works well up to about 70% relative humidity (or a dew point in the high 60°s). Most Americans use air conditioning during hot weather—when the dew point is above 68°F or when the relative humidity outdoors is over 70%.

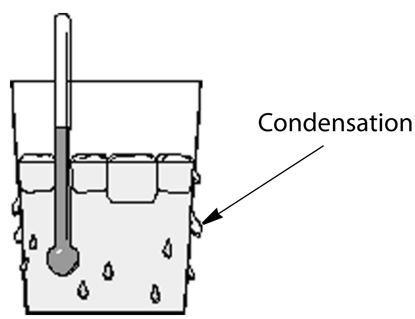
At 70% relative humidity or above, the air feels either hot and sticky, or cold and clammy, and is not comfortable to most people. Air conditioners must remove moisture from indoor air to achieve comfort.

Convection, Radiation, and Evaporation



The human body loses heat steadily by convection, radiation, and evaporation. Summer comfort is often defined as staying cool with a minimum of sweat.

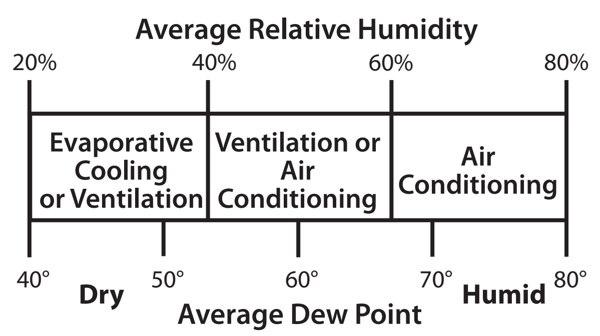
Dew Point



Fill a beverage glass with warm water. Then slowly add ice. When condensation begins to appear, the temperature of the glass has reached the dew point temperature of the air.

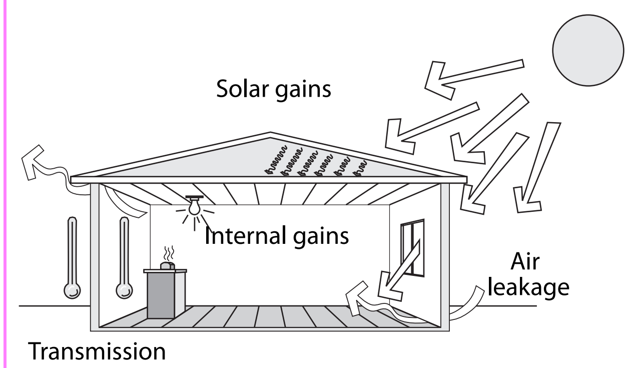
Moving air always makes you feel cooler, because it carries heat away from the skin and increases the evaporation of sweat. Circulating air inside your home is the key element to staying comfortable during hot weather. Rapidly moving air works well by itself, and can be combined with air conditioners, evaporative coolers, and whole-house fans to further improve comfort.

Humidity's Effect on Cooling Strategies



Dew point and relative humidity are two commonly reported indicators of summer humidity. The higher these values are, the more difficult it becomes to provide acceptable comfort without air conditioning.

Four Types of Heat Gains



Solar gain is the dominant heat gain. Air leakage and internal gains are about equally important. Transmission heat gains are usually least important.

Whenever the outdoor air temperature and humidity are comfortable, ventilating with outdoor air will carry heat away from the home and reduce air-conditioning costs.

Heat Gain

During the cooling season, unwanted indoor heat is called *heat gain*. There are four types of heat gain in the home: solar heat, internal heat, air leakage, and temperature-driven heat transmission.

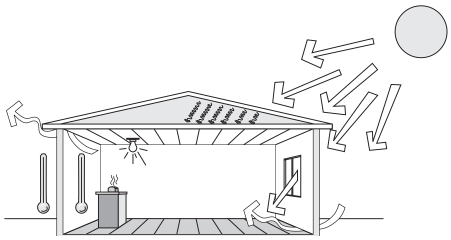
Solar Gain — In most climates, solar heat is the largest heat gain, contributing about 50% of the heat accumulating indoors. Solar energy falling on the roof and coming through the windows accounts for most of this. Walls are less important as a source of solar heat.

Internal Gains — Internal gains include the waste heat from lighting, refrigeration, water heating, and other appliances, as well as the body heat from people inside the home. Efficient appliances produce less waste heat, and so contribute less to summer overheating. Internal gains usually account for around 20% of summer heat gain.

Air Leakage — Air leakage allows hot outdoor air to leak into the home, and cold indoor air to leave. Air sealing helps reduce both summer heat gain and winter heat loss. Air leakage contributes about 20% to summer heat gain.

Heat transmission — Heat transmission through the shell of the home is the least important summer heat gain because the temperature difference between indoors and outdoors is much smaller in summer than in winter. Heat transmission typically represents around 10% of the total cooling load.

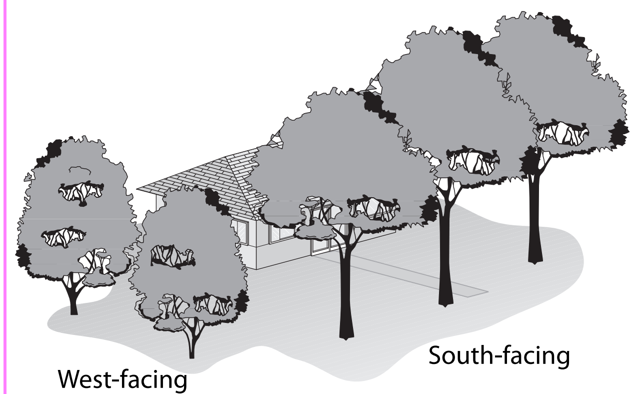
Percent of Total Heat Gain for Components



Component	Low	High
Solar Gains – Windows	15%	35%
Solar Gains – Roof	10%	30%
Solar Gains – Walls	3%	8%
Internal Gains – Heat	10%	25%
Internal Gains – Humidity	5%	15%
Air Leakage – Heat	10%	20%
Air Leakage – Humidity	5%	25%

Every home and homesite has a different distribution of heat gains. For example, homes with little shade have high solar gains while shaded homes have lower solar gains. Homes in humid climates have large humidity heat gains while those in dry climates don't. Homes with awnings have low window solar gain.

Energy-Saving Landscaping



Landscaping is the best long-term cooling investment for residences. Southern exposures need taller trees to block the higher angle of the sun from the south. East and west vegetation should block the lower-angle sun from entering windows during the summer.

Reflectivity

Solar energy falling on the roof and coming through the windows accounts for most of the solar heat accumulating indoors. Walls are less important as a source of solar heat.

Just as insulation levels (R-values) are the most important characteristic for low-energy heating, a well-shaded or reflective home enables low-energy cooling.

The most important places to use shading and reflectivity are on the roof and windows. Energy conservation measures that block the sun before it strikes the roof or windows are the most effective. Trees and other plants that provide shade are the best long-term investment for reducing cooling costs.

Cooling with Landscaping

A well-planned landscaping program can reduce an unshaded home's summer air-conditioning costs by 15% to 50%.

You may have noticed the coolness of parks and forests when compared to nearby city streets. This is because trees and shrubs create a cool microclimate, reducing the shaded area's temperature and absorbed solar heat.

A tree can produce daily cooling effects similar to five average-sized air conditioners running 20 hours per day. Shading and *evapotranspiration* (the process by which a plant releases water vapor) from trees can reduce air temperatures as much as 9°F compared to unshaded areas. Since cool air falls toward the ground, temperatures directly under trees can be up to 25°F cooler than air temperatures above nearby blacktop.

Studies by the Lawrence Berkeley Laboratory found summer daytime air temperatures 3°F to 6°F lower in neighborhoods with mature tree canopies compared to newly developed areas with no trees. Large urban parks are up to 7°F cooler than surrounding neighborhoods. A 25% increase in tree cover will decrease a city's average mid-afternoon July temperature by 6°F to 10°F according to U.S. Department of Energy simulations for Sacramento, California.

Planting trees is ten times more cost-effective than building new power plants for summer cooling. Lawrence Berkeley Laboratory (LBL) estimates that increasing peak-load electrical supplies costs an average of $1.00 per kW-hour, while planting trees decreases peak-load consumption and is estimated to cost ratepayers only $0.10 per kW-hour.

Homeowners can reap big dividends from their landscaping. Studies by real estate agents and professional foresters estimate that the presence of trees raises a home's resale value 7% to 20%.

Shading Windows

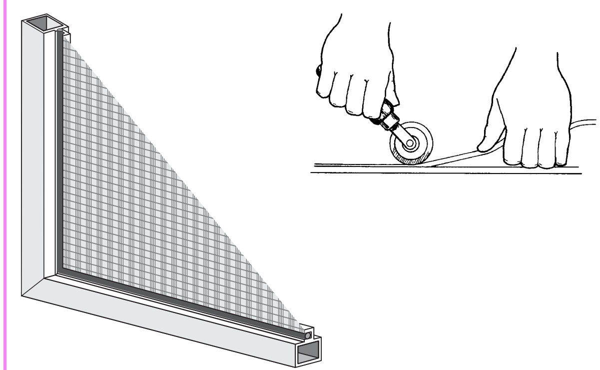
Single-pane, unshaded windows transmit about 85% of the solar heat striking them. This can account for up to 40% of a home's accumulated heat.

Consider these factors when deciding which windows to shade:

- Direction the windows face. South windows transmit the most solar heat. West windows contribute solar heat in the afternoon, just when you want it least. East windows begin heating the home early in the morning, causing more hours of discomfort.
- Location of natural shade from trees, overhangs, and other objects. If windows are already shaded by trees, nearby buildings, or large overhangs, additional shading is unnecessary.
- Total surface area of your windows. Shading devices for larger windows are generally more cost-effective than for smaller windows.

After considering these factors, utilize the following options to block 60% to 90% of the solar heat that currently enters your windows.

Sun Screens



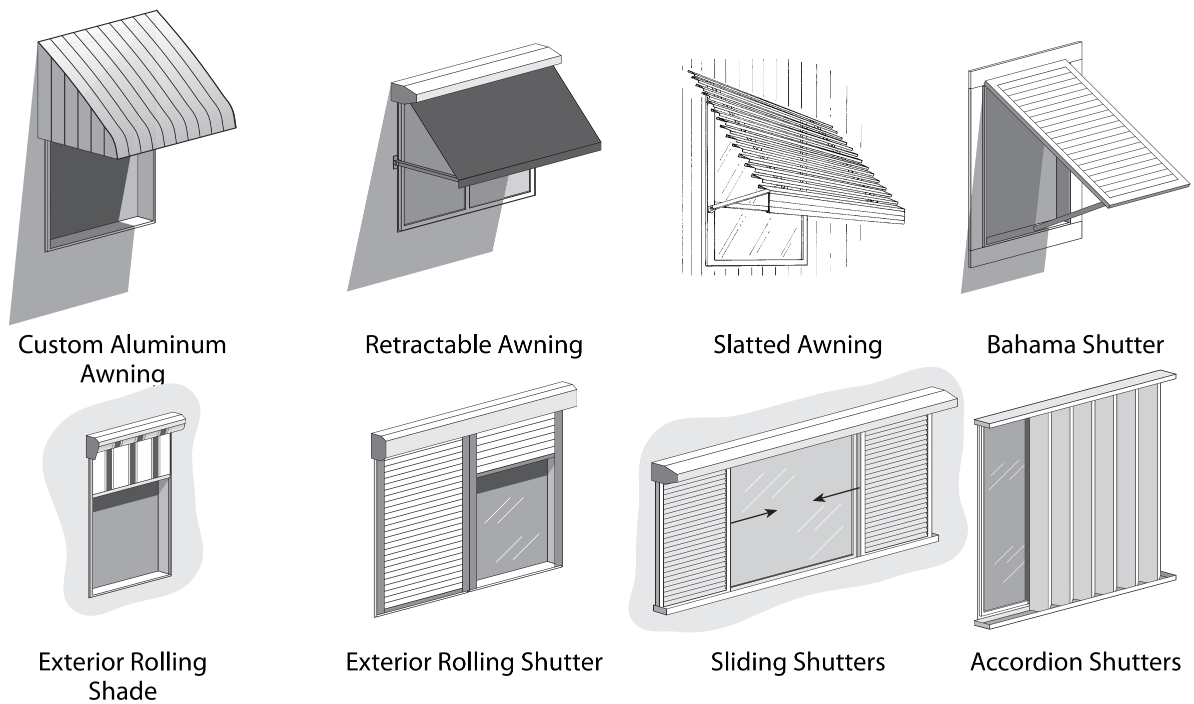
Sun screens are a very economical exterior window-shading device. Sun screen fabric is attached to an aluminum frame using a spline and roller.

Sun screens — Sun screens are often the least expensive window-shading option to retain a view through the window. A sun screen is fabric stretched over an aluminum frame and resembles an insect screen. The fabric absorbs 65% to 70% of the solar heat before it enters the home.

Sun screens must be installed on the exterior of a window to be effective. Therefore, they are not practical for outwardly opening windows, such as awning or casement windows, unless attached to the movable sash.

Reflective films — Metallized plastic window films (similar to those applied to automotive windows) can block 50% to 75% of the solar heat on single-pane glass. A microscopic layer of metal on the film repels solar radiation. Installed on the interior side of single-pane glass, reflective window films repel solar heat, cut glare, and reduce fading. To be most effective, the film must look like a mirror when viewed from outdoors during the daytime. Tinted films that merely color the glass are not as effective in blocking the sun as metallized films.

Exterior Window Shading Devices



Consumer acceptance of reflective window films has been slow because they block daylight in addition to solar heat. Newer films, recently introduced to the marketplace, transmit more light, while blocking most of the heat.

Installing reflective window film is a moderately difficult do-it-yourself project. These films—manufactured with removable protective layers—require careful installation to an absolutely dirt-free glass surface. Unlike sun screens and awnings, reflective window films do not obstruct the operation of any kind of window.

Awnings — Awnings are popular in hot, sunny climates, since they intercept solar heat before it gets to the window. In general, however, awnings are not as good an investment as trees, sun screens, and window films because they are more expensive.

The most important considerations in selecting and designing awnings are:

- Amount of shade desired. The shade an awning produces is closely related to how far the awning drops down over the window. This distance is known as the "drop" of the awning.
- Importance of maintaining a view out the window. Depending on their drop, awnings can cut off a significant portion of a window's view.
- Cost of the awning. Custom-made aluminum or canvas awnings are more expensive than do-it-yourself awning kits or mass-produced awnings.

Awnings on a home's south side need a drop measuring 45% to 60% of the window height to block solar radiation from high in the sky. Awnings on the east and west need to drop 60% to 75% to block solar radiation emanating from lower in the sky in the morning and afternoon, respectively.

Interior window treatments — Interior window treatments with reflective surfaces—metallized or bright white—can block solar heat effectively. An opaque roller shade, with a white surface facing the exterior, rejects about 80% of the solar heat entering the window. Roller shades block most of the light and all the view. White venetian blinds and white slim shades (a smaller-scale venetian blind) reject 40% to 60%. Venetian blinds and slim shades block most of the light and view.

If you want to retain some light or view, install roller shades made with metallized plastic window film. Like reflective films applied directly to glass, metallized plastic roller shades can preserve the view and transmit some light, while blocking most of the heat.

Exterior shutters and shades — Exterior shutters are not as popular as the window treatments described previously and are generally more expensive. But they can provide security and storm protection in addition to solar control.

Bahama shutters hinge at the top of the window. Sliding shutters slide horizontally to cover the window during the heat of the day. The traditional vertically hinged shutters—popular all over Europe—can also be used to block solar heat. Inexpensive exterior bamboo rolling shades are also popular in some warmer regions.

These movable exterior shading methods require a greater daily commitment by the owner than other window-shading devices. Exterior rolling shutters and shades, controlled indoors by motors or manually, are very expensive, but offer very good security and convenience.

Replacement windows — Replacement windows are not a cost-effective measure for reducing cooling costs. But if the windows are being replaced for other reasons, the added cost of low-e insulated glass is well worth the price in almost all U.S. climates. Multifamily buildings in southern climates should have reflective glass and/or architectural shading features, like overhangs and built-in solar screens.

The most important window glass characteristics for cooling are:

- *Solar Heat Gain Coefficient (SHGC)* is the ratio of solar heat passing through the glass to solar heat falling on the glass at a 90° angle. SHGC includes radiant heat transmitted, and also the solar heat absorbed and reradiated indoors. Single pane glass has a SHGC of 0.87.
- *Visible transmittance* measures how much visible light is admitted by the window glass. Visible transmittance is important because the window's main job is to give view and admit light. Special coatings—some of which cut visible light to 30%—may be unacceptable in some applications, such as when windows are small and few in number.
- *Shading coefficient* is a decimal number, like 0.55, that compares the transmittance of a window glass with clear glass. Clear glass has a shading coefficient of 1.00. A reflective glass window with a 0.55 shading coefficient would transmit 55% of the solar energy of clear glass.

See "Windows and Doors" on page 125 for a complete discussion of windows.

Conservation Measures for Roofs

Homes with reflective roof coatings, at least R-19 insulation, and good attic ventilation, may experience two-thirds less solar heat gain than those homes with darker roofs, little insulation, and poor ventilation. Homes with shaded, reflective, insulated, and ventilated roofs will absorb minimum solar energy.

The most effective measures for blocking solar heat through roofs are shading the roof with trees and giving the roof a reflective coating. Either trees or a reflective surface can block most of the solar heat streaming toward the roof and reduce cooling costs 10% to 40%, depending on climate and R-value of attic insulation.

Compared to poorly ventilated roofs, good roof ventilation helps to keep attic temperatures lower. But expect less savings from improving attic ventilation compared to radiant barriers and other sun-blocking measures, because attic heat gain is dominated by heat radiation.

Radiant barriers — A radiant barrier is composed of aluminum foil bonded to kraft paper or roof sheathing. Radiant barriers have easier consumer acceptance than reflective roofs, given the preference of many consumers for dark roof colors. Expect 2% to 10% savings from radiant barriers depending on climate and insulation level. Radiant barriers are fastened to the bottom of rafters or roof sheathing.

Radiant barriers reflect heat radiation coming toward them. They also impede the heat flow by being poor emitters of heat radiation. Radiant barriers must face an air space with their shiny surface to be effective.

Air spaces bordered by radiant barriers have higher R-values than those bordered by common building materials. For example, a vertical air film bordered by a radiant barrier has double the R-value of one bordered by common materials (R-1.35 versus R-0.68). All surfaces not exposed to high winds have relatively still air films near their surfaces.

However, it's important to note that an air film's R-value drops dramatically with air convection, and this fact presents a practical problem in using radiant barriers as insulation. For the radiant barrier to be an effective insulator, it must face a calm air space—one without air convection. In practice, this so-called "dead" air space is difficult to achieve.

Internal Heat

People contribute heat to the air by shedding body heat (sensible heat) and by sweating (latent heat). Each occupant of the home contributes about 300 BTUs per hour of sensible heat and about 150 BTUs per hour of latent heat.

Internal heat also includes the heat from the refrigerator, lights, cooking, entertainment, and housekeeping. This internal release of heat varies widely, in the range of 1500 BTUs per hour to 7500 BTUs per hour, from one house to another.

Reducing internal heat — Because they release less heat into the indoors, energy-efficient appliances and lights pay a second dividend to the buyer during the cooling season.

Other measures to reduce internal heat require the participation of residents:

- Limiting the use of hot water.
- Using exhaust fans to remove moisture.
- Reducing cooking during the heat of the day.

Air Leakage

Air leakage can be a very costly problem for air-conditioned homes, especially in humid climates. Air conditioners remove moisture from the air to cool it and to provide adequate comfort.

The most severe air-leakage problems have been noted in homes with air conditioning duct work in the attic. Duct leakage wastes cooling energy by:

- Allowing cooled air to escape the supply ducts.
- Allowing hot, humid air to enter the return ducts.
- Creating pressure differences between indoors and outdoors that drive air leakage through the building shell.

Measuring air leakage with a blower door or tracer-gas testing is essential to effective air sealing.

Reducing air leakage — Sealing ducts to stop duct leakage pays the fastest dividends for reducing air-conditioning costs. However, duct leakage can be difficult to diagnose and the leaks themselves difficult to find. Part of the duct repair procedure should include the elimination of pressure differences caused by air leakage and poorly designed duct systems. Where ducts are leaky, savings of 10% to 25% on air-conditioning costs are possible from an effective air-sealing job.

Besides ducts, technicians should find and seal large, hidden air leaks before worrying about smaller ones around windows and doors.

Humidity — Humid air suppresses evaporation of sweat from the skin, which causes that sticky discomfort so characteristic of humid weather. Humidity also contributes to the cooling load because humid air contains more heat than dry air at the same temperature.

The latent heat contained in outdoor air leaking into the home is an important heat gain in humid climates because the air conditioner works hard to remove excess moisture and provide adequate comfort. Moisture sources, especially the ground, contribute to poor summer comfort and high cooling costs.

See "Controlling Water Vapor" on page 247 for information on moisture in buildings.

Transmission

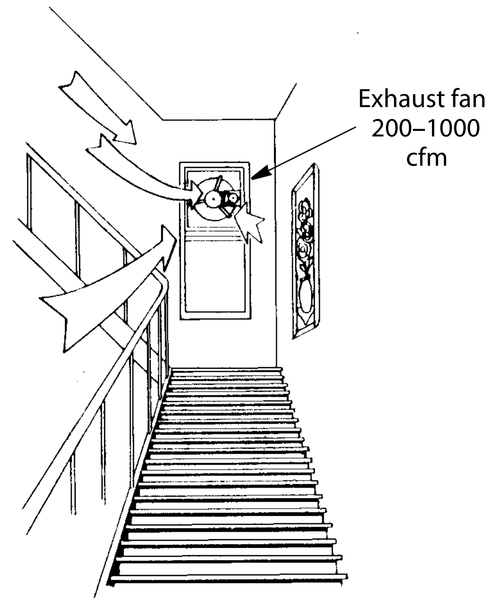
Transmission of heat through ceiling, walls and windows usually amounts to less than 10% of the cooling load. Transmission through the roof and ceiling is driven more by heat radiation than by indoor-outdoor temperature difference.

Dark-colored roofs and walls should have high insulation levels to retard solar heat's transmission through wall and roof assemblies. Attic insulation, to at least R-38, is cost-effective when both heating and cooling are important energy costs.

Cooling with Ventilation

Ventilation can remove accumulated heat from homes by circulating cool outdoor air through the home. Ventilation works best in areas that have hot days and cool nights. Natural or fan-powered nocturnal ventilation flushes out internal and solar heat that builds up during the day.

Window Exhaust Fan



A powerful window exhaust fan on the leeward side of the house can ventilate part of a larger house or all of a smaller one.

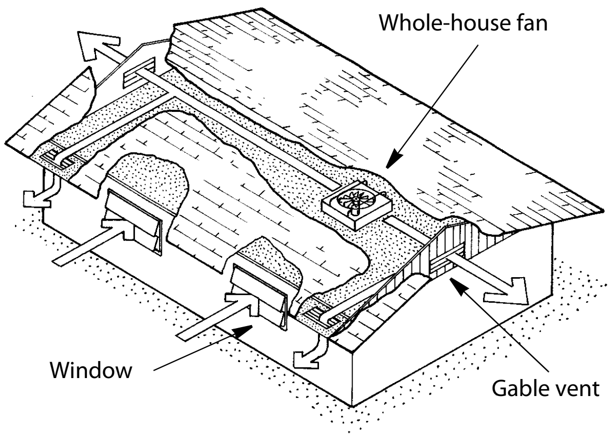
The effectiveness of ventilation for cooling depends on:

- The temperature and humidity of evening and morning air.
- The amount of shade around the building.
- Participation of the residents in opening and closing windows and blinds at the proper time.
- Residents turning fans on at the proper time.

Natural Ventilation

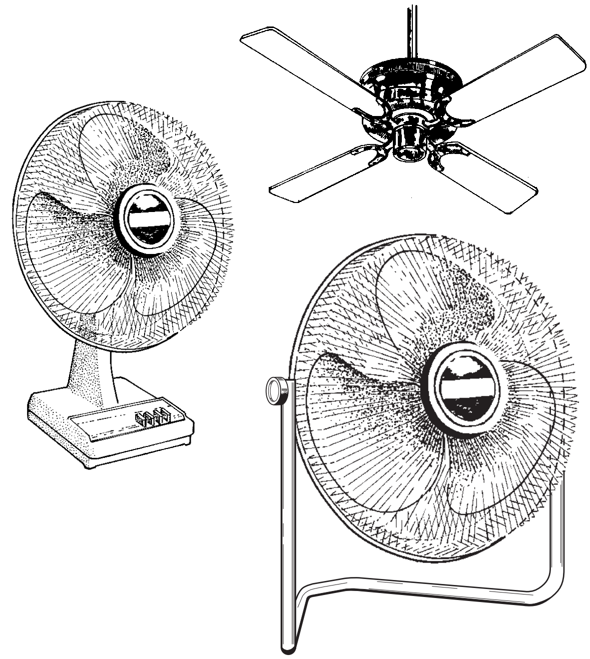
Residents of homes and multifamily buildings can use natural ventilation for cooling by paying attention to wind intensity and daily variation of wind direction and outdoor temperature. Windows, closed against the heat of the day, are opened at night to flush heat out.

Whole-House Fan



A whole-house fan exhausts air through the attic vents, as cooler air flows in through open windows.

Circulation Fans



Floor fans, table fans, and ceiling fans are the most cost-effective electric cooling devices available. They should be used to create a wind-chill effect while whole-house fans, evaporative coolers, and air conditioners are in use.

Fan-powered Ventilation

Fan-powered ventilation, when combined with shading and other low-cost cooling measures, can provide adequate cooling for most of the northern United States.

Powerful window fans and whole-house fans are the best to accomplish power ventilation. Smaller floor, table, and ceiling fans are best used to create a wind chill indoors, and are less effective as whole-house ventilators.

Powerful fans can create strong house pressures that can cause backdrafting or flame roll-out in water heaters. Provide adequate window openings to avoid excessive house pressure.

Attic Ventilation

Homes with well-ventilated attics may have comfort and energy-conservation advantages over homes with poorly ventilated attics. However, attic ventilation is less important than roof reflectance, radiant barriers, and attic insulation in retarding solar heat migrating through the roof and attic. The solar heat migrates mainly by radiation, and attic ventilation can't do much to retard radiation heat transfer.

Air Movement

Air circulation creates a wind chill within the home, helping to cool residents directly. Smaller air-circulating fans are inexpensive to operate compared to larger fans, evaporative coolers, and air conditioners. When residents use air circulation effectively, they save energy and stay more comfortable.

Ceiling fans, floor fans and table fans cool your skin; they don't cool the air. Moving air increases bodily heat loss by convection and sweat evaporation.

Circulating fans can save a significant amount of energy by improving comfort when air-conditioning systems are in use, or in moderate weather they can help occupants reduce air conditioner use altogether. Moving air is more comfortable than calm air; 4° to 8°F of perceived comfort can be achieved from air speeds of 100 to 350 feet per minute. The faster the air speed the greater the cooling effect. The general limit for air speed is somewhere above 350 feet per minute, when paper begins rustling on table tops.