



#3 SPACE COOLING

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Space cooling and heating account for 45 percent of total home energy use and cost a typical family \$677 a year. Depending on where you live, your energy bill could be dominated by cooling energy use in the summer, heating energy use in the winter, or both. Space cooling alone typically accounts for 13 percent of total energy use, costing the homeowner \$197 per year. For states in hotter climates, space cooling can account for over 20 percent of total energy use and cost more than \$350 per year.¹

A well-insulated and tightly sealed home that uses the natural movement of heat and air to maintain comfortable indoor temperatures can reduce cooling costs by up to 50 percent while also saving on heating bills (see *Home Energy Brief No. 4: Space Heating*). The space cooling philosophy is to first minimize the amount of heat that enters the home as well as the amount that is generated

inside the home, and then, if additional cooling is still needed, take steps to increase the efficiency of the cooling equipment and/or buy new and more efficient equipment.

This Brief will cover the following topics:

- **Heat gain:**
How heat enters the home;
- **Passive cooling methods:**
How to minimize heat gain in the home; and
- **Space cooling systems:**
Fans, evaporative coolers, heat pumps, and air conditioners.

HEAT GAIN

Heat naturally flows from warmer spaces to cooler ones until the temperatures in and between the two spaces are equal. In the summer, the home warms up by absorbing heat from outside through its building envelope and by generating heat from within. Heat is absorbed primarily through windows, exterior walls, glass doors, skylights, the roof, ceilings, attic, and foundation. Heat is generated primarily by appliances, lights, and other equipment (see *Home Energy Brief No. 1: Building Envelope* for more detailed information on heat gains and losses in the home).

PASSIVE COOLING MEASURES

You can protect your home from heat gain by implementing a number of *passive cooling measures*. In practice, passive cooling means creating an environment that controls and lowers the amount of heat gain in the home without using electrical equipment such as air conditioners or fans. The U.S. Department of Energy (DOE) estimates that passive cooling measures can reduce energy bills by up to 40 percent.² You should always investigate such measures *before* investing in new cooling equipment. Reducing your cooling load allows you to purchase a smaller and cheaper cooling system. The most effective passive cooling measures, in order of increasing cost, are:

- **Natural ventilation.** By opening windows at night, you can cool the home by flushing out heat and moisture that accumulates during the day;
- **The minimization of indoor heat generation.** For example, using energy-efficient light bulbs, reducing hot water use, using smaller and more efficient appli-

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- No. 7 Electronics
- No. 8 Kitchen Appliances
- No. 9 Whole System Design



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ances, and scheduling heat-producing tasks—like clothes drying—for cooler hours of the day;

- **Weatherization.** Caulking, sealing, and weatherstripping all building envelope seams, cracks, and openings reduces heating and cooling energy requirements;
- **Insulation.** Insulating your home with foam, organic batting (cotton and sheep wool, cellulose, and slag wool) or heat-reflecting foil reduces heat conduction into your living space;
- **Window shading and glazing.** Solar radiation passing through windows can contribute 20 percent of heat gain in hot, humid climates.³ Window shading devices and glazing technology minimize heat gain while transmitting daylight, which reduces electrical lighting needs;
- **Roof whitening and attic ventilation.** These are two effective measures to reduce heat gain by either reflecting heat away from the roof or flushing heat out through the attic; and
- **Trees and landscaping.** Planting broad, leafy shade trees that block the sun will reduce the amount of solar radiation absorbed by the house.

See *Home Energy Brief No. 1: Building Envelope* for detailed information on key passive cooling measures.

Fans can be noisy!

They also can be nearly inaudible, so shop around and make sure you check the noise level of a fan before purchasing it. A quiet fan will have a noise rating of 1.5 sones or less while a noisy fan will have a rating higher than 4.

SPACE COOLING SYSTEMS

If you have implemented the passive cooling measures discussed above and still require supplementary cooling, there are many mechanical cooling systems that you can choose from. Different systems are appropriate for different budgets and climates. This section discusses each of these systems and describes how they work, their cooling capacities, efficiencies, sizing, and costs. The systems are generally listed in order of increasing cost, considering both initial and operating costs. When contemplating buying a new cooling system, consider the options in the following order:

Fans

There are three main types of fans that aid both in cooling and ventilating the home: *portable fans*, *ceiling fans*, and *whole-house fans*. All of these fans operate in a similar fashion: they move air throughout the home and increase the amount of heat that is removed from the home and the objects and people within it. Fans also bring fresh air into the home and can help remove indoor air pollutants (i.e., dust, fumes, moisture, etc.).

Table 1: What size ceiling fan does your home need?⁵

Room area (sq. ft)	Minimum fan diameter (inches)
100	36
150	42
225	48
375	52
400+	Two fans

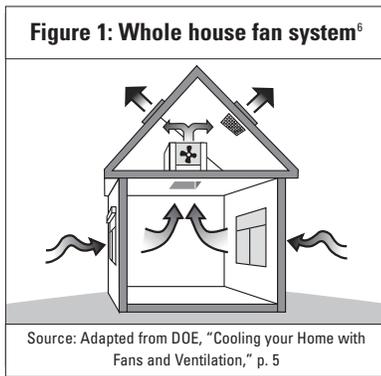
Source: Minnesota Department of Commerce Home Cooling fact sheet, p. 2. www.state.mn.us/cgi-bin/portal/mn/jsp/content.do?action=doc_contentlist&sub-channel=-536881511&programid=536885406&sc3=null&sc2=null&id=-536881350&agency=Commerce

Portable fans: The main types of portable fans include table fans, floor fans, and window fans. Depending on the type, quality, and size, cost varies from under \$10 to over \$200. A small table fan will provide on-the-spot cooling, while larger fans such as window and floor fans can—if placed in or near a window on the cooler side of the home—significantly aid in cross ventilation. Using two window fans can often be better than using one. For example, use one fan to pull in cool air in a lower-floor window and another to blow warm air out an upper-floor window.

Ceiling fans: Ceiling fans can keep a room comfortable by providing airflow throughout a room. In moderate climates, ceiling fans can provide enough cooling to completely replace an air conditioning system. For hotter climates, using ceiling fans in conjunction with air conditioning will allow you to raise the thermostat by as much as 4°F, thereby saving energy while maintaining comfort.⁴ Ceiling fans are considered low-energy consumers, because they typically use about the same amount of energy as a 100-watt light bulb. They can cost between \$25 and \$250 to buy and \$100 to \$3,300 to install.

When purchasing a new ceiling fan, look for ceiling fans with an Energy Star® Label. They typically use 20 to 50 percent less energy and save about \$25 per year in energy costs.

Whole house fans: Whole house fans can often be the most cost-effective way of cooling a home in moderate climates. They provide good air circulation and aid in cooling by pulling cool, fresh air in from lower-floor windows; this air is then typically vented through the



roof. They typically cost around \$500 to install and have very low operating costs (~\$0.01–0.05 per hour of use). Energy Star-rated whole-house fans do exist and use 65 percent less energy than standard models. They also typically make less noise and last longer.

Sizing: This depends on how much ventilating power your home needs, which ultimately depends on the size of your home. Once you know the ventilating power, you can choose a fan that will provide it. DOE recommends using the following formula to figure this out:

$$\text{Ventilating power, ft}^3/\text{min or cfm} = \text{Volume of home} \times (\text{30 to 60 air changes per hour}) \div 60$$

For example, if the volume of your home is 16,000 cubic feet, the ven-

tilating power your home needs would be: $16,000 \text{ ft}^3 \times (30 \text{ to } 60) \div 60 = 8,000 \text{ to } 16,000$ cubic feet per minute. The recommended air changes per hour depend on a number of things, including your climate and floorplan. To get a more exact number for your home and climate, contact a local professional.

Drawbacks: Whole-house fans can be a source of heat loss in the winter and can cause backdrafting from combustion appliances in the home. To prevent heat loss, make sure that the fan is sealed well and an insulated cover is placed over it during the winter. Backdrafting occurs when there is not enough ventilation in the home (i.e., lower-floor windows are not open). This can pull gases from combustion appliances (e.g., water heater, chimney, wood stoves, etc.) into the rest of the home, which can be extremely dangerous. To prevent this, make sure that there is enough ventilation in the home by opening windows, especially on lower floors, when the fan is on. To be on the safe side, you might not want to install a whole-house fan unless these appliances have a direct air-intake line from outside.

Evaporative coolers

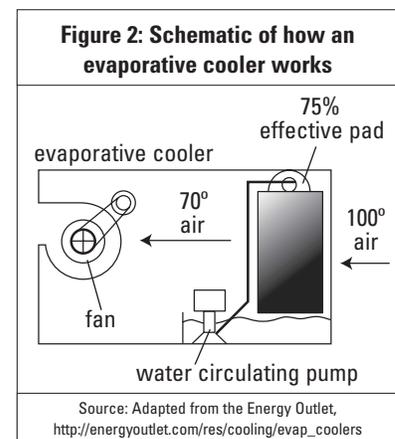
In dry climates, evaporative coolers typically use less than one quarter as much energy as conventional air conditioners and can save hundreds of dollars a year on home cooling costs. They are also less polluting since they don't require the use of toxic chlorofluorocarbons (CFCs) or other refrigerants. They cool air by drawing warm outside air over a wetted media filter (pad). Water evaporating from the pad into the air decreases the air's temper-

ature. A fan then circulates the moist, cool air into the home and pushes warmer air out through open windows. Note: windows or outside vents need to be open in order for an evaporative cooler to function properly.

There are three main types of evaporative coolers: portable units also known as "swamp coolers," fixed room units, and whole-house systems. A portable swamp cooler is typically a small unit that can provide adequate cooling for a small room or a part of a room. Fixed room units are mounted in the wall or in a window and can provide enough cooling for the entire room. Whole-house systems include direct, indirect, or combined direct/indirect systems that are typically ducted. They provide cooling for the main living area of the home and/or each individual room. The cheap and high maintenance swamp coolers of yesterday are a world apart from modern evaporative cooling systems. New systems are more efficient, use less water, and provide years of trouble-free service to cool and clean the air. Given that the technology has certainly changed, the perception of evaporative cooling systems will need to be updated; today they are a high-performance alternative to conventional air conditioning systems.

What is Energy Star®?

Energy Star® is an EPA-backed program that sets strict efficiency guidelines for home products. For products that meet these guidelines, an Energy Star label, shown below, is often placed on the product. Look for this label on the product or in its specifications to ensure you are purchasing a high-efficiency product.



Sizing: Correctly sizing an evaporative cooler for your home or for a room in your home is similar to sizing a whole-house fan—you need to calculate the required ventilating power. To do this, use the same formula used on the previous page for whole-house fans. However, instead of using 30 to 60 air changes per hour use 20 to 40 air changes per hour. The result will be in cubic feet per minute (cfm), which you can then match to the appropriate system. Most evaporative coolers range from 1,000 to 8,000 cubic feet per minute (cfm) while some are as powerful as 25,000 cfm.

Cost: Like other cooling systems, the cost of an evaporative cooler depends mainly on the system's ventilating power: the more power, the more expensive the system. Small, portable units typically range from \$100 to \$400 and have no installation cost. Fixed window or wall-mounted units cost \$800–2,000, including installation. Larger, whole-house systems typically cost \$2,000–4,000 including installation. Evaporative coolers can operate for twenty years or more.

Maintenance: Dirt and mineral sediment can build up in the water pad and filter of the evaporative cooler and should be cleaned or replaced once a month. If the cooler is not used regularly, you can usually get away with doing this once a year. New high-quality systems, however, are equipped with automatic flush systems that can be piped to a nearby garden. Three ways to increase the life of pads include:

- Using high quality water in the system;
- Installing a bleed-off system that dilutes mineral build-up; and/or
- Installing a sump dump or a blow-down system that automatically dumps the water, getting rid of the dirt and particulate build-up.

Drawbacks: Evaporative coolers are not very effective in humid climates because water does not easily evaporate into air that is already high in humidity. As shown below, most eastern U.S. states and much of the Midwest are too humid to use this type of cooling system. However, in the western United States, evaporative coolers

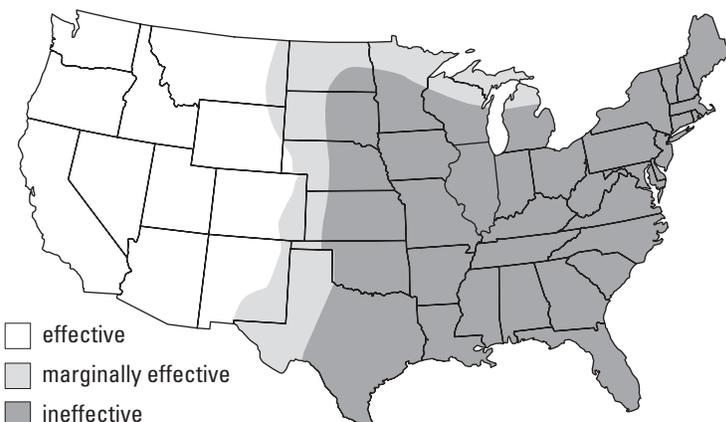
Did you know?

Solar evaporative coolers powered by photovoltaic (PV) cells are now available. This is an ideal system because PV cells operate most effectively during peak hours of the day—the hottest part of the day when electricity is most expensive.

work wonderfully (see Figure 3). This area of the country is also where central air-conditioning installations in new construction is stressing the existing electric supply infrastructure, so installing evaporative coolers is a better solution. Evaporative coolers also use a fair amount of water, which could increase your annual water bill by \$15–20. Typical systems use 3.5 to 10.5 gallons of water per hour. However, the cooler's higher energy efficiency means water consumption is reduced at the power plant. In addition, direct evaporative coolers increase the humidity of the air inside the home, which can lead to discomfort. However, on very dry days, this can make a home more comfortable and can prevent wood furniture, doors, and fabrics from drying out. Indirect evaporative cooling systems, on the other hand, can deliver cool air without raising indoor humidity through the use of heat exchangers.

Figure 3: Map of evaporative cooling effectiveness in the United States

The dry climate of the western U.S. makes evaporative cooling there much more effective than in the Midwest, East, and South.⁷



Heat Pumps

A heat pump can be used for both heating and cooling. In the summer, it acts as an air conditioner, removing heat from air inside the house and carrying it outside. In the winter, it operates in reverse, removing heat from air outside the building and carrying it inside to warm the living space. There are two main types of residential heat pumps: air-source and geothermal, which are also known as *ground-source* and *geoexchange heat pumps*. For additional information on heat pumps, refer to *Home Energy Brief No. 4: Space Heating*.

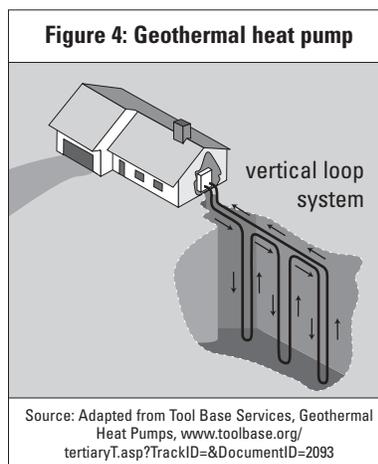
Air-source heat pumps Air-source heat pumps use outside ambient air to cool a home. They are similar to conventional central air conditioning systems except they also have the ability to heat the home. Some models can even provide air circulation, air filtration, humidification, dehumidification, and water heating services. This may sound like an amazing system. However, before rushing out and buying one, note that air-source heat pumps might not *heat* a home any better than an electric heating system in extreme winter climates. A backup system is often necessary to help the air-source heat pump achieve comfortable temperatures in extreme winter climates (see *Home Energy Brief No. 4: Space Heating* for more information on the performance of different types of heating systems).

The efficiency of an air-source heat pump is measured in terms of its heating season performance factor (HSPF) and seasonal energy efficiency ratio (SEER). Currently, national standards require air-source heat pumps to achieve a minimum HSPF of 6.8 and a mini-

um SEER of 10. However, many models are more efficient. We recommend purchasing heat pumps with SEER of at least 13 and a HSPF around 9.0. Also look for heat pumps with Energy Star labels on them. This will ensure that you are purchasing a highly energy-efficient product.

Geothermal heat pumps Geothermal heat pumps use the ground, surface water, or underground water as a heat source and heat sink. They use underground pipes, typically buried 3 to 6 feet below the surface, to take advantage of the ground's relatively constant year-round temperature (see Figure 4). The pipes are usually filled with a heat transfer fluid, which in summer carries heat from inside the house and releases it into the ground thereby cooling your home. In winter, it extracts heat from the ground to heat the home.

Geothermal heat pumps use 23–44 percent less energy than the more commonly used air-source heat pumps⁸ and, according to the Environmental Protection Agency (EPA), they can save a typical homeowner 30 to 70 percent in heating bills and 20 to 50 percent in cooling costs.⁹ This could amount to over \$400 per year in energy savings. The efficiency of this system



is measured by its coefficient of performance (COP) for heating and energy efficiency ratio (EER) for cooling. Systems with Energy Star labels will have a COP ranging from 3.3 to 3.6 and an EER of 14.2 to 16.2 or higher. When purchasing a geothermal system, look for the Energy Star label to ensure you're purchasing a highly efficient product. Many models have efficiencies even higher than the Energy Star system requires, with COPs greater than 5.0 and EERs greater than 17.0.

Sizing: As with all heating and cooling systems, appropriately sizing heat pumps is extremely important. Undersizing or oversizing will result in inadequate performance, higher energy bills, and an uncomfortable home. The best way to ensure correct sizing of both types of heat pump systems is to hire a contractor that uses the *Manual J* sizing method developed by the Air Conditioning Contractors of America (ACCA) or similar methods developed by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE).

Maintenance: There are a number of things you can do to improve the efficiency and life of your heat pump system:

- Have a technician service the entire system annually;
- Check the filters once a month and clean and replace as needed;
- Clean the coils, fans, and ducts at least once a year;
- For air-source units, keep the intake area clear of snow, ice, and debris; and
- For geothermal systems, have a technician check the inside of the heat exchanger and clear away any mineral build-up.

Cost: Air-source heat pumps typically cost \$1,500–5,000, depending on the size and installation requirements. Geothermal systems are typically about twice as expensive to install and typically cost \$7,500–15,000. These up-front costs are high, but geothermal heat pumps can pay for themselves fairly quickly because they have extremely low operating costs. In addition, many utilities offer rebates on such systems to help lower purchase and installation costs. Check with your local utilities to find out what rebates exist in your area.

Conventional air conditioners

Air conditioning is a complex cooling procedure that uses an evaporator and condenser coil, a compressor, an expansion valve, and a refrigerant (fluid or vapor). Air conditioners cool the air by pushing it across coils (cooled by the refrigerant) that absorb the home's heat; meanwhile a fan circulates the cool air throughout the home (see Figure 5 for a schematic of this process). The evaporator is located inside the home where it extracts heat from the air. The compressor then pressurizes the evaporated fluid and sends it to the condenser, which is located outside. The fluid condenses and releases heat to the outdoors. Then the fluid is expanded and pumped back to the evaporator where the cycle repeats itself.

There are two main types of air conditioners: central air conditioners and room air conditioners. Central air conditioners are ducted systems that can cool an entire building. They are the most common type of cooling system in the

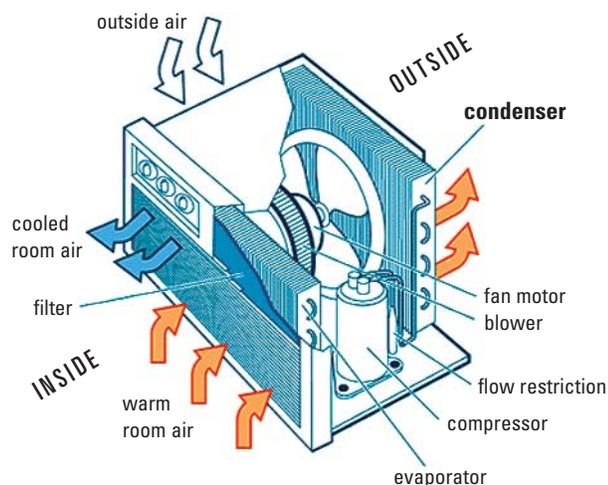
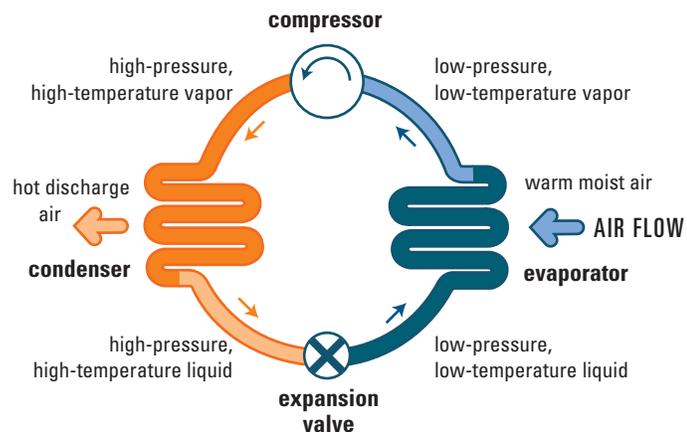
United States. Room air conditioners are generally smaller, individual units that have the ability to cool only a single room. Room air conditioners are typically mounted on a wall or in a window, although there are portable units that can be moved all over the house.

Improving air conditioning efficiency

The average air conditioned home uses over 2,200 kilowatt-hours of energy and costs the average homeowner around \$200 per year, or more. Luckily, there are many things you can do to maximize the efficiency of your air conditioner, improve its life, and save money without sacrificing comfort:

- Sealing ducts can help save up to \$300 on annual cooling and heating costs. Ordinary duct tape is not recommended—instead use mastics (sealants), sheet metal screws, or metal and plastic bands;
- Turn your air conditioner off or turn the thermostat up when you're not home. Turning up the thermostat by 10–15°F during the days when you're out can save 5–15 percent on your energy bills;
- Set your thermostat at 78°F or higher when the air conditioner is in use. DOE estimates that each degree below 78°F increases your energy consumption by eight percent;

Figure 5: Basic cooling cycle (top) and schematic (bottom) of a conventional air conditioner



Source: Adapted from Canada Office of Energy Efficiency, http://oee.nrcan.gc.ca/publications/infosource/pub/home/Air_Conditioning_Your_Home_Section2.cfm

- Install a programmable thermostat to select appropriate times to cool your home;
- Change disposable filters or clean permanent filters monthly;
- Room air conditioners work best when kept cool and out of direct sunlight. Install them on the north-facing side of your home or in conjunction with shade trees and/or other passive cooling measures on the west and south facing sides;
- Locate the compressor (the part that dumps waste heat outside) in a cool shaded place. Clean weeds and debris away and keep the coils on the back of the unit dust free;
- Have a licensed heating and cooling professional conduct a thorough inspection and cleaning of your central air conditioner once every year; and
- Turn off or cycle your central air conditioner during peak hours of the day, when electricity is most expensive. Contact your energy utility for information on “demand response” or “direct load control” options.

Buying a new air conditioner

When buying a new air conditioner consider efficiency, sizing, and installation, because the right decisions can save you up to 30 percent on cooling costs. You should buy a new air conditioner if your existing model is more than ten years old, as such models are often only half as efficient as contemporary models. Sometimes you can achieve energy savings by simply replacing the outdoor condenser, but ask a technician to ensure it is properly matched to the indoor unit. When buying, consider the following:

Energy efficiency: Room air conditioners are rated by their energy efficiency ratio (EER) and central air conditioners are rated by their seasonal energy efficiency ratio (SEER). The higher the number, the more efficient it is and the cheaper it will be to operate. Pre-1992 models often had SEER ratings around 6 and EER ratings around 8. Today, however, national standards require an EER of 9.7–9.8 for room air conditioners and a SEER of 10 for central air conditioners. Higher ratings do exist, and it is recommended that you:

- Choose a central air conditioner with a SEER rating of 13 or higher or a room air conditioner with an EER rating of 11 or higher.
- Make sure your new air conditioner is Energy Star compliant.

- Look for incentives offered by your energy utility—rebates and cash-back offers are often available for purchasing energy-efficient air conditioners.
- If you have a small or well-insulated area to cool, or if you live in a mild climate, a room air conditioner is usually more economical than a central air conditioner.
- Look for energy saving features on the air conditioner, such as a fan-only switch, a condenser on/off switch, variable-speed fan controls, a programmable thermostat, and high-efficiency compressors, motors, fans, and heat transfer surfaces. A slide-out filter also facilitates cleaning.

Sizing: With air conditioning systems, equipment cost is proportional to size, so be precise with sizing. Studies have also shown that about 50 percent of air conditioners are oversized. Choosing the correct air conditioner is very important because it is cheaper to buy and install a smaller unit, and you can save up to 20 percent on operating costs. Oversizing can also lead to indoor discomfort—too large a system will not remove enough humidity, making the home feel cold and damp.

Cost: Similar to evaporative coolers, portable air conditioners range from \$100–1,200 and have no installation costs. Room air conditioners typically cost between \$300 and \$1,500. If installation is needed, add another \$300–600. Central air conditioners typically cost between \$3,000 and \$7,000, including installation.

Did you know?

The American Council for an Energy-Efficiency Economy (ACEEE) lists the top rated air conditioners available.

For more information, visit www.aceee.org/consumerguide/toprac.htm

SUMMARY

Using a conventional air conditioning system is often the most expensive and energy intensive way to cool a home. If you are buying a new air conditioner, first consider reducing heat gain in your home through passive cooling measures and increasing ventilation with low energy fans. Then consider investing in more expensive cooling systems like evaporative coolers, heat pumps, and air conditioners. If you already have an air conditioner, properly maintain it so that it runs at peak efficiency. Always look for the Energy Star label when purchasing new cooling systems. The price tag may be a little higher than on non-Energy Star units, but you will pay off your investment every time you use the equipment.

ADDITIONAL RESOURCES

U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy (EERE) — Comprehensive and useful selection of fact sheets on all aspects of space cooling, including a complete Home Energy Booklet that can be downloaded for free (www.eere.energy.gov/consumerinfo/factsheets.html).

California Energy Commission, Consumer Energy Center — California is at the forefront of green energy initiatives. Their tools and resources are practical and informative, and include information on rebates and incentives (www.consumerenergycenter.org).

Minnesota Department of Commerce, Energy Information Center — Easy-to-read fact sheets and pamphlets containing cost-effective Home Cooling and Home Heating ideas (www.commerce.state.mn.us).

University of Central Florida, Florida Solar Energy Center — Comprehensive resource on all aspects of home energy saving ideas, from this well-recognized research center (www.fsec.ucf.edu).

Geothermal, Geothermal Heat Pump Consortium — A comprehensive resource for anyone looking for more information on ground-source heat pumps (www.geothermal.org).

American Council for an Energy-Efficient Economy (ACEEE) — A nonprofit organization that focuses on advancing energy efficiency. They list today's most efficient home appliances on their website at www.aceee.org/consumerguide/mostenef.htm

NOTES

1. EIA (Energy Information Administration), "Residential Energy Consumption Survey: Consumption and Expenditure Data Tables," (Washington, DC: EIA, 2001), www.eia.doe.gov/emeu/recs/recs2001/detailcetbls.html#total.
2. DOE (Department of Energy), "Energy Efficiency Pays," (Washington, DC: EERE, Undated), www.eere.energy.gov/buildings/info/documents/pdfs/26290.pdf.
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4. DOE, "Cooling Your Home With Fans and Ventilation," (Washington, DC: EERE, Undated), www.eere.energy.gov/consumerinfo/factsheets/ventilation.html.
5. Minnesota Department of Commerce, *Home Cooling*, (St. Paul, MN: MN DOC, Undated), p. 2, www.state.mn.us/cgi-bin/portal/mn/jsp/content.do?action=doc_contentlist&subchannel=-536881511&programid=536885406&sc3=null&sc2=null&id=-536881350&agency=Commerce.
6. DOE, "Cooling Your Home With Fans and Ventilation," (Washington, DC: EERE, Undated), www.eere.energy.gov/consumerinfo/factsheets/ventilation.html.
7. *Home Energy Magazine*, "Refreshing Evaporative Cooling," *Home Energy Magazine*, (September/October 2001), <http://hem.dis.anl.gov/eehem/01/010910.html>.
8. DOE, *Geothermal Heat Pumps; Using the Earth to Heat and Cool Buildings*, (Washington, DC: EERE, September 1999), DOE/GO-10099-727.

Contact your local utility or energy office for information on rebates that may be available in your area on the purchase of new energy-efficient appliances. This publication is intended to help you improve the resource efficiency of your home. You should use your best judgment about your home, and seek expert advice when appropriate. Rocky Mountain Institute does not endorse any products mentioned and does not assume any responsibility for the accuracy or completeness of the information in this Brief. Written by Ramola Yardi, Andy Smith, and Katherine Wang. © Rocky Mountain Institute 2004.

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