STEP 4

PERFECT HEATING, COOLING, AND VENTILATION

Your home will keep you comfortable under all weather conditions. We designed the structure to keep you comfortable with a minimum of energy. However, the structure can't always do the job alone. In most climates, it needs help from equipment that the construction industry calls "comfort systems." These systems perform heating, ventilation, and air conditioning, so they are also called "HVAC systems."

Today, the HVAC industry offers a daunting menu of equipment choices. Fortunately, we can narrow the choices to two heating and cooling combinations that are best for most homes. We will decide which one is best for you. Then, we will explain the critical features of your system so that you can make sure that it is installed flawlessly.

After that, we select special heating and cooling equipment for certain rooms. We learn how to provide cooling at low cost by using ventilation, and in some locations, by using evaporative coolers. We design the ventilation throughout the house for health and odor control. And, we select the most effective and economical methods of controlling humidity.

If you are renovating an existing house or just replacing worn out equipment, your best choices usually are the same as for a new house.

ENERGY COST WORKSHEET

Step A: Convert all energy prices to the same units.

For:	multiply dollars per	by	to get raw cost in $ per million BTU
electricity	kilowatt-hour	293	=
natural gas	therm	10	=
	cubic foot	970	=
	cubic meter	27	=
No. 2 fuel oil	U.S. gallon	7.2	=
	liter	27	=
propane	U.S. gallon	11	=
	liter	32	=
coal	U.S. ton	.05 (variable)	=
	metric tonne	.045 (variable)	=

Step B: Calculate the end-use energy cost.

For:	used in	multiply raw cost by	to get final cost in $ per million BTU
electricity	electric resistance heater or water heater	1	=
	high-efficiency heat pump in mild climate	0.3	=
	high-efficiency heat pump in climate with extended warm and/or cold season	0.4 to 0.7	=
	heat pump water heater	0.4 to 0.6	=
	conventional electric range	1.4	=
	electric oven	1.1	=
	microwave oven	1.8	=
natural gas and propane/LPG	high-efficiency condensing boiler, furnace, or water heater	1.1	=
	good non-condensing boiler, furnace, air heater, or water heater	1.3	=
	gas range	2.5	=
	gas oven	1.1	=
No. 2 fuel oil	high-efficiency, non-condensing boiler or water heater	1.3	=
coal	well designed hydronic boiler or furnace	1.6 to 2.5	=

(Since we are working with an accuracy of only two significant digits, we should round off these estimates to $8 per million BTU for natural gas, $28 per million BTU for fuel oil, and $18 per million BTU for heat pumps.)

Comparing these three energy sources, we see that natural gas would be your most economical source of heating energy, if it is available. If natural gas is not available, you probably would select heat pumps if the climate is temperate enough for them to work well. You would select fuel oil only if the climate is too cold for satisfactory operation of heat pumps.

Don't base any major decisions on small differences in these numbers. If the differences in cost between your energy options are small, it is more important to focus on the likely trends of these costs in the future.

Where to Find Energy Prices

To get energy prices for your home site, contact local energy suppliers. These include the local electric company, the gas company, propane suppliers, and fuel oil dealers, as appropriate. There may be more than one supplier for each source energy. If so, get prices from several retail suppliers.

For electricity, be aware that most electric utilities add charges to your monthly bill, in addition to the cost of the electricity itself. This raises your average cost. Also, electric utilities offer discounts for special terms of service. For example, see the sidebar, *Two Ways to Lower the Cost of Electric Water Heating*, in Step 5.

For a broader perspective, you can get regional prices from the Internet. In the U.S., the Energy Information Administration (EIA) maintains a Web site that gives regional prices for all major energy sources. The EIA Web site also provides historical prices, which are useful for perspective on how the costs of different energy sources have been changing.

Now, you are able to decide which heating and cooling systems are best for your home. Next, we will learn how to design the two major recommended heating systems, hydronic systems and split-system heat pumps.

If a hydronic system is not the best choice for your home, skip the following explanation of hydronic design and go to the explanation of heat pump design that follows it.

Hydronic Radiators and Narrow Convectors

In much of the world outside North America, hydronic heating is done with convectors that are taller and narrower than American baseboard convectors. Figure 4-15 shows a typical example. Commonly, these are made of one or more hollow flat plates, in which the hot water is circulated. However, a convector can have almost any shape, as long as it has sufficient surface area.

Such units are commonly called "radiators," even though they function primarily as convectors. They do emit some heat by radiation because their outer surface is exposed to the room.

The capacity of a hydronic radiator is limited by the low temperature at which it must operate to avoid creating a burn hazard for the occupants. Also, if a unit is mounted somewhat high on a wall, it cannot suck the cold air layer from the floor and warm it.

Certain styles of hydronic radiators can provide heating in rooms where baseboard convectors would not be practical. In particular, they are the most appropriate kind of hydronic heater for shower rooms and toilet rooms. Figure 4-16 is a typical example.

Hydronic radiators usually are made of painted steel, which rusts quickly in the presence of water and urine. If you want to install hydronic heating in a wet space, try to find a unit that is made of corrosion resistant material.

Some manufacturers offer models that are especially elegant in appearance, so they can be used as an element of decor. For example, the fancy hydronic radiator in Figure 4-17 also serves as "towel warmer."

DRW

Figure 4-15. Typical hydronic room heater, in Germany. The front face of the unit heats largely by radiation. In addition, the multiple vertical passages provide considerable heating by convection.

DRW

Figure 4-16. Hydronic radiator with a self-contained thermostat, installed in a toilet room in Germany. The heat from the radiator tends to turn off the thermostat, so response is slow and temperature control is crude.

Hudson Reed

Figure 4-17. A fancy hydronic radiator that is commonly called a "towel warmer." The unit has limited surface area. When it is covered by a towel, its heat emission is further reduced.

A hydronic radiator can be made in virtually any shape into which tubes can be bent.

Heavier units should be supported by the floor, but many newer models are light enough for wall mounting. Similarly, the water connections can come through the floor or through the wall.

Hydronic Fan-Coil Units

As the name implies, a "fan-coil" unit is a heating unit that consists of a coil and a fan. It is mounted in an enclosure that has an outlet at the top and an inlet at the bottom. The finned coil is folded within the enclosure to provide a large heating area, and the fan forces a large volume of air through the coil. As a result, a fan-coil unit has a large heat output in relation to its size. Figure 4-18 shows a typical unit.

Fan-coil units presently are uncommon in single-family homes. They require an electrical connection in addition to the plumbing connections. They have a certain amount of fan noise, and the cabinets take up wall space. Still, consider fan-coil units for spaces that need to be warmed quickly and for spaces that need a lot of heat output from a small unit. For example, you might install one in a home office that is packed with furniture that would interfere with baseboard convectors.

Some fan-coil units are designed to be installed in an equipment closet. This kind of unit heats an adjacent room through a short duct and a grille.

If you install more than one fan-coil unit in a room or zone, pipe heating water to each unit separately.

Mestek

Figure 4-18. An attractive hydronic fan-coil unit.

Hydronic Floor Heating

Hydronic floor heating circulates heating water through tubing that is embedded in the entire floor surface or that is attached to the underside of the floor. In this way, the surface of the floor becomes the room heater.

Floor heating can be installed in concrete slabs and in wood frame floors. It can be installed under tile, hardwood, and dense synthetic materials, such as vinyl and linoleum, all of which conduct heat adequately.

Despite claims to the contrary, it is not prudent to install floor heating if the surface will be covered with carpets, carpet pads, or extensive rugs, all of which insulate the room from the floor heating system. The heat from the water tubing should be able to reach the visible floor surface without overheating the floor material itself.

Floor heating is often called "radiant" heating, which is incorrect. The water coils warm the floor by conduction, and the floor then warms the bottom layer of air in the room – and occupants' feet – by conduction. Finally, the warmed air rises into the space by convection. Radiation from the floor is minor, and it primarily warms the ceiling.

■ Where to Use Hydronic Floor Heating

There are few applications in typical homes where floor heating provides a compelling advantage over other kinds of hydronic heating. As a rule, floor heating may be an option to consider for certain individual spaces, not as a primary method of heating your home.

For formal rooms, one advantage of floor heating is that it is completely invisible in the room, except for the thermostat. It creates no physical or esthetic interference with furnishings. Also, it is completely silent, a benefit that it shares with convectors and radiators.

Floor heating provides good comfort in rooms with tall ceilings because it tends to cancel stratification. The advantage is greatest if the room is poorly insulated. In your home, that would occur only if you choose to build a special room that has a lot of glass. (See *What If You Want a Space with Lots of Glass?*, in Step 2.)

Bathroom floor heating is a deluxe application that is more expensive than other methods of warming a bathroom. The heating is very pleasant, and it helps to dry

HOW HEAT PUMPS AND AIR CONDITIONERS WORK

As its name implies, a heat pump is a device that ***moves*** heat, rather than converting heat from some other energy source. Typically, 50% to 80% of the heating energy that is delivered to the inside of a house by a heat pump is taken from the outdoor environment, where it is free.

Normally, heat flows from a region of higher temperature to a region of lower temperature. If you hold a flame under one end of a metal rod, the heat will flow from the hot end toward the cool end. In the same way, during cold weather, indoor heat flows through the structure of a house toward the outside.

The unique characteristic of a heat pump is its ability to make heat flow in the opposite direction, from a cooler region to a warmer region. In a manner of speaking, a heat pump "pumps" heat uphill toward a higher temperature, against its normal tendency.

How does a heat pump perform this magic? Figure 4-36 shows a simplified heat pump. It uses a substance called a "refrigerant" that circulates between the inside and the outside of the house. The refrigerant changes from a liquid to a vapor, or vice versa, in different parts of the system. The process absorbs heat from the cold outside air and delivers that heat to the inside of the house at a higher temperature.

A heat pump exploits two facts that you may remember from chemistry class. One fact is that compressing a gas (or vapor) makes it hot, and letting a gas expand makes it cool. The other fact is that it takes a lot of energy (called "latent heat") to change a liquid to a vapor. Conversely, the vapor gives up that same amount of heat when it condenses into a liquid. A refrigerant is a material that has a large latent heat, and it can change from liquid to vapor within the operating temperature range of the heat pump.

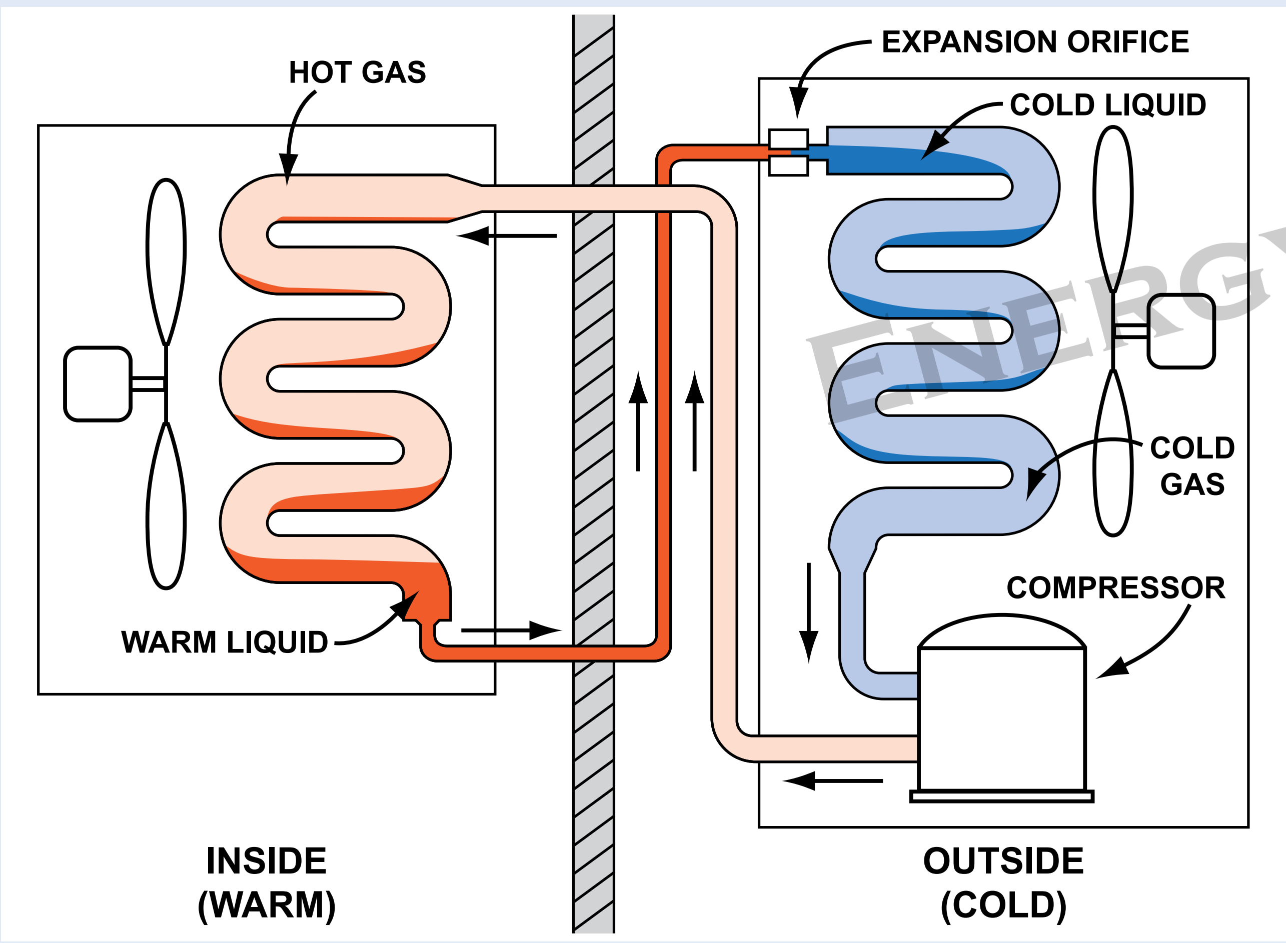

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Figure 4-36. A simplified heat pump. This heat pump extracts heat from the outside air and moves it into the house. Most real heat pumps can move heat in both directions, so they can provide both heating and cooling.

HOW HEAT PUMPS AND AIR CONDITIONERS WORK

Let's start at the compressor in Figure 4-36, and follow the refrigerant as it flows through the heat pump:

(1) The compressor compresses the refrigerant vapor, making it hotter than room temperature. The compressor discharges the vapor to a heat transfer coil located inside the house.

(2) A fan blows house air through the inside coil, which warms the air and cools the refrigerant vapor. As the vapor cools, it condenses into a warm liquid, giving up its large amount of latent heat and providing most of the warmth. The liquid refrigerant drains to the bottom of the coil.

(3) The liquid refrigerant is forced through the "expansion valve" by the discharge pressure of the compressor. The expansion valve is a small orifice that is located at the inlet to the outdoor heat transfer coil.

(4) The outdoor heat transfer coil is at low pressure because it connected to the suction side of the compressor. At the outlet of the expansion valve, the liquid refrigerant encounters this low pressure. This causes a fraction of the liquid to flash into a vapor. The reduction in pressure makes the vapor cold. At the same time, the evaporation absorbs a large amount of energy from the remaining liquid, making the liquid colder than the outside air.

(5) The liquid and vapor flow through the outside heat exchange coil. A fan blows outside air through the coil. The outside air is warmer than the very cold refrigerant inside the coil, so heat flows from the outside air into the refrigerant. The higher outside air temperature causes the liquid refrigerant to change to a vapor, absorbing a large amount of latent heat from the air.

(6) The refrigerant vapor flows to the compressor, and the cycle repeats.

A heat pump needs electricity to operate the compressor, the fan for the inside coil, and the fan for the outside coil. The compressor uses most of the energy. The compressor's need for energy increases along with the difference in temperature between the inside and the outside. Therefore, a heat pump will use more energy to heat a house during cold weather than it will during mild weather.

Also, the heat pump's heating capacity drops as the temperature difference increases. Below a certain temperature, the efficiency and capacity of the heat pump drops so much that it cannot operate effectively. For this reason, ordinary heat pumps are not used in very cold climates.

The simplified heat pump in Figure 4-36 moves heat only from the outside to the inside. Most real heat pumps include a "reversing valve" that can swap the connections of the compressor to the inside and outside coils. In this way, the heat pump can either heat or cool the house.

The electricity used by the compressor ultimately becomes heat inside the refrigerant. This heat is delivered to the warm side of the system, along with the free energy that comes from the cold side. For this reason, a heat pump is more efficient when heating a house than when cooling it.

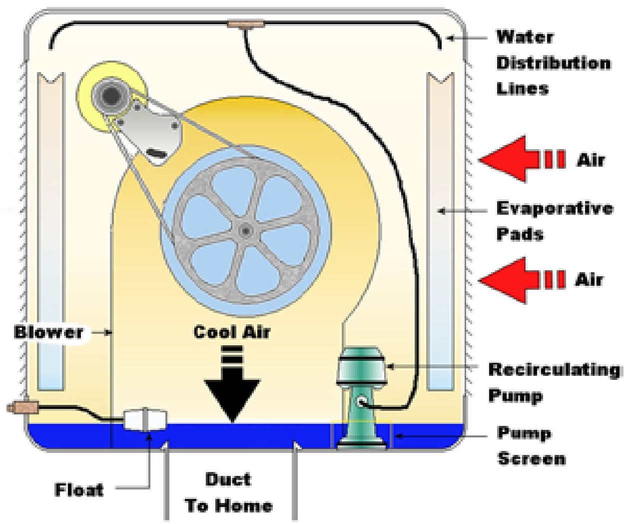
An "air conditioner" is a heat pump that is designed only to pump heat from the inside of the house toward the outside. It lacks a reversing valve. Other than that, there is little difference in construction between an air conditioner and a heat pump, and little difference in manufacturing cost.

Evaporative Coolers for Dry Climates

Conventional air conditioning cools by the same process that is used in your refrigerator. "Evaporative cooling" is a much older kind of cooling that can be used in dry climates. It uses less energy than refrigeration cooling, and the equipment is less expensive. If you live in a dry climate, don't overlook this option.

Before we get into the details, you should know that evaporative cooling is inferior to conventional air conditioning in all respects except its lower energy cost. It is unlikely that you will want it as the primary cooling for your house. If you travel in the American Southwest, where evaporative cooling is common, you will see restaurants and bars advertise that they are "cooled by refrigeration" to reassure potential customers that they ***don't*** use evaporative cooling.

Even if evaporative cooling is not the best choice for the main part of your home, you may want to use it for spaces where temperature and humidity are less critical, such as a glassed-in veranda.



AdobeAir

Figure 4-65. Direct evaporative cooler. This is the simplest and most common kind.

The higher humidity created inside the house by evaporative cooling can promote mildew and structural damage, and it may rust steel tools and other implements. As a rule, it is not prudent to use evaporative cooling for any part of a house that tends to remain cooler or more humid than the rest of the house. This would include basements, bathing spaces, and the laundry area.

Several kinds of evaporative coolers have been developed, but only one is presently popular for use in houses. Specialists call that kind "direct" or "single-stage." Everyone else simply calls it an "evaporative cooler" or "swamp cooler."

How Evaporative Cooling Works

The common type of evaporative cooler is mechanically very simple. Figure 4-65 shows how it operates. A fan blows outside air into the house through a large hole, which may be a window, a wall opening, or a roof opening. A wetted curtain or pad surrounds the fan intake. The outside air is pulled through the wet pad by the fan on its way into the house. A small pump circulates water over the pad to keep it wet.

The machine is packaged in a housing that is installed outside the house. Figure 4-66 shows a preferred method of installation.

Although the equipment is simple, the way it works may not be obvious. Several processes are happening at the same time:

- Entering air evaporates some of the water in the pad.
- The evaporation cools the rest of the water in the pad.
- The entering air is cooled by contact with the pad.
- The moisture that evaporates from the wet pad goes into the entering air stream, increasing its humidity.

The air is coolest where it enters the house from the evaporator. The air picks up heat and becomes warmer as it travels through the house. The air exits from the house, usually through one or more open windows.

An ordinary evaporative cooler is a once-through system. The air cannot be recycled for further cooling because its moisture content is too high. The exhaust air carries away the water that is introduced by the cooler. Also, the exhaust wastes any cooling that remains in the air.

Unlike a heat pump or air conditioner, the evaporative cooler does not take heat energy out of the entering air. Instead, ***it trades temperature for humidity***. This trade can make a person comfortable only if the temperature and the humidity of the entering air are both low enough. And that depends on the climate.

The biggest disadvantage of a conventional evaporative cooler is the excessive humidity that it may create inside the house. A combination of coolness and dampness is not comfortable, and it invites mildew.

Other Kinds of Evaporative Coolers

Among engineers who work with evaporative cooling, the simple kind of evaporative cooler that we just described is called a "direct" evaporative cooler. Other designs have been developed to minimize the humidity and efficiency limitations of direct coolers.

The improved designs use a "heat exchanger." The air inside the house is recirculated through the heat exchanger, and the heat exchanger is cooled by evaporating water. In this way, no humidity enters the house, and none of the cooling effect of the evaporation is wasted. These designs have names like "indirect," "2-stage," and "hybrid."

As this is being written, these improved evaporative coolers for houses are still a rarity, and they are expensive. If they become more available, they are worth considering.

Climates for Evaporative Cooling

Evaporative cooling is limited to climates that are dry. Only dry air can evaporate water strongly enough to create the desired cooling effect.

Evaporative coolers are commonly called "swamp coolers." However, they won't work at all in a swampy climate. Instead, they may turn the inside of your home into a swamp if you operate one in weather that is not dry. In that case, the cooler simply acts as a huge humidifier, which invites indoor condensation and mildew.

The hotter the climate, the drier the outside air must be in order for evaporative cooling to work. As a realistic example, let's assume that you want to achieve an indoor temperature of 78 °F (26 °C). At this temperature, the maximum relative humidity for good comfort is about 60%. The following table shows the outside air conditions that must exist in order for an evaporative cooler to create those desired indoor conditions:

If the outside air temperature is: °F (°C)	the outside relative humidity must be less than (%):
80 (27)	50
85 (29)	38
90 (32)	29
95 (35)	23
100 (38)	16
105 (41)	11
110 (43)	8

Figure 4-66. Evaporative cooler installed through the wall of a house. This location is superior to the more common roof installation because the entering air is cooler and access for maintenance is easier. Do not install through a window.

These numbers* show that the climate must be very dry in order for an evaporative cooler to provide good comfort in a hot climate. If the climate is not dry, an evaporative cooler cannot approach the standard of comfort that is provided by mechanical air conditioning because the air will be too humid.

On the other hand, evaporative cooling may still provide a welcome improvement over no cooling at all. For example, large portable spray coolers have become popular for cooling large tents used at public events, even in climates that are not ideal for evaporative cooling.

* Beware of performance numbers that are published by promoters of evaporative coolers. Such sources may assume that the air inside the house is allowed to rise to 100% relative humidity. That would be very uncomfortable, and it would grow mildew. You don't want high relative humidity inside your house under any circumstances.