Heat engines

by Chris Woodford. *Last updated: July 4, 2016.*

In our age of fuel cells and electric cars, steam locomotives (and even gasoline-powered cars) might seem like horribly old technology. But take a broader view of history and you'll see that even the oldest steam engine is a very modern invention indeed. Humans have been using tools to multiply their muscle power for something like 2.5 million years, but only in the last 300 years or so have we perfected the art of making "muscles"— engine-powered machines—that work all by themselves. Put it another way: humans have been without engines for over 99.9 percent of our existence on Earth!

Now we have engines, of course, we couldn't possibly do without them. Who could imagine life without cars, trucks, ships, or planes—all of them propelled by powerful engines. And engines don't just move us around the world, they help us radically reshape it. From bridges and tunnels to skyscrapers and dams, virtually every major building and structure people have made in the last couple of centuries has been built with the help of engines—cranes, diggers, dumper trucks, and bulldozers among them. Engines have also fueled the modern agricultural revolution: a vast proportion of all our food is now harvested or transported using engine power. Engines don't make the world go round, but they're involved in virtually everything else that happens on our planet. Let's take a closer look at what they are and how they work!

What is a heat engine?

An **engine** is a machine that turns the energy locked in fuel into force and motion. Coal is no *obvious* use to anyone: it's dirty, old, rocky stuff buried underground. Burn it in an engine, however, and you can release the energy it contains to power factory machines, cars, boats, or locomotives. The same is true of other fuels such as natural gas, gasoline, wood, and peat. Since engines work by burning fuels to release heat, they're sometimes called **heat engines**. The process of burning fuel involves a chemical reaction called **combustion** where the fuel burns in oxygen in the air to make carbon dioxide and steam. (Generally, engines make air pollution as well because the fuel isn't always 100 percent pure and doesn't burn perfectly cleanly.)

There are two main types of heat engines: external combustion and internal combustion:

- In an **external combustion engine**, the fuel burns outside and away from the main bit of the engine where the force and motion are produced. A steam engine is a good example: there's a coal fire at one end that heats water to make steam. The steam is piped into a strong metal **cylinder** where it moves a tight-fitting plunger called a **piston** back and forth. The moving piston powers whatever the engine is attached to (maybe a factory machine or the wheels of a locomotive). This is an external combustion engine because the coal is burning outside and some distance from the cylinder and piston.
- In an **internal combustion engine**, the fuel burns *inside* the cylinder. In a typical car engine, for example, there are something like four to six separate cylinders inside which gasoline is constantly burning with oxygen to release heat energy. The cylinders "fire" alternately to ensure the engine produces a steady supply of power that drives the car's wheels.

Internal combustion engines are generally far more efficient than external combustion engines because no energy is wasted transmitting heat from a fire and boiler to the cylinder; everything happens in one place.

How does an engine power a machine?

Engines use pistons and cylinders, so the power they produce is a continual back-and-forth, push-and-pull, or **reciprocating** motion. Trouble is, many machines (and virtually all vehicles) rely on wheels that turn round and round—in other words, **rotational** motion. There are various different ways of turning reciprocating motion into rotational motion (or vice-versa). If you've ever watched a steam engine chuffing along, you'll have noticed how the wheels are driven by a crank and connecting rod: a simple lever-linkage that connects one side of a wheel to a piston so the wheel turns around as the piston pumps back and forth.

An alternative way to convert reciprocating into rotational motion is to use gears. This is what brilliant Scottish engineer James Watt (1736–1819) decided to do in 1781 when he discovered the crank mechanism he needed to use in his improved design of steam engine was, in fact, already protected by a patent. Watt's design is known as a **sun and planet** gear) and consists of two or more gear wheels, one of which (the planet) is pushed up and down by the piston rod, moving around the other gear (the Sun), and causing it to rotate.

Some engines and machines need to turn rotary motion into reciprocating motion. For that, you need something that works in the opposite way to a crankshaft—namely a cam. A cam is a non-circular (typically egg-shaped) wheel, which has something like a bar resting on top of it. As the axle turns the wheel, the wheel makes the bar rise up and down. Can't picture that? Try imagining a car whose wheels are egg-shaped. As it drives along, the wheels (cams) turn round as usual but the car body bounces up and down at the same time—so rotational motion produces reciprocating motion (bouncing) in the passengers!

Cams are at work in all kinds of machines. There's a cam in an electric toothbrush that makes the brush move back and forth as an electric motor inside spins around.

Types of engines

There are half-a-dozen or so main types of engines that make power by burning fuel:

External combustion engines

Beam engines: The earliest steam engines were giant machines that filled entire buildings and they were typically used for pumping water from flooded mines. Pioneered by Englishman Thomas Newcomen (1663/4–1729) in the early 18th century, they had a single cylinder and a piston attached to a large beam that rocked back and forth. Steam was pumped into the cylinder forcing the piston to rise and the beam to move down. Then water was squirted into the cylinder, cooling the steam, creating a partial vacuum, and making the beam tilt back the other way. Beam engines were an important technological advance, but they were much too large, slow, and inefficient to power factory machines and trains.

Steam engines: In the 1760s, James Watt greatly improved Newcomen's steam engine, making it smaller, more efficient, and more powerful—and effectively turning steam engines into more practical and affordable machines. Watt's work led to stationary steam engines that could be used in factories and compact, moving engines that could power steam locomotives. Read more in our article on steam engines.

Stirling engines: Not all external combustion engines are huge and inefficient. Scottish clergyman Robert Stirling (1790–1878) invented a very clever engine that has two cylinders with pistons powering two cranks driving a single wheel. One cylinder is kept permanently hot (heated by an external energy source that can be anything from a coal fire to a geothermal energy supply) while the other is kept permanently cold. The engine works by shuttling the same volume of gas (permanently sealed inside the engine) back and forth between the cylinders through a device called a regenerator, which helps to retain energy and greatly increases the engine's efficiency. Find out more in our main article on Stirling engines.

Internal combustion engines

Gasoline (petrol) engines: In the mid-19th century, several European engineers including Frenchman Joseph Étienne Lenoir (1822–1900) and German Nikolaus Otto (1832–1891) perfected internal combustion engines that burned gasoline. It was a short step for Karl Benz (1844–1929) to hook up one of these engines to a three-wheeled carriage and make the world's first gas-powered automobile. Read more in our article on car engines.

Diesel engines: Later in the 19th century, another German engineer, Rudolf Diesel (1858–1913), realized he could make a much more powerful internal combustion engine that could run off all kinds of different fuels. Unlike gasoline engines, diesel engines compress fuel much more so it spontaneously bursts into flames and releases the heat energy locked inside it. Today, diesel engines are still the machines of choice for driving heavy vehicles such as trucks, ships, and construction machines, as well as many cars. Read more in our article on diesel engines.

Rotary engines: One of the drawbacks of internal combustion engines is that they need cylinders, pistons, and a spinning crankshaft to harness their power: the cylinders are stationary while the pistons and crankshaft are constantly moving. A rotary engine is a radically different design of internal combustion engine in which the "cylinders" (which aren't always cylinder shaped) rotate around what is effectively a stationary crankshaft. Although rotary engines date back to the 19th century, perhaps the best-known design is the relatively modern Wankel rotary engine, notably used in some Japanese Mazda cars. Wikipedia's article on the Wankel rotary engine is a good introduction with a brilliant little animation.

Engines in theory

The pioneers of engines were *engineers*, not scientists. Newcomen and Watt were hands-on, practical "doers" rather than head-scratching, theoretical thinkers. It wasn't until Frenchman Nicolas Sadi Carnot (1796–1832) came along in 1824—well over a century after Newcomen built his first steam engine—that any attempt was made to understand the theory of how engines worked and how they could be improved from a truly scientific perspective. Carnot was interested in figuring out how engines could be made more efficient (in other words, how more energy could be obtained from the same amount of fuel). Instead of tinkering with a real steam engine and trying to improve it by trial and error (the kind of approach Watt had taken with Newcomen's engine), he made himself a theoretical engine—on paper—and played around with math instead.

The **Carnot heat engine** is a fairly simple mathematical model of how the best possible piston and cylinder engine could operate *in theory*, by endlessly repeating four steps now called the **Carnot cycle**. We're not going to go into the theory here, or the math (if you're interested, see NASA's Carnot Cycle page and the excellent Heat Engines: the Carnot Cycle page by Michael Fowler, which has a superb flash animation).

What is worth noting is the conclusion Carnot reached: **the efficiency of an engine (real or theoretical) depends on the maximum and minimum temperatures between which it operates**. Making the temperature of the fluid inside the cylinder higher at the start of the cycle makes it more efficient; making the temperature lower at the end of the cycle also makes it more efficient. In other words, a really efficient heat engine operates between the greatest possible temperature difference. That's why real engines—in cars, trucks, jet planes, and space rockets—work at such enormously high temperatures (and why they have to be built from high-temperature materials such as alloys and ceramics). It's also why things like steam turbines in power plants have to use cooling towers to cool their steam down as much as possible: that's how they can get the most energy from the steam and produce the most electricity.

http://www.explainthatstuff.com/engines.html

How Home Thermostats Work

BY KARIM NICE, PATRICK BROTHERS & EMILIE SENNEBOGEN **HOME & GARDEN | HOUSEHOLD APPLIANCES**

If you have specific heating and cooling needs in order to be comfortable then you've probably spent a little time looking at and operating your home thermostat. This handy little device controls the heating and air-conditioning systems in your house -- the two pieces of equipment that use the most energy, and the ones that have the biggest impact on your comfort and quality of life. In these days of rising energy prices, you might be interested to see how your thermostat works. Believe it or not, it's surprisingly simple and contains some pretty cool technology.

In this article, we'll take apart a household thermostat and learn how it works. We'll also learn a little about digital thermostats, talking thermostats, telephone thermostats and system zoning.

HEATING & COOLING

Modern thermostats are almost exclusively digital, but before we get to those, let's take a trip down memory lane and look at the parts of a non-digital thermostat that you might still find in older homes and motels. Let's start with the **mercury switch** -- a glass vial with a small amount of actual mercury inside. Mercury is a liquid metal -- it conducts electricity and flows like water. Inside the glass vial are three wires. One wire goes all the way across the bottom of the vial, so the mercury is always in contact with it. One wire ends on the left side of the vial, so when the vial tilts to the left, the mercury contacts it -- making contact between this wire and the one on the bottom of the vial. The third wire ends on the right side of the vial, so when the vial tilts to the right, the mercury makes contact between this wire and the bottom wire.

There are two thermometers in this kind of thermostat. The one in the cover displays the temperature. The other, in the top layer of the thermostat, controls the heating and cooling systems. These thermometers are nothing more than coiled bimetallic strips. And what's that, you ask? We'll find out on the next page.

Thermometers and Switches

A **bimetallic strip** is a piece of metal made by laminating two different types of metal together. The metals that make up the strip expand and contract when they're heated or cooled. Each type of metal has its own particular rate of expansion, and the two metals that make up the strip are chosen so that the rates of expansion and contraction are different. When this coiled strip is heated, the metal on the inside of the coil expands more and the strip tends to unwind.

The center of the coil is connected to the temperature-adjustment lever, and the mercury switch is mounted to the end of the coil so that when the coil winds or unwinds, it tips the mercury switch one way or the other.

In non-digital thermostats there are two **switches**. These switches move small metal balls that make contact between different traces on the **circuit card** inside the thermostat. One of the switches controls the **mode** (heat or cool), while the other switch controls the **circulation fan**. On the next page, we'll see how these parts work together to make the thermostat work.

When you move the lever on the thermostat to turn up the heat, this rotates the thermometer coil and mercury switch, tipping them to the left.

As soon as the switch tips to the left, current flows through the mercury in the mercury switch. This current energizes a relay that starts the **heater** and circulation fan in your home. As the room gradually heats up, the thermometer coil gradually unwinds until it tips the mercury switch back to the right, breaking the circuit and turning off the heat.

When the mercury switch tips to the right, a relay starts the air conditioner. As the room cools, the thermometer coil winds up until the mercury switch tips back to the left.

Thermostats have another cool device called a **heat anticipator**. The heat anticipator shuts off the heater before the air inside the thermostat actually reaches the set temperature. Sometimes, parts of a house will reach the set temperature before the part of the house containing the thermostat does. In this case, the anticipator shuts the heater off a little early to give the heat time to reach the thermostat.

The loop of wire above is a kind of **resistor**. When the heater is running, the current that controls the heater travels from the mercury switch, through the yellow wire to the resistive loop. It travels around the loop until it gets to the **wiper**, and from there it travels through the hub of the anticipator ring and down to the circuit board on the bottom layer of the thermostat. The farther the wiper is positioned (moving clockwise) from the yellow wire, the more of the resistive wire the current has to pass through. Like any resistor, this one generates heat when current passes through it. The farther around the loop the wiper is placed, the more heat is generated by the resistor. This heat warms the thermometer coil, causing it to unwind and tip the mercury switch to the right so that the heater shuts off.

http://home.howstuffworks.com/home-thermostat.htm

How Refrigerators Work

BY MARSHALL BRAIN & SARA ELLIOTT HOME & GARDEN | KITCHEN APPLIANCES

The next time you indulge in an ice cold drink on a hot day, you have your refrigerator (and onboard freezer) to thank for the refreshingly chilled beverage. It wasn't so long ago that you'd have to be very rich or well connected to score a chilled drink with a few ice cubes floating inside. Today, we take refrigeration for granted, but once upon a time, fortunes were made shipping large blocks of ice around the world in insulated holds to sell to the rich.

Before refrigeration, preserving food was a big job. You could salt foods, and in winter, you could bury food in a snow drift and hope the critters didn't find it. To stay stocked with the essentials, though, you had to work at it -- or be rolling in money. Refrigeration is one invention that changed the way we conduct our daily lives. We can preserve food more easily nowadays, so we have much less to worry about when it comes to food-borne illnesses. The food supply is more stable, too. That gallon of milk can last a couple of weeks in the fridge as opposed to a couple of hours on your countertop. That's huge. It means you don't need to keep a cow in your backyard if you want a regular supply of milk.

The fundamentals of refrigeration are also at work in another important household appliance: the air conditioner. It's estimated that around 5 percent of all the electrical energy used in the U.S. is expended to keep our homes cool. That's pretty amazing, especially when you consider the fact that the principle behind most refrigeration is simple. Here it is in one sentence: When a liquid evaporates, it absorbs heat in the process. If you want to get rid of heat, you need to coax a liquid to convert to its gaseous state [source: ACEEE].

Parts of a Refrigerator

If you pour a little rubbing alcohol on your skin, it'll feel cold -- really cold. It isn't refrigerated, so how does this happen? Well, alcohol evaporates at room temperature the way water evaporates at a low temperature in an oven. As it evaporates, it absorbs the heat on the surface of your skin, making your skin cooler. A special coolant called a refrigerant functions in a refrigerator the way alcohol works on your skin, except in a refrigerator, the coolant is trapped inside a series of coils. As it makes a circuit through them, it changes back and forth from a liquid to a gas.

To pull off this frosty feat, a refrigerator uses five major components:

- **Compressor**
- **Heat-exchanging pipes** (serpentine or coiled set of pipes outside the unit)
- **Expansion valve**
- **Heat-exchanging pipes** (serpentine or coiled set of pipes inside the unit)
- **Refrigerant** (liquid that evaporates inside the refrigerator to create the cold temperatures)

Understanding Refrigeration

To understand what's happening inside a refrigerator, let's learn a little more about how refrigerants work. You will need:

- An oven-safe glass bowl filled with water
- A thermometer that can measure up to at least 450 degrees Fahrenheit (232.2 degrees Celsius)

Add the thermometer to the water filled bowl and place both in the oven. Set the oven to 400 degrees Fahrenheit (204.4 degrees Celsius).

As the oven heats up, the temperature of the water will rise until it hits 212 Fahrenheit (100 degrees Celsius) and it starts boiling. The water temperature will stay at 212 degrees Fahrenheit (100 degrees Celsius) even though it's completely surrounded by the 400 degrees Fahrenheit environment inside the oven. If you let all the water boil away, the temperature on the thermometer will shoot up to 400 degrees Fahrenheit (232.2 degrees Celsius).

Let's look at this experiment another way: Imagine the existence of an exotic creature able to live happily in an oven at 400 degrees Fahrenheit. Let's call him Max. If Max is hanging out in a 400 degree Fahrenheit oven next to a bowl of water boiling away at 212 degrees Fahrenheit (100 degrees Celsius), how is he going to feel about that water? He's going to think the boiling water is really cold. After all, the boiling water is 188 degrees colder than the 400 degrees Fahrenheit that he thinks is comfortable. That's a big temperature difference!

This is exactly what happens when humans deal with liquid nitrogen. We feel comfortable at 70 degrees Fahrenheit (21.1 degrees Celsius), but liquid nitrogen boils at -320 degrees Fahrenheit (-195.5 degrees Celsius).

If you had a pot of liquid nitrogen sitting on the kitchen table, its temperature would be boiling away at -320 degrees Fahrenheit (-195.5 degrees Celsius) -- to you, of course, it would feel incredibly cold (so cold it would burn you!).

Modern refrigerators use a regenerating cycle to reuse the same refrigerant over and over again. You can get an idea of how this works by remembering Max and his bowl of water. He could easily create a regenerating cycle by taking the following steps:

1. The bowl of water in the oven example boils away, remaining at 212 degrees Fahrenheit (100 degrees Celsius) but producing lots of 400 degree Fahrenheit steam. Let's say Max collects this steam in a big bag.
2. Once all the water boils off, Max pressurizes the steam into a steel container, where the temperature rises to 800 degrees Fahrenheit (426.6 degrees Celsius) as the pressure increases. Now, Max thinks the steel container feels really "hot" because it contains 800 degree Fahrenheit (426.6 degrees Celsius) steam instead of 400 degree Fahrenheit steam.
3. The steel container releases or dissipates its excess heat to the air in the oven, and it eventually drops to the oven's temperature of 400 degrees Fahrenheit. In the process, the high-pressure steam in the container condenses into pressurized water.
4. At this point, Max releases the water from the steel pressurized container into a pot, and it immediately begins to boil, its temperature dropping to 212 degrees Fahrenheit.

By repeating these four steps, Max can reuse the same water over and over again to provide refrigeration.

Did You Know?

If you're at sea level, you'll see that the temperature of water will begin to boil at 212 degrees Fahrenheit (100 degrees Celsius), but if you live in the mountains, where the air pressure is lower than it is at sea level, the boiling point will be a bit lower, say 190 to 200 degrees Fahrenheit (87 to 93 degrees Celsius). This is why many foods have special high-altitude cooking directions printed on the box.

The Refrigeration Cycle
The refrigerator in your kitchen uses a cycle that is similar to the one described in the previous section. But in your refrigerator, the cycle is continuous. In the following example, we will assume that the refrigerant being used is pure ammonia, which boils at -27 degrees F. This is what happens to keep the refrigerator cool:

1. The **compressor** compresses the ammonia gas. The compressed gas heats up as it is pressurized (orange).
2. The **coils** on the back of the refrigerator let the hot ammonia gas dissipate its heat. The ammonia gas condenses into ammonia liquid (dark blue) at high pressure.
3. The high-pressure ammonia liquid flows through the **expansion valve**. You can think of the expansion valve as a small hole. On one side of the hole is high-pressure ammonia liquid. On the other side of the hole is a low-pressure area (because the compressor is sucking gas out of that side).
4. The liquid ammonia immediately boils and vaporizes (light blue), its temperature dropping to -27 F. This makes the inside of the refrigerator cold.
5. The cold ammonia gas is sucked up by the **compressor**, and the cycle repeats.

By the way, if you have ever turned your car off on a hot summer day when you have had the air conditionerrunning, you may have heard a hissing noise under the hood. That noise is the sound of high-pressure liquid refrigerant flowing through the expansion valve.

Pure ammonia gas is highly toxic to people and would pose a threat if the refrigerator were to leak, so all home refrigerators don't use pure ammonia. You may have heard of refrigerants know as **CFCs** (chlorofluorocarbons), originally developed by Du Pont in the 1930s as a non-toxic replacement for ammonia. CFC-12 (dichlorodifluoromethane) has about the same boiling point as ammonia. However, CFC-12 is not toxic to humans, so it is safe to use in your kitchen. Many large industrial refrigerators still use ammonia.

In the 1970s, it was discovered that the CFCs then in use are harmful to the ozone layer, so as of the 1990s, all new refrigerators and air conditioners use refrigerants that are less harmful to the ozone layer.

http://home.howstuffworks.com/refrigerator6.htm

How Heat Pumps Work

BY LAURA COWAN & EMILIE SENNEBOGEN **HOME & GARDEN | HEATING AND COOLING**

When you think about cooling a hot building, you probably don't think of heat pumps. In fact, the words "air conditioner" are likely the first things that come to your head unless you're tight with your pennies. Then you might go with "window fans." As it turns out, a heat pump can both heat and cool, and in some applications, it's preferred to separate heating and cooling systems.

Simply put, a **heat pump** is a device that uses a small amount of energy to move heat from one location to another. Not too difficult, right? Heat pumps are typically used to pull heat out of the air or ground to heat a home or office building, but they can be reversed to cool a building. In a way, if you know how an air conditioner works, then you already know a lot about how a heat pump works. This is because heat pumps and air conditioners operate in a very similar way.

HEATING & COOLING

One of the biggest advantages of a heat pump over a standard heating ventilating and air conditioning (HVAC) unit is that there's no need to install separate systems to heat and cool your home. Heat pumps also work extremely efficiently, because they simply transfer heat, rather than burn fuel to create it. This makes them a little more green than a gas-burning furnace. And they don't just heat and cool buildings. If you've ever enjoyed a hot tub or heated swimming pool, then you probably have a heat pump to thank. They work best in moderate climates, so if you don't experience extreme heat and cold in your neck of the woods, then using a heat pump instead of a furnace and air conditioner could help you save a little money each month.

Heat Transfer and Air-Source Heat Pumps

There are many different kinds of heat pumps, but they all operate on the same basic principle -- **heat transfer**. This means that rather than burning fuel to create heat, the device moves heat from one place to another. There's a key to making this all happen -- heat naturally flows downhill. This means that it tends to move from a location with a high temperature to a location with a lower temperature. Pretty simple. What a heat pump does is use a small amount of energy to switch that process into reverse, pulling heat out of a relatively low-temperature area, and pumping it into a higher temperature area. So heat is transferred from a "heat source," like the ground or air, into a "heat sink," like your home.

One of the most common types of heat pumps is the **air-source heat pump**. This marvel of modern technology takes heat from the air outside your home and pumps it inside through refrigerant-filled coils, not too different from what's on the back of your fridge. The air source variety is pretty basic, and you'll find two fans, the refrigerator coils, a reversing valve and a compressor inside to make it work.

And since you asked, here's how this kind of heat pump works:

This system is more commonly known as an **air-air heat pump,** because it takes heat from outdoor air and transfers it to indoor air ducts. With the right kind of modifications, air-source systems can also work with other types of indoor heating systems.

The key to allowing the air-air heat pump to also cool is the reversing valve. This versatile part reverses the flow of the refrigerant, so that the system begins to operate in the opposite direction. So instead of pumping heat inside your home, the heat pump releases it, just like your air conditioner does. When the refrigerant is reversed it absorbs heat on the indoor side of the unit and flows to the outside. It's here that the heat is released, allowing the refrigerant to cool down again and flow back inside to pick up more heat. This process repeats itself until you're nice and cool.

Air-Source, Ground-Source, and Absorption Heat Pumps

By now, you've learned that **air-source heat pumps** use an outdoor fan to bring air over refrigerant-filled coils. Two sets of these coils transfer this heat indoors, where it's then blown away from the coils by a second fan, and distributed through your home as cool goodness. Some air-source heat pump systems consist of a single packaged unit containing both sets of coils in one box. This box is then installed on the roof of a building with the ductwork extending through the wall. You'll see a lot of larger systems for commercial buildings installed in this way. Home heat pumps are usually split systems with an outdoor and an indoor component installed through the wall. Depending on the type of system, there may be one or more indoor components to distribute heat.

Ground-source heat pumps are a little different. They absorb heat from the ground or an underground body of water and transfer it indoors, or vice versa. The most common type of ground-source heat pump transfers heat directly from the ground by absorbing it through buried pipes filled with water or a refrigerant. These liquid-pumping pipes can be either **closed-loop** or **open-loop** systems, and they operate pretty much exactly how they sound. In a closed-loop system, the same refrigerant or water circulates through the pipes repeatedly. In an open-loop system, water is pumped out of the underground water source, like a well or a man-made lake. From there, the heat is extracted from the water, and that water returns to the well or surface lake. More water is then pumped from the well to extract more heat in a continuous open loop.

Other Kinds of Heat Pumps

If your home doesn't have air ducts to distribute heat, don't fear. You could potentially use a special kind of heat pump called a **mini-split heat pump**. The cutest of all heat pumps, it connects an outdoor air-source unit to multiple indoor units. These indoor units connect to water heat or space heaters. These ductless mini-split systems are useful for retrofitting a home with a heat pump system because their locations outside and inside the home are flexible. Another plus is that the installation only requires a 3-inch (7.6 centimeter) conduit to come through the wall, which is pretty unobtrusive. They're also versatile. The indoor air handlers can be installed in walls, ceilings or on the floor, and they're small to boot.

And who can forget the **reverse cycle chiller** (RCC) heat pump? Instead of heating and cooling air, this bad boy heats and cools water, and can operate efficiently in below freezing temperatures. In an RCC system, the heat pump connects to an insulated water tank that it either heats or cools. Then, a fan and coil system pump heated or cooled air away from the tank and through the ductwork to one or more heating zones. An RCC system can also pump hot water through a radiant floor heating system, so when those bare feet are comfy on a toasty tile floor this winter, you can thank your RCC.

In a typical air-source heat pump, there's the need for a backup burner to supply temporary heat when the system switches into reverse to defrost the coils. This backup burner prevents the system from blowing cold air through the registers while the coils defrost, which is key if your goal is to stay warm. Some might say that the RCC system is superior in that it uses the hot water from the tank to defrost the coils, so no backup burner is needed. This also means the system never blows cold air when it shouldn't, and the result is that you stay nice and warm.

A new type of heat pump showing promise for extreme climates is the Cold Climate heat pump, which operates efficiently at extremely low temperatures -- even below 0 degrees Fahrenheit (-18 degrees Celsius). The Cold Climate heat pump detects the minimum amount of energy needed to provide the desired level of heating or cooling and adjusts its output up or down, so it never wastes energy. It's an extremely green alternative, but is still in its early stages of implementation because of delays in funding, which slowed research. In 2011, Canada invested $4 million in Cold Climate heat system development.

The **All-Climate** heat pump is yet another new kind of pump, which can operate in temperatures as cold as -30 degrees Fahrenheit (-34 degrees Celsius) and can increase efficiency by up to 60 percent over a standard heat pump [source: EERE]. The All-Climate heat pump is designed primarily for heating, though, and won't work efficiently in climates where the heat pump would be in cooling mode most of the time.

Even special heat pumps have limitations. Read on to learn about the pros and cons of heat pumps, and what you need to know before buying one.

http://home.howstuffworks.com/home-improvement/heating-and-cooling/heat-pump3.htm

Geothermal System: How It Works

An electrically powered, geothermal heating and cooling system transfers heat between your house and the earth using fluid circulated through long loops of underground pipe.

Given all the attention being paid to solar power these days, you might be surprised to learn that one of the most promising solutions to high energy costs isn't up in the sky but buried deep under your lawn. Superefficient geothermal heat pumps provide clean, quiet heating and cooling while cutting utility bills by up to 70 percent. "With this technology, everybody could be sitting on top of their lifetime energy supply," says TOH plumbing and heating expert Richard Trethewey.

In principle, a geothermal heat pump functions like a conventional heat pump, by using high-pressure refrigerant to capture and move heat between indoors and out. The difference is that conventional systems gather their heat—and get rid of it—through the outside air. Geothermal systems, in contrast, transfer heat through long loops of liquid-filled pipe buried in the ground.

As our cave-dwelling ancestors discovered long ago, if you go far enough underground, the earth's temperature stays at a constant 50 degrees or so, no matter how hot or cold it gets outside. So while a conventional "air-source" heat pump struggles to scavenge heat from freezing winter air or to dump it into the summer swelter, its "ground-source" counterpart has the comparatively easy job of extracting and disbursing heat through the 50-degree liquid circulating in its ground loop. That's why it takes only one kilowatt-hour of electricity for a geothermal heat pump to produce nearly 12,000 Btu of cooling or heating. (To produce the same number of Btus, a standard heat pump on a 95-degree day consumes 2.2 kilowatt-hours.) Geothermal systems are twice as efficient as the top-rated air conditioners and almost 50 percent more efficient than the best gas furnaces, all year round.

Another advantage is that there's no need for a noisy outdoor fan to move air through the compressor coils. Geothermal units simply pump liquid, so they can be parked indoors, safe from the elements. Most come with

10-year warranties, but they can last much longer. In the 29 years since Jim Partin, one of the technology's earliest adopters, installed one in his Stillwater, Oklahoma, house, he's replaced only two contact switches.

Heat Pump Parts

As with ordinary heat pumps, the refrigerant in a geothermal heat pump runs in a loop through a compressor, condenser, expansion valve, and evaporator, collecting heat at one end and giving it up at the other. The direction of refrigerant flow, which is controlled by the reversing valve, determines whether heat is moving into the house in winter (shown) or being pulled out of it in summer. With the addition of a desuperheater, residual warmth from the system can also supplement a conventional water heater, further reducing energy bills.

Despite these benefits, only 47,000 geothermal units were installed last year in the U.S. That's just a tiny blip compared with the approximately one million conventional heat pumps sold during the same period, even though ground-source heat pumps cost about the same to buy. Here's the rub: You have to bury a lot of pipe—about 1,500 to 1,800 feet for a typical 2,000-square-foot home. (The actual length should be calculated by an expert, based on the optimal heating and cooling loads for the house.) A setup that size could cost as much as $20,000 to install, depending on soil conditions and how much digging and drilling is involved. A house on a big lot, for instance, might be able to use pipes laid horizontally in long, 4-foot-deep trenches. Houses on small lots or rocky ledges could require three or four holes drilled about 300 feet straight down, a much more costly process.

Even with this significant front-end investment, geothermal systems are so energy-stingy that the payback period is remarkably brief. A study by the Air Force Institute of Technology calculated that it takes on average just seven to eight years to recoup costs. Your actual break-even point depends on local utility rates, excavation/drilling costs, how well your house is insulated, the efficiency of the model you choose, and what incentives your state or utilities provide. A good installer who's knowledgeable about heating and cooling as well as your local geology will be able to make those calculations for you.

The current federal incentive is limited to the standard $300 tax credit for Energy Star HVAC installations. (Canadians retrofitting an existing home with geothermal qualify for a $3,500 federal grant.) Some forwardthinking utilities have offered low-interest loans to homeowners willing to adopt the technology. "It's a win-win arrangement," says Steve Rosenstock, energy solutions manager at the Edison Electric Institute, an association of utilities. "The utilities reduce peak demand for heating and cooling as their customers dramatically lower their electric bills." And because the plastic ground loops should last 50 years or more, the payoff for homeowners, and for the environment, can last for generations.

The Basics

What it is

An electrically powered heating and cooling system that transfers heat between your house and the earth using fluid circulated through long loops of underground pipes.

How it works

An indoor heat pump uses a basic refrigeration cycle—evaporation, compression, condensation, and expansion—to capture and disburse heat from and to the ground to warm the house in winter and cool it in summer.

Why you'd want one

Cuts home heating and cooling bills by 30 to 70 percent. Eliminates noisy outdoor compressors and fans. Reduces greenhouse gas emissions by the equivalent of planting 750 trees or taking two cars off the road.

What to look for

For federal tax credits, pumps must meet Energy Star efficiency standards. For closed-loop systems, you need an EER of 14.1 and a COP (coefficient of performance) of 3.3.

Where to get it

To find manufacturers, visit the Geothermal Heat Pump Consortium website. To find trained installers and designers who know the local geology and how to size systems for maximum efficiency, go to the International Ground Source Heat Pump Association's website.

What it costs

$15,000–$20,000 installed for the system, including ground loops, heat pump, and controls. The Database of State Incentives for Renewable Energy (dsireusa.org) provides up-to-date information on state incentive programs.

Can I Retrofit One?

Retrofitting a ground-source system is not difficult, as long as burying the ground loop is feasible. A house will need ducts to distribute cool air on hot days. Those same ducts can provide warm air in winter. Some geothermal heat pumps can hook up to an existing air handler, other units come with their own integral air handler. Houses with hot-water heating can use geothermal systems, too, although additional radiators may be needed because these systems do not reach the higher temperatures of fuel-fired boilers. (That's not a problem for radiant floor heat, which operates at lower temperatures.)

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