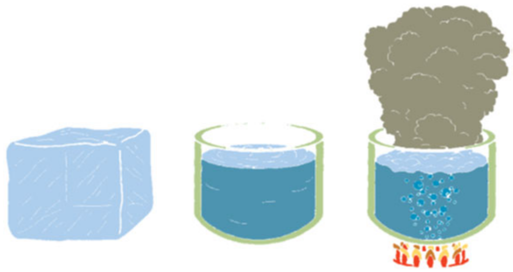


Heat and temperature do not describe the same thing. Heat is an absolute quantity measured in British Thermal Units (BTU's), much like "one cube" describes a quantity of sugar. Temperature (measured in degrees Fahrenheit or Celsius) is a relative measurement similar to how "sweetness" describes "one cube" of sugar dissolved in a cup of coffee. Both "one cube" and "sweetness" are describing a quantity of sugar, but "sweetness" is describing the sugar relative to the coffee. If I added more coffee to the cup, the amount of sugar would be the same, but the "sweetness" would decrease.

Heat is more than a physical concept - it is a feeling. Heat is taught to us at a very young age as a danger to be avoided. Yet, have you ever stopped and thought about what heat really is? How does it move? What are some of the ways we can move it? Heat, commonly described in degrees of temperature, such as Fahrenheit (°F) or Celsius (°C), describes the random motion or "vibration" of molecules. When a substance becomes hotter, its molecules move faster. How fast these molecules move determines whether the substance is a solid, a liquid, or a gas. In a solid, molecules are locked together in position. In a liquid, molecules move and share a loose relationship with each other. Molecules in a gas, share no relationship with each other because they move very fast.

Why Is Liquid Sprayed from a Can Cold?
If a pressurized can of liquid is sprayed continuously, the can becomes cold, and so does the liquid being sprayed. The can becomes cold because the pressure in the can is reduced while spraying, allowing the liquid propellant inside the can to boil and absorb heat. The propellant vapor is further cooled as it decompresses when it hits the open air. Rapid decompression results in a rapid temperature drop.

Understanding the three ways heat moves helps you consider all the heat sources that an air conditioner contends with.

- Conduction is when heat is transferred through a solid such as the metal fins of an evaporator.
- Convection is when a colder gas displaces a warmer gas causing them to move around and circulate.
- Radiant heat is when the sun's rays hit a solid surface causing it to heat up.

■■ Temperature is the measure of the level of energy. Temperature is measured in degrees.
■■ Heat is measured in the metric unit called calorie and expresses the amount of heat needed to raise the temperature of one gram of water one degree Celsius. Heat is also measured in British Thermal Units (BTU). One BTU is the heat required to raise the temperature of one pound of water 1°F at sea level. One BTU equals 252 calories

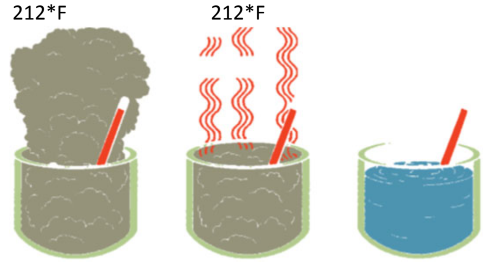
LATENT HEAT Latent heat is the "extra" heat that is needed to transform a substance from one state to another. Imagine that a solid or a liquid is being heated on a stove. When the solid reaches its melting point, or the liquid reaches its boiling point, their temperatures stop rising. The solid begins to melt, and the liquid begins to boil. This occurs without any sensible change in temperature, even though heat is still being applied from the burner. The water in the container on the stove boils at a temperature of 212°F (100°C) at sea level, for as long as any liquid water remains. As heat is further added to the water, heat will be used in changing the state of the liquid to a vapor. This extra, hidden amount of energy necessary to change the state of a substance is called latent heat

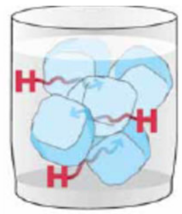
HEAT INTENSITY Intensity of heat is important to us because if it is too cold, humans feel uncomfortable and is measured in degrees. Extremely cold temperatures can cause frostbite and hypothermia. The other end of the scale can also be uncomfortable and may cause heat stress and dehydration. Humans have a temperature comfort zone somewhere between 68°F and 78°F (20°C and 26°C). This comfort zone varies among individuals.

1 GRAM WATER + 540 CALORIES = 1 GRAM VAPOR
1 POUND WATER + 970 BTUs = 1 POUND VAPOR

1 GRAM OF VAPOR – 540 CALORIES = 1 GRAM WATER
1 POUND OF VAPOR – 970 BTUs = 1 POUND WATER

212*F   212*F

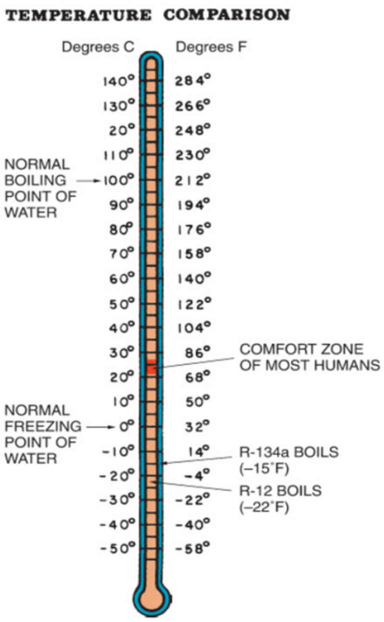




Heat flows into the ice cubes, causing them to melt.

Removing heat is simple. Since heat always goes towards a colder object, all we have to do is give heat a cold thing to flow into.

A good example of this is a iced drink. To cool the drink down, we put in ice cubes. Since ice cubes are colder than the warm liquid, the heat will flow into the ice cubes. The ice cubes absorb the heat and melt, removing the heat from the liquid. Now the drink is much more enjoyable.
Another simple way to remove heat is to use water. If you go the beach on a hot day, you may notice that folks who sunbathe frequently spray themselves with water to keep their skin cool. When they spray water on their skin, the heat from their bodies speeds up the water molecules and causes them to boil. When the water molecules boil, they change to a gas and escape into the air taking the heat with it. Overall, the water gets hot, the skin gets cool. We call this process "evaporation."



RULES OF HEAT TRANSFER Heating and air conditioning must follow the basic rules of heat transfer. An understanding of these rules helps greatly in understanding the systems.
1.Heat always flows from hot to cold. (From higher level of energy to lower level of energy.)
2. To warm a person or item, heat must be added.
3.To cool a person or item, heat must be removed.
4. A large amount of heat is absorbed when a liquid changes state to vapor.
5.A large amount of heat is released when a vapor changes state to a liquid.
6.Compressing a gas concentrates the heat and increases the temperature.

HUMIDITY Humidity refers to water vapor present in the air. The level of humidity depends upon the amount of water vapor present and the temperature of the air. The amount of water vapor in the air tends to be higher near lakes or the ocean, because more water is available to evaporate from their surfaces. In desert areas with little open water, the amount of water vapor in the air tends to be low.

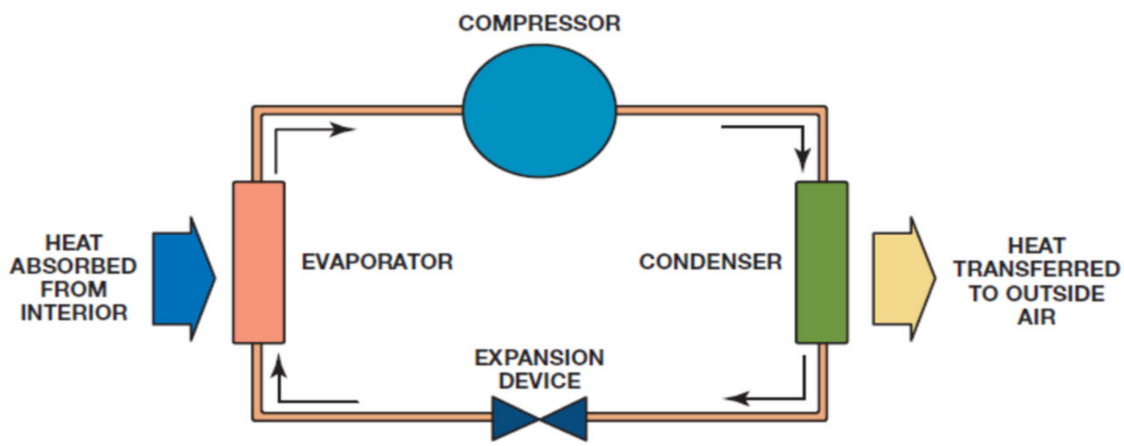
■■ Absolute humidity is the measure of the amount of moisture (water vapor) in the air regardless of the temperature.
■■ Relative humidity (RH) is the percentage of how much moisture is present in the air compared to how much moisture the air is capable of holding at that temperature.

HEATING LOAD Heating load is the term used when additional heat is needed. The actual load is the number of BTUs or calories of heat energy that must be added. In a home or office, burning fuel is the usual way to generate heat using coal, gas, or oil as a fuel. In most vehicles, the heat is provided by the heated coolant from the engine cooling system. This coolant is typically at a temperature of 190°F to 205°F (88°C to 98°C) when the engine reaches its normal operating temperature.

EVAPORATIVE COOLING A method of cooling that works well in areas of low humidity is evaporation of water, commonly called evaporative cooling. If water is spread thinly over the extremely large area of a meshed cooler pad and air is blown across it, the water evaporates. For every pound of water that evaporates, 970 BTU (540 calories per gram) of heat is absorbed. This is the latent heat of evaporation, just as when it is boiled. This is a natural process and uses only the energy required by the blower to circulate the air through the cooler pads and on to the space to be cooled. Disadvantages of evaporative coolers, often called "swamp coolers" includes:
■■ increases the relative humidly
■■ not effective in areas of high humidity because the water does not evaporate rapidly enough to be efficient.
At one time, window-mounted evaporative coolers were used in cars. They were not very popular because they

were unattractive and worked well only in dry areas.

MECHANICAL COOLING Another way to handle a cooling load is by the use of mechanical refrigeration, which is called air conditioning. This system also uses evaporation of a liquid and the large amount of heat required for evaporation. The refrigerant boils so that it changes from liquid to gas, but it is condensed back to gas using an engine or electrically powered compressor to move the refrigerant and to increase its pressure in the system.

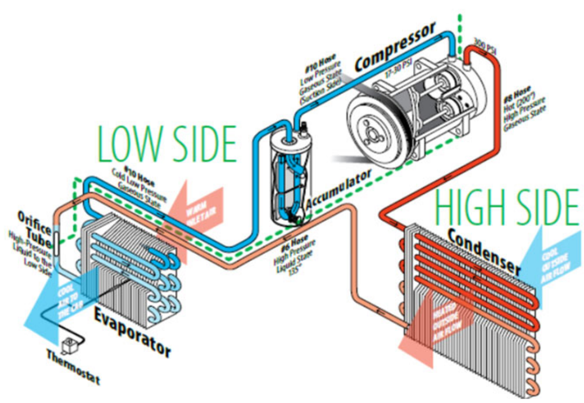


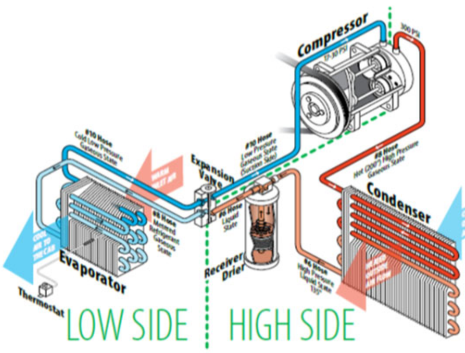
CONTROL OF HUMIDITY Humid cold air feels much colder than dry air at the same temperature.
■■ Humid hot air slows down our natural body cooling system (evaporation of perspiration), so it can make a day feel much hotter.
■■ Air that is too dry also tends to make people feel uncomfortable.
■■ As with temperature, a range of humidity that most people feel comfortable in a relative humidly of about 45% to 55%.

As the air-conditioning system operates, it dehumidifies (removes moisture) from the air. Water vapor condenses on the cold evaporator fins just as it would on a glass holding a cold drink. This condensed water then drops off the evaporator and runs out the drain at the bottom of the evaporator case. In-vehicle humidity is reduced to about 40% to 45% on even the most humid days if the A/C is operated long enough. A good example of this dehumidification process occurs when a vehicle's A/C is operated on cold days when the windows are fogged up. It usually takes only a short time to dry the air and remove the fog from the windows.

CLEANLINESS A side effect of air conditioning is the cleaning of the air coming into the boat as it passes through the cooling ductwork. The act of cooling and dehumidifying air at the A/C evaporator causes water droplets to form on the evaporator fins. Dust and other contaminants in the air that come into contact with these droplets become trapped and are flushed out of the system as the water drops drain from the evaporator. Newer units use a UV light in the A/C and heating systems to clean the air by sterilization.

AC Systems are much like a mother, who uses a sponge to soak up milk from a spilled glass. She soaks it up and then wrings the milk out of the sponge and into the sink. Similarly, an AC system soaks up heat in the cab using evaporation and then squeezes the heat into the outside air using condensation. Let’s take a closer look.
Air conditioners have two basic layouts: the expansion valve system and the accumulator system. We primarily uses the expansion valve system.
With five basic components
1. Expansion device: A restriction in the liquid line of the system, purposely designed to cause a pressure drop.
2. Evaporator: A device that removes heat from the cab air by exchanging it into boiling refrigerant.
3. Compressor: Provides the mechanical energy to move refrigerant and manipulate pressures. This is the heart of the system.
4. Condenser: Designed to exchange heat from the refrigerant to the outside air. Similar to the evaporator.
5. Drier Filter Device: A storage container for extra refrigerant that usually contains a drying agent





LOW SIDE

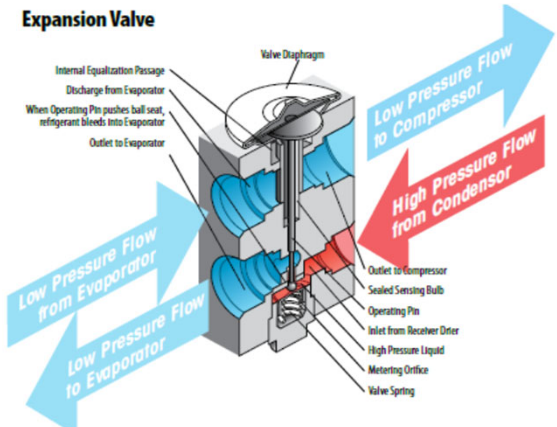
Since the low side has a very low pressure, the refrigerant can begin to boil off into a gas. When the refrigerant changes from liquid to gas it gathers heat from the cab air. The pressure difference is created by an expansion device.

Pressure-Temperature Drop

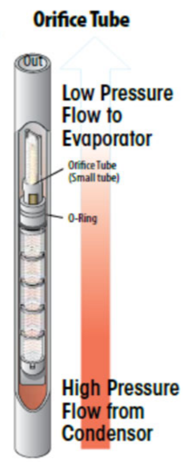
There are two types of expansion device is the component that begins the evaporation process:

1. Thermostatic Expansion Valve (TXV) (left)
2. Orifice Tube (right)

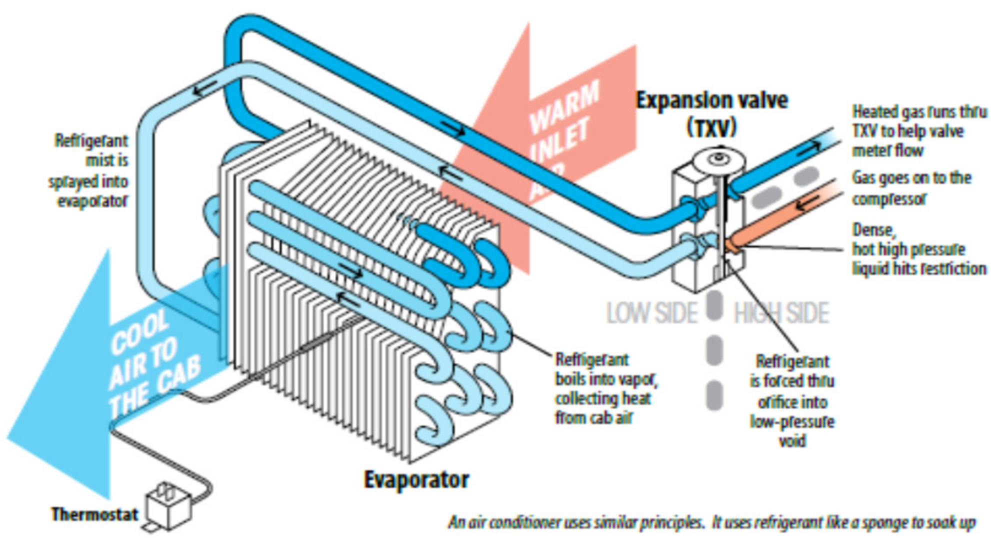
The expansion device creates a pressure drop by restricting the flow of refrigerant around the system. Slowing down the flow of refrigerant causes the compressor to partially evacuate one side of the system. This low pressure void is called the “Suction side” or the “Low side” of the system.



The refrigerant inside of an air-conditioner is essentially a "heat sponge." It very similar to taking a dry sponge and dunking it into a bucket of water. As the water fills the sponge, the sponge expands and becomes heavy with water. Then, when you want to remove the water, you simply squeeze the sponge with your hands and the water comes out.



Cold refrigerant absorbs heat from the cab air while the refrigerant circulates inside the evaporator coil. Heat from the cab air passes through the metal of the evaporator and cause the refrigerant to expand by boiling off into a vapor. This boiling is possible because refrigerants used in AC systems have a boiling point of about one pound per square inch per 1°F. For example, the boiling point of refrigerant is approximately 20°F at 20 psi. As the refrigerant expands by boiling into a vapor, it takes massive amounts of heat with it.



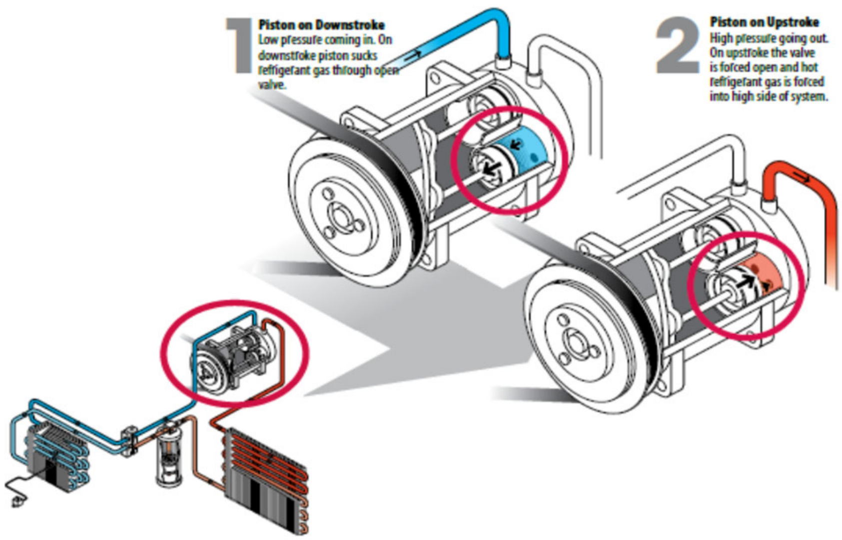
An air conditioner uses similar principles. It uses refrigerant like a sponge to soak up heat (just like a sponge soaks up water). When the refrigerant enters into the thermal expansion valve (TXV) it is essentially a dry sponge. When it passes through the small orifice of the TXV it sprays into the evaporator. As the refrigerant heats up in the evaporator, it expands collecting large amounts of heat, like a sponge expands with

HIGH SIDE

So far, we have learned that the low pressures attract heat into the system by expanding refrigerant. The part of the system that rejects heat into the outside air is known as the high side. It rejects heat by condensing hot vapor into warm liquid and through this process, squeezes heat out of the system. Heat rejection is accomplished using very high pressures (up to 350 psi) and large volumes of air.

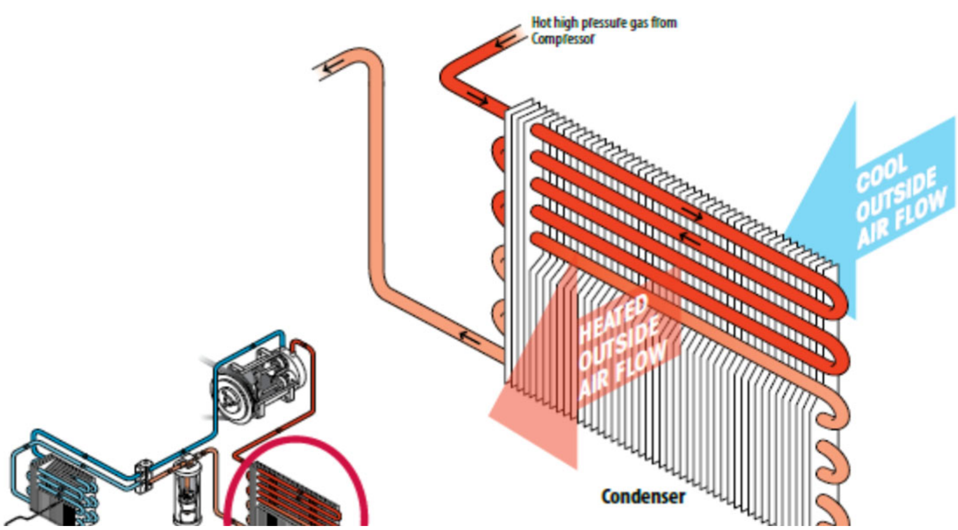
COMPRESSION HEATING

Remember that raising the refrigerant pressure is necessary to begin the process of rejecting heat into the outside air.
On its downstroke (#1 below), the compressor piston collects the expanded refrigerant inside the compressor. On its up-stroke (#2) the piston forces the refrigerant molecules closer together. The refrigerant vapor is raised in pressure, temperature and boiling point before being forced out of the valve plate assembly. The temperature of the vapor is normally two and a half times higher than the temperature of the outside air. Since heat always flows from hot to cold, the refrigerant must be much hotter than the outside air to be able to move heat out of the system



SUB COOLING

The hot, high pressure vapor makes its next stop at the condensing coil. The condenser is just like the evaporator – it is a heat exchanger. It looks a little different from the evaporator because it is more flat and a little larger (an evaporator must fit under the dash). Inside the condensing coil, the gas starts its way from the top to the bottom, cooling down a little with each pass. By the time the refrigerant reaches the lower third of the coil, it cools down enough to change back into a liquid. As a liquid, it continues to cool 15-30°F below its boiling point in a process called "subcooling." Subcooling is an important concept to understand because it will tell what is wrong with the high side of the system. The next modules four, five and six will cover Troubleshooting, Inspection and AC Performance with more detail on subcooling and other topics.



When the expanded refrigerant enters into the compressor, the mechanical force of the piston forces the expanded refrigerant molecules closer together, increasing the pressure (just like when you squeeze a sponge full of water). When the high pressure refrigerant enters into the condenser, the heat is squeezed out into the outside air.

TYPES OF COMPRESSORS

Inside each air conditioning unit is a compressor. The compressor plays the very important role of compressing the refrigerant as it enters the machine in order to increase its temperature. Once heated, the gas leaves the compressor and goes into the condenser so the cooling process can begin. While all AC compressors have the same job, they work in varying ways and offer different pros and cons.

Reciprocating Air Conditioner Compressor

The reciprocating compressor is the most popular type of AC compressor. A piston compresses the air by moving up and down inside of a cylinder. As the piston moves down, it creates a vacuum effect that sucks in the refrigerant. As it moves up, the gas compresses and moves into the condenser. A reciprocating air conditioning compressor is very efficient, as AC units can have up to eight cylinders within the compressor.

Scroll AC Compressor

Scroll air conditioning compressors, like this LG compressor, are newer on the scene. They contain one fixed coil—called the scroll—in the center of the unit, and then there is another coil that rotates around it. During this process, the second scroll pushes the refrigerant towards the center and compresses it. Scroll compressors are quickly becoming as popular as reciprocating compressors because they do not have as many moving parts and are therefore more reliable.

Screw AC Compressor

The screw compressor is extremely reliable and efficient, but it is mainly used in large buildings where there is a vast amount of air that requires continuous cooling. A screw air conditioning compressor contains two large helical rotors that move the air from one end to the other. As the refrigerant moves through the compressor, the space gets smaller, and it gets compressed.

Rotary Air Conditioning Compressor

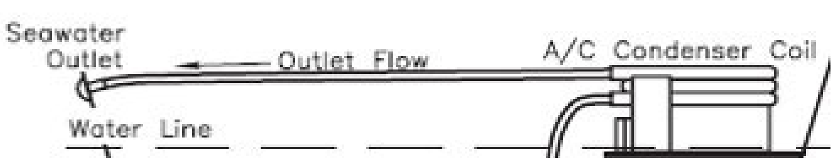
Rotary compressors are small and quiet, so they are popular in locations where noise is a concern. The inside of this type of AC compressor contains a shaft with several blades attached to it. The bladed shaft rotates inside the graduated cylinder, consequently pushing the refrigerant through the cylinder and compressing it simultaneously.

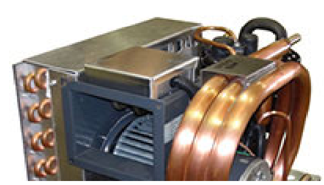
Centrifugal Air Conditioning Compressor

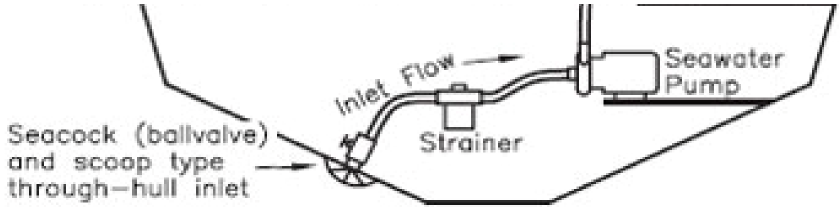
The final type of AC compressor is the centrifugal compressor. As the name implies, it uses centrifugal force to pull in the refrigerant gas and then spins it rapidly with an impeller to compress it. Centrifugal air conditioning compressors are usually reserved for extra large HVAC systems.

Marine Condenser

Unlike traditional air conditioning units, marine AC uses raw seawater instead of air to cool the freon. The freon is pumped inside a copper or titanium tube encased in another tube. Raw water is then pumped in the opposite direction to increase cooling efficiency. Some designs have the freon in the inside tube, a few have the freon on the outside coil.
All units will specify where the raw water should enter and where it should leave to the over-board discharge.

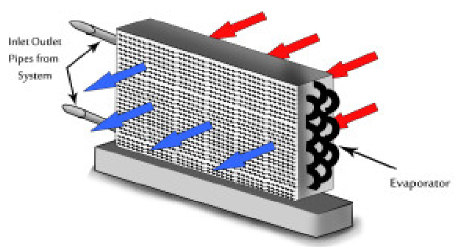






Evaporator

The evaporator removes the heat from the inside compartment. The freon is pumped through a radiator and usually has a fan which blows the inside air across the radiator to cool the air. Specific requirements must be met for supply and return air flow based on the BTU or tonnage of the unit. In a **self contained** unit the condenser, compressor and evaporator are all in one unit. In a **DX** system the compressor and condenser are located remotely from the evaporator. The freon is sent through copper lines between the units.



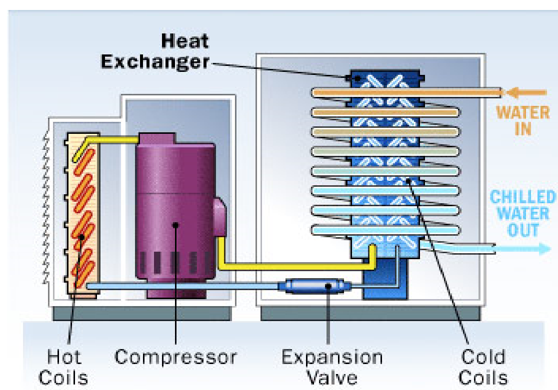
Self Contained

DX System

Chilled Water System

In a chilled water system the heat exchanger cools water in a separated closed loop fresh water supply. The chilled water is then pumped through the boat to each air handler where the fan blows across a radiator filled with chilled water.

Chilled water systems will have two pumps, one for raw water cooling and another to pump the chilled water through the boat.



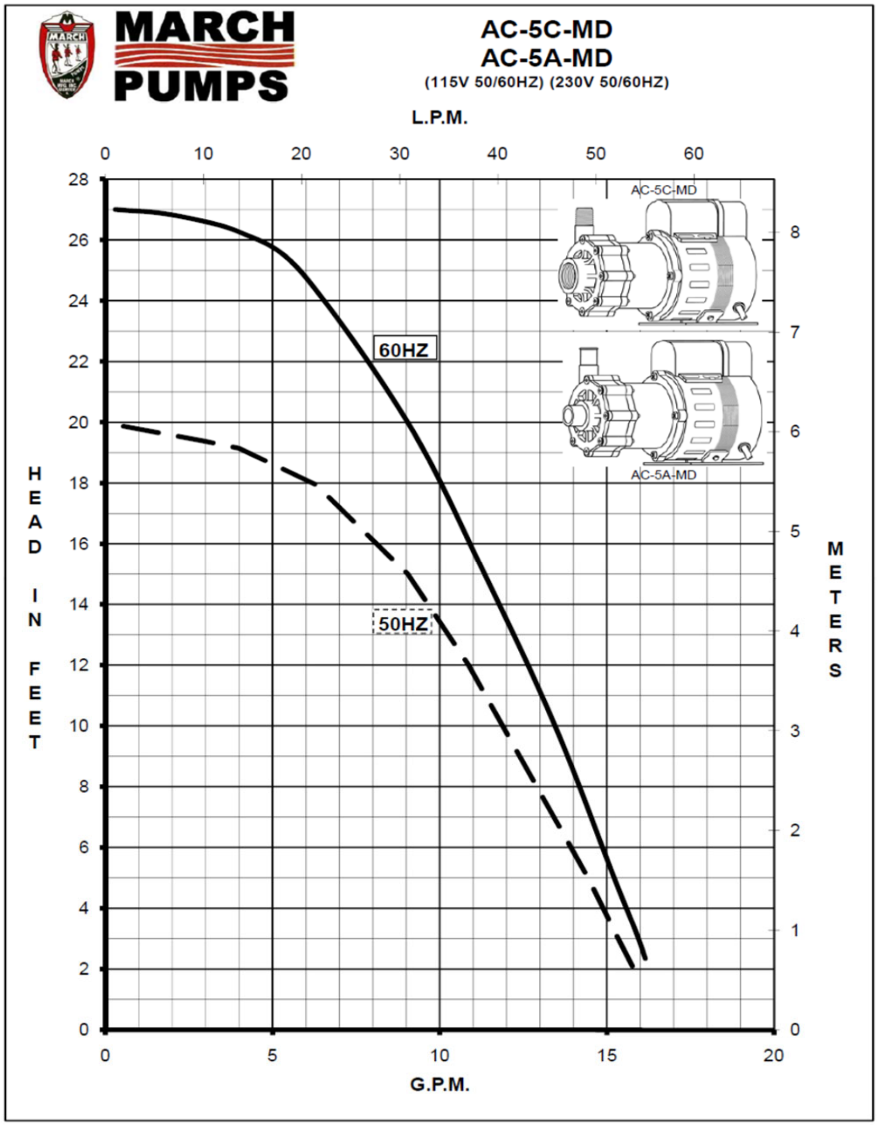
Raw Water Pump

Inadequate raw water cooling is the number one fault with marine air conditioning. Choosing the right pump and installing it correctly is critical. Most raw water pumps are not self priming and must be mounted under the water line. One way to check is to attach a clear hose to the strainer, hold the hose high and see how far the water rises. Be aware the water levels may change, as in a speed boat on plane or a sail boat that heels. All hoses should be marine grade, reinforced and Coast Guard approved. All hardware should be bronze (NOT BRASS). All hoses should be double clamped with a high quality stainless hose clamp. Through hull fittings should be bonded with an 8ga green marine wire.

Determine the required flow for the AC system you are installing. Next select a pump with about 30-50% more capacity than needed. Next determine how high the water must travel from the pump to the AC unit in Ft. If the AC unit is in the salon overhead you may have 10-15 Ft of head pressure.
Determine the total length of pipe or hose being used, add 1ft head pressure for every 10ft of hose.
Add 1ft head pressure for every 90 elbow in the system.
After you total the head pressure, download and compare to the pump curve chart for that pump.
Notice the drastic reduction from 60hZ to 50hZ.

Example: We are installing the pump in the engine room, the unit is in the salon overhead about **15ft** above the AC unit
We will need 20ft of hose or **2ft** of added head rise.
There are three 90 degree elbows needed for us to make the run for **3ft** added head pressure.
Total head rise is **20ft**.

This pump will give us 9GPM or 540GPH
Our 24,000BTU unit requires 480GPH, this pump would actually be on the lite side of what should be used even though it is a 960GPH pump.



Sensors

Many sensors are used for monitoring and control of marine AC systems. A few of the more common ones are:

Temperature sensors, normally two dissimilar metals bonded together that change resistance with temperature changes. These can be tested with a digital multimeter.

Pressure sensors, used extensively to protect the system from high and low pressures, normally will read open or short depending on design.

Flow meters, used to protect units against inadequate water flow. Some are ultra-sonic, most are vane type levers. Again they usually read open or short.