Geothermal Heat Pump Theory

Definition of a Heat Pump

Simply stated a heat pump is an electrically driven mechanical device which absorbs heat energy at one location and transfers it to another. Geothermal heat pumps use the natural heat storage ability of the earth or the earth's groundwater to heat and cool your home or business.

Energy can exist around us in the form of heat, light, mechanical, electrical or chemical energy, and although energy can neither be created nor destroyed, it can be changed from one form to another and moved from place to place. A heat pump derives its name from its ability to "pump" or move heat from one area to another.

Heat pumps do not produce energy by themselves any more than a well water pump can produce water by itself. The well pump needs to be attached to a source of water before it can pump any water. Similarly a heat pump will not produce any heat if not connected to an energy source such as the earth; however, if an energy source is available and the heat pump is able to tap it then vast amounts of energy can be moved at very little cost.

Economics of a Heat Pump

A heat pump can move 3 to 4 times more heat to or from a building than the energy required to operate it.

The energy efficiency of heating equipment can be compared by looking at the rated COP or Coefficient of Performance of the unit. COP is the ratio of energy output to energy input thus a higher COP rating indicates a more efficient unit. The COP of an electric furnace is 1, since each watt of electricity put into it produces the equivalent of 1 watt of heat energy out. The COP of a NORDIC unit is 3 or greater. Each watt the heat pump uses to run its transferring mechanism enables it to draw 2 or more from the earth thus giving a total of 3 or more units out for every 1 unit put in. The heat pump supplies more than 2/3 of your energy requirement from free energy stored in the earth and reduces your heating cost by at least 66%

One of the innovative features of the NORDIC unit is its ability to provide "free" hot water during summer operation. Btu output actually increases during hot water making cycles and the recovery rate is similar to that of a 40 gallon electric hot water heater. Hot water is also provided during winter operation at a saving of 65-70% less than the cost of heating the water with an electric hot water heater.

A typical homeowner can expect this feature alone to save him 20 to 30% of his present electric bill.

Environmentally Responsible

The heat pump is also environmentally friendly since no combustion occurs at the site where it is used. Depending on the source of electrical supply (hydro electric for example) the transmission of energy from the power plant to the home is completely non-polluting to our environment. When the electricity used to operate the heat pump is produced from coal or oil the reduction in air pollution from sulfur and carbon dioxide is reduced by 65 to 75% since the power plant only has to produce 25 to 35% as much power to heat a home as it would if it supplied the same customer using electric baseboard heaters.

Introduction to Heat Pumps

The name heat pump is a relatively new phrase to most people in the heating business and as such the heat pump is viewed as a new innovation to enter the 80's market. However, heat pump is only another manner of saying refrigeration device and we are all familiar with our conditioners, home refrigerators, dehumidifiers, and ice-cream coolers. These devices could also be correctly termed heat pumps since the principle of operation is to remove heat from one place and transfer it to another.

Through common consensus the industry designates a refrigerating device by its method of utilization as either a heat pump or air conditioner. If the prime reason for using a refrigerating device is to produce cooling, then the device is commonly termed a cooler. Similarly, if the prime function of a refrigerating device is to produce heating, then it is commonly called a heat pump. A refrigerating device which can deliver both heating and cooling to a given space is also regarded as a heat pump. For example, take the household refrigerator. It cools the food inside it and delivers the extracted heat to the kitchen via a system of coils at the back of the unit. Nearly everyone has noticed the heat from these coils and perhaps wondered where it came from. All refrigerating devices produce heating and cooling simultaneously. Now that you know we are referring to a refrigerating device when speaking of heat pumps, you will also realize that heat pumps have been around for a long time and are not new technology for the 90's.

The principle of the ``heat pump'' or refrigeration machine was discovered during the 18th century by Lord Kelvin, a prominent British scientist of that age. In 1834, Jacob Perkins, an American engineer, designed an apparatus which artificially produced ice and was the forerunner of our modern vapor compression systems. In 1918, Kelvinator Company marketed the first automatic refrigerator and in 1926, General Electric introduced the first "hermetic" or sealed compressors, a design which is still in use today. During this same period, Carrier Co.

successfully introduced automatic refrigeration units for comfort cooling. Since this time, growth in the industry has been phenomenal. In the future, heat pumps will play an ever increasing role in heating as they have done so long in cooling.

Where does the energy come from?

There are two common sources of energy from which a heat pump could transfer energy:

The AIR around us.
The EARTH beneath us.

Efficiencies of Heat Pumps

The efficiency of a heat pump depends upon the temperature at which it finds its heat **(source temperature)** and the temperature at which it discharges this heat **(sink temperature)**. The greater the difference between the source temperature and sink temperature, the more work is done by the compressor in the heat pump; and consequently, the more cost. In other words, **as the source temperature declines, so will the efficiency of the heat pump**. The prospective buyer will naturally choose the type of heat pump (air source vs. ground source) which gets its heat from the source that remains at the highest temperature for most of the year. During the heating season in our part of Canada (Atlantic Provinces), our mean ground water temperature will remain 47°F (8°C) where the mean winter air temperature is approx. 12°F (-10.4°C). It is for this reason that seasonal efficiencies of a ground source heat pump are much higher than an air source.

Glossary of Terms

Since the following pages will be devoted to the understanding of heat pumps and their applications it will be helpful to become familiar with the following terms:

Heat Pump--A heat pump is any device that moves heat from one place to another.
Heat Source--The area where heat is taken from. (Water, air, etc.)
Heat Sink--The area where heat is deposited. (Inside a home, etc.)
Evaporator--The heat absorbing mechanism in a heat pump.
Condenser--The heat rejecting mechanism in a heat pump.
COP--The coefficient of performance of a heating system is a ratio of the heat we get out divided by the heat we put in electrically.
SCOP--The SEASONAL COEFFICIENT OF PERFORMANCE is the average COP over the entire heating season.
EER -- The ENERGY EFFICIENCY RATIO is the ratio of Btu's of cooling divided by total watts used.
SEER -- Average EER over entire cooling season.

Degree day--the number of degrees that the mean temperature for that day is below 65° F. (eg. mean temp. of 40 for the day--65-40=25 degree days)
CFM--Cubic feet per minute of air flow.
KWH--Kilowatt hours
BTU--British thermal units (method of measuring a quantity of heat). The amount of heat required to raise one pound of water 1° F.
BTU-- WATTS * 3.413
1 WATT = 3.413 BTU'S

Operation of Vapor Compression Systems

Practically all refrigeration systems today operate on the "vapor compression" principle. This term simply means that the heat being removed and transported to another location is accomplished by the alternate evaporation and condensation of a refrigerant usually a man made chemical commonly referred to as a **Freon**. The state of this refrigerant (i.e. whether it exists as a liquid or vapor) is controlled by a compressor which varies the pressure on the refrigerant. To use a simple word picture, the Freon gas which transfers heat in a refrigerating machine or heat pump, has the ability to absorb heat when it changes state from a liquid to a gas much the same way a sponge soaks up water. Similarly, when the Freon changes back into a liquid (in the air coil inside your home) it releases its heat much like wringing out the sponge. It is this process that allows us to absorb heat from ground water, concentrate it through the heat pump system, and deliver it to the home in the form of warm air. To properly grasp the concept, one must bear in mind that the heat pump does not produce heat by itself. It is merely a mechanism that moves heat from one place to another.

Nordic System Operation - (O series) heating

The NORDIC™ passive cooling heat pump incorporates one of the most advanced maintenance free system designs available today. Its simplicity is based on a heating only refrigeration system with direct groundwater cooling coils and domestic hot water generator as built in added features. Most of the parameters which may possibly lead to failure of a refrigeration system have been designed out of the units over the years and those which remain have their functions carefully controlled by internal safety mechanisms.

We can begin the explanation of the actual operation of a heat pump at any point in the system. However, for our purposes, we shall begin at the evaporator. Maritime Geothermal Ltd. uses a counter flow coaxial heat exchanger which is highly resistant to freeze damage. High turbulence created by the water flow makes them relatively self-cleaning, keeping the heat pump in peak operating condition. The layout and design of the water-to-refrigerant heat exchanger is such that our units can maintain a suction pressure equal to most conventional models on less than half the water requirement; or, if equal water is available to each unit, the Nordic™ unit will continue to operate safely on lower temperature water than most competitors. This feature allows the Nordic™ unit to operate in a much more northerly climate without danger of freeze-up. The evaporator is maintained in a 3/4 flooded condition at all times during operation; and, since the suction line is at the top of the evaporator, there is no danger of picking up liquid in this line. Normal suction pressures are in the range of 50 to 60 psig with corresponding evaporator temperatures approximately 30 to 32° F. Once the Freon leaves the evaporator, it is routed to a large suction line accumulator whose purpose is to ensure that absolutely no liquid Freon, which is the # 1 killer of compressors, reaches our compressor. Suction gas temperatures at a point 6" from the compressor are usually in the area of 37 to 39° F giving us a superheat of from 5 to 7° F.

Should the water supply be interrupted for some reason, the Nordic™ unit incorporates a low suction temperature (or pressure) cut-out switch which will automatically shut off the unit before any freeze-up can occur inside the water heat exchanger. Although the low temperature cut-out thermostat is of the automatic reset variety, a lock-out relay prevents the compressor from restarting until either the main power is interrupted or the room thermostat is turned down and then back up again.

The Freon gas travels from the suction accumulator to the compressor which makes the gas more dense and hot by the concentration of a large amount of thermal energy into a small space. The compressor used in a Nordic™ unit is a heavy duty Tecumseh® AV series reciprocating compressor with one of the highest energy efficiency ratios (EER) on the market today. Long life and dependable service can be expected from this compressor since it performs a job much easier on it than what it was designed for. Typical head pressures run in the range of 200 to 250 psig which gives a compression ratio of approximately 3.5 to one. The manufacturer has designed this compressor to work under the much more adverse conditions of an air source heat pump which could often see a compression ratio of 8 to 1, therefore current draw and wear on the compressor when used in a Nordic™ unit is significantly less and results in long service life. Discharge temperatures experienced by the Nordic™ unit are usually between 190 and 200° F. These discharge temperatures are well below accepted standards and there is no danger of internal scoring or breakdown of the oil in the system. From the compressor the hot 198° F. discharge gas enters our tube-by-tube domestic hot water coil which is simply a desuperheater coil that drops the temperature of the dry discharge Freon vapor to approximately 150° F. This domestic hot water generator actually improves the performance of the entire system by initiating slight condensation of the Freon. Operation of the condenser becomes more efficient since all it's surface is wet before it reaches it's actual condensation temperature.

The condenser coil used in the Nordic™ units, has been specially designed to act as a transfer surface for both heating and cooling the household air. The coil has sufficient extra capacity to allow for dirty air filters poor air flow etc, which can produce poor performance until the situation is corrected. The return liquid line is equipped with a large filter-drier to absorb any moisture droplets that may become present in a system. Factory procedures in silver soldering and evacuating our unit will ensure that our systems are clean and dry; however the field technician may not observe all accepted practices when he services the unit, thus admitting contaminants which the filter will catch. Maritime Geothermal Ltd. uses the most efficient expansion system - a TXV to vaporize the return liquid freon. Air distribution is handled by a belt driven blower with a conventional and readily available motor. Unlike some models with direct drive blowers, replacement parts are readily available over the counter in most areas.

Direct Groundwater Cooling - "O" Series

While the NORDIC® proves to be an outstanding performer at heating your home, it becomes even more efficient in the cooling mode.

Most conventional heat pumps provide air-conditioning by reversing the refrigeration cycle, which requires the operation of the main compressor, pump and blower. Power consumption in the cooling mode is the same or higher as in the heating mode. With the Nordic unit however underground water is pumped directly to the air heat exchanger coil. There is no need to operate the compressor which consumes approx. 80% of the power required in the heating mode since underground water below 50°F. is already sufficiently cold enough to provide direct air conditioning.

Central air conditioning and dehumidification is provided for less than 1/5 the cost of a compressor driven system. The capacity of the air-conditioning section in a NORDIC unit can be adjusted by varying the flow of water to the cooling coil while that of a reversible unit is fixed to the capacity of the heating section. This unique feature is important since a reversible heat pump large enough to supply all the heat in a Canadian home will generally be greatly oversized in the cooling mode resulting in short cycling and insufficient dehumidification of the air. Since proper dehumidification of the air is essential in the air conditioning mode, an oversized unit will fail to remove the moisture required leaving the occupants cold and clammy, while the NORDIC unit can be tailored to remove the exact amount of humidity for comfortable living.

Summary

In summary we at Maritime Geothermal Ltd. have produced a system where liquid flooding, high head temperature, moisture, corrosion and excessive pressures are eliminated. We have kept moving parts to a minimum and used the most durable components available. The result is a high quality unit which will perform very satisfactorily for many years and yield energy savings second to no other system on the market today.

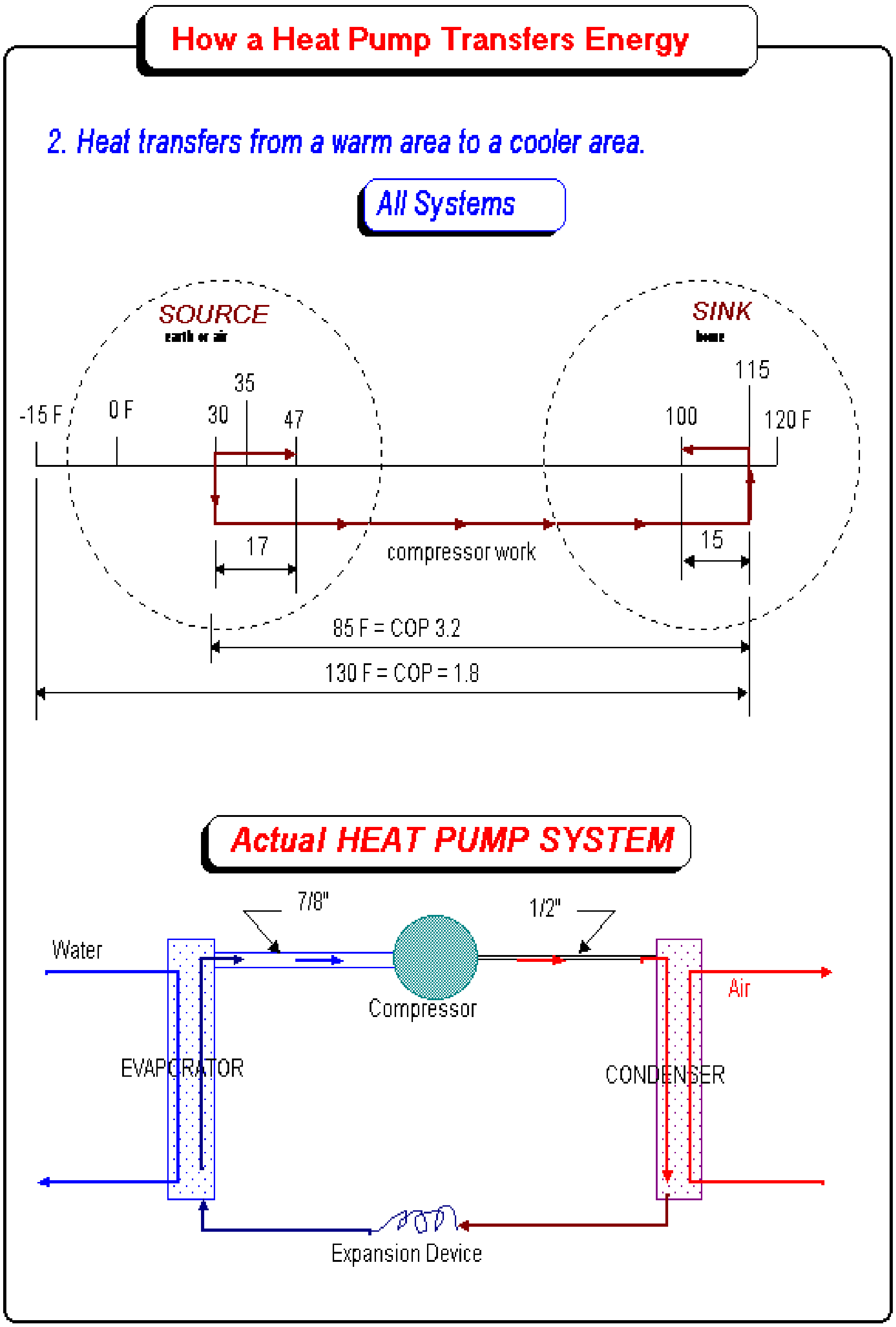
Selecting a Heat Pump for a Particular Region

During the last several years it has become much more common for homeowners to choose a heat pump as the prime heating unit for their homes. Much information is available to the customer to aid him in his decision to choose a heat pump however; information is scarce as to the differences between **air-source** and water-source heat pumps. To grasp the concept of a heat pump in non-technical terms we can consider it to be much like a water pump in its operation.

When a water pump lifts water from one level to another it expends a certain amount of energy. The greater the lift from the source of water to the area where the water is discharged, the more energy it requires to lift it. Similarly, a heat pump transfers heat from a source (well water or outside air) at one temperature to a sink (your home) at another temperature. The greater the difference in temperature between where the heat pump has to find it's heat and the temperature that it has to discharge it's heat the more work the heat pump has to do and consequently the more it will cost the homeowner. One can easily see through a picture diagram that a boy bailing water from a stream and dumping it on the river bank will use less energy than the same boy bailing water and having to climb a 30 foot tree before he can dump the water.

The same situation holds true for heat energy. If we know that we must deliver air to our homes at a temperature of 100° F. to heat it, then every degree we go below that temperature to find a source from which to get our heat makes our system a little less efficient. For example heat pump ``A'' collecting heat from a source temperature of 47° F. and delivering it to a house at 100° F. would be more efficient than heat pump ``B'' collecting heat from a source temperature of 17° F. and delivering it at the same temperature of 100° F. In other words, as the source temperature declines so will the efficiency of the heat pump. It is for this reason that a prospective buyer must look candidly at the geographic area in which he lives when choosing the ``type'' of heat pump.

The prospective homeowner will naturally choose the type (by type we mean AIR-SOURCE or WATER- SOURCE) of heat pump which will get its heat from the source that remains at the highest temperature for most of the year. In Canada that source happens to be the ground beneath us rather than the air. Ground water stays at a relatively constant temperature most of the year and is usually 1 or 2° F. higher than the mean average annual air temperature for any given area. It is for this reason that a water-source heat pump will yield a much higher average annual COP than does a heat pump which gathers its heat from the surrounding air. Typical COP's for a water source heat pump would range from 3 to 3.5 while that of an air-source heat pump, might yield an average COP of 1.7 for the year. The efficiency of a heat pump, which we talked about earlier, is called its COEFFICIENT OF PERFORMANCE or in simpler terms, what we get out for what we put in. A COP of 3.5 means that the heat pump will give 3.5 times as much heat out for a given amount of electricity as the same electricity would give were it converted directly to electric heat.



Effects of wider "Source" and "Sink" temperatures on COP

The COP of any heat pump system is determined by the source and sink temperatures. As seen in part (a) above the greater the distance between "source" and "sink" the lower the COP.

The Nordic heat pump operates like an air conditioner in reverse. Liquid Freon travels to an **expansion device** which lowers its temperature and pressure until it begins to vaporize inside the groundwater heat exchanger or **evaporator.** The warmed Freon gas travels to the **compressor** where it is squeezed into a high pressure hot gas while the chilled water is returned to the earth. The hot gas travels to the air heat exchanger or **condenser** where it condenses and gives up its heat.

A Technical Explanation of COP

From Carnot's experiments and calculations a theoretical equation was established.

$$(1)\ COP\ (carnot) = \frac{Temp\ (high)\ ^\circ\ Kelvin}{Temp\ (high) - Temp\ (low)}$$

All calculations are in Rankine degrees, therefore we must add 460 degrees to every figure we put in the equation. For a room temperature of 72 ° F. on a day when the air temperature was 32 ° F we would have the following equation.

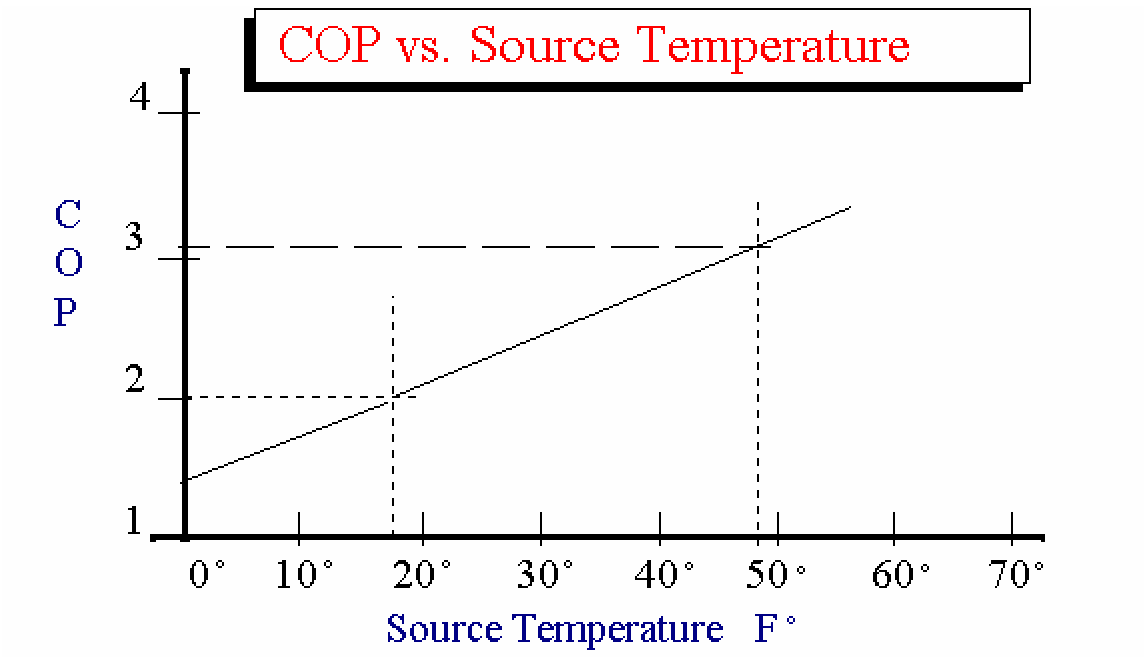
$$COP\ (max\ theoretical) = \frac{(460^\circ + 72^\circ)K}{(460^\circ + 72^\circ)K - (460^\circ + 32^\circ)\ K}$$

$$COP\ (max\ theoretical) = \frac{532}{40} = 13.3$$

As stated above this is the theoretical COP available, however, in actual practice it is found that heat pump efficiency calculations must be based on refrigerant temperature rather than source and sink temperatures. To get heat to transfer from 47 ° F groundwater, the water on the evaporator side (30 ° F) and approximately 100 ° F or 30° F warmer than room temperature to transfer heat to the air in the home. Therefore in the actual equation we must use 30 ° F and 100 ° F as the T (high) and T (low) in equation (1).

(2) COP (less mechanical inefficiencies) = 560°K / (560-490) °K = 560 / 70 = 8

A COP of 8 would be terrific if we could get it, however, due to inefficiencies in the electric motors, compressors, well pumps, etc, we generally end up with a COP corresponding to the bottom line of the graph.



The COP of any heat pump system declines as the source temperature falls.

Typical COP normally attainable

Even with all these inefficiencies a COP of 3 to 4 can generally be maintained under normal conditions of usage thus making the water source heat pump 70 to 80% cheaper to operate than electric heat.

Development to State-of-the-Art today

As little as 15 years ago, heat pumps as a class were relatively poorly designed. Energy efficiency was not a determining factor at the engineer’s drawing board and therefore no great effort was made to produce a heat pump with a high COP. People have become quite aware of the cost of fuel with governments leading the race for self-sufficiency in energy. The result has been a dramatic change in design of heat pumps and their components. Air heat exchangers have gotten larger in surface area so that they don't have to be so hot to transfer their heat to the household air. Water exchangers have gone the same route. The effect is to generally bring refrigerant temperatures closer together, thus raising the COP. Compressors have more efficient designs and greater volumetric efficiency while the newly designed motors that drive them squeeze every BTU/WATT available out of them.

Maritime Geothermal Ltd has incorporated every design innovation to date in an effort to produce one of the most energy-efficient water-source heat pumps available today. Energy costs are controlled by minimizing heat losses or gains and reducing the cost of the energy that must be used to replace these losses or gains. Reducing heat losses and gains accomplished by the addition of insulation, double glass, weather stripping and other standard insulating techniques. Minimizing the cost of replacement energy is accomplished by selecting energy systems that are highly efficient and have reasonable payback periods for anticipated rises in energy costs. Basic fuel costs are based here on the cost per million Btu's and can be calculated for various fuels in the following manner.

Heating value for:

2 Fuel oil ...= 166,000 Btu/Imp. gallon
Propane ....= 110,000 Btu/Imp. gallon
Electricity..... = 3413 Btu/kwh

From the heat content table above, we can calculate the number of Btu's produced by burning a gallon of each fuel if we know the efficiency of the furnace. In other words, how much of the heat contained in a gallon of fuel is USABLE and how much goes up the flue.

Average Efficiencies for Fuel Burning Devices

Oil furnace..........= 65%
Propane furnace. = 75%
Electric furnace...= 100%

EXAMPLE

Cost to produce 1,000,000 Btu's with #2 fuel oil at 65% efficiency.

UBTU (usable Btu's) = Total heat contained/Gal. *Efficiency of furnace
= 166,000 BTU * .65 = 107,900 BTU

Divide the amount of useable heat per gallon (107,900) into the amount of heat you wish to produce (1,000,000 Btu) to find the number of gallons required.
# of gallons required =1,000,000 Btu /107,900 Btu/gal = 9.267 gallons
Multiply the number of gallons required by the present cost per gallon to find the total fuel cost.
gallon required * cost per gal = total fuel cost