

# Heat Pumps

Section 10-6

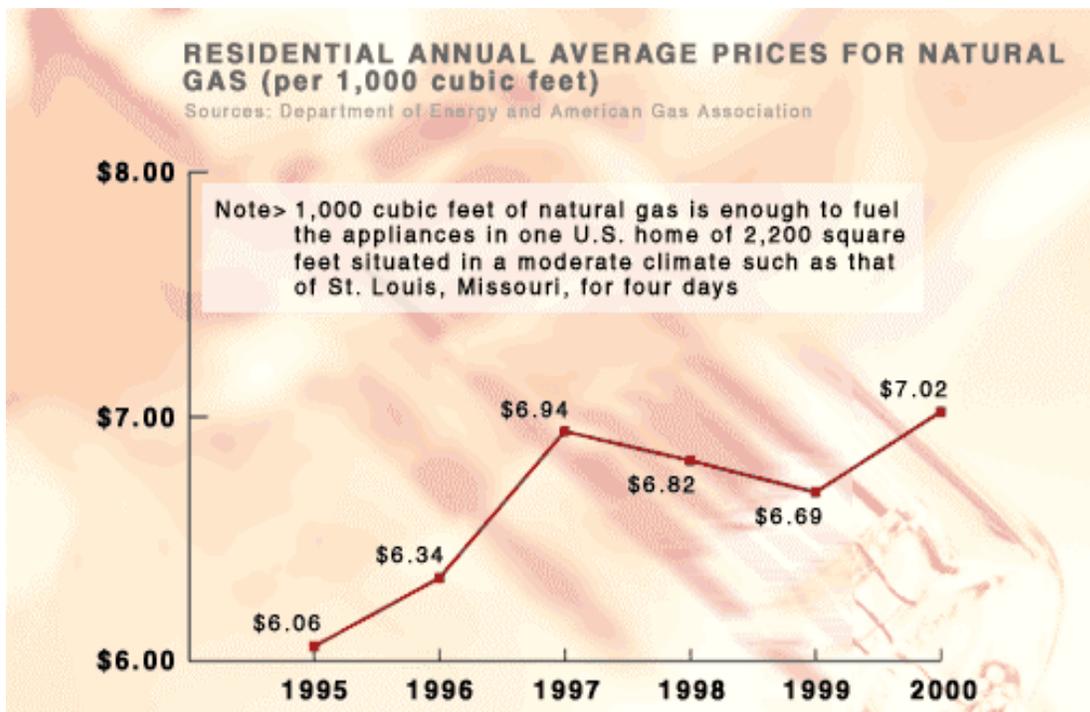
By: Matthew Cloutier

ME 372 Thermodynamics

Instructor: Jesse Adams

Currently many consumers in the U.S. are faced with increasing shortages of electricity and petroleum gas. Figure 1 shows the cost index of natural gas for 2000<sup>5</sup>. Prices have yet to stabilize and continue to increase as the shortages continue. In response to the energy crisis, people are researching ways to conserve energy, reduce the cost of electricity and petroleum gas, and make alternative energy solutions available. Several ways to conserve energy may include turning off extra lights in the house, turning down the thermostat on the heating unit, or turning off the television.

Figure 1 – Price Index of Natural Gas



However, when there is cold weather many people may not be willing to sacrifice their comfort for a couple of dollars in savings. What then can consumers do when faced with high heating bills and the need to stay warm and comfortable? The answer to this may come from alternate heating systems.

One such alternative to current heating systems is called a heat pump. A heat pump is defined as an electrically driven device used to transfer heat energy from one location to another. A heat pump can be used as a heating unit (Figure 2), an air-conditioning unit (Figure 3), or a water heater. Heat pumps are typically used as a heat/cooling unit for houses or building.

There are three main types of heat pumps used for heating and cooling; air-to-air, air-to-water, and air-to-ground. Each system operates in the same fashion except for the way the heat energy is transferred to the sink. A sink is defined as a location where heat energy is dissipated. Heat pumps consist of the following components:

**Compressor** – pump used to push refrigerant through the system.

**Fan** – moves air across coils for heat transfer between the air and refrigerant.

**Condenser Coil** – heat exchanger used to reject heat energy.

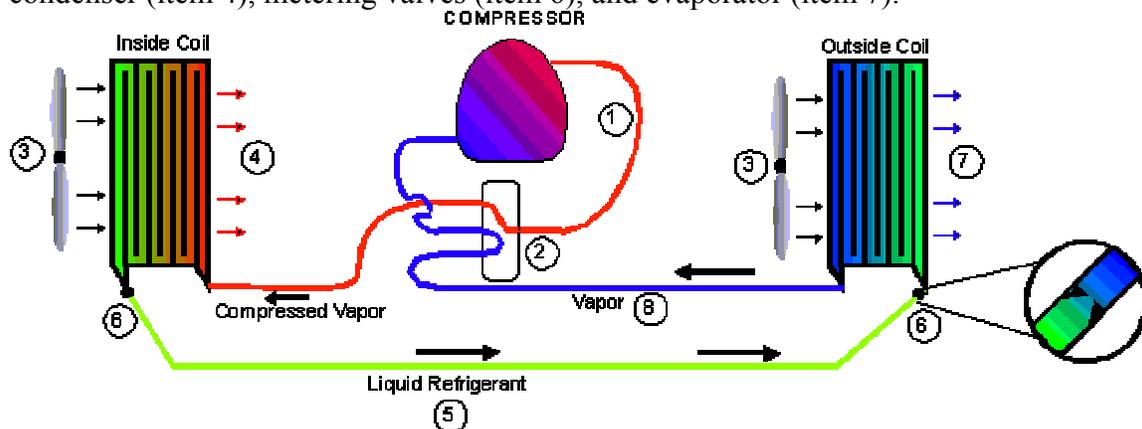
**Evaporator Coil** – heat exchanger used to absorb heat energy.

**Metering Valve** – Controls the flow of refrigerant and allows for phase change from a liquid to vapor.

**Reversing Valve** – Control used to switch between heating and cooling mode.

Figure 2. – Heat Pump Heating Mode

A heat pump consists of a compressor (item 1), reversing valve (item 2), fans (item 3), condenser (item 4), metering valves (item 6), and evaporator (item 7).

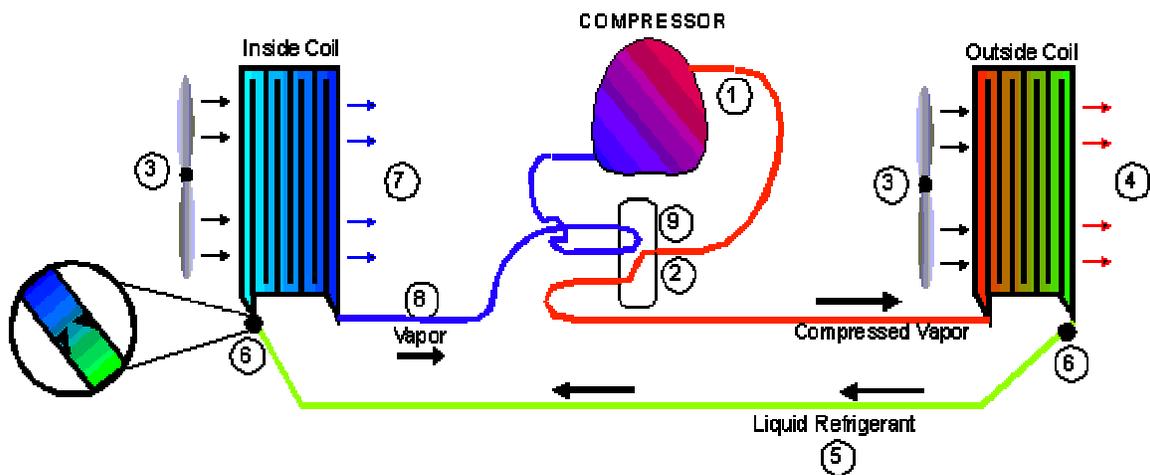


The heat pump uses refrigerant to transfer heat energy. In the heating mode, the compressor pumps the high temperature vapor refrigerant to the condenser coil and cold air is blown over the condenser coil and heat energy is then exchanged. The heated air is then ducted into the house for heating. Once the heat energy is released, the refrigerant cools and condenses from vapor into liquid. The refrigerant passes through the metering valve prior to the evaporator coil. This creates a pressure drop that allows the refrigerant to expand. Once the refrigerant passes through the evaporator, air passes through the coil to further reduce the temperature of the refrigerant and change it back to vapor<sup>1</sup>. The refrigerant returns to the compressor where it repeats the cycle all over again providing heated air to the residence.

When the heat pump is used in the cooling mode, the same components are used, but the flow of refrigerant is in the opposite direction. This reverse flow allows the use of one piece of equipment to perform the operation of both heating and cooling.

Figure 3 – Heat Pump Cooling Mode

A heat pump consists of a compressor (item 1), reversing valve (item 2), fans (item 3), condenser (item 4), metering valves (item 6), and evaporator (item 7)



In the cooling mode, the compressor pumps the high-pressure refrigerant vapor to the reversing valve which directs the flow to the condenser coil. The fan blows cool air and condenses the refrigerant to liquid. Some of the heat energy is released to outside air by the fan as the refrigerant passes through the condenser coil. The liquid refrigerant bypasses the first metering valve and flows to the evaporator coil where it is then metered. The refrigerant absorbs the heat energy from the air blown across the evaporator coil and cools the air as it passes over the coils<sup>1</sup>. This air is then forced through ducts into the house for cooling the residence. The refrigerant in the form of vapor returns to the compressor to start the cycle all over again.

Heat pumps are not limited to air-to-air heat transfer. There are heat pump units that use air-to-water heat transfer. These types of units are used as hot water heaters which are typically found in homes. Instead of dissipating the heat energy to the house, the energy is transferred to a water storage tank. Heat pump water heating systems are three to five times more efficient than natural gas water heaters.

There is another class of heat pumps called geothermal heat pumps. During the summer, soil temperature remains relatively cooler compared to outside temperatures. During winter, soil temperature remains relatively warmer than outside temperatures. Therefore, the heat energy stored in the soil is used for heating and cooling spaces such as residential home or commercial buildings. Geothermal systems use water stored in underground coils or water sources such as wells, storage tanks, or streams. In the heating mode, water circulated through the underground coils absorbs heat energy from the soil. The fluid is then pumped through a heat exchanger located in the heat pump unit. Cooler air from the residence is passed through heat exchanger along with the water. Heat

energy from the warm water is transferred to the cool air supplied from the residence. The warm air is then ducted back into the residence to provide heat. The water then flows back through the underground coil where it picks up heat energy from the soil and begins the process all over again. In the cooling mode, the process is reversed. Water is cooled as it passes through the underground coil. When the water passes through the heat exchanger, heat energy is absorbed from the warm air in the house and cool air is circulated back to the residence. The water flows through the underground coils and heat energy is dissipated while flowing through the cooler soil. Figure 4 is an example of a ground source heat pump. The coils are buried deep underground in both the vertical position as shown or horizontal. Figure 5 is an example of a ground water source heat pump<sup>2</sup>. Because the temperature of soil and underground water supplies do not change very much, the efficiency of geothermal heat pumps is superior to air-to-air heat pumps. The downfall of air-to-air heat pumps is that the coils are exposed to cold temperature. The coils become susceptible to frost, which decreases the heat pump efficiency.

Figure 4 – Geothermal Heat Pump (Ground Source)

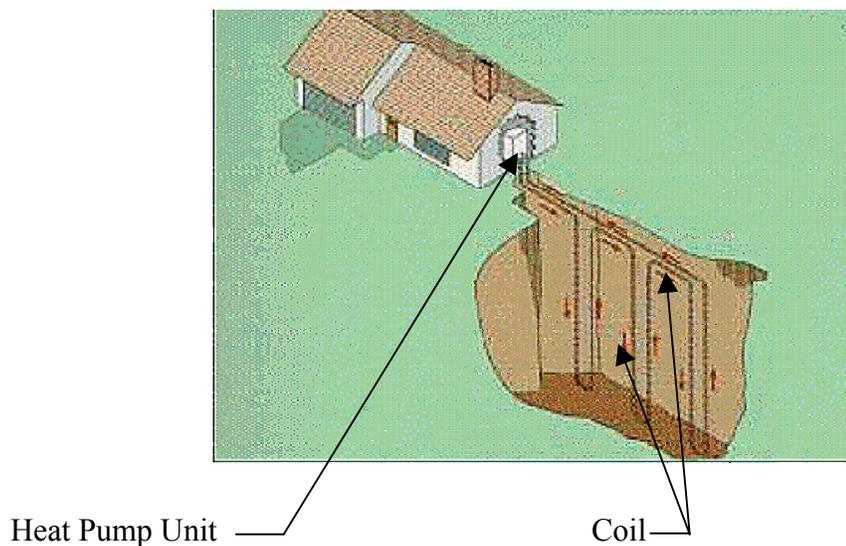
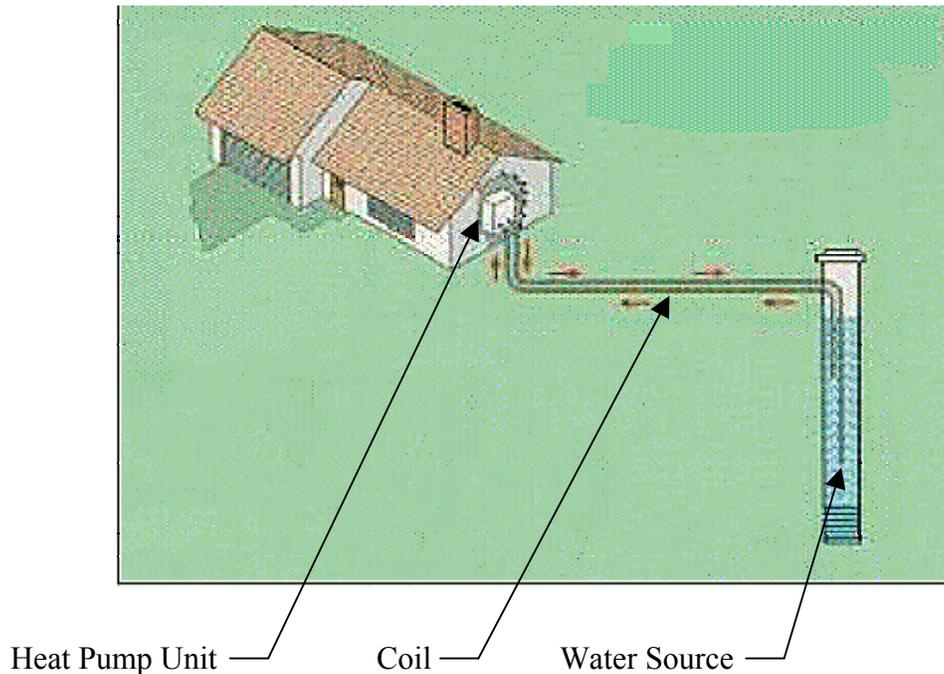


Figure 5. – Geothermal Heat Pump (Ground Water Source)



There are some benefits to be gained with the use of geothermal heat pumps. These heat pump systems are more efficient and cost less to operate than oil, propane, or electric furnaces. Refer to Figure 6, the cost of operation is almost half of current natural gas or resistance heaters that are currently installed in most residential units. Many utility companies offer incentives in order to get more people to switch from traditional heating and air conditioning systems such as natural gas or electric units. Some of the incentives include financial assistance to purchase equipment, rebates on utility bills, low interest loans. Some states even offer generous income tax credits. There are no pollution, odor, or fire hazards with the use of these systems.

Some of the drawbacks of heat pumps include a high initial purchase price, increased installation costs, and efficiency difficulties at low temperatures (20°F to 30°F)<sup>2</sup>. Heat pump systems must be used with electrical resistance back-up heating system due to the operational difficulties at low temperatures. This becomes costly and

defeats the purpose of the heat pump. Another disadvantage is the costly maintenance associated with repairing underground coils.

While a heat pump has its advantages and disadvantages, consumers will ultimately make their decision based on the initial cost and the savings gained. The following is a comparative cost analysis between a heat pump and electric furnace<sup>3</sup>.

|                                       | Heat Pump (2-ton)<br>(air-to-air) | Electric Furnace (15 kW) | Cost Difference |
|---------------------------------------|-----------------------------------|--------------------------|-----------------|
| Installation:                         | \$2500                            | \$1000                   | (+) \$1500      |
| Maintenance:                          | \$50                              | \$20                     | (+) \$30        |
| Energy Consumed:                      | 13,870 kWh                        | 22408 kWh                | (-) 8538 kwh    |
| Energy Cost:                          | \$319                             | \$515                    | (-) \$196       |
| Net saving after installing heat pump |                                   |                          | \$166           |

The net savings would pay for the added cost of the heat pump within nine months of purchase.

Figure 6 – Cost Savings of Heat Pump vs. Gas Furnace

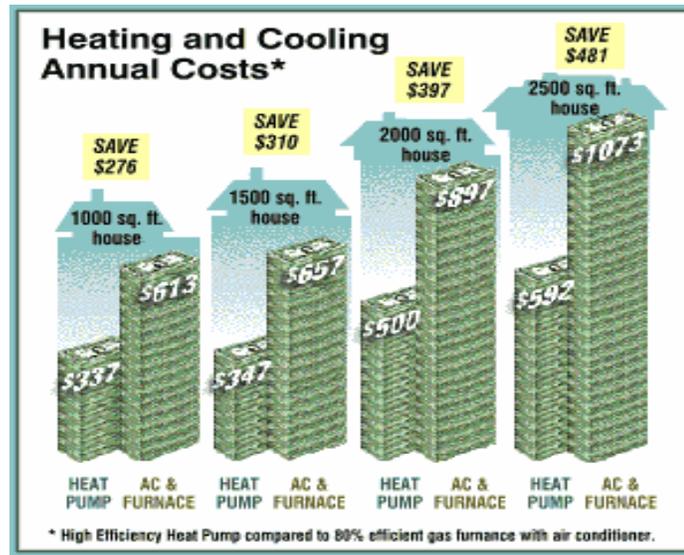


Figure 6. shows the difference between the operating cost of a Heat Pump versus Gas Furnace and Air Conditioning unit. The graph indicated the savings associated with the size of environment that the heat pump must maintain. The data shows that there is a

fifty-percent decrease in the operating cost of a heat pump compared to a gas furnace and air-conditioning unit.

The savings figures alone are not enough to convince consumers to install heat pumps. Many consumers may be skeptical of alternative heating sources due to the lack of popularity. Heating systems run on natural gas and electricity have been inexpensive to operate and have proven reliability. It's only been in the last few months that the consumers have questioned the cost of natural gas and electricity increases. Maintenance of buried coils can be costly or difficult to repair. The main reason heat pumps are not commonly used is because heat pumps may not perform as specified when placed in certain climates. Heat pumps are ideal from climates that do not change drastically. The efficiency of a heat pump depends on the temperature at which it finds its heat (source) and the temperature at which it discharges the heat (sink). The larger the temperature difference between the source and the sink, the more work is done by the compressor in the heat pump; therefore increasing the cost of operation.

When evaluating the efficiency of a home heating or cooling units, there is an important term that is widely used though out the HVAC (Heating, Ventilation, and Air Conditioning) industry, COP (coefficient of performance). Electric (compression) heat pump units, which are typically used for heating/cooling a house, operate with a COP between 2.5–5.0. The ratio of the actual COP of a heat pump and the ideal COP is defined as the Carnot-efficiency, which is express as follows<sup>4</sup>:

Equation #1            
$$\text{COP(HP)} = (\text{Desire output}) / (\text{Required input})$$
$$\text{COP(HP)} = Q_H / W_{\text{net,in}}$$

Equation #2            
$$\text{COP(HP)} = Q_H / (Q_H - Q_L)$$
$$\text{COP(HP)} = 1 / [1 - (Q_H / Q_L)]$$

### Example Problem

A heat pump is used to maintain a house at a constant temperature of 20°C. The energy required to remove heat from the outside air is 5 kJ. The energy required to maintain the house at the desired temperature is 7 kJ. The net work input of the heat pump is 2 kJ. Calculate the COP of the system.

$$\begin{aligned}Q_H &= 7 \text{ kJ} \\Q_L &= 5 \text{ kJ} \\W_{\text{net,in}} &= (Q_H - Q_L) = 2 \text{ kJ} \\COP(\text{HP}) &= 7 \text{ kJ} / 2 \text{ kJ} = 3.5\end{aligned}$$

Note: A heating COP of 3.5 means that the heat energy output of the heat pump is three and half times the electrical input.

As the utility crisis continues, the demand for alternative utilities will rise dramatically. The heat pump may not be the alternative for every application, but it does hold some important advantages over current heating and cooling equipment. Cost and efficiency may be the key factors, which draw customers to the product. The customer can then determine if the system is the right one for their particular needs.

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