AEES–15

ENERGY FACT SHEET

Heat Pumps for Residential Heating and Cooling

Some Questions and Answers

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WHAT IS A HEAT PUMP?

A heat pump is an electrically-powered refrigeration-cycle device which is capable of providing both heating and cooling to a residence. In the summer, it operates like an air conditioner by "moving" heat from inside the house to the outside. In the winter, the refrigerant flow is reversed, "moving" heat into the house by further chilling the already cold outside air and transferring the heat gained in the process to the inside.

HOW DOES A HEAT PUMP WORK?

A heat pump works according to the same principles as refrigerators or air conditioners. In a refrigerator, for example, heat is rejected from inside the refrigerator to the surrounding air. On older models you can actually see the condenser coil on the outside. It is hot when the unit is running because heat from inside is being rejected through this condenser coil.

The basic components of any such system are a compressor, evaporator coils, condenser coils, expansion valve or mètering device, and a reversing valve. Figure 1 shows how the components work together in the cooling cycle of a heat pump. Warm indoor air passes over the indoor evaporator coils and gives up heat to the refrigerant causing the refrigerant to change from a liquid to a cool vapor, or "evaporate". The compressor then pumps the vapor, increasing its pressure to make a hot, high-pressure vapor. When this hot vapor passes through the outdoor condenser coil, heat is given off to the air and the vapor condenses to form a liquid. This hot high pressure liquid passes through an expansion valve, which reduces the pressure, cooling the liquid. The cool liquid refrigerant then passes back through the evaporator and returns to a vapor form, continuing the cycle. Thus, heat has been moved from inside the house to outside, cooling the inside space. The energy required to operate the cycle is the electrical energy which powers the compressor and fans.

When a heat pump is used for heating a home, the refrigerant flow is reversed. The indoor coil now becomes the condenser and the outdoor coil becomes the evaporator (Figure 2). In this mode heat is picked up from the outdoor air by the refrigerant and is moved to the space to be heated. Even though the outdoor air may be 0°F or lower,

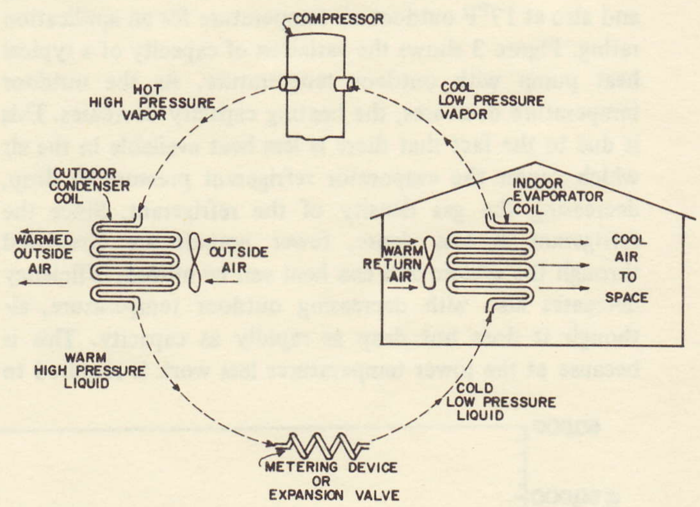

Figure 1.–Heat pump cycle for cooling.

there is still some heat available. Since the refrigerant vaporizes at a very low temperature, some of this heat from the outdoor air can be added to the refrigerant. The compressor pressurizes the cool vapor, which warms it to a usable temperature for space heating. Return air is warmed as it passes over the inside condenser coil, and the refrigerant continues through the cycle.

HOW IS HEAT PUMP CAPACITY RATED?

Heat pumps are rated according to their cooling and heating capacities in BTU's per hour. The capacities for

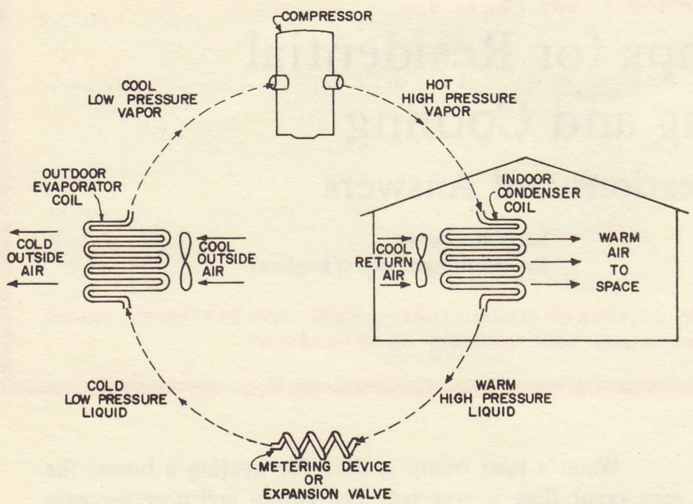

Figure 2.—Heat pump cycle for heating.

heating and cooling are different. They also vary with outdoor temperature. Heating capacities are rated at 47°F outdoor or condenser air temperature for a standard rating and also at 17°F outdoor air temperature for an application rating. Figure 3 shows the variation of capacity of a typical heat pump with outdoor temperature. As the outdoor temperature decreases, the heating capacity decreases. This is due to the fact that there is less heat available in the air which causes the evaporator refrigerant pressure to drop, decreasing the gas density of the refrigerant. Since the refrigerant is less dense, fewer pounds are circulated through the system and less heat can be moved. Efficiency decreases also with decreasing outdoor temperature, although it does not drop as rapidly as capacity. This is because at the lower temperatures less work is required to move the refrigerant through the system, since it is less dense. The S-shaped curve indicates capacity. The straight line represents the change in heat loss of a typical house with temperature. The balance point is where the heat pump capacity is equal to the house heat loss. At outside temperatures below the balance point additional heat must be provided beyond that available from the heat pump if the house is to be kept at the desired temperature.

Cooling capacity is also variable with outdoor temperature, although not as severely, as shown in Figure 4. The variation is less because of the smaller temperature range over which the heat pump operates in cooling. Heat pump cooling capacity is rated at 95°F outdoor air temperature for the condenser coil.

Cooling capacity may also be expressed in tons. Before the era of mechanical refrigeration, ice was used as a cooling medium. A ton of ice melting in 24 hours will absorb heat at the rate of 12,000 BTU/hr. Thus, a heat pump which can remove heat at the rate of 12,000 BTU/hr is referred to as having a capacity of one ton.

HOW IS THE EFFICIENCY OF A HEAT PUMP EVALUATED?

There are several methods of measuring heat pump efficiency. One is the Energy Efficiency Ratio, or EER. The EER is commonly used as a measure of the performance of air conditioners. Since a heat pump acts as an air conditioner when on the cooling cycle, it may also be rated using the EER. The EER is simply the number of useful BTU's of cooling capacity for every watt of electrical energy input required to drive the compressor and fans. For example, if a heat pump is operating on the cooling cycle with a capacity of two tons of refrigeration (24,000 BTU/hr) and is consuming 3,120 watts per hour, including power for fans, the

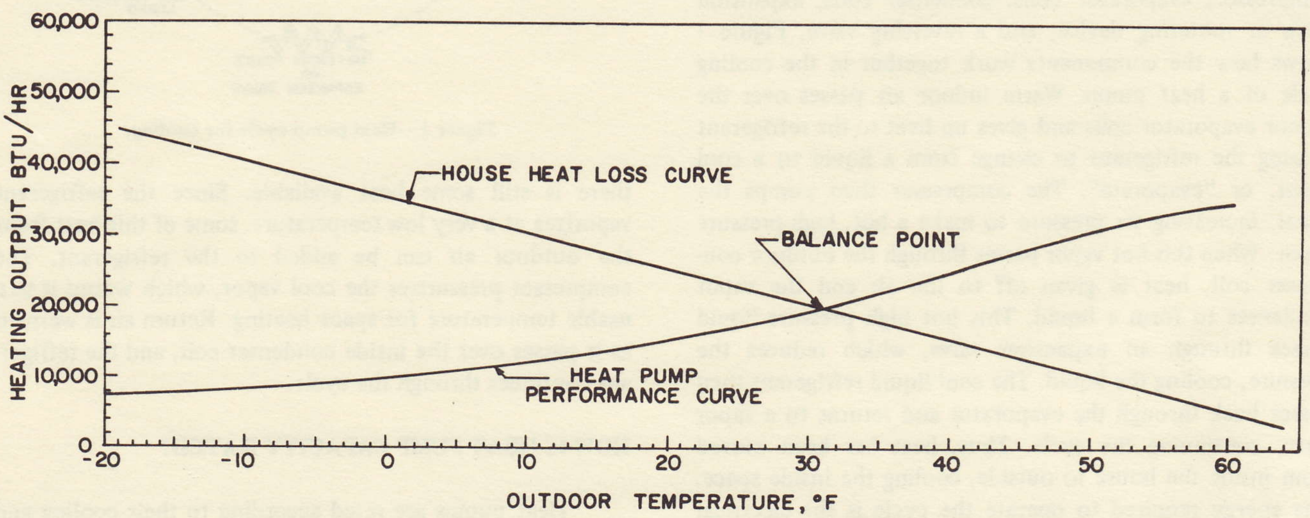

Figure 3.—Typical variation of heat pump heating capacity with outdoor temperature.

EER would be:

$$\frac{24{,}000 \text{ BTU/hr}}{3{,}120 \text{ watts/hr}} = 7.7/\text{BTU/watt}$$

The higher the EER, the more efficient is the unit.

The measure of heat pump efficiency in the heating cycle which has been used for many years is the coefficient of performance, COP. This rating is similar to the EER, except that the comparison is entirely based on BTU's. To determine the COP of a heat pump, the following formula can be used:

$$\text{COP} = \frac{\text{BTU's useful energy pumped}}{\text{BTU's electrical energy input}}$$

To convert the energy input to the compressor and fans to BTU's, we must multiply the wattage by 3.412 BTU's/watt. Thus:

$$\text{COP} = \frac{\text{BTU/hr capacity}}{\text{Unit wattage x 3.412 BTU/watt}}$$

For example, if a heat pump operating at a 40° outdoor temperature has a heating capacity of 25,000 BTU/hr (as in Figure 3) and is consuming 3,660 watts per hour, the COP would be:

$$\frac{25{,}000 \text{ BTU/hr}}{3{,}660 \text{ watts/hr x } 3.412 \text{ BTU/watt}} = 2.0$$

When electric resistance heat is used, it generates 3.413 BTU's of heat for each watt. Therefore, the COP of a resistance heater is one (1.0) and can never be any higher.

Electric resistance heat is produced by the resistance of a coil or wire to the flow of electricity. For example, the heat produced by electric baseboard heaters, the coils on your electric range, or by your toaster is resistance heat. In an electric furnace using resistance heat, air is blown across the coils to warm the air. If the COP of the heat pump in this example is compared with that of resistance heat, it is apparent that the heat pump is more efficient. Under the operating conditions evaluated, the heat pump produces 2.0 times as much heat energy as an electric resistance heater of the same wattage.

Although the heat pump performance looks attractive at 40°F, the COP will drop as outdoor temperature drops. However, it will not fall off as rapidly as the capacity curve of Figure 3, since power input also decreases. Figure 5 indicates the variation of COP with outdoor temperature. Note that at some point the heat pump is no more efficient than an electric resistance heater in producing useful heat, although this point is near the extreme on the scale of winter temperature.

WHAT IS THE SEASONAL PERFORMANCE FACTOR?

The seasonal performance factor (SPF) of a heat pump is an expression of efficiency of the unit similar to the COP. The difference is that the SPF is calculated over the total heating season and includes the portion of the heat supplied through backup electric resistance heat. This has the effect of lowering the SPF from what it would be with a heat pump alone. The SPF varies from slightly above 1.0 (near electric resistance heat) up to typically not more than 2.0, depending upon the installation and maintenance of the unit. Although difficult to estimate, the average SPF of a well installed system is probably in the range of 1.7 - 2.0. An SPF of 1.7 would provide 70% more BTU's of heat output for the electrical energy input than resistance heat alone. This would be a savings of 40% of the total energy used. Of course, the SPF will vary with the severity of the winter, insulation level, quality of construction, type of house and the quality of installation.

DOES A HEAT PUMP FUNCTION AS EFFECTIVELY IN THE NORTH AS IN THE SOUTH?

No. The more severe the winters, the lower the SPF will be. This is due to the fact that the COP of a heat pump decreases as outdoor air temperature decreases, and the

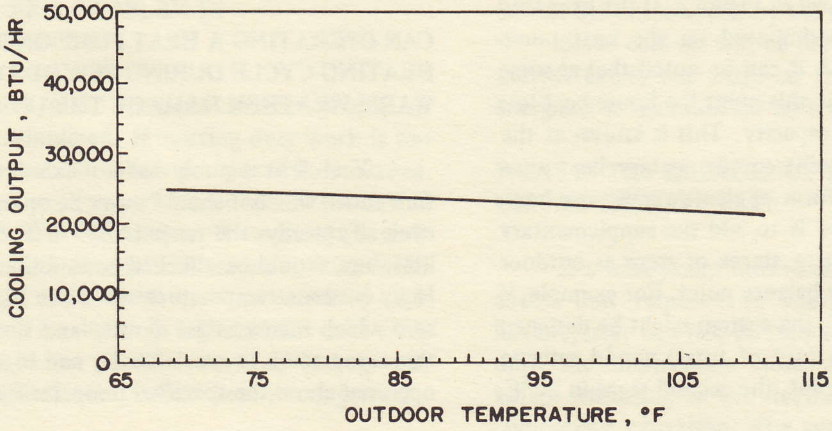

Figure 4.—Typical variation of heat pump cooling capacity with outdoor temperature. This resembles the cooling curve of an equally sized air conditioner.

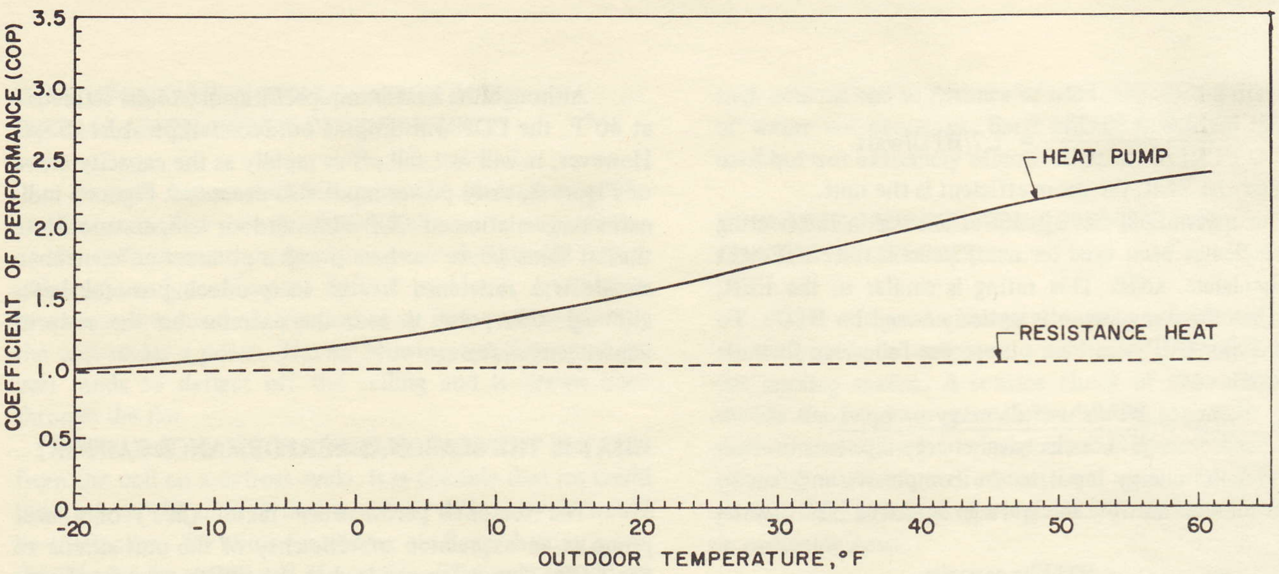

Figure 5.—Typical variation of COP with outdoor temperature. The COP is a measure of a heat pump's efficiency compared to electric resistance heat.

supplementary resistance heat must be used a larger percentage of time.

WHY DO I NEED ELECTRIC RESISTANCE HEAT WITH A HEAT PUMP?

Heat pumps are usually sized for the air conditioning load, since it is generally smaller than the heating load. The reason for sizing the unit based on the smaller load is that the moisture levels in the home can be better controlled in the summer if the heat pump operates over longer periods to cool the home rather than providing relatively short blasts of cold air. Since the unit is sized for the smaller load, some form of supplementary heat must be provided to boost the heating capacity for winter operation; although often a majority of heating hours fall in the range where the heat pump alone can meet the heating requirements.

The capacity of a given heat pump will drop with outdoor temperature, as shown in Figure 3. If the heat load curve of the house is superimposed on the heat pump capacity curve as in Figure 3, it can be noted that at some point the curves intersect. At this point the house heat loss is equal to the heat pump capacity. This is known as the balance point. Below this point supplementary heat must be provided, usually in the form of electric resistance heat.

Recommended practice is to add the supplementary resistance heat in two or three stages or steps as outdoor temperature drops below the balance point. For example, if the balance point is at 32°F, the system might be designed so that the first stage (one third of total) would activate slightly below the balance point, the second stage in 22°F, and the third at 12°F. This would maintain the environment in the house until outside temperature was down to a design temperature of 2°F. The first stage is generally controlled by the indoor thermostat. The other two stages are controlled by thermostats which sense outdoor temperature.

Although the above practice is strongly recommended, often the method of installation is to tie all stages together to the indoor thermostat so that the entire bank of resistance heat is activated if the heat pump cannot warm the home. This will not allow the overall system to operate as efficiently since the total resistance heater bank is called for more frequently. By following the recommended practice of staging the resistance heat in two or three stages, which depend on outdoor thermostats as well as the indoor thermostat, less cycling should be observed, an increased comfort level should be maintained, and the cost of operation will be lowered.

CAN OPERATING A HEAT PUMP ON THE HEATING CYCLE DURING PERIODS OF WARM WEATHER DAMAGE THE UNIT?

Yes! A heat pump has a maximum outdoor temperature above which it should never be operated on the heating cycle. Typically, the range is 70°-75°F. The manufacturer's literature should be checked to find the exact temperature. High outdoor temperature results in high evaporator pressure which increases gas density and flow rate. This causes the compressor to work harder and it may overload when operated above the specified temperature.

WHY DOES THE AIR FROM A HEAT PUMP SYSTEM FEEL COOLER THAN THAT MY OLD FURNACE PROVIDED?

A conventional oil or gas furnace, which burns fuel to produce heat, raises the temperature of the air culculated over the heat exchanger to a relatively higher level than does a heat pump system. The conventional furnace typically delivers 140°F air when the thermostat calls for heat, compared to 90°-100°F air from the condenser on the heat pump system. Since the 140°F air is obviously hot and brings the house temperature up rapidly, the furnace may run for a very short period of time, depending upon the heat need. The heat pump, in contrast, increasing the temperature of the recirculated air in the house only 20°-30°F, tends to feel cooler as the unit gradually adds heat to the home.

IS CHECKING AIR FILTERS IMPORTANT?

Yes! Airflow in the heating cycle of a heat pump is critical to maintenance free operation of the unit. If air flow is reduced due to dirty filters, worn fan motor belts, air returns covered or blocked, or other causes, problems will develop. Reduced air flow causes the condenser coil (the inside coil on the heating cycle) to overheat. This causes the compression ratio to increase and can cause problems in the compressor and also can tend to break down the lubricating oil. The potential compressor problems include a higher amperage draw and thus a higher electric bill and also overheating of the motor windings, which can destroy the compressor if left for long periods. The problems will not be readily apparent, either, due to the fact that warmer than normal air will be circulated to the space, rather than cooler air, in this situation. To avoid these problems filters should be checked and cleaned or replaced often.

CAN DUCT WORK BE A PROBLEM IN MAINTAINING AIRFLOW?

Yes. The ducts must be sized so that proper air quantities can be maintained. If existing duct work is too small, it must be replaced to allow for the airflow needed. Long lengths of duct work not contained within the heated space can be a big source of heat loss. These should be well insulated to reduce that heat loss. Performance can suffer greatly if ducts in an attic, crawl space or unheated basement are not properly insulated. In addition, the duct work should be as air-tight as possible. Any air leakage can increase heat loss and adversely affect heat pump performance.

HOW MUCH AIRFLOW SHOULD BE PROVIDED?

The correct amount of airflow is the amount which will heat or cool the space adequately without being drafty and keep the equipment operating within safe reliability limits. The fan should be sized to provide air-flow in the range of 400-450 CFM/ton. Drafts may be noticeable above 450 CFM/ton. Less than 350 CFM/ton could cause compressor problems in the heating cycle and coil freeze-up in the cooling cycle.

Sometimes drafts are created even with proper air flow due to improper register type or location. If the primary function of the heat pump is heating, high wall locations for air returns should be avoided if possible. Drafts can be created and the heat pump will not operate quite as efficiently as when it draws cooler air along the floor.

WHY DOES MY OUTSIDE UNIT SEEM TO "STEAM" OR "SMOKE"?

During the heating season when outdoor temperatures are below 45°F, frost or ice may periodically build up on the outdoor coil. When frost accumulates in the coil, the amount of air passing over the coil is reduced and the finned surface is insulated by the frost, cutting down on heat transfer. This reduces efficiency. When the efficiency is affected enough to reduce capacity appreciably, the frost must be removed. This is done automatically by reversing the flow of the refrigerant and temporarily operating in the cooling cycle. During this cycle, operation of the reversing valve can be heard, the outdoor fan will stop, the compressor will continue to run and water may drain away from the base pan of the outside unit. After the hot refrigerant which is circulated through the outside coil has melted the frost, the unit will automatically resume a normal heating function. When the outdoor fan restarts, a puff of steam may be blown from the outdoor unit. This is due to water left on the outdoor coil by the melting frost.

Since cool air will be blown into the room during the defrost cycle, one stage of the electric heater is usually energized to maintain the air temperature.

WHAT IS THE EMERGENCY HEAT SWITCH ON THE THERMOSTAT?

If a heat pump fails when the outdoor temperature is above that required to energize the backup resistance heaters, heat will not be supplied to the conditioned space until the thermostats close. In this situation, a manual switch will bring on the electric strip heaters and locks out compressor operation. The system should be operated in this mode only until the heat pump unit can be serviced.

HOW IMPORTANT IS THE LOCATION AND INSTALLATION OF THE OUTDOOR UNIT?

Several factors will influence the placement of the outdoor unit. The unit should be sheltered from prevailing winds. Air recirculation should be avoided. This will reduce efficiency and could cause defrost problems. A common cause is an overhead obstruction of air flow such as locating the unit under a porch. The air blowing out the top of the unit tends to deflect off the ceiling and is drawn back through the fan.

The unit should be placed so that water can drain from the coil on a defrost cycle. It is possible that ice could build up on the unit so that a normal defrost cycle would be ineffective. To allow for proper air flow, drifting snow should also be prevented if possible. The unit should be checked periodically during the winter to make sure there is no ice or snow buildup restricting air flow.

Noise could be a problem if the unit is located near a bedroom. Also, it should be close enough to the house to minimize the length of connections between the outdoor and indoor units.

WHAT ABOUT NIGHTTIME SETBACK OF THE THERMOSTAT?

It is not recommended for heat pump systems. Some energy can be saved through night setback (about 8-10%) in most heating systems. In the case of a heat pump, however, a problem arises when the thermostat is turned back up in the mornings. The thermostat will sense that the temperature is not rising rapidly enough. This will then activate the electric resistance heat and therefore reduce the heating efficiency, negating the positive effects of reducing the thermostat setting.

CAN ZONE HEATING BE INCORPORATED INTO A HEAT PUMP SYSTEM?

It is possible, but only if separate units are used for each zone. Since heat pumps are so dependent on air flow, the registers in each room cannot be shut off individually or performance will be affected. The use of two heat pump units can allow for individual control in two zones, but might involve additional initial expense. However, in some two-story or rambling type houses, the reduction in the duct work required will balance the extra expense.

DO ALL HEAT PUMPS USE OUTSIDE AIR AS THE HEAT SOURCE?

No. Water is also used, although for residential systems air is much more predominant. Wells and other such sources can sometimes be used, although large supplies of water are necessary. Earth-buried coils have also been used but not extremely effectively.

HOW OFTEN SHOULD THE REFRIGERANT CHARGE BE CHECKED?

The refrigerant charge should probably be checked once a year by a competent serviceman, preferably prior to the cooling season. A routine check of filters, belts, etc. should also be done prior to the heating season. In general, maintenance of a heat pump is more critical than it is for other systems. A well maintained unit will give better performance in terms of a higher COP and by saving money in operating costs.

HOW DO I TELL IF MY UNIT IS NOT WORKING?

Obvious situations are those where safety pressure switches or circuit breakers have tripped due to high pressures in the system and/or compressor overload. This may occur when air flow is reduced due to dirty air filters or blocked air registers. It also could be the result of a temporary overload. If the unit repeatedly trips safety devices, then a service repairman should be called.

Some thermostats include a light to indicate when resistance heat is being used. This is a separate indicator from the emergency heat light. If the unit operates on resistance heat for long periods of time on fairly warm days, there may be a problem with the heat pump.

A less obvious problem is when the supply air temperature is either too high or too low. As discussed previously, the supply air temperature will be lower than that of a conventional furnace. Still, it should be at least 10°F above that of the space to be heated. The normal temperature range across the indoor coil is 15°-20°F. This might be checked by using an indoor-outdoor thermometer with the outdoor bulb placed in the supply register while the indoor thermometer is used to measure room temperature. The temperature should be monitored when the resistance heaters are not on and for a period of time to insure that the defrost cycle is not in progress. The problem of supply air temperatures which are too high is more difficult to detect unless the results become apparent in terms of very high temperatures or the tripping of safety switches.

Another test for proper functioning of the heat pump is to simply feel the large line coming into the inside unit. This line should be too hot to hold on to. If it is cool, wait at least 10 minutes and check it again as it will be cool during the defrost cycle.

WHAT FACTORS SHOULD BE CONSIDERED IN COMPARING A HEAT PUMP TO OTHER HEATING SYSTEMS?

The cost of fuel is one major consideration. A heat pump falls somewhere in the midrange of fuel costs. At the present time, natural gas would be cheapest, then fuel oil, heat pump, LP gas, and finally electric resistance heat. Where electricity is the only fuel available, a heat pump has a definite advantage over resistance heat. The initial equipment generally costs more than a conventional heating system, but the heat pump also provides air conditioning in the same unit. Zone heating and night setback of the thermostat are not as practical with a heat pump.

Installation and maintenance are important in the performance of a heat pump system. If qualified individuals are not available to install and service the unit, there may be problems later.

A well installed and maintained heat pump system will be efficient and provide a clean, flameless heat. Particularly where electricity is the only option available and/or air conditioning is desired, a heat pump appears to be a wise choice for heating.

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