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Heat Pump for Heating and Cooling Water for Aquacultural Production[1]

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Aquaculture, a significant industry in Florida, includes the production of ornamental fish, catfish, alligators, oysters, and other aquatic species. The largest portion of aquaculture sales comes from ornamental fish produced primarily in open ponds. Fish are also held and produced in buildings and greenhouses, which often employ flow-through water systems. These systems require large quantities of water and do not provide optimum growing conditions; the energy required to heat these buildings during the winter represents a major production cost.

Some producers are considering indoor recirculating systems, where the only water pumped from the well after the initial filling is makeup water to replace water lost during evaporation and water used to backflush filters. Even these systems require substantial heating during the winter and heating of the make-up well water at other times, since optimum growth temperatures exceed the normal temperature of well water. Cooling is also required during the summer due to heat buildup inside the structure.

HEAT PUMPS FOR HEATING AND COOLING WATER

A heat pump is ideal for this application, since the same mechanical refrigeration system provides both heating and cooling. The heat pump system described here is similar to those used for residential air conditioning systems, except that it is used to heat and cool water instead of air.

A heat pump is a mechanical refrigeration system that pumps heat from the outside to the inside during the winter and from the inside to the outside in the summer. A heat pump operates like an air conditioner working in reverse. An air conditioner removes heat from the air inside a house through an evaporator (cold coil) and discharges it outside through a condenser (hot coil) during warm weather. During cold weather, the heat pump utilizes reversible valves to interchange the evaporator and the condenser. Thus, the hot coil inside and the cold coil outside allow the system to remove heat from the outside and discharge it inside.

A TYPICAL HEAT PUMP SYSTEM FOR HEATING AND COOLING

The system described here uses a typical 2-ton (24,000 Btuh) residential heat pump modified to heat and cool water in the temperature range needed for aquacultural production (Figure 1). Instead of cooling air with an evaporator coil, which is usually located inside the duct system in a residential application, this system uses a copper coil made from copper tubing and located in the water tank. Since copper is toxic to fish, the copper tubing is painted with black epoxy enamel. This coil utilizes two 50-foot circuits of 3/8-inch copper tubing, which cools the water in warm

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weather and heats it in cool weather. Since the temperature range required for aquaculture production is different from that required for residential air conditioning, the 2-ton compressor in the heat pump must be replaced with a 1-ton compressor. This allows the capacity of the compressor to match that of the outside coil, a condition necessary to create the operating temperatures used in aquacultural production. Temperatures are most critical in the cooling mode. If the size of the compressor were not reduced, the outside coil (condenser) would overheat in the cooling mode. Reducing the size of the compressor is easier than increasing the size of the condenser and has the additional advantage of enhancing system efficiency. The system also must be equipped with an automatic switch-over thermostat with separate temperature settings for heating and cooling. The difference between the high- and low- temperature settings, which constitutes the neutral zone, must be determined by the production requirements of each fish species.

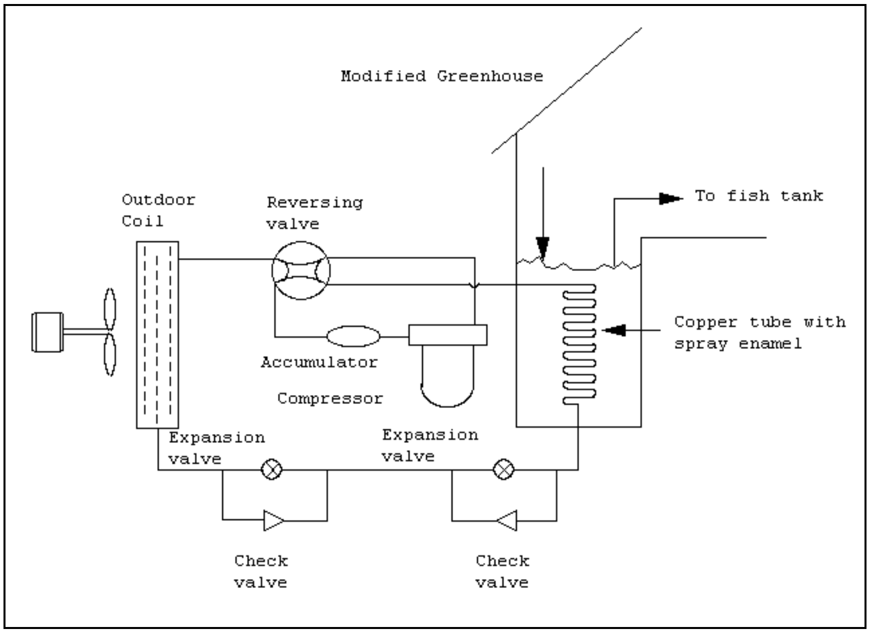

Figure 1. Heat pump system used for heating and cooling in aquaculture.

The heat pump system in this example is installed in a 20 x 30-foot inflated double-poly greenhouse that has been sprayed on the outside with a heavy coat of white paint. Black polyethylene film has been placed on the inside roof of the greenhouse to further reduce the solar load. Another option would be to use white-painted black polyethylene on the outside; however, the white paint has a tendency to peel unless the black polyethylene is treated prior to painting. An exhaust fan, set to operate when the inside temperature exceeds 80°F, provides ventilation for the structure.

PERFORMANCE AND ENERGY EFFICIENCY

In the heating mode, the system produces approximately 18,000 Btuh when the water temperature is 80°F and the outside temperature is 50°F. The power required to operate the system under these conditions is 1.1 kW. This corresponds to an energy efficiency ratio (EER) of 16 Btuh/kW, which represents nearly five times the efficiency of electrical resistance heating. Since it is more difficult to extract heat from air as the temperature is lowered, however, the output of the air source heat pump varies considerably with ambient temperature. Figure 2 shows the performance of this system as a function of ambient temperature; it also demonstrates how the performance of the same unit would change if the air source outdoor coil were replaced with a water source coil using well water (or water from another source) at 72°F. These data are based on a fish tank temperature of 80°F. The advantages of the water source heat pump can be seen clearly in Figure 2. Not only does the pump's capacity remain almost constant for varying ambient conditions, it results in a significant increase in unit efficiency. In the air source heat pump, reduced capacity for lower ambient temperatures is compounded by the need for more heat in cold weather. For most air source heat pump applications, additional heat needed in cold weather is supplied by electric resistance heaters, which are very inefficient. Although it is difficult to obtain water source heat pumps with very small capacities and often impossible or impractical to obtain water for this use, water source heat pumps should always be considered.

HEATING WATER

As indicated earlier in this document, a heat pump's low temperatures (in the 80°F range) make it a very good choice for aquacultural production. The higher the required temperature, the less efficient a heat pump becomes. This is not true for other types of heating systems, such as those that use electric resistance, gas, or oil.

Gas and oil are usually considered to be the least expensive methods of heating water. For low temperature applications, however, a heat pump, particularly a water source heat pump, is less expensive. In Table 1, the costs of raising the temperature of 10,000 gallons of water 10°F are compared for several water-heating methods.

In the demonstration unit described here, the fish tanks contain 500 gallons of water, as do the sump and other components. The estimated annual heating requirement for such a system in Gainesville, FL is approximately 22 million Btu, using 1,300 kWh of electrical energy. At 8 cents per kWh, the annual heating cost would be approximately $100. This represents a savings of approximately 5,000 kWh over the use of electrical resistance heating, or approximately $400 in operating costs.

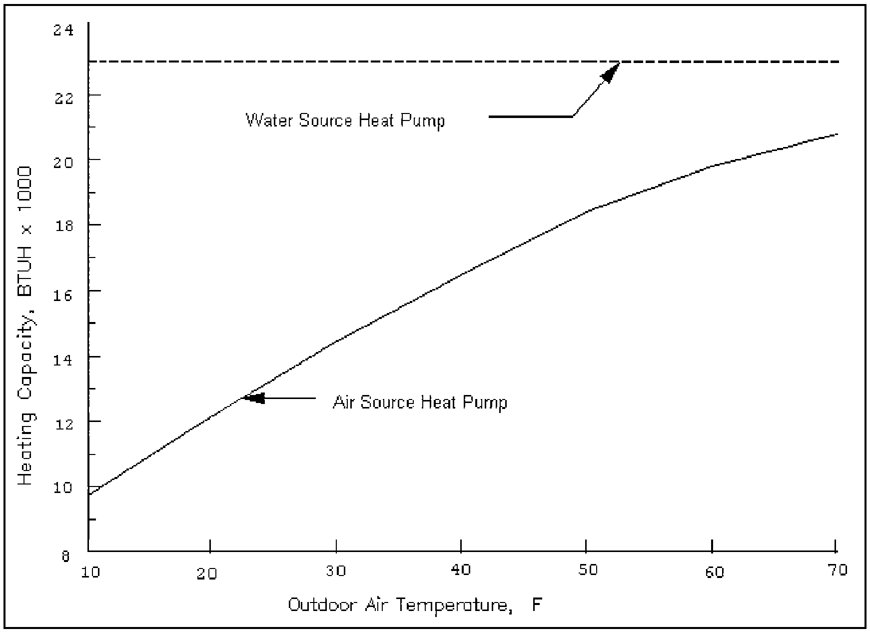

Figure 2. Performance of air source and water source heat pumps.

This air source heat pump system maintains water in the fish tank at temperatures ranging from 80°F to an ambient temperature of approximately 40°F. Therefore, some supplemental heat, such as that provided by electrical resistance heaters, is also necessary. If a water source heat pump were used, supplemental heat would not be needed. Nevertheless, electrical resistance heaters or other sources of emergency heat should be available for use during periods of extremely cold weather or mechanical failure. Lowering the water temperature to a level below 80°F is an option some producers may wish to consider. Insulating the greenhouse structure or using a well-insulated conventional structure would also significantly reduce the heating requirement for such a heat pump system.

COOLING WATER

As previously stated, a heat pump can also be used to cool water. To enable it to perform this function, the system is automatically switched from heating to cooling by the thermostat and reversible valves, as shown in Figure 1. In some applications, both heating and cooling are needed on the same day. How frequently this occurs will depend on the temperature range represented by the distance between the high and low settings on the thermostat. Obviously, the difference between these settings (i.e., the neutral zone) should be as large as the fish can tolerate without undesirable temperature stress. If the thermostat has a very small neutral zone, some means of storing heat should be considered for the system, such as increasing the water capacity, incorporating more mass in the structure, etc.

In the cooling mode, a heat pump operates more efficiently for aquacultural production than for conventional air conditioning because tank water is normally maintained at a higher temperature than air in air conditioned buildings. The cooling capacity of the system is approximately 18,000 Btuh with a fish tank temperature of 82°F, which requires approximately 1.4 kW at an ambient temperature of 90°F. The heat pump's capacity is less variable with ambient temperature than in the heating mode, since the evaporator coil (cold coil) in the fish tank sump is maintained at a relatively constant temperature. A change in evaporator temperature causes a change in the density of refrigerant vapor which, in turn, produces a change in the flow rate of refrigerant through the system. Lower temperatures in the evaporator result in a lower cooling capacity, and the effect of ambient temperature is a significant change in the power requirements for compressor operation. Thus, a water source heat pump is also much more efficient than an air source heat pump for cooling, since well water at 72°F is much cooler than the average ambient temperature during cooling. A water source heat pump is usually about 20% more efficient than an air source heat pump in the cooling mode.

Table 1. Compared costs for heating 10,000 gallons of water 10°F.

Water Source Heat Pump	Air Source Heat Pump	Natural Gas	#2 Fuel Oil	Propane Gas	Electric Resistance
$3.18	$4.06	$6.10	$9.20	$15.06	$19.42
Electricity $.08 per kWh; natural gas $.60 per therm; #2 fuel oil $1.10 per gallon; propane $1.25 per gallon.					

SUMMARY

If the systems used in ornamental fish production are converted from flow-through to recirculating systems, some type of heating and cooling will be necessary. A heat pump system can provide both heating and cooling and, for temperatures required in aquacultural production systems, represents the least expensive method of heating. It is also the most energy efficient, with approximately six times the efficiency of electrical resistance heating when a water source heat pump is used. While the initial cost of the system is significantly higher than that of other heating options, this cost can be justified on the basis that mechanical refrigeration is also needed for cooling.

When selecting a heat pump for aquacultural applications, producers should carefully match the capacities of the compressor, condenser, and evaporator to ensure that the compressor is not overloaded and that high efficiencies (EER) can be obtained. Providing an adequately insulated production structure and increasing thermal mass by incorporating additional water storage capacity or structural mass will also increase the overall efficiency of heat pump systems.