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Evaporative Cooling System for Aquacultural Production[1]

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INTRODUCTION

Florida aquaculture sales totaled $54 million in 1991. This included sales of ornamental fish, catfish, alligators, oysters, clams, and other aquatic produce. The ornamental fish industry accounted for the largest portion ($32.8 million) of the sales. Most of the aquaculture production in Florida takes place in open ponds. These ponds are relatively inexpensive but have problems with loss of fish during cold weather and with predators. Water recirculating indoor facilities offer a method of production that avoids these disadvantages and offers the advantages of decreased water and energy use. A recent study reported in Agricultural Engineering Extension Report 92-6, entitled "Heat Pump for Heating and Cooling Water for Aquacultural Production" demonstrated that a heat pump can be used to effectively heat and cool water for aquacultural production. However, due to the heat build up in the greenhouse type structure, considerable mechanical refrigeration is required. This refrigeration can be expensive and would require considerable energy consumption if several months of cooling were required.

An alternative to mechanical refrigeration is evaporative cooling which has the potential for cooling water for aquacultural production during most of the cooling season. The principles of evaporative cooling systems, such as those used for cooling water in commercial air conditioning systems (cooling towers), are well established but are not yet used to cool water for the lower temperature range (80°Fs) used for aquacultural production.

HOW EVAPORATIVE COOLING WORKS

Evaporative cooling occurs when water is brought in contact with air that has a wet bulb temperature lower than that of the water. As the air and water remain in contact, the heat required for evaporation is taken from the water and the air causing both the water and the air to be cooled. Therefore, evaporative cooling can be used to cool water (e.g., cooling towers for commercial air conditioning) or air (e.g., evaporative pad cooling for greenhouses). For the system described here, evaporative cooling is used to cool both water and air. The amount of cooling that can be accomplished through the evaporative process depends on the humidity level of the air -- the dryer the air, the greater the evaporative cooling potential. However, the water and/or air can not be cooled by evaporative cooling to a temperature lower than the wet bulb temperature of the air. The wet bulb temperature can be measured by placing a wet wick over a thermometer and blowing air across it. For example, on a day when the dry bulb temperature

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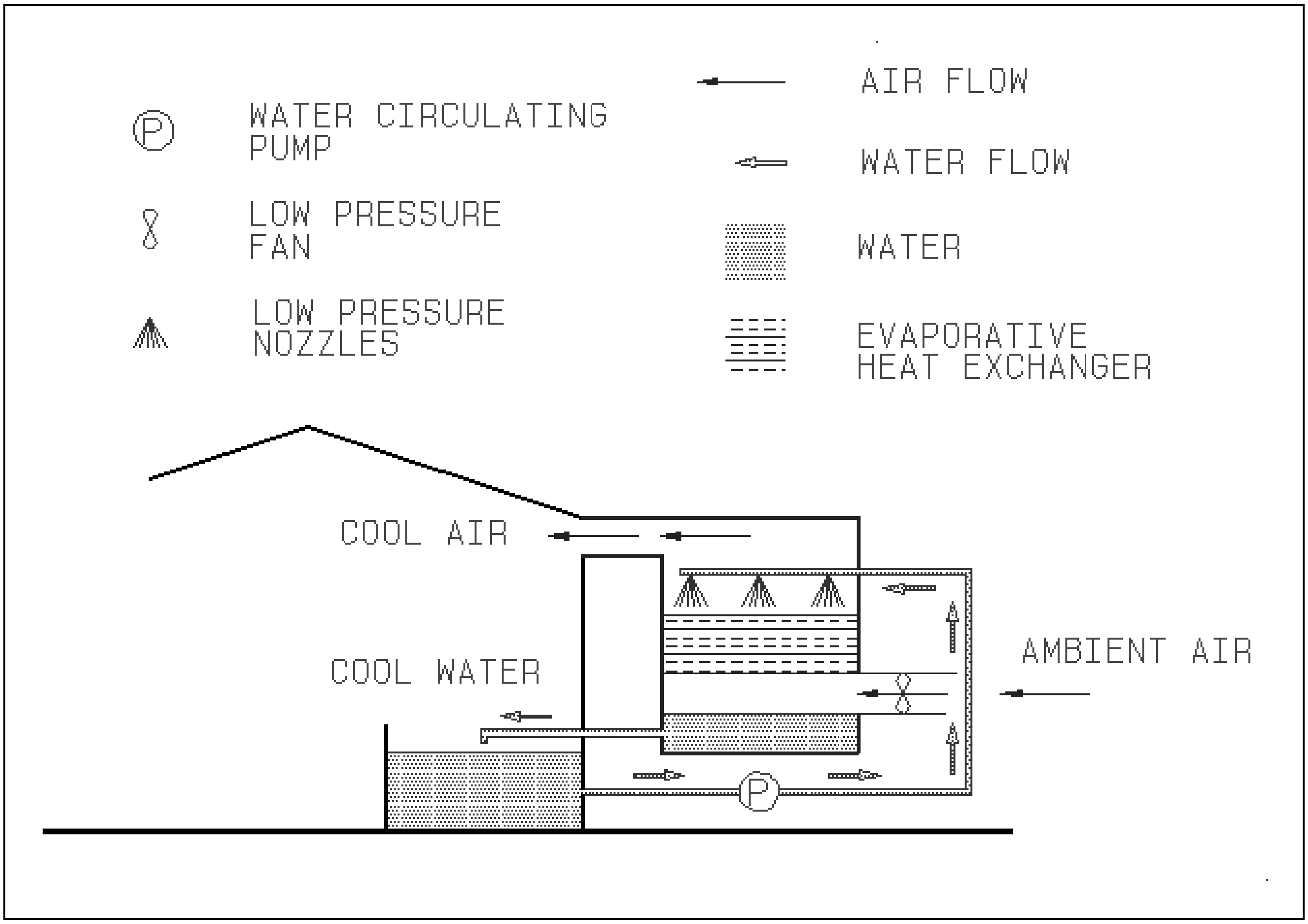

Figure 1. Evaporative cooling system for aquacultural production.

is 95ºF and the relative humidity is 50%, the corresponding wet bulb temperature is 79ºF -- the lower limit for evaporative cooling.

DESCRIPTION OF EVAPORATIVE COOLING SYSTEM

An evaporative cooling system was installed on the small scale demonstration facility for energy efficient ornamental fish production, located at the University of Florida, Energy Research and Education Park. The evaporative cooling system consisted of low pressure spray nozzles, a water-to-air heat exchanger, a water circulating pump and a fan (Figure 1). The heat exchanger was made from polypropylene lines wrapped around layers of wood strips to form a matrix of monofilament lines precisely spaced both vertically and horizontally, containing 2200 linear feet per cubic foot of packing section. Water was sprayed from the nozzles and trickled down over the lines while ambient air was moved upward past the droplets of water. This resulted in a very economical and effective counterflow heat exchanger that could cool water and air to approximately the wet bulb temperature of the outdoor air.

The design wet bulb temperature for Florida, as given in the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) Handbook, ranges between 79-80ºF; the wet bulb temperature does not exceed 80ºF more than 2.5% of the time. Since the desired fish tank temperatures (80-83ºF) are usually above the wet bulb temperature, evaporative cooling systems can be used for cooling water for aquacultural production systems as well as cooling the air inside the aquacultural production structure.

For the 500-gallon fish tank system used in this demonstration, a 1/6 hp pump was required to circulate water at a rate of 12 gallon per minute (gpm) against a 20-foot head through the 2.8 x 2.8 x 2 foot deep heat exchanger. A 1/3 hp fan was required to move outside air through the heat exchanger at a rate of 2500 cubic feet per minute (cfm) and discharge it into the 20 x 30 foot

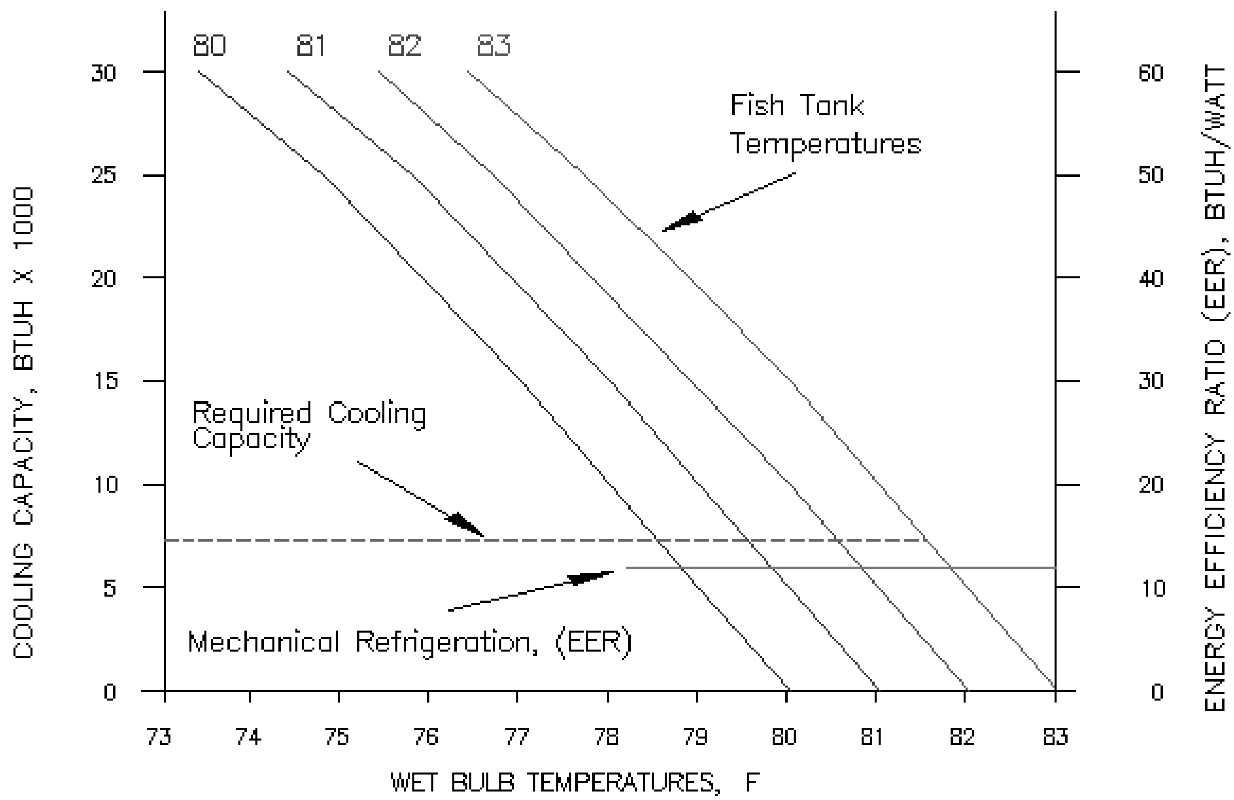

Figure 2. Typical wet and dry bulb temperatures for Florida summer conditions.

greenhouse.

PERFORMANCE OF EVAPORATIVE COOLER

Heat gained by fish tanks and piping was calculated to be about 6,000 British thermal units per hour (Btuh) for a 15ºF temperature difference between the greenhouse temperature and the fish tank temperature. Heat gained from the circulating pumps brought the total heat gain to be about 8,000 Btuh. The evaporative cooler had to remove 8,000 Btuh from the water in order to maintain the fish tank water at the desired temperature.

The performance of the evaporative cooling system is based on data collected from the demonstration system described above (Figure 2). It is seen that the evaporative cooler produced the 8,000 Btuh of cooling required (dashed horizontal line) even when the ambient wet bulb temperature was as high as 78.5ºF with an 80ºF fish tank temperature. If the fish tank was allowed to rise to 83ºF, the evaporative cooler could accomplish the cooling when the wet bulb temperature was as high as 81.5ºF. Wet bulb and dry bulb temperature data measured under Florida conditions in July showed that the wet bulb temperature exceeded 81ºF for only a few hours during a typical three-week period (Figure 3). The wet bulb temperature fell to at least 75ºF on nearly every night. This indicated that the evaporative cooler system should provide for adequate cooling if the particular fish being produced can tolerate the fluctuations in temperature.

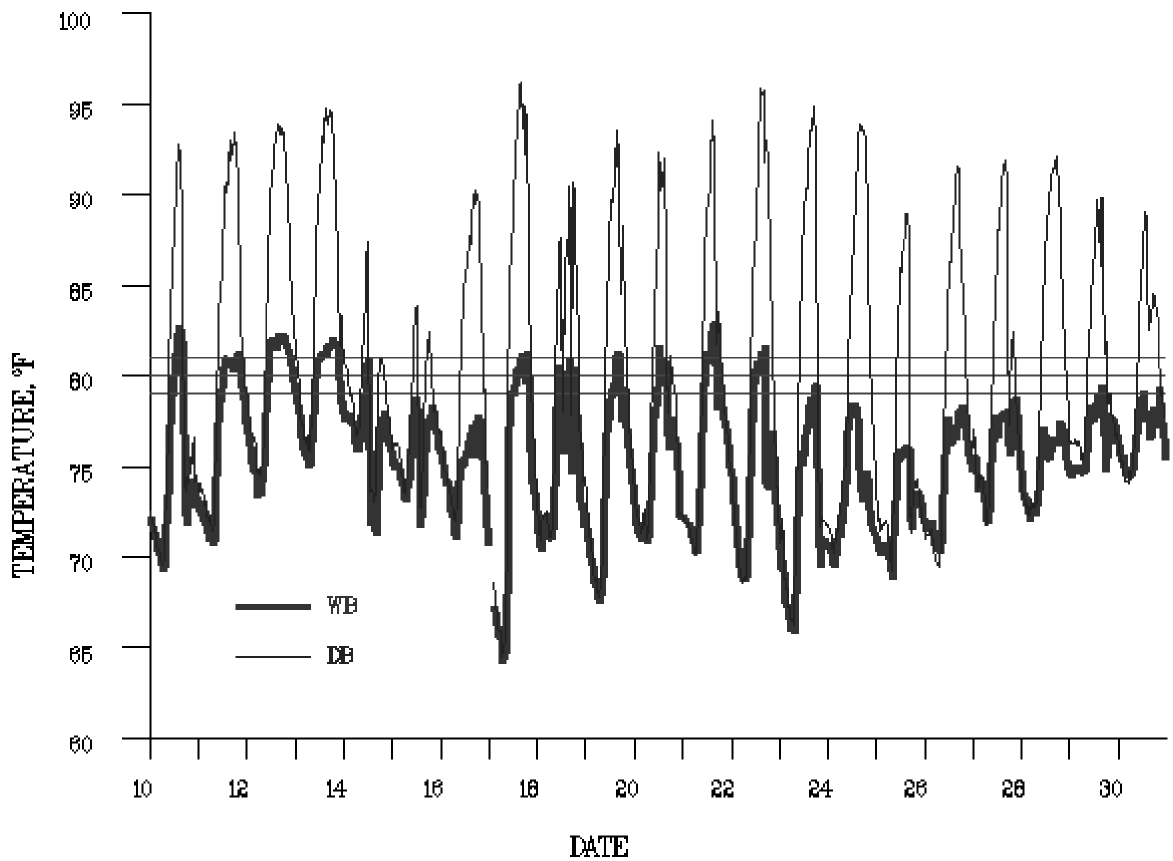

Figure 3. Performance of evaporative cooling system as function of ambient wet bulb temperature. Water flow rate = 12gpm, air flow rate = 2500 cfm, heat exchanger size = 15.7 cubic feet.

SYSTEM ENERGY EFFICIENCY

A comparison of the cooling output per unit of power required (energy efficiency ratio-EER) for the evaporative cooler and mechanical refrigeration (horizontal solid line) is shown in Figure 2.

Generally speaking, the evaporative cooler is more efficient than the mechanical refrigeration when the wet bulb temperature is more than one degree F below the fish tank temperature. In fact, when the wet bulb temperature is 5.0°F below the fish tank temperature, the evaporative cooler is more than four times as efficient as mechanical refrigeration.

For a difference in temperature less than or equal to one degree, mechanical refrigeration may be more energy efficient. For example, the evaporative cooler produced 5000 Btuh of cooling for a 79°F wet bulb temperature and a 80°F fish tank temperature; however, the corresponding EER of 10 was less than the 12 for mechanical refrigeration. This means that the evaporative cooler was less energy efficient at this temperature than mechanical refrigeration and that mechanical refrigeration should be used under these conditions if available.

An argument could be made to not consider the power required to operate the fan on the evaporative cooling system as part of the water cooling system, since all structures will need some ventilation for cooling. An evaporative cooler can maintain the same temperature in the structure as a conventional exhaust fan system with considerably less air exchange since the evaporative cooler produces air 5-10°F lower than the ambient dry bulb temperature. This usually results in a required air exchange rate of less than 50% of that for a conventional exhaust fan. If the fan were not considered part of the evaporative cooling system for the purpose of energy calculations, the EER would be more than doubled for the evaporative cooler. Furthermore, the power required to operate the fan in the ventilation system would be significantly reduced. Another advantage of the evaporative cooling system is that its initial cost is at least 50% less than that of a mechanical refrigeration system. This also has an energy impact since increased equipment costs translate into increased indirect energy input. Indirect energy (energy required to produce product) can be determined by using standard Btu/$ ratios for a particular category of products.

Assuming that one half of the 1240 water surface acres of ornamental fish production in Florida were moved indoors and converted to recirculating systems, it has been estimated that 13 million kWh would be required to operate the mechanical refrigeration water cooling systems. Using a conservative estimate that 75% of the time the cooling could be done with the evaporative cooler, 5 million kWh (6.8×10^{10} Btu of fossil fuel equivalents) could be saved. Considering the savings of evaporative cooling over conventional ventilation for the structure, at least 10 million kWh ($13.6. \times 10^{10}$ Btu of fossil fuel equivalents) could be saved.

SUMMARY

The evaporative cooler demonstrated in this study is inexpensive, simple and considerably more energy efficient than mechanical refrigeration for most conditions. Based on a design wet bulb temperature for Florida of 79-80°F and an analysis of actual weather data, it appears that evaporative cooling can provide essentially all of the cooling necessary for fish tank cooling if the fish can tolerate occasional temperatures in the mid 80s°F. If these temperatures cannot be tolerated, a mechanical refrigeration system is recommended to provide supplemental cooling. The cost to operate the mechanical refrigeration system should be minimal since wet bulb temperatures in excess of 80°F occur only for short periods. The initial cost of the mechanical refrigeration system could be significant; however, if a heat pump is used for heating it would also be available for cooling with very little additional cost.

In addition to cooling fish tank water, the evaporative cooler should improve the working conditions inside the fish production structure by providing a lower air temperature than is possible using conventional ventilation.