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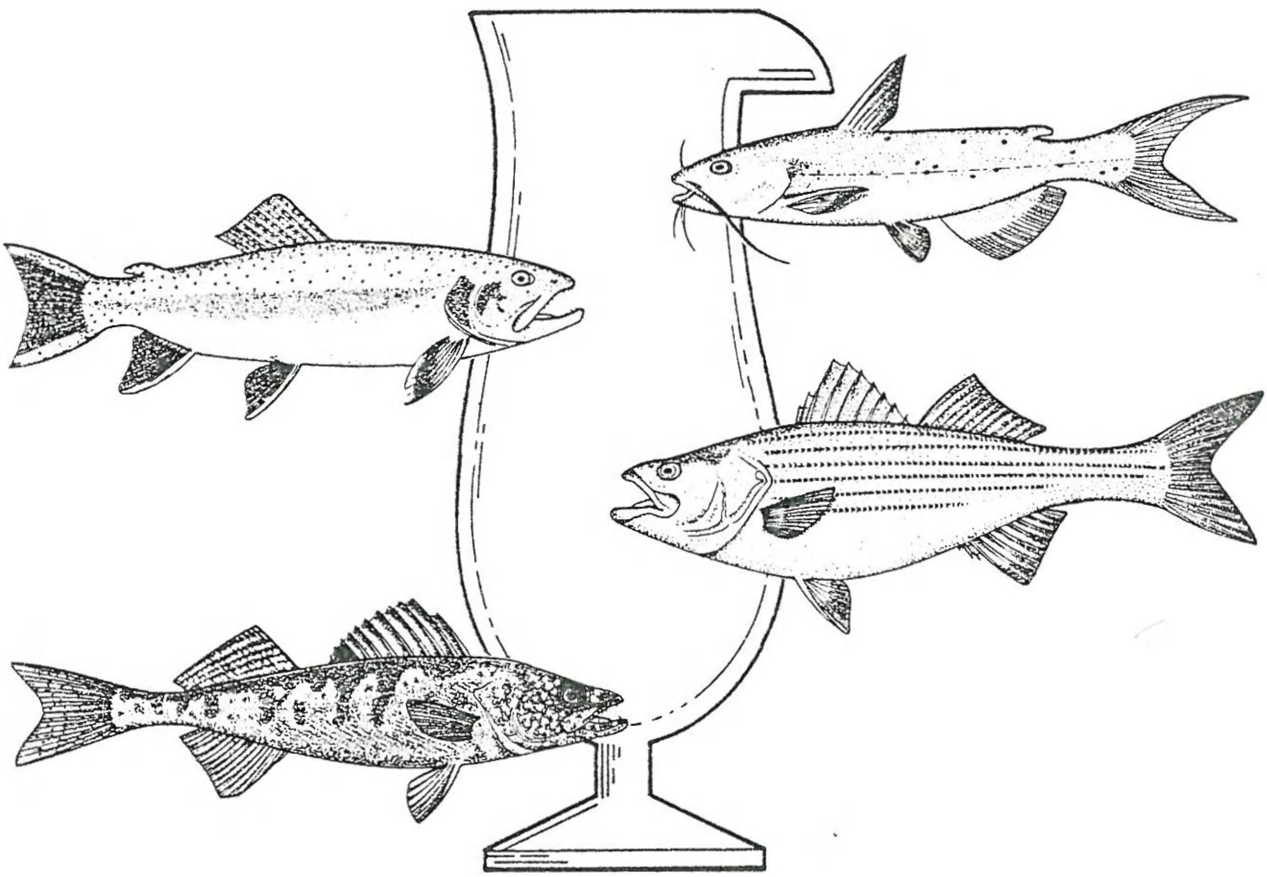

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A Flat-plate Solar Collector System for Use in Aquaculture

Many processes in aquaculture require heating large quantities of water only a few degrees, especially when trying to increase temperatures above ambient for purposes of faster growth or controlled spawning. Costs of heating large volumes of water by conventional methods are prohibitive. Alternative energy sources, such as solar energy, offer a variety of solutions to this problem. A well designed passive solar heating system is the most desirable solar water heating method (Ogle, 1982). Passive systems are not readily adaptable to existing structures and work best when initially designed into the structure. Active solar energy systems are much more flexible and can be more easily retrofitted to existing buildings and site requirements. Concentrating and flat-plate collectors are the two main types of active systems. Concentrating collectors can produce extremely high temper-

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atures but sacrifice efficiency and, therefore, are not conducive to heating large volumes of water only a few degrees. Flat-plate collectors, however, can be 80% efficient in this mode. Due to its efficiency and adaptability, the flat-plate type of system was chosen for use at the Florida Department of Natural Resources Bureau of Marine Research (BMR).

The system was used in a juvenile prawn (*Macrobrachium rosenbergii*) nursery demonstration project. Intensive winter nursery production and subsequent stocking of juveniles effectively extends the prawn growing season in Florida. Willis and Berrigan (1977) stocked juveniles and postlarvae into ponds for a 167 day growout. Prawns stocked as juveniles had a 25% higher harvestable biomass and a 100% increase in the number of individuals reaching marketable size (>30g). Sandifer and Smith (1978) and Smith et al (1981) have also shown better yields when juveniles have been stocked at the beginning of the growout season. Solar heating reduces operating costs in temperate climates, thus increases the feasibility of such a nursery.

The solar heating system used at the BMR consisted of two 3.71 m^2 (40 ft^2) flat-plate collectors, two 310.4 L (82 gal) storage tanks, and a manifold distribution system with heat exchangers. The system was located in and on a 55.74 m^2 (600 ft^2) one story cement block building (Fig. 1) with no wall and ceiling insulation. Foam insulation with an r value of 11 was placed over the windows.

Heat exchangers were placed in four 1250-L (300-gal) fiberglass culture tanks. Culture tank temperature was measured daily (February 20–March 22, 1981) at 0900, when the system was at its lowest temperature. Daily ambient air temperatures were obtained from the National Weather Service observation station at Albert Whitted Municipal Airport, St. Petersburg, Florida, located about 180 m (200 yards) east of the test facility.

Heat exchangers consisted of 3 m (10 ft) of 1.9 cm (0.75 in) I.D. type m copper tubing with a 90 degree elbow 15.24 cm (6 in) from each end (Fig. 1). The ends were soldered to 1.9 cm (0.75 in) female pipe thread adapters which were connected to the outlet manifold on the outlet side and to a control valve on the inlet side. The control valve was connected to a CPVC inlet manifold. The main circulating pump for the distribution system was connected to the outlet manifold. All inlet and outlet lines were insulated with 1.27 cm (0.5 in) wall flexible foam pipe insulation. All copper in the heat exchangers was painted with polyurethane varnish to minimize toxic effects of exposed copper.

Collector plates were made of 0.178 mm (0.007 in) thick copper sheets (Fig. 2) soldered to 1.27 cm (0.5 in) I.D. type m copper tubing. Each copper sheet measured 61 × 15.24 cm (24 × 6 in) with a 0.79 cm (0.31 in) radius depression along the center line to cradle the copper tubing. Each tube was joined with 90 degree pipe elbows and short lengths of tubing so that each was 15.24 cm (6 in) on center (Fig. 3). The top and bottom pipes of each collector were terminated with 1.27 cm (0.5 in) female pipe thread adapters. The entire plate was painted with high temperature resistant flat black paint.

These collector plates were placed in boxes constructed of 2.54 × 15.24 cm (1 × 6 in) redwood frames with a 0.635 cm (0.25 in) tempered hardboard backing. Wood and hardboard parts were weatherproofed with three coats of polyurethane varnish. Foam insulation 7.62 cm (3 in) thick was placed behind the plates and the plates fixed to wooden stand-

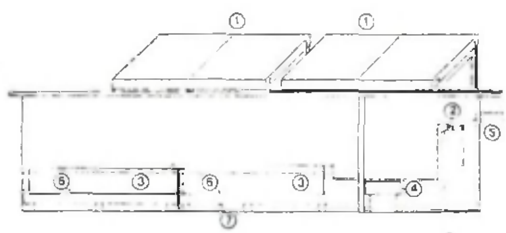

Fig. 1. Overall system layout. 1. Flat-plate solar collector. 2. Storage tanks. 3. Culture tanks. 4. Filter. 5. Collector circulating pump. 6. Heat exchanger. 7. Heat exchanger circulating pump.

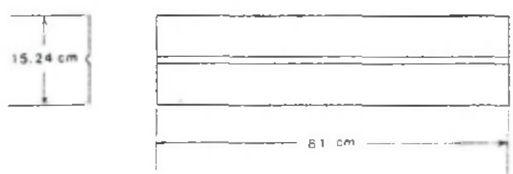

Fig. 2. Copper sheet formed for soldering to pipe.

Fig. 3. Assembled copper collector plate.

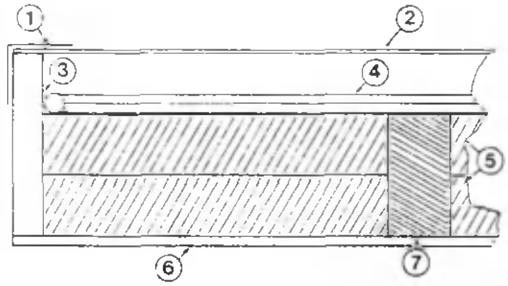

Fig. 4. Section showing assembled collector. 1. Aluminum angle. 2. Kalwall glazing. 3. Redwood board. 4. Collector plate. 5. Foam insulation. 6. Tempered hardboard. 7. Mounting standoff.

offs. The collectors were glazed with Kalwall® fiberglass glazing and the edges sealed with silicone sealant under angle aluminum (Fig. 4).

Two 310.4-L (82-gal) water heaters were used as storage tanks. They were connected in series with the water passing to the heat exchangers exiting the top of the second tank and returning to the bottom of the first tank. The electric heating element was left operational in the second tank to provide backup heat if the storage tank temperature fell below 37.8 C (100 F).

Water going to the collectors was taken from the bottom of the first tank and returned to a special inlet located approximately 90 cm (3 ft) from the tank base. A motorized valve in the collector inlet line prevented convective circulation at night. Normal circulation was provided by a Little Giant MD 5B pump, which was controlled by a commercial differential temperature controller for solar energy systems. Circulation was initiated when the temperature of the collector was 6.67 C (12 F) above the temperature of the water in tank 1 and ceased when the temperature differential decreased to 1.67 C (3 F). Inlet and outlet lines were 1.27 cm (0.5 in) CPVC tubing. Joints between copper and CPVC were sealed with Teflon® tape.

Temperatures in the culture tanks averaged 8.1 C (14.6 F) above the average ambient temperature. Construction of the building gave little or no solar heat gain during the day; thus all heat gained was assumed to come from the collectors. It was also assumed that the building and its contents would equilibrate to average ambient temperature within 24 hours. Solar heating began 3 days prior to the beginning of the experiment. During the experimental period, 313 kilowatt hours of electricity were used for lighting and auxiliary heating. This includes 2 days when the collectors were not functioning and the water was electrically heated. The average solar input to the culture system was 122,750 BTU's per day. This is equivalent to 36.7 kilowatt hours of electricity per day using resistance heating.

This system was designed for an experimental nursery system in a central Florida climate. The building used was similar in construction to many buildings currently used in the central Florida aquaculture industry and thus represented a reasonable approximation of results obtainable by retrofitting existing buildings to utilize solar energy. Assuming a 120 day use period per year in this climate, the system would result in a $305/year savings in electricity costs (based upon $0.07/kwh). This results in a payback period of slightly more than five years in materials costs, possible tax credits not included.

Several improvements in the system are suggested. Most importantly, eliminate CPVC in the construction and use copper throughout. The CPVC tends to "cold flow" when heated, releasing tension at threaded joints and causing leaks. It was estimated that as much as 50% of the energy collected was lost when these leaks developed in the system. Coatings such as epoxies should be used due to lack of abrasion resistance of the polyurethane. Normal tank maintenance activities resulted in exposure of the heat exchangers' copper surfaces in several instances.

A flat-plate solar collector system successfully increased temperatures in a prawn nursery and provided an economical alternative to conventional heating systems. A similar system could be adapted to existing structures and supply supplementary heat for many types of aquaculture.

Acknowledgment

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Materials List

80 ea	61 cm × 15.24 (24 × 6 in) × 0.18 mm (0.007 in) copper/sheet
54.864 m (180 ft)	1.27 cm (½ in) I.D. type M copper tubing
32 ea	1.27 cm (½ in) I.D. copper elbows
4 ea	1.27 cm (½ in) female pipe thread copper adapters
2 ea	Little giant CMD 100-5B *pumps
8 ea	1.905 cm (¾ in) copper female pipe thread adapters
12.19 m (40 ft)	1.905 cm (¾ in) I.D. type M copper tubing
1 ea	Differential temperature controller with freeze sensor
8 ea	1.905 cm (¾ in) copper elbows
4 ea	Solenoid operated valves 24VAC
1 ea	24 volt transformer
4 ea	Thermostats
6.09 m (20 ft)	5 × 5 cm (2 in × 2 in) pine
18.3 m (60 ft)	2.54 × 15.24 cm (1 in × 6 in) redwood
3 ea	10 × 20 cm (4 in × 8 in) sheets tempered hardboard
14.86 m^2 (160 ft^2)	Foam insulation 3.81 cm (1½ in) thick wall
7.43 m^2 (80 ft^2)	Kalwall glazing
60.96 m (200 ft*)	1.27 cm (½ in) I.D. CPVC pipe
*	Misc. CPVC fittings
60.96 m (200 ft)	Foam pipe insulation
0.94 L (1 qt)	Flat black high temperature paint
1.89 L (2 qt)*	Polyurethane varnish
17.07 m (56 ft)	2.94 × 2.54 (1 in × 1 in) aluminum angle
2.44 m (8 ft)	3.81 cm (1½ in) aluminum flat
2 ea	310.4 L (82 gal) water heaters assorted hardware (nails, screws, solder, etc.)
4	Brass ½ in female pipe thread couplings

*Should be replaced with alternate materials.

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