Low-cost active heat storage

Nathan Hurst and Paul Harrison show the results of experiments using car radiators as a controllable thermal mass heat exchanger.

A greenhouse is used to provide ideal growing conditions for plants, and in my case, fish. This means temperatures of roughly 25°C day and night. However, although greenhouses tend to get hot during the day, at night the sun provides no direct heating effect. It's common to heat the greenhouse at night with a heater, but this seems wasteful. After all, the greenhouse receives more than enough heat on average, just not at the right time.

I have a 4.5kL fish tank in my greenhouse in which I grow silver perch and Australian bass in an aquaponics system. For optimal fish growth, the fish tank needs to be heated to a temperature of 25°C. My greenhouse tends to get to around 45°C on a sunny day, and significantly above ambient on an overcast day, but, due to evaporation and poor heat transfer, even on sunny days the fish tank cannot reach its optimal temperature without assistance.

This article describes how I use an active heat transfer system to both keep my fish warm, and my greenhouse cool.

This greenhouse collects the heat for the storage system.

Design

The greenhouse is attached to the north side of our house and is 10 square metres in area. It has excellent solar access. Last year, before installing the radiator system, I had 50% shadecloth all year round as I found that the temperatures got too high in the day even in winter. This year, instead of wasting that excess heat, I store it in the water tank and use it to heat the greenhouse at night.

The tank is partially covered. The water is pumped by a 45 watt pond pump for fish-waste oxidation and to irrigate plants.

Twenty litres per minute of this water is diverted through a Mazda car radiator, which cost $120 from a local wrecker, including two 12 volt electric fans. The electric fans are controlled using a PIC microcontroller and a home-brew PWM control circuit. The radiator is mounted in the rafters near the apex where the heat collects.

The fans can start to move air at about 1.2 watts and use 60 watts at top speed. Due to aerodynamics, every doubling of air movement requires roughly eight times as much electricity. This means that running the fan slowly for a longer time can pay off considerably.

The temperature is measured at several different points in the system using 1-wire bus (www.maxim-ic.com/products/1-wire) temperature sensors. These measure the temperatures of the heat-exchanger water inlet and outlet, the tank, and the outside and greenhouse air. This bus is connected to a computer (running Linux), which controls the fan speed.

The experiment

To test whether the radiator is having any effect on the air and water temperature, I ran the fan fully on, then fully off on a half-hourly cycle. If the radiator were having any effect the greenhouse air temperature and the tank temperature should show a cyclic variation over the same period.

Figure 1 shows a graph on an average autumn day plotted from noon till noon the next day. The temperature variation is quite clear during the sunny portion of both days, and at night once the outside temperature drops significantly.

A tank holding 4.5kL of water stores about 18MJ of energy per degree celsius and based on the tank temperature change of 0.6°C/hour, the system collects about 10MJ of heat per hour of sunshine, or 2.7kW. The amount of energy available from the sun would be no more than 7kW, giving an overall collector efficiency of about 40%.

The total electrical power is hard to measure. The reason for this is that all the electrical devices are used for more than just heat transfer. The pump is required to circulate the water for the fish, and plants and the fans also provide horizontal air flow (important for good plant growth).

The system has used 54MJ in a month, and moved about 1620MJ of heat.

Whole house thermal mass

A house in Melbourne needs cooling in summer. Evaporative cooling is effective, but soon humidifies the air unless fresh make-up air is introduced all the time. It is often cold at night.

In winter the same house needs heating, which could be provided by solar heated water or air, but the most heating is required at night when the sun isn't available.

A solution to these problems is to maintain a thermal store. A thermal store is a large mass kept at a temperature suitable for heating or cooling the house.

The standard approaches for this would put large amounts of masonry or water inside the house and perhaps rely on direct or indirect solar heating. The thermal mass maintains the house at an even temperature. This can be a liability during cold periods, as the thermal mass prevents the house from being heated only when it is occupied. Instead it must be kept heated all the time. You also face a trade-off between large windows to collect the most sunlight during the day, or small windows to minimise heat loss at night.

The greenhouse experiment has shown that car radiators can be used as a cheap and efficient way to move heat in and out of a thermal mass. Let's consider how to extend the idea to the whole house. The thermal mass can be used when it is needed, and kept isolated from the house when it is not.

We can also eliminate the window size trade-off. Rooms with large windows, used to heat the thermal mass during the day, can be isolated from the thermal mass and the rest of the house during the night, when those windows leak heat.

Optimisation

The most efficient heat exchangers operate as counterflow heat exchangers. This means that the two flows (in our case, the water and the air) move in opposite directions. A car radiator, however, has water flowing perpendicular to the airflow. We can, however, still improve things in a number of ways.

Two radiators in series can be used as staged cooling. With the use of a little duct tape, they could share the same fans.

Rather than cooling the air whilst stirring it up, air can be gently moved from floor to ceiling (heating) or ceiling to floor (cooling) inside a duct containing the radiator. This would hide the radiator itself and allow the room to be filled like a multi-level cocktail, with cool air on the bottom and warm air at the top. This can reduce the energy required considerably, and is now common practice in commercial air conditioning systems in Europe.

The fans on radiators use DC permanent magnet motors, so reversing the current reverses the air direction. However, most car radiators are more efficient in one direction than the other.

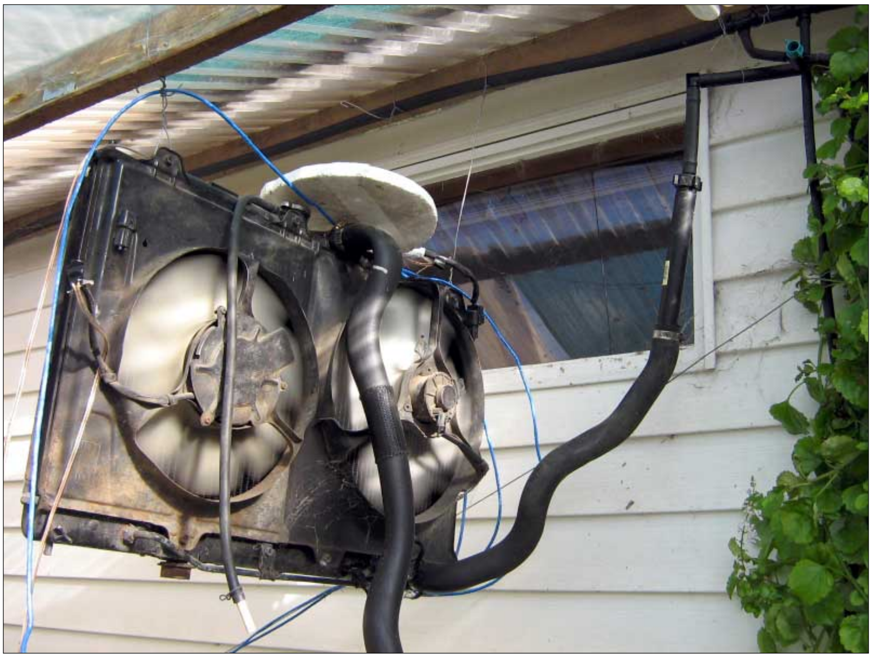
Rather than running the pumps continuously, a set of smaller pumps could be used, their speed modulated for maximum efficiency.

The water store can be actively heated using solar panels or wood stoves and cooled using a 'bong cooler'.

An insulated and air tight thermal store will lose less heat.

The plumbing can be poly pipe, copper or polybutylene house plumbing. But large diameter pipes are helpful to minimise pumping energy costs.

Noise can be controlled by using low-



The radiator and fan assembly, hanging in the greenhouse. It is important that the water flows from bottom to top so that the whole radiator is in contact with the water.

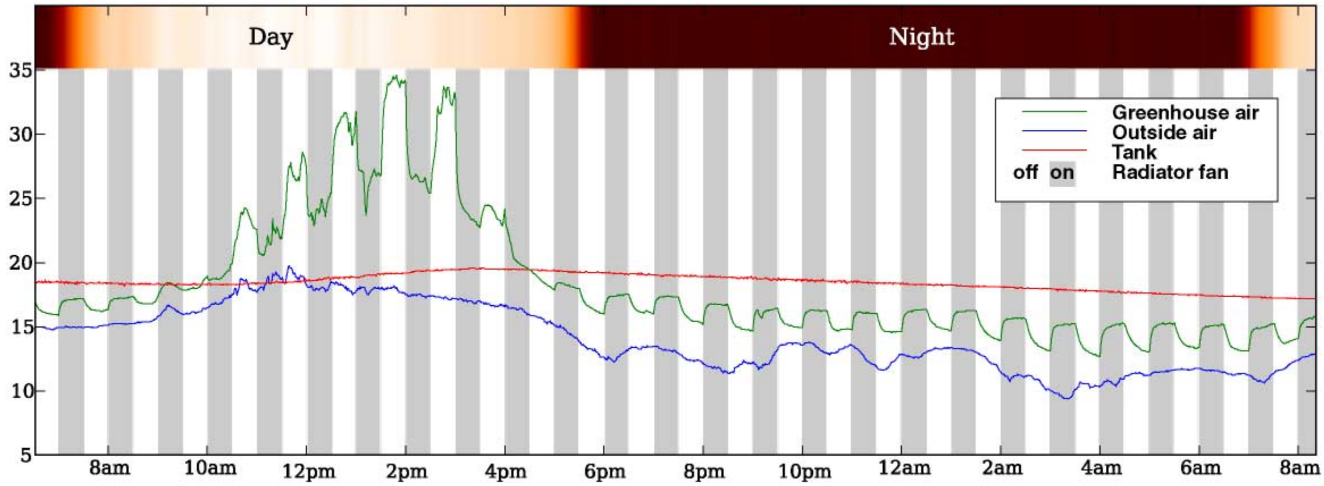


Figure 1. Time versus temperature for an average autumn day.

er fan speeds or using large diameter fans to move the air through the radiators.

Conclusion

Car radiators provide a cheap and ready supply of low cost, high tech heat exchangers for the home alternative energy experimenter.

Attempting to maintain ambient temperatures using an active thermal mass at room temperature is workable, with promising results from the prototype system. The ease of working with air rather than water as a collection fluid, combined with the low cost of car radiators and the advantages of keeping the thermal mass separate from the living area, provides an interesting alternative to a loungeroom full of concrete furniture.

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