Air based solar-thermal “Hot-Box” collector.

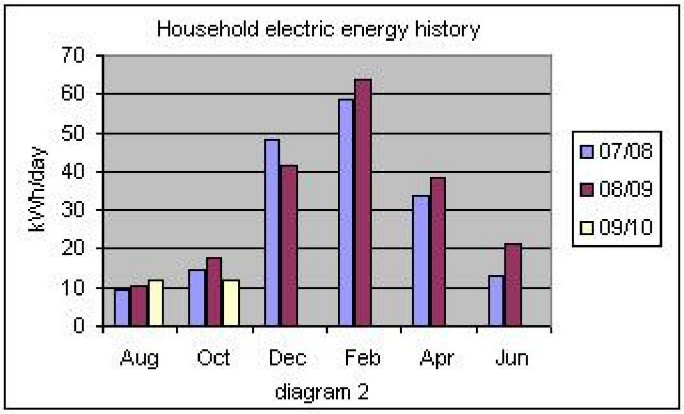
Diagram 1 : The HotBox

- 2 sq m window area
- Minimum $cost / kWh
- Total cost under $1000
- Automatic control
- Measurable results
- Minimum maintenance costs
- Easy to build
- Good appearance
- Wife approved

<u>The AHA moment!</u>
In the course of researching various green-energy options for our house, I realized that **the ability of a solar-thermal collector to harvest energy is mostly a matter of the effective window size**. We could have spent thousands of dollars in an attempt to harness a few kilowatts of solar energy… and take on a big messy construction project. Instead, I deciding to focus on getting the maximum bang-for-the-buck. To heck with convention. Better to challenge myself to design and build an affordable solar-thermal collector to meet the above listed criteria:

The south wall of our house had an 8’ long section of available outside run, at ground level. The spot was about 5’-6” high, and sat below one of our living room windows. I hatched a plan to build a hot-air box, which would transfer captured solar energy via hot air transfer between the collector and our basement. Otherwise the basement requires electric heat. My design would be that of a air-heating solar hot-box, dimensionally optimized for maximum utilization of the space available.

Design parameters



We built our little house during the winter of 2006/07. It is quite well insulated, 820 sq ft, and is oriented to get the most out of the winter sun, while remaining fairly cool in the hot summers. Located at a latitude 50.15 degrees N, we are surrounded by mountains, and our winters are pretty cold. But, we get lots of sunny days. Our primary heating fuel is a combination of electric baseboard and a wood-burning stove.

Analysis of our electric energy consumption history (diagram 2), reveals a summer-time base average energy usage of around 10kWh/day. During the winter-time, this climbs to a peak of about 60kWh/day. The base energy usage is our appliances & hot-water heating. The additional winter load is all electric heat; a ripe target for displacement using harvested energy from a solar collector project.

Solar thermal panels typically utilize a fluid such as glycol for transfer & storage of energy. Water would be great except that it tends to freeze in sub-zero temperatures, and glycol is expensive (up to $10/litre for non-toxic). Why not use air. No troublesome freeze-ups, no pump, no plumbing. Air is free & very easy to move around. The system uses 2 ea 4” diameter air ducts, and a single 4” 121cfm 12VDC electric fan.

- A cold duct draws cool air from near the floor level of the basement, and releases it into the lower front of the hot-box
- A warm duct pulls the heated air from the top back of the hot-box, and blows it into the basement.

The hot-box was designed to accommodate a quantity of heat-storage mass, such as a stacked wall of rock. We live surrounded by rock… rocks everywhere. But initial testing on the hot-box without any added thermal mass, provides excellent results. The planned pile of rocks can be added at a later date.

Control & Energy Measurement

A small dedicated controller provides fully automatic on/off control of the fan by using a differential thermostat. I've equipped the hot-box with 4 temperature sensors

1. Outside air : always in the shade.
2. Hot-box interior : located 2" below the hot-box ceiling
3. Cool vent : sensor immediately adjacent to the cool-air duct in-take
4. Warm vent : located in the warm-air discharge duct, immediately ahead of the fan.

The heat-exchange fan turns ON when the hot-box interior temperature is greater then the cool vent temperature by > 4 DegC. Fan OFF when the hot-box interior temperature is less than the cool-vent plus 2 DegC. This provides the hysteresis necessary so the fan doesn't cycle.

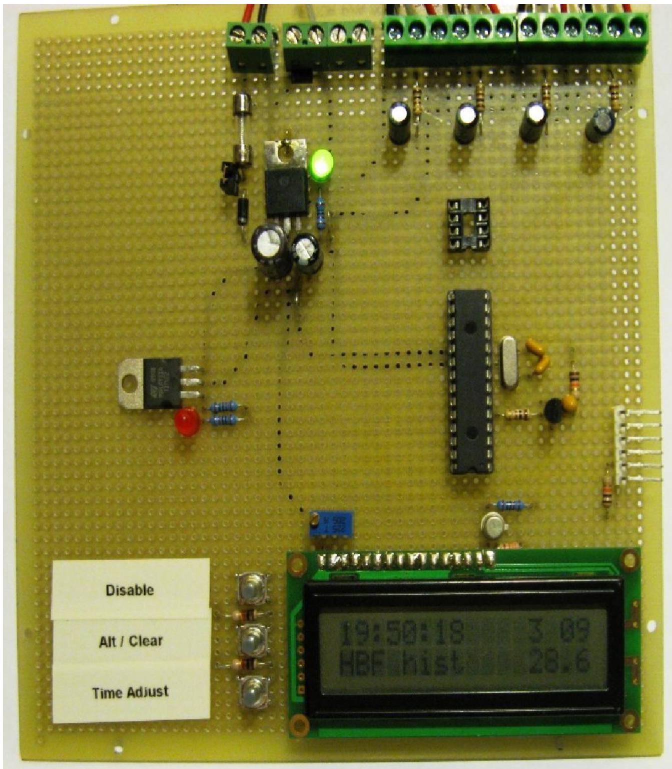


Diagram 3 : 1st prototype controller

By experimenting with the fan, I was able to determine that a rudimentary means of determining the actual air-flow could be determined by simply measuring the fan motor current. With the fan in place on the duct-work, the motor draws about 90% of the current it draws when running qt 13.5 VDC in unrestricted free-air. From this I'll make an educated best guess of about 80% volume air-moving efficiency

The energy to raise 1 cu ft of air 1 degreeC is = .0324 BTU
Instantaneous power : for a fan with 121 cfm * 0.0324 BTU/min = 3.92 BTU/min = 235.2 BTU/hr = 68.93W per degreeC rise.
Multiply by 80% (fan efficiency) = 55.15 W per degreeC rise. The temperature rise is simply the difference between the cool vent and the warm vent, when the fan is running.

Example : if the temperature rise is 10.0 DegC, instantaneous power = 551.5 W
Energy (in WH) is measured by measuring the instantaneous power every 36 seconds, multiply by 0.01 (36 sec is 1/100 of an hour), and accumulating the result.

Fan hours and accumulated kWh are recorded to non-volatile memory every 15 minutes if the fan is running. These values are thus not lost if the controller's power is shut off.

The controller/measurement module consists of a pic18F2525 microcontroller. A 2x16 lcd display provides operating values & accumulated energy information .

Hotbox Construction

The foundation consists of 6x6 pressure-treated timbers sitting directly on well-drained (elevated) ground. Packed sand/gravel sits beneath 2 layers of 1” Styrofoam insulation, with a top-layer of ¾” plywood (dead-level).

The walls of the structure are 2”x4” with R12 insulation, and the roof is 2x6 R22. Regular fiberglass insulation & vapour-barrier, with an interior layer of ½” drywall, mudded & sealed to make it insect-proof. The exterior is sheathed with OSB , trimmed & sided to match the house. Tin roof. The structure snuggles up to the house with no gap. The windows are double-pane glass, set at 60 degrees from horizontal. The unit is sealed air-tight, except for the ducting to the house. All interior surfaces are painted flat-black.

The 2 ducts (4” ea) into the house must both pass through a 12” high pony-wall that sits on top of the house’s insulated concrete wall foundation.

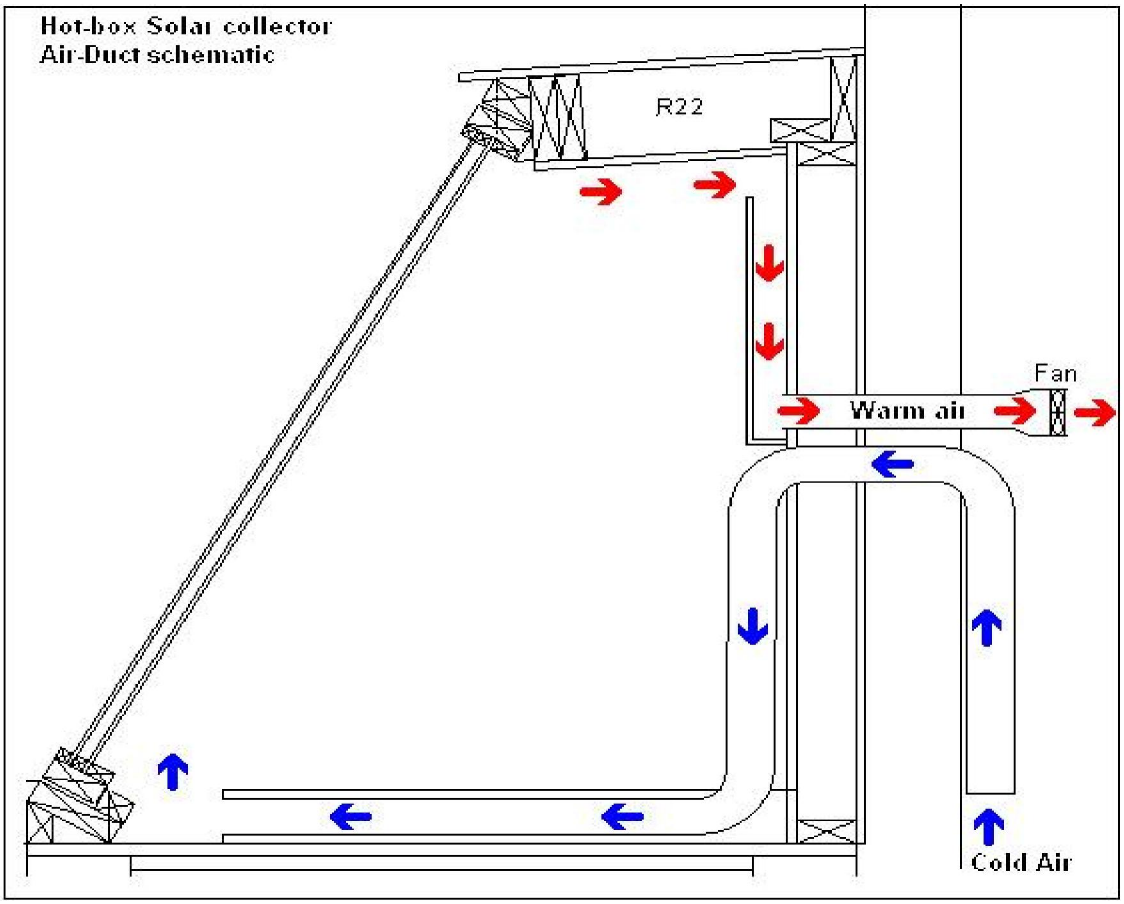


Diagram 4 : Air-vent schematic

The lower horizontal portion of the cold-vent, is constructed of plywood heavy enough to support bricks or rocks pile upon it. The cold-vent pulls air from 2’ above the basement floor.

Construction took a couple weeks of spare-time, with total costs at about $800 CAD, using all-new materials, including an expensive special-order of the glass.

Results

The hotbox solar-thermal collector was completed in late October of 2009, and since then, a few nice sunny days have produced promising results. It's only been a week, of mostly cool cloudy weather, but here are the results so far.

Peak measured instantaneous power output : 1500W
Maximum 1 day energy collected (early November) : 6.7 kWh
Maximum hot-box temperature (fan running) : +50.8 DegC

Fantastic! I'm optimistic that the collector should be able to harvest an average of 4 kWh/day, much higher on a bluebird day, and of course the odd zero-day of clouds & snow.

Residential electricity is still pretty cheap in British Columbia, and system payback, at $0.083/kWh will require about 10,000 kWh harvested. Definitely a few years payback time. However I'd love to challenge anyone out there to come up with an affordable collector that's more cost-effective & achieves quicker payback .

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