SIMPLE RETROFITTED FLAT-PLATE SOLAR WATER-and AIR-HEATERS

L R B Mann
Senior Lecturer in Environmental Studies, University of Auckland(rtd)

Agric Eng'g in NZ confab,Lincoln, Aug 1994;
pub'd in *Agric Eng'g Aus24* (1) 39-42 1995

Introduction This paper could be subtitled "The Goldmine in Your Attic". Since the peak flux of energy from the sun is 1 kW/m^2 (approx. half visible and half IR), the typical Australasian house roof of area ca.120 m^2 receives about 100kW solar radiation, peak (about 20kW mean). Only a few percent of this need be harnessed to make the house considerably more pleasant and healthy. Much or all of that roof can serve as flat-plate solar-thermal devices: 3 - 4 m^2 of glazed black copper harvests a kW or so into hot water, and the rest of the roof a similar thermal power in-room-warming air pumped from under a ridge down into one or more rooms.

The bulk of typical Australasian household energy end-uses being low-temperature heat (water- & room-heating), if these solar-thermal retrofits can supply only a large minority of those consumptions they have the potential, if widely deployed, to supplant several power stations.

Both of the solar-thermal roof modifications reported here have been designed & implemented as retrofits, but are readily incorporated (and more efficient) in new construction. The two technologies are sketched in order.

(a) SWH can be made cheaper by building them *in situ* into the roof. Much packaging & freight, and the collector factory, are obviated. Thermal losses are decreased. The majority of domestic water-heating energy (in summer, 100 - 200 L/d at 60 ¡C) has been supplied from this type of collector comprising a small part (3- 4 m^2) of the roof for each building.

Recent improvements in materials and design make this a relatively economical investment. Because the glazing of the SWH is the roof for that area, this approach starts with a credit of $100 or more from roofing saved. Glazing satisfactory so far has been polycarbonate('Suntuf') or modified acrylate ('Durolite'), both UV-protected by a film on the upper side. The copper collector sheet transfers heat by a heat-conductive glue into 10 - 15m of 20mm copper pipe thermosyphoning to an attic tank. The back of the collector sheet is unusually well insulated - typically, foil then 10cm of styrofoam. The back of that insulation is in a warm, sheltered attic rather than in the wind; and any heat that does getthrough goes into system (b).

Selective surfaces can net more energy owing to low IR emissivity. So farI have used Solkote Hi/Sorb-II paint (Solar Energy Corp., Princeton N.J., USA) which is claimed, if sprayed very thin, to have emissivity only 28% that of ordinary matt-black paint. [addendum 2002: the CuS layer lining an old copper HW cylinder is a free, and suspectedly selective, matt black surface. No paint is needed.]

If it is desired to increase the area of collector (say, to 6m^2 or even more), the marginal costs & losses are low. The returns from increasing area require detailed R&D, because both performance and economics are different from those of adding conventional factory-made modular boxes.

Conventional thermostatted electrical 'topping-up' is readily provided, either in the thermosyphon tank or in an existing 'hot water cupboard' tank. The latter tandem-tanks system is arguably preferable, despite larger thermal losses. The topping-up required by the 2m^{2}single-tank prototype has averaged 3 kWh/d (*i.e.* 0.13kW$_e$) in its 2.5y operation. [updated at 8.5y: 3.0 kWh/d]

This device was designed on criteria for DIY appropriate technology, suitable for handymen. No welding or soldering is needed. It is readily adaptable for tradesman-based installation. The labor *in situ* is about 2 man-d.

Design of flat-plate SWH often gives some emphasis to optimizing the tilt (to *e.g.* the latitude + 10¡), in some examples even arranging to vary that tilt seasonally. This assumes that the radiation to be captured originates from an arc of the ecliptic, and that the collector efficiency drops substantially when the flat plate is not normal to the rays. That is not the best model for regions like Auckland where the 'average sky' is so cloudy that it is more like a hemispherical diffuser dome. Being constrained to the pre-existing roof tilt (often as low as 25¡) is therefore less disadvantageous than some textbooks are often taken to imply. Similarly, the most experienced local flat-plate SWH installers tell me that, even when geometry is further handicapped by absence of any suitable north-facing roof flank, installation on an east or west flank requires in Auckland only some 30-40% extra area to achieve similar performance. It is easy for a focusing animal like us to forget how little orientation matters for flat-plate collectors.

Plumbing for optimal performance needs some R&D and then codification, but some principles have emerged already (within the constraint that mains-pressure hot water systems in my opinion exemplify inherently wasteful vulgar brutalism):-

(1) The attic tank is best bought and installed as bare copper. It is thus cheaper and lighter (but also more fragile). Only after slinging, propping, and plumbing is it insulated - and then far more thoroughly than even the recent standard. The first step, omitted in a conventional clad cylinder, is to polish and lacquer the copper, decreasing its IR emissivity. Temperature sensors may be stuck on at several altitudes; the lowest might operate through a relay the electrical top-up heating (if that is in this cylinder). Glass-wool blanketing is then wrapped on, and finally foil. The resulting insulation can readily improve on even the recent blown-foam standard. The galvanized cladding of normal cylinders would be, in this application, a waste and unnecessary weight.

(2) If there is no attic, the thermosyphon tank will have to be installed on the roof, with suitable weatherproof cladding. The alternative of abandoning the thermosyphon I leave to those who are willing to grapple periodically with replacing pump seals etc. I point out the irony of being unable to use your SWH when the mains are off for an extended period. But of course it is true that pumped systems give far greater freedom of tank positioning. The claim that they also give 25% more stored heat I would like to see tested.

(3) Copper plumbing is not very much more expensive than polybutylene, but is harder for the untrained like me to install. Those who choose polybutylene should prefer brass to

plastic fitting inserts, and should be aware that pinhole leaks are expected in 15y, especially if the water is high in chloride. Trays and ducts (*e.g.* scrap roofing & spouting) should be installed to drain to eaves.

(4) Insulation of vents is oddly neglected. A straight open pipe may well pour a few score watts into the sky; a 'shepherd's crook' with push-on weatherproof foam is the least that is needed. Pressure-relief valves on vents allow shorter vent pipes and may thus pay for themselves (about $50) ultimately; but they become preferable in my opinion only for single-tank systems which otherwise require very tall vents to give sufficient dynamic head. In that connection, supply through header tanks, rather than pressure-reducing valves, should certainly be considered. Among their advantages is obviation of roof-penetrations for venting.

It is hoped to set up a test-bed for SWH at a university. A realistic draw off geometry and schedule is important; MJ delivered into a tank is not a sufficient criterion of performance. The rather exact requirement for a milking shed may deserve priority.

(b) Solar-assisted Air Conditioning The rest of a house roof acts as a flat-plate air warmer. The efficiency (power gained per unit area) of that collector is low, but the large area compensates, and the price is right. Much of a 1908 Auckland wooden bungalow is warmed by several degrees, obviating other heaters, over much of a typical day. Time-temperature graphs have been logged on a Hewlett-Packard 7132A strip-chart recorder using two LM335 (10 mV/¡K) *cf.* Hutton's earlier success using the AD590 (1µA/¡K), to compare the in-house temperatures with those achieved by known electric heater powers. The yield of warm air brought down into the living space by thermostatically-controlled fans can readily average 5 kWh/d for a couple of hundred days each year (Auckland winter, spring and autumn), roughly equivalent to the thermal power of an electric radiator (500 - 2500 W),from investing the electrical power of a smallish light-bulb (90W max, far less idling). The effect can be likened to that of a heat-pump with a C.O.P. in the range 10 - 50; but of course the hours of working are much more limited.

This general concept has been implemented by Hutton, the CSIRO special house hear Melbourne, and at least two other research versions in Australasia, and several 'box in the attic' commercial versions using centrifugal blowers. My versions have all used axial fans.

The simplest fan is a 30W bathroom-exhaust type mounted just below the ridge and pushing air down by a duct. More versatile & powerful is a reversible 80W 'ceiling' fan, dia. 90 or 120 cm, mounted above the ceiling in a duct 50 – 200 cm high.

Fan control uses two LM335: when the temperature excess at the ridge drops below one degree, fan(s) speed is automatically lowered. Shutters are generally not needed, as the lower of the two fan speeds is sufficient to prevent warm air floating back up into the attic.

This class of fan-air system is indicated by the next 6 paragraphs tobe a good example of a **solution-multiplier** (the Clivus composting toilet being a classic example). Stratification within the living-space is considerably rectified; on the lower ('idling')of the two speeds between which the fan is automatically switched, this benefit is still significant. The 10^{-1} kW_t from lights and other electrical devices is thereby made more effective towards room-heating. Fan-duct systems for recirc only were sold by *e.g.* Warmaire in the late 1970s and calculated by G Leach to be more cost-effective than adding insulation to moderately-insulated ceilings.

Standard polyester filters from air-conditioners are incorporated at ceiling level, giving unusually clean air. Protection from airborne allergens may be, for some occupants, the most valuable benefit of this technology.

It is not strictly correct to say that such fan systems decrease the humidity of the warmed air, but they do dry the house very considerably. They are far better value for that purpose than $500 refrigerator-type dehumidifiers.

The whole living-space is slightly pressurized. In districts where significant radon percolates up from under-floor, its levels in the living-space are therefore presumably decreased. Dust exclusion is also assisted.

There are extremely cost-effective incidental benefits for window security. The turnover of air in the living-space is normally such that no window need be opened for months, so barrel locks with keys, too cumbersome for frequent operation, become convenient.

Roof longevity is enhanced by evaporation of condensation from the underside of the metal. Not only the galvanizing but also the purlins will last longer because they are wet less.

The air warmed normally enters the building under the eaves. Large-scale internal recirculation has also been tested, using an internal stairway; this appears to give, as expected, faster warm-up but less total energy gained. The ratio of fresh to recirc air needs research.

A "leaky thermal diode" may be a useful image to keep in mind when designing this type of active flat-plate collector.

The typical attic is, in summer days, like a warm-air 'balloon' at 55- 60 ¡C. Given (preferably)ridge-level vents, this can entrain air lofted from the living-space by reversing the fans, giving solar-assisted whole-house ventilation. There placement air sucked into the living-space comes preferably from a cool basement. Airborne animals can be filtered at one or more stages.

[addendum 2002 The Fourth Mode: on clear summer nights the fast-down mode gives a few kW of cosmic cooling.]

Ordinary dark-red or dark-green roof paint is said to absorb solar energy about 70% as well as matt black. After I painted my dark-red roof with dark brown I was surprised to find for some months decreased efficiency. I think the gloss of the new paint was the (temporary) difficulty, and I continue to suppose that dark brown(acrylic) is the best readily available paint for the purpose.

Hutton's 5 houses had tile roofs; in the Melbourne climate even this inferior membrane proved a collector of worthwhile efficiency. Anodized matt black aluminum might well be thermally much better roofing.

An improved sub-class of roof would have (UV-protected) glazing outside the roof. Tile roofs might well benefit most, proportionally; for metal roofs, special paint would presumably be needed for the higher metal-surface temperatures, and might as well be a selective coating. This glazing would extend the peak power, but especially the net annual energy, from the class of solar air-heater we are considering.

Like SWH this technology needs, and readily incorporates, topping-up(*e.g.* by electrical fan-heaters at outlets from ducts).

A main potential improvement is aerofoil fan-blades rather than (or fitted over) standard crude stamped-steel blades. More heat per unit noise is the goal, noise being the only evident drawback of this technology.

Some useful heat-storage can be incorporated in each building; salt(*e.g.* $CaCl_2$) hydrates appear most suitable but have yet to be acquired.

(c) Barriers to Deployment Reviewing the literature of the late 1970s, especially Lovins' *Soft Energy Paths* and ensuing controversy, one is struck by the inertia of technology in the face of valid argument, and the resulting lack of progress in R&D, let alone deployment, of the technologies required for transition to sustainable energy systems. In that period, Lovins identified solar room-heating as a main, and solar water-heating as a lesser, opportunity for saving electricity and/or other forms of energy. More recently he identified electric motors and controls as a major arena for increased efficiency of electricity usage. Last time I heard him here, he was identifying expensive fluorescent lights as a major saving which electricity retailers might well give away and which you think it might pay you to buy (at least briefly while you listen to him, until he intones "it's pure arbitrage"). Scientists & engineers involved in appropriate technology should think hard about why almost two decades of Lovins-type proof that soft energy technologies are 'economic' has not resulted in much deployment of such technologies. My own tentative explanations are:-

(i) the renewable-energy systems which Lovins so plausibly advocated in the late '70s did not all exist in readily available forms;

(ii) distortions of finance & propaganda continued to favor electric grids;

(iii) schools of engineering and architecture continued, indefensibly, to neglect soft-energy concepts in teaching and research.

Can these disciplines be rescued from the burgeoning fog of digital confusion? If so, it will entail serious design and, especially, practical work which I hope my inventions will stimulate. I have throughout hinted at questions for R&D, and would be glad to co-operate with researchers pursuing any. I am advised that concept(b) is not susceptible of patenting. I warn against hijacking by digital-control fanatics.

Acknowledgements The prototype SWH was constructed with help from members of Solar Action. The electronic control and monitoring systems were designed and made by Clifford Wright, U. of Auckland Architecture dept.

Refs.

Guthrie K 1994 'A review of Australia's solar water heater standards' *Solar Progress 15* (2) 12-13
Hutton D R, Lecis I 1985 'A simple multichannel temperature recording system' *J. Phys. E: Sci. Instrum.18*822-3
Hutton D R, Francey J L A 1985 'How to Use Your Home Roof & Attic as a SunSpace ...' *Solar Progress 6* (2) 8-9
Lovins A et al. (ed. H Nash) 1979 'The Energy Controversy' San Francisco:Friends of the Earth