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PERFORMANCE OF A SOLAR AIR COLLECTOR AT A CEC DEMONSTRATION PROJECT, EASTHALL, GLASGOW

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ABSTRACT

The paper describes the design strategy and performance of an air-driven solar water and ventilation preheat system, an integral part of a CEC Demonstration Project in Glasgow; noting how performance has been compromised partly by inherent, and partly unforseen design aspects - e.g. unexpected intervention by the user. There are 12 collectors and measurements described in this paper are restricted to one which faces South-East with a tilt of 30°. Four stages during the monitoring period are examined - different both in terms of weather conditions and in parts of the system itself which underwent change during the monitoring period. In general terms the efficiency of the system is found to be very low, but there are compensatory features as well as useful lessons for future systems of this type.

KEYWORDS

Solar air collector; water/ventilation preheat; air-to-water heat exchangers; performance monitoring.

INTRODUCTION

This solar air collector system is unusual in that it is designed to fulfill two functions. The first of these is to preheat air in the common entrance stairwells or 'closes' of houses as an integral part of a passive solar cum energy-efficient retrofit, the design and performance of which is described in detail elsewhere (Porteous C. D. A. and Ho H. M. 1992; Ho H. M. and Porteous C. D. A.1993 and 1994). The second is to build on the much lower space heating loads by preheating water, the emphasis now on spring to autumn rather than autumn to spring. Monitoring was from May 1992 to June 1994.

The system itself may also be termed 'hybrid' in that the collectors are an integral part of the 30° pitched roof and the heavy-mass stairwell forms part of the thermal loop, whereas the air is circulated with the assistance of a fan and there are other plumbing accessories as in a normal 'active' set up.

1. BACKGROUND AND DETAILED DESIGN OF SYSTEM

A prevailing concern at the early design stage was that the system should be cheap to instal as part of an energy-efficiency retrofit and general upgrading of the fabric. Since the roofing was in any case being renewed, an integral solar air collector seemed a feasible proposition. The collector glazing substituted for roof tiles, the absorber for roof boarding or 'sarking' on top of the rafters, and the insulation was fixed to the underside of rafters, with a simple boxed plenum at top and bottom of the collector. Work at Napier University (Small D. 1990) suggested that a perforated metal plate absorber would give a satisfactory performance. Fixed to the top of the rafters air would initially flow above the absorber from the stairwell, and then be drawn through small holes into 'ducts' between the rafters - as in Fig. 1.

A cheap, efficient air-to-water heat exchanger was the next concern. A proposition to simply bubble the air from the collector through cold supply water was discarded due to a perceived risk of supporting the 'legionella pneumophila' bacterium. The next option pursued was a standard vehicle radiator. Tests carried out by a group of students at Napier University were encouraging enough to support its use.

The only intervention needed to include the stairwell in the thermal loop was a vertical duct housed within existing stores. Air delivered at the foot of this space having passed through the air-to-water heat exchanger - see Fig. 2 - would result in enhanced air temperature and quality within these common spaces which normally tend to be rather stagnant. Naturally the more efficient the exchanger, the less energy would be available to preheat the stairwell; but the function of stirring and refreshing the air within this space was considered as important as preheating. The thermal loop was also fairly 'open' since the stairwell would be subject to journeys to and from each of six homes, and although this acted against the temperatures which could be achieved within the collector, it acted for air quality at both the outer and inner thresholds of flats. The heavy mass of the concrete stairs, and bounding walls, ceiling and floor, would also act to reduce any tendency to overheat during summer without additional venting.

2. PRACTICAL PROBLEMS WITH SYSTEM

Integrating the collector with the roof construction in the manner described made the task of securing an airtight system quite onerous. Also in one of the instrumented collectors (used for analytical purposes in this paper), the ducting between collector head and heat exchanger was found to have an open end after several weeks of operation - a building contractor's defect. This meant that air from the collector was mixing liberally with air from the loft space before passing through the exchanger.

Although rubber mounting for the fans was fairly successful in limiting noise transmission to bedrooms below, and fans were designed to be switched by a sensor located at the top of the collector (i.e. they would not normally run at night), two problems ocurred. Firstly, there was a manual override which allowed fans to run continuously, and some were left in this position in the early stages. Although this had no effect on a collector's water preheat capability since even during the night the water was always cooler than the outside air temperature, and cooling the stairwell was not a handicap in summer, it had

The collector cover is 6mm clear single glass in standard aluminium glazing bars. Having deducted for bars and flashings, the clear aperture of each collector is 9.65 m^2 (19.3 m^2 per pair of collectors serving a preheat tank for 6 flats). The size is partly a consequence of aesthetic considerations - collectors are visually aligned with the glazed-in verandas in terms of width - and partly practical - the length is limited by available roof from eaves to ridge. Six collectors face almost due South-East and another six due West. The insulated backing to the collector is 50 mm Foamglass, with all joints sealed; the 215 Watts centrifugal fan has a design flow rate of 500 m^3/h at 400 Pa; the insulated fibreglass preheat tank has an actual capacity of 682 litres, and the cold feed tank 227 litres.

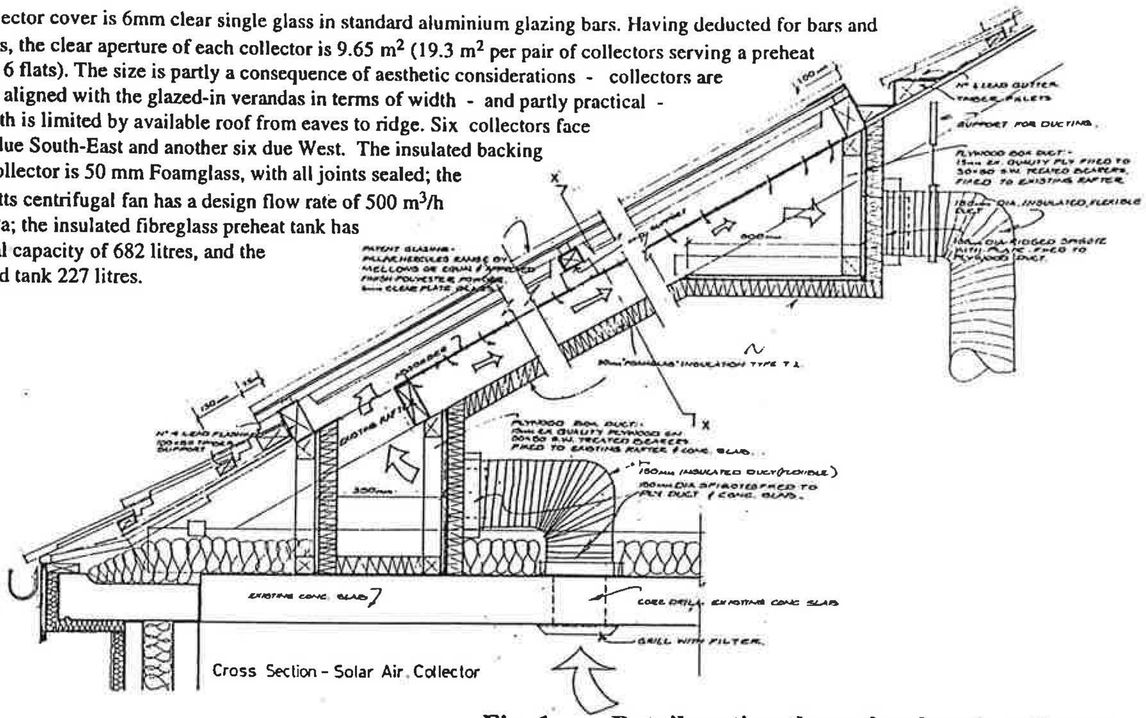

Fig. 1 **Detail section through solar air collector**
Source: Community Architecture Scotland - now CAS Architects

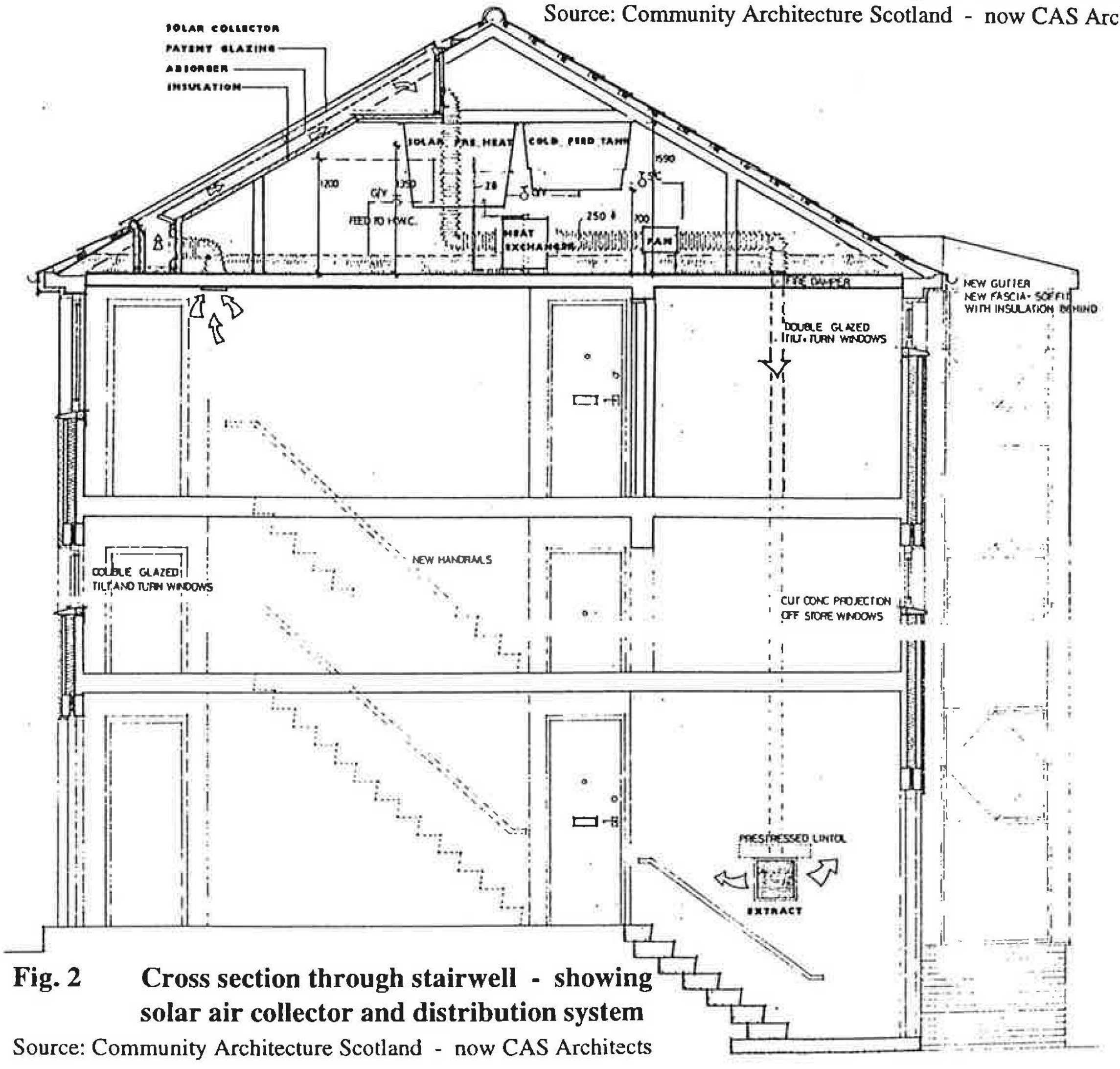

Fig. 2 **Cross section through stairwell - showing solar air collector and distribution system**
Source: Community Architecture Scotland - now CAS Architects

the potential to disturb occupants. Secondly, in one particular case, an occupant who worked night shifts and liked to sleep in the room below the fan during the day, was disturbed enough to insist the fan be switched off. Unfortunately this was the second of two instrumented collectors. The only positive outcome was that the stagnating pair of collectors did not suffer damage from overheating, and comparison of preheated and non-preheated stairwell temperatures was possible - and quite perceptible to the occupants. The control of flow rate by a sliding bar between 'max-min' settings also proved to be a monitoring problem, since it was evident that with relatively frequent visits to the loft space by visitors and contractors during the post-contract period that the setting was intermittently altered.

Another relatively minor problem was that at various stages, due to either rather insubstantial door ironmongery and/or vandalism, the access doors to stairwells were left open for prolonged periods, resulting in the semi-closed thermal loop becoming much more open than intended.

A more important problem concerned the specification of standard vehicle radiators as air-to-water heat exchangers. Although initial trials had been with an alloy radiator which was compatible with copper, the radiators as-fitted were in aluminium. These were subsequently exchanged in mid-October 1992, the new copper exchangers being purpose-made, but not as efficient as the aluminium ones.

3. PERFORMANCE MONITORING

For the purposes of this paper, four scenarios of one week duration are investigated:
Scenario A: 15-21/5/92 - before open end in ducting was sealed up; original heat exchangers;
Scenario B: 6-12/10/92 - after open end in ducting was sealed up; original heat exchangers;
Scenario C: 25-31/3/93 - before additional sealing of complete system; new heat exchangers;
Scenario D: 9-15/7/93 - after additional sealing of complete system; new heat exchangers.

It should be noted that solar radiation measurements were not available for Scenario A. Apart from solar radiation, the following temperatures were recorded: air temperature - 1] outside below eaves, 2] above and below absorber at high, low and middle level, 3] before and after heat exchanger, 4] in the stairwell at the outlet and inlet registers, and at various levels away from the registers; 5] in the loft space at front (solar side) and rear; water temperature - 1] preheat tank at high, middle and low level (sensors on outside of tank), 2] on cold feed pipe to preheat tank, serving six individual hot water cylinders. The water flow rate leaving the 6-flat pre-heat tank was also measured.

Table 1 summarises critical temperatures and their differentials for each scenario. The open ended duct in Scenario A can clearly be seen comparing the very high collector outlet temperatures with the significantly lower values at the inlet to the heat exchanger. The drop across the exchanger is similar for A and B, but equivalent C and D values for the new copper exchanger are predictably much lower. In order to compare system efficiencies, both the solar supply and the water consumption are required. This is summarised in Table 2, the efficiency taken as the ratio $Qs^{\textit{to heat hot water}}$: $Qs^{\textit{incident on collector}}$, where Qs is the quantity of solar energy. The efficiency therefore ignores the $Qs^{\textit{ventilation preheat}}$.

	SCENARIO A			SCENARIO B			
Location - all values	17/5/92	17/5/92	15-21/5/92	10/10/92	10/10/92	6-12/10/92	
diurnal except 9&10	mean	'snapshot'	mean	mean	'snapshot'	mean	
1. Collector inlet	20.17	20.50	19.74	16.48	17.50	15.36	°C
2. Collector outlet	46.65	73.00	39.65	26.93	40.50	20.91	°C
difference 2-1	*26.48*	*52.50*	*19.91*	*10.45*	*23.00*	*5.55*	*K*
3. Inlet to heat exchanger	31.85	43.50	27.74	25.70	39.00	19.80	°C
4. Outlet from heat exch'r.	25.38	30.00	23.04	19.90	27.00	16.78	°C
difference 3-4	*6.47*	*13.50*	*4.70*	*5.80*	*12.00*	*3.02*	*K*
5. Outside	19.12	22.30	16.19	7.08	7.06	9.19	°C
6. Loft space	22.88	26.60	20.57	13.23	13.80	13.62	°C
7. Cold feed	12.97	13.00	12.88	11.10	11.00	11.29	°C
8. Top of preheat tank	30.20	34.50	26.83	17.78	23.00	14.60	°C
difference 8-7	*17.23*	*21.50*	*13.95*	*6.68*	*12.00*	*3.31*	*K*
difference 3-7	*18.88*	*30.50*	*14.86*	*14.57*	*28.00*	*8.51*	*K*
9. Cold feed 24h	12.99	n.a.	12.98	11.13	n.a.	11.30	°C
10. Top of preheat tank 24h	29.22	n.a.	26.18	15.61	n.a.	13.59	°C
difference 10-9	*16.23*	*n.a.*	*13.20*	*4.48*	*n.a.*	*2.29*	*K*
	SCENARIO C			SCENARIO D			
Location - all values	25/3/93	25/3/93	25-31/3/93	13/7/93	13/7/93	9-15/7/93	
diurnal except 9&10	mean	'snapshot'	mean	mean	'snapshot'	mean	
1. Collector inlet	15.16	16.00	13.45	19.75	20.00	18.49	°C
2. Collector outlet	31.50	47.50	21.82	34.67	55.00	26.69	°C
difference 2-1	*16.34*	*31.50*	*8.37*	*14.92*	*35.00*	*8.20*	*K*
3. Inlet to heat exchanger.	29.52	44.50	21.21	34.22	50.50	26.23	°C
4. Outlet from heat exch'r.	26.91	39.50	20.06	32.23	45.50	25.10	°C
difference 3-4	*2.61*	*5.00*	*1.15*	*1.99*	*5.00*	*1.13*	*K*
5. Outside	6.31	6.40	7.36	16.57	15.60	13.46	°C
6. Loft space	13.13	13.70	11.91	21.32	20.00	18.02	°C
7. Cold feed	6.02	6.00	6.29	14.58	15.00	14.08	°C
8. Top of preheat tank	12.68	16.50	11.26	22.33	25.50	18.75	°C
difference 8-7	*6.60*	*10.50*	*4.97*	*7.75*	*10.50*	*4.67*	*K*
difference 3-7	*23.46*	*38.50*	*14.92*	*19.64*	*36.50*	*12.15*	*K*
9. Cold feed 24h	6.06	n.a.	6.38	14.52	n.a.	14.06	°C
10. Top of preheat tank 24h	10.82	n.a.	10.11	21.38	n.a.	18.12	°C
difference 10-9	*4.76*	*n.a.*	*3.73*	*6.86*	*n.a.*	*4.06*	*K*

Table 1 One week collector scenarios A-D - comparative air collector system temperatures

	SCENARIO B		SCENARIO C		SCENARIO D	
	10/10/92	6-12/10/92	25/3/93	25-31/3/93	13/7/93	9-15/7/93
efficiency %, hot water only	8.62	4.39	8.15	6.57	4.60	3.96
hot water consumption (l)	590	2,930	740	3,250	310	2,990
Q_s incident on collector (kWh)	35.6	177.3	50.1	213.9	53.7	356.0

Table 2 One week collector scenarios B-D - comparative efficiencies and water consumption

Having accepted that efficiencies are disappointingly low, it is interesting that although scenario C has a less efficient heat exchanger (HE), the solar water heating efficiency (E^{shw}) for the week is higher than that of scenario B. To offset its HE-handicap, weather conditions are more favourable for C compared with B. Not only is the solar supply some 20% greater over the week and 40% on the sample day, but lower cold feed temperatures result in negligible drops/losses from top of preheat tank to the loft space in the case of C - 0.3 K from 11.30-13.30 on 25/3/93, compared with 7.2 K for B's sample day.

An apparent paradox is that with a 66% greater solar supply over the week, scenario D does not quite manage to match C's rise in collector temperature, probably due to someone having tampered with the fan speed. So D only just exceeds C's weekly rise in water temperature (lines 10-9, Table 1); and since D's weekly consumption is 8% less than that of C, and the difference between air temperature at the HE inlet and cold feed (lines 3-7, Table 1) is significantly lower, so also is the efficiency.

In terms of the ventilation preheat contribution to the stairwell, comparing October '92 and March '93 for the whole month with and without the solar contribution, the difference is somewhat below and above 3K respectively at the coldest lower part of the space.

CONCLUSIONS

1) Although water heating efficiency is low, this is offset by a perceptible rise in temperature within the common stairs, at the same time permitting rapid rates of air change and so good air quality. The system as installed was not strictly value for money. At a cost of £1,660 per house, water and space heating energy pay-back relative to monitored performance is not viable. Nevertheless the freshness combined with free warmth achieved in the entrance area has a value which is real to the occupants.

2) A more efficient air-to-water heat exchanger is required without compromising either cost or practicality (e.g.compatibilty with plumbing pipes); and to cope with temperature differentials between ducts, tanks etc and loft space, these 'hot' components should be well insulated.

3) More work is required in order to optimise fan speed and the setting should be tamper-proof.

4) The collector's perforated absorber plate appears to work well, and although sealing the integrated constructional system required careful attention, the temperature drops between key stages of the system after initial 'snagging' (post-scenario A) indicates that adequate air-tightness was achieved.

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