Comparison of commercial and do-it-yourself solar collectors

Other

THE OPEN UNIVERSITY

ALTERNATIVE TECHNOLOGY GROUP

COMPARISON OF COMMERCIAL AND DO-IT-YOURSELF SOLAR COLLECTORS

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January 1979

"Don't invest in anything that

eats or needs repainting"

Oliver Wendell Holmes

1. INTRODUCTION

Performance testing of flat plate solar collectors is under development in several countries and there are several major research programmes underway, notably the International Energy Agency's Programme on Collector Testing and the European Commission's Programme on Solar Energy, (ISES, 1977a). These programmes aim to develop test procedures for flat plate solar collectors in order to establish standards against which to assess the growing number of commercial solar collector designs entering the market. One survey showed that in 1977 there were over 70 manufacturers of solar collectors in the UK alone, (McVeigh and Schumacher, 1978).

The aim of the work reported in this paper is much more modest, namely to compare two designs of flat plate solar collector for domestic water heating - a commercially available design and a design suitable for do-it-yourself construction. Apart from the idea of doing-it-yourself being an important aspect of the alternative technology philosophy, the economic evidence suggests that whereas do-it-yourself solar water heating systems are likely to be cost-effective in Britain, unless fuel prices increase at a high rate over a long period, professionally installed commercial systems tend not to be cost-effective, (Chapman, 1978; Consumers' Association, 1977). This is largely a matter of price rather than of performance since, as Alan Horton has shown in efficiency tests on sixteen designs of solar panel conducted at the Centre for Alternative Technology, a do-it-yourself design built around a central heating radiator has a thermal performance comparable to that of all but the best commercial designs and considerably better than several of the commercial collectors marketed in 1975-77 (Horton, 1978). Tabor (1978) has commented that solar energy systems designers should not aim for the greatest efficiency in their equipment, but cheaper systems. There is no point, he argues, in adding a few percent to the efficiency of a collector or paring a few pounds off the price of a solar panel when the cost of installing the system is perhaps three times the cost of making it. Tabor does not go so far as to advocate do-it-yourself construction, but suggests that the way to reduce costs is to assemble collectors on-site (presumably from a kit of parts) rather than in a factory.

2. TESTING

The commercial design of solar collector was chosen after a survey of the collectors on the market in 1975. The 'Miromit' collector was selected because it was a well-proven collector representing a common type of design and came from a manufacturer with over twenty years experience of solar heating. The do-it-yourself collector was designed around a central heating radiator, spray-painted black on its upper surface, as this made for simple construction within the reach of the average handyman or woman and according to one survey represented common practice amongst do-it-yourself solar collector makers (Consumers' Association, 1977). (The Miromit was used as the reference panel in the efficiency tests conducted by Horton (1978) and a similar design of do-it-yourself panel was also tested).

Details of the two designs tested are given in Table 1.

Other types of do-it-yourself design not tested include (a) the 'solar roof' collector, such as that described by Brachi (1974) and Vale and Vale (1975), in which an area of dark-coloured roof (glazed or unglazed) acts as the basic collector over which the water to be heated is trickled; (b) a very simple 'swimming pool' heater, such as that described by McVeigh (1977), in which water is trickled between two sheets of plastic film, the upper sheet black, supported on a plywood base. Both are reported to be durable and to give good results.

TABLE 1

Commercial design	Do-it-yourself design
'Miromit' flat plate solar collector. A proven design made in Israel by a company with over 20 years experience in collector design and production.	Designed and constructed by C. Hughes, Open University technician using information from alternative technology journals.
Effective area 1.2m^2	Effective area 1.2m^2
Construction: 7 vertical steel tubes welded to header tubes top and bottom over which is welded thin steel sheet covered on the upper side with a 'selective' coating.* Encased in a galvanized steel box insulated at the back with 2in. thick rockwool. Glazed with 3mm. window glass.	Construction: standard single 27in. x 69in. central heating radiator aerosol sprayed with matt black paint on the upper side. Underside covered with aluminium foil. Encased in a box made from 4in. thick foam polystyrene waterproofed with black polythene sheet. Glazed with 0.030in. PVC sheet fixed with waterproof tape. Subsequently reglazed with 0.125in. perspex.
Price (1975): £85 (1977): £135	Construction cost: £25 (Materials only)

* a coating designed to reduce radiation losses from the absorber surface. A selective coating acts as an efficient absorber of incoming short-wave radiation, but is a poor emitter of long-wave radiation.

For the purposes of comparative testing the two collectors were installed side by side on a laboratory roof at an angle of 45^{o} to the horizontal (the angle which offers the best collection efficiency around the year in Britain) and facing almost due South (see Figure 1). Each collector was connected independently to a 40 gallon plastic water storage tank located in the laboratory below (see Figure 2). Each circuit included a centrifugal pump for water circulation. It is important to ensure that circulation between the storage tank and the collector can only take place when the system is able to gain energy. A separate control unit was used for each collector to switch on its circulating pump when the water leaving the collector was warmer than that in its storage tank. To detect the water temperatures thermistors were located near the outlet of each collector and in each storage tank. The thermistors formed part of a bridge circuit based on that developed by Biotechnic Research and Development for controlling a solar roof (the circuit is described in BRAD, 1975). The temperature difference required between the two thermistors for the circuit to switch on the pump could be adjusted. This is because when flow begins after a stagnant period the panel temperature initially falls. If the temperature differential is set too small the circuit will switch off very shortly after the flow starts leading to a repeated on-off cycle. The adjustable differential permitted the circuit to be set for sensitive operation without 'hunting'.

The thermistor in each tank also served to give comparative readings for the storage water temperature.

3. METHOD

The two collectors were operated at regular intervals over a period of about two-and-a-half years from June 1975. Since both collectors were of equal effective area (1.2m^2), were operating

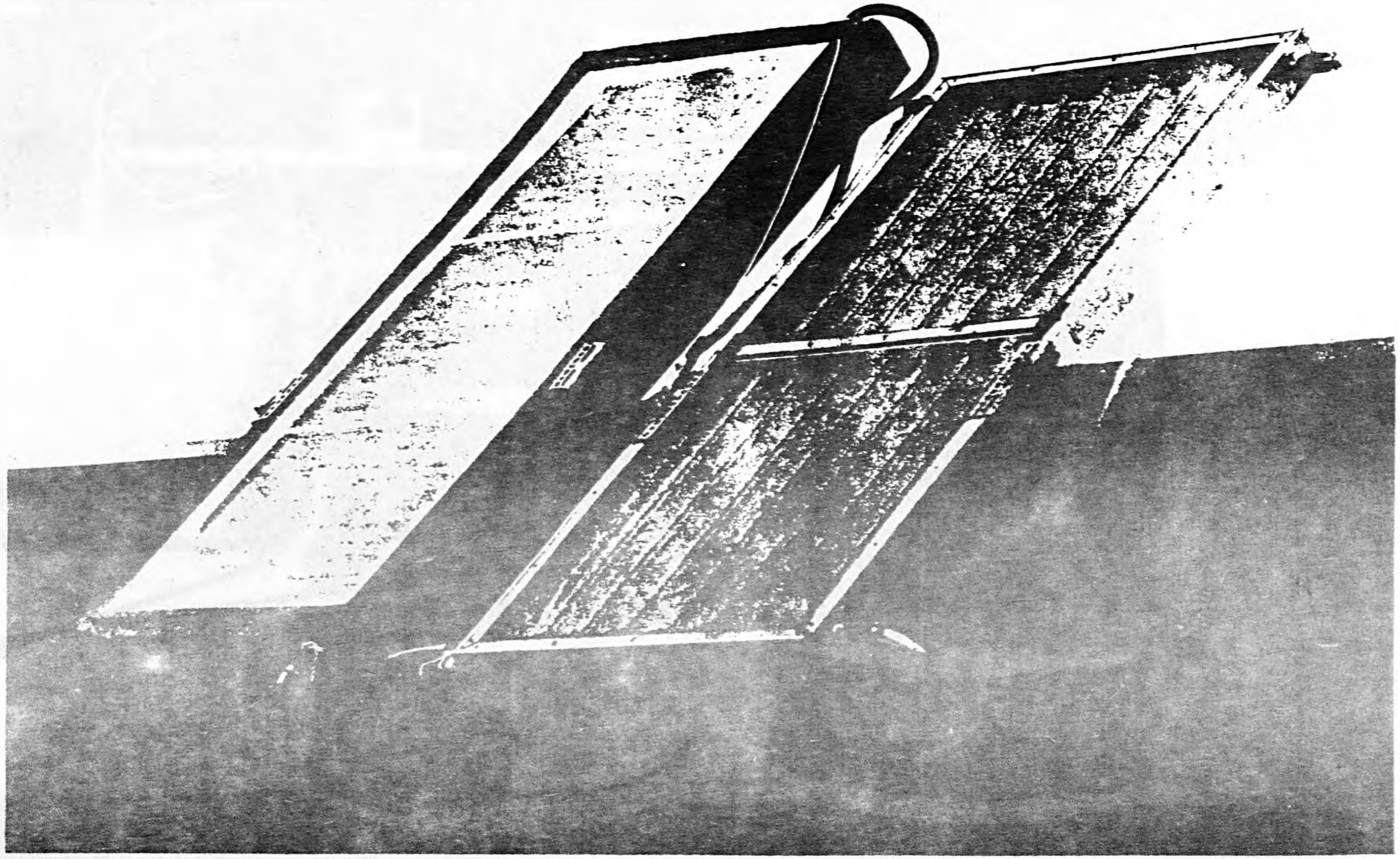

Figure 1

Do-it-yourself solar collector (left) and 'Miromit' commercial solar collector (right) under test

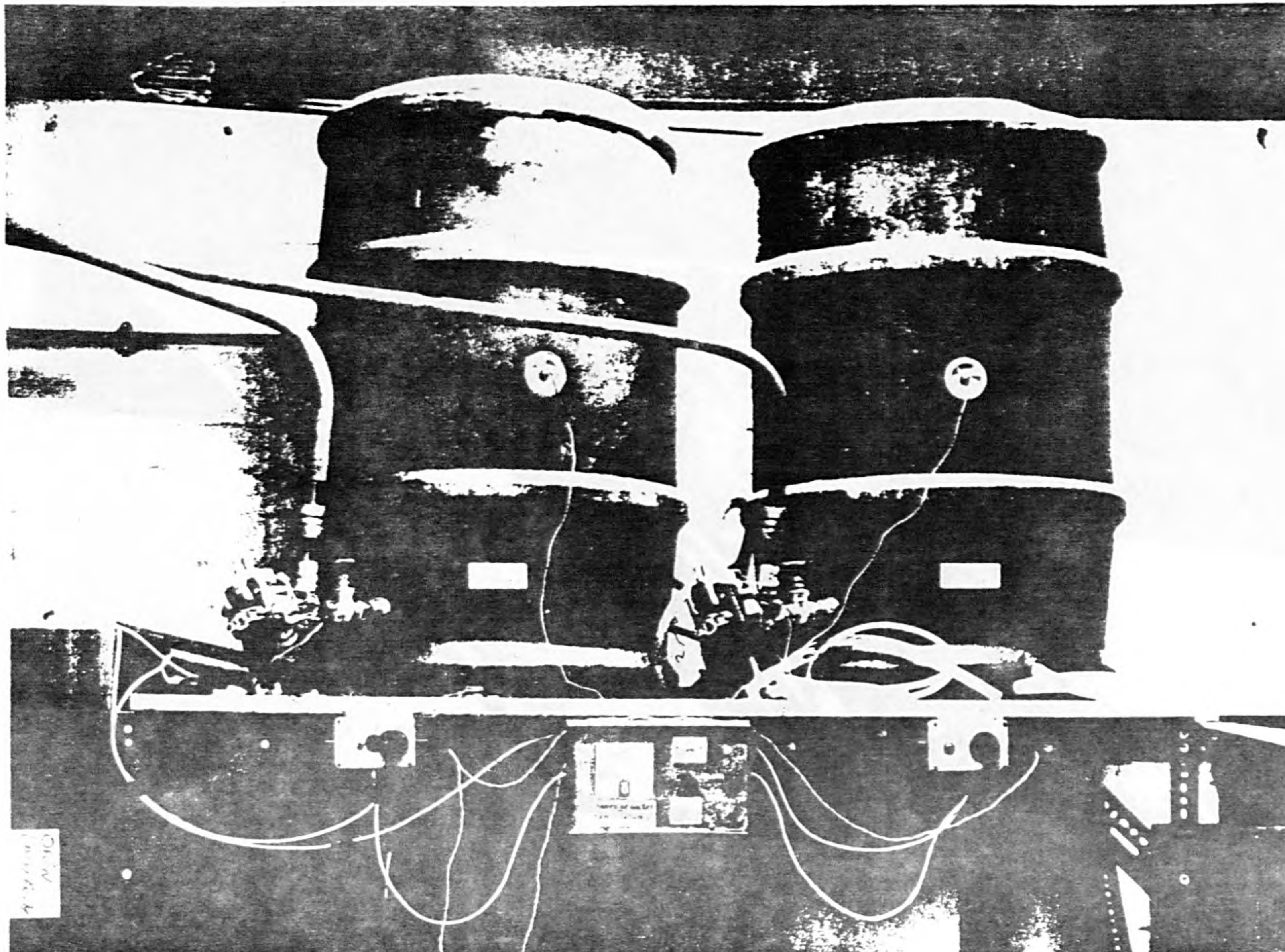

Figure 2

Storage tanks, control systems and pumps for d-i-y and commercial collectors in the same environmental conditions, were heating equal volumes of water and were subject to similar losses from the pipework, storage tanks etc., it was only necessary to compare the rise in temperature in the two storage tanks over a given period in order to obtain a direct comparison of the thermal performance of the two systems.

During a test run the temperature in the storage tanks was monitored at regular intervals. Tests were conducted under a variety of weather conditions during 1976 from mid June, when the mean irradiation is normally at its highest level, to December, when irradiation is normally at its lowest. It should be noted however that the summer of 1976 was exceptionally sunny and hot and mid summer irradiation levels would have been considerably higher than normal.

4. THERMAL PERFORMANCE

The main finding was that, under these test conditions at least, the thermal performance of the two systems was to all intents and purposes, identical. The d-i-y collector system tended to produce marginally higher water temperatures than the commercial collector system in strong sun-shine. In weak sun-shine or under overcast conditions the two systems performed equally well. Sample test results are given in Appendix 1.

The temperature rise in the 40 gallons (211 litres) of water in the storage tanks in a 10a.m. to 5p.m. day ranged from a maximum of 13°C for the d-i-y. collector and 12°C for the Miromit to less than 1°C (see Appendix 1). (In a domestic installation the ratio of hot water storage capacity to collector area is usually around 11 gallons (50 litres) per m^2 to obtain higher water temperatures). Since the tanks were uninsulated it is not very meaningful to give the solar gains represented by these temperature rises, but to give an idea of the gains involved a 12^{o}C rise in the storage tank water would need 2.53KWh (excluding heat losses) requiring a minimum solar gain of 2.11KWh/day/m^2 from our 1.2m^2 collectors.

These findings suggest that, for a domestic hot water pre-heating system using relatively simple equipment, the design of the solar collector itself does not present a critical problem and that it is possible for a do-it-yourself constructor to build a system giving a performance comparable to that of many commercial systems, possibly better. This does not mean that there is no difference between the efficiencies of different designs of solar panel, as Alan Horton has shown in his comparitive efficiency tests on fifteen commercial solar panels and one do-it-yourself panel at the Centre for Alternative Technology in Summer 1977. Some of Horton's results are shown in Figure 3. Results for the Miromit and the d-i-y collector are shown in bold. As can be seen at low values of $\Delta T/I$ (corresponding to the conditions in the tests reported in this paper), the instantaneous efficiency of the Miromit and the d-i-y collector are very similar. The poor performance of certain of the collectors tested by Horton is due to their construction rather than their inherent design. To ensure high performance it is vital that the collector is constructed so as to provide good thermal contact between the absorber surface and the working fluid.

The selective coating on the Miromit collector might have been expected to give it an advantage over the black aerosol paint surface of the d-i-y collector. However at low temperature differences between the heated water in the collector and the surroundings, selective coatings offer no particular advantages, (see Figure 3). The value of a selective surface and the overall efficiency of a solar water heating system depends less on the design of the collector than on the way in which the system is used,

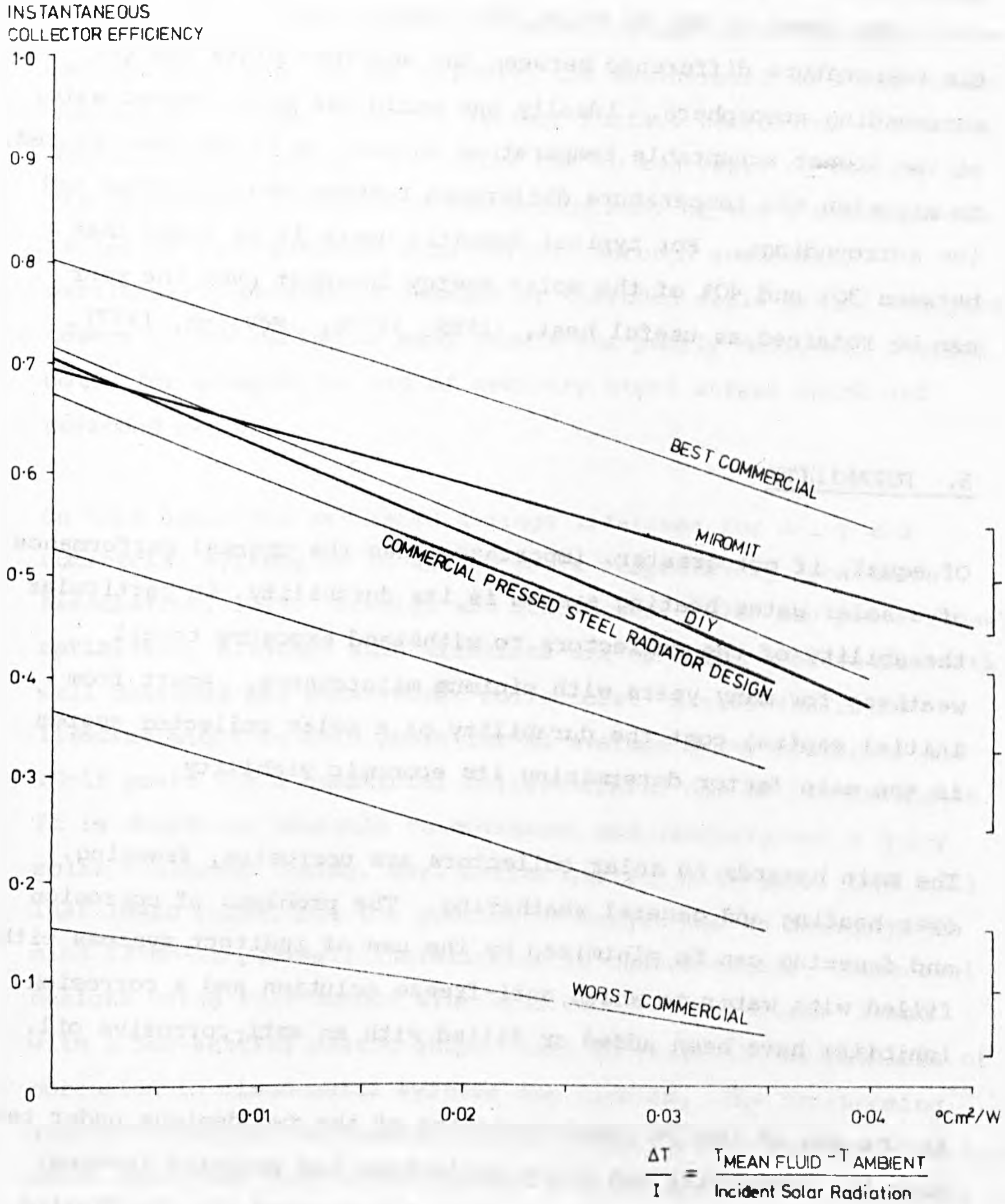

Figure 3

Comparative instantaneous efficiency measurements of selected solar collectors measured at the Centre for Alternative Technology, May-July 1977 (adapted from Horton, 1978).

in particular how much warm water is drawn off and replaced by cold, the times of day at which this occurs and how this affects the temperature difference between the absorber plate and the surrounding atmosphere. Ideally one would use solar heated water at the lowest acceptable temperature as soon as it has been heated, to minimise the temperature difference between the collector and the surroundings. For typical domestic users it is found that between 30% and 40% of the solar energy incident over the year can be retained as useful heat, (ISES, 1977b; McVeigh, 1977).

5. DURABILITY

Of equal, if not greater, importance than the thermal performance of a solar water heating system is its durability, in particular the ability of the collectors to withstand exposure to all weathers for many years with minimum maintenance. Apart from initial capital cost the durability of a solar collector system is the main factor determining its economic viability.

The main hazards to solar collectors are corrosion, freezing, over-heating and general weathering. The problems of corrosion and freezing can be minimised by the use of indirect systems either filled with water to which anti-freeze solution and a corrosion inhibitor have been added or filled with an anti-corrosive oil.

At the end of the 2½ years operation of the two designs under test, both the commercial and d-i-y collectors had resisted internal corrosion well. However, some rain had entered via the glazing strip of the Miromit resulting in some slight rusting of the absorber surface. The d-i-y collector surface was still in good condition. The original PVC glazing sheet on the d-i-y collector had to be replaced with perspex sheet within one year because the PVC buckled in the heat of the 1976 summer. The sun also caused some distortion of the polystyrene insulation on the d-i-y collector and the polythene covering over the insulation had been torn by the wind. While both collectors were still functioning after two years, the casing of the d-i-y collector required refurbishing and, on the Miromit, the weathersealing strip needed replacing in order to avoid further surface corrosion. Likewise Horton (1978) reports that, after one to two years on display at the Centre for Alternative Technology, many of the sixteen panels he tested had 'suffered considerably through weathering, particularly because of leaking or corroded seals around the glass covers'. The casing of many panels was poorly designed: Horton notes, for example, the use of ordinary steel screws which had corroded badly.

On this basis the estimated average lifetimes for d-i-y and commercial systems of 10 and 20 years respectively (Consumers' Association, 1977; McVeigh and Schumacher, 1978) may prove somewhat optimistic, although such lifetimes are no doubt achieveable with well designed and constructed collectors. A more realistic lifetime might be 6-10 years for an average d-i-y collector and 10-15 years for a commercial collector, with one or two overhauls. It is doubtless possible to construct and weatherproof a d-i-y solar collector (using, say, marine quality materials) that will last 15-20 years, but the problem of weight has to be bourne in mind if do-it-yourself installation is contemplated. Commercial designs using roll-bonded aluminium covered with glass fixed with a non-setting mastic should last 20 years if the problems of corrosion in mixed-metal systems are tackled. The forthcoming British Standard for domestic solar water heating systems, the draft of which specifies that solar systems should have a life comparable to that of conventional heating installations (British Standards Institution, 1978), should help to raise the current poor standards of durability.

6. ECONOMICS

The simplest method of assessing the economics of a solar heating system is to calculate the pay-back period.

Pay-back period (in years) $p = \frac{C_o}{A_o}$ where C_o = capital cost of system

A_o = annual value of fuel saved by solar installation

Thus for a $4m^2$ professionally installed, commercial system costing £650 which saves 1300 KWh of on-peak electricity costing 2.5p/KWh;

$$p = \frac{650}{1300 \times 0.025} = 20 \text{ years}$$

For a $4m^2$ d-i-y system of equal efficiency costing £275;

$$p = \frac{275}{1300 \times 0.025} = 8.5 \text{ years}$$

Clearly, to be financially worthwhile, the payback period must be less than or equal to the lifetime of the system. In the two examples given above a commercial system would just recover its capital cost provided that it lasts 20 years without maintenance (which is unlikely), whereas the d-i-y system would recover its cost if it lasted, say, 10 years without major maintenance (which seems possible).

This simple method of economic assessment, however, fails to take into account several factors which determine the actual economics of solar heating systems from the viewpoint of the individual consumer. These are:

- the interest charges on borrowed capital or the opportunity cost of investing savings in solar heating
- the general rate of inflation
- the rate of fuel price inflation
- the actual lifetime of the system
- running costs and maintenance charges
- losses in efficiency over the lifetime of the system

The problem in taking these variables into account is that it is extremely difficult to forecast trends in inflation, fuel prices and interest rates over a long period and, given the lack of experience with solar heating in Britain, to estimate system lifetimes, maintenance costs and efficiency changes.

For the individual contemplating installing solar water heating what is likely to matter is the probably annual cash flow resulting from the investment, suitably adjusted to take account of inflation. In this section I give four examples showing cash flows arising from:

- a professionally installed, commercial system, financed from borrowed money;
- a d-i-y system built from scratch, financed from savings;
- a d-i-y system built from a commercial kit, financed from savings.

The assumptions regarding future inflation rates and fuel prices are the same in each case and it is also assumed that the efficiencies of all the systems compared are equal and that, given regular maintenance, this efficiency stays constant over time.

Example 1

Consider a $4m^2$ professionally installed, commercial system financed from a bank loan repayable over 3 years.

In 1977 the cost of such a system was typically £550-£750 (Consumers' Association, 1977; McVeigh and Schumacher, 1978). Assume a cost of £650.

Over the period 1976-78 the interest on a bank ordinary loan for an investment which attracted full tax relief was in the range 5.9% - 10.1% for a standard rate taxpayer and 3.6% - 6.0% for a higher rate taxpayer. Assume an interest rate of 8%.

Competitive delivered energy costs for water heating in 1977 were:

On-peak electricity	2.45p/KWh
Gas	0.78p/KWh first 1500KWh
	0.52p/KWh over 1500KWh

Corresponding useful energy costs are:

On-peak electricity 2.45p/KWh, assuming 100% efficiency for electric immersion heaters.

Gas 1.6p/KWh-2.2p/KWh, assuming that water is heated by a gas central heating boiler (The calculation of useful energy costs for the gas replaced by solar energy is given in Appendix 2. These depend on the variable efficiency of gas boilers at different loads. In general solar water heating will save gas when the boiler is operating at lower efficiencies during the summer months).

Mean amount of energy collected by the solar heating system is in the range 280-375KWh/m^2/year (McVeigh, 1977). Assume a figure of 350 KWh/m^2/year (Building Research Establishment, 1975; Courtney, 1976).

Mean ammount of energy collected by a 4m^2 system

4 x 350 = 1400 KWh/year.*

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*In fact not all the energy collected will necessarily result in actual fuel savings and so these assumptions are probably optimistic for average British summers. Tests on a 40ft^2 (4m^2) solar-assisted domestic hot water system in a Somerset house by Don Engineering Ltd. using the company's 'Solacyl' collectors (which Horton (1979) indicates have an efficiency similar to that of a d-i-y collector) yielded fuel savings, compared to a standard electric water heating system operating under the same conditions, of 916KWh in the period Sept. 1973-Aug.1974 and 1053KWh in the period Sept. 1974 - Aug. 1975 (ISES, 1977a).

Table 2 CASH FLOW: COMMERCIAL SYSTEM, BANK LOAN

Year	Assumed inflation rate %	Assumed fuel price inflation %	Fuel (on peak electricity) savings £/year	Maintenance charges £/year	Interest rate on loan %	Loan repayment £/year	Net cash flow £/year	Present value of net cash flow £/year	Cumulative cash flow at present values £
1	9.0	13.0	35.49		8	252.24	-216.25	-198.30	-198.30
2	8.0	12.0	40.31		8	252.24	-211.93	-179.93	-378.23
3	7.5	11.5	44.95		8	252.24	-207.29	-163.76	-541.99
4	7.0	11.0	49.89				+ 49.89	+ 36.82	-505.17
5	6.5	10.5	55.13	20			+ 35.13	+ 24.31	-480.86
6	6.0	10.0	60.64				+ 60.64	+ 39.54	-441.32
7	6.0	10.0	66.70				+ 66.70	+ 41.02	-400.30
8	5.5	9.5	73.04				+ 73.04	+ 42.58	-357.72
9	5.5	9.5	79.98				+ 79.98	+ 44.23	-313.49
10	5.0	9.0	87.18	38			+ 49.18	+ 25.92	-287.57
11	5.0	9.0	95.02				+ 95.02	+ 47.70	-239.87
12	5.0	9.0	103.58				+103.58	+ 49.51	-190.36
13	4.5	8.5	112.38				+112.38	+ 51.47	-138.89
14	4.5	8.5	121.93				+121.93	+ 53.41	- 85.48
15	4.5	8.5	132.30				+132.30	+ 55.43	- 30.05
assumed lifetime									
16	4.5	8.5	143.54	75			+ 68.54	+ 27.49	- 2.56
17	4.5	8.5	155.74				+155.74	+ 59.80	+ 57.24
18	4.5	8.5	168.98				+168.98	+ 62.02	+119.26

Assume that the circulation pump is rated at 0.1KW and runs for 1000 hours/year. Net amount of energy saved when electricity is replaced for water heating 1400 - 1000 x 0.1 = 1300KWh/year.

Assume that the system has an expected lifetime of 15 years, given maintenance charges of £20 and £38 after 5 and 10 years respectively.

Assume a starting inflation rate (f) of 9% per year falling gradually to 4.5% over 15 years (Energy Research Group, 1978). Fuel prices in the UK are expected to double in real terms by the year 2000. This corresponds to fuel price increase of (f+4)% per year.

Using the above assumptions for a solar system which replaces on-peak electricity for water heating it is possible to construct a table showing the net cash flow, the present value of this net cash flow and the cumulative cash flow discounted to present values. Table 2 shows these values for our $4m^2$ commercial system financed from an 8% bank loan repaid over 3 years.

As can be seen from Table 2 a professionally installed, commercial system seems unlikely to be cost-effective within an expected lifetime of 15 years. If the life of the system could be extended by a further 3 years at a cost of, say, £75 then a real return might be made.

If the calculations are repeated assuming a constant inflation rate of 10% per year and a corresponding fuel price inflation of 14% per year the result is still a small financial loss (about £17) after 15 years. After 18 years, assuming a refurbishing cost of £100, the result is a financial return of £137.

A professionally installed commercial system is only likely to be cost-effective from the consumers' point of view if its useful life is likely to exceed 15 years and on-peak electricity is replaced for water heating.

Example 2

Consider now a $4m^2$ system costing £650 similar to that in Example 1, but financed from a building society mortgage repayable over 15 years.

In the period 1976-78 interest on mortgates ranged between 5.6% - 7.2% including tax relief for standard rate taxpayers. Assume an interest rate of 6.5% per year.

Using the same assumptions as in Example 1,the cash flows are shown in Table 3. As before the professionally installed, commercial system appears unlikely to yield a financial return within the expected lifetime of the system. If however the lifetime could be extended by say another three years some return might be expected.

Example 3

Consider next a $4m^2$ do-it-yourself system financed from savings.

Estimates of the cost of do-it-yourself systems vary widely because some estimates assume the use of second-hand or salvaged components. Do-it-yourself constructors may also tend to underestimate costs. A do-it-yourself cost of £150-£200 for a $4m^2$ system at 1977 prices is given in Consumers' Association (1977). A more reliable estimate, however, is likely to be that given in McCartney and Ford (1978) who give the following breakdown of component costs for an actual d-i-y system (at 1977/8 prices):

	£
$4m^2$ Home-made collectors at £16.50/m^2 (using second-hand radiators)	65
200ℓ. copper cylinder (indirect)	56
Copper piping	28
Fittings	28
Pump and isolating valves	25
Anti-freeze	7
Pressurised vessel and filling assembly	35
Pump control	30
Total materials cost	275

TABLE 3 CASH FLOW: COMMERCIAL SYSTEM, MORTGAGE

Year	Assumed inflation rate %	Assumed fuel price inflation %	Fuel Saving £/year	Maintenance charges £/year	Loan repayment £/year	Net cash flow £/year	Value of £1 due to inflation	Present value of net cash flow £/year	Cumulative cash flow at present values £
1	9.0	13.0	35.49		69.12	-33.63	0.917	-30.84	-30.84
2	8.0	12.0	40.31		69.12	-28.81	0.849	-24.46	-55.30
3	7.5	11.5	44.95		69.12	-24.17	0.790	-19.09	-74.39
4	7.0	11.0	49.89		69.12	-19.23	0.738	-14.19	-88.58
5	6.5	10.5	55.13	20	69.12	-33.99	0.692	-23.52	-112.10
6	6.0	10.0	60.64		69.12	- 8.48	0.652	- 5.52	-117.62
7	6.0	10.0	66.70		69.12	- 2.42	0.615	- 1.49	-118.81
8	5.5	9.5	73.04		69.12	+3.92	0.583	+ 2.29	-116.52
9	5.5	9.5	79.98		69.12	+10.86	0.553	+ 6.01	-110.51
10	5.0	9.0	87.18	38	69.12	-19.94	0.527	-10.51	-121.02
11	5.0	9.0	95.02		69.12	+25.90	0.502	+13.00	-108.02
12	5.0	9.0	103.58		69.12	+34.46	0.478	+16.47	-91.55
13	4.5	8.5	112.38		69.12	+43.26	0.458	+19.81	-71.74
14	4.5	8.5	121.93		69.12	+52.81	0.438	+23.13	-48.61
15	4.5	8.5	132.30		69.12	+63.18	0.419	+26.47	-22.14
16	4.5	8.5	143.54	75	-	+68.54	0.401	+27.48	+5.34
17	4.5	8.5	155.74		-	+155.74	0.384	+59.80	+65.14
18	4.5	8.5	168.98		-	+168.98	0.367	+62.02	+127.16

TABLE 4 CASH FLOW: DO-IT-YOURSELF SYSTEM

Year	Assumed inflation rate %	Assumed fuel price inflation %	Fuel (on-peak electricity) savings £/year	Capital cost £	Maintenance cost £/year	Net cash flow £/year	Present value of net cash flow £/year	Cumulative cash flow at present values £
1	9.0	13.0	35.99	275		-239.01	-219.17	-219.17
2	8.0	12.0	40.31			+ 40.31	+ 34.22	-184.95
3	7.5	11.5	44.95			+ 44.95	+ 35.51	-149.44
4	7.0	11.0	49.89			+ 49.89	+ 36.82	-112.62
5	6.5	10.5	55.13		10	+ 45.13	+ 31.23	- 81.39
6	6.0	10.0	60.64			+ 60.64	+ 39.54	- 41.85
7	6.0	10.0	66.70			+ 66.70	+ 41.02	- 0.83
8	5.5	9.5	73.04			+ 73.04	+ 42.58	+ 41.75
9	5.5	9.5	79.98			+ 79.98	+ 44.23	+ 85.98
10	5.0	9.0	87.18		13	+ 74.18	+ 39.09	+125.07
11	5.0	9.0	95.02			+ 95.02	+ 47.70	+172.77
12	5.0	9.0	103.58			+103.58	+ 49.51	+222.28
13	4.5	8.5	112.38			+112.38	+ 51.47	+273.75
14	4.5	8.5	121.93			+121.93	+ 53.41	+327.16
15	4.5	8.5	132.30			+132.30	+ 55.43	+382.59

If new radiators or self-built copper tube and sheet absorbers are used the collector costs are given by McCartney and Ford (1978) as £33/m^2, giving a total d-i-y system cost of £341.

Assume a cost of £275 for our d-i-y system.

Assume an expected lifetime of the system of 10 years with a d-i-y maintenance charge of £10 after 5 years. Table 4 shows the cash flows resulting from the installation of such a system making the same assumptions about inflation rates as in the previous examples. As can be seen a low-cost d-i-y system begins to yield a positive return after 7 years if on-peak electricity is replaced. If the life of the system can be extended to say 12 years or more worthwhile financial returns can be made from such a system. It is likely that the do-it-yourself solar energy enthusiast would be satisfied with such an outcome, since the system will have saved energy as well as money.

Strictly however the returns from solar heating should be compared with those from alternative uses for the capital invested (given the same rates of inflation). An individual can for example expect to receive 6.5% interest after tax from a building society share account. If the annual interest foregone on £275 at 6.5% is subtracted from the annual fuel savings before adjusting to present values, the d-i-y solar heating system yields a positive financial return after 11 years instead of after 7 years. This suggests that a d-i-y system can be fully cost-effective if it can be made sufficiently durable to last at least 12 years.

<u>Example 4</u>

Consider finally a 4m^2 system built and installed from a d-i-y kit bought with savings.

Table 5 *CASH FLOW: DO-IT-YOURSELF SYSTEM FROM KIT*

Year	Assumed inflation rate %	Assumed fuel price inflation %	Fuel saving £/year	Capital cost £	Maintenance charges £/year	Net cash flow £/year	Present value of net cash flow £/year	Cumulative real cash flow at present values £
1	9.0	13.0	35.99	450		-414.01	-379.65	-379.65
2	8.0	12.0	40.31			+ 40.31	+ 34.22	-345.43
3	7.5	11.5	44.95			+ 44.95	+ 35.51	-309.92
4	7.0	11.0	49.89			+ 49.89	+ 36.82	-273.10
5	6.5	10.5	55.13		20	+ 35.13	+ 24.31	-248.79
6	6.0	10.5	60.64			+ 60.64	+ 39.54	-209.25
7	6.0	10.5	66.70			+ 66.70	+ 41.02	-168.23
8	5.5	9.5	73.04			+ 73.04	+ 42.58	-125.65
9	5.5	9.5	79.98			+ 79.98	+ 44.23	- 81.42
10	5.0	9.0	87.18		38	+ 49.18	+ 25.92	- 55.50
11	5.0	9.0	95.02			+ 95.02	+ 47.70	- 7.80
12	5.0	9.0	103.58			+103.58	+ 49.51	+ 41.71
13	4.5	8.5	112.38			+112.38	+ 51.47	+ 93.18
14	4.5	8.5	121.93			+121.93	+ 53.41	+146.59
15	4.5	8.5	132.30			+132.30	+ 55.43	+202.02
16	4.5	8.5	143.54		75	+ 68.54	+ 27.49	+229.51
17	4.5	8.5	155.74			+155.74	+ 59.80	+289.31
18	4.5	8.5	168.98			+168.98	+ 62.02	+351.33

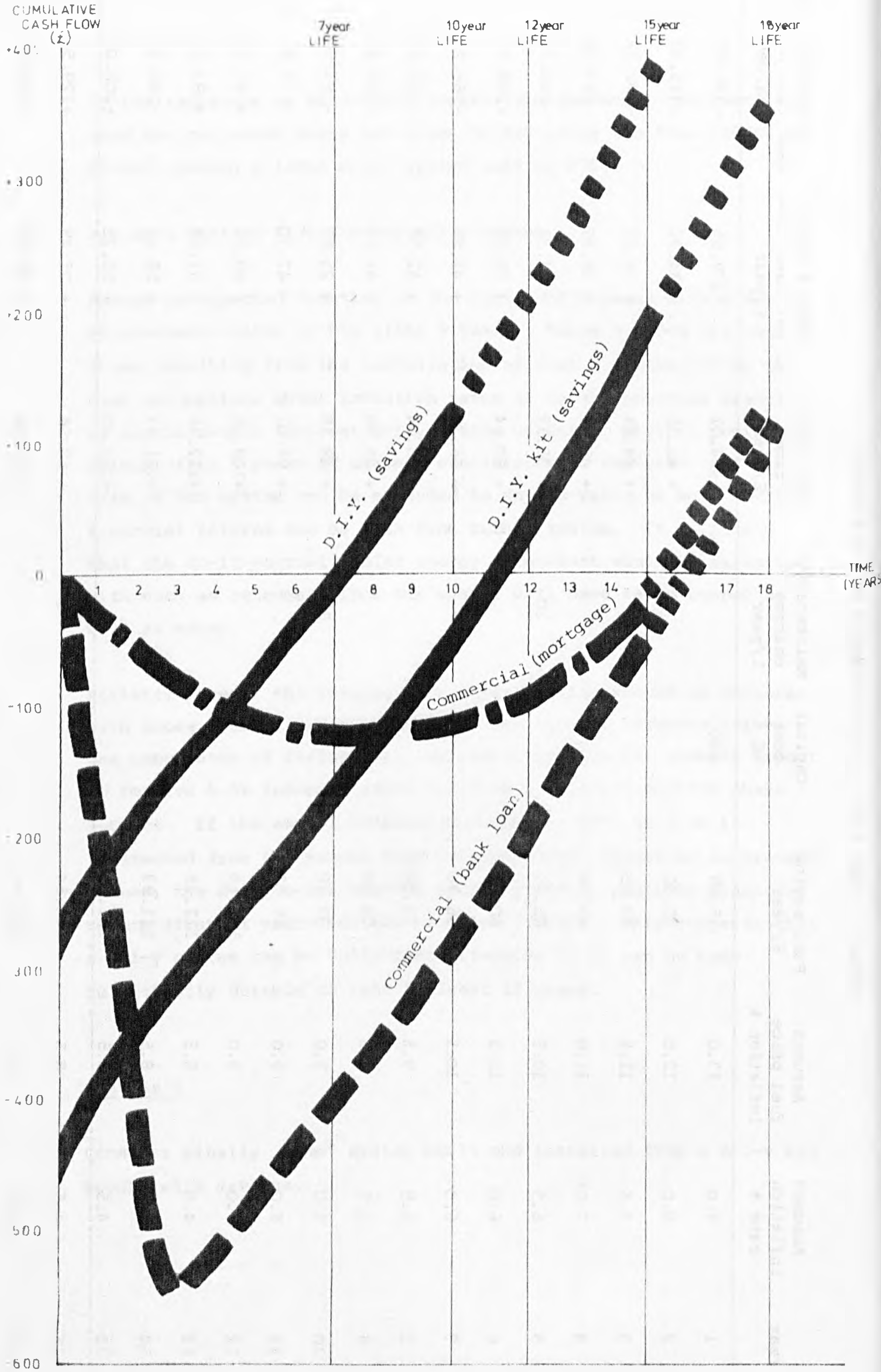
CUMULATIVE CASH FLOW (£)
+400
+300
+200
+100
0
-100
-200
-300
-400
-500
-600
7year LIFE
10year LIFE
12year LIFE
15year LIFE
18year LIFE
TIME (YEARS)
1
2
3
4
5
6
8
9
10
12
13
14
17
18
D.I.Y. (savings)
D.I.Y. kit (savings)
Commercial (mortgage)
Commercial (bank loan)

Figure 4

In 1977 the cost of $4m^2$ solar heating kits were in the range £400-£500 (Consumers' Association, 1977). McCartney and Ford (1978) give the cost of a $3.6m^2$ system using commercially available components at £469. Assume a cost of £450 and an expected lifetime of 15 years with maintenance costs of £20 and £38 after 5 and 10 years respectively.

Table 5 shows the cash flows arising from such an installation under the same assumptions used for previous examples. This seems likely to yield a positive return after 11 years and a worthwhile return within its expected lifetime of 15 years, more if its life can be extended to 18 years.

However, if the annual interest on £450 at 6.5% is subtracted from the fuel savings (as in Example 3) it is found that a d-i-y system from a kit is never fully cost-effective even after 18 years (when the cumulative cash flow would be -£148 at present values). In other words unless a consumer is particularly keen to save energy, they would be better advised to invest their money in a building society than on a d-i-y solar heating kit. Moreover, investment in solar heating to save energy would only be worthwhile after other more cost-effective energy-saving measures (such as loft and cavity wall insulation) had been undertaken.

Figure 4 summarises the tabular data for the above four examples.

7. SOME BROADER CONSIDERATIONS

The question of 'do-it-yourself' versus 'commercial' in the particular case of solar heating systems raises several broader issues that face the alternative technology movement as a whole.

One such issue is whether an aim of the AT movement should be to develop highly efficient technologies using the most advanced methods of research and development, or whether it should be to develop technologies that can be afforded, understood, maintained, and perhaps made, by the average person or group of people. In the case of solar heating technology, as we have seen, the do-it-yourself designer can make equipment of comparable performance to the simpler commercial designs at considerably lower cost. Solar water heating is, however, a relatively simple problem. Where more difficult problems, such as harnessing wind energy, are concerned, in order to achieve worth-while results quite sophisticated techniques and skills may be needed. Do-it-yourself on a 'community' scale can be very successful in developing more sophisticated and larger-scale alternative technologies, as has been demonstrated by the staff and students of Tvind College in Denmark who designed and built the world's largest wind generator, rated at 2MW.

Another issue is whether alternative technology equipment should be evaluated in the same way as other capital equipment, on the basis of how much financial return it offers to the individual consumer, firm, or other investor. In the case of solar heating, the installation of a system has costs and benefits some of which can be measured in financial terms and others which cannot. For example a d-i-y solar heating system is not only more likely to be cost-effective than a commercial installation, but offers the user the opportunity to experiment and to 'tinker'. Some people would regard this as a benefit, others as a cost. Again, some might be prepared to put up with the possible unsightliness of some d-i-y installations, while others would object. On the other hand the real d-i-y enthusiast would probably wish to minimise adverse visual impact and integrate the system into the building design or even design the whole building around a solar heating system - there are numerous examples of such self-built 'solar homes' in the United States. McCartney and Ford (1978) argue that the advantages of solar heating which may be most important are those which are most difficult to quantify;

> 'Householders who install a system ... move a step closer to self-sufficiency ... and set a valuable example to their community. The community itself will benefit because each solar system installed means less fossil fuel will be burned and the air will be cleaner and the environment more healthy. ... The development of solar technology will help to conserve the fuel reserves still remaining, thereby extending their benefits to future generations and easing the tensions which will undoubtedly arise between nations if there is a sudden and drastic cut in the accustomed levels of energy supply.'

Nevertheless it is unlikely that solar heating would be adopted on a large scale if it was not financially attractive to consumers. Apart from the urgent need to develop cheap (and lightweight) systems for d-i-y installation, there are several measures which would bring about an improvement in the economics of solar heating. The economics of a single building do not reflect the national gains in energy conservation from increased solar energy use. Some governments, such as those of the USA and France, are therefore offering financial incentives to encourage solar installations, through for example tax relief to householders. In Britain the Parliamentary Select Committee on Science and Technology has recommended that grants be provided to householders wishing to install solar water heating systems (similar to those already available for loft insulation).

Another important consideration is that manufacturing and installing solar heating systems as part of a national programme of energy conservation seems likely to generate more new jobs than could be created by an equivalent investment in new generating capacity. Elliott (1979) has estimated that a national programme of solar collector installation costing £5,000m over a 20 year period would generate half a million job-years directly and indirectly.

It is necessary, however, when considering these wider benefits to also take into account possible costs and disbenefits. For example, a major solar installation programme in Britain could worsen the load problems of the electricity industry by further reducing electricity demand in the summer while hardly reducing peak demand in mid-winter. There may also be safety penalties involved if increased numbers of people are to be involved in building work (especially on a d-i-y basis).

Finally there is the question of whether alternative technologies should imply a different way of life and/or a different society. Certainly there is no requirement for household-scale solar heating to imply either; in fact solar heating could be acquired simply as another consumer product, like say a home freezer. Even do-it-yourself alternative technologists should be under no illusion that they are cutting themselves off from the industrial system; in fact they are likely to be making use of many of its most sophisticated materials and products - plastics, electronic components, copper piping etc. - to make what they need. Nevertheless, in order to make most efficient use of a technology such as solar water heating, a change in life-style may be implied (using hot water when the sun comes out) or a change in attitude (cutting down on energy use in general). It seems likely that the do-it-yourself alternative technologist would be more willing to match his or her life-style to the vagaries of alternative systems and to make more allowances for any loss of convenience than the person who hires a firm to install a commercial system simply to save money. An interesting compromise is the commercial kit for do-it-yourself installation. This offers the satisfaction and control over the product of doing-it-yourself without the need for great skill. AT equipment manufactured in kit form could well provide an important market for a growing alternative production sector.

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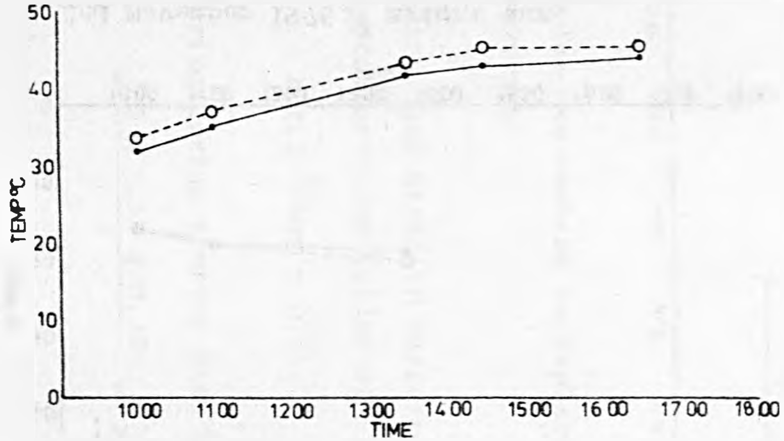
ACKNOWLEDGEMENTS

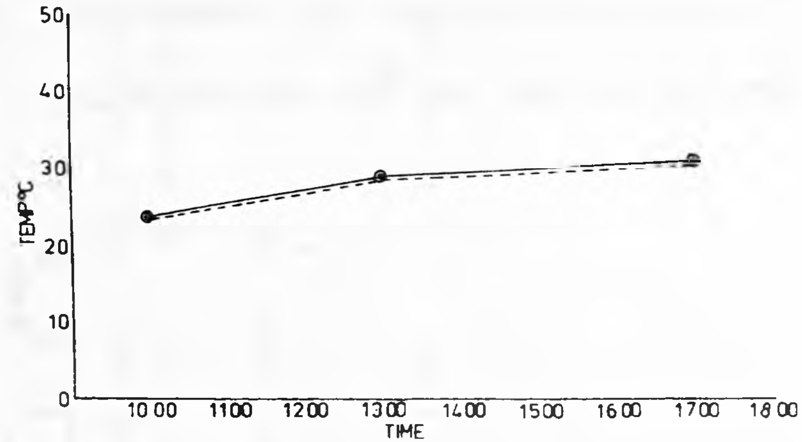
This work was supported by a grant from the Open University Research Committee. The author would like to express his appreciation for the work done by Cyril Hughes in designing, building and testing the solar collectors described in this paper.

APPENDIX 1

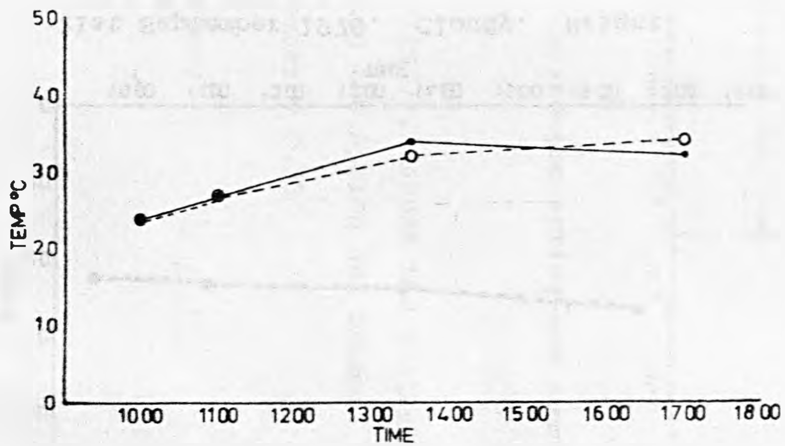
Sample temperature v. time graphs for Miromit and do-it-yourself solar collectors, June-December 1976.



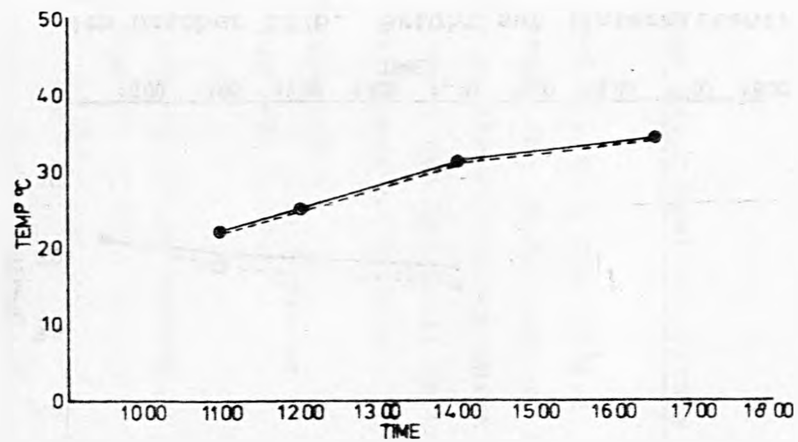
23rd June 1976. Bright sun. Clear sky. Light west wind.



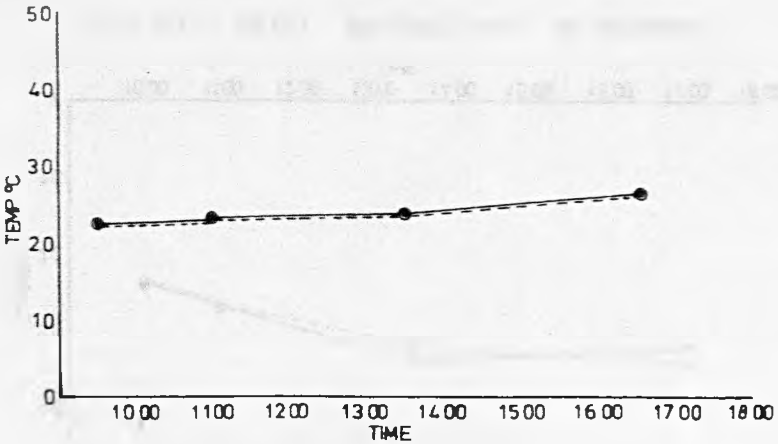
14th July 1976. Bright. Overcast. Sunny spells. Moderate S.W. breeze.



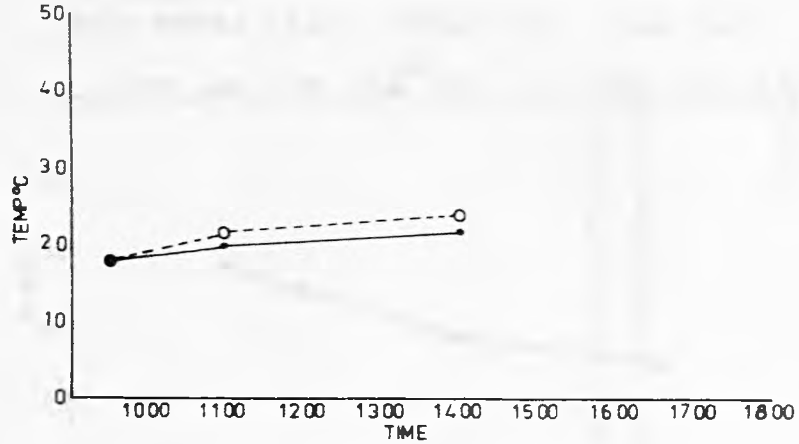
27th July 1976. Bright sun, no breeze.



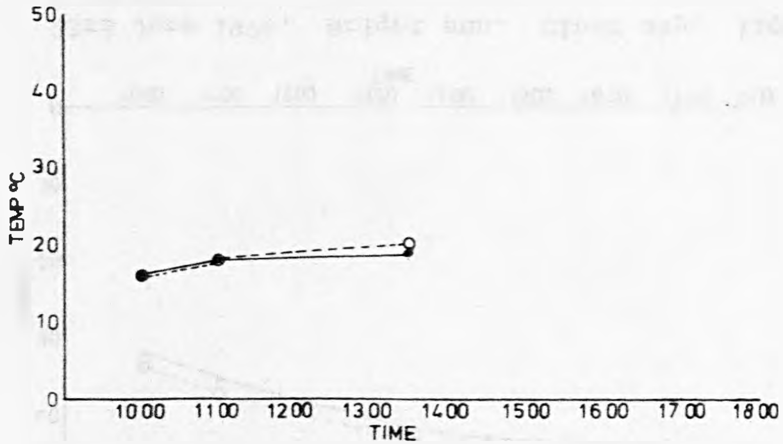
11th August 1976. Bright sun. Clear sky, no breeze.



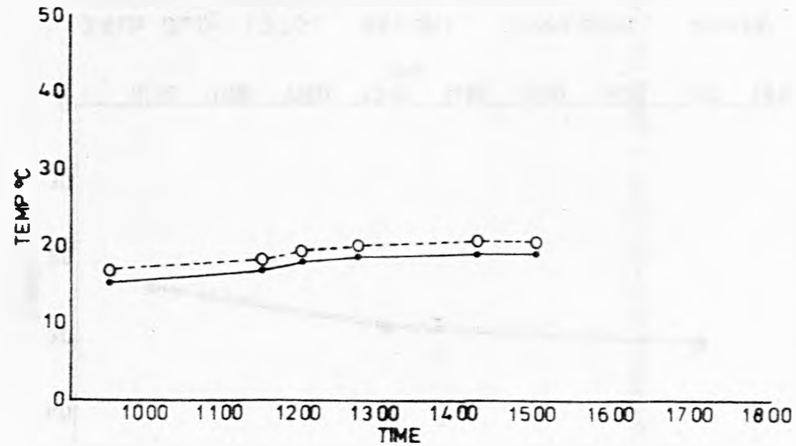
21st September 1976. Cloudy. Bright.
Light S.W. breeze.



4th October 1976. Bright sun (intermittent)
Light S.W. breeze.



2nd November 1976. Bright sun.
Occasional cloud. Moderate S.W. breeze.



9th December 1976. Bright sun, no breeze.

—•— MIROMIT   o--- DIY

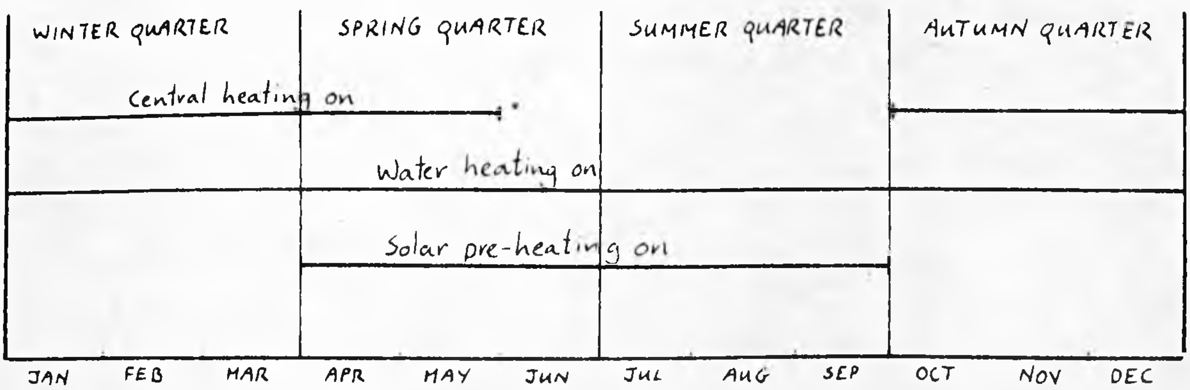
APPENDIX 2

Useful energy cost of gas replaced by solar water heating systems

If solar water heating is used in conjunction with a gas central heating system which also provides hot water, the useful cost of the gas replaced by solar heat depends on the gas boiler efficiency which in turn depends on the load pattern over the year and the total amount of gas consumed per quarter in the two-part domestic tariff:

0.78p/KWh (first 1500 KWh/quarter) }
0.52p/KWh (over 1500 KWh/quarter) } 1978 prices

If we assume the following pattern for space and water heating, including solar pre-heating, during the year:



Solar pre-heating is replacing gas only during the spring and summer quarters.

Using data given in Barratt and Everett (1977), assume the following approximate gas boiler efficiencies during the spring and summer:

April - May = 0.55;   June - September = 0.35

During spring quarter mean boiler efficiency

$$= \frac{2 \times 0.55 \times 0.35}{3} = 0.48$$

Useful gas cost for water heating (water heating load < 1500 KWh/quarter)

$$= \frac{0.78}{0.48} = 1.63\text{p/KWh}$$

During summer quarter mean boiler efficiency = 0.35

Useful gas cost for water heating

$$= \frac{0.78}{0.48} = 2.23\text{p/KWh}$$

If solar pre-heating of hot water replaces equal amounts of gas in the spring and summer quarters.

$$\text{Mean useful energy cost of gas replaced} = \frac{1.63 + 2.23}{2} = 1.93\text{p/KWh}$$

This compares with a useful energy cost of 2.45p/KWh for on-peak electricity for water heating at 1978 prices.