5GE

APPENDIX III SOLAR ENERGY

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1. INTRODUCTION

This report examines the possible use of solar radiation for producing low grade heat. It does not consider energy farming, the use of ocean temperature differences as a means of driving turbines, the potential for wind power, etc. - all these are indirect uses of solar energy and constitute separate technologies.

Although overseas research is proceeding into methods of converting solar radiation into electricity, it is unlikely that these programmes will produce plant that makes "solar electricity" an economic alternative before the end of the century. However, a great deal of New Zealand's energy is currently used for low grade heating; a function that can be performed readily by solar energy. This potential for energy substitution (for coal, oil, gas and electricity) makes solar energy a candidate for a place among the future suppliers of energy for this country.

2. AVAILABLE ENERGY

The maximum intensity of solar radiation at the Earth's surface is about 1 kW/m^2, but the intensity on a fixed surface at optimum tilt and direction in New Zealand would average on a continuous basis only 170 W/m^2. After allowing for the inevitable inefficiencies in collection, this represents a relatively small energy flux density, the use of which is generally complicated by the intermittent and variable nature of the incident radiation.

The ratio of the radiation received on Earth to that measured outside the atmosphere is a meaningful comment on the intervening atmosphere. A ratio of 0.75 means that only the inevitable losses caused by scattering and absorption of radiation by the atmosphere have taken place, while a value of 0.1 implies heavy overcast. This ratio ($\bar{K}$-value) is shown for the main New Zealand centres for each month of the year in Table 1.

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* Edited from a larger report by B.V. Walker.

TABLE 1

Average Values of $\bar{K}$ for the Main Centres

Month	Auckland	Ohakea	Wellington	Christchurch	Invercargill
Jan	0.57	0.59	0.59	0.53	0.54
Feb	0.53	0.58	0.51	0.56	0.53
Mar	0.54	0.53	0.51	0.52	0.47
Apr	0.54	0.53	0.49	0.51	0.43
May	0.47	0.49	0.42	0.47	0.43
Jun	0.45	0.46	0.42	0.46	0.41
Jul	0.49	0.47	0.40	0.46	0.47
Aug	0.50	0.50	0.48	0.55	0.51
Sep	0.53	0.53	0.51	0.49	0.54
Oct	0.51	0.53	0.53	0.55	0.52
Nov	0.51	0.58	0.52	0.58	0.52
Dec	0.52	0.55	0.55	0.60	0.54

The seasonal increase of cloud in winter is clearly demonstrated, but more noticeable is the fact that there is not a great deal of difference between New Zealand centres in terms of "available solar energy".

3. THE USE OF SOLAR ENERGY FOR SPACE HEATING AND WATER HEATING

Current methods of solar space heating and water heating all relate to single buildings - usually single houses. No system is intended to satisfy the full energy requirements at all times of year and relies on conventional back-up sources to take over the thermal load during periods when the demand is heavy and/or solar radiation minimal. This is particularly true of space heating where the maximum load is imposed at times of minimum sunshine. American research in this area is directed towards using the same solar collectors during the summer to power absorbtion refrigerators for air conditioning. In this way they hope to achieve maximum use of equipment (capital) and thus improve the economics of the system. But whether for space heating or water heating, individual house systems supply realistically only between 30 and 60% of the total required energy.

The problem lies in the long term storage of the collected heat. This is normally held in insulated tanks of water or graded rock placed somewhere in the basement. A solar water heater will have a tank capable of holding only one or two day's water supply, while space heating stores when fully charged could cope with from three to seven days of mid-winter heating. Storage beyond these periods is generally regarded as uneconomic because the stores become large and expensive, take up too much house space, and lose a considerable fraction of their heat by uncontrolled conduction.

While all these systems save fuel, they do nothing towards reducing peak demands for energy - an important factor when heating uses an on-line supply such as gas or electricity. Oil or coal heating does not have this problem to the same extent because of the "stock pile" held at the house.

To date, solar water and space heating has been on such a small scale that the need for complete self-supporting systems has not arisen. However, if solar technology is to become a significant supplier of energy it must, in the long term, stop relying on other energy sources. This is only feasible if collection, storage and distribution of heat is carried out on a yearly basis. Sunshine, while unpredictable in the short term, is fairly constant over a year (standard deviation ± 2.5%) - certainly much more reliable than rainfall with which New Zealand has,for many years, run a successful hydro-electricity system.

The solution lies in an increase in the scale of storage so that energy collected during favourable summer months can be used in winter. This can be achieved without an increase in overall scale by combining the relatively small stores in individual houses into a single store shared by a number of houses. In assessing the "effectiveness" of heat stores of this type, the important parameter is the ratio of storage capacity to heat loss. In physical terms this means the ratio of volume to area of the container. Typically, a single solar space heating system might have a tank of 20,000 litre capacity which, if built as a cube, has a volume to area ratio of 0.45. If 100 houses share a large tank of equivalent total volume (2×10^6 litres), the ratio of volume to area rises to 2.06 which means that, for the same thickness of insulation, losses are reduced to less than a quarter of those of the 100 individual systems. Further, if the thermal insulation used on the 100 individual tanks is placed about the single large tank, the thickness increases by a factor of 4.5 because of the effectively reduced gross area of the large tank. Overall, the effectiveness of the storage system is increased by a factor of 20 without increasing the amount of materials used or reducing the effective storage. These figures are intended to illustrate that storage beyond one week starts to look more feasible when common stores are used.

Preliminary calculations by DSIR indicate that a group of 100 houses, each using 10 000 kWh/year for hot water and space heating, could be totally supported in this respect by solar energy if, each house has a collector area of 20 m^2, and they share a communal thermal store of 10 million litre (10 metre cube) capacity. Various options are open, e.g. larger collector areas and smaller storage tanks, but the figures given are adequate to allow a very rough pricing exercise.

In terms of equivalent generating capacity each 100 house module "generates" 114 kW(e) at a cost of about $4400 per installed kilowatt including all reticulation costs and the heating hardware within the house. Electrical energy to run pumps and controllers should not exceed 10 kW, maintenance changes would be small and "fuel" free. Expected life of the main components of the system would be 20 years +.

To the individual householder, the value of the system as an investment is very marginal - $180/year (electricity at 1.8 c/kW) for an investment of $5000. However, from a national point of view, the necessary initial investment and continuing cost of fuel to supply this energy by some other means, may be sufficiently high to warrant a closer examination of the "solar alternative". No significant engineering problems are known and the scheme could be enlarge to cover whole districts, with collectors and stores sited some kilometers away from the homes being serviced.

The cost of energy for the 100 "house equivalent" system described (assuming running expenses and servicing take 15% of savings) is shown in Table 2 for a variety of interest rates, plant life and initial capital investment.

The installed cost of collectors, plus reticulation and the cost of unit heaters in the home, would be about $200/$m^2$ - current cost of collectors is about $100/$m^2$. Engineering experts suggest that the cost of a tank (or tanks) of 10 million litre capacity, fully insulated and buried underground would be liberally financed with $300 000. This amounts to $7000/house. If a specialist industry develops using mass production techniques and modular construction, and if account is taken of the savings in conventional hot water and heating services and roofing replaced by collectors, the overall cost might be of the order of $½ M, which is $5000/house and represents about 15% of the total value of the house and section being serviced.

TABLE 2

Cost of Solar Energy for a "100 House-Equivalent" System

Interest Rate		6	8	10	12	14	16
		Energy cost (cents/kWh)					
Plant Life 20 yrs							
Capital	$ .5M	4.90	5.81	6.70	7.64	8.61	9.63
	.4M	3.92	4.64	5.36	6.11	6.89	7.70
	.3M	2.94	3.49	4.02	4.58	5.17	5.78
	.2M	1.96	2.32	2.68	3.06	3.44	3.85
Plant Life 30 yrs							
Capital	$ .5M	4.17	5.06	6.18	7.08	8.16	9.24
	.4M	3.34	4.05	4.94	5.66	6.53	7.39
	.3M	2.50	3.04	3.71	4.25	4.90	5.55
	.2M	1.67	2.02	2.47	2.83	3.26	3.70
Plant Life 40 yrs							
Capital	$ .5M	3.81	4.78	5.90	6.91	8.05	9.16
	.4M	3.05	3.82	4.72	5.53	6.44	7.33
	.3M	2.29	2.87	3.54	4.15	4.83	5.50
	.2M	1.52	1.91	2.36	2.76	3.22	3.66

Calculations based on:

$$\text{Unit charge} = \frac{\text{Capital } (1-V)}{V(1-V^n) \times \text{Annual units produced}}$$

$$\text{Where} \quad V = \frac{1}{1 + \text{Interest Rate}} \qquad n = \text{Plant life}$$

4. DOMESTIC SOLAR WATER HEATING

Serious research and development in the solar energy field has been restricted almost entirely to domestic water heating. DSIR research has shown that:

1. For a daily demand of 200 litres of water at 50°C, a solar collector of about 4 m^2 in combination with a standard 180 litre

storage cylinder is the most economic size.

2. The average home, depending on climate, uses from 11 to 15 gigajoules (3000 to 4200 kWh) or electricity annually for heating water, and that a solar heater of the type described above can supply from 45 to 55% of this.

3. Year round performance is not markedly different for collectors at tilts between 15° and 50° providing they faced within 30° of north. Tilt determines the time of year at which savings are made but has little effect on the overall yearly performance.

4. The temperature at which the water is usea (i.e. the thermostat control temperature) is of great importance. For example, the proportion of heat supplied by a solar heater drops from 59% with a thermostat setting of 52°C, to 34% at a thermostat setting of 70°C.

5. Single glazing is as effective as double glazing, and increasing the collector area by 40% increases savings by only 24%.

6. The best New Zealand sites will save about 8 gigajoules annually - the worst about 6.5 gigajoules.

Since units of the type described are generally intended for installation on individual homes, the economics are giverned by the retail price of electricity or gas - this varies from district to district. Assuming an increase of 3% per year in the real cost of energy, a solar heater with a life expectancy of 20 years, and maintenance at 10% of annual savings, then the economic price to the householder is shown in Table 3. Interest reates were chosen to reflect the likely nett income from investment after tax.

TABLE 3

Economic Cost of Domestic Solar Water Heaters

Interest Rate (%)	5	6	7	8	9	10
	Economic Price ($)					
Cost of Electricity (cents/kWh)						
0.8	207	189	173	159	146	135
1.0	259	236	216	199	183	169
1.5	388	354	324	298	274	254
2.0	517	472	432	397	365	339
3.0	776	708	648	596	549	508

Currently, domestic solar water heaters built to the dimensions appropriate to the above table (4 m^2 of flat plate collector and one day's storage) have an installed cost of $600 and upwards. There are a number of firms producing in relatively small numbers, and the manufacturing techniques tend to be labour-intensive, while installation costs contribute a significant amount to the overall cost. Once properly installed, however, domestic solar water heaters appear to give little trouble, and need minimum maintenance apart from the occasional painting of the collector cases.

A major firm is at present tooling up for production of a unit developed by DSIR. When produced in quantity, this unit has certain manufacturing advantages as a result of the design and choice of materials. It is hoped that these units will be cheaper than those currently on the market, and that a streamlining of installation procedures will reduce the amount of on-site work.

No units have been developed specifically for industrial use where a more sophisticated collector may be needed to produce water at higher temperatures than those normally used in the home.

5. THE POTENTIAL FOR SOLAR ENERGY

Despite the many hundereds of solar water heaters already in operation, and the three solar houses, the effect of these could not be detected in the total national energy pattern. Consequently, without a background of experience, it is impossible to extrapolate into the future, particularly as the rate of implementation will depend largely on political decisions. The best that can be done is to list the options and try to estimate the impact that each will have on energy supplies of the future. The time scale is not important until a target for performance is set.

In the first instance, solar water and space heating is most likely to make an impact in the domestic field. While industry uses considerable quantities of low temperature heat, most of this is produced within the industry itself at relatively cheap rates, and it is unlikely that industry would be interested in making a change until the costs of the alternatives become competitive. In considering the options in terms of "houses", it should be appreciated that this includes suitable commercial and institutional buildings - hospitals, hostels, schools and light industry.

The options are listed in Table 4, showing, for each option, the energy savings, the equivalent generating capacity of the self-contained solar system, and an approximate cost for each particular option. In deriving this latter, it has been assumed that the installed cost of a domestic solar water heater would be $500, and the cost of a "100 house equivalent" scheme $400 000. Both prices are below existing costs or estimates, but can be expected to reach these levels if hardware is produced in the quantities indicated in the table.

TABLE 4

ENERGY SAVINGS, EQUIVALENT GENERATING CAPACITY, AND COST OF SOLAR ALTERNATIVES

Number of Group Solar Water and Space Heating Schemes. (House equivalents)	Number of Domestic Solar Water Heaters	0	50000	200000	600000	1000000
	Energy (000 Terajoules)	0	.36	1.44	4.32	7.20
	Generation (Megawatts)	0	0	0	0	0
	Cost (Million dollars)	0	25	100	300	500
	Energy	3.60	3.96	5.04	7.92	
100000	Generation	100	100	100	100	
	Cost	400	425	500	700	
	Energy	7.20	7.56	8.64	11.52	
200000	Generation	200	200	200	200	
	Cost	800	825	900	1100	
	Energy	10.80	11.60	12.24	15.12	
300000	Generation	300	300	300	300	
	Cost	1200	1225	1300	1500	
	Energy	14.40	14.76	15.84	18.72	
400000	Generation	400	400	400	400	
	Cost	1600	1625	1700	1900	
	Energy	36				
1000000	Generation	1000				
	Cost	4000				