Monitoring of solar domestic hot water systems at the National Research Council of Canada
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NATIONAL RESEARCH COUNCIL OF CANADA

DIVISION OF ENERGY

MONITORING OF SOLAR DOMESTIC HOT WATER SYSTEMS AT THE NATIONAL RESEARCH COUNCIL OF CANADA

by

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Presented at Intersol 85
Biennial Congress of the the
International Solar Energy Society
Montreal, Canada, 23-29 June 1985

Ottawa

June 1985

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ABSTRACT

Eight solar domestic hot water systems were monitored under controlled conditions for two years. The systems delivered 1.5 - 2.0 GJ/m^2 annually, with net solar system output essentially proportional to incident energy. The performance of these and other systems are discussed and compared.

KEYWORDS

Solar energy, water heaters, solar domestic hot water, monitoring

INTRODUCTION

In 1981, the National Research Council built a solar domestic hot water (SDHW) test facility in Ottawa (45°27'N, 75°37'W, elevation 98m), to obtain performance data on SDHW systems in a northern environment. The main objectives of the monitoring program were:

a) determination of SDHW system energy output and reliability;
b) identification of promising generic system types;
c) generation of a data base for comparison to field measurements and development of computer models;
d) improved understanding of system operation leading to better cost-effectiveness.

Shewen, Sibbitt and Chamberlain [1] reported on early results from this program.

TEST FACILITY DETAILS

The facility consists of an 18 x 4 m trailer and a collector rack oriented at 0° surface azimuth and 45° slope. Eight SDHW systems, described in Table 1 were monitored for the period 82-06-30 to 84-06-29. Systems 1-8 are shown schematically in Fig. 1 (a)-(e), respectively. Each employed approximately 5 m^2 of single-glazed, selective surface, flat plate collector, and operated in a solar-preheat mode with a 273 L electric tank

TABLE 1 SDHW Systems' Description

No.	Description	A_a (m^2)	V (L)
1	Drainback: Coil in external drainback tank	4.95	273
2	Drainback: Load-side tank in storage tank	4.77	454
3	Glycol thermosyphon: Coil wrapped tank-in-tank	4.77	454
4	Pressurized drainback: No heat exchanger	4.73	310
5	Drainback: Load-side coil in storage tank	4.77	454
6	Glycol: Collector-side coil in storage tank	5.13	303
7[1]	Recirculation: No heat exchanger; seasonal system	5.19	273
8	Drainback: External shell & tube heat exchanger	5.26	273

[1]Boiling-condensing thermal diode collectors.

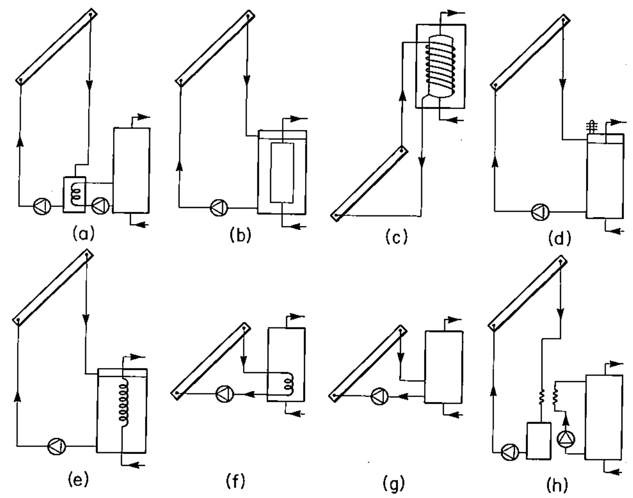

Fig. 1 Solar system schematics

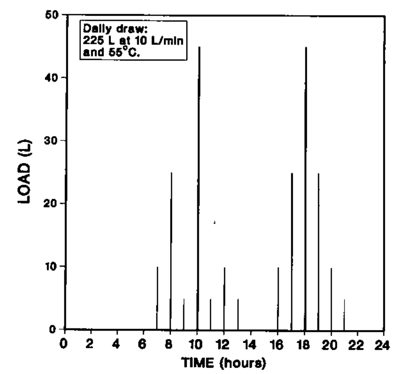

Fig. 2 Load profile

set to deliver water at 55°C. A daily load of 225 L, shown in Fig. 2, was imposed on each system. A tempering valve set at 60°C prevented overheating of the delivered water.

Figure 3 is a monitoring schematic. The solar system output, Q_S, was measured by precision resistance temperature detectors and flowmeter connected to an integrating heat meter; an additional flowmeter monitored the load. Parasitic energy, Q_{PAR}, and auxiliary energy were obtained by means of kWh meters. A counter and timer measured daily pump cycles, N, and run-time, T_{ON}. Horizontal radiation, H, and 45° radiation, H_T, were measured by precision pyranometers, indoor ambient temperature was also measured. An Ottawa engineering company, TES Ltd., operated the facility under contract. Data were recorded daily (excluding weekends and holidays) at 15:00 hours. At this time outdoor ambient, system inlet and outlet temperatures were measured. Short-term data were collected for six additional systems, described in Table 2, during the period 84-07 to 85-05.

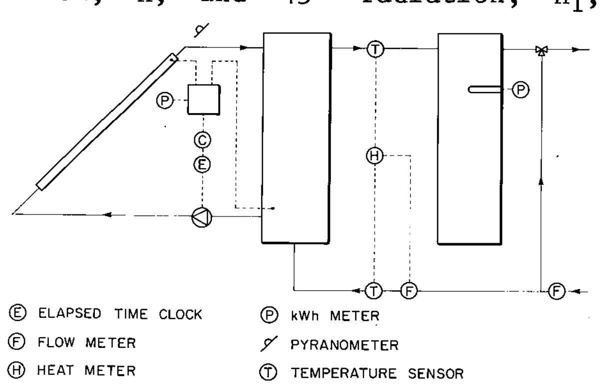

Fig. 3 Monitoring System Schematic

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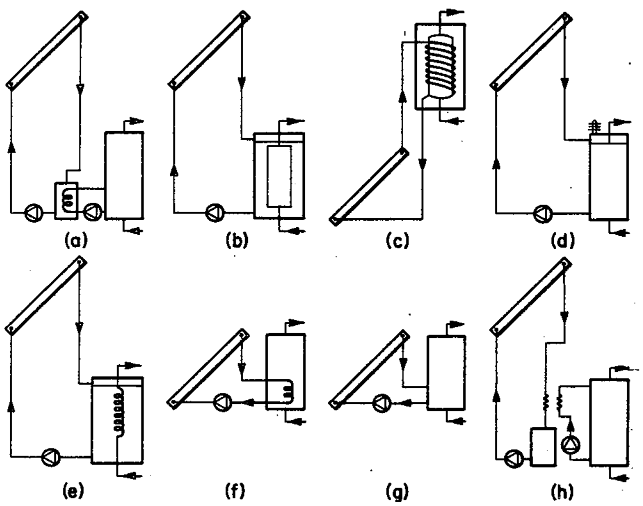

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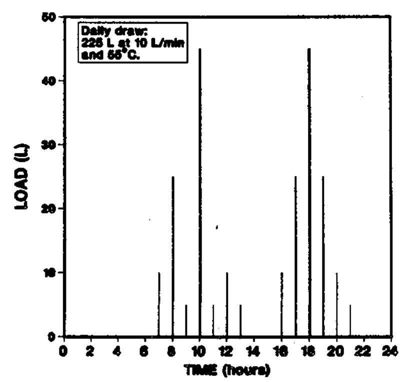

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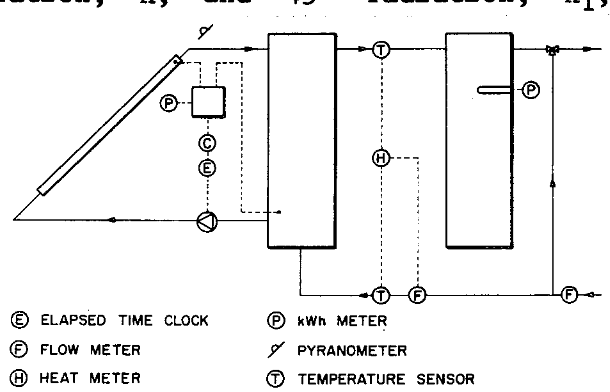

Fig. 3 Monitoring System Schematic

TABLE 2 Modified Systems' Descriptions

No.	Description
9	4 with evacuated-tube collectors
10	6 with photovoltaic pump and controller
11	3 with water as collector fluid
12	11 with collector-loop coil removed
13	7 with single-tank, improved collectors
14	2 with reduced storage volume
15	2 with reduced storage volume

RESULTS AND DISCUSSION

The data collected were used to prepare monthly and annual summaries. Table 3 is a summary of the annual performance of the eight systems over the two year period. Efficiency, η, and solar fraction, f, are defined by,

$$\eta = Q_{NET}/A_aH_T = (Q_S - Q_{PAR})/A_aH_T \quad (1)$$

$$f = Q_{NET}/(Q_L + Q_{LOSS}) \quad (2)$$

Q_L is the theoretical load based on set-point and measured mains temperature, and Q_{LOSS} is an estimate of auxiliary tank losses. All quantities are monthly or annual summations. These definitions account for parasitic energy consumption (some of which increases Q_S). All values are based on aperture area, A_a, allowing for comparison between systems with different collectors.

The range of efficiencies (27 to 37%) correspond to annual net outputs, q_{NET}, of 1.5 to 2.0 GJ/m^2. These values would be increased by larger loads or smaller collector areas. Comparison of the efficiencies for the two years show good agreement. Systems 2, 3 and 5 with identical collectors and storage volumes, V, span the entire range, showing that design parameters other than collector characteristics have a major impact

TABLE 3 Two Year Performance Summary

	82-07 to 83-06 H_T = 5.11 GJ/m^2 Q_L = 15.4 GJ Q_{LOSS} = 2.5 GJ			83-07 to 84-06 H_T = 5.63 GJ/m^2 Q_L = 15.2 GJ Q_{LOSS} = 2.5 GJ			Overall $\bar{H}_T$ = 5.37 GJ/m^2 $\bar{Q}_L$ = 15.3 GJ $\bar{Q}_{LOSS}$ = 2.5 GJ				
No.	q_{NET} (GJ/m^2)	η	f	q_{NET} (GJ/m^2)	η	f	N (c/d)[1]	T_{ON} (h/d)	q_{NET} (GJ/m^2)	η	f
1	1.58	.31	.44	1.65	.29	.46	5	4.0	1.62	.30	.45
2	1.61	.31	.43	1.83	.32	.49	8	2.6	1.72	.32	.46
3	1.93	.38	.52	2.04	.36	.55	N/A	-	1.99	.37	.53
4	1.64	.32	.43	1.80	.32	.48	29	3.8	1.72	.32	.46
5	1.43	.28	.38	1.50	.27	.40	3	2.9	1.46	.27	.39
6	1.55	.30	.45	1.64	.29	.48	19	3.8	1.60	.30	.46
7[2]	N/A	N/A	N/A	N/A	N/A	N/A	11	5.6	1.32	.31	.39
8	1.51	.30	.45	1.67	.30	.50	12	3.5	1.59	.30	.47

[1] Cycles per day.
[2] All quantities except f based on operating season 83-03 to 83-10.

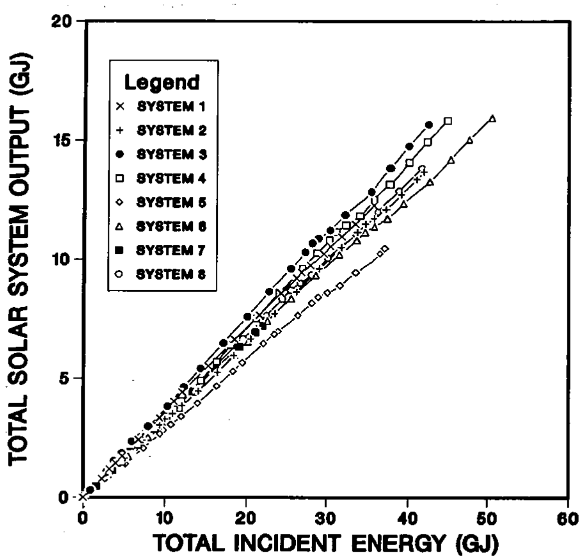

Fig. 4 Solar system output vs. input

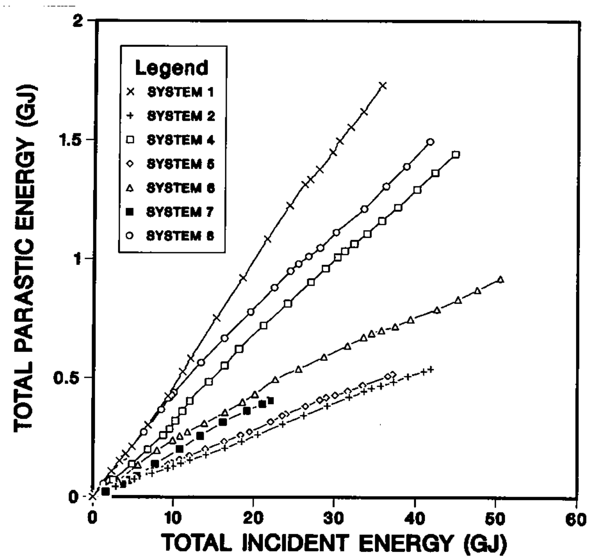

Fig. 5 Parasitic energy vs. input

on system performance. Measurements show that the thermosyphon operates with a high degree of stratification while systems 2 and 5 do not. Tests also suggest that the tank-in-tank heat exchanger is more effective than the load-side coil. The drainback, system 2, avoids the problem of glycol maintenance. It has been argued that the winter shut-down performance penalty for systems such as 7, is justified on a cost basis.

Figures 4 and 5 are summations of the data used to calculate q_{NET}. It can be seen that seasonal effects on these performance measures are second order. This appears to be due to the way in which ambient and mains water temperature vary with insolation. Systems 1, 8 and 4 all had reduced net energy figures as a result of parasitic consumption.

Figure 6 shows the seasonal variation of monthly efficiency and solar fraction; for clarity only systems 3 and 5 are shown. Figures 7 and 8 show climatic conditions for the same period; all values being site-measured except exterior ambient which was taken from [2]. Note the relatively stable efficiency profile in Fig. 6. The loss term, Q_{LOSS}, in Eqn. (2) was interpolated from results of experiments on a 273 L electric tank at different mains temperatures. Note that the choice of reference load (for another water heater, real or theoretical, or for the system itself) and the inclusion of a loss term, all affect the value of f. Long inlet pipes can cause substantial reductions in real DHW system load requirements.

Maintenance was performed regularly and as necessary. Estimates were made for approximately 20% of the data which were not available or rejected because of system malfunction, start-up transient maintenance or to conduct special tests. Some of the controller set-points differed significantly from specifications. These (and collector-loop flow rates) were adjusted when possible. A design problem; an incorrect tank-sensor placement on system 6, was rectified.

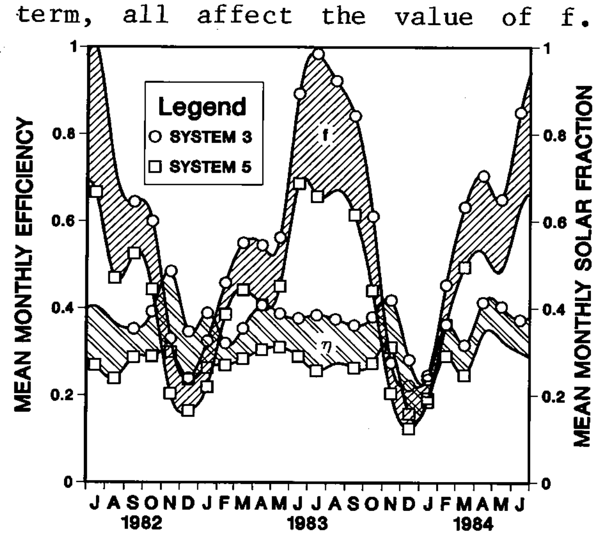

Fig. 6 Monthly system performance

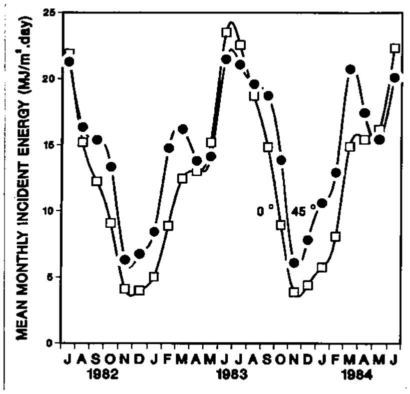

Fig.7 Incident energy

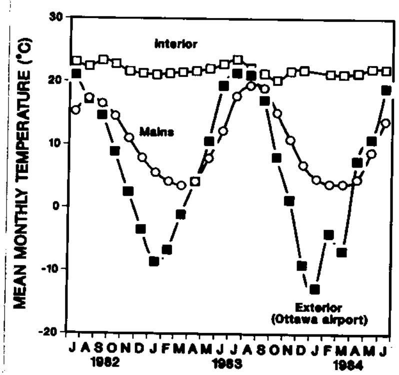

Fig.8 Temperatures

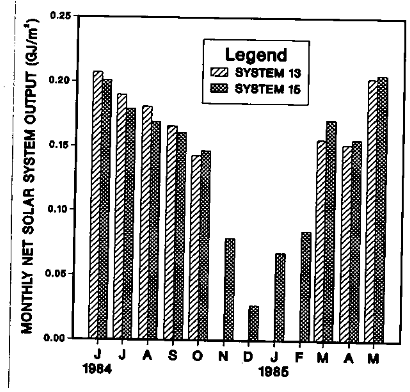

Fig.9 System comparison

A compressor was replaced on system 4. System 3 blew-out its glycol charge once, thereafter operating without problem.

Useful results were also obtained from the short term tests. The efficiency of system 4 was increased to approximately that of the thermosyphon when the collectors were replaced by evacuated tube collectors. No change in performance was detected when the system 3 collector loop fluid was changed from propylene glycol to water during warm weather operation. Replacement of the system 6 pump and controller with a photovoltaic powered and controlled pump did not improve the system efficiency, despite the change to low variable rate circulation and zero purchased parasitic energy. Significant differences in output were observed for two identical systems (14 and 15). Figure 9 shows that by operating with approximately equal output for the eight brightest months of the year, system 13 delivered 1.4 GJ/m^2, or about 85% of the year-round system 15 output.

CONCLUSIONS

SDHW systems have been shown to deliver 1.5 - 2.0 GJ/m^2 annually in the Ottawa environment. The best performer, a freeze-protected thermosyphon and the worst, an active system with a load-side coil heat exchanger, had identical collectors and storage volumes showing the importance of system configuration on thermal performance. Agreement in annual system efficiency for the two years suggests that long-term performance of systems, under controlled conditions and at moderate solar fractions, may be predicted with some confidence.

ACKNOWLEDGEMENT

The authors wish to thank T. Onno who initiated much of the work described in this paper.

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[2] Monthly Radiation Summary, Ottawa International Airport, Atmospheric Environment Service, Environment Canada, July 1982-June 1984.