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Solar space heating with air and liquid systems

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Seasonal and annual performance data are available on only a limited number of the several thousand solar space heating systems now in operation. The emerging information indicates that most of the heat required in buildings can be supplied by solar energy delivered from flat-plate collectors and stored overnight in tanks of water and bins of rock pebbles. Numerous mechanical and operational problems, mainly in liquid collection and storage systems, demand attention. Annual costs of solar heating equipment and its installation usually exceed current values of energy savings, but fuel prices are expected to escalate at rates which often favour solar purchase today.

Detailed performance data on several types of solar heating and cooling systems in buildings of identical design are presented, compared and interpreted. Maintenance and repair requirements are noted and contrasted, and forecasts of use in various applications are presented.

1. Introduction

Solar House I and Solar House II in the Solar Village at Colorado State University are nearly identical buildings located approximately 30 m apart. Both buildings are residential size with about 130 m^2 of floor space on the first floor and equal area in the basement. Both floors are heated and cooled. The south wall of the basement is above grade while the north wall is below grade. Collectors are mounted on the roof and tilted at 45° from horizontal and facing southward; the storage and mechanical equipment for heating and air conditioning are located in the basements. The buildings are used for offices for the staff and graduate students of the Solar Energy Applications Laboratory and are occupied nearly every day. The heat demand at an outdoor temperature of -23.3 °C is 17.5 kW.

2. System characteristics

2.1. *Liquid system: Solar House I*

The solar heating and cooling system in C.S.U. Solar House I has been in operation since August 1974. The solar heating and cooling system, shown schematically in figure 1, consists of flat-plate, liquid-heating collectors, water storage, lithium bromide absorption chiller, and gas-fired auxiliary water boiler. The double glazed, site built, non-selective collectors occupy an overall roof area of 71.3 m^2 with an absorber area of 67.0 m^2. Solar heat is stored in an insulated steel water tank of 4275 l capacity. Figure 1 also shows a domestic water heating system consisting of a 364 l preheater tank and a 150 l conventional gas-fired hot water tank. A 50 % solution of ethylene glycol and water flows through the collectors and is separated from the storage tank fluid with a counterflow heat exchanger.

The cooling unit is an Arkla Solaire WF-36 absorption water chiller with a charge modified from 52 to 50 % lithium bromide to match cooling water temperatures usually prevailing at this location. In the commercial version, the chiller has a design point of 38 MJ/h at typical cooling water temperatures of 29 °C. The C.S.U. chiller has a capacity of 50 MJ/h at a coefficient of performance (c.o.p.) of almost 0.8, and it can be operated at generator temperatures as low as 66 °C with a corresponding capacity of 20 MJ/h.

During November and December 1976, an additional set of evacuated tube collectors (made by Corning Glass Works) was mounted on a test bed adjacent to Solar House I. The set of collectors on the test bed consists of 36 modules and each module has six evacuated tubes, with a total absorber area of 1.11 m^2, that covers a mounting area of 1.92 m^2. When mounted on the test bed, the gross area required for collectors and manifolds is 75.2 m^2 although the total absorber area is 39.9 m^2. There is a separate storage tank with 4275 l capacity for the evacuated tube collector system.

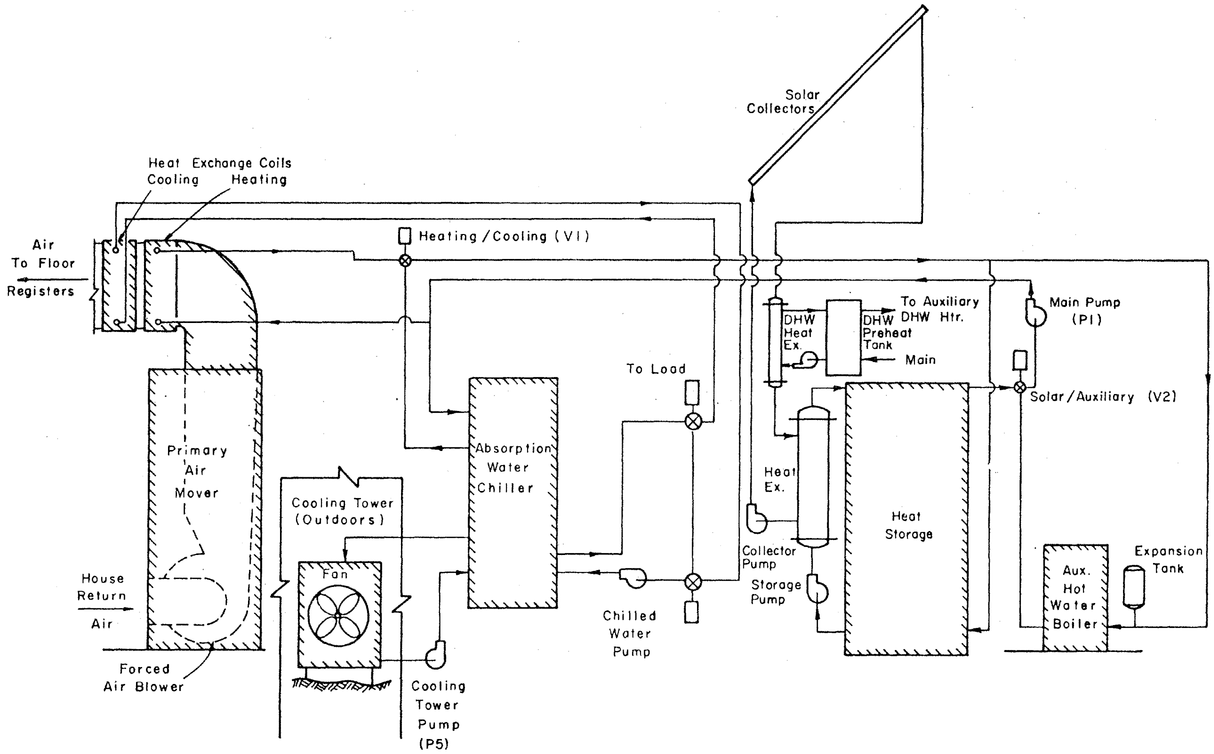


FIGURE 1. Solar House I heating, air conditioning and hot water equipment.

The piping and accessories are arranged so that either the flat-plate collectors on the building roof or the evacuated tube system can deliver heat to the same space and domestic hot water loads in House I. In October and November 1976, the flat-plate collector on the house roof was used, and in the following months, the Corning evacuated tube collector was used.

The house is heated by air from a heat exchanger supplied with solar heated water from the thermal storage tank or from an auxiliary boiler. Cooling requirements are met by use of cold water circulated from the Arkla chiller or from cool storage.† Heat energy is supplied to the chiller by hot water either from thermal storage or the auxiliary boiler. Heat rejection from the chiller is to water circulated through a cooling tower outside the building. Service hot water is

† The use of cool storage was found to be a negligible advantage, so was discontinued.

heated by exchange with the hot collector fluid and stored in a 364 l (80 gallon) tank followed by a conventional gas-fired water heater. Heat is transferred to the main storage by circulating a non-freezing solution of ethylene glycol through the collector and through an exchanger in which water from storage is heated.

2.2. *Air heating system: C.S.U. Solar House II*

The solar heating and nocturnal cooling air system in C.S.U. Solar House II has been in operation since 1 February 1976. The collectors in the system, shown schematically in figure 2, are site-built and occupy an overall roof area of 68.4 m^2 with 64.1 m^2 net collector area. The storage consists of 10.2 m^3 of pebbles of 1.9–3.8 cm size, and a gas-fired auxiliary duct furnace is connected to the heat distribution system of the house.

Domestic water preheating is accomplished by an air-to-water heat exchanger with storage in a 300 l tank. The hot water heater is gas fired with a capacity of 150 l and is limited in temperature to 60 °C.

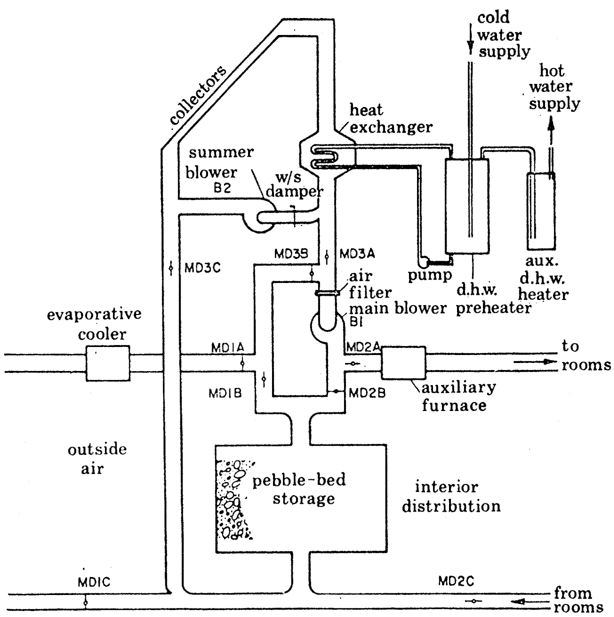


FIGURE 2. Schematic diagram of the air solar system in Solar House II. MD = motorized damper.

The system is operated by a single blower during the heating season with two sets of three motorized dampers to direct heat from the collectors to the house or to storage, and from storage to the house. A second blower is used in the summer to preheat water while the main blower circulates cool air from the evaporative cooler to storage and from storage to the conditioned space.

2.3. *Modes of system operation*

There are five basic operation modes for heating with the solar system shown in figure 2: (1) heating the rooms directly with heat collected from the collectors; (2) heating the rooms from the collector and auxiliary furnace during periods of low solar radiation and high heating load; (3) storing solar heat when room heating is not needed; (4) heating the rooms from storage during non-sunshine hours; and (5) heating from storage and supplementing with the auxiliary furnace when the heating load is large or when storage has been depleted. It will be noted that room air is circulated through storage even after useful heat has been depleted from storage. The reason is the pressure drop across storage is small and therefore little power is needed to circulate air through storage. During the $2\frac{1}{2}$ years of testing, there have been only a few occasions when storage has been completely depleted.

Table 1. Monthly and annual averages of daily energy quantities (MJ/day) and fractions, Solar House I

month and year	total solar†	solar to storage‡	solar to load	solar to heating	auxiliary to heating	solar to hot water	auxiliary to hot water
Oct. 1976	1404	191	183	65	0	47	61
Nov. 1976	1086	159	174	124	113	46	60
Dec. 1976							
Jan. 1977	1087	415	396	360	110	36	52
Feb. 1977	1149	360	379	338	37	41	60
Mar. 1977	1394	566	285	229	12	57	41
Apr. 1977	852	297	227	108	20	119	84
May 1977	—	—	—	—	—	—	—
June 1977	—	—	—	—	—	—	—
July 1977	—	—	—	—	—	—	—
Aug. 1977	1287	439	417	0	0	73	47
Sept. 1977	1584	537	452	0	0	50	38
f.p.c.	1248	175	179	94	56	47	61
e.t.c.	1227	436	359	259§	45§	63	54

month and year	solar to cooling	auxiliary to cooling	solar fraction heating	solar fraction cooling	solar fraction heat and cool	data base days	solar fraction hot water
Oct. 1976	71	64	1.00	0.53	0.68	28	0.44
Nov. 1976	4	0	0.52	1.00	0.53	19	0.43
Dec. 1976							
Jan. 1977	0	0	0.77	—	0.77	20	0.40
Feb. 1977	0	0	0.90	—	0.90	12	0.41
Mar. 1977	0	0	0.95	—	0.95	29	0.58
Apr. 1977	0	0	0.86	—	0.86	21	0.63
May 1977	—	—	—	—	—	—	—
June 1977	—	—	—	—	—	—	—
July 1977	—	—	—	—	—	—	—
Aug. 1977	344	459	—	0.43	0.43	13	0.61
Sept. 1977	402	236	—	0.63	0.63	17	0.57
f.p.c.	38	32	0.63	0.54	0.60	24	0.43
e.t.c.	373‖	348‖	0.85	0.52	0.67	19	0.54

f.p.c. = flat plate collector average, Oct.–Nov. 1976.
e.t.c. = evacuated tubular collector average, Jan.–Sept. 1977.

† Based on 75.2 m^2 gross collector area Jan.–Mar. and Aug.–Sept.; 25.1 m^2 8 days, 50.1 m^2 4 days, and 75.2 m^2 9 days, all in April; and 71.3 m^2 gross collector area for Oct.–Nov.

‡ Solar to storage includes solar to hot water.

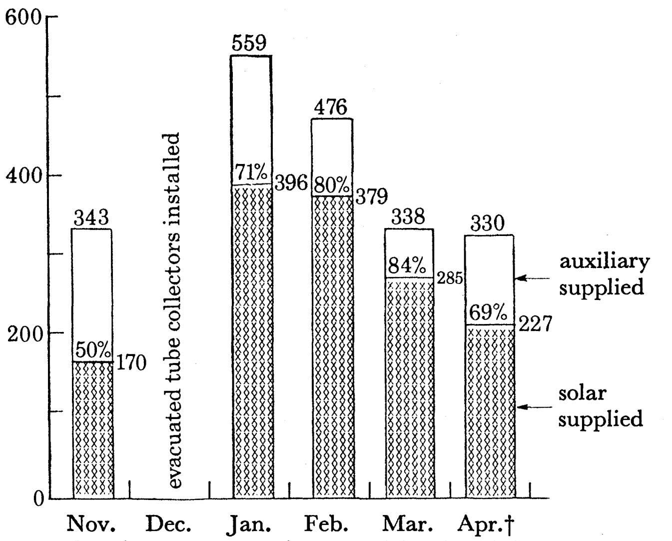
§ Averages for four winter months only.

‖ Averages for two summer months only.

3. Performance of systems

3.1. *Liquid systems thermal performance: Solar House I*

A summary of monthly and annual energy use for space heating, domestic hot water (d.h.w.) heating, and space cooling is presented in table 1 and figures 3 and 4. The collector performance is presented in figure 5. The first two months of data were obtained with the system employing flat-plate collectors, whereas heating and cooling during the following ten months were supplied by the evacuated tube collector system.



† Note reduced collector area for part of April as defined in table 1.

Figure 3. Solar and auxiliary contribution to total space heating and d.h.w. heating in Solar House I, 1976–7 heating season.

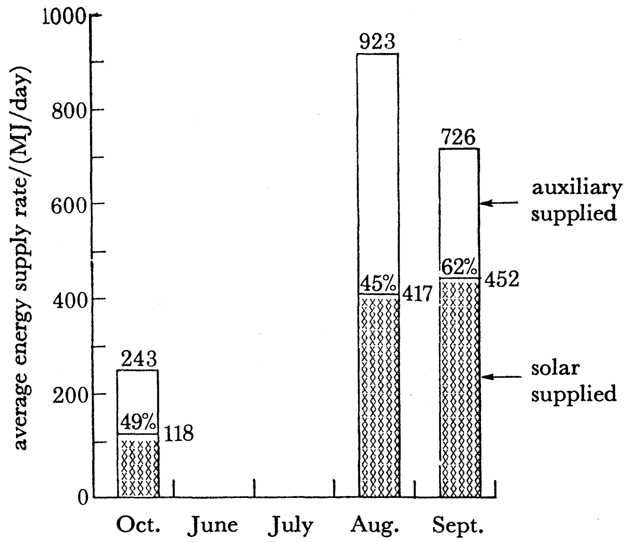


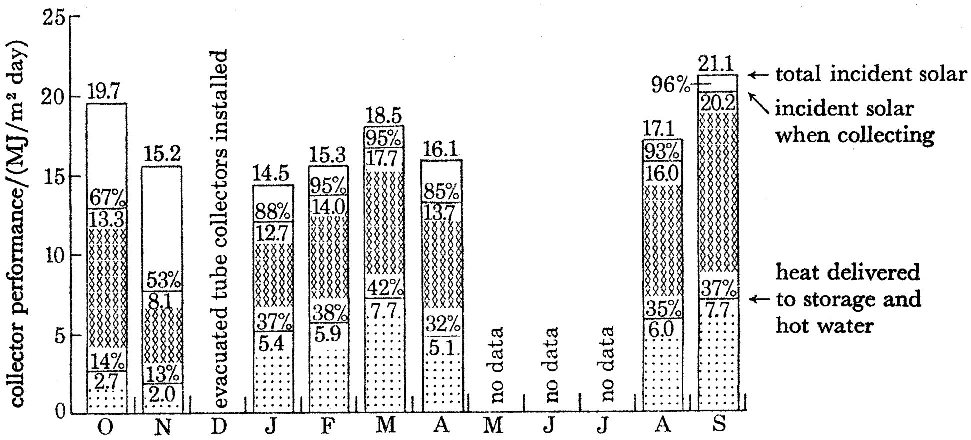
Figure 4. Solar and auxiliary contribution to space cooling and hot water heating in Solar House I, 1976–7 cooling season.

Solar collection and solar space heating were unusually low in November. In previous years, a similar (but not identical) system with the same collector provided more than 90 % of the space heating in November, rather than about 50 % supplied in 1976. This difference is largely accounted for by unusually severe weather conditions on 12–15 November and 27–30 November 1976.

Following the installation of the evacuated tube collector, the performance of the system increased by a sizeable amount. Figure 3 shows that over 70 % of the heat required for hot water and space heating were supplied by solar. Of the 51034 MJ required for these uses in the January–April period, solar provided 75.5 %.

3.1.1. *Hot water heating*

The solar contribution to hot water supply in October and November was roughly half its share in previous years. As indicated below, similar results were obtained with the evacuated tube collector. The decreased solar heat delivery to hot water is due to moving the hot water exchanger to the collector loop. Formerly, water was solar heated whenever main storage temperature was sufficient. The new design provides solar heated water only when collection is possible *and* when collection temperature is below main storage temperature. The frequency and duration of this dual occurrence are insufficient for the heating of a large fraction of the water supply. Although this design prevents depletion of needed temperatures in main storage, important for cooling operations, the loss of water heating capability (particularly when heat in storage is not needed for other uses in spring and fall), is greater than the gains from increased solar heating and cooling. Return of the hot water exchanger to storage heat supply has therefore been decided.



Data based on 71.3 m² flat-plate collector area and 75.2 m² evacuated tube collector area, both equal to total occupied area, including space for manifolds.

† Collector area reduced during April, 4 days at 50.1 m², 8 days at 25.1 m², 9 days at 75.2 m².

FIGURE 5. Collector performance of the liquid system in Solar House I.

3.1.2. *Liquid collector comparison*

Comparison of the data on the system employing evacuated tube collectors with the flat-plate results shows, in figure 5 and table 1, (*a*) high solar collection, high collector efficiency, and high fraction of space heating load carried by solar energy from the evacuated tube collector; (*b*) higher solar hot water delivery, but less than can be obtained by relocating the hot water exchanger; and (*c*) over half of the large cooling requirements met by solar.

Radiation data are based on total area occupied by the evacuated tubular array, about half of which is effective absorber area. Based on this total area, the fraction collected is about double the flat-plate figure. Per unit absorber area, the improvement is nearly fourfold.

3.1.3. *Cooling comparison*

Although very limited cooling data were obtained with the flat-plate system in October, it is evident that major improvements resulted from the change to evacuated tube operation. The portion of the cooling load carried by solar was about 50% (compared with 45% and 62% in August and September 1977), but the August and September cooling loads were over five times as great as in the previous October. The solar supplied to cooling, 417 and 452 MJ/day in August and September, at an averate c.o.p. of 0.6, provided about 63 kWh per day, which would normally be sufficient for a comparable residence in the Fort Collins summer climate. The much higher cooling demand in C.S.U. Solar House I is due to heat losses from the storage tank and other hardware in the equipment room, high electricity use for instruments, motors, and lighting at office intensities, and to heat generation by two or three times the normal residential human occupancy.

3.2. *Air system performance: C.S.U. Solar House II*

Performance data spanning three heating seasons and two cooling seasons have been secured. Daily and monthly quantities of solar heat and heat from fuel for space heating and domestic hot water were continuously measured. Table 2, for January 1977, illustrates the scope of data procured and results computed on a daily basis throughout the winter. A daily average of approximately 355 MJ were supplied to the house during the winter, of which about 262 MJ were from the solar system, for an average solar contribution of 73 %. Figure 6 shows that monthly percentages varied from 58 to 65 % in January and November to 88 and 97 % in April and May, respectively. Total energy deliveries through the seven months were 50 599 MJ of solar heat, 18 741 MJ auxiliary heat, and 4693 MJ of electric fan power.

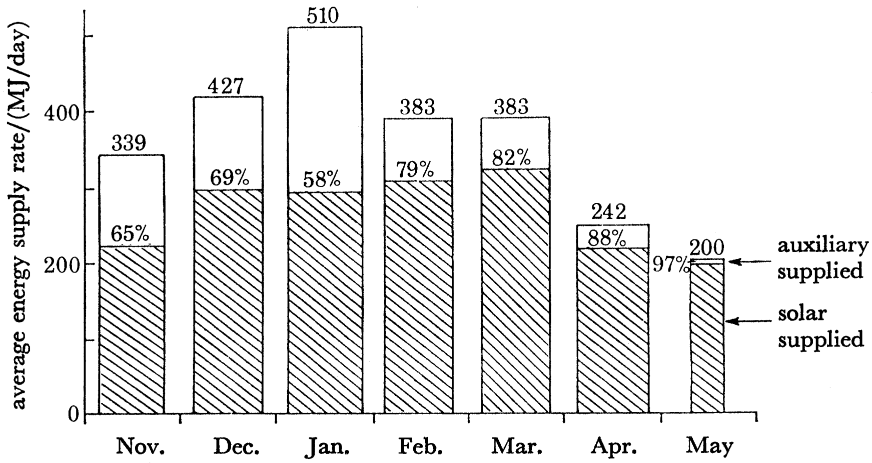


FIGURE 6. Solar and auxiliary contribution to total space and domestic hot water heating load in Solar House II, 1976–7 heating season, air system.

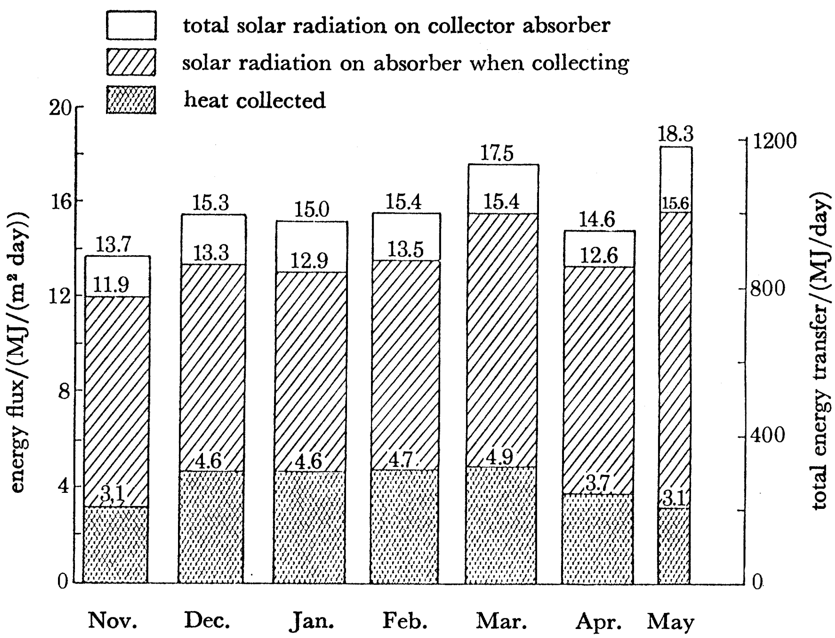


FIGURE 7. Monthly average daily performance, Solar House II, 1976–7, air system.

Table 2. System performance for January 1977 (MJ/day), air system

space and domestic hot water heating

day	energy required			solar energy used			auxiliary energy used			solar fraction		
	space	d.h.w.	total	space	d.h.w.	total	space	d.h.w.	total	space	d.h.w.	total
1	828.9	82.1	911.0	246.7	82.1	328.2	582.8	0.0	582.8	0.30	1.00	0.36
2	380.0	74.7	454.7	351.2	74.7	425.9	28.8	0.0	28.8	0.92	1.00	0.94
3	320.4	77.2	397.6	135.5	67.5	203.0	184.9	9.7	194.6	0.42	0.87	0.51
4	672.6	34.8	707.4	6.0	0.0	6.0	666.6	34.8	701.4	0.01	0.00	0.01
5	408.3	59.1	467.4	8.5	43.1	51.6	399.8	16.0	415.8	0.02	0.73	0.11
6	364.5	64.1	428.6	125.8	59.0	184.8	238.7	5.1	243.8	0.35	0.92	0.43
7	435.8	84.7	520.5	355.5	78.3	433.8	80.3	6.4	86.7	0.82	0.92	0.83
8	699.8	36.9	736.7	12.8	0.0	12.8	687.0	36.9	723.9	0.02	0.00	0.02
9	678.6	85.0	763.6	305.9	70.5	376.4	372.7	14.5	382.2	0.45	0.83	0.49
10	446.1	62.8	508.9	218.6	49.5	268.1	227.5	13.3	240.8	0.49	0.79	0.53
11	389.9	103.3	493.2	369.4	88.8	458.2	20.5	14.5	35.0	0.95	0.86	0.93
12	373.8	41.7	415.5	6.1	0.0	6.1	367.7	41.7	409.4	0.02	0.00	0.01
13	494.9	96.0	500.9	278.4	96.0	374.4	126.5	0.0	126.5	0.69	1.00	0.75
14	384.5	75.9	460.4	240.8	70.5	311.3	143.7	5.4	149.1	0.63	0.93	0.68
15	623.6	32.4	656.0	6.7	2.1	8.8	616.9	30.3	647.2	0.01	0.06	0.01
16	457.7	86.9	544.6	193.7	81.3	275.0	264.0	5.6	269.6	0.42	0.94	0.50
17	321.0	77.3	398.3	240.6	71.9	312.5	80.4	5.4	85.8	0.75	0.93	0.78
18	396.0	45.0	441.0	15.5	19.2	34.7	380.5	25.8	406.3	0.04	0.43	0.08
19	444.3	93.7	538.0	347.7	93.7	441.4	96.6	0.0	96.6	0.78	1.00	0.82
20	505.5	98.2	603.7	491.5	98.2	589.7	14.0	0.0	14.0	0.97	1.00	0.98
21	172.4	53.0	225.4	172.4	53.0	225.4	0.0	0.0	0.0	1.00	1.00	1.00
22	257.0	20.7	277.7	7.2	0.0	7.2	249.8	20.7	270.5	0.03	0.00	0.03
23	484.8	77.9	562.7	339.9	77.9	417.8	144.9	0.0	144.9	0.70	1.00	0.74
24	437.0	70.1	507.1	359.0	70.1	429.1	78.0	0.0	78.0	0.82	1.00	0.85
25	345.0	90.9	435.9	332.8	90.9	423.7	12.2	0.0	12.2	0.96	1.00	0.97
26	301.2	79.9	381.1	227.1	72.1	299.2	74.1	7.8	81.9	0.75	0.90	0.79
27	372.7	97.7	470.4	372.7	97.7	470.4	0.0	0.0	0.0	1.00	1.00	1.00
28	459.8	84.0	543.8	358.5	84.0	442.5	101.3	0.0	101.3	0.78	1.00	0.81
29	449.8	80.7	530.5	343.7	80.7	424.4	106.1	0.0	106.1	0.76	1.00	0.80
30	371.0	87.6	458.6	371.0	87.6	458.6	0.0	0.0	0.0	1.00	1.00	1.00
31	370.0	86.0	456.0	370.0	86.0	456.0	0.0	0.0	0.0	1.00	1.00	1.00
total	13556.9	2240.3	15797.2	7210.6	1946.4	9157.0	6346.3	293.9	6640.2	—	—	—
mean	437.3	72.3	509.6	232.6	62.8	295.4	204.7	9.5	214.2	0.53	0.87	0.58

day	collector performance: total incident	collector performance: solar while collecting	collector performance: heat from collector	collector performance: average eff.	storage: heat in	storage: heat out	storage: heat loss	storage: change in storage	electric energy: electrical energy for solar	electric energy: electrical energy for house
1	1062	974	349.9	0.36	194.6	172.5	4.9	16.2	25.9	232.1
2	1300	1193	453.4	0.38	266.2	226.2	10.0	17.5	29.2	250.1
3	642	530	195.3	0.37	102.9	106.1	6.5	−14.2	17.0	340.1
4	0	0	0.0	—	0.0	4.7	5.0	−11.0	2.5	320.2
5	702	547	171.5	0.31	87.4	86.5	5.5	−7.1	18.7	302.3
6	787	568	187.5	0.33	97.1	89.9	6.5	−3.8	19.9	311.7
7	1229	1137	443.9	0.39	292.5	266.7	11.5	−1.4	27.8	267.0
8	405	0	0.0	—	0.0	11.8	5.0	−17.8	2.2	275.5
9	1441	1197	387.2	0.32	215.5	201.9	5.8	5.0	27.3	266.4
10	994	818	269.1	0.33	145.4	139.9	6.5	−5.5	26.5	309.9
11	1372	1290	487.8	0.38	300.6	256.5	11.0	18.5	31.4	294.6
12	286	0	0.0	—	0.0	4.7	5.1	−11.2	2.1	284.5
13	1206	1100	400.3	0.36	243.7	208.5	8.6	17.3	27.0	241.2
14	1024	896	320.3	0.36	190.7	172.4	8.6	0.4	27.7	287.3
15	376	59	8.5	0.14	1.5	0.8	5.0	−5.3	4.0	259.5
16	1002	848	296.4	0.35	152.6	128.7	5.5	15.9	22.2	248.4
17	1033	929	329.7	0.35	205.1	178.6	8.6	8.6	27.1	255.3
18	416	133	33.7	0.25	8.9	8.5	5.1	−6.1	6.9	224.2
19	1321	1247	454.2	0.36	287.6	264.3	9.0	3.8	31.6	302.4
20	1368	1299	507.6	0.39	331.5	237.2	12.0	65.3	32.2	240.8
21	906	803	293.3	0.37	174.4	96.0	9.0	58.9	26.7	157.1
22	96*	12*	5.2*	0.43*	0.0	0.0	5.3	−7.3	4.4	206.9
23	1210	1137	419.1	0.37	268.7	258.1	8.6	−7.3	33.4	256.4
24	1406	1280	437.8	0.34	273.9	253.7	9.5	−0.8	36.5	321.2
25	1526	1431	499.4	0.35	326.2	233.5	12.0	63.7	36.9	336.0
26	864	673	244.0	0.36	142.8	188.0	8.8	−64.0	20.5	323.4
27	1519	1437	496.5	0.35	325.2	280.3	12.7	13.4	36.2	315.2
28	1402	1293	421.3	0.33	255.6	263.8	10.2	−31.4	33.8	333.7
29	1360	1188	420.6	0.35	245.0	238.3	9.0	−12.8	30.3	270.3
30	1491	1344	478.0	0.36	286.3	254.4	10.0	9.4	34.9	293.4
31	1466	1379	486.8	0.35	316.5	268.2	12.0	18.8	37.6	326.9
total	31212	26742	9498.3	—	5738.4	5100.7	252.2	125.7	740.4	8654.0
mean	1007	863	306.4	0.36	185.1	164.5	8.1	4.1	23.9	279.2

As shown in figure 7, average daily radiation incident on the 45° collector surface during the seven months varied from 13.7 MJ/m² in November to 18.3 MJ/m² in May, and, during collector operation, averaged 13.6 MJ/(m² day), representing about 87 % of the incident total. Average useful daily solar energy collected varied from 3.1 MJ/m² in May to 4.9 MJ/m² in March, with a total winter average of 4.1 MJ/m². The useful recovery thus averaged 30 % of radiation received during collector operation and 26 % of total incident solar energy. The recovery of total incident radiation varied from 31 % in January and February to 17 % in May.

As shown in table 2, the daily quantities of energy provided to the building for space heating and water heating vary considerably from day to day. The total energy used in Solar House II can be determined by adding the electric energy supplied, which is listed in the last column in the table, to the total space and domestic hot water load. Electricity used to operate the solar system is tabulated separately (next to last column) and is included in the electric energy used in the building. The electric energy needed to operate the solar system through the seven months amounted to 7.4 % of the total solar energy used for space and d.h.w. heating. When interpreted in terms of coefficient of performance, that is, the ratio of solar energy supplied to electric energy needed to operate the solar system, the c.o.p. is 13.5 for the 1976–7 heating season.

4. Comparison of systems

The performance of the collectors functioning with the systems may be compared in figures 5 and 7. Energy rates are shown vertically against months along the horizontal axis. Liquid and air flat-plate collectors are compared in November 1976, and the evacuated tube liquid-heating collectors may be compared with the air-heating flat-plate collectors from January to April 1977.

Data for November show that the flat-plate air system operated over a longer period of the day, on average, than the flat-plate liquid system. The principal reason for the longer operating period during a day, and hence for the heating season, is stratification of heat in the pebble-bed storage, as opposed to a non-stratified water storage tank in the liquid system. Because the air delivered to the collector in the morning is always at room temperature (in winter), collection of heat begins earlier in the morning for the air system than the flat-plate liquid system. In the liquid system the storage tank temperature is 10–50 °C greater than room temperature, and collection is delayed until the collectors are at least 15 °C above storage tank temperature. In the afternoon, the liquid system stops earlier than the air system because the warm water supplied to the collector from the storage exchanger requires higher solar intensities for useful collection. In an air system, as long as the air temperature from the collector is greater than the air temperature at the bottom of the pebble-bed storage (which is near room temperature for much of the heating season), the system will continue to collect useful heat.

Comparison of January–April data in figures 5 and 7 shows that the evacuated tube collectors on House I have a significantly greater efficiency than either of the flat-plate collectors. The evacuated tube collectors have a selective absorber coating, while the double glazed flat-plate collectors have flat black absorber coatings. Because of reduced heat losses, the evacuated tube collectors operate over a longer daily period than do flat-plate liquid collectors, but for about the same period as flat-plate air collectors. On average, the evacuated tube collectors on Solar House I operated while 89.5 % of the total measured solar radiation was being received while the flat-plate air collectors operated during receipt of 86.5 % of the total daily radiation.

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In November, the air-heating collectors delivered about one-third more heat than the flat-plate liquid-heating collectors. (In several months of the previous heating season, the average difference was also about one-third.) The evacuated tube collectors delivered about 15% more heat than the air collectors in January–April and might be expected to deliver about 50% more than the flat-plate liquid collectors on Solar House I, although a direct comparison was not made for the same period of operation. Considerably more electricity was used by both liquid systems than by the air system, but minimal power use was not an objective in these experiments.

5. Conclusions and summary

These performance comparisons must be viewed with regard to several non-comparable factors, and should therefore not be considered conclusive. Although the two houses are of the same design, their heat requirements differ and vary considerably. Secondly, the three collectors are not the same size, the overall external (occupied) areas being 71.3 m^2 (flat-plate liquid), 68.4 m^2 (flat-plate air), and 75.2 m^2 (evacuated tube). The absorber area of the evacuated tube is, however, only 39.9 m^2 and the total panel area, excluding manifold space, is 50 m^2. (Efficiencies may be based on either of these alternate areas by simple ratio.) Thirdly, discontinuities in the recorded data do not simultaneously occur, so computed heat quantities do not always cover identical periods. And, finally, these specific systems, with their faults on the one hand, and their carefully controlled operation on the other, cannot be assumed to represent all systems even of the same general types.

With these considerations in view, the system comprising an evacuated tubular collector, lithium bromide absorption water chiller and associated equipment can effectively provide solar heating and cooling to a building. It can supply substantially greater energy for space heating and cooling than is obtainable from a system with an equal occupied area of good quality, flat-plate collectors, and a greater fraction of the domestic hot water can be obtained by supplying its heat from main storage rather than from the collector. The cost-effectiveness of the system, in comparison with one employing a good flat-plate collector, can be determined when commercial pricing data are made available.

It is further concluded that an air-heating solar system can effectively provide space and domestic water heating in residential buildings. During the heating season from 4 November 1976 to 16 May 1977, the system provided 15600 MJ of heat, which was 73% of the total load. Heat delivery per unit collector area was about one-third greater than provided by the flat-plate liquid system, and about 15% less than delivered in the evacuated tubular collector system of 10% larger gross area but only 62% of the absorber area.

Although air leaks in the collectors and ducts can reduce the effectiveness of the solar system, the basic advantages of the air type are that the heat transfer fluid will not boil or freeze, materials used in the system have a long life, and maintenance requirements are minimal.

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