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Solar Domestic Water Heating:
A Case Study

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This is a first-year performance report on the operation of a domestic solar water heater. The system being reported on is installed in CEDAR RIDGE, the solar research house designed and built by the author near Mexico, Missouri.

System Description

The CEDAR RIDGE water heating system consists of the usual components. Included are:

Collectors—(6) manufactured steel flat plate, liquid collectors, single glazed and mounted at a 53°* incline, with azimuth angle equal to 14° east of true south. The collector array is flush mounted in the roof and consists of 72 *net* square feet of absorber area. The absorber panels are interconnected through top and bottom manifolds plumbed from the back (attic) side. The absorbers are painted with a silicone-base flat black paint and back insulated with unbonded fiberglass to an R-16 level.

Storage—storage for the system consists of a "stoned lined" steel tank of 120 gallon capacity. Located in the basement and designed especially for solar applications, this massive tank weighs 500 lbs. empty (approximately 1500 lbs. filled) and stands almost six feet tall. The tank is factory insulated with 2 inches of fiberglass insulation. Contained in the bottom of the tank is a corrugated, double walled, coiled copper heat exchanger. A single, 4500W, 220V electric element mounted in the upper 1/3 of the tank provides backup heat. The standard temperature/pressure relief valve adorns the top of the tank(see Fig. 2).

120 gallon storage tank weighs 1,500 pounds when full. Flexible conduit near top leads to single 4,500 watt back-up element.

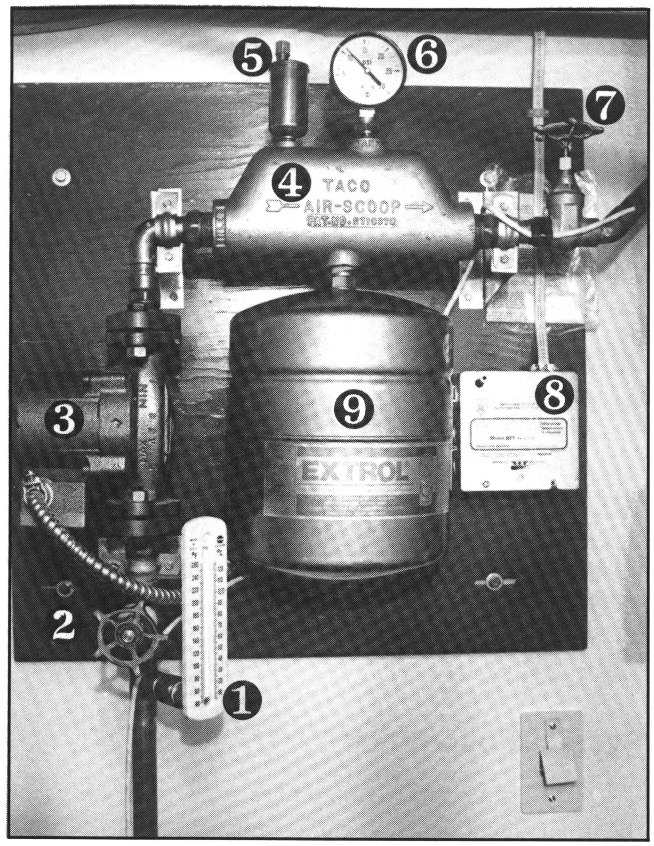
Control/Regulation—A self contained control panel consisting of: isolation valves, air eliminator and vent, 1/20th H.P. fluid pump, pressure gauge, differential controller (thermostat), and expansion tank, is mounted adjacent to the storage tank (see Fig. 3). Thermometers were installed in the fluid supply and return lines to monitor operating temperatures. Thermistors installed on the storage tank wall and at the outlet of one of the highest absorber panels sense on/off temperatures and for safety reasons provide automatic shut down when 160°F water is accumulated. A swing check valve used to prevent reverse thermosiphoning and located in the array supply line completes the plumbing.

**The generally prescribed mounting angle for year-round solar water heating is latitude (39° for Mexico, MO.) +5° or 44 call it 45°. CEDAR RIDGE'S south facing roof is slanted at the optimum space heating angle, 53°, for Mexico's latitude. The water heating array was installed accordingly rather than interfere with architectural lines even though a slight decline in summertime performance results.*

Fluid—A petroleum based, industrial heat transfer fluid is being used to conduct heat from the array to the storage tank heat exchanger. This lightweight oil will not freeze or boil at the expected annual operating temperature extremes and is very compatable with the steel absorber panels and other system metals (see "Mechanical Problems").

Plumbing Lines—All fluid supply and return lines are 3/4" type M hard drawn copper. Absorber panel interconnection was accomplished using neoprene elbows attached with split ring clamps. Two additional air vents installed in the attic automatically vent air trapped in the upper sections of the system. *All* fluid lines from basement to array are insulated with a pre-formed foam pipe insulation.

Monitoring Equipment—A flow meter is installed ahead of the storage tank in the cold water supply line to record gallons of water passing through the tank. Two ordinary kilowatt-hour meters are installed elsewhere in the basement and record back-up element and fluid pump electrical consumption. All of the meters are for research purposes and will normally not be found on the typical water heating system.



Water heater control panel—(1) monitoring thermometer, (2) isolation valve, (3) circulating pump, (4) air eliminator, (5) air vent, (6) pressure gauge, (7) isolation valve, (8) differential thermostat, (9) expansion tank.

Performance Comments and Observations

A chart depicting early system performance appears in table 2. While the "bottom line" figures look quite promising, it should be stressed that accurate assessment of *long term* performance will have to be deferred for some time yet.

One item of immediate interest lies in column 3—gallons per day consumption. Standard design practice dictates an average of 20 gallons of hot water per day per person which in the case of CEDAR RIDGE would total 80 gallons for the four member family. From a low of 48 GPD to a high of slightly over 90 GPD, an average of 62 GPD (22 percent below the norm) actually passed through the tank. The wide fluctuation in per diem usage is attributed solely to laundering practices. The relatively low **total** consumption is attributed to: 1) the inherently conservative electro-mechanical water distribution system used throughout the house; and 2) a conscious effort on the part of the family to conserve water.

Another point that is not apparent from table 2 data is the variation in incoming water temperatures. The storage tank electric element thermostat has been set to provide 120°F water at the faucet. However, at start-up and for some 3-4 weeks following, the inlet temperature was a very chilly 43°F, some 10-12 degrees lower than would normally be expected. With the season change and warmer air and ground temperatures, the water inlet temperature rose to a maximum 72°F. The extreme fluctuation in inlet temperature is thought to be the result of the water district's main being buried close to the surface just east of CEDAR RIDGE. Naturally, the greater the difference between incoming and delivered water temperatures, the ΔT, the more the system, electric or solar, has to work to provide the desired temperature water.

Some may have trouble accepting the 120°F. base point around which this data originates. This figure (120°), rather than the usual 140°F-plus, was selected for the following reasons: 1) The adult human body can safely accept temperatures in the 105 - 120°F range; 2) The results of laundering with 120-degree water have been acceptable: 3) Newer model dishwashers are designed to heat incoming water to temperatures required for proper sanitizing and dish cleaning; and 4) Annual savings of approximately 7% can be realized with such a reduction, i.e. 140° to 120°F.

While it may initially seem that such a reduction makes the solar contribution figures look better, one must also note that the figures *do not* give credit for water delivered during the summer, water which was often in the 150 - 160°F range.

Columns 7, 8, and 9 all deal with calculated "savings" and need to be looked at rather critically. An important factor is the low cost per KWH when compared to the 8-10¢/KWH in other parts of the country. In addition, the present rate structure of the Rural Electric Cooperative supplying CEDAR RIDGE is the declining block type in which the more consumption the lower the rate. As warmer weather arrives, electrical demand for space heating drops to practically zero correspondingly reducing total monthly consumption. The end result has been a failure to move into the cheaper rate block hence increasing the KWH cost of what electricity was used.

Perhaps what most people will find of greatest interest from Table 2 data is columns 10, 11, and 12, the per cent solar contribution. But again, the entire picture is not apparent. The all-important insolation (solar radiation) factor figures prominently in these columns. For example the nearly 86 percent solar contribution during week 6 occurred during a week in which the sun made an appearance every day. The following week provided a very respectable solar contribution (77.9 percent), but there was bright sun for only 2 days of the week. The difference lies in water usage. Week 6 consumption was the highest of the year while week 7 was a below average consumption week. The obvious conclusion to be draw from this comparison is that high water usage tasks (laundering, whirlpool bathing, carwashing, etc.) should be conducted during periods of high insolation (sunshine).

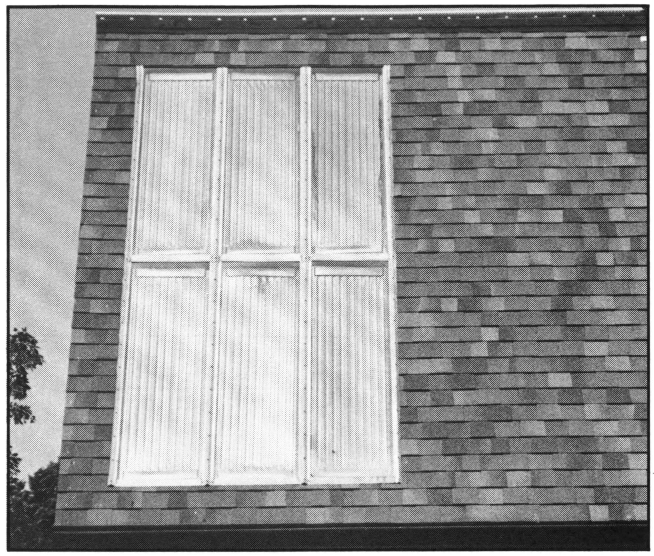
A critical examiner of Table 2 figures will most certainly note the 14 consecutive weeks during which the sun provided ALL of the required heat. It should also be noted that with the exception of just 4 scattered weeks, the sun provided at least 65% of the required heat during the last 6 months of 1980.

It is a common misconception that for a solar system of any type to work, one has to have a bright, cloudless sky. *Nothing could be farther from the truth!* An excellent case-in-point occurred during the record breaking snow date of April 14, 1980. During this particularly dreary day, CEDAR RIDGE'S solar water heating system operated from shortly after 9:00 A.M. until approximately 3:30 P.M. Mid-day fluid return temperature (fluid coming from the array into the storage tank heat exchanger) fluctuated between 90-102°F. Needless-to-say, with incoming water temperature at 50°± considerable heating action can take place. The combination of ultra-violet and infrared radiation and the "green-house effect" at the collector are sufficient to provide *much* useful heat even without bright sunshine.

Mechanical Problems

As with any emerging technology, the presence of bugs in the system is practically inevitable. And the CEDAR RIDGE system is no exception.

After all plumbing for the system had been completed, but prior to charging with transfer fluid, an air



Six-panel array, 72 square feet net area, installed flush in the roof.

pressure check was conducted. The outcome of this test was a leak in one of the six absorber panels necessitating the replacement of the panel.

Approximately one week later and after a week of operation, the fluid line pressure relief valve failed, discharging a small quantity of fluid into a catch bucket. Investigation revealed the failure of an "O"-ring inside the valve mechanism. On checking with the solar manufacturer, it was learned that the "o"-ring was made of a material that was not compatible with the petroleum based transfer fluid being used. On the manufacturer's advice, the entire valve was removed and the opening capped.

Footnote 8, Table 2, is short but certainly not very sweet and represents a very peculiar occurance. Through some yet unexplained quirk, the manufactured, diaphragm-type expansion tank, supposedly factory charged to 12 P.S.I., during a routine check was found to contain a charge of over 20 P.S.I. This situation was immediately corrected but resulted in a series of disturbing consequences.

A day or so later, the control panel pressure gauge read "0" with the pump in operation. Investigation revealed the failure of the expansion tank diaphragm along with the rupturing of THREE of the six absorber panels. Subsequent discussions with the manufacturer have resulted in the belief that the over charged expansion tank, now unprotected by a pressure relief valve, placed the entire system under too much pressure. The result of this incident was some 10½ days of down time. Due to the manufacturing technique employed in producing the absorbers, a system of the type in question is designed to operate normally in the 12-15 P.S.I. range. Pressures 50-60% in excess of normal are simply too much to expect with these panels.

In month five of operation, the last malfunction occurred. In this instance the culprit was the printed

System Installation Costs

As a part of the on-going research being conducted at CEDAR RIDGE, accurate records of materials costs and labor charges have been kept. The following chart (table 1) lists the installation costs associated with the system.

Table 1-Solar Water Heater Installation Costs[1]

LABOR[2]					
Structural (roof) framing, flush mounted collector-					
	10 hours @ $10.00	=	$100.00		
	12 hours @ $ 3.50	=	$ 42.00		
	4 hours @ $ 7.00	=	$ 28.00		
	26 hours @ 6.83 avg	=	$170.00		
				$170.00	
Plumbing, electrical, insulating -					
	40 hours @ $10.00	=		400.00	
	Labor Total				$ 570.00
MATERIALS					
TD120-6 HDE system w/controls				$1,257.90	
Tubing, valves, fittings				138.56	
Absorber & pipe insulation				28.50	
Mastics/sealants/cap screws				21.50	
Control wire				6.00	
Transfer fluid				36.00	
	Materials Total				$1,488.46
	Grand Total				2,058.46

[1]All figures as of late '79, early '80

[2]The owner/author contributed the major portion of the installation hours for this system and did not pay himself. While the actual installation hours are correct (actually quite liberal) the total dollar values are included to show what a less than skillful homeowner might have to pay for a "professional" installation.

circuit board inside the differential thermostat (see Fig. 3). But this time, Mother Nature is suspect. On the evening of the preceding day, a severe electrical storm moved through the area and lighting around the RIDGE was quite intense. The following morning the system failed to start up automatically. The failure was traced to the controller which was immediately replaced following less than 2 hours of down time.

Since the entire system is covered by the manufacturer's 5-year limited warranty replacement of the defective absorber panels and expansion tank, aside from the loss of service, it presented no problem. The replacement costs of the controller was assumed by the owner. However, re-installation of the new parts was the responsibility of the author since solar warranties typically *do not* cover labor charges.

On the whole it is felt that after a somewhat rocky start, the CEDAR RIDGE system is now performing admirably. Mistakes by the author have been made in the quest for solar water heating experience. The results of these mistakes were viewed positively and minor set-backs were expected. The end result, however, is a water heater operating as a well designed system should operate—efficiently.

Want More Information?

Additional information on solar water heating can be found in Home Economics Guides:

GH5996 Solar Domestic Hot Water Heating Systems

GH5253 Solar Water Heating: Selecting Equipment

Solar enthusiasts should also be aware of the Conservation and Renewable Energy Inquiry and Referral Service (CAREIRS), P.O. Box 8900, Silver Springs, MD 20907 or Call toll-free, (800) 523-2929.

And if you would like to be placed on the mailing list to receive periodic updates on the CEDAR RIDGE system contact the author at the following address: Bob Cusick, Housing Specialist, UMC Extension Center, Courthouse-4th Floor, Mexico, Missouri 65265, Phone (314) 581-3231.

Table 2

PERFORMANCE DATA

Month	Col. 1 Week	2 Usage, Gal.	3 Gal/day	4 KW, all elect.[2]	5 KW, actual	6 KW, pump	7 Savings, this wk.[3] $	8 Accrued Savings $	9 Avg. Sav/wk. $	10 % solar this wk.[6]	11 Monthly Avg.	12 Avg. % Solar[7]
	start-up[1]											
Mar.	1	359	51.0	67.2	24	3	1.50[4]	1.50	—	64.3	44.9	—
	2	480	68.6	90.0	67	4	.70	2.20	1.10	25.5		44.9
Apr.	3	491	70.1	92.0	51	4	1.30	3.50	1.17	44.5	62.0	44.8
	4	421	60.1	78.8	37	3	1.94[5]	5.44	1.36	53.0		46.8
	5	498	71.1	87.0	31	5	2.55	7.99	1.60	64.4		50.3
	6	633	90.4	106.2	15	6	4.26	12.25	2.04	85.9		56.3
May	7	417	59.6	67.9	15	4	2.44	14.70	2.10	77.9	75.2	59.4
	8	450	64.3	71.1	12	5	2.70	17.40	2.18	83.1		62.3
	9	510	72.9	79.4	33	4	2.12	19.40	2.16	58.4		62.0
	10	490	70.0	76.3	28	7	2.06	21.46	2.15	63.3		62.1
	11	410	58.6	59.8	4	4	2.59	24.05	2.19	93.3		64.9
Jun.	12	490	70.0	69.1	12	6	2.56	26.61	2.22	82.6	52.0	66.4
	13	440	62.9	61.0	4	5	2.60	29.21	2.25	93.4		68.5
	14[8]	580	82.9	—	70		0.00	29.21	2.09	—		63.6
	15	450	64.3	60.2	41	5	0.71	29.92	1.99	31.9		61.5
Jul.	16	567	81.0	74.5	3	5	3.32	33.24	2.08	96.0	99.2	63.7
	17	378	54.0	46.9	0	5	2.09	35.33	2.08	100.0		65.8
	18	356	50.9	43.3	0	5	1.91	37.24	2.07	100.0		67.7
	19	390	55.7	47.4	0	5	2.12	39.36	2.07	100.0		69.4
	20	349	49.9	41.6	0	4	1.88	41.24	2.06	100.0		70.9
Aug.	21	335	47.9	39.9	0	4	1.80	43.04	2.05	100.0	100.0	72.3
	22	369	52.7	43.1	0	5	1.90	44.94	2.04	100.0		73.6
	23	434	62.0	50.7	0	4	2.33	47.27	2.06	100.0		74.7
	24	472	67.4	57.4	0	5	2.62	49.89	2.08	100.0		75.8
Sep.	25	390	55.7	46.5	0	4	2.12	52.01	2.08	100.0	100.0	76.8
	26	349	49.9	41.6	0	5	1.83	53.84	2.07	100.0		77.7
	27	384	54.9	47.6	0	4	2.18	56.02	2.07	100.0		78.5
	28	484	69.1	61.2	0	5	2.81	58.83	2.10	100.0		79.3
Oct.	29	552	78.9	72.5	0	5	3.37	62.20	2.14	100.0	93.3	80.0
	30	413	59.0	55.2	0	4	2.56	64.76	2.16	100.0		80.7
	31	301	43.0	41.0	11	3	1.35	66.11	2.13	73.2		80.5
	32	430	61.4	61.7	0	4	2.88	68.99	2.16	100.0		81.1
Nov.	33	399	57.0	60.2	5	4	2.56	71.55	2.17	91.7	77.5	81.4
	34	413	59.0	63.3	0	5	2.91	74.46	2.19	100.0		81.9
	35	445	63.6	68.2	17	3	2.41	76.87	2.20	75.1		81.7
	36	354	50.6	57.7	28	3	1.33	78.20	2.17	51.5		80.9
	37	334	47.7	55.2	17	3	1.76	79.96	2.16	69.2		80.6
Dec.	38	386	55.1	65.7	29	3	1.45[9]	81.41	2.14	55.9	46.0	79.9
	39	336	48.0	57.2	45	2	0.44	81.85	2.10	21.3		78.4
	40	490	70.0	83.4	21	5	2.47	84.32	2.11	74.8		78.3
	41	380	54.3	64.7	44	2	0.80	85.12	2.08	32.0		77.2
Jan.	42	480	68.6	87.5	51	4	1.40	86.52	2.06	41.7	63.7	76.4
	43	373	53.3	68.9	28	3	1.63	88.15	2.05	59.4		76.0
	44	429	61.3	80.3	20	3	2.47	90.16	2.06	75.1		76.0
	45	428	61.1	77.0	29	4	1.89	92.51	2.06	62.3		75.7
	46	432	61.7	80.9	16	3	2.66	95.17	2.07	80.2		75.8
Feb.	47	556	79.4	105.5	48	3	2.34	97.51	2.07	54.5	70.6	75.3
	48	450	64.3	84.3	32	4	2.08	99.59	2.07	62.0		75.0
	49	465	66.4	85.9	6	4	3.27	102.86	2.10	93.0		75.4
	50	437	62.4	81.8	22	4	2.40	105.26	2.11	73.1		75.4
Mar.	51	530	75.7	94.1	61	4	1.25	106.51	2.09	35.2	67.0	74.6
	52	450	64.3	82.1	1	5	3.27	109.78	2.11	98.8		75.1

SEE SUMMARY, NEXT PAGE

SUMMARY

Col. 1 Week	2 Usage, Gal.	3 Gal/day	4 KW, all elect.[2]	5 KW, actual	6 KW, pump	7 Savings, this wk.[3] $	8 Accrued Savings $	9 Avg. Sav/ wk. $	10 % solar this wk.[6]	11 Monthly Avg.	12 Avg. % Solar[7]
	22,639 Gal. Tot.	62.2 Avg.	3442. Tot.	978 Tot.	212 Tot.		109.78 Tot. $	$2.11 Avg.			75.1% Ann.
	435 Avg. GPWK	GPD	KW	18.8 KW/Wk.	4KW/ Wk.						Avg.

[1]start-up occurred 3-15-80, weeks are consecutive

[2]assumes no solar assist - calculated using formula: $\frac{(Gal)\ (8.3)\ (Sp.ht,\ H_2O)\ (outlet\ temp\text{-}inlet\ temp)}{3413} = KW$

[3]pumping costs have been subtracted

[4]electricity costing 3½¢/KWH

[5]electricity costing 5¢/KWH

[6]calculated solar contribution

[7]cumulative solar contribution since start-up

[8]system down 10½ da.; expansion tank failure

[9]electricity costing 4 1/3¢/KWH

Bob Cusick is a UMC Housing Specialist working in the Mid-Missouri area. He is a solar advocate and practitioner and since 1979 has been involved in CEDAR RIDGE, a hybrid solar research residence designed and built by Mr. Cusick near Mexico, Missouri. For the most part, the information contained in this guide is drawn from personal experience and observation.

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