Domestic Solar Water Heating

In the Desert

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A review of the requirement for solar heating of domestic hot water in desert conditions, including recommendations, examples, and a schematic.

Domestic Solar Water Heating (DSWH) has a high ROI (return-on-investment) compared with many stocks and bonds. However, there is still an investment. Whether totally contracting the entire design and installation or doing some to the work yourself, the homeowner needs to understand the various design constraints and operating conditions for a dependable system. The materials for the basic systems will cost ~$2,000 -$3,000; the cost of labor will vary with location, system size, and homeowner contribution, but should be approximately the same as the cost of the materials.

The following will describe a solar domestic hot water heating system for desert applications. The desert conditions include at least one hard freeze per year and are independent of whether one is in the high, mid, or low desert (function of altitude). This description will use parameters typical for Nye and Esmeralda Counties in Nevada (mid and high desert). While most of the population of Esmeralda County is in the high desert and most of the population of Nye County is in the mid desert, since the population centers in Nye County are much further south, the differences in latitude are partially compensated for by the differences in altitude and air quality. Solar collectors work better with higher ambient temperature and higher insolation (solar radiation); however, the differences between the northern part of Esmeralda County and the southern part of Nye County are not large enough to significantly affect the accuracy of the estimations provided herein.

The first concern is sizing the system. All components for the system come in a limited number of fixed capacities. Given the climate conditions, i.e., insolation and ambient temperature, the system must be sized to prevent over-heating during the summer, yet provide most of the hot water for the home. A reasonable target is for the solar system to provide ~90% of needed hot water during the summer and ~ 50% of needed hot water during the winter. Over-heating reduces the system lifetime and can increase maintenance costs. While the major concern is over-heating or stagnation, some variability is allowed with the total collector area vs. the quantity of hot water needed.

The first parameter to consider is the amount of hot water that will be used. The amount of hot water will be a function of the number and ages of people in the household and their lifestyle. For example, an older retired couple will not use as much hot water per person as a younger couple with children.

The schematic in attachment A is for the SolarRoofs System 5 Platinum water heating system. Solar collectors and other components are available from other manufacturers and distributors (see Attachment B); however, this example system is representative of an optimal system for the desert.

The performance, i.e., BTU's produced of the solar collector, is a function of a number of parameters that can vary by application and environment. The key parameters are:

1. The materials and construction methods of the solar collector. These are fixed for any given collector, but can vary by manufacturer, type, and model.

2. Environmental conditions, including insolation (a measure of the power of the solar radiation) and ambient temperature. The BTU's produced are a function of mounting angle of the solar collector, which affects the amount of insolation available, and the ambient temperature at the collector.
3. Application conditions including the desired hot water temperature and quantity.
4. System conditions including flow rate and system efficiencies, e.g., heat transferred in the collector and heat exchanger, heat loss in the piping.

Given the number of possible variables, in order to estimate the size of the optimum system for the two scenarios, a number of conditions will have to be estimated or assumed. The following heuristics (rules-of-thumb) are assumed:

1. One square foot of collector area per ~2 gallons of storage.
2. ~8.3 BTUs are required to raise one gallon of water 1 ºF.
3. Heat exchanger efficiency and piping heat loss of 20%.

The following conditions are estimated:

1. Inlet cold-water temperature of 55 ºF in the summer and 50 ºF in the winter.
2. Target hot water temperature of 125 ºF.
3. The water temperature will rise during the day; the ambient temperature will rise, and then fall. An average of the ΔT between the inlet water and ambient temperatures will be used to estimate performance.
4. The NREL Redbook (http://rredc.nrel.gov/solar/pubs/redbook/) data was used to find insolation and temperature data.
5. The SolarRoofs SRCC report was used to estimate performance of the collectors.
6. The solar collectors are mounted parallel to a roof with a 4 in 12 pitch.

The two major components of the solar DHW heating system for sizing are the solar collectors and the storage tank. The storage tank is either 80 or 120 gallons. The expected hot water gallons produced for 4 different array areas are in attachment C. The assumptions for insolation and ΔT's are embedded in the tables.

The schematic in Attachment A is of a closed-loop system using an "anti-freeze" heat transfer fluid. The primary loop is the heat transfer fluid circulating through the solar collector and the heat exchanger in the storage tank. The secondary loop is the domestic water entering the storage tank, which is the back-up hot water heater, before use.

The solar panel is the flat-plate glazed collector from SolarRoofs suitable for domestic hot water heating. There will be some variation in performance by manufacturer and for various models by any given manufacturer, so one should consider the information herein to be as an example.

The primary loop must be pressurized. The optimum pressure is a function of the static head loss, which is a function of gravity and the characteristics of the heat transfer fluid. The static head loss in psi (pounds per square inch) is 0.433 x the difference in feet from the highest to the lowest point in the piping; e.g., if the total height difference is 20 feet, then the loop should be pressurized to a minimum of ~ 9 psi at the inlet of the pump. Generally, the system is pressurized at double or triple the gravity head loss for additional margin, as well as to increase the boiling temperature of the heat transfer fluid. Pressurizing the system will minimize wear on the circulation pump. At least one pressure gauge is required to measure system pressure. In order to determine the dynamic head loss another pressure gauge is required. One pressure gauge is at the inlet to the pump, the other is at the outlet. The ΔP across the pump should be ~ 3-6 psi. The dynamic head loss is a function of the flow rate of the fluid and the pipe parameters, e.g., material, diameter, number of turns. Pressurization of the loop minimizes starting current and wear on the mechanical components of the pump. The operating current is a function of the flow rate.

An expansion tank is required to maintain the correct pressure because the heat transfer fluid volume changes as a function of temperature. In general, the expansion tank volume should be about 0.066 times the volume of the fluid, e.g., if the system holds 5 gallons of heat transfer fluid, then the expansion tank should hold ~ 0.33 gallons of fluid (e.g., empty when cold, full when hot). A rule-of-thumb is to expect the heat transfer fluid to have a ΔT of at least 200 ºF.

While solar DHW heating systems may not justify the cost of a BTU (or energy) meter, a flow meter is desirable to optimize system performance. The heat transfer efficiency through any heat exchanger is a function of the flow rate, if the flow is too high or too low, the efficiency is less. In general, the solar collector efficiency is more sensitive to the flow rate than the efficiency of the heat exchanger in the storage tank. Therefore, the flow should be optimized around the identified flow rate of the solar collector, typically ~0.5 - 1 gpm. The actual flow should be slightly higher to compensate for piping friction loss. When collectors are in series, the flow rate of one collector is the needed flow rate; when collectors are in parallel, the flow rate is the flow rate of one collector multiplied by the number of collectors in parallel. When a flow meter is not available, the flow can still be optimized by measuring the ΔT across the collectors and the ΔT between the collector inlet and the storage tank.

The operation of the system is provided by a differential temperature controller. When the temperature at the solar collector is sufficiently higher than the temperature in the storage tank, the controller starts the circulation pump. This differential temperature is typically 15-20 ºF, in order to assure the pump does not start, and then stop intermittently while the fluid warms, e.g., when the colder heat transfer fluid enters the solar collector.

The controller senses temperatures using thermocouples. Ideally, the controller will have a digital display to show the actual temperatures. An analog temperature gauge at key locations is useful for correlation and trouble-shooting. The ΔT across the solar collector should be about the same as that across the storage tank heat exchanger; given the storage volume and collector area follow the rule-of-thumb of 1 ft^2 area/2 gallons of volume (balancing the ΔT's is accomplished using the flow control valve). The temperature of the heat transfer fluid coming out of the heat exchanger should be only 1-2 ºF higher than the temperature of the water (in the storage tank). One thermocouple is mounted on the copper pipe at the outlet of the solar collector. Typically there is a thermocouple mounted inside the storage tank, otherwise one can be externally mounted on the copper pipe from the hot water outlet of the storage tank. Most thermocouples have a nominal resistance of 10,000 Ω (ohms), so can be readily measured with a DMM (digital multi-meter), then use the applicable chart to convert the resistance to the temperature.

The pump should be sized to the application. A maximum 1/10 horsepower (75 W) pump with an output of 3 gpm is more than adequate for DSWH, even smaller power consumption pumps will work with systems that need lower flow rates. Since the actual flow rate will be a function of the static and dynamic head loss (gravity and pipe friction), the flow rate may need to be adjusted for optimum performance.

A heat transfer fluid is required for freeze protection. DowFrost HD is strongly recommended because of the high tolerance for temperature variation and long-term life (strongly resists degradation due to high temperatures). Since high-efficiency flat-plate collectors are susceptible to damage induced by high temperatures, having a fluid that will continue to transfer heat (cool the collector), even at high operating temperatures or during stagnation (no circulation at high temperature) is very desirable.

Isolation valves are desired for corrective maintenance, i.e., to replace or repair components. A flow control valve is needed to set the optimum flow. The isolation and flow control valves should be of globe (ball) design (not gate). Check valves are needed to assure proper direction of flow, e.g., when filling the primary loop, to prevent thermo-siphoning. Air vents help remove gases from the heat transfer fluid, gas bubbles can cause numerous problems. Pressure (not temperature) relief valves are for safety.

Piping should be copper or stainless steel. If a small system, e.g., one or two small collectors, with total short (<100 feet) pipe length, then the outside diameter can be ½ inch. If there are two or more larger collectors or a long pipe length, then the pipe outside diameter should be ¾ inch. Most joints should be brazed, although good compression fittings may be suitable in some systems. Unions and threaded fittings are appropriate for items that may require maintenance, e.g., pump, tanks, air vent. All primary loop piping needs high temperature insulation. The secondary loop piping before the tempering valve may need high temperature insulation. The other hot water piping should have normal hot water pipe insulation.

A tempering valve is required to assure the hot water used in the house is not too hot. Solar heating can cause water to reach temperatures that cause scalding. Both the thermostat on the water heater, e.g., when used in winter, and the tempering valve should be set to 125 ºF. This is hot enough to prevent organic growth in the system and effective for cleaning clothes and dishes, as well as easily mixed with cold water for comfortable hygiene.

Given the mechanical issues with fluid connections, solar collector panels are normally placed on fixed mounts. The issues of concern are location and the angles of azimuth and elevation.

Solar collectors should always be mounted in locations that are not shaded by trees, buildings, or other obstructions. If some shading is unavoidable, then make sure there is no shading between 8 AM to 4 PM in the summer and 9 AM to 3 PM in the winter.

Solar collectors should face due south (when using a compass, correct for magnetic declination). If there are mountains or other large obstructions that shade the collectors during the optimum solar collecting intervals, the collectors can be oriented up to 15 º to the east or west (e.g., a facing from 165 º to 195 º), to minimize the shading, with little loss of output.

In order to optimize total annual performance, the solar collectors for hot water heating should be mounted at an angle no greater than that of the latitude. Since the collectors are normally mounted parallel to the roof, the collectors will be at the roof pitch angle, e.g., ~ 9 º for a 2 in 12 pitch and ~ 18 º for a 4 in 12 pitch.

If possible, solar collectors should not be mounted directly in the wind path (e.g., mount below the top of the roofline); the cooling reduces performance and has an additional tensile stress on the roof structure.

Solar collector performance ratings are determined using ideal angles, i.e., facing due south and a normal angle of incidence. Since the actual mounting will rarely meet those conditions, the rated performance will rarely be achieved. Thus, one should design the system to be slightly larger than what is needed to compensate for these effects. Given that solar collectors only come in fixed areas, one just chooses the collector area size slightly larger than the minimum area calculated.

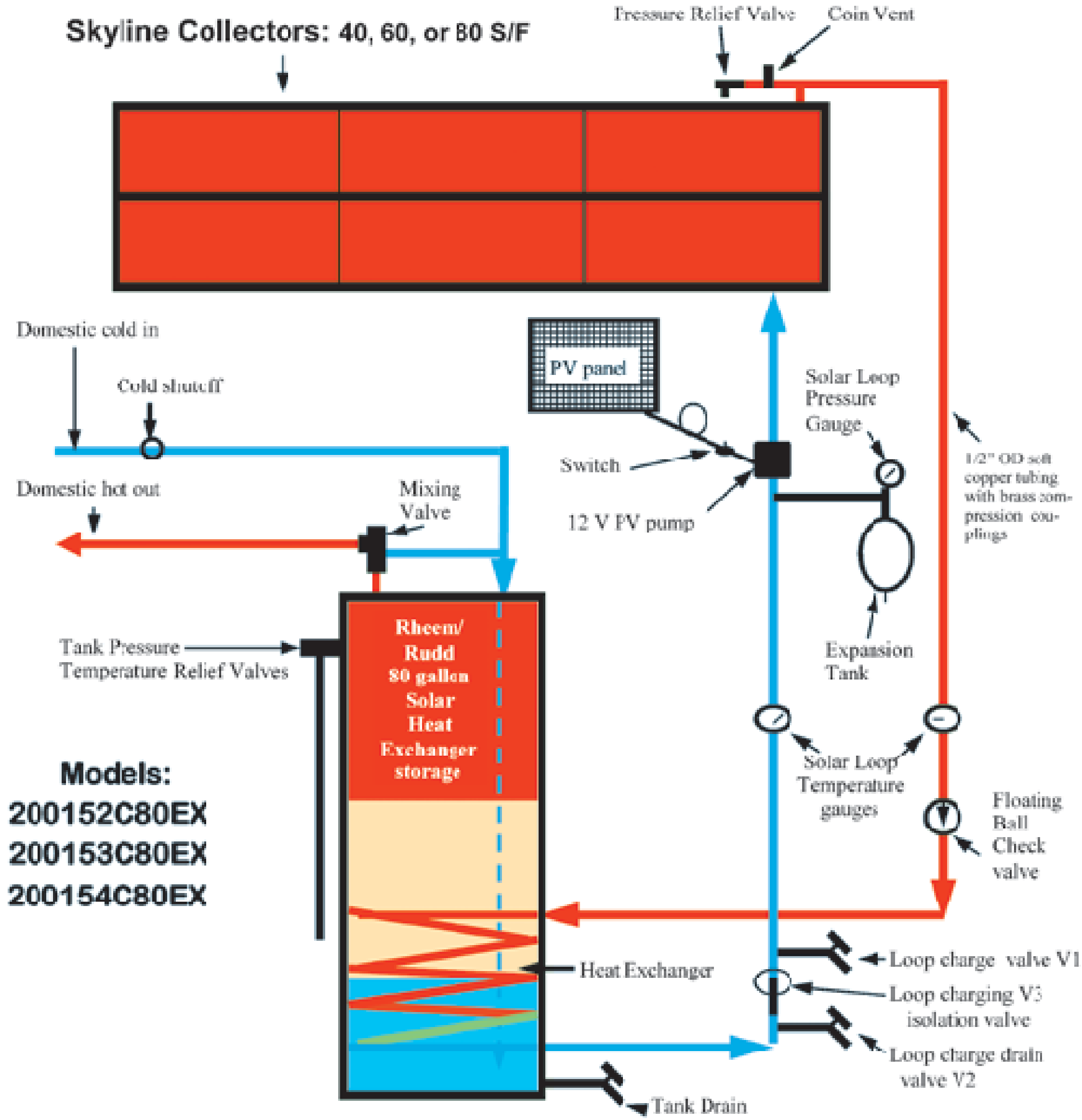
References:

Solar Hot Water Systems 1977 to Today Lessons Learned; Tom Lane; www.ecs-solar.com
Solar Energy Pocket Reference; Christopher Martin & Yogi Goswami; ISES; www.ises.org
SRCC, http://www.solar-rating.org/

Conversion Constants:

1 kWh = 3.6 MJ ≈ 3414.426 BTU
1 m^2 ≈ 10.76 ft^2
1 MJ/m^2 ≈ 0.27778 kWh/m^2 ≈ 88.114 BTU/ft^2
ºF = 1.8*ºC + 32

Attachment A
SolarRoofs System 5 Platinum



Attachment B

Manufacturers:

Solar Collectors:	SolarRoofs	http://www.solarroofs.com/
	SunEarth	http://www.sunearthinc.com/;
	Heliodyne	http://www.heliodyne.com/index.html;
	AET	http://www.aetsolar.com/
Storage Tanks:	Rheem/Ruud	http://www.rheem.com/
Controllers:	Goldline	http://www.goldlinecontrols.com/;
	SunEarth	http://www.sunearthinc.com/;
	Heliodyne	http://www.heliodyne.com/index.html
	IMC	http://www.solar.imcinstruments.com/
Heat Transfer Fluid:	DowFrost HD	http://www.dow.com/
Pumps:	Grundfos	http://www.grundfos.com/;
	Taco	http://www.taco-hvac.com/;
	Laing	http://www.lainginc.com/
Expansion Tanks:	Radian Extrol	http://www.amtrol.com/;
	Goulds	http://www.goulds.com/
Pipe Insulation:	Insul-Tube	http://www.kflexusa.com/products/insultube/
	Easy Flex	http://www.easyflexusa.com/html/main.html

Suppliers:

AAA Solar	http://www.aaasolar.com/
cisolar	http://www.cisolar.com/
King Solar	http://kingsolar.com/

Installers:

American Wind & Solar	http://www.americanwindsolar.com/home

Attachment C

Gallons of Hot Water Produced per Month by Array Area

	ΔT_1 = Ti (inlet fluid temperature) - Ta (ambient air temperature); 8.3 BTU to raise 1 gallon 1 °F													
	Efficiency includes 20% heat loss from piping and heat exchanger; ΔT_2 is desired hot water temp - well water temp (70 °F summer, 75 °F winter)													
Month	Days	Insolation	ΔT_1	ΔT_2	Efficiency	Panel	Hot Water Gallons Produced per Day				Hot Water Gallons Produced per Month			
							30	40	60	80	30	40	60	80
	per					Output	27.36	37.02	55.53	74.04	27.36	37.02	55.53	74.04
	Month	BTU/ft²-day	°F	°F	%	BTU/ft²-day	ft²	ft²	ft²	ft²	ft²	ft²	ft²	ft²
January	31	1332.2	90	75	80%	292	10.3	13.9	20.8	27.8	318.4	430.9	646.3	861.7
February	28	1622.2	36	75	80%	711	25.0	33.8	50.8	67.7	700.5	947.8	1421.7	1895.6
March	31	1984.7	36	75	80%	870	30.6	41.4	62.1	82.8	948.8	1283.8	1925.7	2567.6
April	30	2351.7	9	70	80%	1289	48.6	65.7	98.6	131.4	1360.0	1840.2	2760.3	3680.4
May	31	2474.0	9	70	80%	1356	51.1	69.1	103.7	138.3	1478.5	2000.5	3000.7	4000.9
June	30	2582.8	-9	70	80%	1416	53.3	72.2	108.3	144.4	1493.7	2021.0	3031.5	4042.1
July	31	2451.4	-9	70	80%	1344	50.6	68.5	102.8	137.0	1464.9	1982.1	2973.2	3964.3
August	31	2365.3	-9	70	80%	1297	48.9	66.1	99.2	132.2	1413.5	1912.5	2868.8	3825.1
September	30	2211.2	9	70	80%	1212	45.7	61.8	92.7	123.6	1278.8	1730.3	2595.4	3460.6
October	31	1871.4	9	75	80%	958	33.7	45.6	68.3	91.1	1043.8	1412.3	2118.4	2824.6
November	30	1459.1	36	75	80%	640	22.5	30.4	45.7	60.9	675.0	913.4	1370.0	1826.7
December	31	1268.7	36	75	80%	556	19.6	26.5	39.7	52.9	606.5	820.7	1231.1	1641.4
										Total	12782.4	17295.5	25943.2	34591.0

Attachment D

kWh Equivalent to Produce Solar Hot Water Gallons

Month	Days	Output	ΔT_1	Panel	kWh Produced per Day				kWh Produced per Month			
					30	40	60	80	30	40	60	80
	per			Output	27.36	37.02	55.53	74.04	27.36	37.02	55.53	74.04
	Month	BTU/ft^2-day	ºF	kWh/ft^2-day	ft^2	ft^2	ft^2	ft^2	ft^2	ft^2	ft^2	ft^2
January	31	292.1	90	0.086	2.3	3.2	4.8	6.3	72.6	98.3	147.4	196.5
February	28	711.5	36	0.209	5.7	7.7	11.6	15.4	159.7	216.1	324.2	432.3
March	31	870.5	36	0.255	7.0	9.4	14.2	18.9	216.4	292.8	439.2	585.5
April	30	1289.3	9	0.378	10.3	14.0	21.0	28.0	310.1	419.7	629.5	839.3
May	31	1356.4	9	0.398	10.9	14.7	22.1	29.4	337.2	456.2	684.3	912.4
June	30	1416.0	-9	0.415	11.4	15.4	23.0	30.7	340.6	460.9	691.3	921.8
July	31	1344.0	-9	0.394	10.8	14.6	21.9	29.2	334.1	452.0	678.0	904.0
August	31	1296.8	-9	0.380	10.4	14.1	21.1	28.1	322.3	436.1	654.2	872.3
September	30	1212.3	9	0.355	9.7	13.2	19.7	26.3	291.6	394.6	591.9	789.2
October	31	957.6	9	0.281	7.7	10.4	15.6	20.8	238.0	322.1	483.1	644.1
November	30	639.9	36	0.188	5.1	6.9	10.4	13.9	153.9	208.3	312.4	416.6
December	31	556.5	36	0.163	4.5	6.0	9.1	12.1	138.3	187.2	280.7	374.3
						Annual Total			2915.0	3944.2	5916.2	7888.3
				Annual Value of solar kWh @ $/kWh				$ 0.11	$ 320.65	$ 433.86	$ 650.79	$ 867.72
								$ 0.12	$ 349.80	$ 473.30	$ 709.95	$ 946.60
								$ 0.15	$ 437.25	$ 591.62	$ 887.44	$ 1,183.25