STUDY OF SOLAR WATER HEATER ENERGY SAVINGS IN MULTI-FAMILY HOUSING

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A Study of Solar-Assisted Gas Water Heaters for use in Multi-Family California Buildings

Prepared for: Southern California Gas Company

Prepared by:

Shawn Martin
Vice President of Technical Services
Solar Rating & Certification Corporation (ICC-SRCC™)
3060 Saturn Street
Suite 100
Brea, California 92821
www.solar-rating.org

Jeff Thornton
President
Thermal Energy System Specialists (TESS) LLC.
3 North Pinckney Street
Suite 202
Madison, Wisconsin 53703
www.tess-inc.com

STUDY of solar water heater energy savings in multi-family housing

A STUDY OF SOLAR-ASSISTED GAS WATER HEATERS FOR USE IN MULTI-FAMILY CALIFORNIA BUILDINGS

OVERVIEW

Domestic solar water heating systems have long been used in the California market and incentivized by various programs. The technology has been supported by both regulators and utilities alike as a means of increasing energy efficiency while reducing greenhouse gas emissions. The Southern California Gas Company requested performance modeling to support a potential incentive program for solar water heaters within existing incentive program structures for energy efficient technologies. This differs from the approaches used commonly in the past that either used a flat incentive or a customized, complicated incentive program using an extensive online performance calculator. This study seeks to provide the data needed to structure and justify a deemed program for solar water heating technologies in multi-family homes. It builds on a previous, similar study conducted for single-family homes.

PROJECT DESCRIPTION

Southern California Gas Company (SoCalGas) initiated this project to develop estimated annual energy savings for a range of solar water heating systems for the purpose of designing and establishing a deemed energy efficient rebate program. Task 1 under the project focused exclusively on the application of solar thermal water heaters to single-family homes. Task 2 of the project focused on the use of solar water heaters in multi-family home applications as described below.

The performance of several solar water heater designs in multi-family buildings located in each California Climate Zone were modeled using the TRNSYS simulation software package. The results provide annual energy consumption for several systems commonly used for multi-family building applications, all using backup water heaters fueled by natural gas. For each solar water heating system, building type and California location, a reference water heater fueled only by natural gas was also analyzed to estimate annual energy consumption. The annual energy savings were calculated for each case by taking the difference of the annual energy consumption for the solar water heating system and the corresponding gas-only reference water heater and accounting for the increased parasitic power consumption of the solar water heating systems.

For both sets of analyses, an updated version of the CSI Thermal Commercial & Multifamily Residential Incentive Calculator was used. This online, public calculator was developed for the CSI Solar Initiative Thermal Program by contractors Energy Solutions and Thermal Energy System Specialists (TESS). TESS developed the thermal analysis engine that was used as the basis of the calculator using the TRNSYS program. For this study, an updated version of that analysis engine was utilized.

This study was conducted by the Solar Rating & Certification Corporation (ICC-SRCC) in partnership with Thermal Energy System Specialists (TESS). ICC-SRCC is an accredited certification body specializing in compliance assessment of solar heating and cooling products. It certifies solar thermal collectors under the OG-100 program and domestic solar thermal water heating systems under the OG-300 program. TESS is an engineering consulting company specializing in the modeling and analysis of energy systems.

REVIEW OF MULTIFAMILY HOT WATER LOAD CURVES

The project began with an extensive review of the available system-level hot water draw patterns ("load curves"). Hot water usage in multi-family residential buildings differ from single-family homes in scale, configuration and plumbing layout, resulting in a diversified and complex load. The objective of the review was to compare the available hot load curve models to provide options for use in subsequent analyses. The sources reviewed included:

- DEER 2021 Water Heater Energy Use Calculator v. 4.0
- *CSI Thermal Program Handbook*, 2019
- *CSI Thermal Multifamily/Commercial Standard 100 Incentive Calculator User Guide*, v6, 5/2014
- *ASHRAE Handbook – HVAC Applications 2011*, Chapter 50
- *Energy Use and Domestic Hot Water Consumption*, NYSERDA 1994
- *Domestic Hot Water Loads, System Sizing and Selection for Multifamily Buildings*, Goldner and Price
- *Building America Research Benchmark Definition*, Hendron and Engebrecht, 2010
- *Building America House Simulation Protocols*, Hendron and Engebrecht, 2010

The hot water load curves reviewed are shown in Figure 1, normalized with respect to the total daily consumption for the purpose of comparing the shapes.

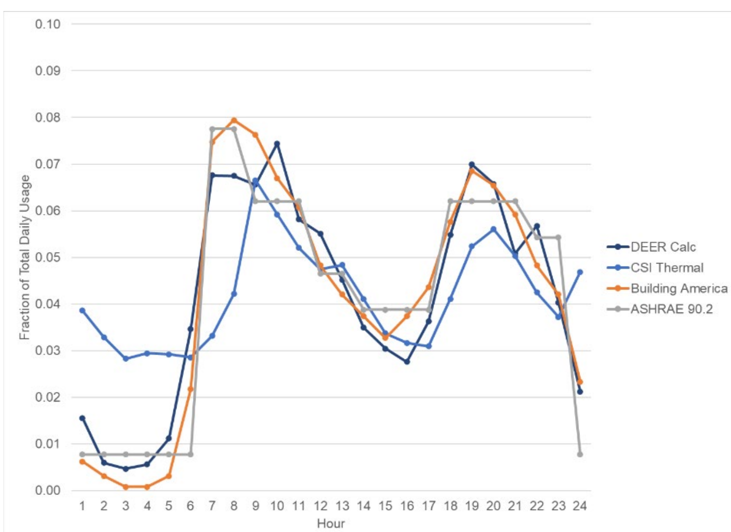

Figure 1: Comparison of Normalized MFH Hot Water Draw Profiles (per Unit)

DEER2021 Water Heater Energy Use Calculator

The DEER 2021 Water Heater Energy Use Calculator v4.2 ("Calculator") has been developed to provide a common methodology to estimate the energy savings associated with a range of water heating technologies compared to common legacy water heaters for various building types. For multi-family buildings, it conducts hourly calculations of energy consumption by a selected water heater based on input parameters, and a single hot water draw profile scaled to 38 gallons per day of cumulative use. The normalized profile is shown in Figure 1 and the cumulative daily hot water volume per unit is fixed at 38 gallons per apartment.

CSI Thermal Program

The CSI Thermal incentive program utilized a single normalized draw profile, scalable with total daily hot water consumption as shown in Figure 1. The load profile was scaled using a daily consumption multiplier that was a function of the number of apartment or condo units as shown in Table 1. The basis for the profile shape and multipliers are found in the ASHRAE Handbook, as described in the following section.

Table 1: Maximum Daily Multi-Family Hot Water Consumption (CSI Thermal Handbook, Appendix E)

Number of Apartments/Condo Units	**Maximum Daily Consumption (gal/unit)**
2-20	42
21-50	40
51-100	38
101-200	37
201+	35

2011 ASHRAE Handbook – HVAC Applications, Chapter 50

The ASHRAE Handbook describes different approaches to hot water load characterization. In the first, a variety of hourly flow profiles for various building types are provided. The entry for apartment buildings is shown in Figure 3.

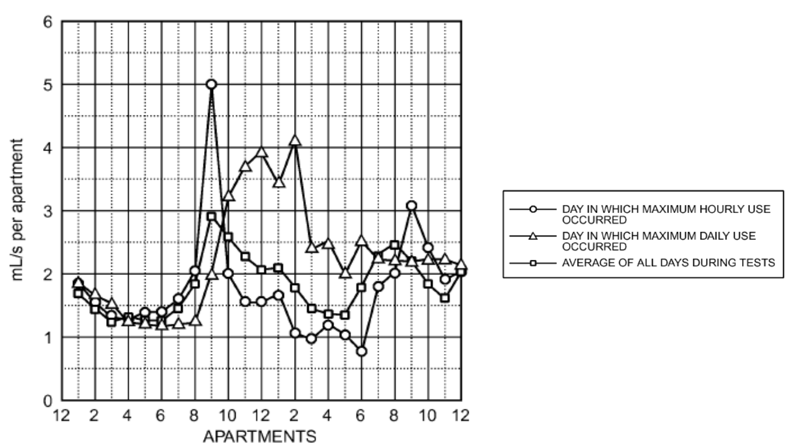

Figure 2: Hourly Flow Profile for Apartment Buildings (ASHRAE Handbook, HVAC Applications, Chapter 50, Figure 24 extracted)

In this approach, ASHRAE provides different profiles for different use scenarios:

- Average of all days
- Day in which the maximum hourly use occurred
- Day in which the maximum daily use occurred

It goes on to specify the Maximum Hourly, Maximum Daily and Average Daily consumption values for apartments as a function of the number of apartments in the building, as shown in Table 2 below.

Table 2: Daily Hot Water Demands for Apartments (ASHRAE Handbook - HVAC Applications, Chapter 50, Table 7, extracted)

APARTMENT BLDG	**HOT WATER DEMAND (GAL/UNIT)**		
NUMBER OF UNITS	**Maximum Hourly**	**Maximum Daily**	**Average Daily**
≤ 20	12.0	80.1	42.1
50	10.0	73.1	40.0
75	8.5	66.0	38.0
100	7.0	60.1	37.0
≥ 200	5.0	51.5	35.1

The Handbook also provides an alternative to the singular volumes based on size in Table 2. This second approach provides Low/Medium/High use guidelines, drawing on the work of Goldner and Price, and shown cumulatively in Figure 3. ASHRAE's suggested demographics associated with each use guidelines are given below in Table 3.

Table 3: ASHRAE Occupant Demographics for Use Guidelines (ASHRAE Handbook, Chapter 50, p. 15)

LOW	**MEDIUM**	**HIGH**
• All occupants working • One person working, while one stays at home • Seniors • Couples • Middle income • Higher population density	• Families • Singles • On public assistance • Single-parent households	• High percentage of children • Low income • On public assistance • No occupants working • Families • Single-parent households

Table 8 Hot-Water Demand and Use Guidelines for Apartment Buildings (Litres per Person at 49°C Delivered to Fixtures)

	Peak Minutes							
Guideline	5	15	30	60	120	180	Maximum Daily	Average Daily
Low	1.5	3.8	6.4	10.6	17.0	23.1	76	53
Medium	2.6	6.4	11.0	18.2	30.3	41.6	185	114
High	4.5	11.4	19.3	32.2	54.9	71.9	340	204

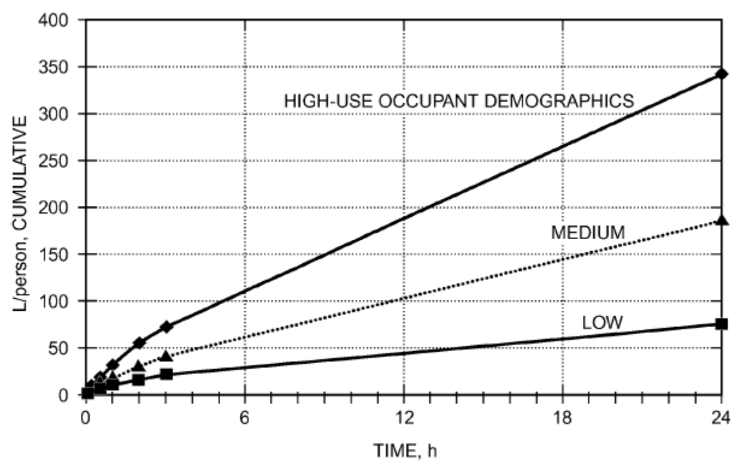

Fig. 15 Apartment Building Cumulative Hot-Water Use Versus Time (from Table 8)

Figure 3: ASHRAE Alternative LMH Demand Guidelines (ASHRAE Handbook, Chapter 50, Table 8 & Figure 15)

Building America House Simulation Protocols

The Department of Energy's Building America program has developed protocols for whole-building energy simulation in the Building America Research Benchmark Definition (Hendron and Engebrecht, 2010) and Building America House Simulation Protocols (Hendron and Engebrecht, 2010). The DHW models are based on a synthesis of several scientific references and studies and estimate how water consumption for specific end uses like showers, bath, sinks, dishwashing and laundry. For multi-family installations, they also discriminate between in-unit laundry and central laundry facilities. The results are programmed into BA's Analysis Spreadsheets. For all, it assumes that the hot water setpoint is 130°F and the mixed temperature for showers, sinks and baths is 110°F. The normalized Building America hot water draw pattern for units with in-unit laundry is shown in Figure 1 for comparison.

NYSERDA Energy Use and Domestic Hot Water Consumption Study

The 1994 NYSERDA study monitored a total of 30 multifamily buildings of various types, collecting domestic hot water flow in 15-minute increments for 14 months. The building stock reviewed ranged from 17 to 103 apartments, with 5 or 6 above-ground stories. The average number of occupants was found to be 2.1 per unit. They were divided into two categories – those constructed prior to 1902 and those constructed 1902-1928. These types were selected given their prevalence in NYC. It found that the average daily consumption per apartment was 68% greater than that indicated by ASHRAE. It noted distinct differences in consumption weekdays vs. weekends and seasonally. These findings are shown in the figures below.

Note that given the age of the structures studied and the date of the study (1994), the use of water-conserving plumbing fittings and equipment can be assumed to be low. Therefore, the results may not be representative of the annual consumption observed in newer construction or facilities that have undergone renovation and/or retrofit in recent years.

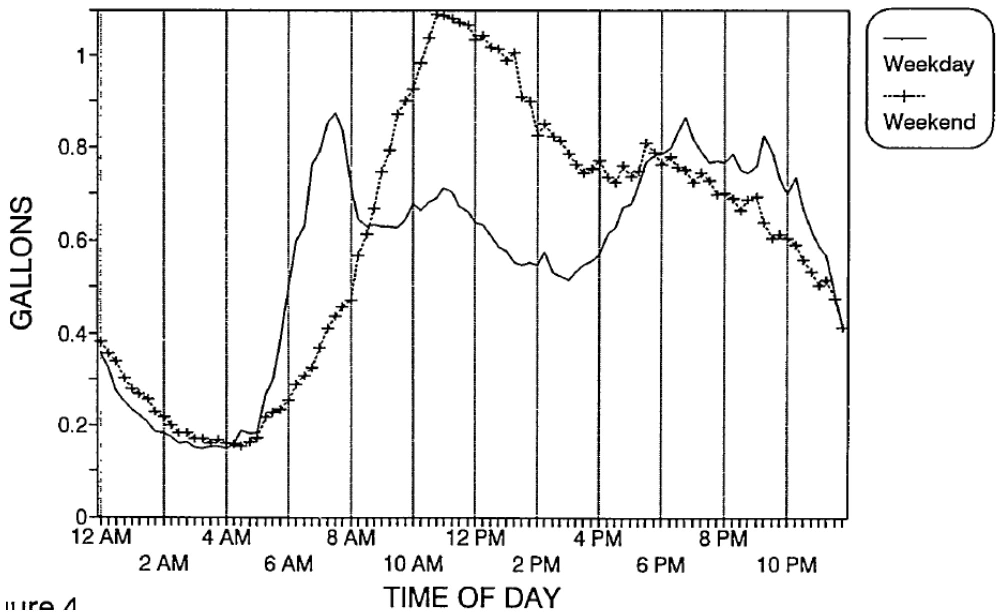

Figure 4: Weekday vs. Weekend Consumption Per Capita, (NYSERDA, Figure 4)

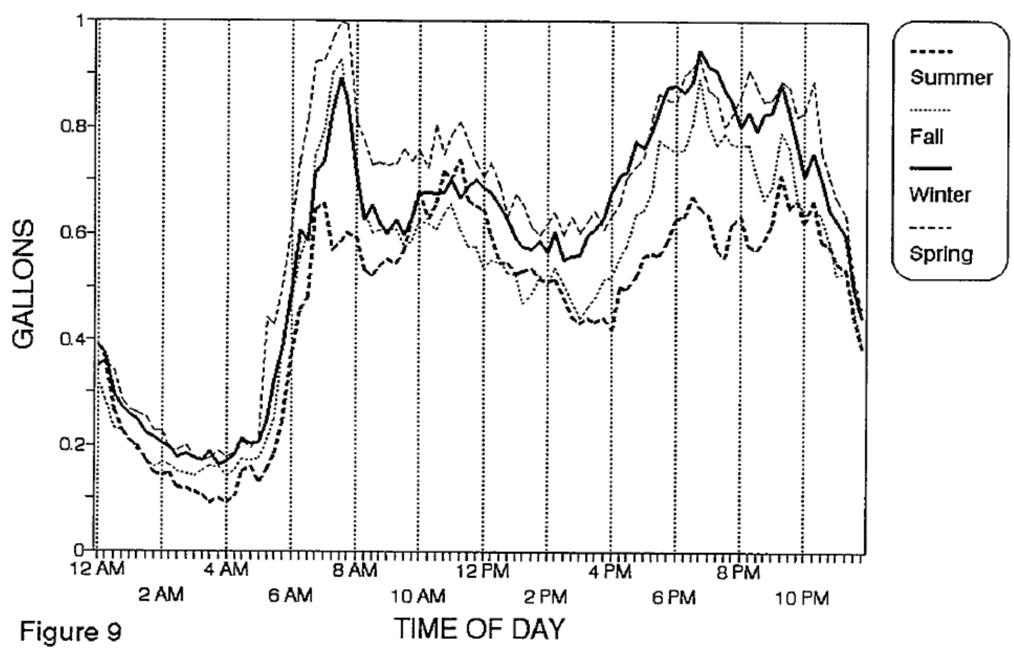

Figure 5: Seasonal Variations, Weekday Consumption per Capita (NYSERDA, Figure 9)

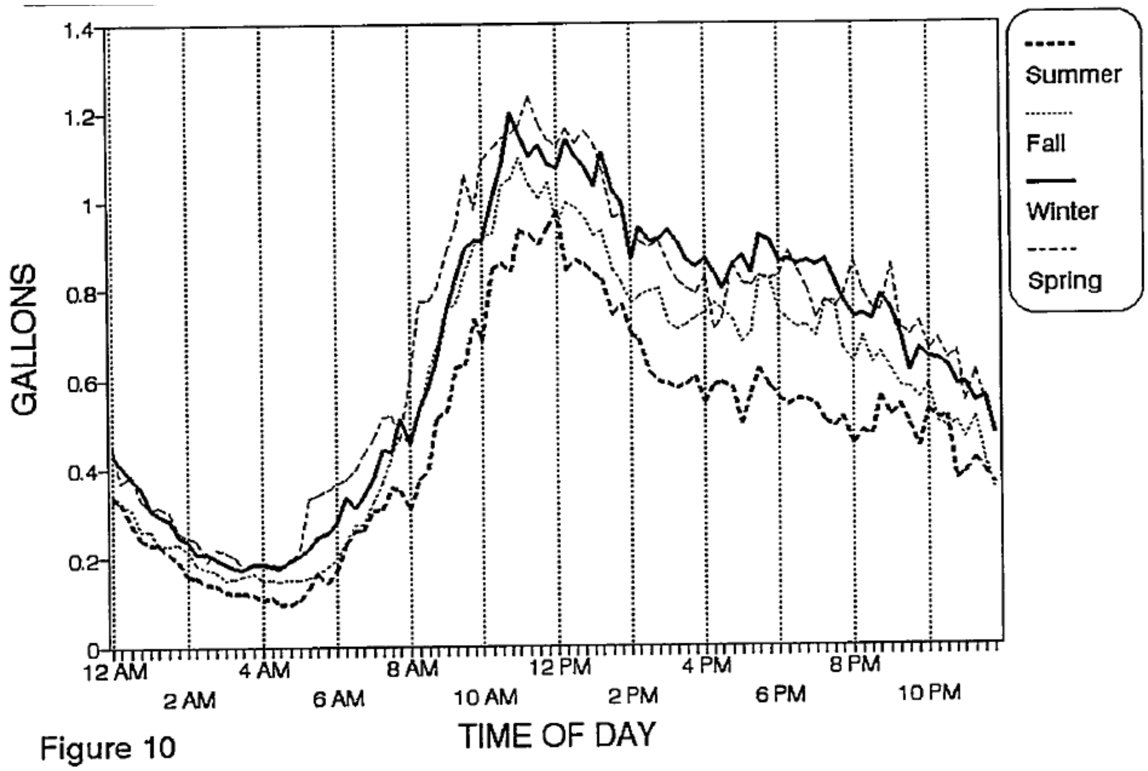

Figure 6: Seasonal Variations, Weekend Consumption per Capita (NYSERDA, Figure 10)

The NYSERDA document proposed a "Low-Medium-High" (LMH) set of guidelines as a more representative approach than that employed in the ASHRAE Handbook profiles published at the time. This was further expanded and explained in a subsequent paper, *Domestic Hot Water Loads, System Sizing and Selection for Multifamily Buildings*, by Goldner and Price, as shown in Table 4 below.

Table 4: Proposed LMH National Guidelines (Goldner & Price, Table 2)

Table 2. National: Low - Medium - High Guidelines: Hot Water Demands and Use for Multifamily Buildings

	Maximum Hour	Peak 15 Minutes	Maximum Day	Average Day
Low	3.0 gal (11.0 L)/person	1.0 gal (4.0 L)/person	20.0 gal (76.0 L)/person	14.0 gal (53.0 L)/person
Med	5.0 gal (19.0 L)/person	2.0 gal (6.5 L)/person	49.0 gal (185.0 L)/person	30.0 gal (114.0 L)/person
High	9.0 gal (34.0 L)/person	3.0 gal (11.5 L)/person	90.0 gal (340.0 L)/person	54.0 gal (205.0 L)/person

	Peak 5 Minutes	Maximum 2 Hours	Maximum 3 Hours
Low	0.4 gal (1.5 L)/person	5.0 gal (18.0 L)/person	6.1 gal (23.0 L)/person
Med	0.7 gal (2.5 L)/person	8.0 gal (31.0 L)/person	11.0 gal (41.0 L)/person
High	1.15 gal (4.4 L)/person	14.5 gal (55.0 L)/person	19.0 gal (72.0 L)/person

Notable is the following quote:

> *"While flow curves show the general usage patterns of a building, peaking times and flows are used to more closely identify demands on/requirements of the boiler. There is an exact coincidence of 60- and 15-minute maximum demand times on the weekends. During weekdays the mornings have a close match of 60- and 15-minute demands, and there is an exact match during the evening periods.*" (Goldner & Price, p. 6).

MODEL UPDATES

The models used by the CSI Thermal Multi-family Calculator were updated for the purposes of this study as described in the subsections below.

TRNSYS Engine

Since the initial creation of the CSI Thermal Calculator, new editions of the TRNSYS modeling software have been released. The original calculator was ported from version 17 to version 18 of the TRNSYS engine.

Hot Water Load Curve

The preceding multi-family hot water draw profiles were considered for use in the subsequent modeling effort. Ultimately the hot water draw profile utilized by the CSI Thermal program was found to be an appropriate representation of hot water usage in multi-family buildings, and appropriate in scale for a deemed program in California. Further, the calculator and accompanying assumptions were used successfully in the CSI Thermal Program as evidenced by various assessments. Therefore, the CSI Thermal draw profile was retained. The daily cumulative hot water draw was set at 40 gallons per day per unit, per the project specification of an average building size of 40 (see Table 1). This also corresponds well with the 38 gallons per day per unit specified by the DEER Hot Water Calculator.

As shown in Figure 1, the shape of the draw profiles used by the DEER Calculator, CSI Thermal Program and Building America Program were very similar. The normalized ASHRAE 90.2 profile is also shown for comparison with the curves reviewed in the previous residential study. All showed a dual-peak pattern, with comparable timing and scale of each peak. This is not surprising, given that the structure of each was based in whole or in part on the methods described in the ASHRAE Handbook.

While the ASHRAE Handbook provided more detailed approaches, they are better suited to more comprehensive analyses representing consumption over short time periods. For the characterization of hot water consumption over longer periods, more generalized approaches were preferred. The occupancy of multi-family buildings is, by nature, fluid and subject to frequent change. Therefore, the mix of low, medium and high-use occupancies will be variable.

The NYSERDA data was the most detailed and specific, but unfortunately could not be accurately applied to this project. It was based on water consumption in older buildings, prior to the implementation of wide-spread water efficiency measures for domestic plumbing fittings in the 1990s. Therefore, the current per-capita water use in California is likely to be measurably lower. Further, the differences in climate between California and New York, further limit the applicability of the findings to CA climate zones. Future enhancements to the modeling described in this study could incorporate both seasonal and weekday/weekend variations for multi-family buildings of different sizes. To do so, however, more appropriate datasets of contemporary California hot water use would be necessary.

The selected draw profile per multifamily unit is shown in Figure 7. The total for the building is determined by multiplying each hourly value by the number of units. As with the single-family residential draw profile, the flow is assumed to be constant for each hour, such that the prescribed hourly draw volume is attained.

Constants and Other Assumptions

Several constants and assumptions used in the multi-family model were updated to correspond to the DEER Calculator and the previous studies for single-family residential construction. The key assumptions used in modeling for the sensitivity analyses and subsequent larger sample modeling are shown in Table 5. Note that the CSI Thermal Multifamily Model is capable of analyzing several other cases that were not utilized in this study. They include: collector tracking, solar tanks with auxiliary heating devices, concentrating collectors, tankless backup water heaters, parallel and series collector connections, multiple solar tanks and single-tank systems.

Table 5: MFH Calculator Constants, Assumptions and Parameters

PARAMETER	DESCRIPTION	VALUE
SETPOINT TEMPERATURE	Backup water heater setpoint temperature	135°F
TANK STRATIFICATION LEVEL	Stratified	10 nodes
RECIRCULATION PUMP FLOW	Flow rate of hot water recirculation pump	GPD/1000 +0.5 in GPM
RECIRCULATION DUTY CYCLE	Hot water recirculation system run-time.	100%
RECIRCULATION PUMP POWER	Power consumed by the recirculation pump is a function of the total daily hot water consumption.	1/25 + GPD/50,000 (hp)
INDOOR AMBIENT TEMPERATURE	Indoor air temp in vicinity of tank (°F)	$T_{amb}+1/3*(72°F-T_{amb})$
COLLECTOR SHADING FACTOR	Measure of the degree of shading on the collector	1.0
COLLECTOR INSTALLATION SLOPE	Angle of the plane of the collector with respect to horizontal.	30 degrees, Fixed
COLLECTOR AZIMUTH	Fixed installation direction of the collector.	Due South (180°), Fixed
GLYCOL CONCENTRATION	Concentration of polypropylene glycol used in the solar loop of Configurations 14 & 16	40%
AVERAGE FLUID TEMPERATURE FOR FLUID PROPERTIES	Fluid properties are assumed to be fixed and are based on the average temperature given.	40°C (104°F)
SOLAR COLLECTOR THERMAL CAPACITANCE	Thermal capacitance of the solar collectors is assumed to be a fixed value.	10 kJ/m^2°K
COLLECTOR LOOP FLOWRATE	Collector flowrate GPM=1 gpm/collector x Number of Collectors (assuming all collectors are series connected)	1 gpm/collector
NODES PER MODULE	Number of isothermal nodes per module along the flow path.	50
NODES PER PIPE	Number of isothermal nodes per length of piping along the flow path.	10

Mains Water Temperatures

The mains water temperatures throughout the year and for each climate zone were updated to match those used in the DEER Calculator, as shown in Table 6 for CA Climate Zone 6, for example.

Table 6: Monthly Water Mains Temperatures for CA Climate Zones (°F)

CACZ	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	49.5	48.7	48.6	49.0	50.5	52.0	53.2	54.0	54.1	53.4	52.2	50.8
2	53.7	52.3	52.1	52.8	55.6	58.4	60.8	62.3	62.5	61.2	58.9	56.2
3	54.5	53.4	53.3	53.8	55.8	57.8	59.6	60.7	60.8	59.9	58.2	56.2
4	55.7	54.1	54.0	54.8	57.7	60.7	63.3	64.9	65.0	63.7	61.2	58.3
5	53.6	52.7	52.7	53.1	54.8	56.5	58.0	58.9	59.0	58.2	56.8	55.1
6	58.9	57.8	57.7	58.2	60.4	62.6	64.5	65.7	65.8	64.9	63.0	60.9
7	60.2	59.3	59.2	59.7	61.5	63.2	64.8	65.8	65.9	65.1	63.5	61.8
8	60.7	59.5	59.4	59.9	62.3	64.7	66.7	68.0	68.1	67.0	65.1	62.8
9	60.2	58.7	58.6	59.3	62.1	64.9	67.4	68.9	69.1	67.8	65.4	62.7
10	59.9	58.2	58.0	58.9	62.2	65.5	68.3	70.1	70.3	68.8	66.0	62.8
11	55.8	52.8	52.6	54.0	59.8	65.5	70.5	73.6	73.9	71.3	66.5	60.9
12	55.6	53.5	53.3	54.3	58.4	62.5	66.1	68.3	68.5	66.7	63.2	59.3
13	57.0	54.0	53.8	55.2	60.8	66.3	71.1	74.2	74.5	72.0	67.3	61.9
14	55.2	52.2	51.9	53.4	59.2	65.0	70.0	73.2	73.5	70.9	66.0	60.4
15	68.4	65.5	65.3	66.6	72.2	77.7	82.4	85.5	85.7	83.3	78.6	73.3
16	45.3	42.7	42.4	43.7	48.7	53.8	58.1	60.9	61.1	58.9	54.6	49.8

MODEL SENSITIVITY ANALYSES

The updated model was subjected to a variety of sensitivity analyses to evaluate the impact of various changes on the results provided by the updated model, compared to the original (CSI Thermal) model.

The first analysis evaluated the impact of the update from the v17 to v18 TRNSYS engine. A 40-unit apartment building consuming 1,600 gallons per day in CA Climate Zone 9 was modeled using both the v17 and v18 models. A total of 12 different solar water heater combinations were modeled using the v17 and v18 engines, yielding 24 sets of results shown in Table 7. The three most common collectors installed in CSI Thermal multi-family projects were modeled in four different system configurations. Two of the collectors were glazed flat plate types (GFP) and one was an evacuated tube (ET). The system configurations varied the heat exchanger type (external/immersed) and location (supply side/load side) with freeze protection measures (glycol/drainback). Each system consisted of 15 solar thermal collectors mounted at a slope of 30 degrees from horizontal and oriented due South. A 1,200 gallon, unfired hot water storage tank fed a 500 gallon commercial gas water heater.

Table 7: Sensitivity Analysis of TRNSYS Engine Change for SWH Systems

	ANNUAL ENERGY SAVINGS (therms)						
COLLECTOR ▸	10001803 GFP		2010115A GFP		2009042B ET		
SOLAR SYSTEM CONFIGURATION TRNSYS ENGINE ▸	17	18	17	18	17	18	
14: External Supply Side Hx w./ Glycol Freeze Protection	2471	2446	2437	2412	2550	2539	-0.82%
16: Immersed Supply Side Hx w./ Glycol Freeze Protection	2338	2310	2302	2273	2476	2463	-0.99%
18: External Supply Side Hx w./ Drainback Freeze Protection	2505	2467	2471	2433	2562	2541	-1.29%
102: Immersed Load Side Hx w./ Drainback Freeze Protection	2413	2380	2380	2345	2511	2492	-1.20%
	-1.27%		-1.32%		-0.63%		-1.08%

The results shown are an average of 1.08% lower using the v18 model versus the v17 model. This change was primarily attributed to an increase in the power consumption of the recirculation pump between versions. Specifically, the collector loop pump was changed from 15 Watts/gpm to 30 Watts/gpm for glycol systems and to 40 Watts/gpm for drainback systems between the v17 and v18 models. The tank/heat exchanger pump for systems with external heat exchangers was dropped from 15 Watts/gpm to 10 Watts/gpm. The changes to the resulting annual energy savings were deemed to be negligible and the updated, v18 model was selected for all modeling and analyses that followed.

Sensitivity Analysis – Storage Volume

A series of models where then run for one collector type using the updated v18 engine, varying the solar storage tank volume to study the sensitivity of that parameter. The results are shown in Figure 7 for collector 2007032A, a glazed flat plate collector.

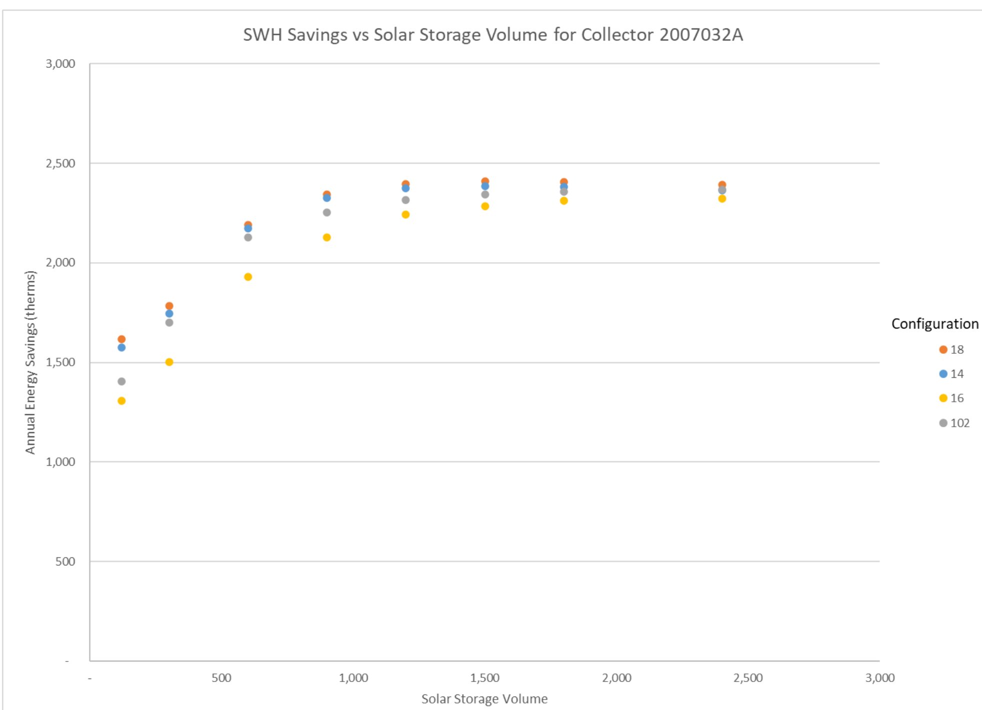

Figure 7: Solar Storage Tank Sensitivity

As is evident from the figure, the annual energy savings scales with solar tank volume in a linear fashion until reaching an inflection point around 1,250 gallons, at which point further increases yield little or no additional savings. This inflection point is expected to be a function of the maximum daily hot water load, the number of collectors and (to a lesser extent) the system configuration. For example, Configuration 18 levels at approximately 1,250 gallons, while Configuration 16 levels at a somewhat higher level of 1,500 gallons. The general trends were maintained when the other 9 collectors were modeled.

Sensitivity Analysis – Building Size

An analysis of the impact of the number of units, and therefore the daily hot water load, was conducted. It studied each of the (4) SWH configurations with (4) different collectors, each for 13, 27, 40, 80 and 120 unit buildings. The total daily hot water load for each was set at approximately 40 gallons per day per unit. The number of collectors also scaled with the total hot water load. Given the linear relationship between number of units, daily hot water load, and the number of collectors, the linear relationship with annual energy savings is not surprising. The results of the building size sensitivity analysis are shown in Table 8.

Table 8: Building Size Sensitivity Analysis Results

COLLECTOR OG-100 NO.	QTY COLLECTORS	SOLAR TANK VOLUME	QTY MFH UNITS	HOT WATER LOAD	TOTAL EFFECTIVE COLLECTOR AREA	ANNUAL ENERGY SAVINGS (THERMS) PER CONFIG			
		(Gallons)		(gpd)	(m^2)	14	18	102	16
2007032A	5	400	13	533	10.94	758	765	768	751
10001912	5	400	13	533	12.63	866	873	878	858
2007032D	5	400	13	533	8.78	635	637	641	631
2009042B	5	400	13	533	12.26	835	835	842	833
2007032A	10	800	27	1,067	21.87	1,583	1,598	1,565	1,536
10001912	10	800	27	1,067	25.25	1,815	1,831	1,794	1,763
2007032D	10	800	27	1,067	17.55	1,327	1,333	1,311	1,296
2009042B	10	800	27	1,067	24.51	1,751	1,754	1,736	1,729
2007032A	15	1200	40	1,600	32.81	2,376	2,397	2,314	2,244
10001912	15	1200	40	1,600	37.88	2,731	2,752	2,657	2,590
2007032D	15	1200	40	1,600	26.33	1,996	2,004	1,948	1,908
2009042B	15	1200	40	1,600	36.77	2,643	2,648	2,595	2,571
2007032A	30	2400	80	3,200	65.61	4,328	4,365	4,251	3,847
10001912	30	2400	80	3,200	75.76	4,811	4,857	4,567	4,497
2007032D	30	2400	80	3,200	52.65	3,712	3,731	3,681	3,365
2009042B	30	2400	80	3,200	73.53	4,960	4,996	4,773	4,665
2007032A	45	3600	120	4,800	98.42	5,647	5,741	5,563	5,094
10001912	45	3600	120	4,800	113.65	5,927	6,056	5,938	5,547
2007032D	45	3600	120	4,800	78.98	5,198	5,234	5,181	4,550
2009042B	45	3600	120	4,800	110.30	6,422	6,571	6,399	6,075

MULTIFAMILY HOUSING SOLAR WATER HEATER MODELING

The primary objective of this project is the estimation of the annual energy consumption for a larger sample of representative solar water heating systems using gas backup water heaters, consistent with the methodology used in the CSI Thermal Calculator. The updated version of the model using the v18 TRNSYS engine was used for all modeling that follows.

A total of 40 discrete systems were modeled in each of the (16) California Climate Zones over a period of one year. Four different system configurations, shown in Table 9, were modeled with each of 10 of the most common solar thermal collectors installed for multi-family projects in the CSI Thermal Program, listed in Table 11. The system configurations varied the heat exchanger type (external/immersed) and location (supply side/load side) with freeze protection measures (glycol/drainback). Where glycol is used as the fluid in the solar loop, it is assumed to have a concentration of polypropylene glycol of 40%. For drainback systems, water is used as the working fluid in the solar loop. Fluid properties are assumed to be constant in the models and are based on a 40°C (104°F) average fluid temperature.

The schematics for each type are shown in detail in Appendix B. Additional information on the performance metrics reported for solar water heaters can be found in Appendix C.

Table 9: System Configurations for MFH Modeling

CONFIG	HEAT EXCHANGER	FREEZE PROTECTION
14	External Supply Side Heat Exchanger	Glycol
16	Immersed Supply Side Heat Exchanger	Glycol
18	External Supply Side Heat Exchanger	Drainback
102	Immersed Load Side Heat Exchanger	Drainback

Each configuration used the same components in each, as specified in Table 10, except for the solar thermal collectors, which are listed in Table 11. For the calculation of energy savings, the gas consumption of each solar water heating system is compared to the gas consumption of the same reference commercial storage water heater (500 gallons, 82% efficiency), installed without solar collectors. In all cases it is assumed that, a recirculation pump is installed on the building's plumbing system that is running at all times (100% duty cycle) with a flowrate as specified in Table 5.

Table 10: System Components

COMPONENT	SPECIFICATION
SOLAR TANK (NO HX)	1200 gallons nominal (actual volume 90% of nominal), vertical with a L/D ratio of 2.608, R12.5 insulation (50% losses).
SOLAR TANK (W./IMMERSED IN-TANK HX)	1200 gallons nominal (actual volume 90% of nominal), Hx surface area = 0.1 ft^2/gal, 11.02 m coil length, R12.5 insulation (50% losses)
DRAINBACK TANK	Vol= 10 + 2 x Number of Collectors (gallons), heat loss coefficient 3 kJ/hm^2K, rectangular shape with the height 2/3 the side length
EXTERNAL HEAT EXCHANGER	0.4 effectiveness for double-wall type, 0.5 for single-wall type
SOLAR AND HX PUMPS	30 W/gpm, 90% motor efficiency, 60% overall efficiency
GAS STORAGE WATER HEATER	500 gallons nominal commercial gas storage water heater with 82% overall efficiency
CONTROLLER	Differential temperature controller with a 20°F turn-on and 5°F turn-off deadband. Temperature sensors are located 1/3 of the height from the bottom of the solar storage tank and on the outlet line of the solar collector array.
SOLAR THERMAL COLLECTORS	See Table 11.

PIPING	Type L copper sized to maintain 4 ft/s or less velocity at peak flow. Total length = 50' + 5' x Number of Collectors (divided equally between supply and return lines).
PIPE INSULATION	¾" thick insulation with k=0.04 W/m°K

Arrays of 15 identical solar thermal collectors connected in series were modeled for each configuration and collector combination. The collectors were mounted at the ideal slope and azimuth for each location (slope of ~30-35 degrees from horizontal) and oriented due South (180 degrees) on fixed (non-tracking) mounts). The collectors included (8) glazed flat plate models and (2) evacuated glazed tube models. Each collector was certified under the SRCC OG-100 program, providing the measured collector performance data required for system modeling.

Table 11: Solar Thermal Collectors for MFH System Modeling

					SINGLE COLLECTOR		**ARRAY OF COLLECTORS**		
INDEX	**OG-100 NO.**	**MFG**	**MODEL**	**TYPE***	**GROSS AREA (M^2)**	**EFFECTIVE AREA (M^2)**	**COLLECTOR QTY**	**TOTAL GROSS AREA (M^2)**	**TOTAL EFFECTIVE AREA (M^2)**
1	10001803	SunEarth	TRB-40	GFP	3.804	2.39	15	57.06	35.78
2	2010115a	Heliodyne	410 001	GFP	3.740	2.36	15	56.10	35.38
3	2007032a	SunEarth	EP-40	GFP	3.800	2.19	15	57.00	32.81
4	10001912	Heliodyne	410 001+	GFP	3.913	2.53	15	58.70	37.88
5	10002008	SolAqua	4X10H	GFP	3.720	2.32	15	55.80	34.74
6	2010115d	Heliodyne	408 001	GFP	2.993	1.89	15	44.90	28.36
7	2007032d	SunEarth	EP-32	GFP	3.051	1.76	15	45.76	26.33
8	10001804	SunEarth	TRB-32	GFP	3.050	1.91	15	45.75	28.60
9	2009042b	Jiangsu Sunrain	TZ58/1800-30R	ET	5.241	2.45	15	78.62	36.77
10	10001893	Jiangsu Micoe	SZ58/1800-30HA	ET	4.858	2.39	15	72.87	35.92

* Glazed Flat Plate (GFP), Evacuated Tube (ET)

Effective area (TESS, 2019) was calculated from the gross area, thermal efficiency at a standard operating condition, and an estimate of the incidence angle modifier impact for each collector. For this study of SWH systems in a warm climate, the standard conditions were assumed to be an incident solar radiation of 800 W/m^2, an inlet temperature to ambient temperature difference of 20°C, and a flow rate equal to the test flow rate for the collector. In equation form the effective area can be calculated for glazed flat plate collectors as:

$$A_{eff} = A_g \, \eta_{nom} \, \overline{IAM_T}$$

And for evacuated tube collectors as:

$$A_{eff} = A_g \, \eta_{nom} \, \overline{IAM_T} \, \overline{IAM_L}$$

Where the variables are defined as:

Ag The gross area of the collector as provided on the test report.

η_{nom}	The efficiency of the collector at an irradiance of 800 W/m^2, an inlet temperature 20°C above the ambient temperature, and with a fluid flow rate equal to the published test flow rate.
$\overline{IAM}_T$	The average transverse incidence angle modifier from 0 degrees to 60 degrees.
$\overline{IAM}_L$	The average longitudinal incidence angle modifier from 0 degrees to 60 degrees.

The effective area normalizes the collector area to account for variations in different solar thermal collector technologies (glazed flat plate and evacuated tube) and for variations in thermal performance of similar collectors. The result, provided in square meters, permits the thermal efficiency performance of different collectors to be compared on an area basis. It does not, however, account for other system variations, such as total storage volume, heat exchanger effectiveness or control system logic which are addressed in the full system modeling.

TRNSYS Solar Water Heater Energy Use Calculation Methodology

Models were created using the TRNSYS simulation software for each of the representative sample water heating systems in order to estimate the annual energy consumption of each. The models utilized updated versions of the CSI Thermal Multi-Family Calculator, modified to use v18 of TRNSYS as described in the preceding sections. The same CSI Thermal draw pattern was utilized, with the daily hot water draw set to 1600 gallons per day, representative of an average 40-unit multifamily building in California. As with the preceding single family residential analysis, the backup water heater setpoint was 135°F. The same California Climate Zone v2 weather files were used to provide the beam, diffuse and longwave (infrared) radiation, ambient temperature and wind speed at the collector throughout the year for each location. Given the height of installation, a solar shade factor of 1.0 (no shading) was assumed for each system.

The TRNSYS models solve the energy balance equations for the system on one-minute timesteps, utilizing the instantaneous weather and hot water demand conditions described. The cumulative energy consumed (gas and electricity as applicable) is reported for the entire year for each of the 40 solar water heaters (10 collectors x 4 configurations) and the reference storage water heater. The total annual energy content in the hot water load and the reference gas storage water heater is shown for each climate zone in Table 12. Note that the hot water load varies by climate zone since the incoming water temperature varies by location. This means that the energy required to achieve the same hot water temperature and maintain it varies somewhat.

For each solar water heater modeled, the absolute energy consumption is modeled and then subtracted from the consumption of the reference water heater to obtain the annual energy savings by climate zone. Summaries of these results are shown graphically for CA Climate Zone 9 in Figures 8 and 9 below. Tabular results for each solar water heating system in CA Climate Zone 9 are provided in Table 13 and the full dataset for each climate zone is provided in Appendix A.

Table 12: Annual Load and Reference Water Heater Energy

	HOT WATER LOAD (THERMS)	REFERENCE HEATER GAS CONSUMPTION (THERMS)
CZ1	4,041	5,243
CZ2	3,755	4,884
CZ3	3,767	4,898
CZ4	3,648	4,749
CZ5	3,826	4,969
CZ6	3,540	4,610
CZ7	3,501	4,560
CZ8	3,444	4,489
CZ9	3,440	4,482
CZ10	3,424	4,463
CZ11	3,470	4,526
CZ12	3,582	4,666
CZ13	3,426	4,465
CZ14	3,495	4,556
CZ15	2,877	3,769
CZ16	4,023	5,230

It should be noted that while ever effort was made to approximate common conditions in 40-unit buildings around the state, actual energy savings will inevitably differ for each installation. The analyses conducted assume an identical hot water use profile repeated each day. Changes to the timing or volumes of the hot water draws will impact actual savings. Other influences will include collector installation direction, angle, shading, piping length, size and insulation, control mode and pump speed. And of course, actual weather conditions will vary daily and annually compared with the typical weather conditions used for modeling.

While the absolute savings for any given project and installation will vary, models of this type can be used to compare the relative performance and savings associated with different technologies and system types. By comparing these technologies on a consistent basis – with the same installation, usage and environmental conditions, the relative attributes can be studied.

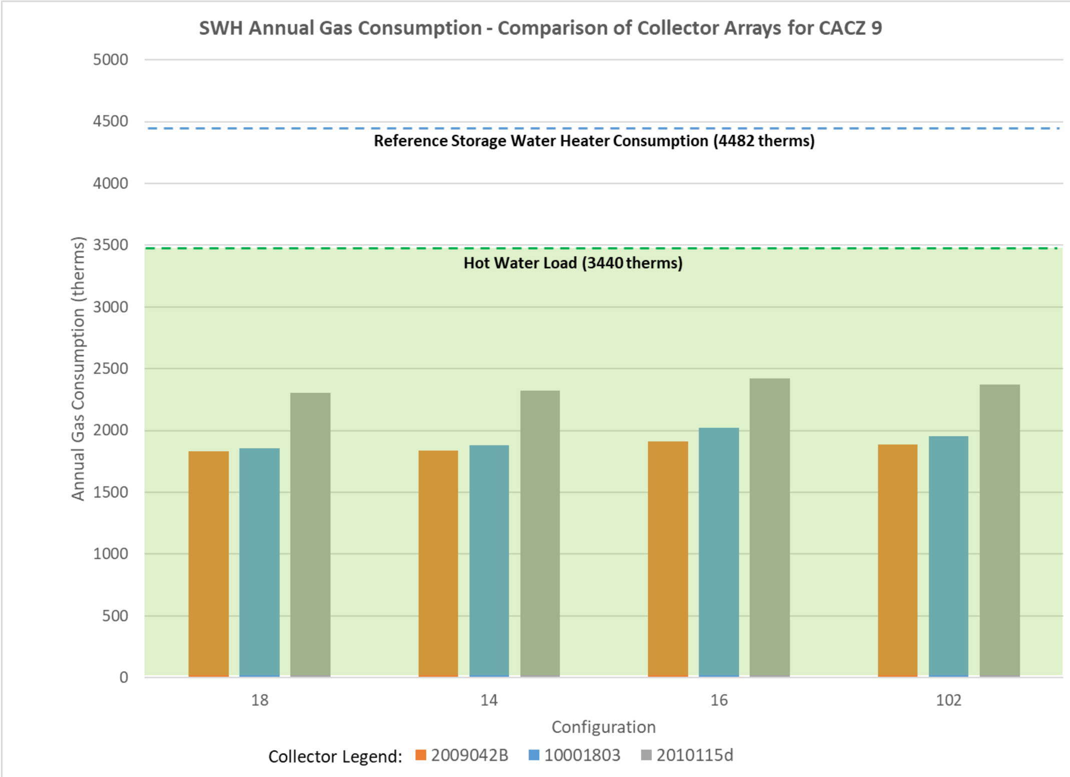

Figure 8: Annual Gas Consumption for Select SWH Systems in CA Climate Zone 9

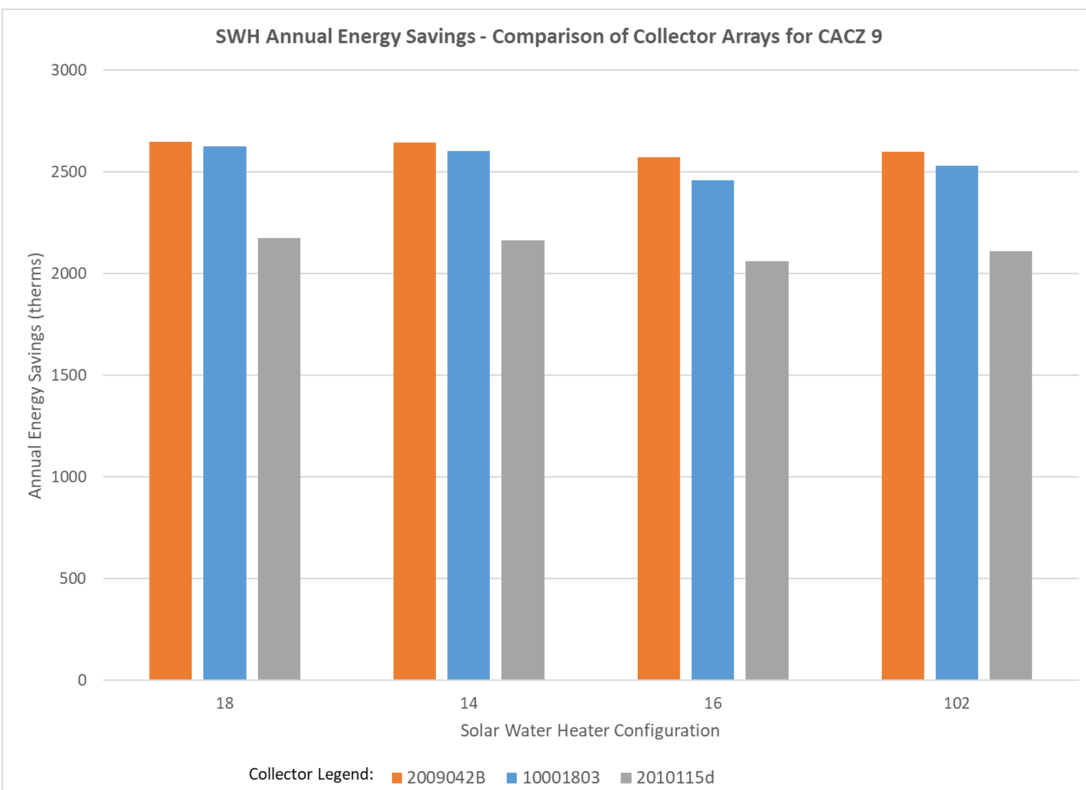

Figure 9: Annual Energy Savings Comparison by Collector for CACZ 9

Table 13: MFH Solar Water Heater Annual Energy Savings in CA Climate Zone 9

	ANNUAL ENERGY SAVINGS (THERMS)			
	External Supply-Side Hx, Glycol	Immersed Supply-Side Hx, Glycol	External Supply-Side Hx, Drainback	Immersed Load-Side Hx, Drainback
COLLECTOR	Config 14	Config 16	Config 18	Config 102
10001803	2601	2632	2623	2529
2010115A	2578	2457	2601	2505
2007032A	2383	2431	2404	2322
10001912	2738	2250	2759	2664
10002008	2513	2596	2535	2442
2010115D	2162	2367	2175	2109
2007032D	2001	2059	2010	1954
10001804	2181	1913	2193	2128
2009042B	2645	2080	2648	2597
10001893	2601	2571	2634	2587

Figures 9 and 10 characterize the results by showing some key relationship between parameters. Figure 9, for example, shows the annual energy savings in CA Climate Zone 9 for the largest (2009042B), average (10001803), and smallest (2010115D) collector arrays, respectively. Not surprisingly, the largest array by gross area provides the greatest annual energy savings. However, a comparison of the gross area and annual savings shows that the relationship does not scale in a linear fashion.

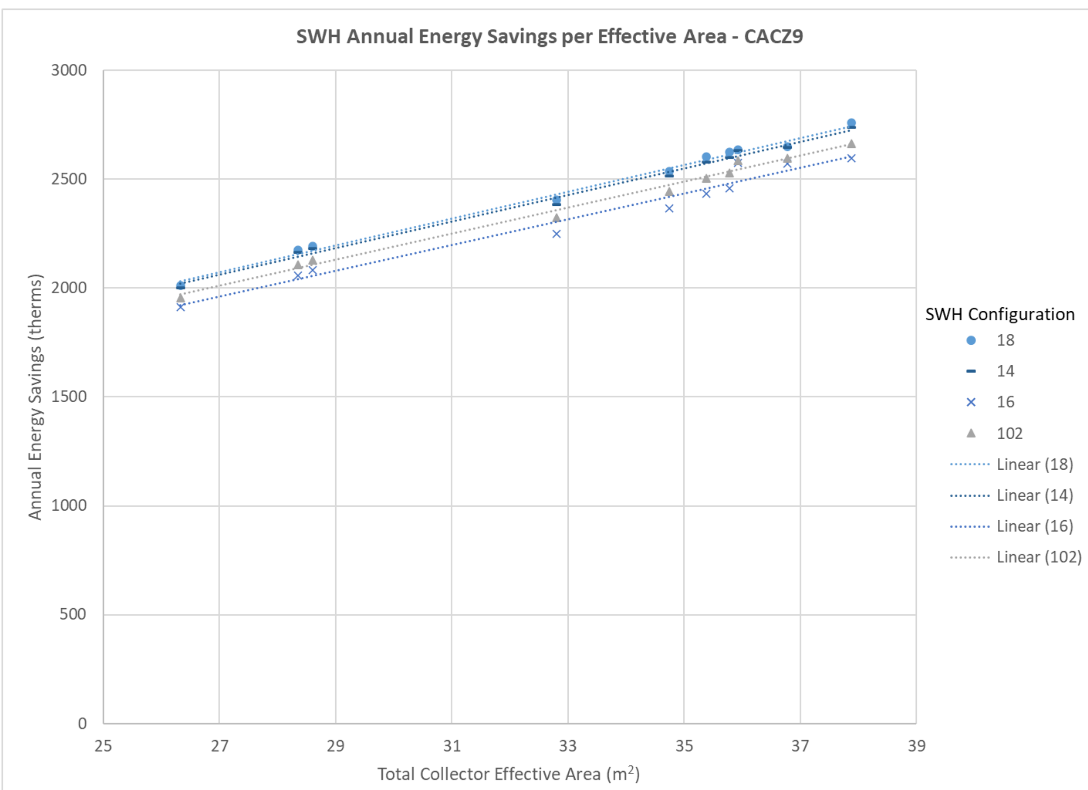

Figure 10: Annual Energy Savings as a Function of Effective Area CACZ 9

This leads to Figure 10, where the annual energy savings are shown as a function of effective area for each configuration in CA Climate Zone 9. Here it can be seen that the relationship is highly linear within each configuration. And the slope of the linear fits is nearly identical for the four configuration types. Therefore, annual energy savings can be characterized within a given configuration using the effective area parameter.

Additional Electrical Energy Consumption Results

Most types of solar water heaters make use of electrical controls and pumps. This additional energy consumption is generally small, but is irregular, since pumps turn on and off throughout the day depending on the demand, control strategy and weather conditions. This energy consumption is unique to solar water heaters and therefore must be accounted for in the calculation of net energy savings. Because it is a net savings, it does not include electrical energy consumption associated with the auxiliary water heater in a stand-alone configuration, used for reference. Therefore, the energy consumed by recirculation pumps, used in both solar and reference water heating systems, is not included.

Peak electrical energy use is of concern in each climate zone at particular times of the day and year. Therefore, the average net parasitic electrical energy consumption was modeled on an hourly basis for each system and each climate zone throughout the year. An example is provided below for the month of September in each climate zone for system Configuration 18 with Collector 10001803.

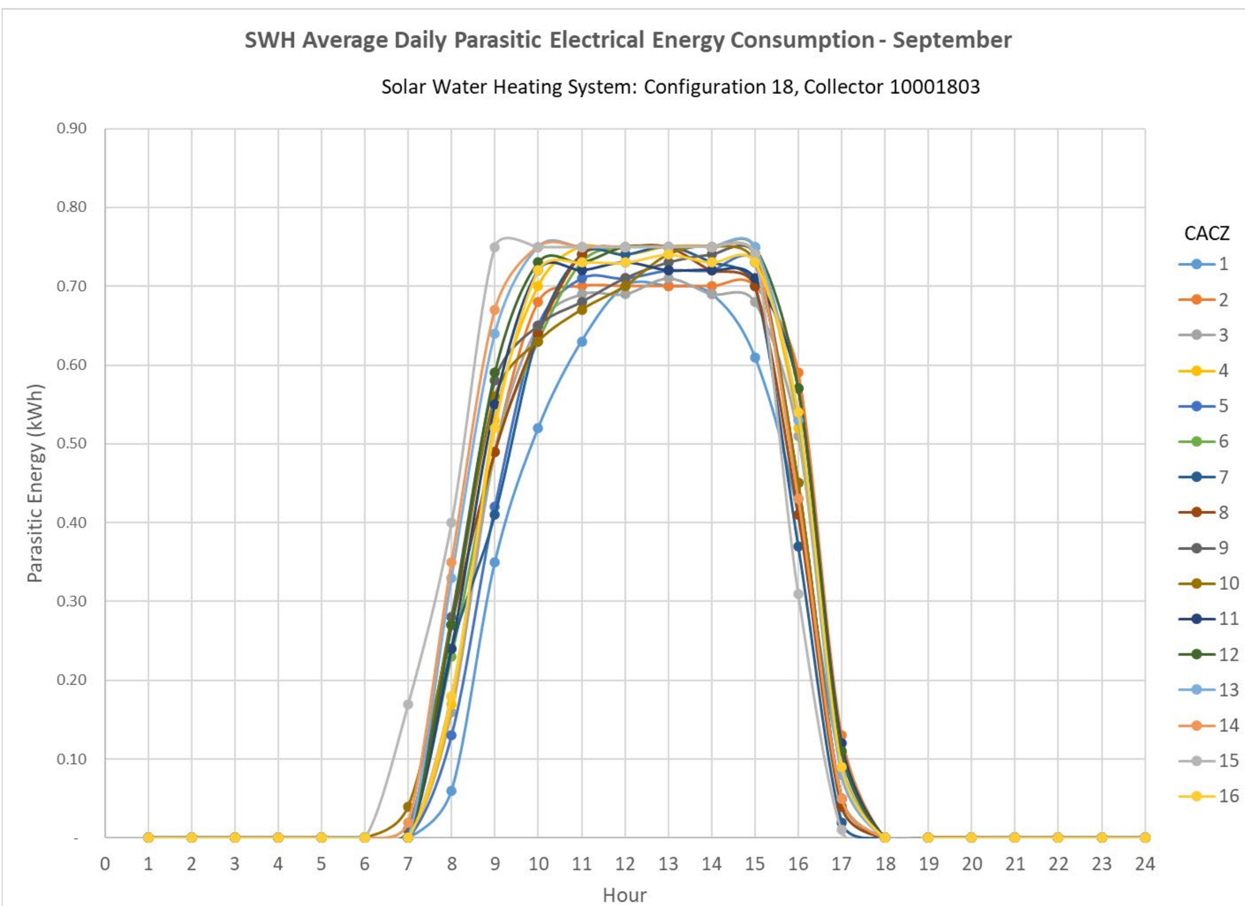

Figure 11: September Average Hourly Parasitic Electrical Consumption - SWH Config 18, Collector 10001803

SUMMARY

A project was undertaken by the Solar Rating & Certification Corporation (ICC-SRCC) and Thermal Energy System Specialists (TESS) to model the energy savings associated with several representative types of solar water heating systems with gas backups in California 40-unit multi-family buildings. The conditions and assumptions were modeled using an updated version of the CSI Thermal Multifamily Hot Water Calculator. The results from the updated model were compared to the results from the original CSI Thermal Multifamily Calculator and were found to agree within approximately 1%. Various other modeling validation runs were completed to test the model and its sensitivity to a variety of variables.

TRNSYS models were then created for 40 solar water heating systems (10 different collectors x 4 different configurations) using a 1600 gallon per day hot water load, corresponding to a 40-unit multifamily building in California. The annual energy savings for each system in each CA climate zone was reported. Analysis revealed a linear relationship between annual energy savings and total collector effective area within a given configuration for the systems studied. The annual additional parasitic electrical energy consumption for each solar water heating system in each climate zone was also calculated. The additional parasitic energy draw represents the total additional electrical energy consumed by the solar water heaters to operate their electrical components such as pumps, sensors and differential controllers. The results generally peaked and plateaued between 10 AM and 3 PM with modest variation between the 16 CA Climate Zones.

Appendix A: Solar Water Heater Annual Energy Dataset

The following table details the individual annual energy savings and additional parasitic energy consumption for each solar water heating system in each CA climate zone derived from the TRNSYS modeling described in this report.

Each associated parameter is also described below:

Configuration (Config): Solar water heater system layout varying the heat exchanger type and location and freeze protection method. See Table 7 for index numbers and descriptions.

Backup: Backup water heater installed in each solar water heating system intended to provide the additional heat required to meet the hot water load not met by the solar array. Also known as auxiliary water heater.

CACZ: California Climate Zone as specified by the California Energy Center (CEC)

Annual Energy Savings: Total annual energy saved by using the specified solar water heating system compared to the annual energy consumed by the reference water heater in a standalone configuration (without solar), for a given CA Climate Zone.

Hot Water Draw Pattern: Volumetric hot water demand over a 24-hour time period for a given building.

Hot Water Load: Ideal energy input required to raise the temperature of the incoming water to the hot water setpoint and satisfy the volumetric demand associated with the building over one year for a given location.

Effective Area (A_{EFF}): Normalized collector area based on performance at a specific, standardized rating condition in units of square meters.

Additional Annual Parasitic Energy Consumption (kWh): Total additional electrical power consumed by the solar water heating system to operate and meet the load in the specified climate zone.

Reference Water Heater: Conventional commercial 500 gallon gas-fired storage water heater used as the reference (base) water heater for calculating energy savings.

		ANNUAL ENERGY SAVINGS PER CA CLIMATE ZONE (THERMS)															
Config.	Collector	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
18	10001803	1904	2466	2451	2549	2652	2588	2551	2646	2623	2721	2512	2619	2692	2922	2840	2422
18	2010115a	1887	2445	2429	2527	2631	2565	2527	2623	2601	2699	2491	2597	2670	2898	2820	2399
18	2007032a	1742	2265	2252	2343	2435	2367	2337	2426	2404	2496	2320	2411	2483	2690	2629	2224
18	10001912	2005	2594	2584	2685	2789	2728	2689	2786	2759	2861	2632	2750	2812	3066	2956	2551
18	10002008	1840	2385	2367	2464	2565	2498	2463	2557	2535	2631	2432	2534	2608	2827	2758	2339
18	2010115d	1583	2048	2034	2116	2203	2145	2114	2193	2175	2257	2103	2183	2258	2439	2397	2011
18	2007032d	1461	1894	1887	1962	2040	1983	1957	2030	2010	2085	1948	2020	2088	2258	2216	1863
18	10001804	1598	2065	2052	2135	2221	2165	2134	2214	2193	2276	2122	2203	2278	2461	2416	2030
18	2009042b	1958	2499	2491	2588	2640	2632	2583	2676	2648	2736	2579	2685	2757	2971	2871	2488
18	10001893	1935	2480	2477	2574	2629	2618	2568	2662	2634	2724	2565	2667	2741	2959	2868	2472

14	10001803	1887	2447	2429	2529	2628	2565	2528	2623	2601	2698	2494	2600	2671	2899	2822	2402
14	2010115a	1869	2425	2407	2506	2606	2540	2504	2599	2578	2675	2472	2576	2648	2873	2800	2379
14	2007032a	1727	2243	2228	2321	2411	2346	2316	2403	2383	2473	2297	2385	2461	2664	2611	2202
14	10001912	1989	2575	2563	2665	2766	2706	2667	2765	2738	2840	2616	2733	2795	3044	2940	2532
14	10002008	1824	2365	2345	2443	2540	2475	2440	2533	2513	2607	2414	2514	2587	2803	2737	2319
14	2010115d	1572	2035	2020	2104	2189	2130	2098	2179	2162	2244	2089	2168	2243	2424	2384	1999
14	2007032d	1453	1885	1878	1951	2030	1976	1949	2021	2001	2077	1938	2009	2077	2246	2206	1854
14	10001804	1588	2053	2038	2122	2206	2150	2118	2198	2181	2264	2108	2188	2264	2445	2405	2018
14	2009042b	1952	2494	2484	2582	2634	2627	2578	2673	2645	2733	2573	2677	2752	2966	2867	2482
14	10001893	1931	2481	2475	2570	2625	2614	2563	2657	2632	2723	2565	2667	2738	2956	2870	2471
16	10001803	1789	2313	2297	2391	2483	2423	2388	2478	2457	2550	2366	2462	2537	2744	2687	2272
16	2010115a	1769	2289	2271	2364	2457	2396	2361	2451	2431	2523	2340	2435	2510	2715	2660	2246
16	2007032a	1640	2122	2106	2194	2281	2215	2187	2271	2250	2334	2170	2253	2326	2512	2464	2082
16	10001912	1890	2443	2430	2528	2621	2564	2527	2621	2596	2693	2496	2598	2672	2896	2823	2403
16	10002008	1725	2229	2211	2302	2393	2331	2298	2386	2367	2456	2279	2371	2446	2643	2592	2187
16	2010115d	1501	1940	1926	2004	2085	2030	2001	2076	2059	2137	1992	2068	2139	2308	2271	1906
16	2007032d	1393	1805	1794	1867	1942	1886	1861	1932	1913	1985	1851	1920	1985	2143	2105	1773
16	10001804	1518	1961	1947	2026	2105	2053	2023	2099	2080	2159	2014	2091	2162	2333	2295	1928
16	2009042b	1901	2426	2415	2513	2563	2553	2507	2599	2571	2659	2506	2605	2681	2885	2800	2413
16	10001893	1886	2426	2422	2517	2571	2561	2511	2604	2574	2664	2514	2611	2688	2900	2819	2414
102	10001803	1839	2380	2365	2460	2556	2495	2458	2551	2529	2623	2422	2529	2591	2820	2740	2338
102	2010115a	1820	2359	2342	2436	2533	2471	2434	2526	2505	2599	2402	2506	2570	2795	2720	2314
102	2007032a	1688	2187	2174	2261	2351	2287	2259	2342	2322	2409	2237	2323	2396	2593	2541	2145
102	10001912	1940	2506	2496	2594	2691	2634	2595	2690	2664	2762	2513	2655	2684	2944	2826	2464
102	10002008	1776	2300	2282	2374	2469	2407	2372	2462	2442	2534	2348	2444	2515	2726	2663	2256
102	2010115d	1534	1986	1970	2051	2132	2080	2049	2126	2109	2189	2040	2118	2189	2365	2323	1951
102	2007032d	1423	1841	1835	1907	1981	1929	1904	1972	1954	2028	1894	1964	2029	2193	2154	1811
102	10001804	1551	2004	1990	2071	2150	2101	2069	2147	2128	2209	2060	2139	2210	2388	2344	1972
102	2009042b	1928	2449	2444	2539	2587	2582	2535	2625	2597	2683	2522	2636	2693	2911	2812	2441
102	10001893	1905	2436	2435	2526	2582	2573	2523	2614	2587	2675	2512	2622	2682	2907	2811	2427

		ADDITIONAL ANNUAL PARASITIC ENERGY CONSUMPTION PER CA CLIMATE ZONE (kWh)															
Config.	**Collector**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
18	10001803	1666	1789	1846	1921	1909	1976	1949	1989	1868	1939	1800	1867	1906	2061	1984	1810
18	2010115a	1660	1783	1840	1915	1904	1970	1943	1983	1863	1933	1794	1860	1901	2055	1981	1802
18	2007032a	1575	1712	1765	1842	1833	1886	1861	1905	1786	1861	1732	1791	1831	1980	1917	1730
18	10001912	1700	1815	1873	1948	1931	2004	1977	2014	1894	1961	1817	1886	1916	2075	1979	1838
18	10002008	1644	1772	1828	1904	1895	1957	1930	1972	1851	1923	1787	1852	1894	2048	1979	1791
18	2010115d	1574	1744	1797	1877	1871	1925	1894	1943	1823	1900	1773	1833	1883	2037	1982	1758
18	2007032d	1475	1674	1720	1800	1799	1834	1804	1859	1753	1826	1699	1756	1803	1956	1899	1684
18	10001804	1582	1753	1807	1887	1880	1935	1904	1955	1832	1908	1782	1844	1892	2048	1991	1769

18	2009042b	1788	1966	2029	2123	2086	2175	2141	2192	2049	2118	2006	2071	2118	2288	2182	2012
18	10001893	1757	1927	1993	2084	2050	2133	2101	2150	2010	2080	1964	2029	2074	2241	2144	1973
14	10001803	1473	1536	1582	1636	1613	1685	1667	1687	1596	1641	1530	1585	1615	1728	1682	1548
14	2010115a	1466	1530	1576	1630	1608	1678	1661	1681	1591	1636	1524	1579	1610	1723	1680	1541
14	2007032a	1404	1468	1512	1567	1548	1612	1598	1619	1530	1578	1469	1517	1550	1661	1629	1479
14	10001912	1501	1558	1605	1657	1632	1705	1688	1708	1617	1659	1543	1603	1625	1739	1677	1571
14	10002008	1457	1523	1569	1622	1602	1672	1653	1675	1584	1630	1521	1575	1606	1720	1680	1533
14	2010115d	1402	1488	1538	1599	1582	1645	1622	1652	1558	1610	1505	1551	1592	1715	1677	1505
14	2007032d	1333	1426	1474	1537	1525	1581	1560	1591	1493	1551	1444	1489	1527	1650	1612	1445
14	10001804	1410	1496	1546	1606	1589	1654	1631	1661	1566	1617	1512	1560	1600	1722	1684	1515
14	2009042b	1587	1678	1729	1793	1759	1844	1823	1848	1749	1790	1694	1747	1785	1904	1836	1711
14	10001893	1560	1649	1700	1762	1729	1813	1791	1817	1718	1762	1663	1715	1750	1869	1805	1682
16	10001803	1417	1375	1435	1443	1429	1482	1485	1484	1426	1444	1360	1419	1434	1474	1470	1391
16	2010115a	1410	1368	1429	1437	1424	1477	1480	1478	1420	1439	1352	1412	1428	1469	1465	1383
16	2007032a	1390	1346	1402	1408	1394	1445	1449	1446	1397	1415	1322	1380	1398	1434	1437	1355
16	10001912	1436	1394	1452	1459	1445	1497	1500	1499	1442	1460	1380	1436	1449	1486	1479	1414
16	10002008	1407	1367	1427	1435	1422	1475	1478	1476	1418	1437	1349	1410	1426	1467	1464	1381
16	2010115d	1394	1362	1423	1435	1420	1475	1478	1477	1415	1437	1345	1406	1424	1471	1469	1375
16	2007032d	1368	1336	1393	1404	1387	1444	1447	1445	1390	1411	1313	1372	1391	1436	1439	1343
16	10001804	1402	1370	1429	1441	1427	1482	1484	1484	1422	1444	1354	1413	1432	1477	1474	1384
16	2009042b	1526	1497	1546	1559	1541	1594	1596	1596	1545	1566	1499	1537	1559	1594	1584	1532
16	10001893	1506	1477	1528	1540	1524	1577	1578	1579	1526	1544	1478	1519	1537	1573	1564	1510
102	10001803	1149	1364	1398	1465	1462	1496	1470	1522	1425	1492	1378	1436	1468	1620	1545	1375
102	2010115a	1141	1358	1391	1457	1456	1487	1461	1514	1418	1485	1374	1430	1465	1614	1543	1367
102	2007032a	1071	1297	1325	1391	1393	1408	1382	1441	1355	1421	1315	1359	1406	1539	1487	1295
102	10001912	1195	1389	1429	1495	1487	1533	1505	1552	1449	1516	1364	1453	1449	1618	1513	1403
102	10002008	1126	1349	1380	1446	1446	1473	1444	1501	1409	1477	1372	1423	1466	1607	1544	1356
102	2010115d	1086	1330	1356	1422	1423	1443	1414	1477	1393	1459	1360	1405	1450	1589	1540	1328
102	2007032d	1019	1270	1294	1356	1360	1370	1343	1404	1329	1391	1296	1335	1377	1512	1466	1261
102	10001804	1092	1339	1365	1431	1432	1454	1423	1487	1402	1467	1369	1414	1460	1601	1550	1337
102	2009042b	1258	1517	1567	1642	1624	1677	1640	1704	1584	1650	1545	1610	1640	1812	1712	1544
102	10001893	1235	1492	1540	1614	1601	1645	1607	1673	1559	1624	1517	1583	1612	1785	1683	1519

Appendix B: Solar Water Heating System Configuration Schematics

The solar water heating systems selected for modeling and study consist of 40 separate combinations consisting of 4 configurations modeled with 10 different collector arrays. Two of the four configurations use drainback freeze protection and two use glycol. For heat exchangers, two use immersed heat exchangers in the solar tank and two use external heat exchangers. Schematics for the four configurations are shown below.

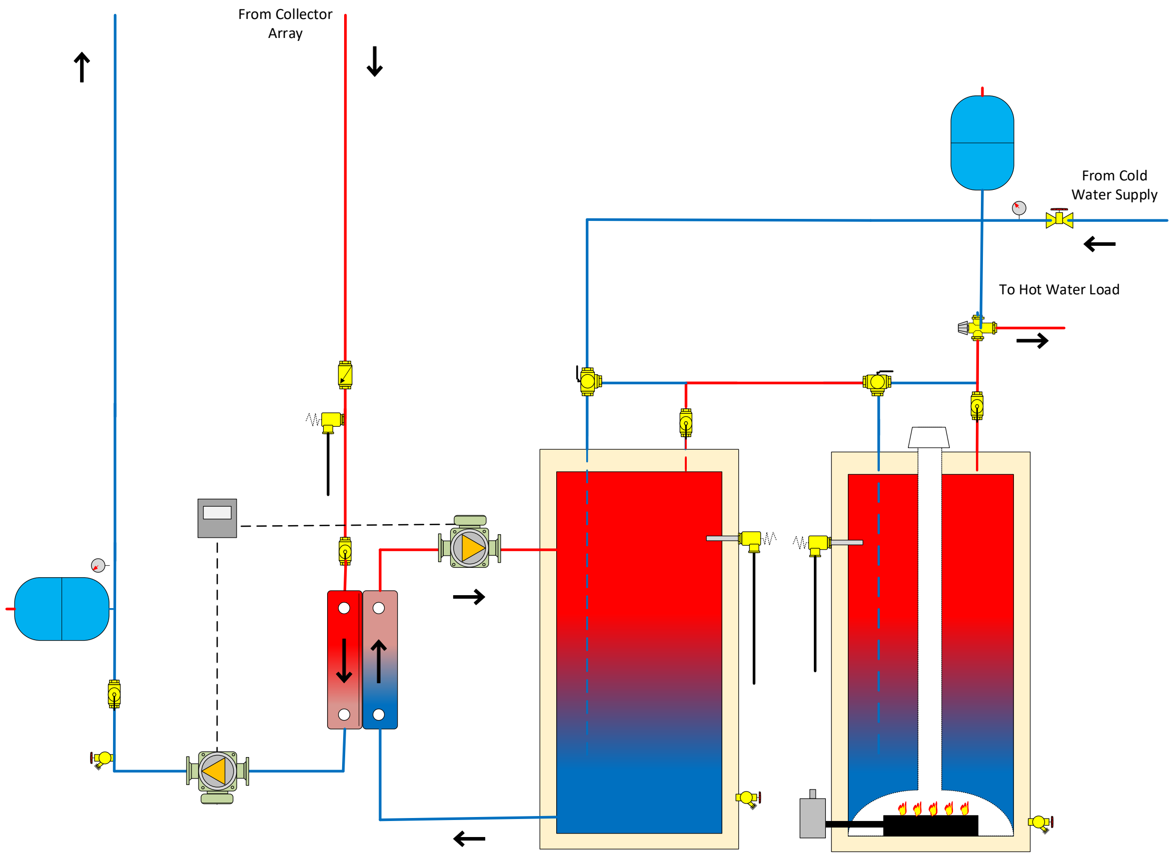

Figure B1: System Configuration 14 - External Supply Side Heat Exchanger with Glycol Freeze Protection

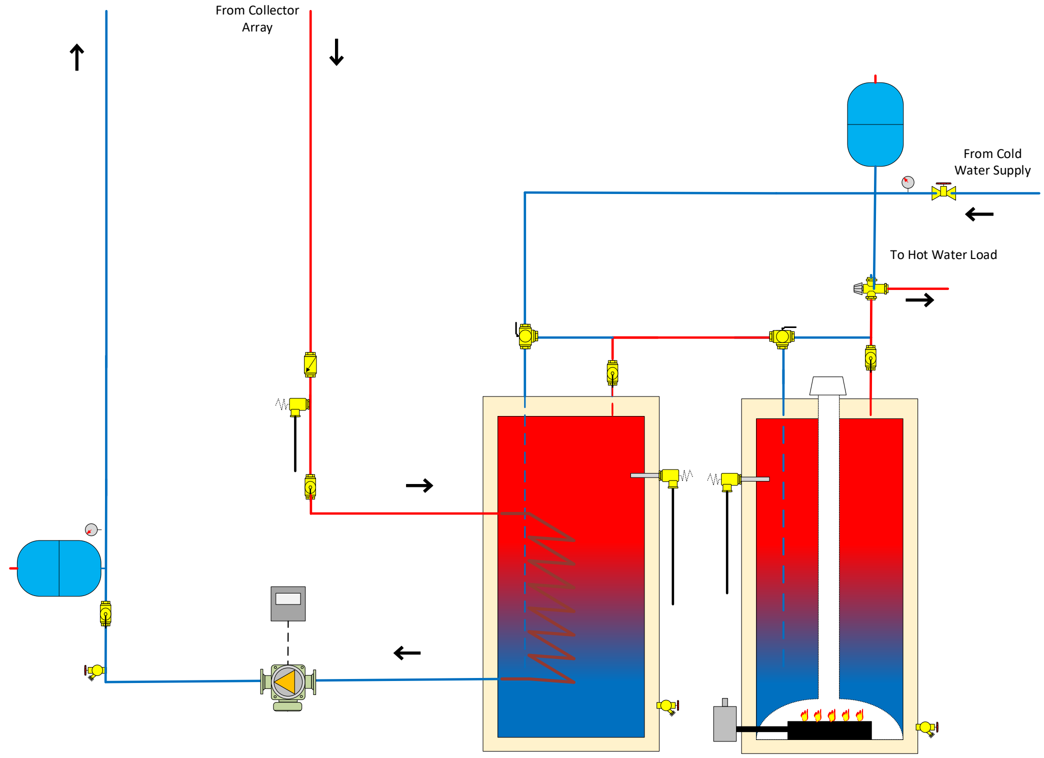

Figure B2: System Configuration 16 - Immersed Supply Side Heat Exchanger with Glycol Freeze Protection

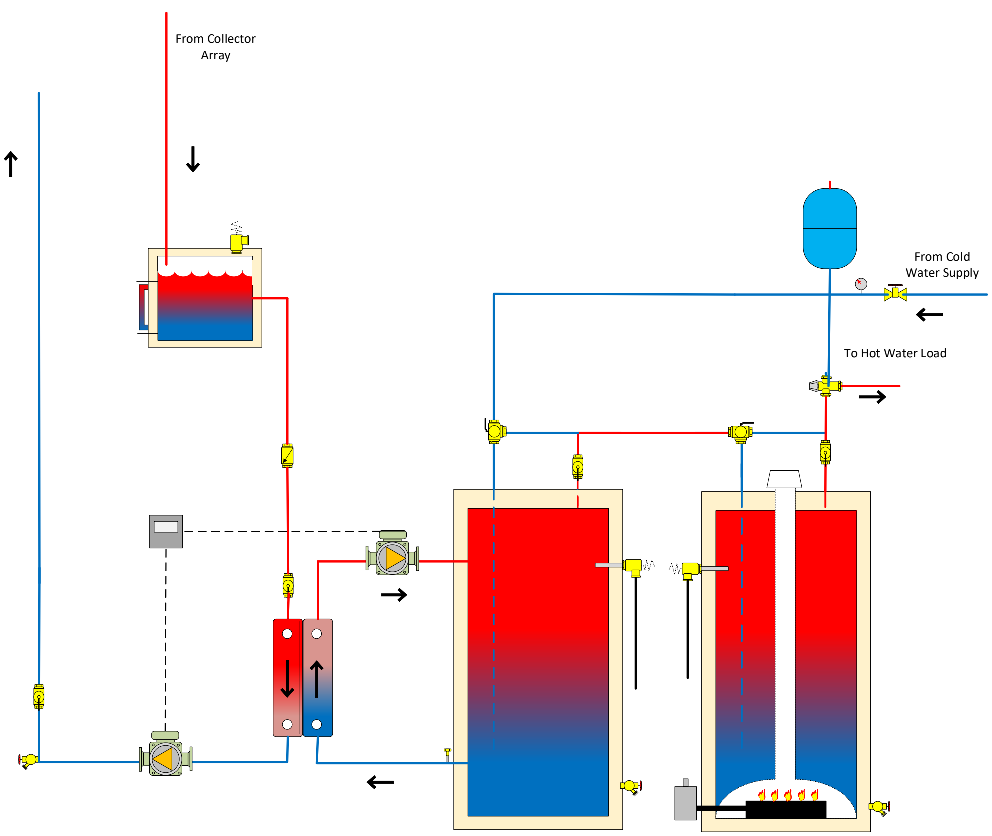

Figure B312: System Configuration 18 - External Supply Side Heat Exchanger with Drainback Freeze Protection

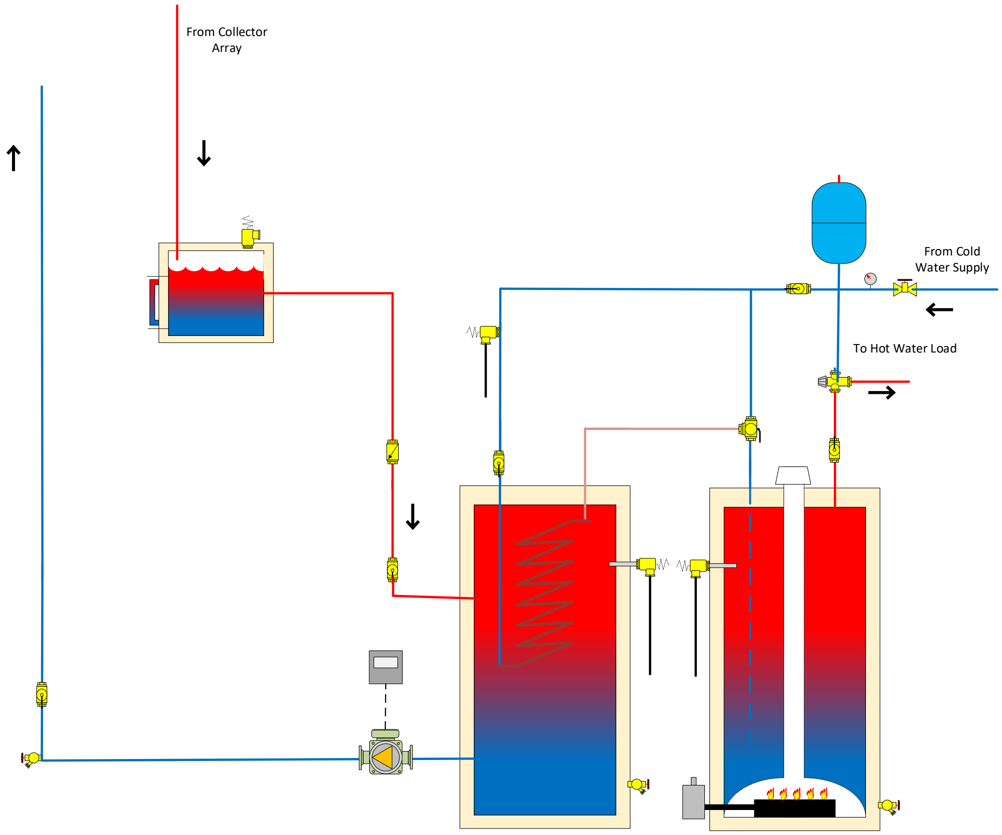

Figure B4: System Configuration 102 - Immersed Load Side Heat Exchanger with Drainback Freeze Protection

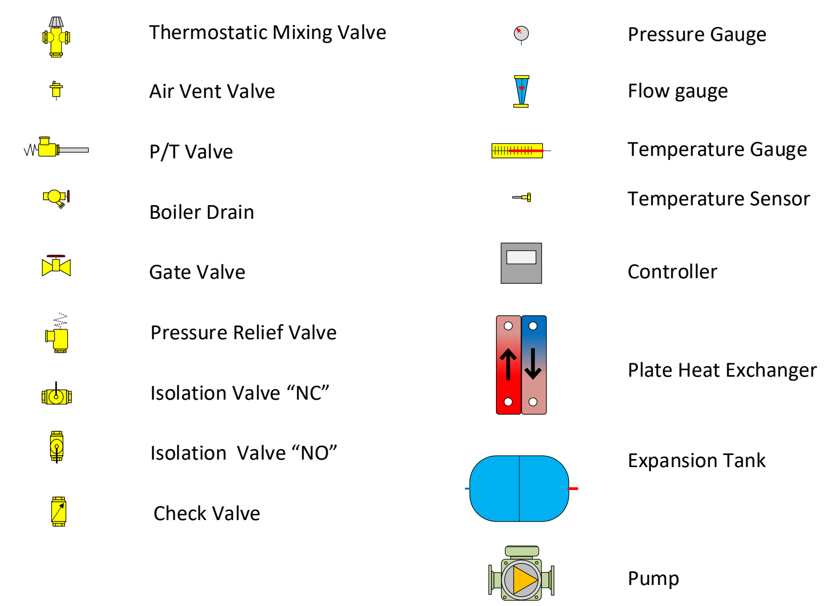

Figure B5: Schematic Symbol Legend

Appendix C: Solar Water Heating System Performance Metrics

Solar water heating systems differ from traditional, fuel-only water heaters in that they utilize a time-dependent solar energy source. Typically, these systems utilize two fuel sources, where the solar portion is irregular but prioritized. Backup water heaters consuming fuels such as natural gas, make up the difference between the solar energy supply and the hot water energy demand. As a result, the metrics used to describe the performance of solar water heaters are somewhat different from those used for traditional water heaters.

Note that the metric will vary with the assumptions used. Variations in parameters such as the collector mounting angle and azimuth, annual hot water load, setpoint temperature, building size, storage tank volume, heat exchanger configuration and freeze protection mechanism will all have impacts on the overall annual energy savings observed in the real world.

The solar water heater performance metrics provided in this analysis include the following:

Effective Area (A_{EFF}). Effective area is a metric developed to normalize the area associated with a collector in order to account for the variation in different solar thermal technologies. It permits the thermal efficiency performance of different collectors to be compared on an area basis. The effective area is calculated for the collectors in each system based on a specific rating condition. The actual gross collector area (A_G) is measured using the length and width of the projected area exposed to solar radiation, as established in the ISO 9806 standard.

$$A_{eff} = A_g \ \eta_{nom} \overline{IAM}$$

Annual Energy Savings. The Annual Energy Savings is the difference between the energy consumed by the solar water heater and a reference water heater over a period. The user must determine whether the calculation will include parasitic electrical energy or only the energy consumed by the gas auxiliary water heater. If including parasitic electrical energy, it must be converted to a gas equivalent in therms. The conversion is 29.3297 kWh/therm.

$$AES = Q_{REF} - Q_{AUX} - Q_{PAR}$$