CSI-Thermal Multifamily/Commercial OG-100 Incentive Calculator User Guide
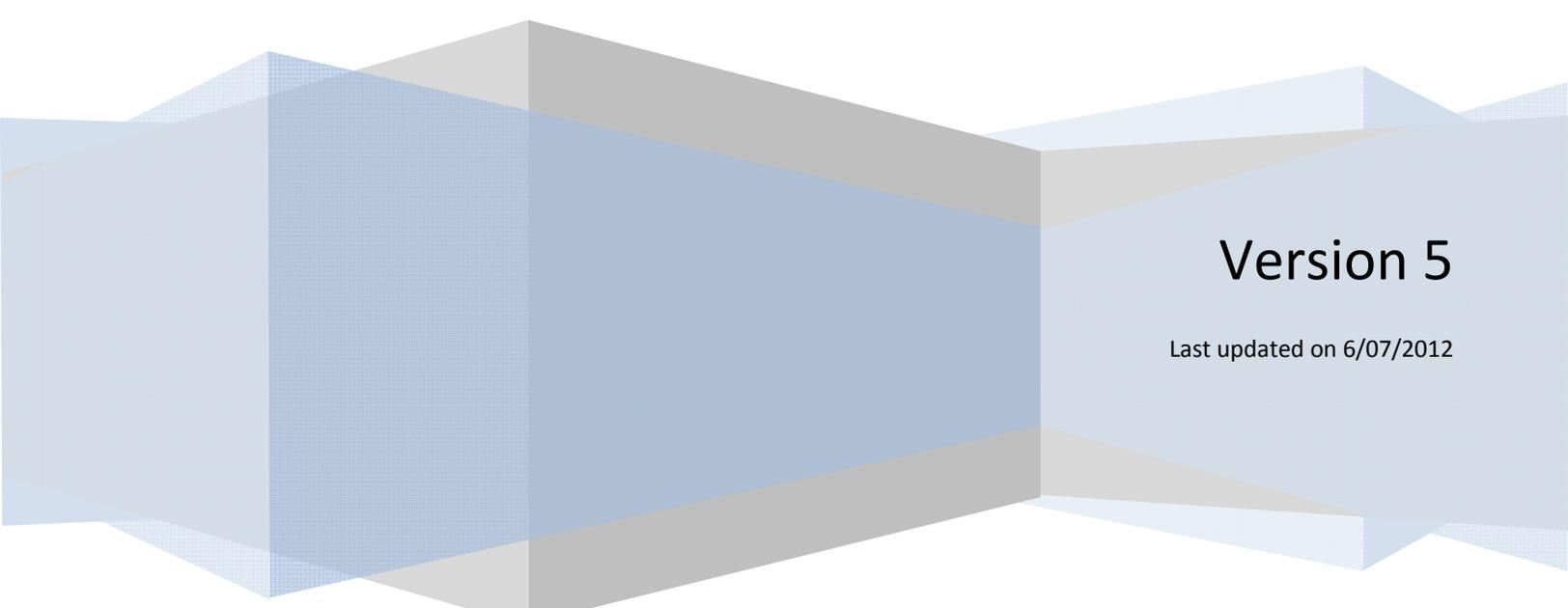
Version 5

Last updated on 6/07/2012

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CSI-Thermal Multifamily/Commercial

SRCC OG-100 Incentive Calculator Guide

1. Guide Overview

The Multifamily/Commercial OG-100 Incentive Calculator Guide provides a detailed explanation of how the CSI-Thermal incentive is determined. Program Administrators developed the on-line calculator tool, which blends a set of fundamental design assumptions with the below mentioned list of inputs. The calculator can be accessed at www.csithermal.com. Users may access the public version which is separate from the application process, or the application version which is embedded into the application process.

The sole purpose of the calculator is to determine a CSI-Thermal incentive amount based on a number of key inputs for a given proposed system. Results may not match those you assume or have estimated using different models. The calculator should not be used as a performance guarantee. Actual performance of a solar thermal system may differ from the results of the CSI-Thermal calculator. If you have a performance estimating tool that you like, continue to use it. However, the CSI Thermal Incentive Calculator must be used to determine the incentive amount.

The calculator uses Transient Energy System Simulation (TRNSYS) software to model each system and produce an incentive, based on conventional energy displaced by solar energy.[1]

2. TRNSYS Engine

The TRNSYS Tool is a flexible tool designed to simulate the transient performance of thermal energy systems. The development of TRNSYS began in 1975 as a joint project between the University of Wisconsin-Madison Solar Energy Lab and the University of Colorado Solar Energy Applications Lab. More than 35 years later, TRNSYS is a well respected energy simulation tool under continual development by a joint team made up of the Solar Energy Laboratory (SEL) at the University of Wisconsin-Madison, The Centre Scientifique et Technique du Batiment (CSTB) in Sophia Antipolis, France, Transsolar Energietechnik GmBH in Stuttgart, Germany and Thermal Energy Systems Specialists (TESS) in Madison, Wisconsin.

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[1] Please note that the final incentive amounts are subject to change based upon the configuration of the as-built system and other program requirements detailed in the CSI-Thermal Handbook.
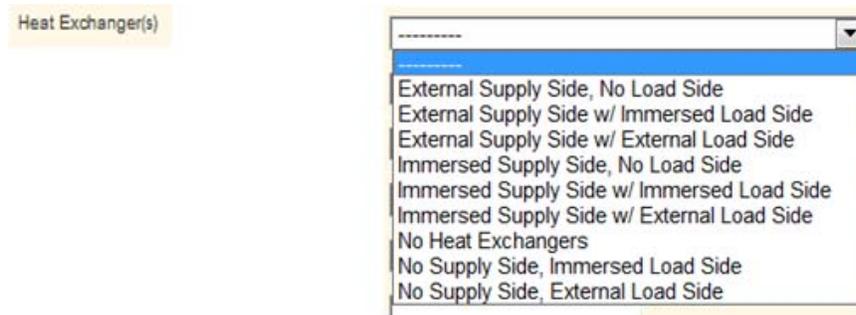
The CSI-Thermal Program Administrators have contracted with TESS to develop the CSI-Thermal Multifamily/Commercial OG-100 Incentive Calculator, which uses the TRNSYS engine to estimate the annual displaced conventional gas, propane or electric energy in order to calculate the incentive amount for each project.
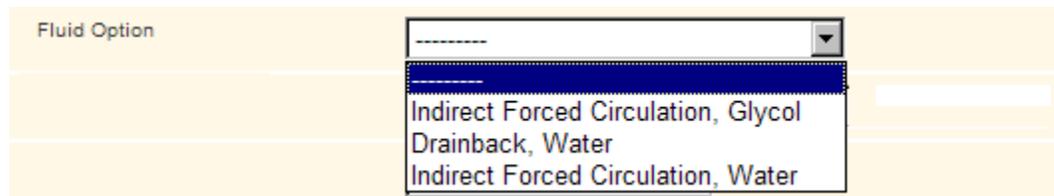
3. Required Calculator Inputs

The combined inputs of the calculator are simulated by TRNSYS to estimate the annual displaced conventional gas, propane or electric energy to heat the stated Gallons per Day (GPD).

For the first three data entry fields – Heat Exchanger(s), Fluid Option and Tank Configuration, click on the arrow to access a drop down list of possible configurations based on the type of heat exchanger, freeze protection type, and number of tanks.
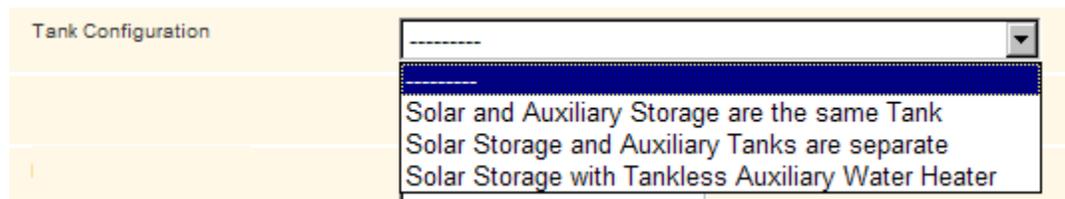
- **"Heat Exchangers"**:

Heat Exchanger(s)

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External Supply Side, No Load Side
External Supply Side w/ Immersed Load Side
External Supply Side w/ External Load Side
Immersed Supply Side, No Load Side
Immersed Supply Side w/ Immersed Load Side
Immersed Supply Side w/ External Load Side
No Heat Exchangers
No Supply Side, Immersed Load Side
No Supply Side, External Load Side
```

"Fluid Option":

Fluid Option

```
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----------
Indirect Forced Circulation, Glycol
Drainback, Water
Indirect Forced Circulation, Water
```

- **"Tank Configuration"**:

Tank Configuration

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Solar and Auxiliary Storage are the same Tank
Solar Storage and Auxiliary Tanks are separate
Solar Storage with Tankless Auxiliary Water Heater
```

Description of Tank Configurations:

- Solar and Auxiliary Storage is the same Tank = the solar system and a conventional backup heater are the same tank. Also referred to as 1-tank systems.

- Solar Storage and Auxiliary Tanks are separate = solar storage and backup water heater storage are separate tanks. For systems with more than 2 tanks, select this option (you will have the opportunity to further define the number of tanks in a different input field below). Also referred to as 2-tank systems.

- Solar Storage with Tankless Auxiliary Water Heater = 1 solar storage tank, with a backup tankless, on-demand water heater, or boiler. Also referred to as 1-tank with tankless backup systems.

- Immersed Load Side Heat Exchanger Drainback systems, No Supply Side, for 2-tank systems only.

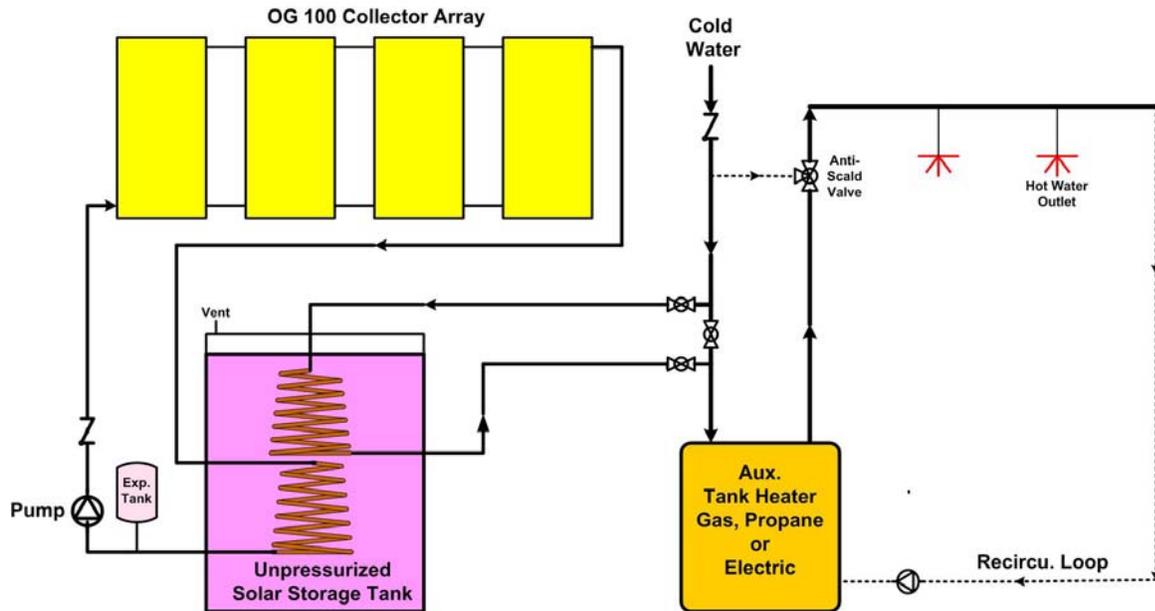Three examples of tank configuration schematics are shown below:

Example A – Immersed Load Side HX Drainback System with Tank Heater
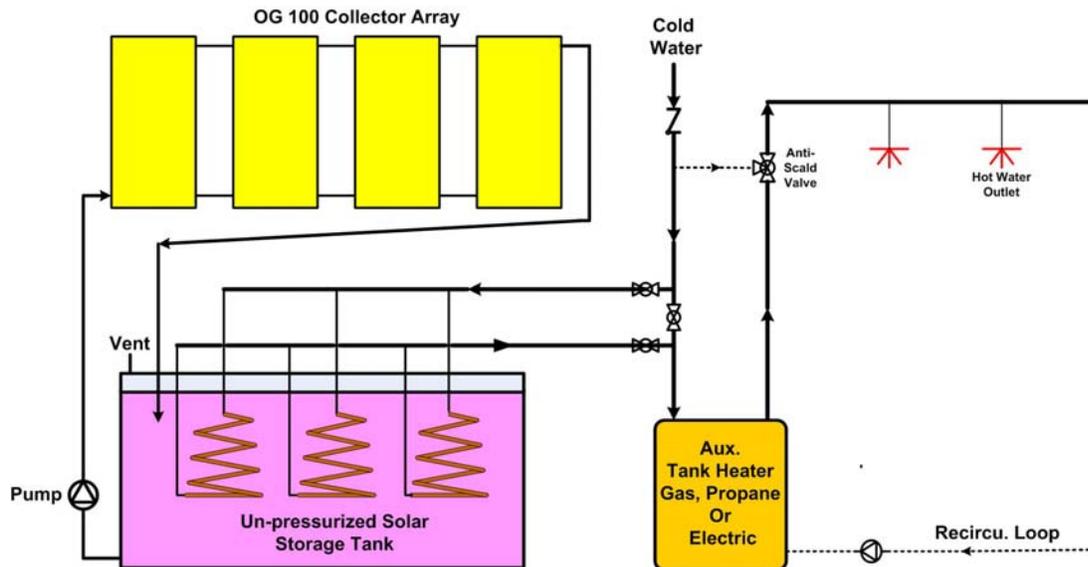
Example B – External Supply Side HX Indirect Forced Circulation System with Tank-less Heater
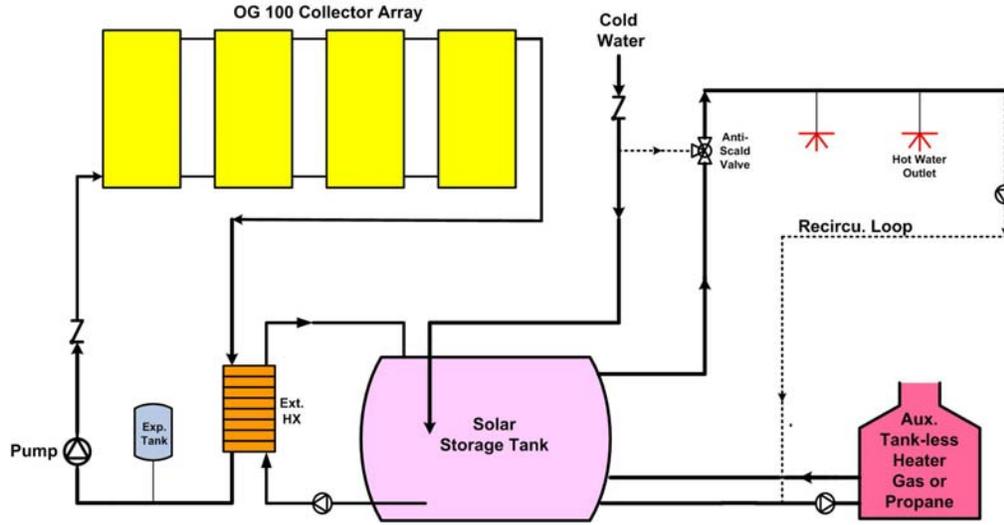
Example C – Immersed Supply Side and Immersed Load Side HX IFC System with Tank Heater

- "**Collector**": To enter the collector you would like to simulate, type in the collector manufacturer name, model number, or SRCC OG-100 number and a list containing all matching

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entries should appear. This calculator obtains data from the SRCC online directory of OG-100 certified collectors on a regular basis. This includes glazed, unglazed, and concentrating collectors.

- o This calculator is unable to model ICS and Thermosiphon systems, since they are only provided an OG-300 certification and not an individual OG-100 collector certification. ICS and Thermosiphon systems for multifamily and commercial projects are eligible for a CSI-Thermal incentive; however, a manual simulation must be run by the Program Administrators to model these projects. Please contact the appropriate Program Administrator, based on the utility service territory where the project site is located.

- o For newly certified collectors that are not yet on this list, please contact SRCC to determine when their online directory will be updated to include the newly certified equipment. Unfortunately, the application may not be submitted until the equipment is listed in the SRCC online directory.
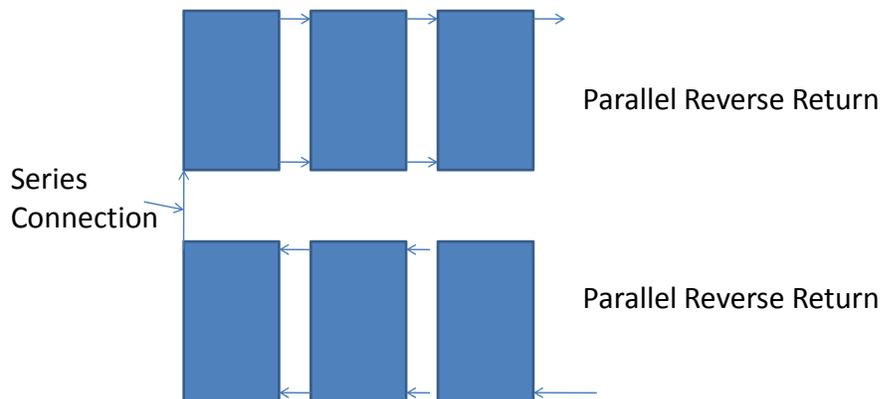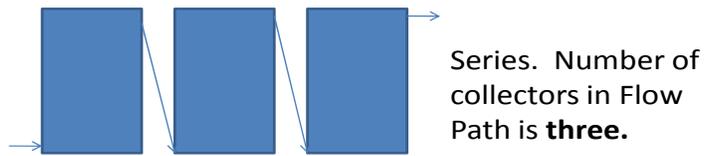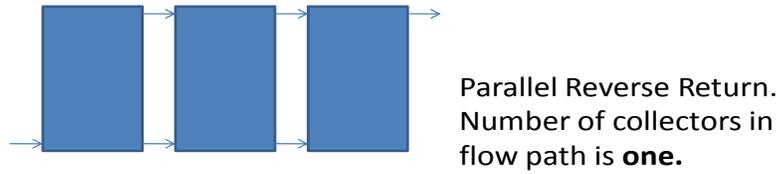

- • "**Number of Collectors**": Enter the total number of collectors, not the square footage.

- • **"Average Collector Module Area"**: Upon selection of a collector, this data is automatically pulled from the SRCC OG-100 database. This value should only be edited if the OG-100 certification for that specific collector states "ALL SIZES OF THIS COLLECTOR MODEL ARE CERTIFIED" and the average size of collectors used differs from the default value of the SRCC database.

- • "**Number of Collectors in Series per Flow Path**": Enter the number of collectors in series per flow path. In other words, how many collectors or banks of collectors are heating the same molecule of water? Every time a molecule of water is heated by one collector and then by a second collector, some collection efficiency is lost because of the warmer temperature fluid

entering the second collector.   This input field is NOT asking for the number of collectors in each bank. See below for a visual representation of flow path.

Note below how collectors connected in parallel have two connections between each collector, while those connected in series have only one.

Parallel Reverse Return.
Number of collectors in
flow path is **one.**

Series. Number of
collectors in Flow
Path is **three.**

Series
Connection

Parallel Reverse Return

Parallel Reverse Return

The number of collectors in the flow path is **two.**

Parallel Reverse Return

Parallel Reverse Return

The number of collectors in the flow path is **one.**

Series

Series Connector

Series

The number of collectors in the flow path is **six.**
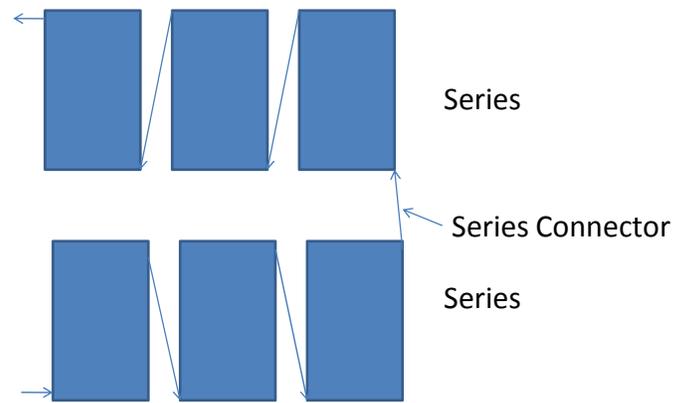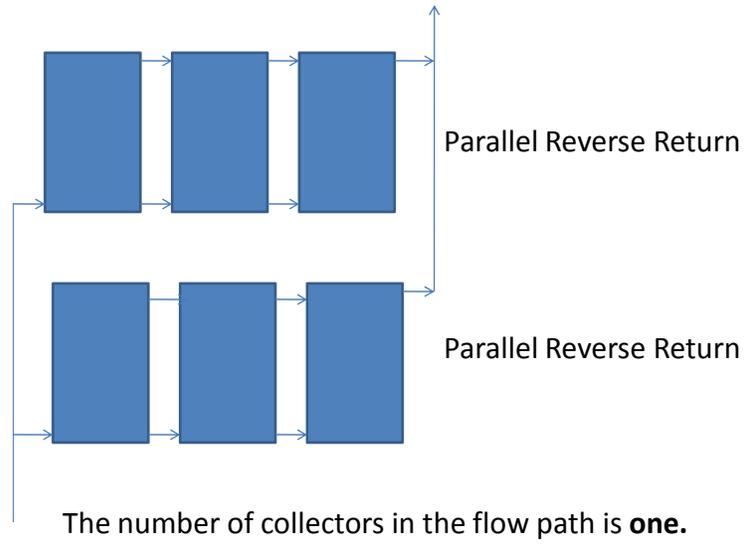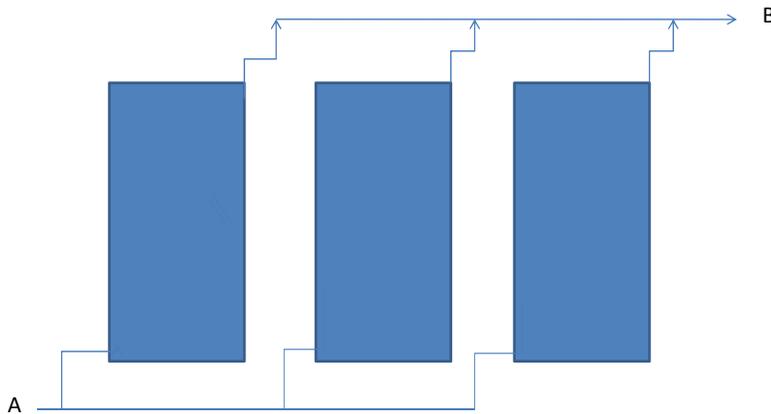
These collectors may have internal parallel piping or internal serpentine piping. Either way, the parallel external manifolds cause each molecule of water passing from A to B to flow through only one collector. The number of collectors in the flow path is **one.**

- "**Total Solar Storage Capacity**": Enter the total gallons of solar storage. For your reference, 1-tank and 2-tank systems are defined above under Tank Configuration.

    o   For 1-tank systems, enter the tank volume. (E.g. If the total capacity of a one tank system is 300 gallons, enter 300 gallons for the total solar storage capacity).

    o   For 1-tank drain back systems this is the volume of the drain back reservoir plus the storage tank.

    o   For a 2-tank system, this is the volume of the solar storage tank only (do not include the volume of the auxiliary storage).

   o   For a 2-tank drain back system, this is the volume of the drain back reservoir plus solar storage tank. Note. On large drain back systems, the drain back tank is often large and serves as the total solar storage.

- "**Total Number of Solar Tanks**": Enter the number of solar storage tanks. Do not include the small drain back reservoirs or the water in the recirculation loop in this number.

- "**Total Backup Storage Capacity**": Enter the gallon capacity of the backup heater. For a tankless heater enter zero. For a heater that heats only the upper part of the tank, enter the capacity of that portion.

- "**Total Number of Backup Tanks**":   Enter the number of backup storage tanks (this is typically 1).

- "**Backup Fuel Source**": Click on the arrow to access a drop down list of backup water heater options.
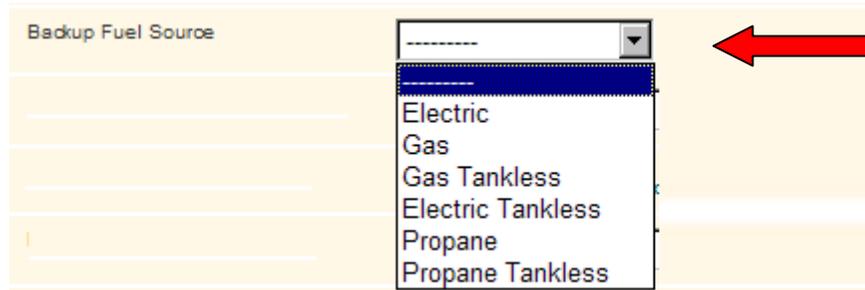
- **Maximum Auxiliary Heat Capacity**": Auxiliary refers to the backup water heater. Look at the nameplate on the backup water heater for the gas or propane capacity in BTUH or the electric element capacity in kW, and enter this value.

- "**CEC Climate Zone**": Click on the arrow to access a drop down list of the 16 California Energy Commission (CEC) Climate Zones.
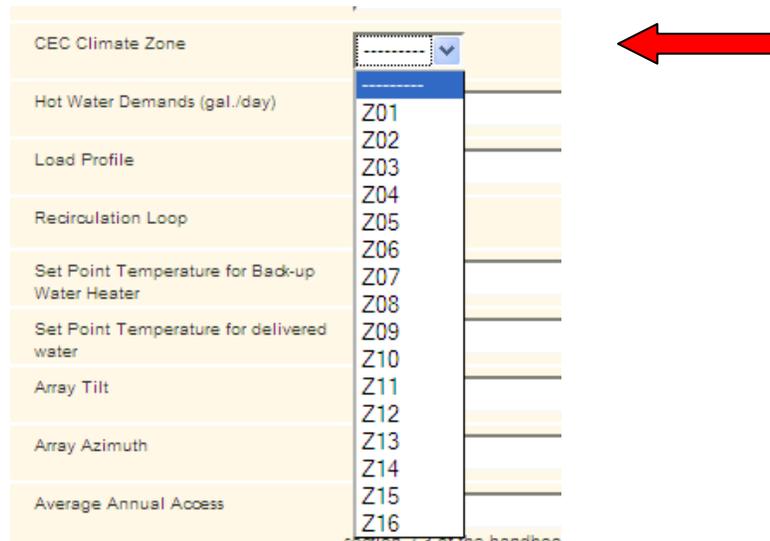
To determine the CEC Climate Zone of the project site, refer to the CEC Climate Zone Manual posted on www.gosolarcalifornia.org/solarwater. Enter the zip code of the project site in the "Find" box at the top of the PDF, and hit enter. Some zip codes are in multiple climate zones. Hit "Enter" multiple times to find all climate zones for that zip code. Applicant may select the appropriate climate zone in these cases.

ZIP	CITY_NAME	CECZONE
95410	Albion	1
95412	Annapolis	1
95521	Arcata	1
95524	Bayside	1
95525	Blue Lake	1
94922	Bodega	1
94923	Bodega Bay	1
95417	Branscomb	1
95528	Carlotta	1
95420	Caspar	1
95421	Cazadero	1
95427	Comptche	1
95531	Crescent City	1
95432	Elk	1
95503	Eureka	1
95501	Eureka	1
95536	Ferndale	1
95437	Fort Bragg	1

- "**Hot Water Demand (gal./day)**": Hot water demand refers to the gallons per day (GPD) of hot water used. Section 6.3.2 of the CSI-Thermal Handbook provides sizing guidelines for multifamily and commercial projects. Since the results are highly sensitive to GPD, the possibility of overheating or potential gaming to get higher incentives is high. To mitigate these concerns, a set of input GPD values based on industry studies have been adopted and are defendable.

    o   Refer to Appendix D (Maximum GPD Guideline Table) of the CSI-Thermal Handbook to determine the maximum allowable GPD based on type and size of building. The GPD values in the table are maximum values, and systems may be sized using a lesser GPD assumption.
    o   Building types not listed in the Maximum GPD Guideline Table must do one of the following to determine GPD value:

        ▪   Meter Actual Consumption: Meter hourly actual hot water consumption using an in-line water flow meter with accumulator for a minimum of 60 calendar days and adjust for seasonal variability. Hot water consumption calculation and load shape determination must be stamped by a P.E.
        ▪   Meter hourly natural gas or electric consumption at the water heater for a minimum of 60 days and adjust for seasonal variability. Water heater gas or electric meter consumption calculation and load shape determination must be stamped by a P.E.

- "**Load Profile**":   Click on the arrow to access a drop down list of load profile options. Select the type of business or institution that matches the hot water load of the building. Refer to Attachment A: Multifamily/Commercial OG-100 Incentive Calculator Load Profiles, for the

complete load profiles for each building type. If the building type is not listed on the dropdown list, please select "Other" and follow directions under "Load Profile Data" File below.

- o "**Number of Units**": Required when the following load profiles are selected: Multi-family, Hotels/Motels. Refers to the number apartment units or motel rooms.
- o "**Number of Beds**": Required when the following load profile is selected: Nursing Homes
- o "**Number of People**": Required when the following load profile is selected: Office Building and Student Housing
- o "**Number of Full meals served**": Required when the following load profiles are selected: Food Service (full meals), Food Service (fast food). Refers to the average number of full meals served per day.
- o "**Number of Students**": Required when the following load profiles are selected: Elementary Schools (Year round operation), Elementary Schools (10 month operation), Junior High Schools (Year round operation), Junior High Schools (10 month operation), Senior High Schools (Year round operation), Senior High Schools (10 month operation)
- o "**Number of 10 lbs per washing machine**": Required when the following load profile is selected: Coin-op Laundries. The "10 lbs" refers to the throughput of laundry washed on average per day. For example, a laundry facility with 2000 pounds average throughput per day, enter 200.

- **"'Other' Load Profile":** When a building type is not listed in the Maximum GDP Guideline Table in Appendix D, Applicants must meter hourly actual hot water consumption, natural gas, electric, or propane consumption used for water heating as described in Section 6.3.2 and Appendix H of the CSI-Thermal Handbook. A Professional Engineer (P.E.) must use the metered data along with additional analysis and calculations to come up with a custom load profile to gather hourly hot water draw for one year. The load profile must show hourly hot water gallon demand for a typical year (8760 hours) and the status of the recirculation loop for each hour as outlined in the following example:

Table H1
Load Profile Data Example

Elementary Schools (10-month)		
Hour	Hot Water Draw Gallons/Hour	Recirculation Loop Pump Status 1=On: 0=Off
1	0.000	0
2	0.000	0
3	0.000	0
4	0.000	0
5	0.000	0
6	0.000	0
7	0.000	0
8	73.75	1
9	43.22	1
10	70.27	1
11	40.82	1
12	20.06	1
13	22.64	1
14	28.07	1
15	28.64	1
16	12.55	1
17	11.06	1
18	0.000	0
19	0.000	0
20	0.000	0
…8760	0.000	0

The load profile data must be uploaded to the calculator in a tab delimited format document using the template provided in Table H1. A GPD value must also be entered for system sizing verification.

To upload a load profile, go to Load profile data field and click on the Browse button, select the file that you want to upload and click Open. A custom load profile will be calculated using the uploaded data.

- "**Recirculation Loop**".
    - o If the building has an operational recirculation loop, check the box:
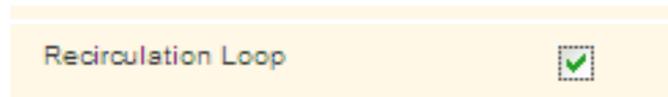
    - o If a recirculation loop is not present, leave the box unchecked:

- "**Set Point Temperature for Back-up Water Heater**": Enter the set point value in $^{\circ}$F (usually around 140 $^{\circ}$F).

- "**Set Point Temperature for delivered water**": This is the mixing valve set point temperature. Enter this value in $^{\circ}$F.

- **"Tracking"**: Click on the arrow to access the drop down list of tracking options.
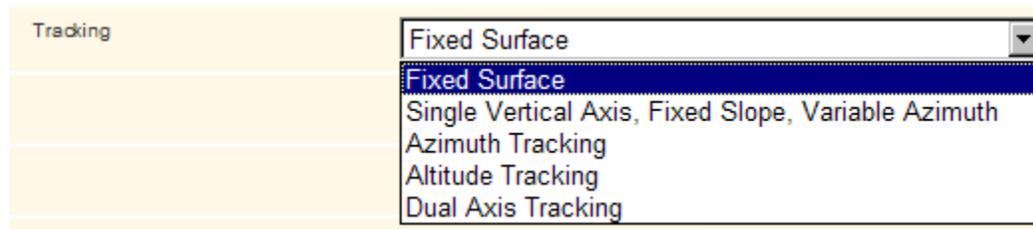
    - o **"Fixed Surface"** : Non-tracking collector with a fixed tilt and azimuth

    - o **"Single Verticle Axis, Fixed Slope, Variable Azimuth"**: Collector rotating on a verticle axis with a fixed tilt

    - o **"Azimuth Tracking"**: Collector tracking on a single axis oriented north to south. Collectors track east to west throughout the day

    - o **"Altitude Tracking"**: Collector tracking on a single axis oriented east to west. Collectors track the altitude of the sun in the sky throughout the day

- o **"Dual Axis Tracking"**: Collector traking on a dual axis. Collectors track the location of the sun in the sky througout the day (altitude and azimuth)

- "**Array Tilt**":   Enter the degree tilt from horizontal of the collector array.

- "**Array Azimuth**": Enter the <u>True Azimuth</u>.   True South is 180 degrees. To find True Azimuth in California add the magnetic variation to the magnetic compass reading of the collector array (13 degrees in Southern California, 15 degrees in Northern California).

- "**Average Annual Access**": Enter the integer percent for the average annual solar access to the collector array between the hours of 10am and 3pm. Use a shade analysis device to determine this value.

- "**Project Name**": Enter the project name and reservation ID (if available). This is used for your reference and will be included on the results email. This input field only applies to the public version of the calculator.

- "**Email Address**": Enter your email address. This input field only applies to the public version of the calculator..

When using the Public Calculator, remember to click on the Submit for Calculation button to initiate the request. This process typically takes about 15 minutes to complete, but may take longer if the system is processing many requests or the complexity of the proposed system. You will receive an email when your results are ready.

4. Getting Started

As you start using the calculator, there are a few things to keep in mind:

- Please allow time for your results to be returned; results may take up to 24 hours.

- Input fields are validated against the program eligibility requirements.

- Please contact your local Program Administrator for program questions. Contact information is listed at www.gosolarcalifornia.org/solarwater

- If you experience technical difficulties please contact support at <u>support@csithermal.com</u> or 888-323-3133.

5. Assumptions

- **Collector Fluid**:

    - 40% propylene glycol for all systems requiring an anti-freeze solution
    - water for drainback systems
    - water for indirect forced circulation systems with water

    Fluid properties are constant during the simulation and were based on a 40 C (104 F) average fluid temperature.

- **Weather**:

California climate zone data in Energy+ format will be used to drive the annual simulations. The wind speed required by the TRNSYS external pipe models and un-glazed solar collector models will be reduced to 30% of the value from the data file to account for local obstructions and near-surface effects. Solar shading of the collector surface is not accounted for in the TRNSYS simulations (but it easily could be) but rather used to provide a linear multiplier on the calculated rebate (calculated in the web tool).   The weather data is provided on an hourly basis and the TRNSYS program interpolates the data for us in its sub-hourly calculations (currently set to 1-minute timesteps).

- **Environment Temperature:**

The environment temperature for heat loss calculations for the storage tanks and tank/HX piping is assumed be that of semi-conditioned space.   The temperature of semi-conditioned space is defined to be 1/3 of the temperature difference from the ambient temperature to 72 F:

$$T_{environment} = T_{ambient} + (72 \text{ F} - T_{ambient})/3$$

- **Flat Plate and Evacuated Tube Solar Collectors**:

    - Parameters provided by the user selection of an OG100 solar thermal collector from the web site:
        - Gross collector area
        - collector intercept efficiency,
        - collector 1st- order loss coefficient and 2nd-order loss coefficients
        - as-tested flow rate
        -
        - 1st-order and 2nd-order incidence angle modifiers coefficients for flat plate collectors

- 1st-order and 2nd-order transverse incidence angle modifiers coefficients and 1st-order and 2nd-order longitudinal incidence angle modifiers coefficients for evacuated tube solar collectors.

- o Parameters provided by the user from the web site:
  - # of collector modules
  - # of panels in series per parallel flow path
  - Collector tracking method
  - Slope of collector surface (0=horizontal, 90=vertical)
  - Azimuth of collector surface (180=south,270=west, 0=north, 90=east)
  -

- o Assumed parameters:
  - Thermal capacitance of the solar collectors is set to 10 kJ/m2.K
  - 50 thermal nodes (isothermal temperature section) per module along the flow path

- **Concentrating Collectors**:

  - o Parameters provided by the user selection of an OG100 solar thermal collector from the web site:
    - collector aperture area
    - collector efficiency factor
    - incident angle modifier for diffuse radiation
    - longitudinal incident angle modifier constant
    - transverse incident angle modifier constant
    - heat loss coefficient
    - temperature dependence of the heat loss coefficient
    - wind speed dependence of the heat loss coefficient
    - sky temperature loss coefficient
    - effective thermal capacity
    - wind dependence of zero loss efficiency
    - test flow rate

  - o Parameters provided by the user from the web site:
    - # of collector modules
    - # of panels in series per parallel flow path
    - Collector tracking method
    - Slope of collector surface (0=horizontal, 90=vertical)
    - Azimuth of collector surface (180=south,270=west, 0=north, 90=east)

- o Assumed parameters:
    - ▪ Thermal capacitance of the solar collectors is set to 10 kJ/m2.K
    - ▪ 50 thermal nodes (isothermal temperature section) per module along the flow path

- **Collector Piping**:

Assumed parameters:

- o All pipes in the model are assumed to be standard size Type L copper pipes sized to maintain 4'/second or less fluid velocity at peak flow conditions; up to a 2" nominal size. The inner and outer diameters for these commonly used copper pipes are listed below.

Nominal Size	Outer diameter	Inner diameter
3/8"	0.500"	0.430"
1/2"	0.625"	0.545"
5/8"	0.750"	0.668"
3/4"	0.875"	0.785"
1"	1.125"	1.025"
1 ¼ "	1.375"	1.265"
1 ½ "	1.625"	1.505"
2"	2.125"	1.985"

Beyond 2 inches, the inner diameter of the pipes are ideally sized to maintain the 4'/second criteria and the outer diameter is calculated based upon the ratio of the outer diameter to the inner diameter for the nominal 2" Type L copper pipe.

- o The total length of the collector loop piping (from the collector to the heat exchanger and back for indirect systems and from the collector to the tank and back for direct systems) is calculated as:
  Total Length = 50' + 5' * Number of Collector Modules

  This length is divided equally amongst the collector supply and return lines.

- o All collector loop pipes are assumed to be insulated with ¾" pipe insulation with a thermal conductivity of 0.04 W/m.K (similar properties to an Aerogel-like material).
- o Internal and external fluid convection resistances are accounted for in the model.
- o Pipes have a temperature distribution along the flow direction (10 nodes per pipe) with the amount of stratification set from an earlier analysis that looked at simulation speed versus accuracy.

- Collector pipes are assumed to be located outdoors and are exposed to the ambient temperature and reduced ambient wind speed for convective losses with long-wave radiation losses (emissivity=0.9) calculated based upon the sky temperature.

- **Collector Pump**:

Assumed parameters:

- Collector-side flow rate is set at 1 gallon per minute through each collector except for concentrating collectors where it is set to the test flow rate. The total collector loop flow rate is then:
  - Gallons per Minute = Collector flow rate * # Collector Modules / # Collectors in Series per Parallel Loop
- Pump power assumed to be a linear function of flow rate and set at 15 Watts/gpm.
- The pump is assumed to have a motor efficiency of 90% and an overall efficiency of 60%.

- **External Heat Exchanger (External HX Systems Only)**:

Assumed parameters:

- The external heat exchanger will be modeled as a constant-effectiveness heat exchanger with an effectiveness of 0.4 for all double-wall cases (separation of glycol and water).
- The external heat exchanger will be modeled as a constant-effectiveness heat exchanger with an effectiveness of 0.5 for all single-wall cases (separation of water and water).
- The heat exchanger has no thermal losses.
- The effectiveness of the heat exchanger does not change with time (no fouling).

- **Tank/HX Pump (External HX Systems Only)**:

Assumed parameters:

- Tank-side volumetric flow rate is set equal to the collector-side volumetric flow rate.
- Pump power assumed to be a linear function of flow rate and set at 15 Watts/gpm.
- The pump is assumed to have a motor efficiency of 90% and an overall efficiency of 60%.

- **Tank/HX Piping (External HX Systems Only)**:

Assumed parameters:

- All pipes in the model are assumed to be standard size Type L copper pipes sized to maintain 4'/second or less fluid velocity at peak flow conditions; up to a 2" nominal size. The inner and outer diameters for these commonly used copper pipes are listed below.

Nominal Size	Outer diameter	Inner diameter
3/8"	0.500"	0.430"
1/2"	0.625"	0.545"
5/8"	0.750"	0.668"
3/4"	0.875"	0.785"
1"	1.125"	1.025"
1 ¼ "	1.375"	1.265"
1 ½ "	1.625"	1.505"
2"	2.125"	1.985"

- Beyond 2 inches, the inner diameter of the pipes are ideally sized to maintain the 4'/second criteria and the outer diameter is calculated based upon the ratio of the outer diameter to the inner diameter for the nominal 2" Type L copper pipe.
- The total length of the tank loop piping (from the tank to the heat exchanger and back) is set to 40' with the length divided equally amongst the supply and return lines.
- All tank loop pipes are assumed to be insulated with ¾" pipe insulation with a thermal conductivity of 0.04 W/m.K (similar properties to an Aerogel-like material).
- Internal and external fluid convection resistances are accounted for in the model.
- Pipes have a temperature distribution along the flow direction (10 nodes per pipe) with the amount of stratification set from an earlier analysis that looked at simulation speed versus accuracy.
- Tank loop pipes are assumed to be located within semi-conditioned space and are exposed to a prescribed environment temperature for calculation of both the convective and long-wave radiation losses (emissivity=0.9). The pipes are assumed to be in stagnant air (no air velocity) with a horizontal orientation for natural convection heat transfer calculations.

- **Immersed Load Side HX (Drainback 2-tank systems only)**

Assumed Parameters:

- Surface area of HX to unpressurized storage tank volume = 0.1 sf. ft. per gallon.

- **Solar Controller**:

Assumed parameters:

- o The controller used to turn on and off the collector-side pumps is assumed to be a differential controller with a 20 F turn-on deadband and a 5 F turn-off deadband. The controller is sensing the collector fluid outlet temperature and a storage tank fluid temperature located near the bottom 1/3 of the storage tank (node 8 of 10 in the solar tank).
- o The controller does not allow short cycling of the pumps, enforcing a 5 minute minimum run-time and 5-minute minimum off-time condition.
- o The controller will also check the temperature of the storage tank; ceasing pump operation if the storage tank reaches 170 F. The pump will only then be enabled when the storage tank temperature falls below 160 F.
- o The controller also watches the collector fluid temperature and will turn on the pumps if the collector temperature reaches 300 F; provided the top of the solar storage tank has not reached the 175 safety limit. The pumps will shut off when the collector temperature falls below 280 F or if the top of the storage tank reaches 170 F.

- **Drainback Tank (If Present)**:

Assumed parameters:

- o The volume of the drainback tank is set from a linear function of the number of collector modules and is set by: Gallons = 10 + 2 *Modules
- o The heat loss coefficient for the drainback tank is set to 3 kJ/h.m2.K
- o The drainback tank is assumed to be rectangular in shape with the height being 2/3 the length of the sides.
- o The drainback tank is assumed to be fully mixed at all times.
- o The drainback tank is assumed to be located within semi-conditioned space.

- **Solar Storage Tank**:

- o Parameters provided by the user from the web site for the storage tank:

    - Total nominal volume of primary storage (gallons)
    - Number of identical primary solar storage tanks
    - Type of auxiliary heat input (electric, electric tankless, gas, gas tankless, propane, or propane tankless)
    - Nameplate auxiliary heating input rate for 1-tank systems

The primary (solar) storage tank for this project, for systems with immersed heat exchangers, is based loosely on the popular 120 gallon version of the Bradford-White PowerStor storage tank (immersed heat exchanger). Detailed model calibrations have been done in TRNSYS in order to set the immersed heat exchanger free convection parameters for this storage tank such that the results from the model closely match the published I=B=R ratings for the tank.

Assumed parameters:

- o The fluid volume is 90% of the user-provided nominal storage volume
- o The solar storage tank will be modeled as a single storage tank with parameters chosen to mimic a user-specified number of storage tanks connected in parallel.
- o The tanks are assumed to be located within semi-conditioned space.
- o Stratification is modeled in the storage tank through the use of 10 uniform-temperature layers (nodes) in the storage tank.
- o The overall heat loss coefficient of each solar storage tank is calculated using an algorithm provided by ASHRAE Standard 90.1-2007, Addendum k, Table 7.8.
  - For solar storage tanks with electric backup and having less than or equal to 12 kW of rated heating capacity, the energy factor for the tank is calculated as 0.97-0.00132*Gallons. From the calculated energy factor, the heat loss coefficient of the storage tank can be derived.
  - For solar storage tanks with electric backup and having greater than 12 kW of rated heating capacity, the heat loss in BTU/h from the storage tank at a water-to-air temperature difference of 70 F is calculated as 20+35*√Gallons. From the calculated heat loss, the heat loss coefficient of the storage tank can be determined.
  - For solar storage tanks with gas or propane back-up, the assumption is made that the heating system is external to the storage tank (gas or propane boiler with an immersed heat exchanger etc.). The storage tank can then be described as an un-fired storage tank with a corresponding level of insulation of R12.5. The losses for the modeled tank are doubled from the theoretical R12.5 insulation to account for thermal shorts and other tank heat loss as done in the SRCC OG300 standard.
  - For solar storage tanks in preheat systems (no auxiliary heat input), the assumption is made that the tank is an un-fired storage tank with a corresponding level of insulation of R12.5. The losses for the modeled tank are doubled from the theoretical R12.5 insulation to account for thermal shorts and other tank heat loss as done in the SRCC OG300 standard.

The total heat loss coefficient for all of the solar storage tanks is then calculated and a single storage tank, with the same height-to-diameter ratio, a volume equal to the volume of all the individual storage tanks, and an effective heat loss coefficient that

provided the same total heat loss coefficient as the sum of the individual tanks, is then modeled.

- o The ratio of the height of the solar storage tank to the diameter of the solar storage tank is assumed to be that of the 120 gallon storage tank; 2.608:1
- o In all systems where water is heated by the collector loop and returned to the storage tank, the heated water is assumed to enter at the very top of the storage tank (node 1) unless the primary storage tank contains an auxiliary heating system (electric or gas but not gas tankless). In the case where the solar storage contains an auxiliary heating system, the heated water enters the tank just below the heated section of the storage tank (node 4). The return water to the collector loop is assumed to occur from the bottom of the solar storage tank (node 10).
- o The mains water enters at the very bottom of the storage tank (node 10) and exits at the very top of the storage tank (node 1). Cold water inlets through a diptube are not considered in this analysis.

If the system configuration in question has an immersed heat exchanger then the following assumptions apply:

- o Immersed heat exchangers separating glycol from potable water are assumed to be double-wall heat exchangers while immersed heat exchangers separating water from potable water are assumed to be single-wall heat exchangers.
- o The inner diameter of the coiled tube heat exchanger piping is set to 0.03306 meters and the outside diameter of the coiled tube heat exchanger is set to 0.03810 meters. These values are based on published data for the Powerstor series storage tanks.
- o The length of each heat exchanger coiled tube is 11.02 meters (this value is based on published data for the Powerstor series storage tanks)
- o The thermal conductivity of the heat exchanger material is assumed to be 50 kJ/h.m.K for double-wall immersed heat exchangers and 150 kJ/h.m.K for single-wall immersed heat exchangers. These values were used in the calibration of the tank model to published data for the Powerstor series tanks which allowed us to set the natural convection coefficients to best match the published performance data (different for single and double-wall cases).
- o The diameter of the coiled tube heat exchanger was set to 0.3508 meters with a tube-to-tube spacing of 0.05588 meters.
- o The number of identical coiled tube heat exchangers in the storage tank is calculated based on the ratio of the total user-specified solar storage tank volume to the volume of the 120 gallon base tank (with a non-integer number of heat exchangers possible).
- o The coiled tube heat exchanger is located near the bottom of the storage tank with the uppermost sections in node 6 (heated fluid entrance) and the lowermost sections in node 9 (heated fluid exit).

- When the heat exchanger is charging the solar storage tank, a convective mixing loop is assumed to occur with heated fluid rising from the heat exchanger to the top of the storage tank (or just below the auxiliary heated section of the tank), turning, and returning to the bottom of the storage tank. The mass flow rate of this convective loop is strictly a function of the volume of the fluid that is unheated by the auxiliary heater; 150 kg/h for tanks without auxiliary heat and 100 kg/h for tanks with the upper section heated by auxiliary. These values were obtained by matching TRNSYS simulation models to measured SDHW performance for tanks similar in construction to the Powerstor series of tanks. These convective mixing flow rates are then multiplied by the ratio of the total solar storage volume to 120 gallons.

If the system configuration in question has an auxiliary heating system in the primary storage tank then the following assumptions apply:
- The upper 30% of the primary storage tank is assumed to be heated by auxiliary.
- The efficiency of the heating device is set by the type of device; 0.98 for electric systems and 0.82 for gas or propane systems.
- The capacity of the auxiliary heating device is provided by the user in the web tool.
- The capacity of the auxiliary heating device for the base system (comparison system) is calculated by doubling the rate of energy required to raise the maximum hourly hot water draw from the mains water temperature to the user-specified hot water auxiliary setpoint temperature.
- The setpoint of the auxiliary-heated section of the tank is provided by the user with an assumed 5 degree Fahrenheit deadband temperature difference for the controller.
- The thermal losses from the auxiliary heater to the environment, and from any exposed pipes in the auxiliary heating system, are ignored.
- The small parasitic pump power (if any) associated with the auxiliary heating system is ignored.

- **Auxiliary Storage Tank (If Present)**:

Parameters provided by the user from the web site for the auxiliary storage tank:

- Nominal volume of auxiliary storage tank (gallons)
- Number of identical auxiliary storage tanks
- Type of auxiliary heat input (electric, gas, or gas tankless)
- Nameplate auxiliary heating input rate for back-up system

The auxiliary storage tank for this project is also based loosely on the 120 gallon version of the Bradford-White PowerStor storage tank.

Assumed parameters:

- o The fluid volume is 90% of the user-provided nominal storage volume
- o The auxiliary storage tank will be modeled as a single storage tank with parameters chosen to mimic a user-specified number of auxiliary storage tanks connected in parallel.
- o The tank is assumed to be located within semi-conditioned space.
- o Stratification is modeled in the storage tank through the use of 10 uniform-temperature layers (nodes) in the storage tank.
- o The overall heat loss coefficient of each storage tank is calculated using an algorithm provided by ASHRAE Standard 90.1-2007, Addendum k, Table 7.8.
    - For storage tanks with electric backup and having less than or equal to 12 kW of rated heating capacity, the energy factor for the tank is calculated as 0.97-0.00132*Gallons. From the calculated energy factor, the heat loss coefficient of the storage tank can be derived.
    - For storage tanks with electric backup and having greater than 12 kW of rated heating capacity, the heat loss in BTU/h from the storage tank at a water-to-air temperature difference of 70 F is calculated as 20+35*√Gallons
    - For storage tanks with gas or propane back-up, the assumption is made that the heating system is external to the storage tank (gas or propane boiler with an immersed heat exchanger etc.). The storage tank can then be described as an un-fired storage tank with a corresponding level of insulation of R12.5. The losses for the modeled tank are doubled from the theoretical R12.5 insulation to account for thermal shorts and other tank heat loss as done in the SRCC OG300 standard.

    The total heat loss coefficient for all of the auxiliary storage tanks is then calculated and a single storage tank, with the same height-to-diameter ratio, a volume equal to the volume of all the individual storage tanks, and an effective heat loss coefficient that provided the same total heat loss coefficient as the sum of the individual tanks, is then modeled.

- o The ratio of the height of the auxiliary storage tank to the diameter of the auxiliary storage tank is assumed to be that of the 120 gallon storage tank; 2.608:1
- o The heated water from the storage tank enters at the very bottom of the storage tank (node 10) and exits at the very top of the storage tank (node 1). A diptube is not considered in this analysis.
- o The return water from the recirculation loop (if enabled) enters at the very bottom of the storage tank (node 10) and exits at the very top of the storage tank (node 1).
- o If the auxiliary storage tank has an electric heating system then the tank is heated by two immersed electrical heating elements. The uppermost heating element, and its

associated thermostat, is situated such that the upper 30% of the auxiliary storage tank is heated (node 3). The lower heating element, and its associated thermostat, is situated such that the upper 70% of the auxiliary storage tank can be heated by this heating element (node 7). The upper heating element is controlled to maintain the temperature at the user-specified set point temperature with a temperature deadband of 15 F. The lower heating element is controlled to maintain the temperature at the user-specified set point temperature with a temperature deadband of 5 F. The heating elements are controlled in a master/slave arrangement where the lower heating element is only enabled if the upper heating thermostat is satisfied. The efficiency of the electric heating devices is 0.98. The capacity of each auxiliary heating device is calculated by halving the user-specified auxiliary heating rate. The capacity of each auxiliary heating device in the base system is calculated by doubling the rate of energy required to raise the maximum hourly hot water draw from the mains water temperature to the user-specified hot water auxiliary setpoint temperature.

- o If the auxiliary storage tank has a gas or propane heating system then the entire tank is heated from the bottom (node 10) by a gas or propane heat source with an efficiency of 0.82. The thermostat for the heating system is located near the bottom of the tank (node 9) and is controlled to maintain the user-specified temperature setpoint with a temperature deadband of 5 F. The capacity of the auxiliary heating device is then simply the user-specified auxiliary heating rate. The capacity of the auxiliary heating device in the base system is calculated by doubling the rate of energy required to raise the maximum hourly hot water draw from the mains water temperature to the user-specified hot water auxiliary setpoint temperature.

- o If the user-entered auxiliary heat capacity is less than the capacity required to meet the maximum peak load, then the capacity required to meet the maximum peak load is used. If the user-entered auxiliary heat capacity is greater than the capacity required to meet twice the maximum peak load, then the capacity required to meet twice the maximum peak load is used.

- **Tankless Gas Water Heater (If Present)**:

Assumed parameters:

- o The tankless water heater in the solar system has a user-defined capacity and the tankless water heater in the base system has an unlimited capacity to meet the hot water demand.
- o The capacity is perfectly adjustable such that device exactly meets the temperature demand.
- o The efficiency of the tankless water heater is 0.82 for gas or propane tankless systems and 0.98 for electric tankless systems.

- o No thermal losses or parasitic energy consumption is modeled.
- o The setpoint temperature for the tankless system is set to the desired water delivery temperature (a user-specified value).

- **Tempering Control**:

The system is assumed to have two separate tempering valves which restrict the delivery temperature of the heated water by bypassing part of the mains water stream around the storage tank and mixing it back in with the heated water coming from the tank. The first tempering valve (only for a two tank system) limits the temperature of the water leaving the solar storage tank on the load-side to 160 F (limit on temperature entering the auxiliary storage tank). The second tempering valve limits the temperature of the water being delivered to the load to the user-specified hot water delivery temperature.

- **DHW Loads**:

Parameters provided by the user from the web site:

- o Daily hot water consumption (gallons)
- o DHW Profile

The table at the end of this document lists the hourly fraction of daily hot water consumption for each of the draw profiles available to the user.

Assumed parameters:

- o The minimum flow rate at any time is assumed to be at 0.5 gallons per minute. For example if at 2 am the draw schedule and draw volume dictate that the total amount of hot water drawn over the hour is 2 gallons, then the system will deliver 0.5 gpm of heated water for 4 minutes at the beginning of the hour and sit idle for the remainder of the hour (as opposed to drawing 2 gallons per hour for the entire hour). This is done to avoid the unrealistic continuous trickle of hot water over an hour which can occur during low-draw periods.
- o The water entering the solar storage tank is assumed to be at mains water temperature.
- o The main water temperature is based upon an algorithm developed by NREL based on measured data and is a function of the time of year and the monthly average ambient air temperatures for the location. This mains water temperature profile is on average about 6 degrees Fahrenheit warmer than the algorithm used in the OG-300 rating program (F-Chart method). This will significantly alter the results when compared with standard OG-300 systems.

- **Hot Water Delivery Pipes**:

Assumed parameters:

- o All hot water pipes in the model are assumed to be standard size Type L copper pipes sized to maintain 4'/second or less fluid velocity at peak flow conditions; up to a 2" nominal size. The inner and outer diameters for these commonly used copper pipes are listed below.

Nominal Size	Outer diameter	Inner diameter
3/8"	0.500"	0.430"
1/2"	0.625"	0.545"
5/8"	0.750"	0.668"
3/4"	0.875"	0.785"
1"	1.125"	1.025"
1 ¼ "	1.375"	1.265"
1 ½ "	1.625"	1.505"
2"	2.125"	1.985"

Beyond 2 inches, the inner diameter of the pipes are ideally sized to maintain the 4'/second criteria and the outer diameter is calculated based upon the ratio of the outer diameter to the inner diameter for the nominal 2" Type L copper pipe.

- o The DHW load is assumed to be removed at two points in the system; one-half of the load is removed at the half-way point down the pipe run and the remaining load is removed at the end of the pipe run.
- o The length of the hot water pipe from the storage/heating system to the first load point is calculated as: Pipe Length = 25' + 0.05' * Gallons of Hot Water Usage per Day
- o The length of the hot water pipe from the first load point to the second load point is calculated as: Pipe Length = 25' + 0.05' * Gallons of Hot Water Usage per Day
- o All DHW pipes are assumed to be insulated with ¾" pipe insulation with a thermal conductivity of 0.04 W/m.K (similar properties to an Aerogel-like material).
- o Internal and external fluid convection resistances are accounted for in the model.
- o Pipes have a temperature distribution along the flow direction (10 nodes per pipe) with the amount of stratification set from an earlier analysis that looked at simulation speed versus accuracy.
- o All DHW pipes are assumed to be located within semi-conditioned space and are exposed to a prescribed environment temperature for calculation of both the convective and long-wave radiation losses (emissivity=0.9). The pipes are assumed to

be in stagnant air (no air velocity) with a horizontal orientation for natural convection heat transfer calculations.

- **Recirculation Pump (If Present)**:

Assumed parameters:

- o The constant-speed recirculation pump power will operate 24 hours a day, 7 days a week with a motor efficiency of 90% and an overall pump efficiency of 60%.
- o The flow rate for the circulation loop pump was set from a linear relationship assumed between a typical value for a small system and a typical value for a large system. The flow rate is calculated as:
- o Pump Flow (gpm) = 0.5 + Gallons of Hot Water Usage per Day / 1000
- o The power for the circulation loop pump was set from a linear relationship assumed between a typical value for a small system and a typical value for a large system. The pump power draw is calculated as:

    Pump Power (hp) = 1/25 + Gallons of Hot Water Usage per Day / 50,000

- **Recirculation Loop (If Present)**:

Assumed parameters:

- o The length of the recirculation loop pipe from the end of the supply line back to the heating device is equal to the length of the pipe run from the heating device to the second (and final) load draw point:
- o Pipe Length = 50' + 0.1' * Gallons of Hot Water Usage per Day
- o The diameter of the recirculation loop piping is assumed to be the same as the hot water supply pipes.
- o All recirculation loop pipes are assumed to be insulated with ¾" pipe insulation with a thermal conductivity of 0.04 W/m.K (similar properties to an Aerogel-like material).
- o Internal and external fluid convection resistances are accounted for in the model.
- o Pipes have a temperature distribution along the flow direction (10 nodes per pipe) with the amount of stratification set from an earlier analysis that looked at simulation speed versus accuracy.
- o All recirculation loop pipes are assumed to be located within semi-conditioned space and are exposed to a prescribed environment temperature for calculation of both the convective and long-wave radiation losses (emissivity=0.9). The pipes are assumed to be in stagnant air (no air velocity) with a horizontal orientation for natural convection heat transfer calculations.
- o For single-tank systems, the recirculation fluid enters the primary storage tank at the height of the auxiliary heat inlet to the tank (node 3) and exits at the top of the storage

tank such that the remainder of the tank is not heated by the auxiliary energy source and this energy is not sent out into the collector loop.

- o For two-tank systems, the recirculated fluid enters the bottom of the auxiliary storage tank (node 10) and exits at the top of the storage tank.
- o For gas or propane tankless water heater systems, the recirculated fluid is returned to the inlet of the tankless water heater and mixed with heated water from the primary storage tank.

- **Base DHW System**:

    Assumed parameters:

    - o The base water heating system is driven by the same water draw profile and mains water temperature as the SDHW system.
    - o When compared against single-tank SDHW systems with integral auxiliary heat, the base DHW storage tank will have the same volume, height, and heat loss coefficients as the primary solar storage tank.
    - o When compared against two-tank SDHW systems, the base DHW storage tank will have the same volume, height, and heat loss coefficients as the auxiliary solar storage tank.
    - o When compared against tankless SDHW systems, there will be NO base DHW storage tank.
    - o The base DHW tank, or tankless water heater, is assumed to be located within semi-conditioned space.
    - o Stratification is modeled in the base DHW storage tank through the use of 10 uniform-temperature layers (nodes) in the storage tank.
    - o The mains water enters at the very bottom of the storage tank (node 10) and exits at the very top of the storage tank (node 1). A diptube is not considered in this analysis. For tankless systems, the mains water mixes with any recirculated water before entering the tankless water heater.
    - o For DHW systems with a storage tank, the return water from the recirculation loop (if enabled) enters at the very bottom of the storage tank and exits at the very top of the storage tank.
    - o In electric systems, the base electric tank is heated by two immersed electrical heating elements. The uppermost heating element, and its associated thermostat, is situated such that the upper 30% of the auxiliary storage tank is heated (node 3). The lower heating element, and its associated thermostat, is situated such that the upper 70% of the auxiliary storage tank can be heated by this heating element (node 7). The upper heating element is controlled to maintain the temperature at the user-specified auxiliary set point temperature with a temperature deadband of 15 F. The lower heating element is controlled to maintain the temperature at the user-specified auxiliary set point temperature with a temperature deadband of 5 F. The heating

elements are controlled in a master/slave arrangement where the lower heating element is only enabled if the upper heating thermostat is satisfied. The efficiency of the electric heating devices is 0.98. The capacity of each auxiliary heating device is calculated by doubling the rate of energy required to raise the maximum hourly hot water draw from the mains water temperature to the user-specified hot water auxiliary setpoint temperature.

- o In gas or propane systems, the entire DHW tank is heated from the bottom (node 10) by a gas heat source with an efficiency of 0.82. The thermostat for the heating system is located near the bottom of the tank (node 9) and is controlled to maintain the user-specified auxiliary temperature setpoint with a temperature deadband of 5 F. The capacity of the auxiliary heating device is calculated by doubling the rate of energy required to raise the maximum hourly hot water draw from the mains water temperature to the user-specified hot water auxiliary setpoint temperature.
- o All assumptions surrounding the tankless water heater for the SDHW system will apply here as well (thermal losses, efficiency, capacity, heat loss etc.)
- o The base DHW system utilizes a tempering valve to limit the temperature of the water delivered to the load (user-specified delivery temperature).
- o The base DHW system utilizes exactly the same DHW pipes and recirculation system as the SDHW system.

- **Calculation of Savings**:

The TRNSYS model calculates the energy savings of the SDHW system as compared to the DHW system in the following manner:

- o Auxiliary Energy Savings = Annual Auxiliary Energy Used by the Base DHW System - Annual Auxiliary Energy Used by the SDHW System
- o Parasitic Energy Savings = Annual Parasitic Energy Used by the Base DHW System - Annual Parasitic Energy Used by the SDHW System
- o Delivered Energy Savings = (Annual Energy Delivered to the Load by the SDHW System - Annual Energy Delivered to the Load by the DHW System) / Efficiency of Auxiliary Heater
- o Total Annual SDHW Savings = Auxiliary Energy Savings + Parasitic Energy Savings + Delivered Energy Savings

- **Load Profiles:** All usage profiles except Laundry come from ASHRAE HVAC Applications 2007 section 49.18, figure 24. The Laundry usage profile comes from a Federal Technology Alert on Commercial Heat Pump Water Heaters found at: http://www1.eere.energy.gov/femp/pdfs/FTA_HPWH.pdf

  Refer to *Attachment A: Multifamily/Commercial OG-100 Incentive Calculator Load Profiles* for the load profiles for each building type.

6. Summary of Outputs

Once the OG-100 incentive calculation is complete, the following outputs will be provided to the requestor:

- **Estimated annual displaced energy:** therms for systems with natural gas or propane backup water heaters; kWh for systems with electric backup water heaters.

- **Estimated incentive amount:** based on the estimated annual displaced energy, using the current incentive step level rate. For propane backup water heaters, annual therms saved shall be converted to kWh for incentive calculation.