CALIFORNIA SOLAR INITIATIVE (CSI) THERMAL IMPACT REPORT

Final

Submitted to:
California Public Utilities Commission

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June 21, 2018

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EXECUTIVE SUMMARY

This report presents a comprehensive impact evaluation of the statewide California Solar Initiative Thermal (CSI-T) Program. Established in 2010,[1] the CSI-T program has provided incentives for the installation of solar water heating (SWH) systems in single family, multifamily, commercial, and commercial pool facilities across the state. The program has reported a natural gas displacement of over 4.2 million therms, an electricity displacement of 931 MWh, and has over 4,300 systems statewide between the evaluation period of 2010 and 2016.

The CSI-T program was designed to promote the installation of SWH systems in the Pacific Gas & Electric (PG&E), Southern California Edison Company (SCE), San Diego Gas and Electric (SDG&E), and Southern California Gas Company (SCG) regions. The Center for Sustainable Energy (CSE) acts as the program administrator for the CSI-T program in the SDG&E region, while the other three utilities act as their own program administrators. The four goals of the program are: [2]

- Significantly increase the size of the SWH market through achieving the displacement of 463 million therms and 275.7 million kWh over the 25-year life of the systems through natural-gas and electric-displacing SWH systems, and achieve an expansion of the market for other solar thermal technologies in addition to SWH through the installation of 200,000 solar thermal systems in homes and businesses;
- Support reductions in the cost of SWH systems of at least 16% through a program that increases market size and encourages cost reductions through market efficiency and innovation;
- Increase consumer confidence and understanding of SWH technology and their benefits;
- Engage in market facilitation activities to reduce market barriers to SWH adoption, such as high permitting costs, lack of access to information, and lack of trained installers.

ES.1 EVALUATION OVERVIEW

The purpose of this evaluation is to assess the impact of the program on electricity and natural gas demand, assess the number of systems installed and the greenhouse gas emission reductions achieved through these installations. Unless otherwise stated, the evaluation team reports first-year, therm-equivalent savings for all systems, meaning that the savings for electric- or propane-backup SWH systems

[1] CPUC Decision 10-01-022. January 21st, 2010. http://docs.cpuc.ca.gov/PUBLISHED/FINAL_DECISION/112748.htm.

[2] As noted in the CSI Thermal Program Handbook. http://www.gosolarcalifornia.ca.gov/documents/CSI-Thermal_Handbook.pdf

are converted from kWh to therms, as over 90% of the systems installed utilized natural-gas backup auxiliary heating.

Part of evaluation team's responsibility is to develop findings and recommendations to improve the impacts of future programs. This requires comparison of the program accomplishments reported by the PAs (*expected results)*[3] to the evaluation findings (*actual results)*. The difference between these two analyses are described here:

- Expected Results: These are the results of the analysis performed on the Public Export of the CSI Thermal incentive application database. Expected system performance data reported in the public database are the result of the CSI Thermal Public Calculator, a tool for determining the appropriate incentive level based on a number of key inputs for a system application.[4] Here, the evaluation team looked at the overall population of CSI-T participants and the claimed savings by the program broken out by budget program, PA, and SWH equipment types. Cost trends over the years of the program were also analyzed.
- Actual Results: These are the findings based on the evaluation activities performed. These include developing energy savings impacts and program-level gross realization rates (GRRs),[5] as well as environmental and economic impacts.

The CSI-T impact evaluation focused on several main activities:

- Analysis of expected results including energy savings, cost trends, and breakouts by program and system types,
- Onsite data collection and solar thermal system metering,
- Cleaning and processing of the metered data,
- Simulation of system performance through the Transient System Simulation Tool (TRNSYS)[6] software package,

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3 These program accomplishments are reported in the CSI Thermal incentive application database. The public version of this can be downloaded from http://www.csithermalstats.org/download.html, and is the version used by the evaluation team for their analysis.

4 *See* https://www.csithermal.com/calculator/

5 GRRs are a metric to provide a comparison between actual and expected results and are defined as the ratio between the two. To develop program-level GRRs, the site-level results need to be weighted up to the population. More on this process can be found in Section 3: Evaluation Approach.

6 TRNSYS is produced by Thermal Energy System Specialists, LLC (TESS). This software is used as the simulation for the CSI-Thermal solar hot water expect savings calculations. http://www.trnsys.com/

- Site-specific savings calculations,
- Rolling up the site-specific savings to population level savings estimates.

In order to develop the actual results which, assess the energy impacts of the program, the evaluation team utilized both metered data and TRNSYS simulated performance data to create the final evaluated savings at a site-level. Metering equipment was installed on a sample of solar thermal systems to determine the amount of energy delivered to each system. To realize the amount of energy the solar thermal system saves, the team had to also understand how the baseline system would have operated. Because the evaluation team did not have first-hand knowledge how the baseline system operated prior to the installation of the solar thermal system, the evaluation team relied on the TRNSYS simulations to calculate the savings between the simulated solar thermal system and the simulated baseline system. From there, a relationship was observed, on a site-by-site basis, between the amount of solar energy delivered to the solar thermal system, and the amount of energy saved based between the simulated solar thermal and the simulated baseline system.

The simulated baseline system was designed to reflect what the typical conditions of a water heating system at a facility would be prior to the installation of the SWH system. Because the actual pre-SWH conditions at the facility is often unknown (as the system is often already removed), the team established the baseline system using standard water heating efficiencies and system configurations.

ES.2 PROGRAM FINDINGS – EXPECTED RESULTS

The first analysis step taken was to analyze the program tracking data with the purpose of understanding the installed projects, their costs, and the claimed savings. These findings from this analysis form the basis for the expected results, or the findings resulting from the analysis of the program participation rates and project installations. The first analysis allows the evaluation team to understand the assumptions that went into program planning and execution, and answer potential questions that include, but are not limited to;

- How are energy savings estimated for different SWH technologies?
- How much do these systems cost, and how has the cost changed over the course of the program?
- Where were the systems installed, and how much effort and budget were spent on the different budget programs and technology types?

Through this analysis, the evaluation team can provide more direct and actionable recommendations. These CSI-T program expected results findings through December 2016 are highlighted in the bullets below and show an overview of the CSI-T participant population and expected savings.

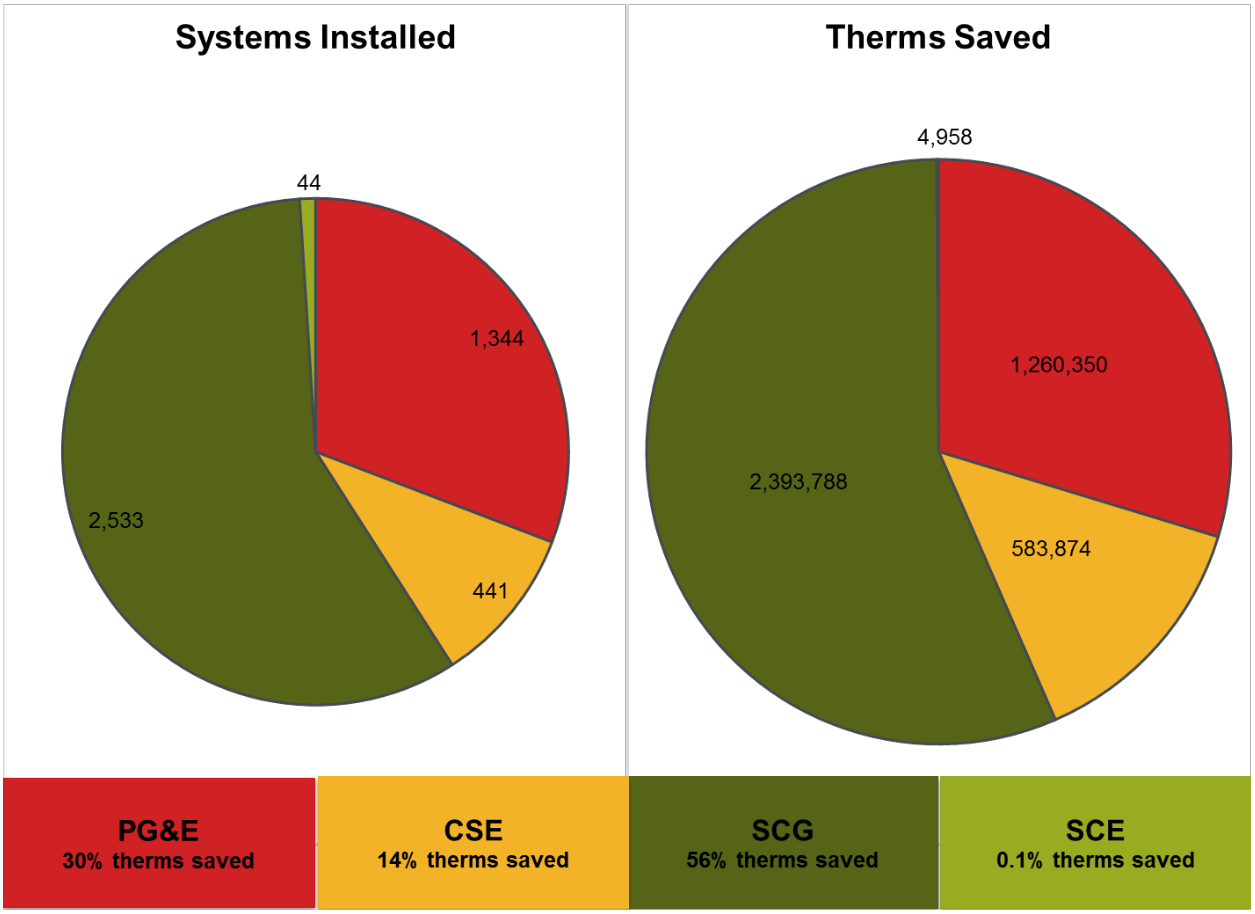
- Over **4,300** SWH system installations were installed.
- **4.2 million Therms** and **930 MWh** were expected to be saved.
- Commercial Pool budget program grew to almost **40%** of the total program's savings in just three years.
- Single-family Residential systems made up **50%** of the installations but only **6%** of the Therms saved.
- Cost of installation saw a decrease of **13%** since program inception.
- Natural Gas customers expected to see **$4.3 million** and Electric customers expected to see **$225k** in savings through the SWH systems. Commercial/Multifamily and Low Income Multifamily customers alone expected to see over **$3 million** in savings.

Figure ES-1 shows the system counts and expected therm-equivalent savings by program administrator, while Table ES-1 shows the total incentives paid. The expected savings for each program administrator are generally proportional to the number of projects rebated in each program administrator's service territory, along with the share of the total program incentives paid out. SCG makes up over 50% of the number of projects, expected savings, and the total incentives paid. PG&E follows, with a share of close to 1/3 of the projects.

TABLE ES-1: TOTAL INCENTIVES PAID

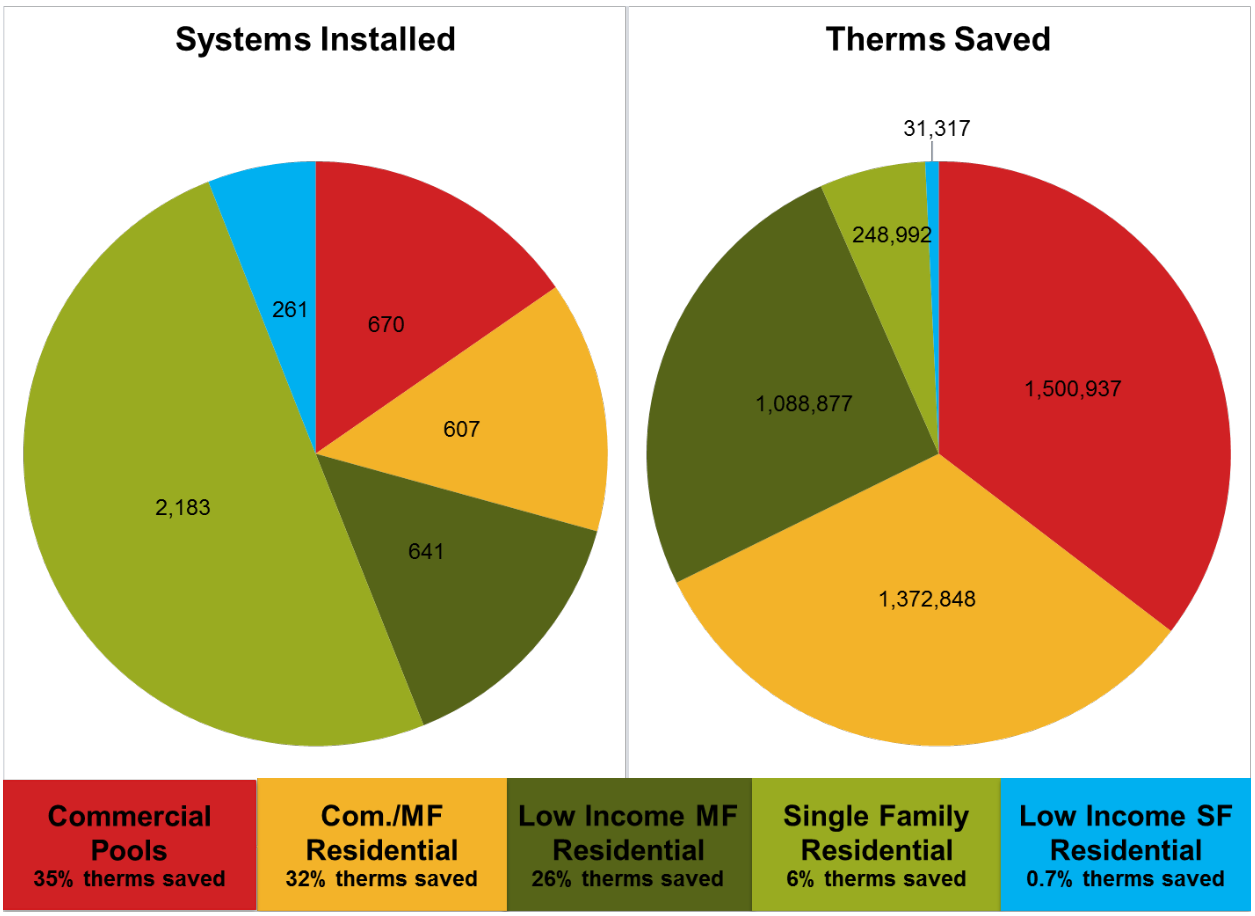
PA	Total Incentives Paid	Share of Incentives
PG&E	$20,707,125	33%
CSE	$7,835,352	13%
SCE	$64,081	0.001%
SCG	$33,930,411	54%
Total	**$62,536,969**	**100%**

FIGURE ES-1: SYSTEM INSTALLATIONS AND EXPECTED THERMS SAVED, BY PROGRAM ADMINISTRATOR



The CSI-T program categorizes projects into five budget programs; Commercial Pools, Commercial / Multifamily Residential, Low Income Multifamily Residential, Single Family Residential, and Low Income Single Family Residential. When comparing the same system installation and expected savings results by budget program, we see a different relationship between system counts and expected savings than we saw above in Figure ES-1. The left pie graph, below in Figure ES-2, shows that Single Family Residential systems make up the largest share of total installations (50%), but they only account for six percent of the total expected therms saved. Commercial Pools, Commercial/Multifamily Residential, and Low Income Multifamily Residential programs, however, each make up about 15% of the total installations each, but each account for between 26%-35% of the total therms saved.

FIGURE ES-2: SYSTEM INSTALLATIONS AND EXPECTED ANNUAL THERMS SAVED BY BUDGET PROGRAM



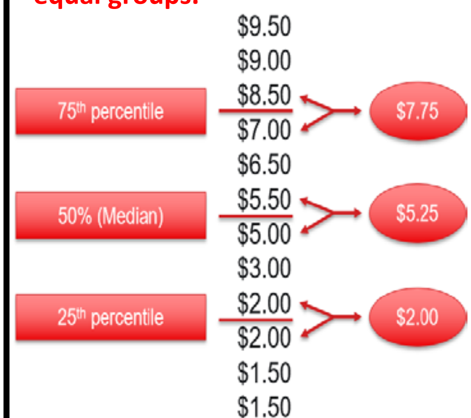
Cost Results

A second goal of the CSI-T program is to support reductions in the cost of solar thermal systems of at least 16 percent. Looking only at the overall project cost can be rather misleading, as different system types and different budget programs result in very different trends in $/therm. However, Indirect Forced Circulation (IFC)[7] systems made up well over 50% of all systems installed. This indicates that any overall program-wide trends in system costs are likely to driven by these systems, for both commercial/multifamily and single-family programs. Figure ES-3 depicts the statistics around all systems installed (except Commercial Pools), weighted by the expected savings, year-over-year. These include the mean, the 25th and the 75th percentile, and a trendline. These percentiles are a frequency distribution of the system costs for all installed systems. If all the system costs were ordered numerically in ascending order and then split into four equal groups, the 25th percentile (in green) displays a lower range of data between the 25th percentile and the mean. Similarly, the 75th percentile represents an upper range of data between the mean and the 75th percentile of the system costs. The sidebar to the right shows a clear example how to calculate percentiles. The mean represents the average system cost. This graphical representation shows the range of system costs for individual projects across the program. The blue trendline illustrates the downward trend in weighted costs per therm as the program progressed. This linear trend line was fitted to the average weighted cost of all systems and shows a 13% reduction in costs between 2010 and 2016, very close to the 16% goal, which represents a year-over-year trend of just under $1/therm.

CALCULATING PERCENTILES

Example:

12 costs ordered in ascending order and separated into four equal groups.



Commercial Pools are not included in Figure ES-3 because they have a much lower average $/therm, represent a large number of

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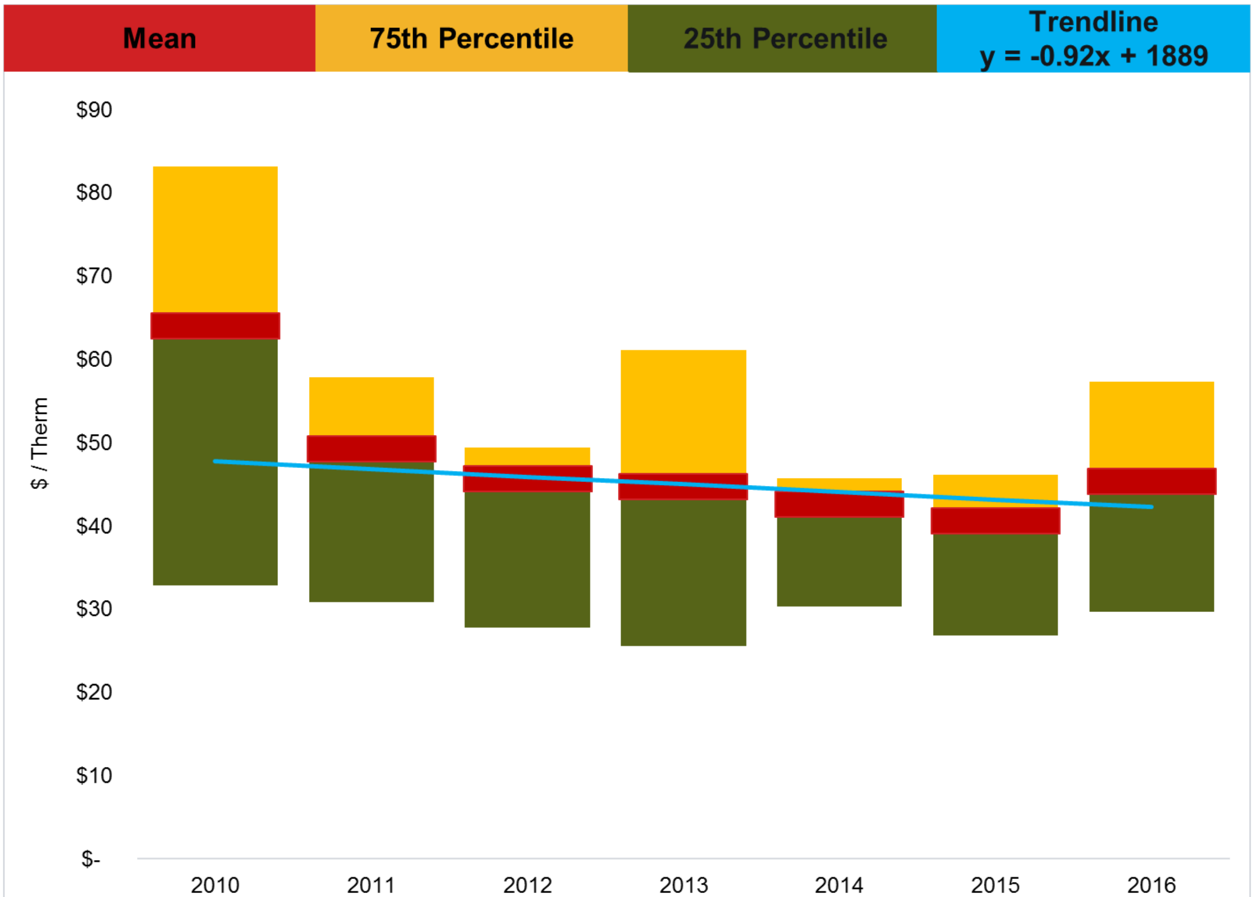
7 IFC systems use a pump to circulate a working fluid in a closed loop consisting of the collectors, piping, and a heat exchanger. The heat exchanger is used to transfer heat from the working fluid to the water in the storage tank. The CSI-Thermal handbook notes: “There are two types of Indirect Forced Circulation systems- active closed loop glycol and closed loop drainback.

- Active closed loop glycol systems are protected by a mixture of propylene glycol and water in the collector loop.
- Closed loop drainback systems, in sunny conditions, pump water through the collectors capturing heat which is transferred to the potable water supply via a heat exchanger. Closed loop drainback systems drain the water from the collectors when the pump shuts down.

More details can be found in Section 2: Program Results. Active systems like this are generally believed to be more efficient than their passive-system counterparts and are therefore more likely to be installed.

systems, and did not enter the program until 2014. The inclusion of them would therefore skew the overall program cost downwards significantly in later years of the program. However, a separate analysis was performed for them (discussed in Section 2), and the evaluation team found minimal differences in average costs for pool systems over the three years. depict

FIGURE ES-3: OVERALL EXPECTED SAVINGS-WEIGHTED TREND IN SYSTEM COST ($/THERM)



* Systems with the manufacturer, Fafco Inc., were removed from the Single Family and Low Income Single Family budget programs starting in 2017, and have therefore been removed from the cost analyses. These systems were identified as poor performers, and really designed only for commercial pool applications.

** All currency values have been converted to 2016 dollars to allow comparison across years.

ES.3 PROGRAM FINDINGS – ACTUAL EVALUATED RESULTS

Table ES-2 below summarize the main program evaluation findings, by budget program and by program administrator, and provides the major reasons for discrepancy in the expected versus actual savings. The sample was chosen to be statistically significant by Budget Program, but not by Program Administrator. The overall program results meet 80/20 confidence and relative precision level, as did the Commercial/Multifamily Residential results. A confidence and relative precision of 80/20 means that there is an 80% probability that the actual population GRR is within 20% of the actual evaluated GRR. The higher the confidence band, and the lower the relative precision, the better the evaluation findings are at predicting the results. However, results for the other four remaining budget programs were not statistically significant at this level.

TABLE ES-2: SUMMARY OF ACTUAL PROGRAM RESULTS

Budget Program	GRR*	Reasons for Discrepancy
Commercial Pools	48%	Zero Savers Low Solar Usage Night-time Solar Losses
Low Income Multifamily Residential	72%	System Performance Issues
Commercial / Multifamily Residential	82%	
Low Income Single Family Residential	22%	Updates to SRCC Models Actual Flow Rates Unglazed Systems
Single Family Residential	47%	
Overall Program GRR: **65%**		**2.7 million Therms saved** **

Annual Equivalent GHG Emissions Saved: **1,500 homes** ***

* GRRs are a metric to provide a comparison between actual and expected results. These are defined as the ratio between the two. To develop program-level GRRs, the site-level results need to be weighted up to the population. More on this process can be found in Section 3: Evaluation Approach. Overall program results and Commercial/Multifamily Residential results are statistically significant at 80/20 confidence/precision. The other results do not meet the 80/20 threshold and are provided for informative purposes only.

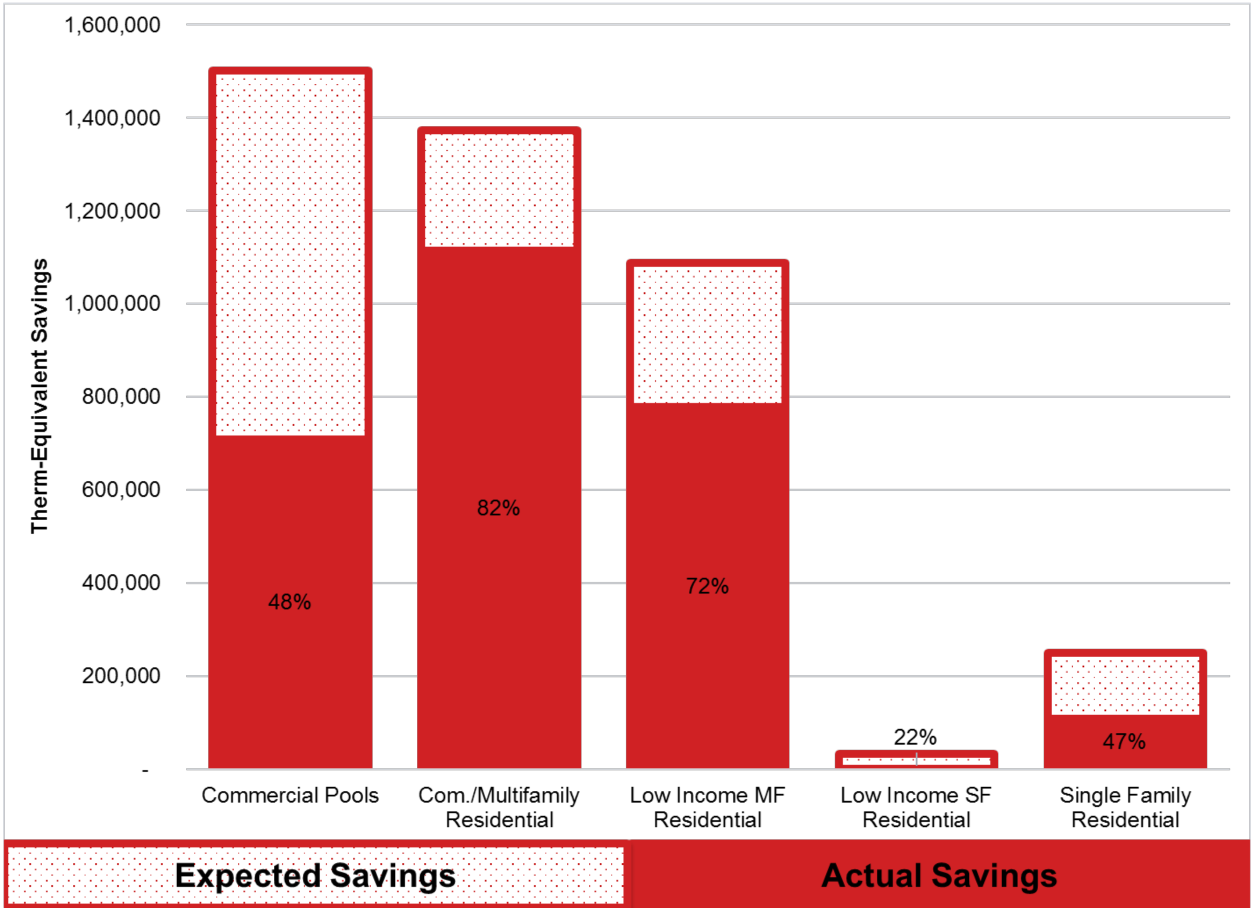
** Therms savings represent the total therm-equivalent savings.

*** Annual GHG emissions are based on EPA calculator. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

System Performance Findings

The overall program-level realization rate was 65%. The realization rate represents the ratio between the expected results, or what was reported by the program, and actual results that are a result of the evaluation. Figure ES-4 below displays the expected and actual savings for each budget program. The single-family programs had the lowest expected savings, but also the lowest realization rates. Commercial Pools had the highest expected savings, but only had a realization rate of less than 50%. Both the commercial and multifamily programs performed relatively well, with realization rates greater than 70%, and emerged as the highest performers and the highest savers. Reasons for this are discussed below.

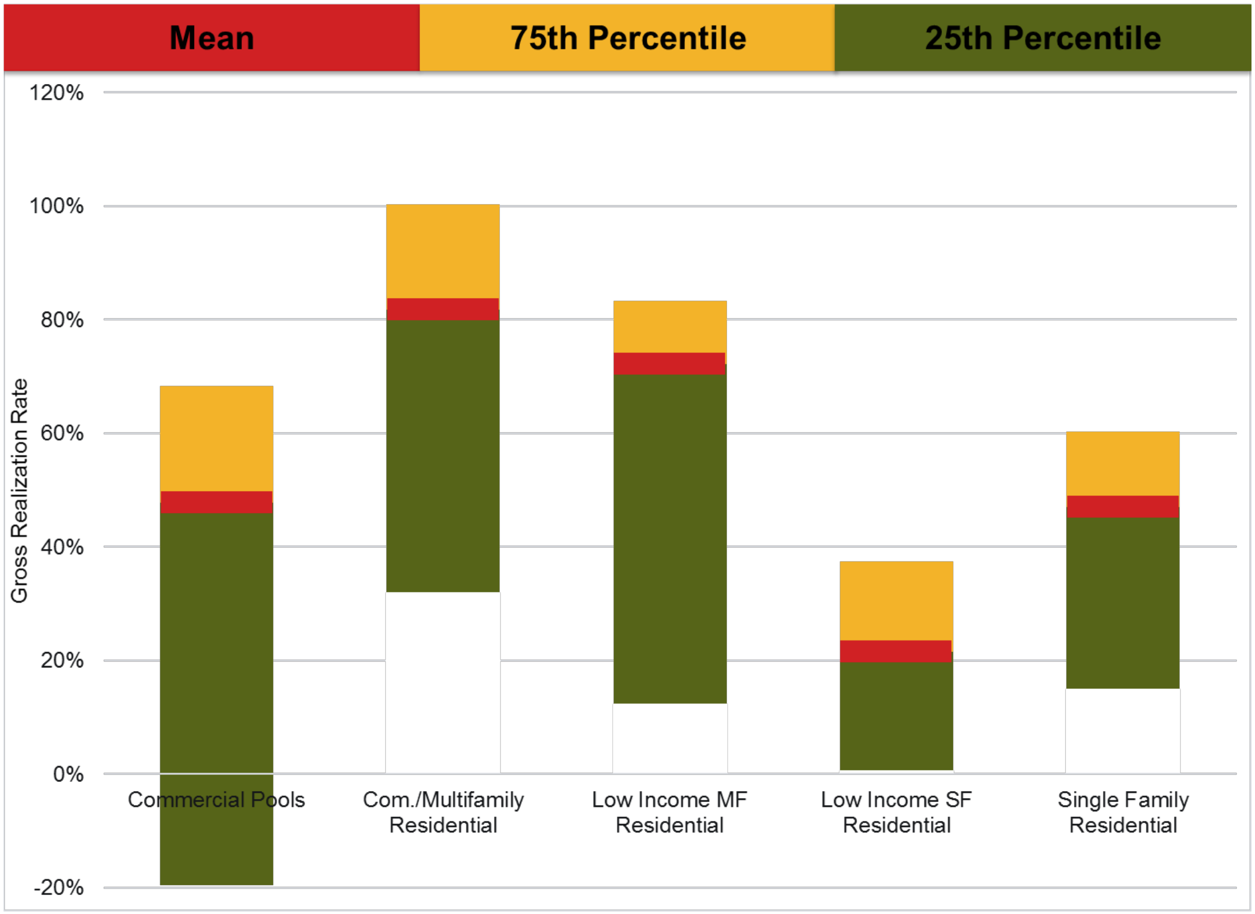
FIGURE ES-4: EXPECTED VERSUS ACTUAL THERM-EQUIVALENT SAVINGS



* GRR results are only statistically significant at 80/20 confidence/precision for Commercial/Multifamily budget program.

Figure ES-5 displays the mean GRR, the 25th quartile, and 75th quartile results for each of the budget programs. As discussed previously, these percentiles are a frequency distribution of the GRRs results for all installed systems. If the GRRs were ordered numerically, the 25th percentile (in green) displays a lower range of data between 25th percentile and the mean of the GRR results. Similarly, the 75th percentile represents an upper range of data between the mean and 75th percentile. The mean represents the average GRR. While the mean GRR value was 48% in the Commercial Pool budget program, there were projects within the 25th percentile which saw GRR as low as -19%. Although the mean GRR in the Commercial / Multifamily Residential budget program was 82%, there were projects within the 75th percentile that had a GRR of 100%, indicating that they saved the amount of natural gas that they were expected to.

FIGURE ES-5: GROSS REALIZATION RATES BY BUDGET PROGRAM SHOWING UNCERTAINTY IN RESULTS



Statistical Significance

Statistical significance is an indication of how well the sample represents the population. This is based on two factors, confidence and precision. The confidence level represents the probability that the interval contains the target quantity (in this case, the GRR), while the precision expresses the interval that is believed to contain the population value. For example, stating that the total program meets 80/20 confidence and precision suggests that there is an 80% probability that the program GRR is 65% ± 13%. A typical confidence level for energy efficiency evaluations is 90%, with a 10% relative precision.[8] The sample was originally drawn to meet the 90/10 confidence and precision targets for as many budget programs as possible. However, solar thermal systems exhibit broad performance variations that are not necessarily observed in many energy efficiency or other solar technologies that complicate accurate simulation of savings. The evaluation team explored the 90/10, 80/20, and 70/30 tests for statistical

8 Noted in the Uniform Methods Project Protocols, Chapter 11: Sample Design Cross-Cutting Protocol. Section 2.3.

significance. The team looked to see if a distribution showed 10% precision under a 90% confidence interval. If it did not, we changed to see if it showed 20% precision under an 80% confidence interval, and finally, if this was not obtained, we changed for 30% precision under a 70% confidence interval. The overall program met 80/20 confidence and precision targets, but when looking at the results by budget program, the only Commercial / Multifamily Residential budget program met this level of confidence and precision. Table ES-3 shows the results of these tests for each of the budget programs.

TABLE ES-3: SUMMARY OF STATISTICAL PRESION BY BUDGET PROGRAM

Budget Program	Confidence / Precision
Commercial Pools	Fail 70/30
Commercial / Multifamily Residential	Pass 80/20
Low Income Multifamily Residential	Fail 70/30
Low Income Single Family Residential	Fail 70/30
Single Family Residential	Fail 70/30
Total Program	Pass 80/20

Although many of the budget programs do not meet the 80/20 confidence and precision,[9] there are some noteworthy findings uncovered throughout this evaluation that are important to consider for future program offerings.

As part of the analysis, the evaluation team attempted to quantify the highest reasons for discrepancy between the expected and actual savings. Table ES-4 highlights these for each of the program types. For Commercial Pools, the evaluation team identified three factors that collectively, reduced the expected savings for the sample by 50%. These included zero-saver pools, which received no savings as the systems were either removed or the SWH system did not displace any natural gas, pools which saw night time solar losses, and pools that saw little solar usage throughout the year. For the commercial and multifamily facilities, system performance issues were the main driver of these reductions, accounting for a 13% reduction across the sampled sites. On a site-level, there were many other factors that altered savings; in the extreme cases, some site savings were reduced to zero and others where the savings were quadrupled, but due to significant site to site variability, many of these issues cancel each other out when averaged across all sampled sites. For single family systems, updates to ratings by the Solar Rating and Certification Corporation (SRCC),[10] updates to the gallons per day (GPD) water draw, and unglazed system

[9] All budget programs meet 60/40 confidence and precision.

[10] The original OG-300 ratings are proprietary to SRCC, so the models were not able to be replicated exactly. New protocols are currently being finalized between TRNSYS and SRCC, so these new models were used to mimic the original models mandated by SRCC. Two noticeable changes included upgrades to mains water temperatures and reductions in savings for wrap-around heat exchangers.

performance all accounted for a 51% reduction in savings across the sampled sites. Further discussion for all discrepancy factors can be found in Section 4.

TABLE ES-4: MAJOR REASONS FOR DISCREPANCY BY BUDGET PROGRAM

Program Types	Reason for Discrepancy	Percent Reduction
Commercial Pools	Zero Savers	16%
	Night Time Solar Losses	13%
	Little Solar Usage	21%
Commercial & Multifamily	System Performance Issues	13%
Single Family	Updates to SRCC Models	26%
	Actual GPD	15%
	Unglazed System Performance*	10%

* These systems are no longer marketed for Single Family programs.

ES.4 PROGRAM RECOMMENDATIONS

The evaluation team crafted program recommendations reflecting the findings we identified during the evaluation. The layout of these recommendation includes an issue description followed by a recommendation to mitigate or further explore the highlighted issue.

Recommendation 1 – No Existing Pool Heaters: Update program requirements so that for existing pools, the installation of a SWH system must offset natural gas usage. This could be by replacing an existing heater (an older solar hot water heater would be eligible). Written exceptions could be considered if the customer is truly wanting to try out solar heating prior to purchasing a natural gas heater, but these are more likely to be the minority and should be considered on a case-by-case basis.

Explanation 1: There were two pools in the Commercial Pool sample where the evaluation team determined, through conversations with the site contact, that no pool heat previously existed prior to the installation of the SWH system, and there were no plans to install a pool heater. The team contacted two additional pool facilities which had received CSI-T incentives, and found that these, also, did not ever have a pool heater installed previously. The Program Rules specifically have allowed these situations in the attempt to displace future natural gas usage. However, contractors for earlier projects seem to have taken advantage of this at some facilities to offer systems 'free of charge'. The PAs and the CPUC have taken steps through the capping of Commercial Pool incentives to minimize these effects, but the evaluation team suggests taking this one step further to restrict program eligibility to those systems that offset existing natural gas usage.

Recommendation 2 - Night Time Pool Solar Losses: Requiring automated controls for pools will ensure that water isn't sent up to the collectors when ambient conditions are less than ideal. Additionally, pool maintenance staff must be fully trained and aware of the system controls, and all manual valves must be clearly labeled.

Explanation 2: When the metered data was analyzed, there were several pools where the team found the solar pump to be running at night, sending heated water up to the solar collector. Running the water through the collectors at night will cool the pool down as the heat from the pool is lost to the cooler atmosphere through the collectors. In some instances, this was found to be a deliberate action by pool operators and was observed at several sites on days that pool water temperatures exceeded 100°F, in attempts to cool the pools down. However, there were other scenarios where the pool was cooled at night, but then heated by auxiliary heating the following morning. This required additional energy that would not have been needed, if the solar pump had not been running throughout the night. It was the latter situation we evaluated that as an energy loss. It often appeared that the manual valves that sent water up to the collectors were not closed at night time. Additionally, there was at least one facility where the metered data showed that water was flowing through the solar loop only at night time, and it would stop during the day, for months at a time. This suggests that the pool maintenance staff were unaware of which direction the manual valve should be turned, and mistakenly turned it the wrong way every morning and evening.

Recommendation 3 – Shallow Pools: The program should explore whether expected savings can be adjusted based on pool depth. The depth of the pool had a large effect on the actual savings realized by the commercial pool sites, especially those located in the desert. The shallower pools saw very little solar energy delivered through the SWH system to the water during the summer time, because the SWH systems were shut off. A large portion of the expected program savings came from pools in this region, which resulted in a large impact to pool savings.

Explanation 3: Commercial Pools have a specific set-point temperature below which additional heat is typically added. As the pool also receives heat directly from the sun during the day and the depth of the pool can have a significant effect on how quickly the pool will heat up, many pools were found to have far lower summer savings than expected. These pools were much shallower, 4-5 feet in depth, and found in the eastern desert regions of the state. The evaluation team found that these pools often had water temperatures upwards of 100 °F, far higher than the mid-80°F set-point temperatures. Because the water temperatures were already so much higher than the set-point temperatures, no additional solar heat was required, and therefore, the SWH system was turned off during much of the summer months, when the highest savings were expected.

Recommendation 4 – Single Family Flow Rates: Further study should be performed on the average daily water draw in California, and an updated value, specific to California, should be used in place of the ASHRAE load of 64.3 GPD. The evaluation team further suggests exploring an average water load based on the number of occupants in the home. Discussions with SRCC should ensue to ensure that modifications to SRCC OG-300 assumptions such as flow rates, will not invalidate the SRCC equipment rating.

Explanation 4: The expected savings for single family residential SWH systems are based on daily water draws of 64.3 gallons per day. The source for this value comes from ASHRAE,[11] and assumes six equal daily draws of 10.7 gallons. However, out of the 19 single family homes that were sampled, 11 were found to have a daily water heating load of less than half of this expected value. The number of occupants appeared to have a considerable effect on the water draw, however this factor is not considered in the expected savings.

Between 2012 and 2017, California has experienced severe drought throughout the entire state, and has subsequently enacted water-reduction efforts throughout the state, not only through water restrictions but also through water efficiency efforts and public outreach. The drought is a potential driver of the reduced daily usage, but the other evident driver is the number of occupants in the household. The meter data collected suggests a correlation between the number of occupants and the average daily water load of the home.

To date, the program has operated under the assumption that AB-1470 and CPUC D.10-01-022 have required the use of OG-300 savings ratings, and therefore have used the SRCC OG-300 assumptions, including the use of the 64.3 GPD as the metric to calculate savings. Per discussions with the PAs, this legislation may only require the use of OG-300 certified equipment, but not the use of all SRCC assumptions.

Recommendation 5 - Customer Performance Metering (CPM) Requirement: Require CPM systems to actually log data. These CPM systems have the potential to cost-effectively gather additional data on the performance of these systems. These systems are intended to provide feedback to hosts about performance and ideally prompt proactive maintenance. Not storing the data that are captured by these meters is lost opportunity. Ensuring that these meters are logging the data could open doors for increasingly cost-effective program evaluations and improve system performance by alerting hosts to performance issues that could be resolved through maintenance.

Explanation 5: The CSI-T program requires all systems with a capacity over 30 kW_{th} to install CPM for a period of five years from the start of operation. This metering equipment must, at a minimum, provide

[11] ASHRAE 118.2 Method of Testing for Rating Residential Water Heaters.

the quantity of solar energy delivered, and an onsite or remote display of continuous, cumulative BTU measurement. Seventy-one percent of the Commercial Pools visited by the evaluation team met the 30kW$_{th}$ threshold to require CPM. However, only a single pool was found to be logging the CPM data – the majority of meters had no memory cards installed.

Recommendation 6 – Performance Based Incentives (PBI): Care should be taken to ensure that facilities meeting the requirements for PBI are providing the required data and these data are being stored for use in evaluations. Historically, evolving program rules have made this requirement difficult to meet, yet it does appear that the PA's and their data contractor have now developed more robust processes to collect and retain PBI data.

Explanation 6: The CSI-T program requires that all solar thermal systems with a capacity greater than 250 kW$_{th}$ or systems designed for process heat, solar cooling, space heating, or a combination of these, take a PBI. The evaluation team was only able to gather the required PBI data for two of the five sites that required a PBI in the population.

1 INTRODUCTION

The California Solar Initiative Thermal (CSI-T) Program has incentivized 4,362 projects as of December 31, 2016, and tracked over 4.2 million therms in expected energy savings. This section provides program policy background, an overview of the CSI-T Program objectives, and the synopsis of the evaluation scope of work.

1.1 PROGRAM BACKGROUND

California's history with SWH has been a blend of expansive growth followed by sudden and deep contractions in the industry. Due to plentiful solar resources, high energy prices, and attractive federal and state tax credits as well as utility rebates, many Californians were quick to adopt SWH technologies in the late 1970s and 1980s.[1] The SWH industry in the state grew rapidly; however, this expansion was accompanied by growing pains. Several poorly designed and installed systems were sold at excessive prices, and failed to perform as expected, creating a perception that SWH systems were both costly and inefficient.[2] In addition, with the sudden drop in fossil fuel prices in 1986 and loss of solar tax rebates, interest in SWH declined and the SWH industry largely disappeared. By 1990, over 95 percent of all SWH dealers nationwide went out of business.[3] SWH developers in California retreated for the next two decades and stayed in business by operating in niche markets such as pool heating and repairing existing solar systems.

Since 2000, increasing energy costs, growing concerns over greenhouse gas (GHG) emissions and improvements in SWH technology have led to a resurgent interest in SWH. A study by the National Renewable Energy Laboratory (NREL) indicates the technical potential energy savings associated with lower cost SWH systems could exceed 100 trillion Btu of natural gas within California.[4] Similarly, a report by Environment California notes that increased use of SWH in California could reduce natural gas consumption, possibly causing lower gas prices, while simultaneously reducing GHG emissions. In 2006, the California Public Utilities Commission (CPUC) initiated the Solar Water Heating Pilot Program (SWHPP) as part of the larger California Solar Initiative.[5] Goals of the SWHPP were twofold: 1) to help promote the

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1 California Energy Commission, 2006 Integrated Energy Policy Report Update, CEC-100-2006-001-CMF, January 2007, p. 61.

2 A. McDonald and J. Bills, "The Kentucky Solar Energy Guide: Chapter 6: A Brief History of the American Solar Water Heating Industry," out of print, but found at http://kysolar.org/ky_solar_energy_guide, p. 39.

3 Sunvelope, *History of Solar Water Heating*, http://www.sunvelope.com/TechData.pdf

4 P. Denholm, et al., *The Technical Potential of Solar Water Heating to Reduce Fossil Fuel Use and Greenhouse Gas Emissions in the United States*, National Renewable Energy Laboratory, NREL/TP-640-41157, March 2007.

5 CPUC Decision 06-01-024, January 12, 2006, http://docs.cpuc.ca.gov/published/Final_decision/52898.htm

use of SWH and, 2) to evaluate the impacts of the pilot program on SWH equipment prices, demand, and cost-effectiveness.

The SWHPP started in July 2007 as an 18-month incentive pilot program implemented in San Diego Gas and Electric's (SDG&E) territory and administered by the Center for Sustainable Energy (CSE, formerly known as the California Center for Sustainable Energy). In July 2008, the CPUC modified the original decision establishing the pilot program.[6] The modified decision contained a number of key changes to the original 2006 decision including: 1) extending the SWHPP beyond the initial 18-month timeframe; 2) allowing new residential and commercial construction to be eligible for the program; 3) extending the market research evaluation work beyond the San Diego region; and, 4) requiring the CPUC Energy Division to hold a workshop on the SWHPP evaluation plan within 60 days of the ruling.

In January 2009, Itron completed the Interim Evaluation Report of the SWHPP.[7] The following year, the statewide California CSI-T Program was established.[8] Figure 1-1 below provides an overview of key events in the history of the program and rebated capacity over time.

Initially the program only offered incentives to single family residential SWH systems and program participation was relatively low. Shortly after, the program was expanded to multi-family and commercial buildings. In March 2011, Itron completed the SWHPP Final Evaluation Report. In October of the same year, the CPUC created the Low Income Solar Water Heating Program. Between 2011 and 2013 the program saw relatively moderate growth compared to previous years.

On February 28, 2013, the CPUC approved Decision 13-02-018 incentivizing new technologies other than those providing end-use hot water and on August 15, 2013, the CPUC approved Decision 13-08-004 incentivizing solar swimming pool heating (except for single family residences). The eligibility of pool heating projects has dramatically changed the composition of the program. Since the inclusion of pool heating projects, over half of the 2015 and 2016 projects were for the pool heating end-use.

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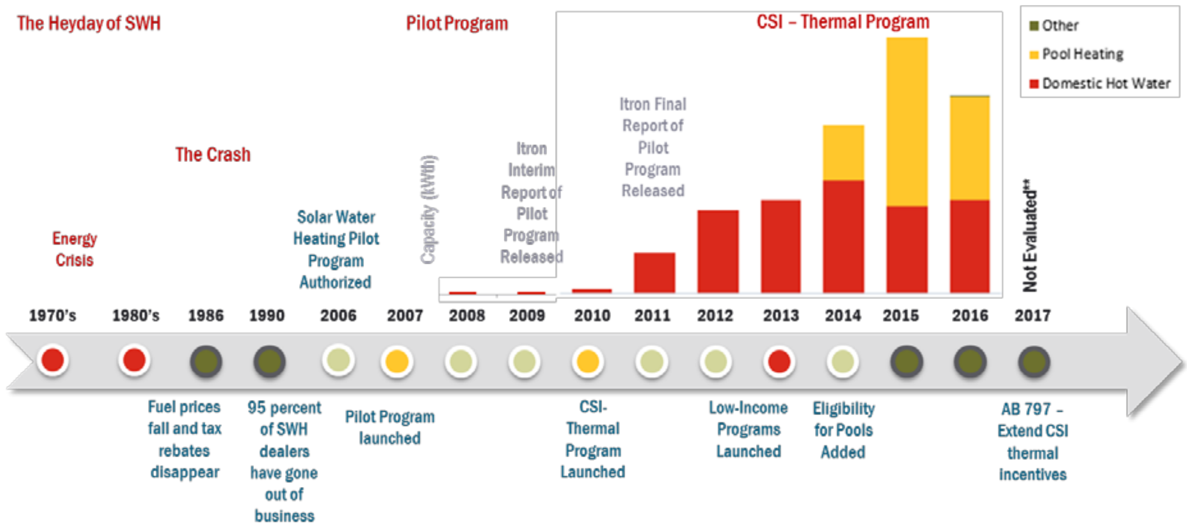
6 CPUC Decision 08-06-029, July 2, 2008, http://docs.cpuc.ca.gov/published/FINAL_DECISION/84844.htm

7 www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=7646

8 CPUC Decision 10-01-022, January 21, 2010. http://docs.cpuc.ca.gov/published/final_decision/112748.htm

FIGURE 1-1: CALIFORNIA SOLAR THERMAL TIMELINE



* The capacity shown is based on the year that the incentive was approved.

** The impact evaluation has only gone through the end of 2016, so the expected impacts of 2017 have not been analyzed or included here.

1.2 CSI-T PROGRAM OBJECTIVES

The CSI-T Program was designed to promote the installation of solar water heating systems in the Pacific Gas & Electric (PG&E), Southern California Edison Company (SCE), SDG&E, and Southern California Gas (SCG). The four goals of the program are as follows:

- Significantly increase the size of the SWH market through achieving the displacement of 463 million therms and 275.7 million kWh over the 25-year life of the systems through natural-gas and electric-displacing SWH systems, and achieve an expansion of the market for other solar thermal technologies in addition to SWH through the installation of 200,000 solar thermal systems in homes and businesses;
- Support reductions in the cost of SWH systems of at least 16% through a program that increases market size and encourages cost reductions through market efficiency and innovation;
- Increase consumer confidence and understanding of SWH technologies and their benefits; and
- Engage in market facilitation activities to reduce market barriers to SWH adoption, such as high permitting costs, lack of access to information, and lack of trained installers.

1.3 EVALUATION SCOPE OF WORK

This report is an assessment of the CSI-T Program's impact on electrical energy, natural gas, and GHG emissions. Projects are categorized into five budget programs; Commercial Pools, Commercial / Multifamily Residential, Low-Income Multifamily, Single Family Residential, and Low-Income Single Family Residential. The program impacts are reported across these budget programs, SWH technologies, and utility service territories. In addition to these impact metrics, we provide the following analysis:

- Determination of the number and type of CSI-T systems incentivized by the CSI-T program;
- Analysis of SWH system installed costs and trends over time;
- Analysis of new thermal technologies that have emerged because of the CSI-T program;
- Quantification of the economic benefits achieved by the CSI-T program through the installation of SWH systems;
- Listing of safety considerations related to installed SWH systems; and
- Recommendations to improve the CSI-T program structure and modelling parameters.

2 PROGRAM OVERVIEW

This section provides the expected program results of the CSI-T program, which is based on application data taken from the California Solar Statistics website, administered through a joint effort between the California Energy Commission (CEC) and the California Public Utilities Commission (CPUC). The CSI-T program began accepting applications in 2010. This section provides an overview of the CSI-T projects through December 31, 2016.[1] The evaluation team analyzed the number of systems installed, expected annual energy savings, costs, and cost trends for projects rebated by the CSI-T program.

2.1 CLASSIFICATIONS OF PROGRAMS AND SYSTEMS

The analysis in this report section is by budget program and by system type. A brief description of the different classifications is provided here, along with an overview of the incentives provided.

2.1.1 System Types

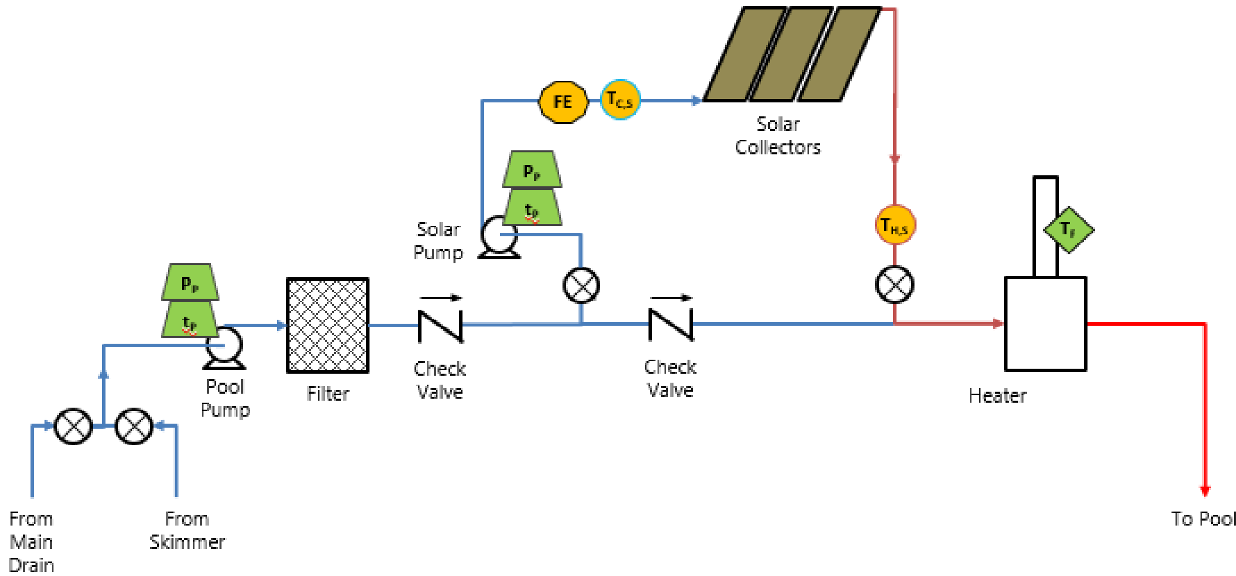
Active Solar Water Heating Systems: Active solar water heating systems use pumps and controls to circulate water or a heat-transfer fluid to and from the collectors. Active systems are generally believed to be more efficient than passive systems, but costlier.[2] There are two main types of active solar water heating systems:

- **Direct forced circulation:** A direct forced circulation system is an open system without a heat exchanger that uses a pump to circulate potable water from the storage tank to the collectors to be heated. Except for commercial pool applications, these are largely disallowed in the CSI-T program due to concerns about potential freezing. In the case of commercial pools, the pool water is circulated directly through the solar collectors and back into the pool and therefore requires either manual or automatic gravity draining to prevent freezing. Additionally, pool water can be circulated through the collectors to forestall freezing but this has the downsides of increasing heating load in addition to not requiring active control to avoid freeing. Figure 2-1 below shows an example of the direct forced circulation system designed for a pool.

[1] Program results are displayed for all systems with an Application Status of “Incentive Approved”, “In Payment”, or “Paid”.

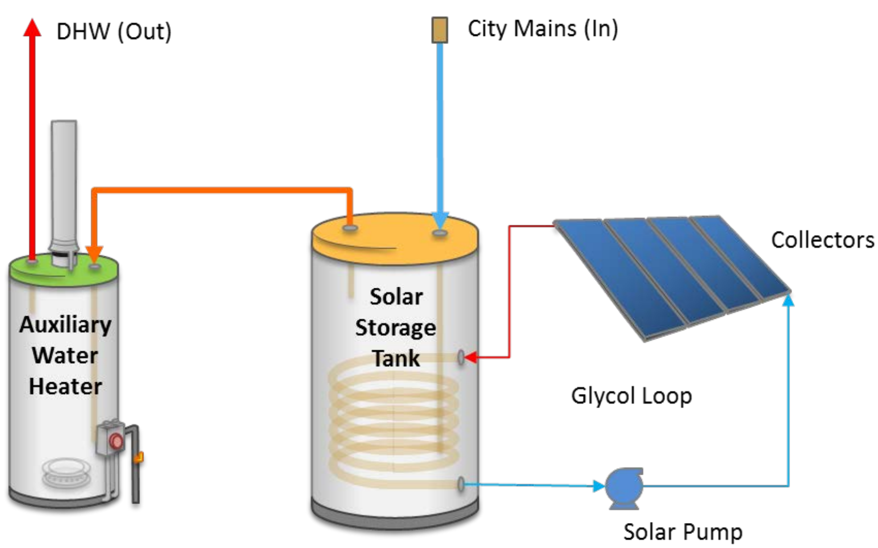
[2] https://energy.gov/energysaver/solar-water-heaters

FIGURE 2-1: COMMERCIAL POOL DIRECT FORCED CIRCULATION DIAGRAM



- **Indirect forced circulation:** An indirect forced circulation system is a closed system with a heat exchanger that can be configured with either antifreeze or drainback freeze protection. A pump circulates the heat transfer fluid from the panels to the heat exchanger, and a second pump may circulate water from the tank to a heat exchanger. Antifreeze systems use glycol as the heat transfer fluid, whereas drainback systems have an additional tank that allows water to drain out of the collectors to protect the system from freezing and overheating. An example of one configuration of this loop can be seen below in Figure 2-2.

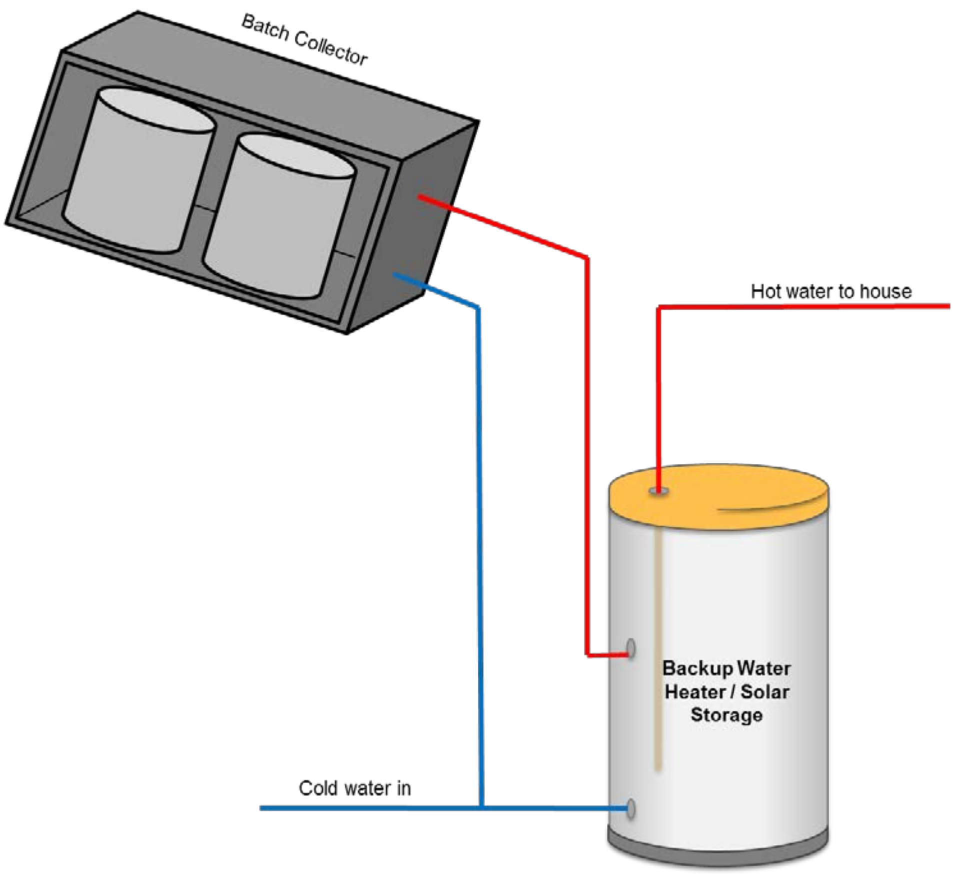
FIGURE 2-2: INDIRECT FORCED CIRCULATION WITH GLYCOL LOOP



Passive Solar Water Heating Systems: Passive solar water heating systems do not require pumps or controls and rely solely on natural convection to circulate the water. There are two main types of passive SWH systems:

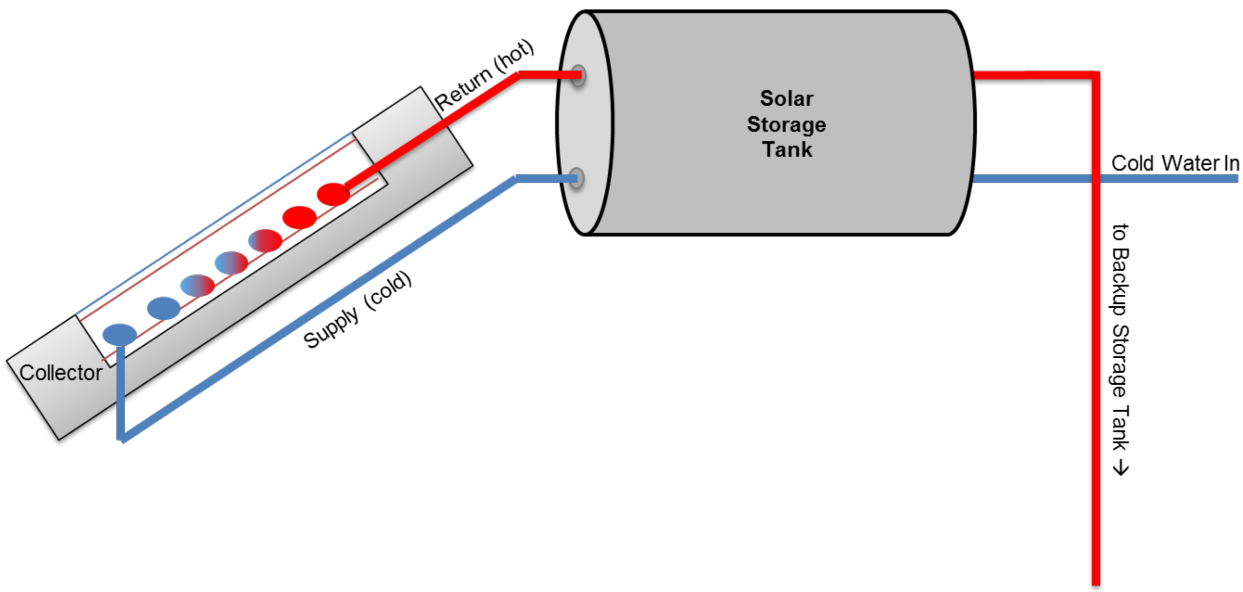
- **Integral collector storage:** An integral collector storage (ICS) system, commonly known as a "batch" system, combines the collector and storage tank into a single unit. Large black tanks or tubes are housed in an insulated box, which preheat cold water as it passes through. ICS systems work best in warm climates with evening water heating loads as the hot water is stored outside and can quickly lose heat over night or during cloudy conditions.

FIGURE 2-3: INTEGRAL COLLECTOR STORAGE DIAGRAM



- **Thermosyphon:** A thermosyphon system consists of solar collectors mounted below a storage tank. The heated water from the collectors flows upward into the tank by natural convection while cooler water returns to the panels to be reheated.

FIGURE 2-4: THERMOSIPHON DIAGRAM



2.1.2 Budget Programs

Commercial Pools: Commercial Pool installations have the primary purpose of reducing consumption of natural gas for heating pool water.[3] These do not include single-family residential solar pool heating systems. These systems primarily use unglazed collectors to directly heat pool water.

Commercial / Multifamily Residential: Systems installed at Commercial and Multifamily Residential facilities will directly consume solar heated potable water, as opposed to using the solar heated water as a medium to carry heat or for some other end-use. Examples of eligible domestic hot water (DHW) end-uses include apartment buildings with central DHW systems, convalescent homes, hotels and motels, military bachelor quarters, school dormitories with central DHW systems, and prisons. Examples of eligible commercial end uses include commercial laundries, laundromats, restaurants, food processors, agricultural processes, and car washes.

[3] Electric pool heating is very rare in California and program rules only allow for offsetting natural has water heating.

Low Income Multifamily Residential: A low income multifamily facility must meet the definition of low income residential housing provided in Public Utilities Code (PUC) Section 2861(e), or at least 50% of all units at the facility must have participated in a Commission-approved and supervised gas corporate Energy Savings Assistance Program (ESAP) administered by PG&E, SCG, or SDG&E, as set forth in PUC Section 2866(c).

Single Family Residential: A single-family residential dwelling is defined as a group of rooms, such as a house, an apartment, or a mobile home which provides complete single-family living facilities in which the occupant normally cooks meals, eats, sleeps, and carries on the household operations incident to domestic life. Single family residential systems that deliver DHW are eligible under this budget program. This budget program does not include systems used for pool heating or space heating or cooling.

Low Income Single Family Residential: In addition to the Single Family Residential qualifications above, a low-income facility must meet the definition of low income residential housing provided in Public Utilities Code (PUC) Section 2861(e), or have participated in a Commission-approved and supervised gas corporate ESAP administered by PG&E, SCG, or SDG&E. Eighty percent of the systems installed in the Low Income Single Family Residential program (all systems prior to 2016), were identified to be unglazed collectors. These systems are typically reserved for pool heating, as they are effective at heating large volumes of water by a small temperature rise. Therefore, these systems have since disallowed from all budget programs except Commercial Pools.

2.1.3 Incentive Structure

Table 2-1 shows the incentive structure, in $/therms, for each budget program in each year.[4] The values were calculated by taking each installed system's current incentive amount and dividing by the estimated therm savings, then taking the average over each budget program within each year. There is a general trend toward higher incentive dollars per therms over time in the Single Family Residential budget program, but no significant trend seems to appear in other programs.

[4] 'Year' denotes the year in which an incentive was approved.

TABLE 2-1: INCENTIVE STRUCTURE BY YEAR AND BUDGET PROGRAM ($ / THERMS)

Year	Commercial Pools	Commercial/ Multifamily Residential	Low Income Multifamily Residential	Single Family Residential	Low Income Single Family
2010	-	$13.16	-	$11.97	-
2011	-	$13.21	-	$11.01	-
2012	-	$13.65	$20.00	$13.65	-
2013	-	$14.10	$19.57	$17.78	$24.82
2014	$6.87	$13.16	$19.23	$19.14	$22.97
2015	$6.54	$13.21	$24.13	$25.18	$25.72
2016	$5.70	$13.16	$24.41	$57.91	$28.48
Average	**$6.32**	**$15.94**	**$21.33**	**$32.79**	**$25.43**

* All currency values have been converted to 2016 dollars.

** In 2016, temporary additional incentives were approved for SCG Single Family and Commercial/Multifamily applications, in response to the 2015 gas leak in Aliso Canyon.

2.2 SUMMARY OF RESULTS

The expected annual energy savings for each CSI-T project are estimated using the Transient System Simulation Tool (TRNSYS)[5] software package. The simulations vary somewhat based on the program-defined budget program:

- **Single Family Residential & Low Income Single Family Residential:** The expected savings for these systems are based on published annual ratings by the Solar Rating and Certification Corporation (SRCC). These ratings are referred to as OG-300 ratings and reflect the configuration, equipment details, and location of the solar domestic hot water system. These are calculated from a custom TRNSYS-based simulation engine operated by SRCC.
- **Commercial / Multifamily Residential & Low Income Multifamily Residential:** The expected savings for these systems utilize a custom-built TRNSYS simulation engine for the CSI-T program and reflect customer-submitted conditions including tank configuration, heat exchanger type, collector arrangement, auxiliary heater information, estimated hot water demand, and building type, among others.

[5] TRNSYS is produced by Thermal Energy System Specialists, LLC (TESS). This software is used as the simulation for the CSI-Thermal SWH expected savings calculations. http://www.trnsys.com/

- **Commercial Pools:** As with multifamily and commercial systems, commercial pool saving estimates are based on a series of customer-submitted system details which are modeled in a custom TRNSYS simulation engine built for the CSI-T program. The required inputs into these models include pool size, location, pool cover details, solar collector details including number, type, orientation, and auxiliary heater information.

The first-year savings expected by the program are estimated at over four million therms between the program's inception and the end of 2016. Over a 25-year expected life of the SWH systems, expected savings represent over 106 million therm-equivalent[6] lifetime savings. Table 2-2 summarizes CSI-T installations by program administrator, with SCG seeing the highest proportion of installations and savings, making up almost 60% of the expected savings.

TABLE 2-2: SYSTEM INSTALLATIONS BY PROGRAM ADMINISTRATOR

Program Administrator	Systems Installed	Expected Annual Savings (Therms)*	Savings Proportion
PG&E	1,344	1,260,350	30%
CSE	441	583,874	14%
SCE**	44	4,958	0.1%
SCG	2,533	2,393,788	56%
Total	**4,362**	**4,242,970**	**100%**

* Electrical system savings, given in kWh, have been converted to therms.

** The backup fuel for all 44 systems installed by SCE were propane or electricity. Natural gas systems represented 93% of all systems installed.

Table 2-3 displays similar information to Table 2-2, grouping the installed systems by their associated budget program. The Commercial Pools program represents the largest expected savings, with over 1.5 million first-year therm savings claimed, followed closely by the Commercial/Multifamily Residential and Low Income Multifamily Residential budget programs. Single Family systems made up about half of the systems installed, but on average, these systems were much smaller, and therefore made up only 6% of the expected savings.

6 Therm-equivalent savings mean that all savings for electric- or propane-backup SWH systems are converted from kWh to therms for reporting purposes. Over 90% of the systems installed utilized natural-gas backup auxiliary heating.

Table 2-3 also shows the average incentive paid by budget program. Single Family Residential and Low Income Multifamily Residential systems were found to have received, on average, the highest rebate per expected equivalent Therms savings, while Commercial Pools received the lowest average incentive. Single family residential systems are typically more expensive that other system types, and the higher average incentives provided are designed to offset some of that additional cost. On January 29, 2015, the CPUC approved a modification to the CSI-T program which included higher incentive levels for all-natural gas budget programs except for Commercial Pools.[7]

TABLE 2-3: SYSTEM INSTALLATIONS BY BUDGET PROGRAM

Budget Program	Systems Installed	Expected Annual Savings (Therms)*	Fraction of Overall Savings	Average Incentive ($/Therms) **
Commercial Pools	670	1,500,937	35%	$6.32
Commercial / Multifamily Res.	607	1,372,848	32%	$15.94
Low Income Multifamily Res.	641	1,088,877	26%	$21.33
Single Family Residential	2,183	248,992	6%	$32.79
Low Income Single Family Res.	261	31,317	0.7%	$25.43
Total	**4,362**	**4,242,970**	**100.0%**	**$14.98**

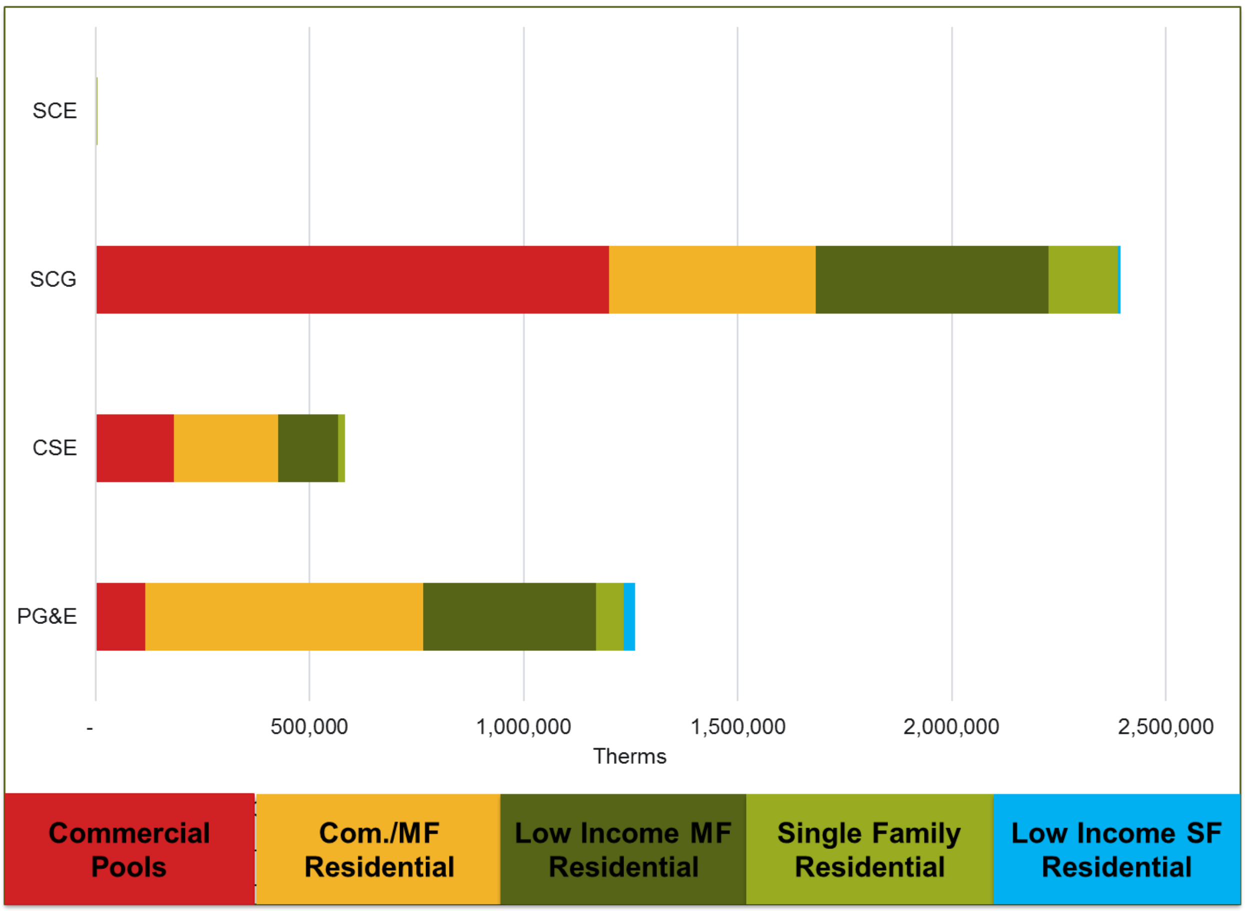
* Electrical system savings, given in kWh, have been converted to Therms.

** All currency values have been converted to 2016 dollars.

[7] Approved in D.15.01.035

Figure 2-5 shows the magnitude of expected therm-equivalent savings by program administrator (PA) across each budget program. The majority of savings from Commercial Pool installations have come from SCG, making up 35% of the entire program savings. Most of the remaining savings within PG&E and SCG come from their respective Commercial/Multifamily Residential and Low Income Multifamily Residential budget programs. The Single Family Residential savings make up only a small percent of savings for each PA.

FIGURE 2-5: EXPECTED THERM SAVINGS BY PA AND BUDGET PROGRAM

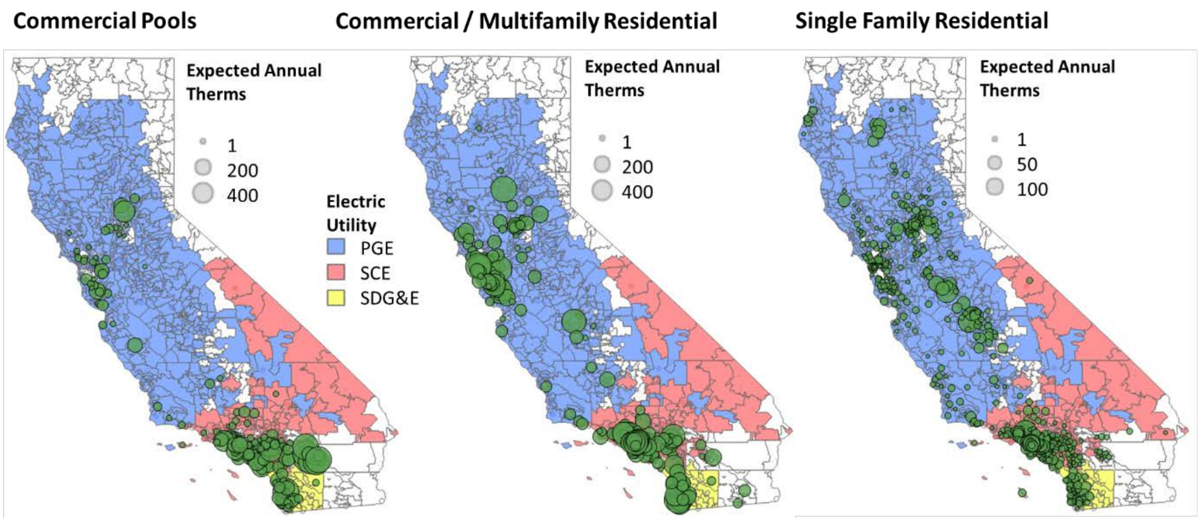


* Electrical system savings, given in kWh, have been converted to equivalent Therms.

** SCE had (1) Commercial/Multifamily residential system totaling 51 therm- equivalent savings, and (43) Single Family Residential systems totaling 4,907 therm-equivalent savings.

Figure 2-6 displays the location of the installed systems by budget program, as well as the expected annual therms installed, grouped by zip code. Single Family systems had the greatest number of installations, dispersed throughout the state, while Commercial Pools and Commercial/Multifamily Residential facilities had fewer installations but greater expected savings.

FIGURE 2-6: MAP OF CSI-T INSTALLATIONS



* The Commercial / Multifamily Residential map and the Single Family Residential map include their low-income program counterparts.

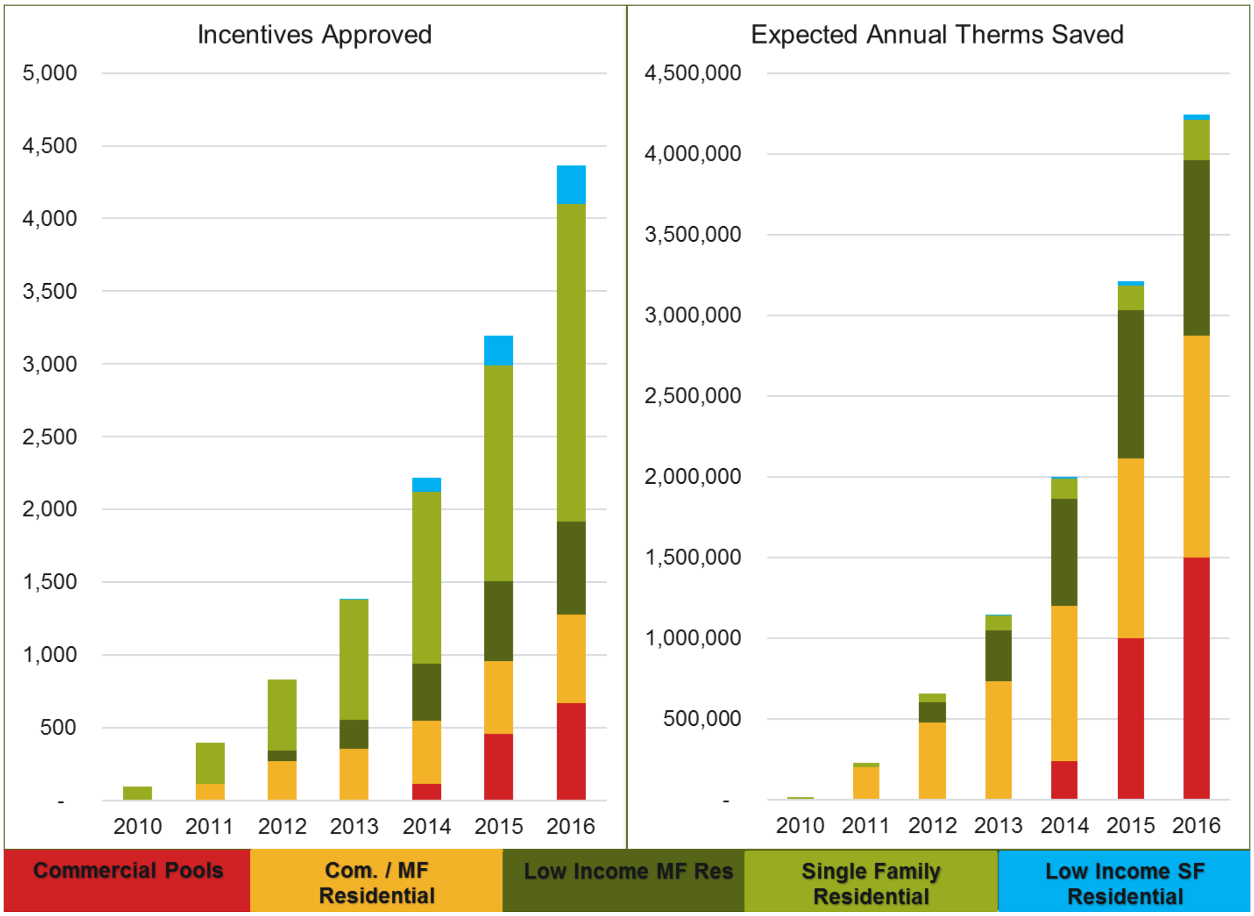
2.3 CSI-T STATISTICS BY BUDGET PROGRAM

2.3.1 Installations over Time

Over 4,300 systems were incentivized between 2010 and 2016. The cumulative systems incentivized, by budget program, are shown in Figure 2-7. During 2010 and 2011, only the Single Family Residential and Commercial / Multifamily Residential budget programs were active. Low Income Multifamily Residential was added in 2012, followed by Low Income Single Family Residential in 2013 and Commercial Pools in 2014. While Single Family Residential systems represent close to half the total number of systems in the program, their share of estimated energy savings represents only 6% of all expected savings between 2010-2016 (see Table 2-3).

Although Commercial Pool projects did not enter the program until 2014, Figure 2-7 below shows the speed at which these systems developed into an integral part of the program, very quickly gaining significant market share. The largest increase in Commercial Pool expected savings were claimed in 2015, with over 300% more Commercial Pool systems installed in 2015 than 2014.

FIGURE 2-7: CUMULATIVE SYSTEMS INSTALLED BY BUDGET PROGRAM



2.3.2 Installations by Backup Fuel Type

Table 2-4 displays the number of systems installed with each type of backup fuel. Solar water heating systems backed up by natural gas represent the clear majority of systems; over 90% of the systems installed. Electrical backup heating deployed by PG&E, SCE and CSE exist almost exclusively (242 out of 248) within the Single Family Residential budget program (the other six were installed within the Commercial/Multifamily Residential program). Additionally, 47 of the 48 propane systems were installed within the Single Family Residential program.

TABLE 2-4: SYSTEM INSTALLATIONS BY BACKUP FUEL TYPE

Backup Fuel Type	Systems Installed	System Distribution	Therm Savings	kWh Savings
Electric	248	6%	-	745,346
Natural Gas	4,066	93%	4,211,191	-
Propane	48	1%	-	185,792
Total	**4,362**	**100%**	**4,211,191**	**931,138**

Comparison to Goals

The CSI-T program has a goal of increasing the size of the solar thermal market in California by increasing the adoption of solar thermal technologies. Its natural gas-displacing system goal was to reach 463 million therms over the 25-year life of the SWH systems.[8] The CSI-T Program was set to run through 2017, but was recently extended to July 31, 2020 through AB 797.[9] Figure 2-8 below shows the pace at which the program's lifetime therm savings have grown. So far, the program has achieved just under a quarter of its lifetime therm goal. The program has been steadily increasing in its natural gas-displacing projects, seeing a 32% increase in expected therm savings between 2015 and 2016. The figure below shows the cumulative lifetime savings for each year of the program and a trend line across the points to extrapolate the expected lifetime savings through 2020. These results show that on the program's current trajectory, by 2020 the CSI-T Program should achieve about 275 million therm savings over the lifetime of the projects it rebated, roughly equal to the annual amount of natural gas used to heat water for 45,000 homes, yet only about 60% of the program's goals.[10] A secondary goal of the program was to displace 275.7 million kWh per year, however, this goal is combined with the CSI General Market, where most of the budget has been used for solar photovoltaic (PV) system incentives. Electric-displacing solar thermal systems have played a small part in the CSI General Market due to the share of natural gas water heaters in residences

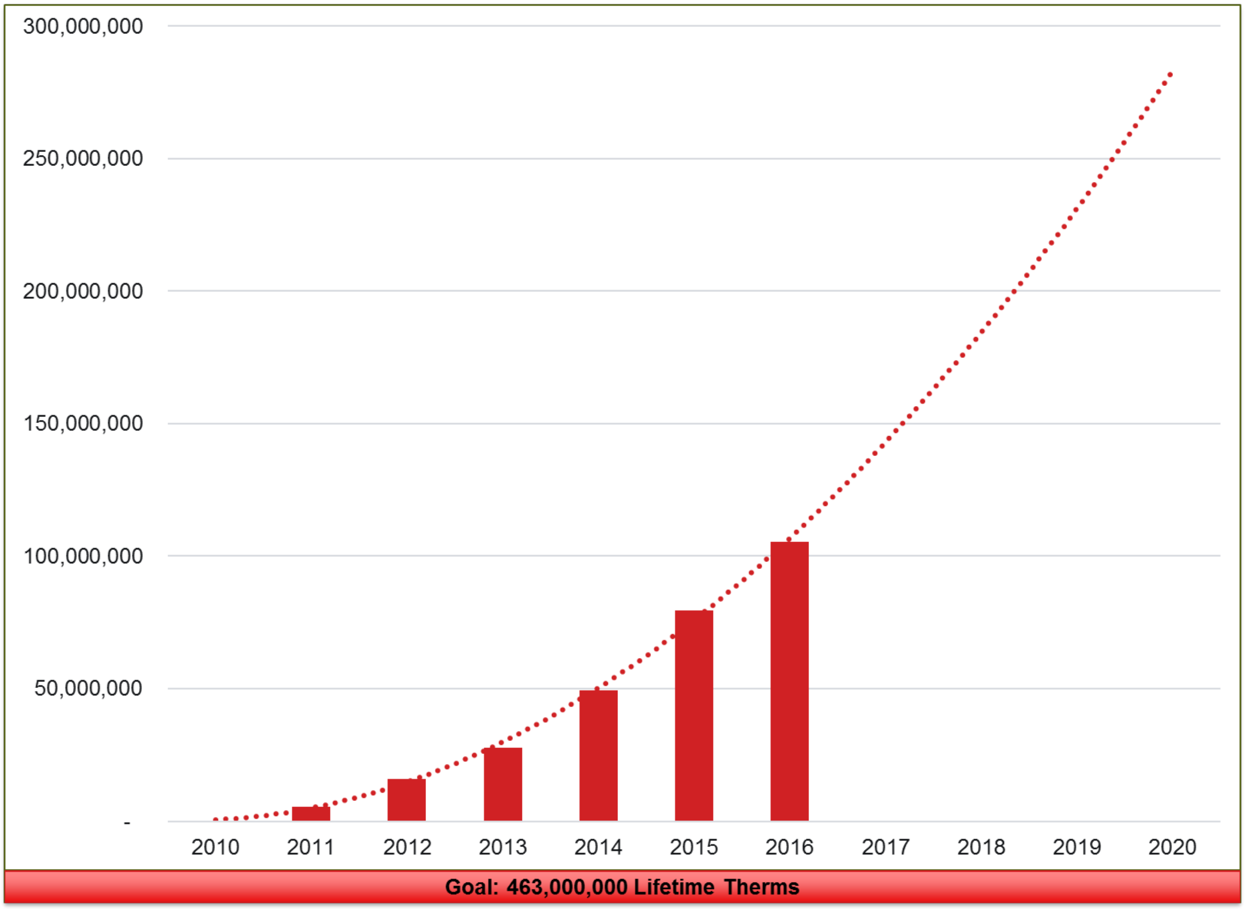
8 California Solar Initiative- Thermal. Program Handbook. Pg. 5. October 2016. http://www.gosolarcalifornia.ca.gov/documents/CSI-Thermal_Handbook.pdf

9 https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201720180AB797

10 Assuming 240 annual therms per water heater.

across California far outweighing the share of electric water heaters, with 80% to 90% of residents heating their DHW with natural gas.[11]

FIGURE 2-8: LIFETIME THERM SAVINGS AND GOALS

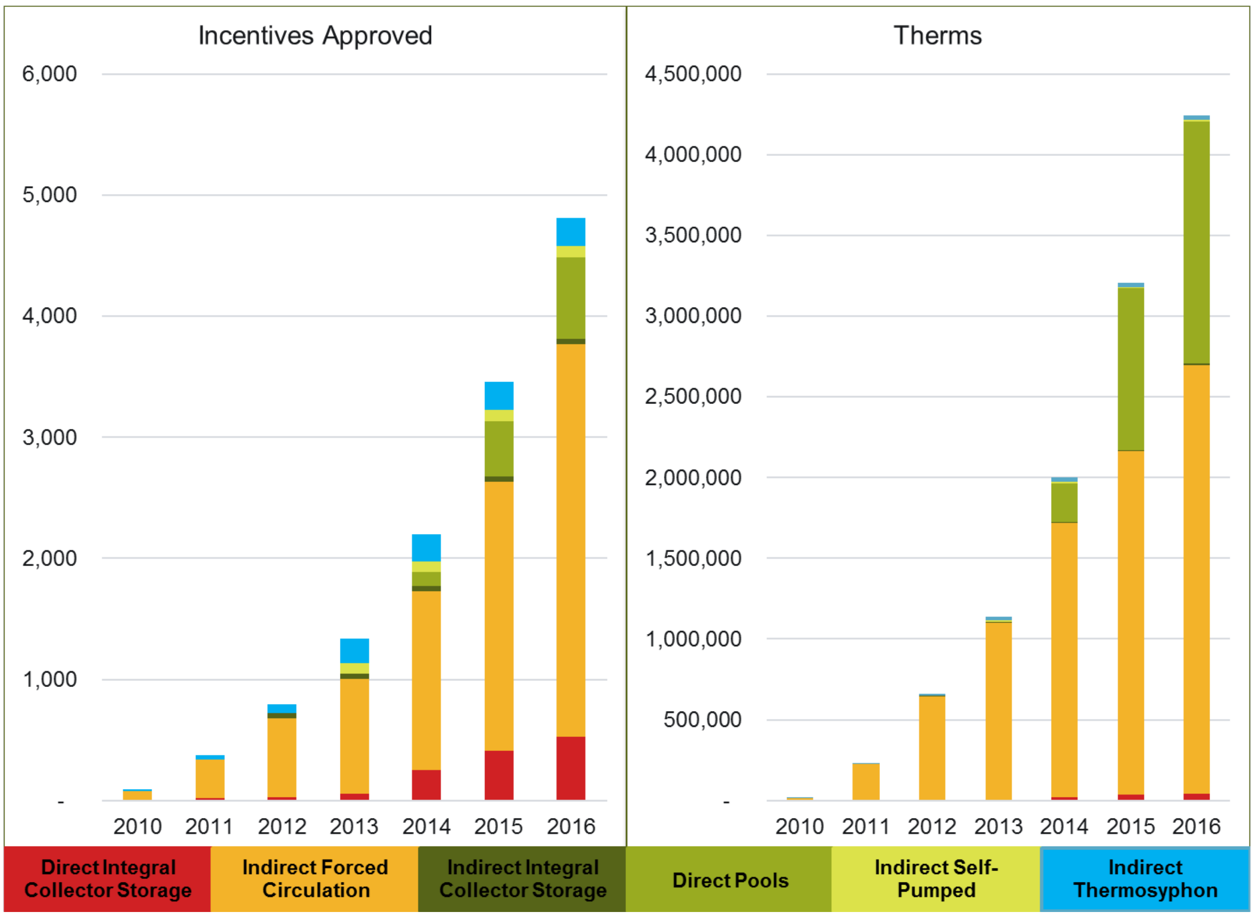


[11] Confirmed by the 2012 California Lighting and Appliance Saturation Survey (CLASS) and the 2009 California Residential Appliance Saturation Survey.

2.4 CST-T STATISTICS BY SYSTEM TYPE

Figure 2-9 displays the cumulative number of incentives paid, sorted by system type. While there are a wide variety of system types currently deployed, over half of the systems installed and the therm-equivalent expected savings are from Indirect Forced Circulation systems, which have been prevalent since the program's inception. In more recent years, Direct Pools and Direct Integral Collector Storage systems have emerged. Direct Integral Collector Storage systems have seen a significant growth, but have made little impact on the overall expected savings, as 99% of these have been installed in single family residential facilities, and therefore account for a lower portion of the savings.

FIGURE 2-9: CUMULATIVE SYSTEMS INSTALLED BY SYSTEM TYPE



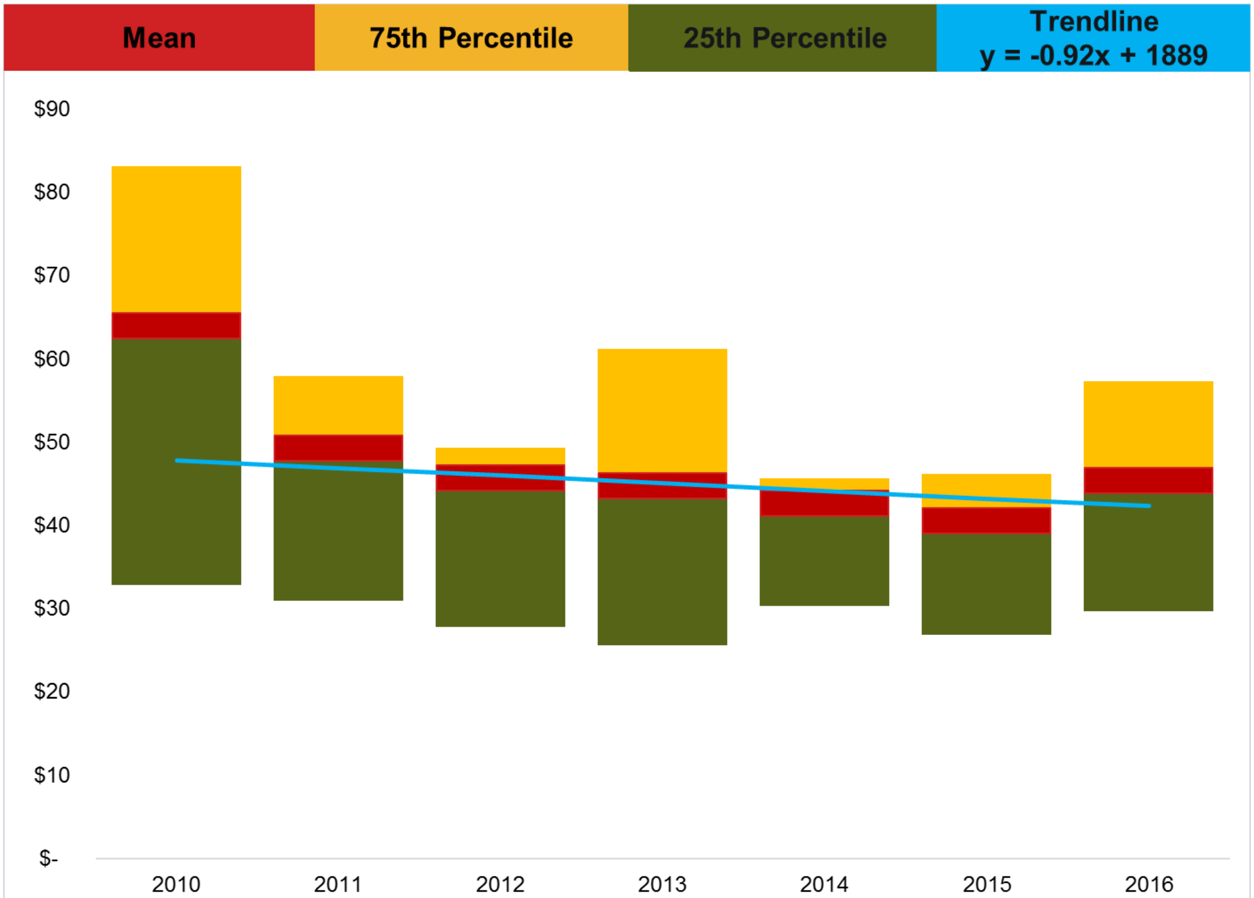
2.5 CSI-T COSTS

A second goal of the CSI-T program was to support reductions in the cost of solar thermal systems of at least 16 percent. This sub-section explores cost trends across the length of the program, as well as trends in incentive structures. A separate discussion is provided on the estimated financial impacts of the program, as well as a breakout of system ownership.

2.5.1 Installation Costs Over Time

Looking only at the overall project cost can be rather misleading, as different system types and different budget programs result in varying trends in $/therm. However, Indirect Forced Circulation (IFC) systems make up well over 50% of all systems installed (as seen above in Figure 2-9). This indicates that any overall program-wide trends in system costs are likely to be driven by these systems, for both the commercial/multifamily and single-family programs. From Figure 2-10 below, which shows the weighted statistics around all systems installed (except the Commercial Pools Program), there is a downward trend in weighted costs per therm as the program progressed. When fitting a linear trend line to the weighted mean of all systems, the evaluation team found a 13% reduction in costs between 2010 and 2016.

FIGURE 2-10: OVERALL WEIGHTED TREND IN SYSTEM $/THERM



* This graph shows the general trend of all systems except Commercial Pools. These results have been weighted by expected savings.

** Systems manufactured by Fafco Inc. were removed from the Single Family and Low Income Single Family budget programs starting in 2017, and have therefore been removed from the cost analyses. These unglazed collector systems were identified as poor performers, and really designed only for commercial pool applications.

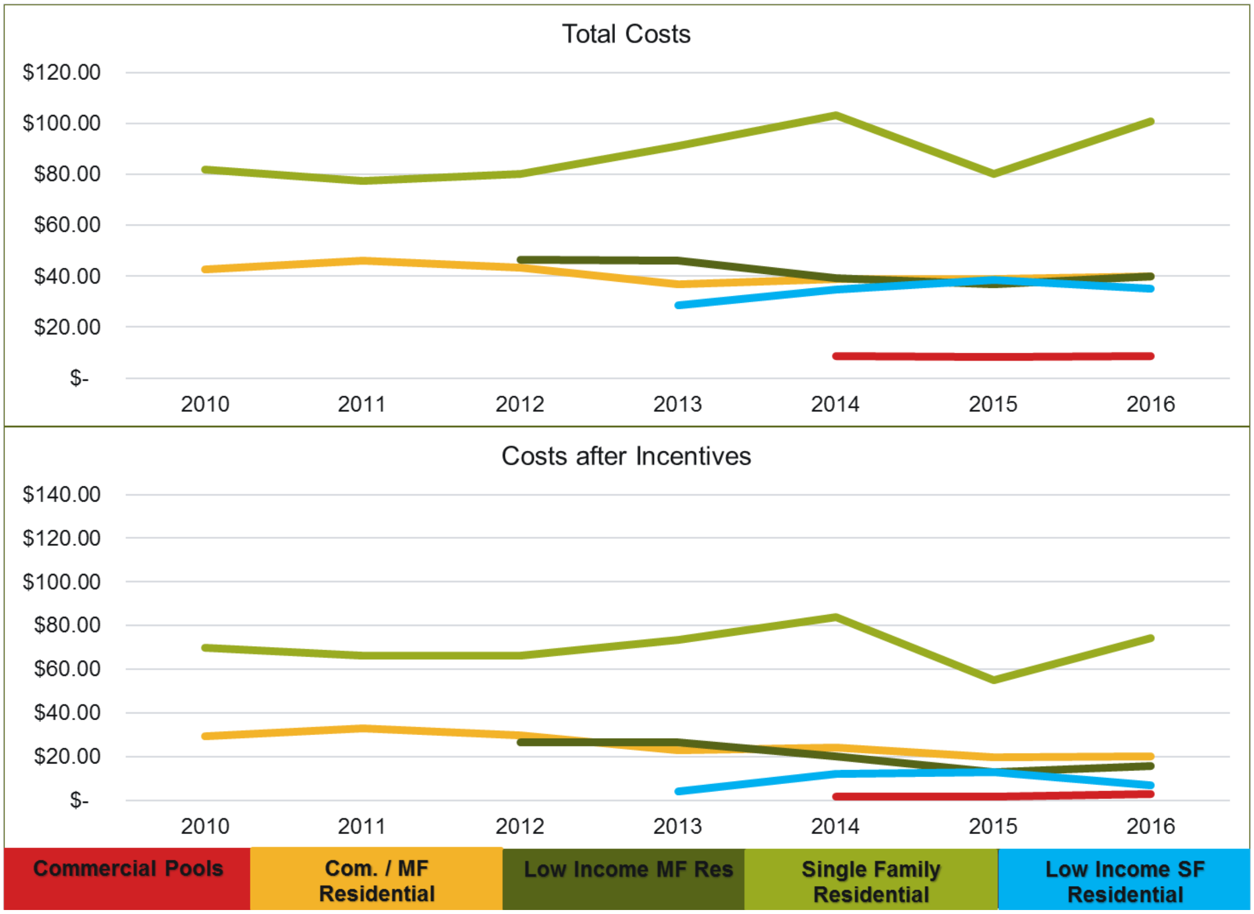
Commercial Pools are not included in Figure 2-10 above because they have a much lower average $/therm, represent a large number of systems, and did not start until 2014. The inclusion of them would skew the overall program cost downwards significantly. A separate analysis was performed for them, and this initial review suggested that there are minimal differences in average costs over the three years. However, this is a limited time frame to gauge any real trends.

A second analysis was performed at the budget program level, to review the total costs of the systems installed in different budget programs, and how the incentive levels have affected the total costs to the customer. Figure 2-11 below shows the comparison of both total costs (in $/therm) to the total costs after incentives. After incentives, Commercial Pool project costs have dropped to $3/therm, although this was an increase from the $1.69/therm seen in 2014. Starting January 29th, 2015, CPUC D.15-01-035 was issued which capped the pool incentive at 50% of the project cost, which explains the slight 2016 increase in costs.[12] Single Family Residential systems in this analysis, on the other hand, are shown to have the highest costs, even after incentives.[13] Although a temporary decrease in costs was seen in during 2015, the costs increased again during 2016. One plausible explanation for this increase in 2016 costs may have to do with the fact that almost 60% of the Single-Family systems included in this analysis were found to be made by a single manufacturer, and almost 50% of the systems installed were installed by only three solar contractors. All of these systems installed by the three major solar contractors were located in the SCG territory.

12 This was later temporarily rescinded for Commercial Pools in the SCG territory between April 15th, 2016 – December 31st, 2016 in response to the Aliso Canyon leak. SCG made up the majority of the Commercial Pool sample, which also explains why there wasn't more of an increase in pool costs.

13 About 75% of the 2016 Single Family Residential systems are not included in this analysis. In 2016, temporary additional incentives were approved for SCG projects, in response to the 2015 gas leak in Aliso Canyon.

FIGURE 2-11: SAVINGS-WEIGHTED[14] AVERAGE COSTS (TOTAL FOLLOWED BY AFTER INCENTIVES) ACROSS PROGRAM YEARS BY BUDGET PROGRAM ($/THERM)



* All currency values have been converted to 2016 dollars and weighted by Therm savings.

** In 2016, a shift in incentives was approved for SCG projects (CPUC approved Advice No. 4953) which temporarily increased incentives for Single Family and Commercial/Multifamily applications. This affected 75% of the 2016 Single Family projects and 38% of the Commercial/Multifamily projects, which were removed from this analysis.

*** These results include the Fafco, Inc. systems, as removing them would not result in only one point of data for Low Income Single Family systems (2016 data). No Fafco, Inc. systems were installed during 2016.

[14] Weighted by expected annual savings.

2.5.2 Estimated Financial Savings based on Standard Utility Rates

A key factor in customer value and industry longevity is how much customers might expect to save annually on their utility bills by installing a solar thermal system. To investigate the financial impacts, the evaluation team first analyzed electric and natural gas rates throughout the different utility regions.[15] As each rate was split into multiple tiers, a maximum unit energy consumption (UEC) for each budget program was calculated based on the Residential Appliance Saturation Survey[16] results and EIA consumption data.[17] This maximum UEC was then used to determine the usage tier and associated rate for each utility, region, and budget program. The population of CSI-T participants was then mapped to these usage tiers and their associated rates by utility, region, and budget program. The evaluation team found that different utilities mapped usage tiers differently; SDG&E and SCE mapped participants by California Climate Zone. PG&E mapped participants by zip code, and SCG mapped participants by city. Table 2-5 and Table 2-6 display the estimated financial impacts observed by CSI-T customers from the installation of SWH systems. These impacts are based on the expected electric and gas savings. Over $4.3 million was expected to be saved annually by customers with natural gas backup heating, and over $225,000 by customers with electric backup heating. Commercial and Multifamily Residential customers expected the largest savings of over $1.85 million annually, followed by Low Income Multifamily Residential customers at almost $1.4 million annually and Commercial Pools at over $800,000 annually. These were based on common tariffs for each PA and Sector (Single Family, Multifamily, or Commercial).[18] Southern California Gas Company saw the highest number of savings for customers with natural gas backup heating while PG&E customers saw the largest savings overall at just under $2 million annually. Most of the savings for each PA came from the following budget programs:

- PG&E: Commercial & Multifamily Residential, followed by Low Income Multifamily Residential;
- SDG&E: Commercial & Multifamily Residential, followed by Low Income Multifamily Residential and Commercial Pools;
- SCE: Single Family Residential; and
- SCG: Split rather evenly between Commercial Pools, Commercial & Multifamily Residential, and Low Income Multifamily Residential.

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15 Where possible, the evaluation team used 2016 electric and gas rates, however, the no historical rates could be identified for the non-residential sectors for gas, so 2017 rates were used.

16 https://webtools.dnvgl.com/rass2009/UECReports.aspx?id=20092003&tabid=2

17 https://www.eia.gov/consumption/commercial/data/2012/bc/pdf/b7.pdf

18 Dates of tariffs varied by program administrator or sector, as the same range was not always found, but they were based on tariffs in place around the end of 2016 to early 2017.

TABLE 2-5: FINANCIAL IMPACTS FROM SWH REPLACING ELECTRIC BACKUP HEATING

Program Administrator	Commercial Pools	Commercial / Multifamily Residential	Low Income Multifamily Residential	Single Family Residential	Low Income Single Family Residential	Total
Pacific Gas and Electric	-	$12,081	-	$94,141	-	$106,221
San Diego Gas and Electric	-	$12,909	-	$84,473	-	$97,381
Southern California Edison	-	$242	-	$28,173	-	$28,415
Southern California Gas Company	-	-	-	-	-	-
Total	**-**	**$25,231**	**-**	**$206,787**	**-**	**$232,018**

TABLE 2-6: FINANCIAL IMPACTS FROM SWH REPLACING NATURAL GAS BACKUP HEATING

Program Administrator	Commercial Pools	Commercial / Multifamily Residential	Low Income Multifamily Residential	Single Family Residential	Low Income Single Family Residential	Total
Pacific Gas and Electric	$81,664	$997,815	$626,347	$80,848	$43,284	$1,829,959
San Diego Gas and Electric	$124,999	$327,917	$189,906	$12,380	-	$655,202
Southern California Edison	-	-	-	-	-	-
Southern California Gas Company	$825,207	$515,342	$580,299	$177,918	$5,626	$2,104,392
Total	**$1,031,870**	**$1,841,074**	**$1,396,552**	**$271,147**	**$48,910**	**$4,589,552**

As discussed in previous sections, although the Single Family Residential budget program received a high number of participants, the savings for this budget program were relatively small, and therefore resulted in a much smaller overall financial impact than other budget programs.

2.5.3 System Ownership

The majority (over 90%) of the systems installed are owned by the host customer. This breakdown, and the system costs per-therm, are shown below in Table 2-7. Systems owned by the host customer were typically found to represent the lowest per-therm costs, although this is likely partially due to the large number of commercial pools in that category.

TABLE 2-7: SYSTEM OWNERSHIP BY BUDGET PROGRAM

Budget Program	Lease	Owner/Tenant***	Power Purchase Agreement
Commercial Pools	-	$6.32	-
Commercial/Multifamily Residential	$14.78	$15.90	$16.62
Low Income Multifamily Residential	$19.87	$21.12	$24.03
Single Family Residential	$17.20	$35.51	$30.15
Low Income Single Family Residential	-	$28.48	-
Total	**$18.84**	$14.40	**$20.57**
Number of Systems	**144**	**4,161**	**57**

* Currency values have been converted to 2016 dollars.

** The cost basis for third-party systems may or may not represent the actual invoiced cost to the customer. Differences may be attributable to methods of reporting for third-party contractors.

*** "Owner/Tenant" category has been combined with "Host Customer is System Owner", as it is not clear how these two differ.

2.6 SUMMARY

The CSI-T program has seen growth over the course of the six years since its inception. The achievements of the CSI-T program are highlighted below.

- Over 4,300 systems installed, 4.2 million expected annual therms savings, and almost 1 million expected annual kWh savings.
- Dramatic growth for SWH systems in Commercial Pools, making up over one third of the overall expected savings in only three years.
- Single-Family Residential systems represented the highest number of installations (2,183), but only accounted for 6% of the total expected therms saved.
- Cost reductions in SWH system projects of 13% over the six years of the program.[19]
- Over $4.3 million in annual bill savings expected by the 4,000-natural gas-displacing customers, and over $225,000 annually for the 300 electric-displacing customers.
- Over $3 in annual million in bill savings expected by Commercial/Multifamily and Low Income Multifamily customers.

19 Not including Commercial Pools.

3 EVALUATION APPROACH

This section describes the methodology and approach the evaluation team used to calculate the impacts presented in Section 4. We describe what metering equipment was used to collect data, how the quality of the data was ensured, how the data were translated into evaluated savings for each site, and finally how the metered sample was used to estimate program wide impacts. All reported savings are reported on a typical year basis to match expected annual savings.

The evaluation of program impacts, and the examination of system performance rely on meter data from two distinct sources:[1]

- **New metering installed by the evaluation team:** These measured the delivery of solar energy to the heating loads, and as possible, the operation of pumps, total water heating load, and auxiliary heater operation.
- **Performance Based Incentive (PBI) Metering:** Installed at larger Multifamily and Commercial sites that measure energy delivery to the heating load. Few of these metering systems existed, but two with available data were used to feed evaluation results.

3.1 EVALUATION METHODOLOGY

The CSI-T program evaluation focused on several main activities:

- Onsite data collection and solar thermal system metering,
- Cleaning and processing of the metered data,
- Simulation of system performance, and
- Site-specific savings calculations.

The evaluation team utilized metered data combined with TRNSYS simulated performance data to create final evaluated savings at a site-level. Metering equipment was installed on the solar thermal system to understand how much energy was being delivered to these systems. To calculate the amount of energy the solar thermal system saves, the team had to also understand how the water heating system would have operated in the absence of the SWH system (i.e., a baseline system). Because the evaluation team did not have first-hand knowledge how the baseline system would have operated prior to the installation of the SWH system, we relied on the TRNSYS simulations to calculate the savings between the solar

[1] The evaluation team had originally intended to collect Consumer Performance Metering (CPM) to support this evaluation but this proved to be problematic so was abandoned.

thermal system and the baseline system. From there, a relationship was observed, on a site-by-site basis, between the amount of solar delivered by the solar thermal system, and the amount of energy saved based by the SWH system relative to the baseline system in the TRNSYS simulations.

The simulated baseline system was designed to reflect what the typical conditions of a water heating system at a facility would be prior to the installation of the SWH system. Because the actual pre-SWH conditions at the facility are often unknown (as the system is often already removed), the team established the baseline system using standard water heating efficiencies and system configurations.

For commercial pool baselines, the baseline system included the same pool, pool cover, temperature set-points, location, and activity levels as the SWH system, but without the collectors, collector pumps, and solar controllers. For multifamily and commercial simulations, the baseline system was based on the SWH system information for the same water draw, auxiliary heater type, volume, and recirculation controls. The baseline system for the single-family residential system was set at a 50-gallon tank, with the same draw profile, draw volume, and heater set-points as the SWH system.

The following sections describe the evaluation steps in more detail.

3.1.1 Onsite Visits, Data Collection, and Metering

Site Inspections and Non-Metered Data Collection

The evaluation team performed site inspections to verify system installations as well as key inputs to the system configurations which could affect savings, and identify any installation or safety issues. The purpose of these inspections was primarily to ensure accuracy in the expected savings estimates through confirming system configurations, collector and solar loop and hot water details, piping insulation and water heater data, and household or facility information. Additional observations were noted, such as system leaks, water temperatures, presence of low-flow devices, and customer feedback on the system performance. These surveyor notes help to explain any discrepancies between expected savings estimates and evaluated savings. A copy of the data collection form can be found in Appendix A.

Metering Equipment

Non-invasive temperature and flow metering is desirable for this project due to liability and warranty concerns as well as ease of installation and removal. However, non-invasive meters vary considerably in their accuracy. There are a variety of factors that were considered when determining the proper metering solution at a given site including: pipe type (copper, CPVC, PEX, etc.), the relationship between pipe diameter and expected flow rate, and system type/configuration (e.g. passive vs. active). The evaluation team developed a recommended metering approach which optimized the balance between sampling error, measurement error, and cost. Table 3-1 below describes the equipment and highlights the attributes that were used to make the decision to use that piece of equipment.

TABLE 3-1: RECOMMENDED METERING EQUIPMENT

Meter		Description	Attributes
Enthalpy-Based Metering	Sunnovations Ohm	The "Ohm" meter is a minimally invasive residential-specific metering solution that is installed through the temperature and pressure release valve (T&P) on the water heater. This is a unique heat metering device that does not rely on a flow meter. Instead, an enthalpy sensor placed inside the tank measures the total heat energy within the tank and separately quantifies heat energy used, solar contribution, backup heater contribution, and standby losses.	Cost: Low to medium Accuracy: Reported manufacturer accuracy of less than 2.5% (independently verified error of 0.7% with an equipment uncertainty of 0.75% for measurement of energy used). Itron field testing showed that the average difference to flow meter data for water heating load across a four-month period was -3%.
Flow-Based Metering	Dynasonics TFX Ultra Transit Time Meter	The Dynasonics TFX Ultra and Flexim FLUXUS are ultrasonic flow and heat meters. They utilize factory calibrated ultrasonic transducers to measure flow and matched pairs of temperature sensors to capture the temperature differential. Heat measurements are integrated internally.	Cost: Medium Accuracy: Reported manufacturer accuracy ±1% of reading at rates > 1 FPS, ±0.01 FPS at rates lower than 1 FPS. Itron bench testing on a ¾" pipe showed 5% error in flow measurement at 2 GPM (1.45 FPS), 10% error at 1 GPM (0.73 FPS), and 30% error at 0.25 GPM (0.18 FPS).
	Flexim Fluxus ADM		Cost: High Accuracy: Reported manufacturer accuracy ±2% of reading at rates > 0.82 FPS. Itron bench testing on a ¾" pipe showed < 1% error in flow measurement at 0.03 GPM (0.022 FPS).
Backup Fuel and Solar Pump Metering	Current Transducer(s) WattNode Pulse	Current transducers measure instantaneous amperage. WattNode Pulse measures line voltage and power factor. The WattNode Pulse converts all three measurements into kW.	Electric sites only.
	Flame sensor	For gas sites, a simple flame sensor (thermocouple) will be used to determine when the backup heater is firing. Backup water heater manufacturer specifications, along with on/off readings from the flame sensor will be used to calculate therm usage.	Gas sites only.
	Pump status relay	Simple relay indicating solar circulation pump status as on / off	Used for active solar thermal systems to detect malfunction and estimate parasitic load.

TABLE 3-1 (CONT'D): RECOMMENDED METERING EQUIPMENT

Meter		Description	Attributes
Data Acquisition	Obvius Acquisuite A8812	Versatile data acquisition server that is ideal for collecting electric, water, gas, steam, and other energy parameters over the web.	Connects up to 32 Modbus devices through RS-485 and TCP/IP, as well as 8 user selectable inputs for pulse, analog and resistive output devices.

The minimally-invasive Sunnovations Ohm meters were used for single-family residential homes (with active systems) and some small multi-family and commercial facilities. The Ohm meter was selected for use at sites that have low flows that would be difficult to accurately capture without very expensive flow meters such as the Flexim. The Flexim costs as much as many single-family SWH systems and therefore is not a cost-effective residential metering solution. The Ohm meter provided a low-cost solution that adequately captures the relevant solar and backup system heat readings for these low-load sites. Additionally, the Sunnovations Ohm meter came with a user-friendly web-based dashboard that was used as a recruitment tool for residential homes and small businesses. In addition to providing data to host customers, the Sunnovations software automates transfer of data to Itron which minimized data processing time. If a home wireless network was not accessible for the Ohm meter, Dynasonic or Flexim flow meters were used with the Obvius Acquisuite.

Dynasonic ultrasonic time transit meters were used on the largest number of sites, and are ideal for multifamily and commercial facilities with sufficiently high flows (> ~ 1-2 FPS; i.e. 0.6 – 1.2 GPM for ½", 9.8 – 19.6 GPM for 2"). This solution provided a good compromise between cost and accuracy for most sites. In addition to the flow meter and temperature sensors, current transducers combined with WattNode Pulse meters recorded instantaneous power (kW) as well as total energy (kWh) for electric backup heaters. For gas sites, gas usage was calculated using a simple flame sensor that recorded on/off times combined with manufacturer specifications. Data from all metering points at these sites were fed into an Obvius Acquisuite A8812 data logger capable of several weeks of data storage, along with a cellular modem to upload data to FTP sites at regular intervals.

The more expensive Flexim flow meters were primarily used at single family sites with passive systems, and any multifamily or commercial sites with very low flows or particularly challenging metering scenarios. The remainder of the metering components at these sites (WattNode Pulse meter, Obvius logger, etc.) remained the same as described for the Dynasonic systems.

The number of different meter and flow meter types installed are shown below in Table 3-2 by Budget Program and System Type. As described above, the smaller and simpler systems, found mostly in residential and smaller multifamily sites, utilized Ohm meters, while the more complex systems used Obvious meters with Dynasonic or Flexim meters.

TABLE 3-2: NUMBER OF METERS INSTALLED BY METER TYPE AND BUDGET PROGRAM

Budget Program	System Type	Metering Type	Obvius Flow Meter Type	Quantity of Sampled Sites
Commercial Pools	Active	Obvius	Dynasonic	22
Commercial Pools*	Active	NA	NA	4
Commercial/Multifamily Residential	Active	Obvius	Dynasonic	20
Commercial/Multifamily Residential	Active	Obvius	Flexim	8
Commercial/Multifamily Residential	Active	Ohm	NA	3
Low Income Multifamily Residential	Active	Ohm	NA	5
Low Income Multifamily Residential	Active	Obvius	Dynasonic	16
Low Income Multifamily Residential	Active	Obvius	Flexim	5
Low Income Single Family Residential	Active	Ohm	NA	4
Single Family Residential	Passive	Obvius	Dynasonic	1
Single Family Residential	Active	Ohm	NA	8
Single Family Residential	Passive	Obvius	Flexim	6

* There were four sites in the sample determined to be zero savers, which were not metered.

Wind speed data at the collectors was also logged for four solar pool heating sites utilizing unglazed collectors. Ambient temperature and humidity were also measured, as these are factors that affect system efficiency and can be measured cost-effectively. Two anemometers were installed per site to capture wind speeds at the solar array and at a height of 10 meters. This information helps to quantify the effects of wind, temperature, and humidity on system performance, and supports inputs for TRNSYS models. Analysis of these data will be presented in the upcoming CSI-T Technical Report.

3.1.2 Data Cleaning and Processing

Itron metered facilities were separated into two categories for data cleaning and processing. These categories were based on the type of meter installed at the facility, Ohm meters or Obvius data loggers. Because of the differences in metering equipment and format of data received, different data cleaning and quality control procedures had to be performed.

Ohm-Metered Sites

Ohm data were downloaded from the Sunnovations website on a site-by-site basis. New data are uploaded from the Ohm meter to the Sunnovations server on an hourly basis in fifteen-minute increments, where it records the timestamp, the solar energy delivered, heater, usage, and energy losses in cumulative watt-hours (Wh). Additionally, temperatures (°F) of the solar loop into the tank, solar loop out of the tank, and at the top of the tank are provided. An optional data column contains the auxiliary tank temperature for two-tank systems.

Once data are downloaded, all months of data from a site are combined into a single site-level dataset. The energy columns are transformed from units of Wh to BTU. An additional 'interval BTU' column is then created, which represents the instantaneous, incremental energy rather than the cumulative energy gain. As part of the data cleaning and quality control, any data logged from the day of install was removed, and the file is then gleaned for gaps in the timestamps greater than fifteen minutes and flagged at each indiscretion.

Often, gaps in data appear to occur when the Ohm system is not able to write out the data to the Sunnovations server. However, during this time, the system is still recording the cumulative energy values internally. As they are not being written out however, after a gap in data, there is usually an implausible spike in the incremental energy flows. The evaluation team identified these spikes and set the data point to missing in these situations.

Finally, a data backbone is created in 15-minute increments over the duration of the meter installation for each site, and filled with clean data. This step is taken to ensure that no 15-minute time interval is skipped. The final data are then merged with weather data from the California Irrigation Management Information System (CIMIS)[2] station nearest to each site.

Obvius Data Logger Sites

Sites with either Dynasonic or Flexim ultrasonic flow meters use Obvius data loggers to record measurements in one-minute intervals. Data collected include flowrate (gallons per minute) and temperature (degrees-F) at various locations in the system, as well as pump runtime and power draw (Watts). Flow meters and temperature sensors are placed to measure energy delivered to the water by either the solar storage tank or collectors. Some systems required a second flow meter be installed to capture all data necessary for analysis.

New data are uploaded from the Obvius data logger to an FTP site daily. Data are downloaded and combined into a single site-level dataset. As part of the data cleaning and quality control process, any data recorded from the day of install is removed. The remaining data are reviewed for gaps and other anomalies. The two most common data quality issues are low signal strength of flow meter readings and missing auxiliary heater flue temperature data. Observations with low signal strength, caused by air in the pipe or turbulent flow, are dropped. Missing flue temperature readings result from sensor and wiring being exposed to high temperature exhaust. Gaps occur as flue temperature increases and resume once temperatures return to ambient conditions. An algorithm was developed to determine runtime of the heater and fill these gaps based on changes in flue temperature.

[2] http://www.cimis.water.ca.gov/

A data backbone is created in one-minute increments over the duration of the meter installation for each site and filled with the cleaned data. This step is taken to ensure no one-minute time interval is skipped. The data are exported and read into DView for visual quality control. This process compares flow rates, temperatures and pump runtimes against expected minimum and maximum values.

3.1.3 Simulation of Savings

TRNSYS is directly used as the simulation engine for the CSI-Thermal online calculator for both commercial pools and commercial/multi-family SWH systems for rebate purposes, and indirectly used as the basis for the single-family residential systems. Therefore, it made sense to utilize TRNSYS determine see how the real-world systems, based on the onsite visits and metered data, compare to the simulated models. To accomplish this, a series of modeling steps were conceived to track the changes in predicted performance from the information in the public tracking data[3] to the final simulations which reflect all of the known information gleaned from the site visits and from the site-measured data.

Simulation Creation Process

The first step in the TRNSYS modeling process for the commercial swimming pool systems, the multi-family/commercial SWH systems and the single-family residential SWH systems was to re-create the simulation results for the systems that were submitted to the online calculator. Based on project information provided by the CSI-Thermal team, each of the project sites was re-simulated in the latest version of the CSI-Thermal TRNSYS engine (v11). This eliminates any bias caused by systemic changes in the modeling program over the past several years (wind speed assumptions have changed for example) and allows the comparisons to be made on an equivalent project-by-project basis. The results from these new simulations were then compared to the original results and any significant discrepancies were investigated. The next steps in the modeling process are specific to the type of system being studied and are discussed individually in the following sections.

[3] Public tracking data for the program can be accessed on the CSI Thermal Statistics website. http://www.csithermalstats.org/download.html.

Commercial Pools: Based upon onsite visits, deviations from the system details in the public tracking data to the real-world installations were noted and quantified. The deviations included the following items:

- Solar collector model and size,
- Total number of collectors and number of collectors in series,
- Collector tilt and azimuth,
- Rough estimate of solar shading,
- California Climate Zone (location),
- Pool type (indoor or outdoor) and size,
- Pool use (seasonal or all year),
- Pool cover usage, and
- Pool set-point temperature.

There are a large set of variables that are assumed in the TRNSYS models that were not verified and/or changed based on the site visit. These items include pump flow rates and power consumption, pipe sizes (to/from the arrays and to/from the pool), sheltering of the pool from wind and solar, and pool activity level to name just a few. A full list of the assumptions for the pool models can be found in the handbook for the CSI-Thermal Commercial Pool program.

The second step in the pool modeling process was to simulate the pool systems based on the actual onsite findings and compare the results to the system designs from the public export tracking data. It should be noted that several of the actual onsite system findings required modifications to the TRNSYS representation of the solar pool system to better match the real-world conditions. This includes the addition of multiple solar collector arrays (different slopes and azimuths for the collectors at a location) and the elimination of the auxiliary heating systems for some of the pools.

In all cases, the TRNSYS engine calculates the savings for the solar pool system based on a comparison to a baseline pool heating system. This baseline pool heating system is modeled with the same pool (same size and same indoor/outdoor location), in the same climate location, with the same heating set points, and with the same operation (seasonal/all-year and pool cover usage) as for the solar pool case.

Commercial / Multifamily Residential and Low Income Multifamily Residential: Based upon onsite visits, deviations from the system details in the public tracking data to the real-world installations were noted and quantified. The deviations included the following items:

- Solar collector model
- Total number of collectors and number of collectors in series
- Collector tilt and azimuth
- Rough estimate of solar shading
- California Climate Zone (location)
- Type of Building (used to set the DHW draw profile)
- Recirculation loop for hot water (yes or no)
- System configuration (# of tanks, location and type of heat exchanger, auxiliary heat source, freeze protection, etc.)
- DHW consumption estimate (based on # of occupants, loads of laundry, # meals served etc.)
- Solar storage capacity (number of tanks and total volume)
- Auxiliary water heater capacity (number of tanks, total volume, and total auxiliary heating capacity)
- Set point for auxiliary heater and for delivered water (tempering setting)

There is a large set of variables that are assumed for the TRNSYS models that were not verified and/or changed based on the site visit. A few of these items include pump flow rates and power consumption, pipe sizes (to/from the arrays, recirculation loop, etc.), and solar & recirculation control setting. A full list of assumptions for the commercial/multi-family SDHW models can be found in the handbook for the CSI-Thermal Commercial SWH program.[4]

There were several modeling steps in the commercial/multifamily modeling process which enabled the evaluation team to understand the affect that different changes had on the overall savings:

- Step 1: Re-developing simulation models based solely on the submitted information in public tracking data.
- Step 2: Modeling deviations from system information in the public tracking data to system findings determined from the onsite visits (assuming no change to TRNSYS model configurations).

4 https://www.csithermal.com/media/docs/Standard-100_Calculator_User_Guide_20140520.pdf. Section 5 highlights the assumptions made for the Commercial/Multifamily parameters.

- Step 3: Updating the TRNSYS model with revised site-specific system configurations. The original calculations are built on standard system configurations for different system types. Unlike commercial pool systems which were simple and typically matched the TRNSYS configurations nicely, the commercial/multifamily systems were more complex, with the location of piping and valves at different points in the system.
- Step 4: Revising simulations based on real average water draw across the metering period. The original simulations are based on user-specified flow rate (gallons per day), typically referenced from the Maximum Gallon Per Day Guideline Table.[5] These flows are updated based on the metering data collected.

As with the commercial pool simulations, energy savings are calculated in the TRNSYS engine, based on a comparison to a baseline DHW system.

Single-Family Residential and Low Income Single Family Residential: Unlike the commercial pool and the commercial/multi-family SDHW systems, the residential SWH system rebates are not based on a customized TRNSYS engine written for the CSI-Thermal program, but based on ratings by the SRCC, and referred to as OG-300 ratings. These are a certification for a complete solar thermal system to the current ICC 9010/SRCC 300 Solar Thermal Systems Standard.[6] These reflect many assumptions about a residential SWH system, including a water draw profile (daily amount of 64.3 gallons), and a collector slope and azimuth, to name a few. As the rating package is proprietary to SRCC, the evaluation team did not have access to the actual system models used to estimate single family savings. However, TESS and SRCC are currently finalizing details to use TRNSYS models for a new rating engine, therefore TESS utilized these new models to mimic the set of conditions mandated by SRCC in their OG-300 protocol, and closely estimate the ratings for these single family residential systems.[7]

As with the other system types, these single family residential systems were compared to a baseline system to estimate the energy saved.

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5 The table can be found in Appendix E, Table E-1 of the CSI-Thermal Handbook. http://www.gosolarcalifornia.ca.gov/documents/CSI-Thermal_Handbook.pdf

6 The standards can be viewed on SRCC's website, http://www.solar-rating.org/standards/index.html

7 It is critical to note that the "ratings" that we calculate are not to be considered SRCC ratings and should be referred to as estimated ratings. Only SRCC can generate official SRCC rating for residential SDHW systems.

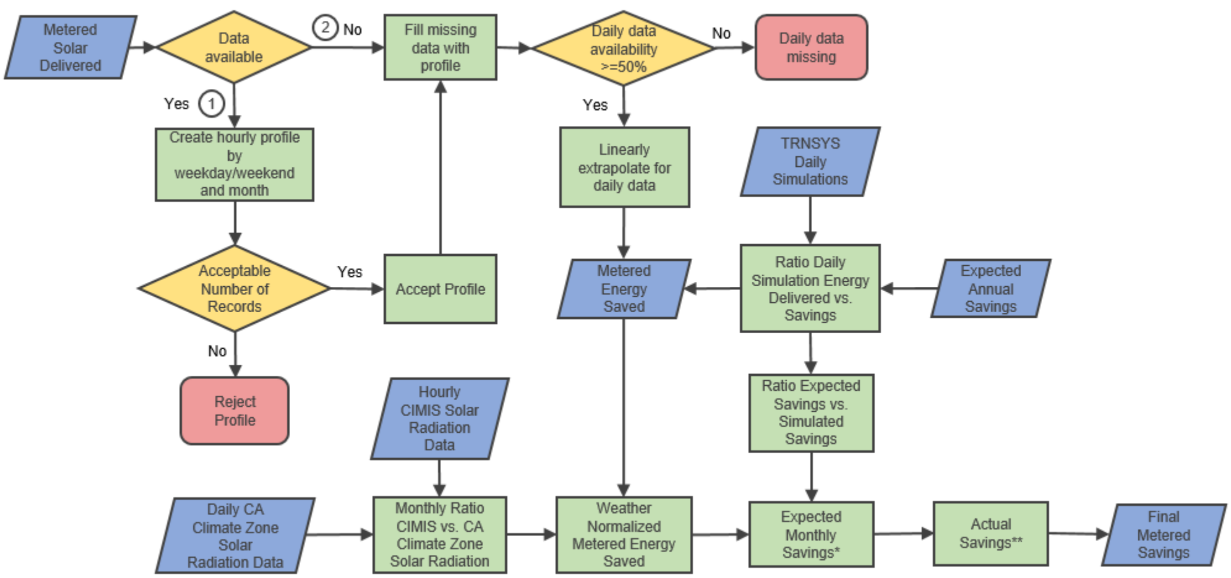
Site-Specific Savings Calculations

The savings calculations for SWH systems were mostly consistent across all budget programs and metering types. Once the data cleaning and quality control was completed, the evaluation team focused on analysis of the metered data. The analysis procedures to calculate actual savings followed four main steps:

- Fill in missing metered data,
- Calculate savings from the metered energy delivered by multiplying metered solar by the relationship between simulated energy saved to simulated solar energy,
- Normalize savings to typical year weather, and
- Compare to expected savings.

These steps are summarized in the flow chart in Figure 3-1 below.

FIGURE 3-1: SAVINGS CALCULATIONS FLOW CHART



Fill in Missing Data

Metering data can be missing for a variety of reasons. All the metering equipment installed at these sites are linked to an internet connection, and therefore will upload time-series data automatically. However, this makes them susceptible to lapses in internet connectivity, and in these situations, data will be missing. Other possibilities can involve failing metering equipment or temperature probes.

The evaluation team took several steps to fill in missing data where necessary. The first involved creating an hourly profile for each site. For Commercial Pools, this hourly profile was created by season as pool operation is not expected to vary much within a season. Commercial Pools all used Obvius data loggers, which provided data in one-minute increments. The hourly profile represented the average values of one-minute data for that hour, throughout the season. If the hourly profile had over 1,000 one-minute records of good, usable data for the season, the profile was deemed to be a valid profile. This profile was then merged back onto the time-series data, and anywhere a value was missing, and the profile was deemed to be valid, the missing data were filled in with the profile data.

For other facility types, the evaluation team created this hourly profile slightly differently. Rather than creating the hourly profile by season, it was created by month and day-type (weekday versus weekend). Residential facilities are more sensitive to differences based on day types and time of year than pools are, so a finer profile was believed necessary. For Obvius-metered sites, the number of records within the month to consider the profile valid were changed to 500 for weekdays and 200 for weekends. For Ohm-metered sites, the data were provided in 15-minute increments rather than 1-minute increments, so the number of records for a valid profile were set to 24 for both weekends and weekdays, representing 20% of the month.

Once the hourly profile fills in the sub-hourly time-series data where a valid profile was available, the metering data were summed up to the daily level where a second level of data filling was performed. If a day had a minimum of 50% of the time-series records with good data, the total energy for a given day was extrapolated linearly based on the available data. Otherwise, the daily energy flow was set to zero.

The final step of data filling occurred at the very end, and accounted for any days where missing data remained after the previous two steps. Once energy savings were calculated at a daily level, which required several other analysis steps described in the following sections, the dataset was analyzed to see what percent of the month had daily energy savings values. If over 70% of the days in the month were populated with a daily energy saved value, the overall monthly savings were extrapolated based on the number of days of data, and the number of missing days of data. If data existed for less than 70% of the month, then the entire month was set as missing.

Calculate Energy Savings based on TRNSYS Simulations

The on-site metering data provided site-specific energy flows for analysis over the course of the year. These data were analyzed to get an understanding of when the system received energy from solar versus auxiliary heat, what the site's water heating loads were, and the set point temperatures of the system. The Ohm meters calculated these energy flows based on several tank temperature measurements. The water draw, however, is not directly measured, so energy flows are calculated internally based on changes in enthalpy in the storage and backup heater tanks. The Obivus-loggers, on the other hand, included flow meters which were able to directly measure the water flowing through the solar loop. These data, used in conjunction with the temperature sensors, were used to calculate the energy delivered. However, because the metering data provided the data to analyze energy delivered to the system, not energy saved, the evaluation team still needed to understand the relationship between the energy delivered to a system and the energy saved. To do this, the evaluation team relied on TRNSYS simulation data. The TRNSYS simulation data provided daily data on both energy delivered and energy saved. The evaluation team used this linear relationship between the two to come up with a site-specific equation that would relate the metered energy delivered to a calculated energy saved. The minimum, maximum, and average slopes for each budget program are shown below in Table 3-3.

TABLE 3-3: ENERGY DELIVERED TO ENERGY SAVED SLOPES BY BUDGET PROGRAM

Budget Program	Metering Type	Minimum Slope	Maximum Slope	Average Slope
Commercial Pools	Obvius	0.84	1.10	0.92
Commercial/Multifamily Residential	Obvius	1.08	1.22	1.19
Commercial/Multifamily Residential	Ohm	1.14	1.19	1.17
Low Income Multifamily Residential	Obvius	0.85	1.24	1.18
Low Income Multifamily Residential	Ohm	1.03	1.22	1.16
Low Income Single Family Residential	Ohm	0.78	1.15	0.94
Single Family Residential	Obvius	0.55	1.63	1.06
Single Family Residential	Ohm	0.30	1.30	0.71

As shown in Table 3-3, the slopes can vary greatly based on different site-specific factors. The Commercial and Multifamily Residential budget programs were found to have an energy delivered to energy saved ratio of almost 1.2, which was the highest of all budget programs. The Low Income Single Family Residential program had the largest range, resulting from the poor performing unglazed collector systems. Commercial Pools and Single Family Residential systems saw average slopes of just under 1.0.

Normalize Savings to Typical Year Weather

The final step in creating actual monthly savings was to normalize to typical weather. The expected savings were all based on California Climate Zone (CA CZ) weather data.[8] To normalize the metered data, the first step was to map each site to CIMIS weather stations based on longitude and latitudes to identify the closest CIMIS station to each site. The CIMIS stations provide hourly weather and solar radiation data, although, similarly to the metered data, they can also be susceptible to missing data. To account for

[8] http://www.energy.ca.gov/maps/renewable/building_climate_zones.html. The weather data was created to demonstrate compliance with Title 24.

missing data, the evaluation team normalized the weather by taking monthly averages for both CIMIS and CA CZ data. The metric that was averaged across both datasets was the Solar Radiation.

The evaluation team calculated a monthly ratio of CA CZ Solar Radiation to CIMIS Solar Radiation data. This ratio was multiplied by the daily metered energy delivered to calculate a weather-normalized energy delivered value.

Compare to Expected Savings

For most sites, finalizing the actual site-level savings based on metering data ended with the step above. But an additional step was needed for Commercial Pools, as well as a few other sites. The meter installs for Commercial Pools did not start until late in 2016, which did not allow for a full year's worth of data collection to calculate actual savings from. This was also the case for a few other sites, where a month or two of data were missing. Therefore, the evaluation team had to decide how to annualize savings to compare to the expected, annual savings.

Two approaches were discussed for this; the first method was to extrapolate savings for the missing months based on the ratio of CIMIS solar radiation to CA CZ solar radiation for the months where data were missing. The second method was to calculate a site-level gross realization rate for the months where metered data were available, and use that gross realization rate to calculate annual savings. Both scenarios had their potential biases.

The first approach assumed that the only factor to savings was solar radiation. However, there are many factors that could affect savings, with solar radiation being only a single factor. For Commercial Pools, there were multiple sites where the months with the highest solar radiation saw the lowest savings. The second approach had the exact opposite potential problem, in that seasonal variations would not be accounted for. This could potentially result in a seasonal bias, especially for Commercial Pools which did not have as much metered data through the summer.[9]

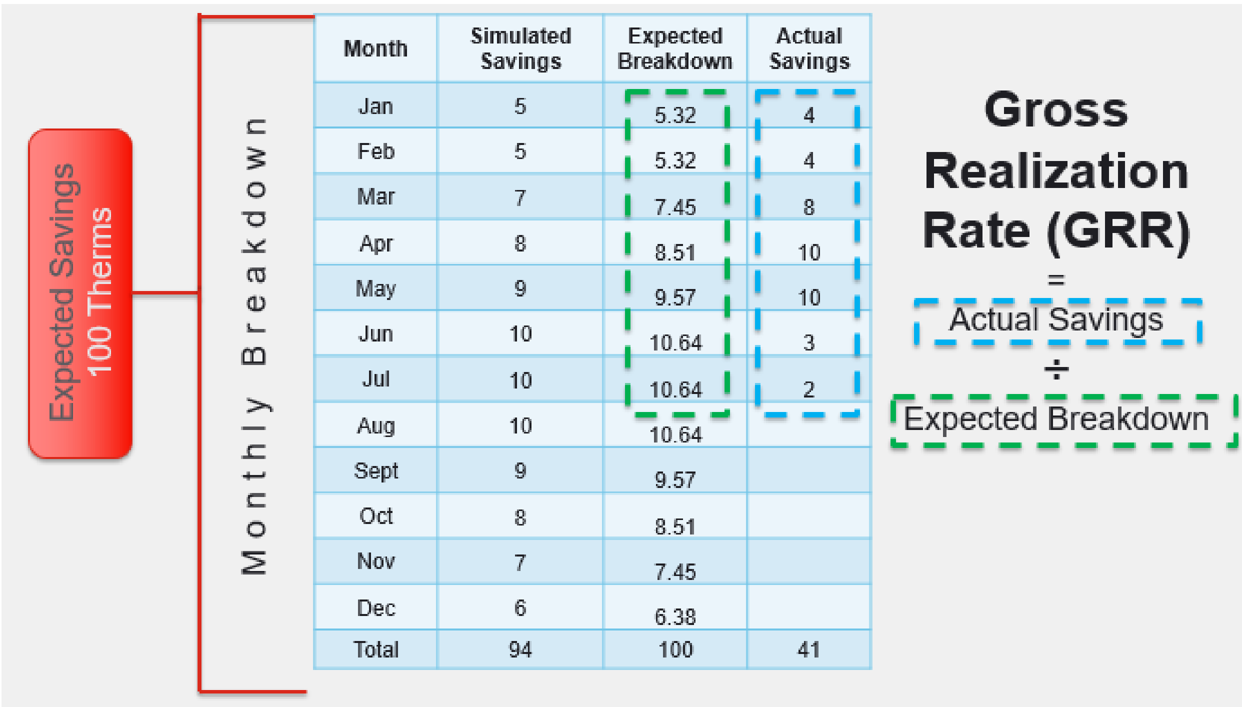
ANALYSIS OF ADDITIONAL POOL METERED DATA

Analysis of additional data found that contrary to what is expected, the addition of summer data for Commercial Pools reduced annual savings for the Commercial Pools budget program. This was due primarily to lower than expected summer usage and discrepancies in seasonal operation claims. These findings were not included in the overall results for this impact report.

[9] These findings are highlighted in the sidebar. For the evaluation report, the metered data was cut off at the end of June, but due to timing between the cut-off date and the date of the final report, additional metering data allowed the evaluation team to provide insights into how this roll up methodology would affect savings based on real data.

However, the evaluation team decided that there was enough annual data to lessen this impact and make this an acceptable approach. Figure 3-2 below shows an example of how the final gross realization rates were calculated.

FIGURE 3-2: CALCULATING FULL YEAR SAVINGS FOR SITES WITH PARTIAL YEAR METERED DATA



Month	Simulated Savings	Expected Breakdown	Actual Savings
Jan	5	5.32	4
Feb	5	5.32	4
Mar	7	7.45	8
Apr	8	8.51	10
May	9	9.57	10
Jun	10	10.64	3
Jul	10	10.64	2
Aug	10	10.64	
Sept	9	9.57	
Oct	8	8.51	
Nov	7	7.45	
Dec	6	6.38	
Total	94	100	41

3.2 STRATIFICATION AND WEIGHTING

Aggregating sample-level savings to the population was performed in several steps. The sample was originally pulled based on budget program and Customer Performance Metering (CPM) requirements,[10] and therefore the evaluation team reviewed the final sample sizes and savings based on these metrics. The CPM metric is required for facilities with an installed capacity greater than 30 kW_{th}. The size differences between these projects and the non-CPM projects was the reasoning behind using this category as a sampling metric, in attempts to capture the effects of the larger sites with the metering requirements. Several stratification approaches were reviewed to ensure that the final sample and stratification method accurately reflected the population, but in the end, the evaluation team decided to

10 The original metering plan memo has been attached in Appendix B.

use the original level of stratification expressed in the original sampling plan, by Budget Program and CPM requirement.

Each stratum was weighted using a savings weight, shown in Equation 1, which is equal to the total therm savings of the stratum's sample, and divides it by the total therm savings of the stratum's population. The stratum-level weights were then multiplied by the site-level therm savings. This meant that the largest sites had a larger effect on the overall gross realization rate (GRR). The equations for the weights are shown below:

$$Savings\ Weights_{stratum} = \frac{(\sum_{stratum} Therms_{sample})}{(\sum_{stratum} Therms_{population})}$$

EQUATION 1

$$Savings\ Weights_{site-level} = Savings\ Weights_{stratum} \times Therms_{site}$$

EQUATION 2

4 SYSTEM PERFORMANCE

4.1 OVERVIEW OF PERFORMANCE

This section summarizes the evaluated impacts for the CSI-T Program. The evaluation team calculated the program's annual impact of therm-equivalent energy savings, looking at combinations of budget program, system type, and program administrator. Greenhouse gas emission reductions from the installation of SWH systems were also analyzed. The evaluation team identified the reasons for discrepancy between expected and actual, evaluated savings. These reasons for discrepancy were broken down by program type to better understand the Program's primary drivers of performance. Finally, the differences between expected and actual system and incentive costs per therm were reviewed, along with any site-specific system eligibility and safety findings.

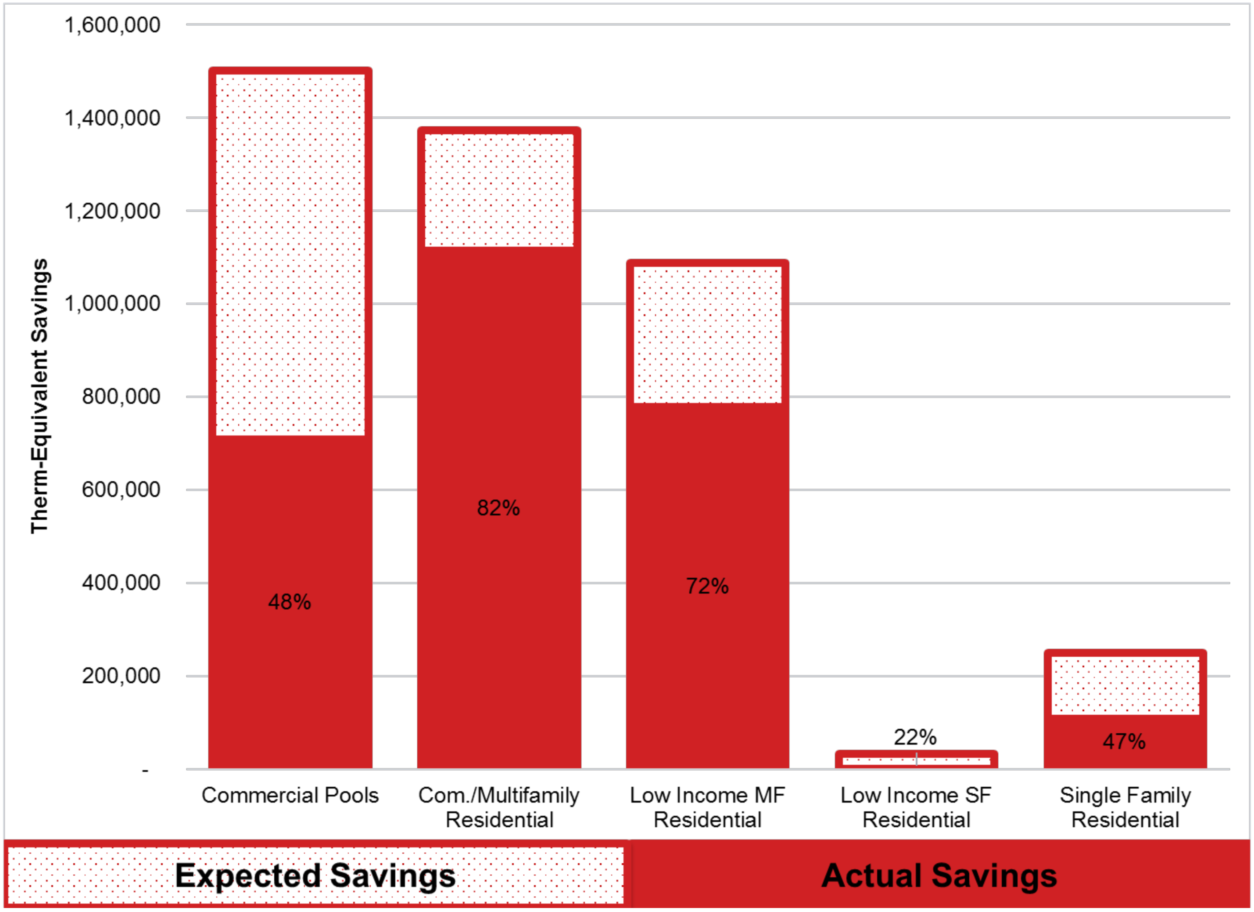
4.1.1 Performance by Budget Program

The evaluation of the CSI-T program yielded an overall program-level gross realization rate (GRR) of 65%.[1] Figure 4-1 shows a comparison of expected and actual therm-equivalent savings, by budget program. The Commercial Pools budget program was expected to have the highest equivalent therm savings, followed by the Commercial/Multifamily and Low Income Multifamily programs. However, due to reasons discussed further on in this section, the Commercial Pools budget program only achieved about half of its expected savings. The Commercial/Multifamily and Low Income Multifamily programs, on the other hand, performed very well, and achieved over 70% of their expected savings. The overall gross realization rates and related evaluation statistics are found below in Table 4-1. Note that no program exceeded expected savings.

[1] The gross realization rate is defined as the percent of the expected savings that are actually realized.

$$GRR = \frac{Savings_{Expected}}{Savings_{Actual}}$$

FIGURE 4-1: EXPECTED VERSUS ACTUAL SAVINGS BY BUDGET PROGRAM



* GRR results are only statistically significant at 80/20 confidence/precision for Commercial/Multifamily budget program.

Table 4-1 also shows the budget programs which a precision of ±20% at 80% confidence. Although the sample was originally drawn to meet on 90/10 confidence and relative precision requirements, the overall results met 80/20 confidence/precision. This was due to a number of factors that increased variability within the sample. Solar thermal systems exhibit a range of complexities that are not necessarily observed in other solar technologies like photovoltaics that complicate accurate estimation of savings. Examples of this variability are discussed further on in this section. The confidence level represents the probability that the interval actually contains the target quantity, while the precision expresses the interval that is believed to contain the estimator. For example, stating that if the total program meets 80/20 confidence and precision suggests that the program GRR is 65% ± 13%. The evaluation team explored the 90/10, 80/20, and 70/30 tests for statistical significance. The team looked to see if a distribution showed 10% precision under a 90% confidence interval. If it did not, we changed to see if it showed 20% precision under an 80% confidence interval, and finally, if this was not obtained, we changed for 30% precision under a 70% confidence interval. The overall program met 80/20 confidence and precision targets, but when looking at the results by budget program, the only Commercial / Multifamily Residential budget program met this level of confidence and precision.

TABLE 4-1: CSI-THERMAL PROGRAM EVALUATION RESULTS BY BUDGET PROGRAM

Budget Program	Gross Realization Rate	Confidence / Precision
Commercial Pools	48%	Fail 70/30
Commercial/Multifamily Residential	82%	Pass 80/20
Low Income Multifamily Residential	72%	Fail 70/30
Low Income Single Family Residential	22%	Fail 70/30
Single Family Residential	47%	Fail 70/30
Total Program GRR	**65%**	Pass 80/20
Total Program Actual Savings	**2,749,655 therms**	

4.1.2 Performance by System Type

System performance for different system types was analyzed by budget program, shown below in Figure 4-2, with the purpose of trying to understand whether different systems appeared to face difference challenges with respect to performance. Table 4-2 also shows the minimum and maximum site-level GRRs within each budget program and system type, for comparison. The sample of both Commercial/Multifamily Residential and Low Income Multifamily Residential systems included only Indirect Forced Circulation (IFC) systems with differing types of freeze protection, either drainback or glycol.[2] When comparing results by budget program, it appears that the IFC-drainback systems performed much differently for the Low Income Multifamily program than they did for the Commercial/Multifamily program, achieving less than a 30% realization rate for the low-income program. However, comparing all IFC-drainback systems, over 70% of them achieved realization rates less than 50%, with only three systems driving the higher results for the IFC-drainback systems in the Commercial/Multifamily Residential program.

Four different system types existed within the sample of the Single Family Residential program, Direct Integral Collector Storage (DI), IFC with both types of freeze protection, and Indirect Thermosiphon (IT) systems. These also had a range of system performance, with gross realization rates between 22% and 79%. Again, the IFC-drainback systems performed worse than the IFC-glycol systems, and while IT systems saw the highest average performance of all the single-family systems, this higher average was driven by a single high performing system.

[2] A handful of other system types such as ICS and thermosiphon are installed under these programs. However, the savings for these are estimated using single family SRCC-OG300 and are tiny when compared to expected budget program savings.

It is important to note that because the evaluation team did not use "system type" as a strata variable in their sample design, the results displayed here by budget program and system type are not statistically significant and are provided for informative purposes only. These findings indicate that while factors like system type and freeze protection type (drainback versus glycol) may affect savings, other drivers of solar water heating system performance are more significant for this sample.

FIGURE 4-2: SYSTEM TYPE PERFORMANCE ACROSS BUDGET PROGRAMS AND SYSTEM TYPE

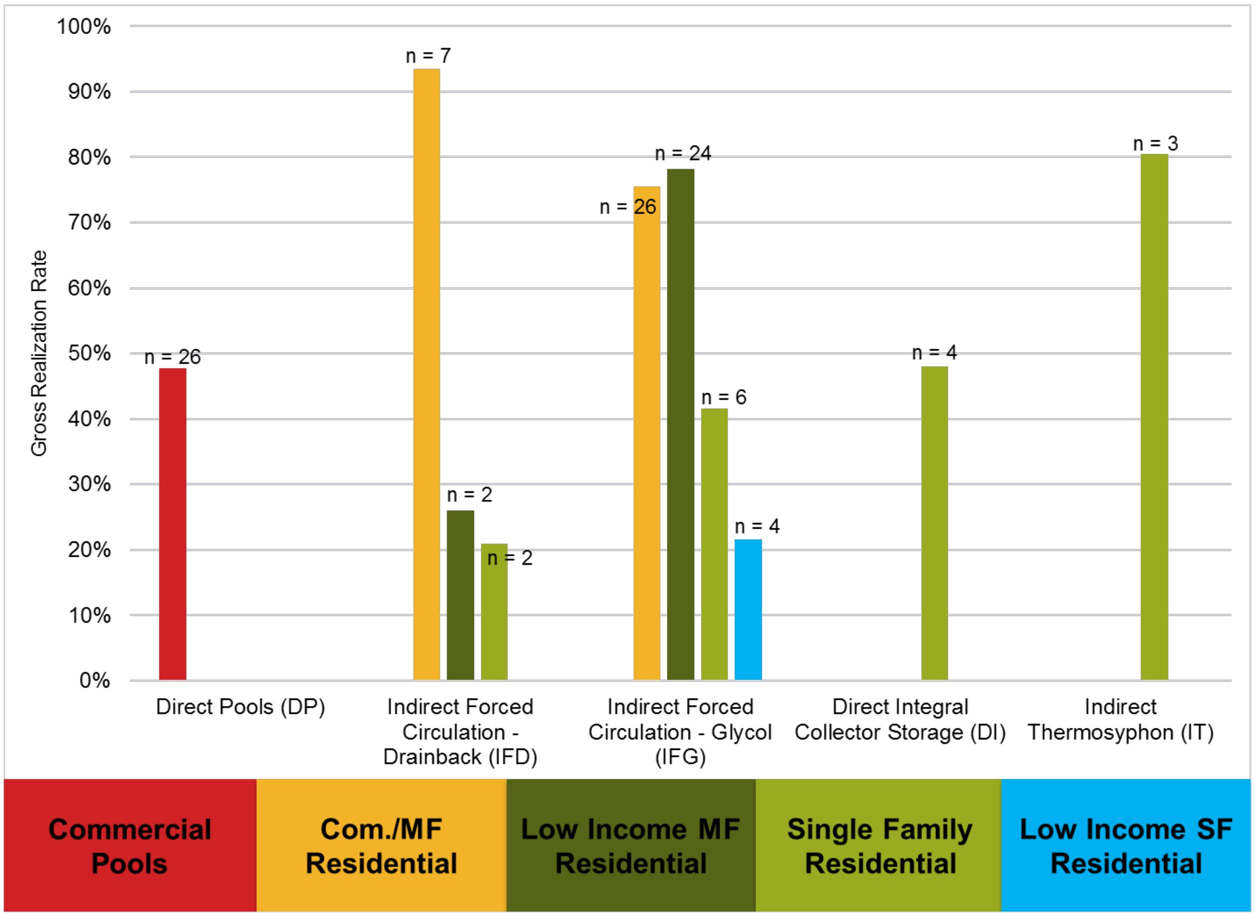


TABLE 4-2: CSI-THERMAL PROGRAM EVALUATION RESULTS BY BUDGET PROGRAM AND SYSTEM TYPE

Budget Program	System Type	GRR	Min. GRR*	Max. GRR	n
Commercial Pools	Direct Pools	48%	-97%	537%	26
Commercial/Multifamily Residential	IFC - Drainback	93%	28%	209%	7
	IFC - Glycol	75%	1%	283%	26
	IFC - Drainback	26%	21%	39%	2
Low Income Multifamily Residential	IFC - Glycol	78%	-1%	426%	24
Low Income Single Family Residential	IFC - Glycol	22%	1%	40%	4
Single Family Residential	Direct Integral Collector Storage	48%	1%	72%	4
	IFC - Drainback	21%	13%	27%	2
	IFC - Glycol	42%	11%	82%	6
	Indirect Thermosyphon	81%	13%	152%	3
Total		**69%**	**-97%**	**537%**	**104**

* A negative GRR represents systems a SWH system that actually results in a higher natural gas energy usage than the baseline system. These cases are explained in further detail below.

** The evaluation sample was not pulled based on system type, and therefore results by system type are not designed to be statistically significant at the 80/20 level. These are provided for informative purposes only.

4.1.3 Performance by Program Administrator

System performance for the three major PAs in the sample was also analyzed (Table 4-3), and by PA and Budget Program (Figure 4-3). PG&E was found to have the highest GRR at 98%, followed by SCG at 49% and CSE at 45%. Although the findings for PG&E look substantially different than those for CSE and SCG, four large projects drive these findings. As seen in Figure 4-3, the PG&E Commercial Pool GRR is 143%. However, one large project drove this GRR up, with a value of over 500%. The PG&E Commercial / Multifamily Residential sector was driven by one of the two PDP projects, which saw a GRR of just over 100% but made up almost 45% of the PG&E Commercial / Multifamily Residential savings. Finally, the two largest projects in the PG&E Low Income Multifamily sample saw realization rates over 200%. Reasons for some of these discrepancies are discussed in Section 4.2.

SCG also saw large swings in GRRs, ranging from -97% to 426%. While there were some very high realization rate projects in this sample, there were also many with very low GRRs, less than 50%. These lower-GRR projects ultimately brought the overall GRR for SCG down to 47%. One driver of these lower savings is the large number of commercial pools with lower than expected savings in SCG's service territory. CSE, overall, was only found to have a single pool site with a GRR over 100%.

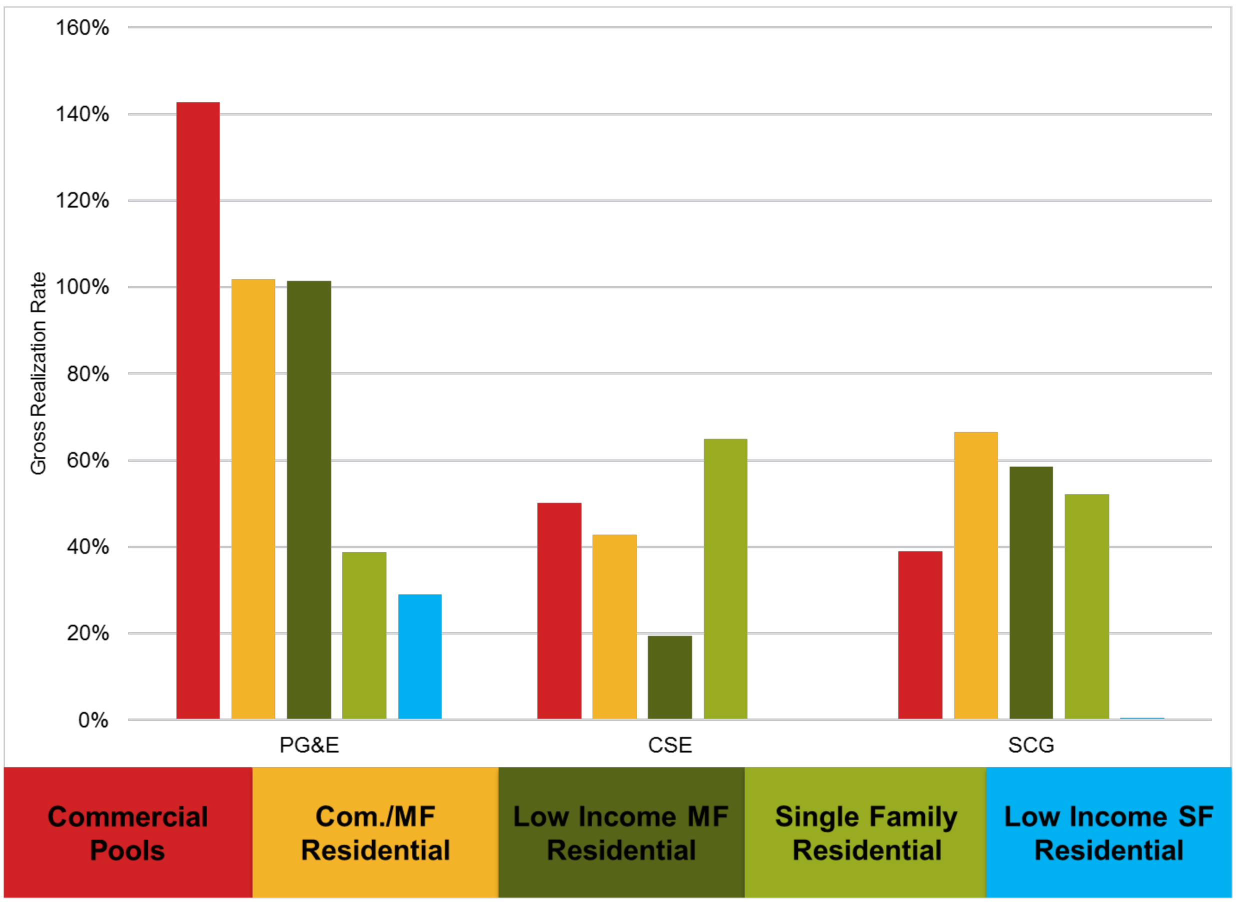
Like system type, it is important to note that because the evaluation team did not use "PA" as a strata variable as a stratification variable, therefore, the results displayed here by budget program and PA are only for the metered sites and may not be statistically significant at this level. These are provided for informative purposes only.

TABLE 4-3: CSI-THERMAL PROGRAM EVALUATION RESULTS BY PA

PA	GRR	Min. GRR	Max. GRR	n
PG&E	98%	0%	537%	39
CSE	45%	0%	105%	12
SCG	49%	-97%	426%	53

* The evaluation sample was not pulled based on Program Administrator, and therefore results by system type are not designed to be statistically significant at the 80/20 level. These are provided for informative purposes only.

FIGURE 4-3: PROGRAM ADMINSTRATOR PERFORMANCE ACROSS BUDGET PROGRAMS



* The evaluation sample was not pulled based on Program Administrator, and therefore results by system type are not designed to be statistically significant at the 80/20 level. These are provided for informative purposes only.

4.1.4 Environmental and Economic Impacts

Quantifying GHG impacts that result from the installation of solar thermal systems were another area of focus for the CSI-T program evaluation. These impacts were quantified in units of CO_{2e}, which represents the amount of CO_2 that would have the equivalent global warming impact. The evaluation team utilized the CSI-T Statistics emissions factors prescribed by the Air Resources Board for fuel- and territory-specific offsets. These factors are presented below in Table 4-4.

TABLE 4-4: EMISSIONS FACTORS AND SOURCES AS PRESENTED BY CSI THERMAL STATISTICS

Fuel	Emissions Factor	Units	Source
Natural Gas	0.0053156	MT CO_{2e}/Therm	ARB Scoping Plan, Appendix II (2008), p.I-231[3]
Propane	0.2099	MT CO_{2e} /MWh	ARB's Regulation for the Mandatory Reporting of Greenhouse Gas Emissions (MRR), Section 95115 (Stationary Fuel Combustion Sources)[4]
Electricity – PG&E	0.202	MT CO_{2e} /MWh	PG&E Testimony in A.15-06-001[5]
Electricity - SCE	0.33	MT CO_{2e} /MWh	SCE Testimony in A.14-06-010[6]
Electricity – SDG&E	0.325	MT CO_{2e} /MWh	SDG&E Testimony in A.14-04-018[7]

The overall findings for greenhouse gas emissions impacts are summarized in Table 4-5 below. Overall, the program was found to save over 14.5 thousand metric tons of CO_{2e} annually. The evaluation team also looked at the total metric tons saved since the inception of the program, in 2010, and found that over 42 thousand metric tons of had been saved. The EPA provides comparisons of greenhouse gas emissions to equivalent results. Cumulative program savings since 2010 are equivalent to the annual greenhouse gas emissions output for over 4,400 homes.[8]

3 https://www.arb.ca.gov/cc/scopingplan/scopingplan.htm

4 https://www.arb.ca.gov/cc/reporting/ghg-rep/regulation/mrr-2014-unofficial-02042015.pdf

5 https://www.pge.com/en_US/residential/your-account/your-bill/understand-your-bill/bill-inserts/2015/june/archive-june-2015-bill-inserts.page

6 https://www.sce.com/wps/wcm/connect/3567e431-76eb-493d-8ee4-c566de347c65/GHG_Notice.pdf?MOD=AJPERES

7 https://www.sdge.com/sites/default/files/regulatory/GHG_Revenue_and_Reconciliation_Application.pdf

8 Total home energy usage from all fuel sources were converted from their various units to metric tons of CO_2, and added together to obtain total CO_2 emissions per home. https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

TABLE 4-5: GREENHOUSE GAS REDUCTION DUE TO PROGRAM

Budget Program	Annual GHG Reduction [MT CO_2 eq.]	Cumulative GHG Reduction [MT CO_2 eq.] **
Commercial Pools	3,812	6,961
Commercial/Multifamily Residential	5,974	21,142
Low Income Multifamily Residential	4,178	11,954
Low Income Single Family Residential	36	76
Single Family Residential	648	1,934
Total	14,648	42,067

* This column represents cumulative GHG reduction between 2010 and 2016.

4.2 DISCREPANCY FACTORS

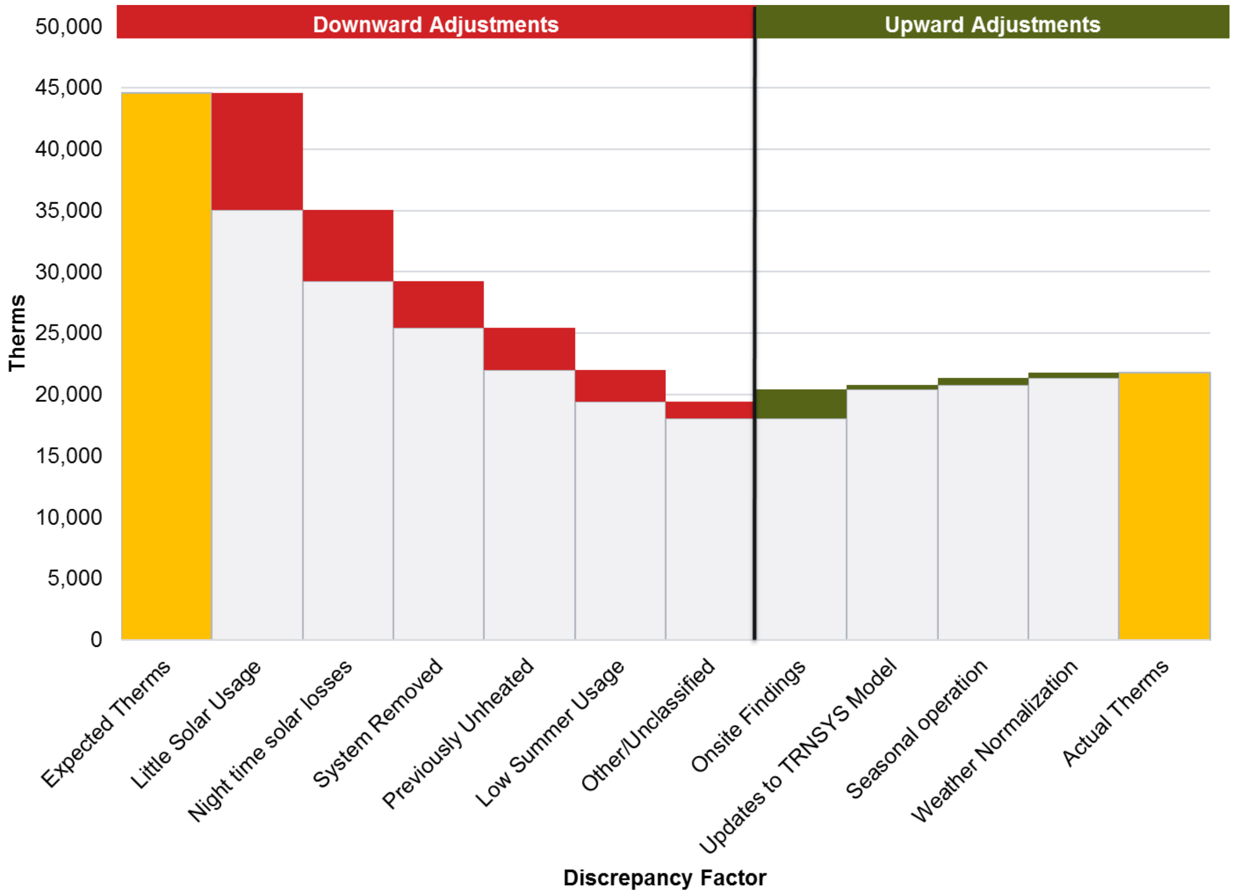
Many of the metered sites showed much lower or higher than expected savings. The evaluation team worked to identify the reasons for these difference, which are summarized in this sub section at the budget program level.[9] The upcoming Technical Report will go into much more depth on these reasons per site with more detailed analysis of both metered and simulated performance.

4.2.1 Commercial Pools Budget Program

Eighty percent of the Commercial Pool installations were in SCG territory, and therefore made up the largest portion of the Commercial Pools evaluation sample. Commercial Pools saw more zero-saver sites than other facility types, and unlike other facility types, an external source to heat water is not a critical piece of daily energy usage for every facility, as there were sites in the sample which were found to not have existing pool heaters prior to the installation of the solar thermal system. The evaluation team attempted to quantify the reasons for why the evaluated savings looked so different than what was expected. Figure 4-4 displays the positive and negative discrepancy factors identified in the Commercial Pool sample that led to the overall gross realization rate. Zero savers, night time solar losses, and little solar usage were the main drivers of the reduction in savings, accounting for a 50% reduction in the expected savings of the sampled sites. As the majority of these sampled facilities were located in the SCG territory, it was not feasible to break out discrepancy factors by PA and provide any reasonable disaggregation of results. A description of the major discrepancy factors follows.

9 The discrepancy factors identified here are representative of the sampled sites, but the percent changes have not been weighted and are not designed to be rolled up to the population.

FIGURE 4-4: DISCREPANCY FACTORS FOR THE COMMERCIAL POOL SAMPLE



Little Solar Usage

Four of the sites in the sample were categorized under this discrepancy factor. For these sites, the metered hot and cold temperatures for these facilities showed little to no change during the duration of the metering period, or the pump which sent water up to the collectors never turned on, resulting in very few savings throughout the duration the pump was installed. In some cases, it appears that a manual valve was being turned on and off regularly, but it was often turned the wrong way. In other cases, it appeared that the system was never being used.

One facility was also found to have an excessively high amount of auxiliary heater usage. The metered data showed that the solar pump only turned on occasionally to send water up to the collector, but whenever the solar pump turned on, the metered data also showed the auxiliary heater operating. This trend was identified even into the summer months, indicating a poorly functioning solar thermal system which required excessive auxiliary heating. Overall, the reduced solar usage at these sites resulted in a 21% reduction in savings for the Commercial Pools sample.

System Removed

Of the 120 sites visited as part of this CSI-T program evaluation, Commercial Pools were the only budget program to see systems which had been removed. The overall effect on the Commercial Pools sample was to reduce savings by 9%. These were identified at two facilities. One site contact cited a leak in the system as the reason for removal, and another site contact noted that the new owners of the facility made the decision to remove the system, without providing more detail. Because the evaluation team determined that these sites were no longer producing solar energy to heat the pools, these sites were classified as 'zero savers'. Although these situations are hard to predict, they do represent real-world situations that arise, that will affect the overall program results, and were therefore included in the sample.

Previously Unheated

A second reason for assigning zero savings to pool facilities had to do with pools which prior to installation of solar water heating systems, had no pool heating, and therefore no natural gas consumption. We should note that the program rules as they stand currently, purposely allow the installation of solar water heating systems at pools where no existing pool heating occurs, with the intent of displacing potential future usage of natural gas.[10]

Despite the program rules, the purpose of the evaluation is to quantify energy, environmental, and economic benefits achieved by the CSI-T program. For both facilities, discussions with the site contact yielded the finding that the site contacts had no intention of installing a heating system at the facility. These facilities were approached by solar thermal contractors who told the facility that the contractor could install solar thermal systems for free at their facility. The analysis of system costs and incentives for these two facilities yielded the finding that one facility received their system for free after incentives, and for the second facility, the incentive covered 95% of the system cost.[11] While the systems at these facilities are heating the pools with solar energy, they are not displacing any existing heating source, or any potential heating source, and therefore do not qualify for savings. The evaluation team also contacted two other pool facilities and determined similar findings. However, because these two additional sample points were not randomly selected, and were instead, sample points of convenience, these were not included in the sample results, but are noted as potential indication of a larger concern. We should note that there was one pool in our sample which had a solar heating system that had failed. In our conversations with the site contact, we learned that they had opted to replace the solar water heater

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[10] There was another facility in the sample which previously had an older solar water heater which broke. Instead of replacing it a natural gas heater, they used the program to install a newer solar water heating system. In this situation, the savings were accepted, as they displaced potential natural gas usage.

[11] On January 29th. 2015, the program rules were modified per CPUC D.15.01.035 which capped the Commercial Pool incentives at 50% of the system costs in attempts to minimize this effect.

rather than going with a natural gas heater. Therefore, we determined that this met the requirement of avoiding natural gas usage, and calculated savings for this site.

Overall, these sites resulted in an 8% reduction in savings for the Commercial Pools sampled sites, and only a 2% overall reduction, when rolled up to the population, in the total savings by budget program.

The PAs and the CPUC have taken steps through the capping of Commercial Pool incentives to minimize effects of installers offering solar pool heaters "free-of-charge". However, a program recommendation is to take this one step further and update program requirements so that for existing pools, the installation of a SWH must replace an existing heater (an older solar water heater would be eligible). Written exceptions could be considered if the customer is truly wanting to try out solar heating prior to purchasing a natural gas heater, but these are more likely to be the minority and should be considered on a case-by-case basis.

Night Time Solar Losses

The team found evidence of the solar pump running at night, sending heated water up to the solar collector, at several commercial pools. Running the water through the collectors at night will often drop the pool temperatures as the heat from the pool is lost to the atmosphere through the collectors. To determine the effect this had on savings, the evaluation team looked at pool temperatures, as well as pool heater set-point temperatures to determine whether this practice appeared to be purposeful. In some of the pools in the hotter regions of the state, the pool temperatures were found to get extremely warm – upwards of 100 degrees, during warmer months. When this was the case, it appeared that site contacts intentionally ran water through the collectors in the evening in attempts to cool the pool. However, there were two pools where this did not seem to be the case. In both cases, the evaluation team discovered that the auxiliary heater was often turned on in the morning after to increase the pool temperature and account for the energy losses during that evening. Because of this finding, the evaluation team calculated negative savings for these periods of time solar energy appears to be unintentionally lost through the collectors, which resulted in a 13% reduction in savings for the Commercial Pools sample.

A recommendation to minimize this is to require automated controls for pools will ensure that water isn't set up to the collectors when conditions are less than ideal. As seen throughout this report, the cost of pool heating systems is minimal compared to heating for other budget programs. Another suggestion would be to ensure that pool maintenance staff are fully aware of the system controls, and to ensure that all manual valves are clearly labeled.

Low Summer Usage

Summer time is when solar water heater systems are typically expected to see the highest savings. The weather is typically the warmest, and there is the highest amount of solar radiation. However, the evaluation found that for Commercial Pools, this wasn't always the case. Because Commercial Pools are typically kept at a certain temperature, the pool receives heat directly from the sun during the day, and the depth of the pool can have a significant effect on how quickly the pool will heat up, many pools in the warmer portions of the state were actually found to have far lower summer savings than expected. These pools were shallow, 4-5 feet in depth, and found in the more desert regions of the state. The evaluation team found that these pools saw temperatures upwards of 100 °F, far higher than the mid-80°F setpoint temperatures, and therefore, the solar water heater was turned off during much of the summer months. This resulted in a 6% reduction in expected savings.

A recommendation to address this is to evaluate how expected savings would change based on the depth of the pools.

Onsite Findings

There were several system details that were confirmed by the engineers during their onsite visit, including:

- Multiple solar collector arrays facing different directions,
- Updating the collector descriptions to accommodate different azimuths and tilts, and
- The elimination of the auxiliary heating systems for some pools.

The overall effect of these changes was found to increase the savings for the Commercial Pools sample by five percent.

Updates to TRNSYS Models

The first step for each of the budget programs was to recreate the simulation results for each of the sampled sites using inputs that were submitted through the online calculator. These sites were replicated using the latest version of the CSI-Thermal TRNSYS engine (v11). This step eliminated any bias caused by systematic changes in the modeling program over the past several years. One example of this change includes wind speed assumptions. For Commercial Pools and Commercial and Multifamily Residential project types, this was a minor update. For the single-family facilities, this was a bit more complex, and is described in further detail below. This update resulted in a minor increase in savings for the Commercial Pool sample points.

Seasonal Operation

The pools in the evaluation sample were classified either by May through October operation, or Year-Round operation. This designation was provided in the public tracking export, and verified onsite by the onsite engineers. There were three sites which were originally designated as May through October, but identified onsite and through metering data to operate year-round. Another site claimed to run year-round, but was found to only operate May through October. The overall effect of the seasonal operation findings was to increase the pool savings by 1%.

There are two potential reasons why there were a higher number of pools specified as seasonal which were found to run year-round. The first has to do with the drainback requirements. The program manual specifies that seasonal pools may use drainback as their freeze protection type, which is usually less expensive. The second reason is that a pool cover is automatically assumed in the savings calculator for seasonal pools (the option for no pool cover is completely taken away for these customers). These two reasons combined may contribute to the increased number of pools claiming to be seasonal.

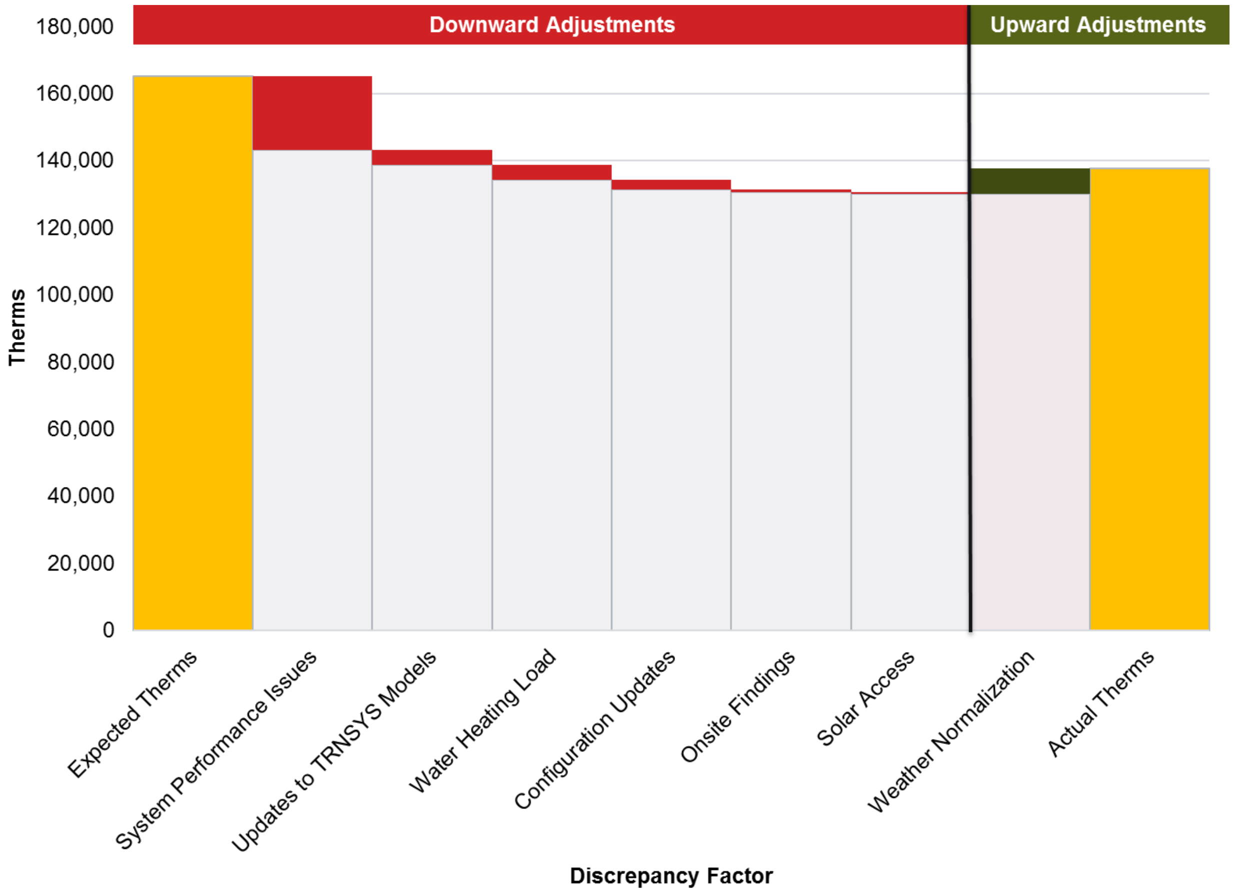
Weather Normalization

The final step taken by the evaluation team was to normalize the savings to represent typical weather conditions, as described in Section 3. The expected savings were simulated using CA CZ weather data, so adjustments were made to the metered data based on the comparison of CA CZ irradiance and the actual irradiance. California saw historically wet weather during the winter of 2016-2017, which could explain the lower actual irradiance seen in the actual weather, resulting in upwards adjustments of actual savings due to weather normalization. This finding in consistent across all budget programs.

4.2.2 Multifamily Residential & Commercial Budget Programs

Commercial and multifamily facilities saw the highest GRRs across all budget programs. Figure 4-5 below shows the discrepancy factors identified in the sampled commercial and multifamily sites. Commercial/Multi-family and Low Income Multifamily budget programs saw very similar distribution of discrepancy factors and were therefore combined into a single figure below. The TRNSYS simulation model which calculated the expected savings did a good job estimating the therms saved for these two budget programs, and the largest average discrepancies between expected and actual savings were made up of system performance issues identified through system metering.

FIGURE 4-5: DISCREPANCY FACTORS FOR THE MULTIFAMILY RESIDENTIAL AND COMMERCIAL SAMPLE



The evaluation team also looked at the site-level distribution of each of these discrepancy factors, shown below in Figure 4-6. The figure shows a box-and-whisker[12] plot of each discrepancy factor, and the individual effect on each sampled commercial and multifamily site's gross realization rate. Although on average, system performance reduced the total sample savings of these two programs combined by 13%, the site-level effect ranged from -3% all the way up to 489%.[13] Although the remaining discrepancy factors, on average, only contributed to up to a three percent reduction for each factor, on a site level, each of these could have a tremendous impact on savings. The water heating load discrepancy factor, for example, showed a 100% reduction in savings for one site, up to a 353% increase in savings.[13] The following subsections explain this in more detail.

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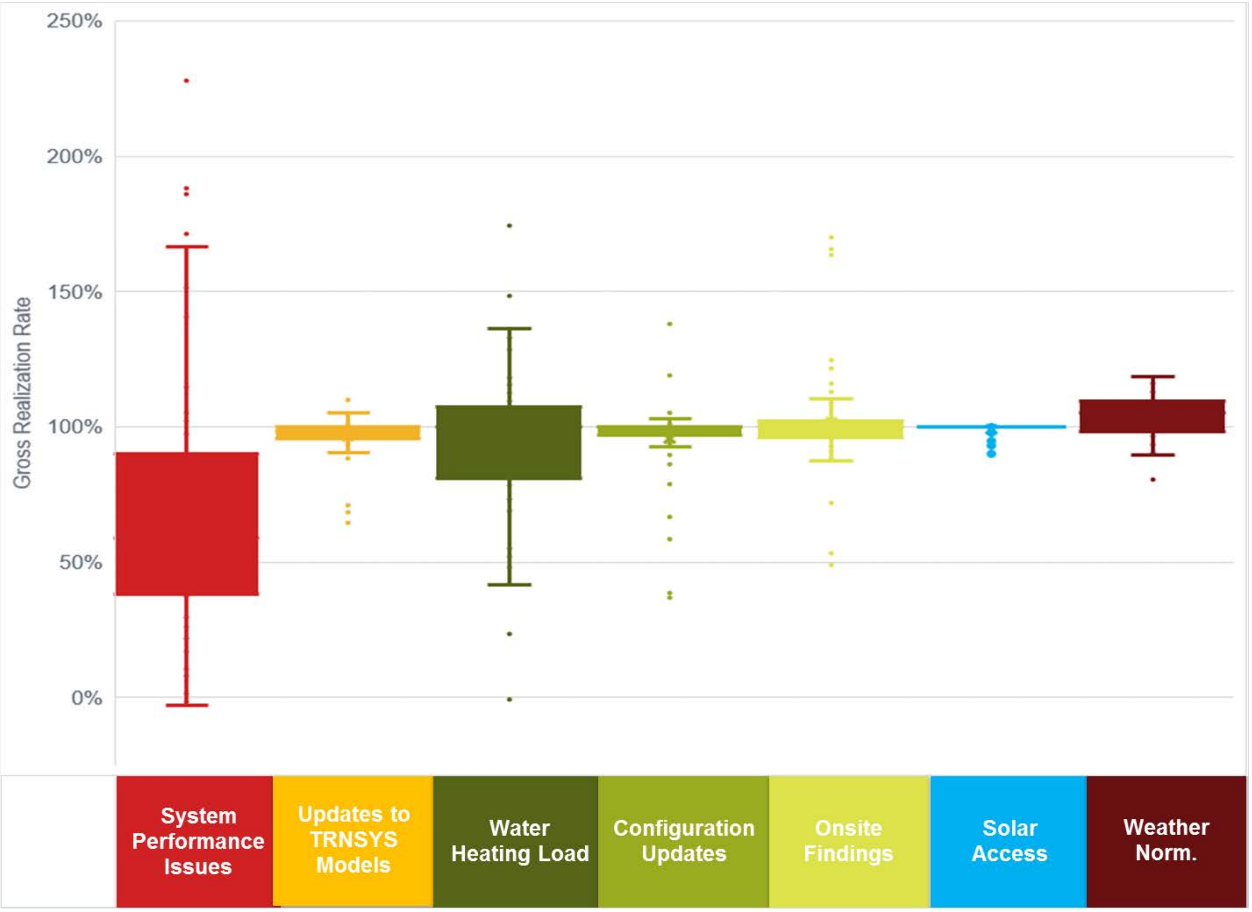
12 A box-and-whisker plot depicts the range of the data, with the box representing 50% of the data between the first and third quartiles of data for each budget program. The lines outside the box, the 'whiskers', indicate variability outside the upper and lower quartiles, and any point outside the whiskers are considered outliers.

13 The graph was shrunk down to a maximum of 250% to more easily see the individual points.

FIGURE 4-6: SITE-LEVEL DISTRIBUTION OF THE AFFECT OF EACH DISCREPANCY FACTOR FOR COMMERCIAL AND MULTIFAMILY FACILITIES



System Performance Issues

System performance issues are defined as changes in savings calculated through the metering data. Each site could have multiple reasons for poor system performance but isolating the impact of each one is challenging. These reasons include major soiling on the panels, leaking or corrosion identified on the collectors and piping, or non-functioning pumps.

One interesting finding is that out of the 29 commercial / multifamily facilities with actual saving less than half of expected savings, two thirds of the host customers reported having no issues with their SWH systems. This indicates that customers are either not at all familiar with their SWH systems (one contact did mention that they had no idea they even had a SWH system), or that the expected savings were far higher than they should have been. These system performance issues will be expanded upon in the upcoming technical report, where we will also discuss the seven facilities which saw, based on the metering data, actual savings that were over 50% higher than the expected savings.

Water Heating Load

The original simulations are based on user-specified flow rate (gallons per day), typically referenced from the Maximum Gallon Per Day Guideline Table.[14] As the water heating load for each site was directly measured through the installed meters,[15] the evaluation team reviewed how the actual load compared to the expected water load, and what affect that had on the overall savings. The metered data were used to create an average-gallons per day (GPD), across the entire metering period. At the site-level, there was a single site which showed such a low flow rate due to the system not working as it should, that it actually resulted in negative savings. On the other hand, there was a site where the increased flow rate resulted in a 252% increase in savings. For the metered sample, all these increases and decreases in savings only accounted for an overall reduction in savings of 3%.

Configuration Updates

Unlike the other budget programs, where almost every installation fit neatly into the original configurations, the commercial/multi-family systems routinely had systems that didn't quite fit into the original configurations. To account for this impact on the savings, the evaluation team modified many of the original configurations to account for the differences. The most common differences included:

- Changing the location and existence of tempering values that mix cold water to temper hot water from the auxiliary or solar tanks to not exceed a set point,
- Introduction of mains water directly to the collector heat exchanger instead of into the solar storage tank,
- Location of where the recirculation water re-enters the SWH/DHW system.

Other less common changes that occurred included:

- Control modifications to direct the solar-heated water to the auxiliary tank directly,
- The use of wrap-around heat exchanger tanks instead of external or immersed heat exchangers,
- Multiple solar collector arrays,
- The connection of the storage tanks from parallel connections to series connections.

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[14] The table can be found in Appendix E, Table E-1 of the CSI-Thermal Handbook. http://www.gosolarcalifornia.ca.gov/documents/CSI-Thermal_Handbook.pdf

[15] For a handful of systems, metered performance data were collected using the Ohm system that does not measure flow rates but does estimate water heating load.

Similarly, to the onsite findings, the overall effect on the *sample-level* savings were minimal, only producing a 2% reduction. At the site-level however, these findings again had a huge impact at some of the facilities. As shown above in Figure 4-6, these updates resulted in changes to savings that ranged between a reduction of 63% to an increase of almost 40%.

Onsite Findings

There were multiple system details that were confirmed by the engineers during their onsite visit, including:

- Solar collector model
- Total number of collectors and number of collectors in series
- Collector tilt and azimuth
- California Climate Zone (location)
- Type of Building (used to set the DHW draw profile)
- Recirculation loop for hot water (yes or no)
- Type of system (# of tanks, location and type of heat exchanger, auxiliary heat source, freeze protection, etc.)
- DHW water consumption estimate (based on # of occupants, loads of laundry, # meals served etc.)
- Solar storage capacity (number of tanks and total volume)
- Auxiliary water heater capacity (number of tanks, total volume, and total auxiliary heating capacity)
- Set-point for auxiliary heater and for delivered water (tempering setting)

While the overall effect of these changes made very little difference to the overall sample savings, there was quite a variation at the site level based on these findings. Figure 4-6 above shows the effect of this discrepancy factor, resulting in anywhere from a 51% reduction in savings to 70% increase in savings.

Solar Access

Solar access, a value from 0% to 100%, is the insolation available on a surface with the panel at the tilt and azimuth specified by the user. A value of 100% represents the total amount of insolation incident on that surface without shade within the field of view from the surface. Therefore, it is possible to have 100% solar access even when there is shade nearby, as long as the shade is not within the field of view of the panel. Although an average annual solar access is defined in the public tracking data, the expected savings are calculated based on a solar access value of 100%. There were only 11 multifamily sites which saw a solar access value that differed from 100%, ranging from 90% to 99%. The overall effect was less than 1% of the sample-level savings.

4.2.3 Single Family Budget Programs

There were a series of adjustments made to the Single Family Residential and Low Income Single Family Residential programs savings, which reduced the overall savings for these two budget programs significantly. Updates made in the model simulations as well as findings from actual onsite performance each affected the budget program-level results negatively. As the findings for the Low Income Single Family Residential budget program differed significantly from the finding of the Single Family Residential budget program, the discrepancy factor graphics for two budget programs were separated. Figure 4-7 shows a waterfall chart with the discrepancy factors and their effect on the sample savings for the Single Family Residential program, while Figure 4-8 shows the same information for the Low Income Single Family Residential program.

FIGURE 4-7: DISCREPANCY FACTORS FOR THE SINGLE FAMILY RESIDENTIAL BUDGET PROGRAM SAMPLE

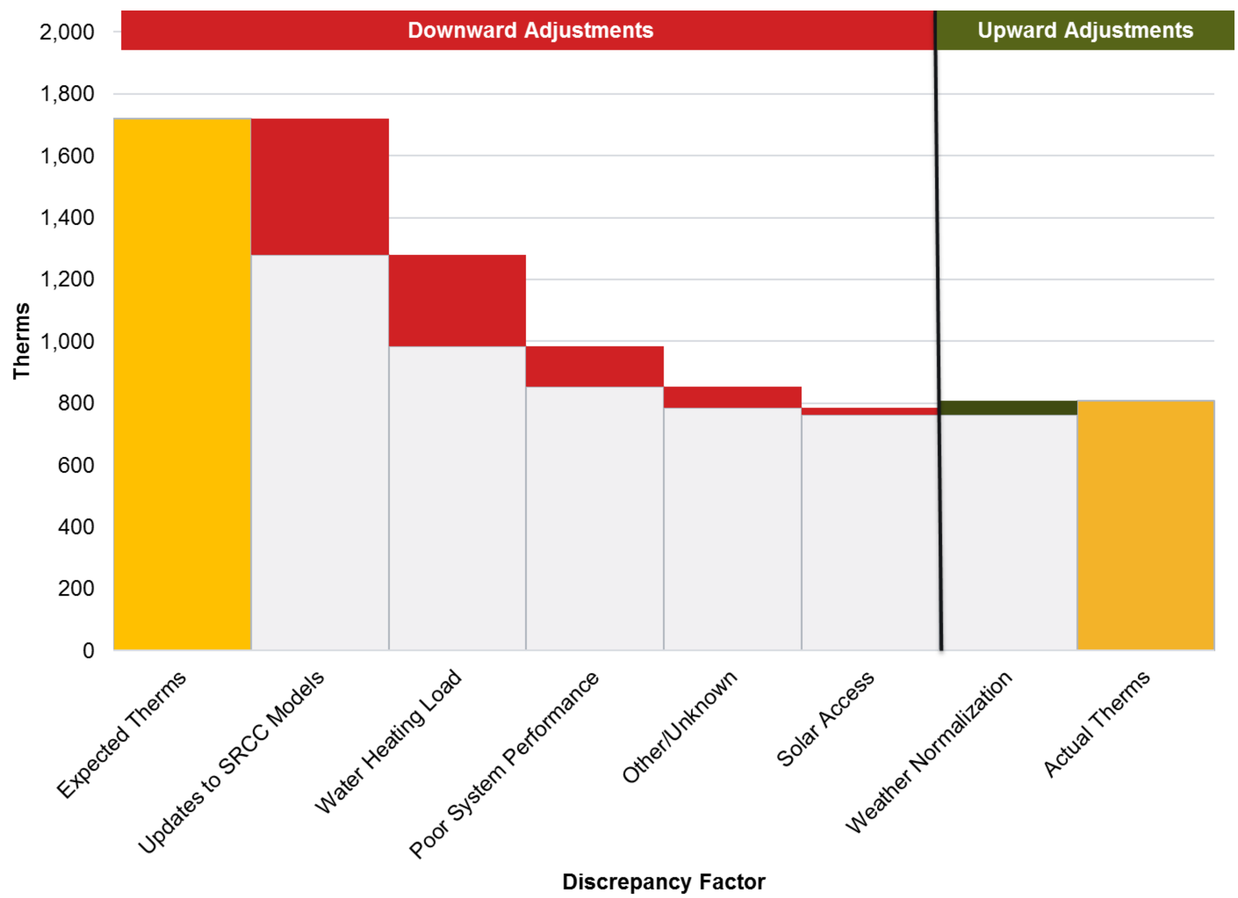
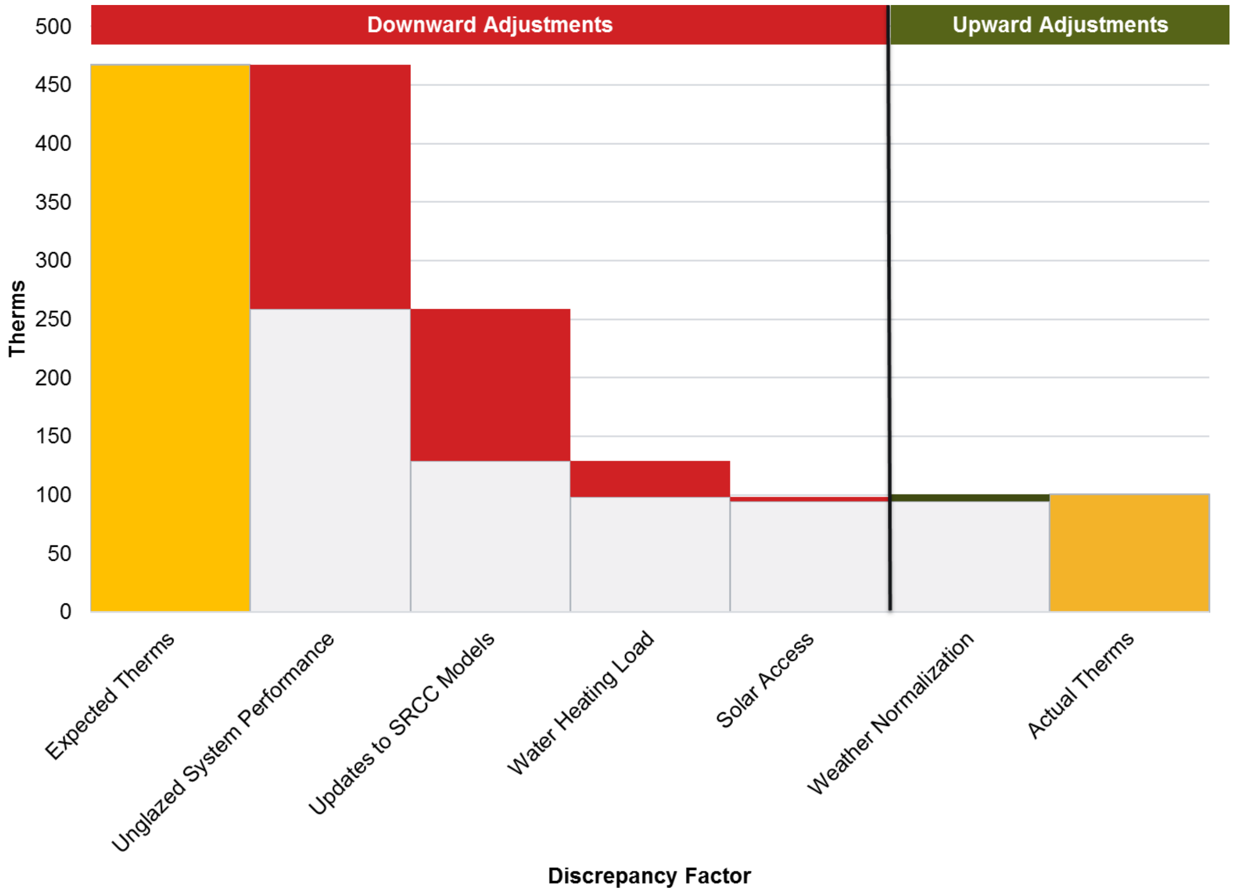


FIGURE 4-8: DISCREPANCY FACTORS FOR THE LOW INCOME SINGLE FAMILY RESIDENTIAL BUDGET PROGRAM SAMPLE



Updates to SRCC Models

The original expected savings were pulled from OG-300 ratings published by SRCC. These were proprietary models, so the evaluation team was not able to replicate the models exactly. However, TESS and SRCC are currently finalizing details to use TRNSYS models for a new rating engine, therefore TESS utilized these new models to mimic the set of conditions mandated by SRCC in their OG-300 protocol, and closely estimate the ratings for these single family residential systems.[16] Two of the most noticeable changes had to do updates made to the mains water temperatures and reductions in expected savings to systems with wrap-around heat exchangers. The updates to these model simulations reflected the largest

[16] As noted in Section 3, these OG-300 ratings are set by the SRCC, and reflect the current ICC 9010/SRCC 300 Solar Thermal Systems Standard. It is critical to note that the "ratings" that we calculate are not to be considered SRCC ratings and should be referred to as estimated ratings. Only SRCC can generate an official SRCC rating for residential SWH systems.

overall reduction in savings for single family sites, contributing to a 26% reduction in the overall gross realization rate.

Water Heating Load

ASHRAE 118.2, Method of Testing for Rating Residential Water Heaters, specifies that the average residential flow rates of water heaters, in gallons per day, is to be 64.3, spread out across six daily water draws of 10.7 gallons. The SRCC rated energy savings are based on this daily water draw. However, the evaluation team found that 11 of the 19 sites where we analyzed the water draw showed less than half of the daily GPD that was expected, and only three sites had right around the expected daily flow of 64.3.[17] The number of occupants were found to range from 2 to 12,[18] which were found, as expected, to have an observable effect on the daily water draw of the house. Overall, updates to the daily water consumption were found to reduce the expected savings for these Single Family Residential and Low Income Single Family Residential sample points by 15%.

To date, the program has operated under the assumption that AB-1470 and CPUC D.10-01-022 have required the use of OG-300 savings ratings, and therefore have used the SRCC OG-300 assumptions, including the use of the 64.3 GPD as the metric to calculate savings. Per discussions with the PAs, this legislation may only require the use of OG-300 certified equipment, but not the use of all SRCC assumptions.

A recommendation to first address these findings is to discuss with SRCC to confirm that updating savings assumptions will not nullify the SRCC certification for the equipment. Secondly, further study should be performed on the average daily water draw in California, and an updated value should be used in place of the ASHRAE load of 64.3 GPD. The evaluation team suggests exploring further an average flow rate based on the number of occupants in the home.

Unglazed System Performance

Eighty percent of the systems installed through the Low Income Single Family Residential program, and 11 percent of the systems installed in the Single Family Residential program utilized unglazed collectors. These are typically used for pool heating. These systems can be considered a simple form of solar water heating, where a dark material absorbs sunlight and transfers the energy to a fluid behind the dark surface. Glazed systems have an advantage over unglazed systems, as the glazing material helps trap heat in the collector, reducing heat losses back to the environment. The advantage of unglazed collectors is they are less expensive. Section 2 discusses the costs of Commercial Pool systems versus system costs in

[17] The evaluation team plans on discussing the water draw in more depth in the follow up, Technical Report.

[18] One facility also had 18 occupants, but it was determined to actually be a multifamily facility in the single family sample.

other budget programs, and the Commercial Pools were found to be a fraction of the other costs.[19] These unglazed collectors made up all of the sites in the Low Income Single Family Residential sample, and resulted in a 45% decrease in the Low Income Single Family Residential budget program performance. No Single Family Residential budget program sampled sites had unglazed collectors.

Poor System Performance

During the analysis, one site in the sample was found to have very little difference between the hot and cold solar temperatures, resulting in much lower performance than expected. There were several reasons identified for why this system performed poorly. During the onsite inspection, the customer reported that the system installation was 'bungled', and they never had any real connectivity to the system. The system is set up as a single-tank system, and it appeared that the temperature set-points and controls never seemed to be set up correctly. The system was also attempting to serve the space heating load with hydronic baseboard heating. This one site reduced the overall savings for the single-family category by six percent.

Solar Access

Solar access, a value from 0% to 100%, is the insolation available on a surface with the panel at the tilt and azimuth specified by the user. A value of 100% represents the total amount of insolation incident on that surface without shade within the field of view from the surface. Therefore, it is possible to have 100% solar access even when there is shade, as long as the shade is not within the field of view of the panel. Although an average annual solar access is defined in the public tracking data, the expected savings are calculated based on a solar access value of 100%. For the sites that fell under the Single Family Residential and Low Income Single Family Residential programs, 11 out of 19 were confirmed to have an average annual solar access of 100%. However, the remaining sites did see solar access values between 79% and 99%. This had a minor effect on the overall program savings, but can result in significant drops in savings for sites with large access issues.

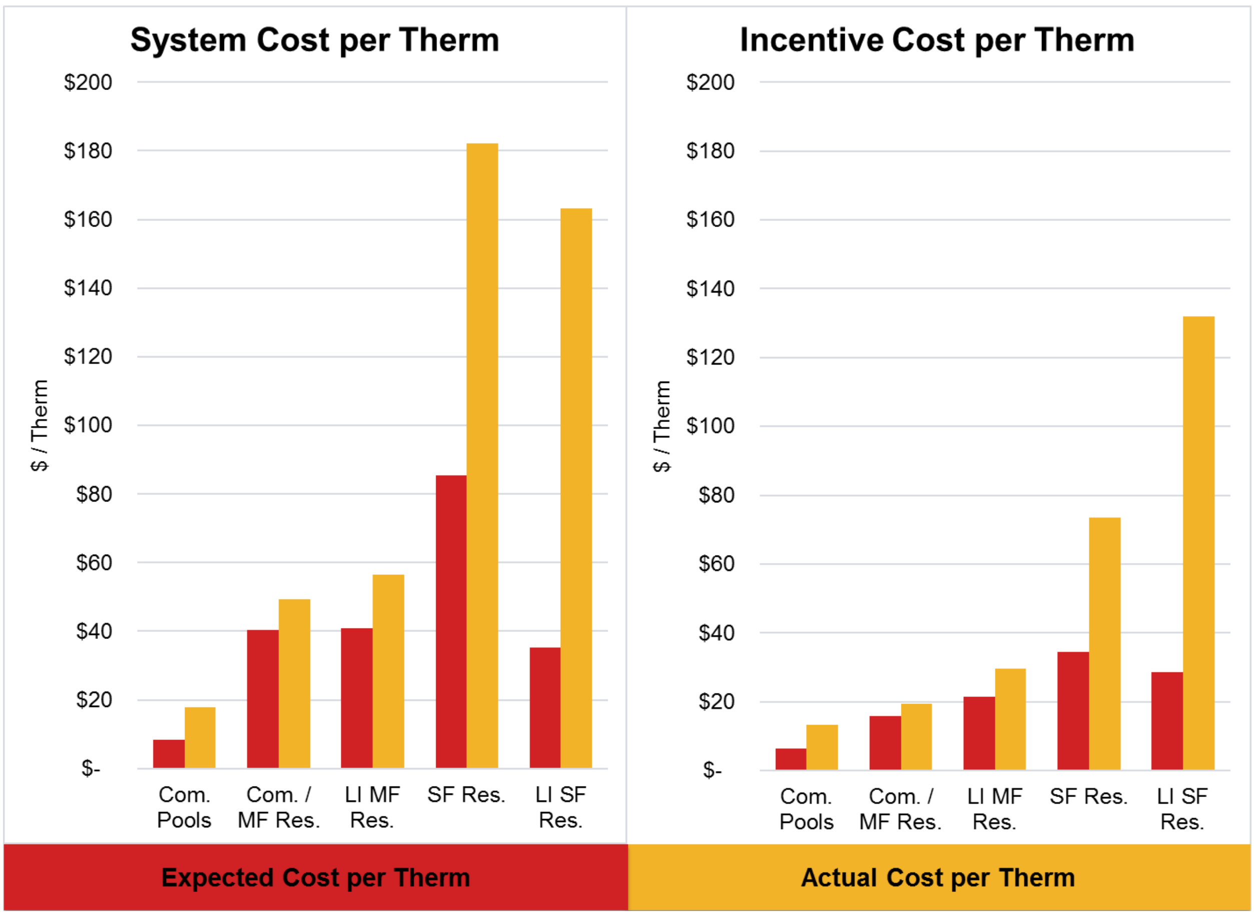
4.3 EXPECTED VERSUS ACTUAL SYSTEM COSTS PER THERM

The evaluation team revisited the system costs and the incentive costs after the evaluation had quantified actual savings. Because of the changes in actual savings, especially for some of the budget programs, the evaluation looked at how these costs per therm may have changed, based on the actual evaluated findings, and whether this would cause significant changes in the cost structures of the different budget programs. Figure 4-9 shows the comparison of the System Cost/therm and the Incentive Cost/therm,

[19] The costs of these systems, associated with other budget programs, were not analyzed, as they provided skewed results, and have been removed from future program offerings.

between expected and actual therm savings. From looking at system costs, the cost per therm for Low Income Single Family Residential systems are over three times higher than what was expected, followed by Single Family Residential systems which cost over twice as much per therm saved than expected. Commercial pools also show an increase, although their average cost per therm is still lower than all the other budget programs. Similarly, for incentives, the Single Family Residential and Low Income Single Family Residential budget programs, on average, are providing incentives between $73/therm and $132/therm based on the actual therms saved for the programs.

FIGURE 4-9: COMPARISON OF EXPECTED AND ACTUAL COST AND INCENTIVES PER THERM



4.4 SITE-SPECIFIC FINDINGS

This section describes some of the site-specific, system eligibility, safety audit, and failure analysis findings that the evaluation team came across onsite. The information in this section is designed to inform program administrators about issues from the field for future program offerings.

4.4.1 System Eligibility

The CSI-T program guidebook[20] was reviewed to verify that the sampled sites met the minimum requirements as specified in the guidebook. Two findings from this review had to do with Pipe Insulation and Pool Covers. Although these findings did not affect the final evaluated savings, the team felt they were important enough to note. The team also identified several other concerns having to do with pool heaters and Consumer Performance Metering, and while they did not directly violate requirements from the guidebook, they did present concerns for the program.

Pool Covers

The program guidebook states that pool covers are assumed, and considered in the calculations. Out of the 33 year-round pools that were chosen as part of the initial sample, 24 were confirmed to have no pool covers, three used a liquid pool cover, and three were confirmed to have physical pool covers. Three more were not confirmed. Although the evaluation team was not able to determine the impact of assuming a pool cover on the overall program-level savings, 80% of the pools in the sample were confirmed to not have a pool cover, undermining the calculation assumptions. It is the evaluation team's understanding that the pool cover assumption is deliberate to drive more efficient behaviors.

Pipe Insulation

The program guidebook states that all systems except pools must have a minimum of r2.6 insulation on all exposed and accessible hot water piping. Seven percent of the sites surveyed did not have interior pipe insulation, and an additional 10% of sites were found to have no exterior pipe insulation. The team was not able to identify whether the insulation was never installed or if it was removed or damaged since the system was installed.

Non-Heated Pools

The section above on Discrepancy Factors discussed commercial pools which had no prior heating systems. There were a total four pool facilities identified by the evaluation team, which were found to have no pool heating prior to the installation of the solar water heating system. The site contact also confirmed that they had no intention of installing pool heating. In the situations of both facilities, it wasn't until a solar water heating contractor arrived and let them know that they would install the system for free, that they decided to heat the pools. Two of these pools were part of the evaluation sample, while the other two sites were sampled points of convince, and were not used in the final sample.

[20] http://www.gosolarcalifornia.ca.gov/documents/CSI-Thermal_Handbook.pdf

Customer Performance Metering (CPM) and Performance-Based Incentives (PBI)

The CSI-T program has metering requirements, depending on the capacity or the end-use served by the solar-heated water. For systems with an installed capacity greater than $30kW_{th}$, the program requires the installation of Consumer Performance Metering (CPM) for a period of five years from the start of operation. This metering equipment must, at a minimum, provide the quantity of solar energy delivered, and an onsite or remote display of continuous, cumulative BTU measurement. Seventy-one percent of the commercial pools facilities in the sample and 55% of the commercial/multifamily facilities in the sample met this requirement for CPM metering. A similar program requirement is Performance Based Incentive (PBI) metering, which requires that all solar thermal systems with a capacity greater than 250 kW_{th} or systems designed for process heat, solar cooling, space heating, or a combination of these, take a PBI. To do this, the performance at a site is to be measured by a BTU meter. There were five sites in the entire program population that met these criteria. However, the requirements for PBI metering have evolved over time.

The engineers attempted to collect the logged data at thirty-one of the CPM facilities, and discovered that although the metering equipment was in place, three facilities actually had a memory card installed to log the data. Two of these facilities were pools, and one was a Multifamily site. This represents a lost opportunity for additional data at minimal cost.

A similar finding was discovered when the evaluation team attempted to collect the PBI metering data, and data for only two facilities was available. These facilities were paid out via up-front payments rather than a PBI.

These situations represent a loss of opportunities for additional data at a minimal cost. The program administrators should ensure that CPM and PBI facilities collect the data and make that available upon request.

4.4.2 Safety Audit Findings

The safety audit included on-site inspections to identify malfunctioning or poorly adjusted thermostatic mixing valves and a measurement of delivered hot water temperatures. Both these activities were done to assess the risk of scalding. Other issues, such as loose electrical wiring or poor insulation, were also found onsite and noted in the onsite surveys. This section summarizes the safety audit findings for three different categories: Thermostatic mixing valve, hot water temperature, and other issues.

Thermostatic Mixing Valve

Thermostatic mixing valves are necessary at solar installations to ensure that mixed, hot water is maintained at a desired temperature. The valves result in minimized risk of scalding and thermal shock.

The onsite engineer found thermostatic mixing valves present at 43 multifamily/commercial sites and 22 single family sites. There were eight sites where it is uncertain if a mixing valve was present; seven of these were multifamily/commercial sites and one was a single-family site. One single family site did have a mixing valve, but it was not working properly and it was delivering water at 146°F, which is too high for a residential setting. While in evaluation we usually strive to merely observe and not interfere, in this case, there was a very real danger of scalding. Therefore, the customer was informed of the high temperature water and the customer agreed to attempt to lower the setpoint.

Delivered Hot Water Temperature

Delivered hot water temperature was measured at various outlets to determine the hot water temperature after stabilization. These temperatures were noted and used to assess the risk of scalding at each site. According to the American Society of Plumbing Engineers (ASPE) guidelines[21] and the 2016 California Plumbing Code, hot water temperatures in lavatories, showers, and bathtubs should be limited to 120°F. Meal service restaurants may have water temperatures go up to 140°F.

Nineteen multifamily/commercial sites were found to have hot water temperatures exceeding 120°F. Seventeen out of 19 were multifamily residential buildings. One of the non-residential sites was a meal service restaurant, where the water temperature was 149°F; this exceeds the allowable maximum of 140°F. Another site was a coin-operated laundry. The highest allowable temperature for a laundry sink is 120°F; the measured water temperature at this site was 140°F.

Six single family sites were found to have hot water temperatures exceeding 120°F. The highest observed temperature was 146°F. As stated in the above section, the high temperature was due to a thermostatic mixing valve that was not operating correctly.

While these high temperatures may not be the direct result of the solar thermal system, they do provide some cause for concern due to increased scald potential.

[21] https://www.aspe.org/sites/default/files/webfm/pdfs/ASPE_Standard_15_Hot_Water_Temperature_and_Control.pdf

Other Safety Issues

While thermostatic mixing valves and hot water temperatures were the primary safety-related focuses of the site visits, other safety issues were also identified and noted in site documentation.

Two multifamily/commercial sites were found to have poor insulation. One single family site was also found to have about 8 ft. of domestic hot water supply line to be uninsulated. The customer stated that they were advised by a professional to not insulate this line.

At one pool site, the wiring in the timer was found to be loose and arcing. The evaluation team fixed this issue. At another pool site, melted plastic was found in the breaker box, likely due to high temperatures. The site manager was informed of the issue.

4.5 SUMMARY OF RESULTS

The CSI-T program was found to achieve over 2.7 million equivalent-therms saved, with a program-level gross realization rate of 65%. The following points highlight the findings of the program:

- Budget Program GRRs: Commercial Pools – 48%, Low Income Multifamily Residential – 72%, Commercial / Multifamily Residential – 82%, Low Income Single Family Residential – 22%, and Single Family Residential – 47%.[22]
- The main reasons for savings discrepancy for commercial pools had to do with zero savers, low solar usage, and night time solar losses. For commercial and multifamily facilities, it had to do with poor system performance, and for single family facilities it was boiled down to updates to SRCC models, updates to actual flow rates, and unglazed system performance.
- Gross realization rates by program were 98% for PG&E, 49% for SCG, and 45% for CSE. The high PG&E results were driven by a small number of larger overperformers.
- The total program was determined to have had the annual equivalent effect on greenhouse gas emissions as equivalent to the annual greenhouse gas emissions output from over 1,500 homes.

[22] Gross realization rates meet 80/20 confidence and precision requirements for the Commercial / Multifamily Residential budget program only.

APPENDIX A DATA COLLECTION FORMS

- CSI Thermal Pools Onsite and Metering Form
- CSI Thermal MF & Commercial Onsite and Metering Form
- CSI Thermal RES SWH Onsite and Metering Form

CSI Pools Onsite and Metering Form Rev 11/22/16

Itron ID		IOU	
CSI Application Code		Street Address	
Sample Strata		City	
Appt. Date		Zip Code	
Appt. Time		Wtr Heater Location	
Actual Date of Site Visit		Best Time to Contact	
System Owner Business Name		Secondary Contact Name	
System Owner Name		Secondary Phone Number	
System Owner Email Address		Secondary Email	
System Owner Phone Number		System Owner Cell Phone Number	
Solar Install Contractor Business Name		Solar Maint Contractor Name (If different)	
Solar Install Contractor Email Address		Solar Maint Contractor Email (If different)	
Solar Install Contractor Phone		Solar Maint Contractor Phone (If different)	
Primary Site Contact Name, if different from above			
Primary Site Phone #, if different from above			
Primary Site Email Address, if different from above			
Is there a natural gas or electric pool heater onsite?		How many pool heaters are there? (If more than 2, then thank and terminate.)	
Was the pool heater in use when you learned about the program? (If "no", then thank and terminate).		Is the pool heater(s) still in use today?	

How many years have passed since the pool heater was used? (If more than 2 years before solar was installed, then thank and terminate).					
Did you remove the pool heater because of the performance of the solar system?		How many years have passed since the pool heater removed? (If more than 2 years before solar was installed, then thank and terminate).			
FOR NEW CONSTRUCTION: Was the pool designed to use solar exclusively, so no heater was installed?					
How many swimming pools and/or spas are heated by the single solar system? (If more than 2, thank and terminate).					
What is the size (in inches) of the piping going into and out of the pool heater? (If not 2", 2.5", or 3", then thank and terminate).					
Does customer ever turn off backup pool heater and rely solely on solar?					
Did your new rebated solar thermal system replace an older solar thermal system? (Yes/No)		If old solar thermal was replaced, what was the Age (in years) of the system at the time of replacement?		What was its Condition? (See rating)	
Could we install anemometers here? (1 at each end of array and 1 on a pole 10 meters or 33 feet above the ground)		Additional info regarding anemometer installation (if needed)			
Notes on customer perception of system performance (reported failures, leaks, maintenance, etc.)					
Comments					

A. Collector (check or enter correction under each pre-populated entry)
If roof is not accessible, collect as much info as possible from ground or roof edge. Use binoculars if needed and take pictures of collectors and potential shading features).

System Install Date:	Collector Panel Name/Number	Model	Quantity	Tilt (deg)	Azimuth True-N = 0 (compass deg)	Soiling (Light, Medium, Heavy, No soiling)	SRCC Collector ID	Collector Square Footage
Verify:						Soiling & Square Footage Notes:		

Number of Collectors in Series		Verify Collector in Series Quantity:	
If there are more than one collector, how are they plumbed? (List number in Series and Series in Parallel)		Notes:	
Leak Indications (Y/N) Note any evidence of failure; check for leaking fluid or signs of past leaks (e.g., stains, corrosion, hard water deposits)		Notes:	
Annual Average Solar Access (in % based on interference from shading)		Verify:	
Is exterior piping insulated? (Y/N)			
Approximate total length of exterior collector pipe (in feet) - insulated or uninsulated		Notes / Clarify if mix of insulated and uninsulated pipe	
Is the roof flat (Y/N)?		Does the roof have space to mount a weather station pole (with a tripod of guy-wires)?	

B. Pool information

Pool Type (Wading, Spa, Public, Etc.):			
If Pool Type is "Other" provide the pool type here:			
Pool Location Type (Outdoor/Indoor):		Verify or Update:	
Pool Cover Use:		Verify or Update:	
Pool Operating Schedule:		Verify or Update:	
Pool Setpoint Temperature:		Verify or Update:	
Pool Surface Area (square footage):		Verify or Update using Google Maps/Earth Satellite Imagery:	
Pool Volume (in gallons):			
Average Pool Depth in Feet (IF POOL VOLUME IS UNKNOWN):			
Spa Pool Onsite?			
If Yes, Is It Connected To Same Solar Hot Water Loop as Pool?		If Yes, Does It Share the Same Water Heater as the Pool?	
Flow Gauge on Recirculation System?		If Yes, Is Flow Data Available?	
Pressure Gauge on Filtration System?		If Yes, Enter Spot Pressure Readings (psi):	

Description of anything surrounding the pool site, such as trees, buildings, or fencing, that blocks wind or shades the pool. Please be descriptive (chain-linked fence surrounding 3 sides of the pool, 2-story buildings on 2 sides of pool, etc.):

C. Solar Hot Water Information

Ownership (Host owned, Leased, Power Purchase Agreement (PPA))		Verified:	
Flow Type (Direct/Indirect)		Verify or update:	
Specify Pump Manufacturer (enter N/A if passive)		Notes:	
Specify Pump Model Number (enter N/A if passive)		Notes:	
Specify Pump Location (enter N/A if passive)			
Specify Pump Control Manufacturer		Notes:	
Specify Pump Control Model		Notes:	
Does the Pump Controller Log Data? If so, can we access it and how?			
Specify Pump Power (AC or DC(PV))			
Spot Power Reading on Solar Pump, if AC powered			

Specify Pump Control Scheme (Temp/Time/None)			
Is Micro SD data available? If so, please download data.			
Freeze Protection (Type) Note any evidence of failure in System Notes field below		Verify or update:	
Notes on System including condition of pump and its proper operation (running when it should be or when it should not be running), or any evidence of failures, and freeze protection status (see comment); for any glycol leaks a) check glycol pressure and b) check for pump failure.			

D. Solar Collector Loop Information

Pipe Material (Select one or specify)		Other:	
Collector Return Line Pipe Size		Notes:	
Collector Supply Line Pipe Size (Select one or specify)		Other:	
If pressure gauge present, then enter Solar Loop Pressure (in PSIG) (if below 5 psi look for failures, leaks, etc.) Drainback systems rarely have pressure		Notes:	
Piping to Collectors Insulated (Y/N)		Notes:	

Description of anything surrounding pool site that produces shading on collectors (such as trees, buildings, fences, etc.):

E. Pool Heater Information			
Pool Heater Primary Fuel (gas/propane/electric)		Verify or update:	
Maximum Pool Heater Rating (Please note either kW or BTU/h)			
Manufacture Date (mo/yr)			
Manufacturer			
Model Number(s)			
Total Number of Pool Heaters			
Prior to installing the solar array which months of the year did you heat the pool?		Addl Details:	
Prior to installing the solar array what temperature setting was typically used (in degrees F)?			

F. Pool Pipe Info (non-solar, pipe entering from street and exiting water heating system to facility)			
Pipe Material (Select one or specify)		Other:	

Cold Inlet Pipe Size (from city) (Select one or specify)		Other:	
Hot Outlet Pipe Size (to home/bus) (Select one or specify)		Other:	
Interior Non-Solar Piping Insulated (Y/N)		Notes:	

G. Metering Information			
For gas or propane backup -- was a flue duct temperature sensor installed? (Y/N)	Yes	Number of flue temperature sensors installed:	
Relay installed on solar Pump (y/n – confirmation/reminder to install)			
FOR DYNASONIC INSTALLS - Ensure that the transducers are installed at the recommended distances (in Pipe Diameters) from disturbance sources (pipe Ts, elbows, diffusers, reducers, couplings, etc.) Refer to Dynasonic Transducer Positioning worksheet (tab) (Y/N)		If NO, record # of diameters :	
Time of Forced Upload			
One minute interval data Start Time		Stop Time:	
Flow Meter Signal Strength?			
Flow Meter S/N			
Simm #			
Obvius S/N			

Channel Input 1 (specify parameter)	
Channel Input 2 (specify parameter)	
Channel Input 3 (specify parameter)	
Channel Input 4 (specify parameter)	
Channel Input 5 (specify parameter)	
Channel Input 6 (specify parameter)	
Channel Input 7 (specify parameter)	
Channel Input 8 (specify parameter)	

I. Metering notes (problems, challenges, departures from protocol, and anything else noteworthy)

Reminder: Check to make sure all labels are in place on installed equipment and cables.

Reminder: Complete customer agreement document and obtain customer signature in CudaSign App.

Itron

CSI MF & Commercial Onsite and Metering Form Rev 6/20/2016

Itron ID		IOU	
CSI Application Code		Street Address	
Sample Strata		City	
Appt. Date		Zip Code	
Appt. Time		Wtr Heater Location	
Actual Date of Site Visit		Best Time to Contact	
System Owner Business Name		Secondary Contact Name	
System Owner Name		Secondary Phone Number	
System Owner Email Address		Secondary Email	
System Owner Phone Number		System Owner Cell Phone Number	
Solar Install Contractor Business Name		Solar Maint Contractor Name (If different)	
Solar Install Contractor Email Address		Solar Maint Contractor Email (If different)	
Solar Install Contractor Phone		Solar Maint Contractor Phone (If different)	
Primary Site Contact Name, if different from above			
Primary Site Phone #, if different from above			
Primary Site Email Address, if different from above			
Notes on customer perception of system performance (reported failures, leaks, maintenance, etc.)			
Does customer ever turn off backup water heater and rely solely on solar?			
Have there been, or is there going to be any building changes that would affect water consumption. If yes, applicable dates and changes.			
Comments			

A. System Configuration	
1. Solar and Auxiliary Storage are the same Tank and Drainback provides Freeze Protection 2.. Solar and Auxiliary Storage are the same Tank and Glycol provides Freeze Protection 3. Solar Storage and Auxiliary Tanks are separate and Drainback provides Freeze Protection 4. Solar Storage and Auxiliary Tanks are separate and Glycol provides Freeze Protection	5. Solar Storage with Tankless Auxiliary Water Heater and Drainback provides Freeze Protection 6. Solar Storage with Tankless Auxiliary Water Heater and Glycol provides Freeze Protection 7. Other – Specify Below
System Configuration (Select One)	
System Configuration Notes (Indicate Confidence). If thermosiphon, check to see if the electric heater element is wired and active.	
Expected Instrument System	
Utilized Instrument System	

B. Collector (check or enter correction under each pre-populated entry)
If roof is not accessible, collect as much info as possible from ground or roof edge. Use binoculars if needed and take pictures of collectors and potential shading features).

System Install Date:	Collector Panel Name/Number	Model	Quantity	Tilt (deg)	Azimuth True-N = 0 (compass deg)	Soiling (Light, Medium, Heavy, No soiling)	SRCC Collector ID
Verify:						Soiling & Square Footage Notes:	
Number of Collectors in Series						Verify Collector in Series Quantity:	
If there are more than one collector, how are they plumbed? (List number in Series and Series in Parallel)						Notes:	
UV Protection? (Y/N) Note condition of paint (white typically), sleeving or flashing.						Notes:	
Leak Indications (Y/N) Note any evidence of failure; check for leaking fluid or signs of past leaks (e.g., stains, corrosion, hard water deposits)						Notes:	
Annual Average Solar Access (in % based on interference from shading)						Verify:	
Is exterior piping insulated? (Y/N)			Exterior Pipe Insulation Thickness			Exterior Pipe Insulation Materials:	
Jacket Sleeving Present on Exterior Pipe insulation						Jacket Sleeving Material	

Approximate total length of exterior collector pipe (in feet) - insulated or uninsulated			Notes / Clarify if mix of insulated and uninsulated pipe		
Notes on Panels (location, access, condition, maintenance, shading or any other observations about the panels that may be impacting performance of the system)					
C. Facility information					
Building Type (Load Profile from Tracking):		Verified Building Type:			
If Building Type is "Other" provide the building type here:					
Hot Water Demand Unit of Measure (from Tracking):		Hot Water Demand Unit of Measure Calc'd:			
GPD per Unit of Measure (from cell D49)		Verified quantity of Units to Align with cell G49 - Enter number		Calc. Avg HW GPD	#N/A
Average Number of Bedrooms per Unit, for Apartments/Condos ONLY			NA		
Average Occupancy, for All Lodging (apts, condos, dormitories, hotels, motels, nursing homes, military barracks, etc.) - Enter number 0-100 (%)					
Notes on Hot Water Demand, Building Type, Units of Measure or Other Factors impacting HW Demand, (such as seasonal considerations for hotels/motels; restaurant meal preparations for breakfast, lunch or dinner)					

D. Solar Hot Water Information - Inside of Building			
Ownership (Host owned, Leased, Power Purchase Agreement (PPA))		Verified:	
Drainback Tank Manufacturer (if not applicable enter "N/A")		Notes:	
Drainback Tank Model Number (if not applicable enter "N/A")		Notes:	
Solar Storage Tank (NOT WATER HEATER) Manufacturer (if not applicable enter "N/A")		Notes:	
Solar Storage Tank (NOT WATER HEATER) Model (if not applicable enter "N/A")		Notes:	
Solar Storage Tank (NOT WATER HEATER) Size (Gal) (if not applicable enter "N/A")		Verify or update:	
Total Number of Solar Storage Tanks		Verify or update:	
System Type (Manufacturer)		Verify or update:	
System Model Number		Verify or update:	
Type of Heat Exchanger		Verify or update:	
freeze Protection (Type) Note any evidence of failure in System Notes field below			
Specify Pump Manufacturer (enter N/A if passive)		Notes:	
Specify Pump Model Number (enter N/A if passive)		Notes:	
Specify Pump Location (enter N/A if passive)			
Specify Pump Control Manufacturer		Notes:	
Specify Pump Control Model		Notes:	
Does the Pump Controller Log Data? If so, can we access it and how?			

Specify Pump Power (AC or DC(PV))			
Spot Power Reading on Solar Pump, if AC powered		☐ Table Formatting	If temp & flow gauges are present, mark check box to the left AND complete table to the right. Else leave un-checked & do not complete table.
Specify Pump Control Scheme (Temp/Time/None)			
Stagnation Protection (Type) Note any evidence of failure in System Notes field below		Verify or update:	
Freeze Protection (Type) Note any evidence of failure in System Notes field below		Verify or update:	
Notes on System including condition of pump and its proper operation (running when it should be or when it should not be running), or any evidence of failures, and freeze protection status (see comment); for any glycol leaks a) check glycol pressure and b) check for pump failure.			
E. Solar Collector Loop Information (Inside of building)			
Pipe Material (Select one or specify)		Other:	
Collector Return Line Pipe Size		Notes:	
Collector Supply Line Pipe Size (Select one or specify)		Other:	
If pressure gauge present, then enter Solar Loop Pressure (in PSIG) (if below 5 psi look for failures, leaks, etc.) Drainback systems rarely have pressure		Notes:	
Piping to Collectors Insulated (Y/N)		Note condition of insulation:	
Interior Solar Loop Pipe Insulation Thickness?		Interior Pipe Insulation Material:	

F. Water Heater Information (If Single Tank System, then enter storage/water heater info here.)					
Water Heater Primary Fuel (electric/gas/propane)				Verify or update:	
Type of Water Heater (Storage, On-Demand, Boiler)				Verify or update:	
Maximum Water Heater Rating (Please note either kW or BTU/h)					
Manufacture Date (mo/yr)					
Manufacturer					
Model Number(s)					
Water Heating Tank Size (Gal) (if not applicable enter "N/A")				Verify or update:	
Total Number of Water Heater (non solar) Tanks				Verify or update:	
Tank Wrapped in External Insulation? (Y/N)		External Tank Insulation Thickness		Ext. Tank Insulation Materials:	
Water Heater (DHW non solar tank) Setpoint (take picture if possible, temperature if available or low/medium/high)				Verify or update:	
Thermostatic Mixing Valve (Y/N)				Is mixing valve protected by a heat trap or drop-in hot water pipe?	
Thermostatic Mixing Temperature Set Point (in °F)				Verify or update, if available	
Thermostatic Mixing Relative Setting (Hot-Med-Cold)				Delivered hot water temp after stabilization (in °F)	

G. Water Pipe Info (non-solar, pipe entering from street and exiting water heating system to house)			
Pipe Material (Select one or specify)		Other:	
Cold Inlet Pipe Size (from city) (Select one or specify)		Other:	
Hot Outlet Pipe Size (to home/bus) (Select one or specify)		Other:	
Interior Non-Solar Piping Insulated (Y/N)		Notes:	
Interior Non-Solar Piping Insulation Type			
Interior Non-Solar Piping Insulation Thickness			
Non-Solar Water Recirculation Pump Present (Y/N)		Notes:	
Non-Solar Water Recirculation Pump Type (Speeds)	Fixed 3-Speed Pump	Multi-speed Recirc Pump Setting:	3rd Speed
If yes, Water Recirculation Pump Control Type		Make / model and notes for timer settings, dead bands, etc.	
H. Water Heater Metering Information			
Ohm Installations ONLY [Single tank (drainback and glycol), dual tank (drainback and glycol)]			
Type of customer internet router (Ethernet or wireless)			
Location of customer internet router and Ohm "Amber" unit (for future reference and maintenance or removal)			
Amber Serial Number (modem / data router)			
Emily Serial Number (temperature transmitter / logger)			
Ohm Sensor 1 Serial Number (Solar Tank if there is one, otherwise hot water heater)			
Ohm Sensor 1 Length (Short, Medium, Long) Water heating Tank Size (Short ~50 gal, Medium ~80 gal, Long ~ 120 gal)			
Ohm Sensor 2 Serial Number			
Ohm Sensor 2 Length (Hot Water Hear - Only if separate solar storage tank) (Short, Medium, Long) Solar Storage Tank Size (Short ~50 gal, Medium ~80 gal, Long ~ 120 gal)			
Enthalpy and temperature sensors installed on solar tank (if single tank, this is the only tank)			

Confirm Enthalpy sensor installed on backup hot water heater tank (input 2; Only for 2 Tank Systems)	
Temperature element installed on piping from the solar array on the roof to the heat exchanger inside or attached to the Hot Water Heater or Solar Storage Tank (for a two-tank system) and cable connected to the Emily / Temperature Transmitter port labelled HX In (Yes, installation completed onsite / No)	
Temperature element installed on piping from the heat exchanger in the Hot Water Heater or Solar Storage Tank (for a two-tank system) to the solar array on the roof and cable connected to the Emily / Temperature Transmitter port labelled HX Out (Yes, installation completed onsite / No)	
System Information Updated on Sunnovations Website (when DCF indicates in colored cells that there is only one tank or a different tank volume listed) (Yes/ No)	

Flexim or Dynasonic Installations ONLY			
Gas or Propane Backup	Flue pipe temp sensor installed (Y/N)		
Relay installed on solar Pump (y/n – confirmation/reminder to install)			
If Thermostatic Mixing present, Metering Location (Outside T / Inside T). Include in your system diagram. Sketch on paper and take a photograph. Provide locations of mixing valve and recirc pumps, and distances (especially vertical) between solar and back-up tanks. (See worksheet for TMV Location.)			
FOR FLEXIM INSTALLS - Ensure that the transducers are installed at the recommended distances (in Pipe Diameters) from disturbance sources (pipe Ts, elbows, diffusers, reducers, couplings, etc.) Refer to Flexim Transducer Positioning worksheet (tab) (Y/N)		If NO, record # of diameters :	

FOR DYNASONIC INSTALLS - Ensure that the transducers are installed at the recommended distances (in Pipe Diameters) from disturbance sources (pipe Ts, elbows, diffusers, reducers, couplings, etc.) Refer to Dynasonic Transducer Positioning worksheet (tab) (Y/N)		If NO, record # of diameters :	
Time of Forced Upload			
One minute interval data Start Time		Stop Time:	
Flow Meter Signal Strength?			
Flow Meter S/N			
Simm #			
Obvius S/N			
Channel Input 1 (specify parameter)			
Channel Input 2 (specify parameter)			
Channel Input 3 (specify parameter)			
Channel Input 4 (specify parameter)			
Channel Input 5 (specify parameter)			
Channel Input 6 (specify parameter)			
Channel Input 7 (specify parameter)			
Channel Input 8 (specify parameter)			
DID YOU CLEAR OUT AND RENAME UNUSED CHANNELS PRIOR TO MOUNTING ANTENNA?			

I. Metering notes (problems, challenges, departures from protocol, and anything else noteworthy)

Reminder: Check to make sure all labels are in place on installed equipment and cables.

Reminder: Complete customer agreement document and obtain customer signature in CudaSign App.

CSI RES SWH Onsite and Metering Form Rev 3/2/2016

Itron ID			
CSI Application Code		Street Address	
Sample Strata		City	
Appt. Date		Zip Code	
Appt. Time		Wtr Heater Location	
Actual Date of Site Visit		Best Time to Contact	
Primary Contact Name		Secondary Contact Name	
Primary Phone Number		Secondary Phone Number	
Primary Email Address		Secondary Email	
Solar Contractor Name		Solar Contractor Phone	
Notes on customer perception of system performance (reported failures, leaks, maintenance, etc.)			
Does customer ever turn off backup water heater and rely solely on solar?			
Have there been, or is there going to be any, any household changes that would affect water consumption (child to college?) If yes, applicable dates and changes.			
Comments			

A. System Configuration	
Two Tank Active (solar storage tank and water heater tank) Single Tank Active (solar storage and water heating tank at the same) Two Tank Active Drain Back Single Tank Active Drain Back (solar storage and water heater are the same tank)	Single Tank Passive Thermosiphon Single Tank ICS Other
System Configuration (Select One)	

System Configuration Notes (Indicate Confidence). If thermosiphon, check to see if the electric heater element is wired and active.	
Expected Instrument System	
Utilized Instrument System	

B. Collector (check or enter correction under each pre-populated entry) If roof is not accessible, collect as much info as possible from ground or roof edge. Use binoculars if needed.								
System Install Date:	Mfg.	Model	Quantity	Tilt (deg)	Azimuth True-N = 0 (compass deg)	Soiling (L= Light, M = Medium, H = Heavy, N = No soiling)	SRCC (or IAPMO) Number	Collector Square Footage
		Verify:				Soiling & Square Footage Notes:		
If there are more than one collector, how are they plumbed? (Series or Parallel)						Notes:		
UV Protection? (Y/N) Note condition of paint (white typically), sleeving or flashing.						Notes:		
Leak Indications (Y/N) Note any evidence of failure; check for leaking fluid or signs of past leaks (e.g., stains, corrosion, hard water deposits)						Notes:		
Annual Average Solar Access (in %)						Verify or notes:		
Is exterior piping insulated? (Y/N)			Exterior Pipe Insulation Thickness			Exterior Pipe Insulation Materials:		
Jacket Sleeving for Exterior Pipe insulation						Jacket Sleeving Material		

Approximate total length of exterior collector pipe (in feet) - insulated or uninsulated		Notes / Clarify if mix of insulated and uninsulated pipe	
Notes on Panels (location, access, condition, maintenance, shading or any other observations about the panels that may be impacting performance of the system)			

C. Household information			
Type of Home (Single Family Detached (SFD), Single Family Attached (SFA), or Mobile Home (MH))		Other Specify:	
Square Footage of Living Space		Verify or update:	
Number of bedrooms		Verify or update:	
Number of full bathrooms (includes shower/tub)		Verify or update:	
Number of half bathrooms (only sink and toilet)		Verify or update:	
Washing Machine (Y/N)			
Dishwasher (Y/N)			
Low flow shower heads? (Y/N)			
Faucet aerators? (Y/N)			
Are there any other hot water consuming end-uses not listed above? If so, please describe and estimate daily hot water use (in gals). If hydronic heat, call Itron or PM immediately, but if there is something else please note here.			

Months per year occupancy		Verify or update:	
Number of full-time residents in the house ages 16 and over		Verify or update:	
Number of full-time residents in the house under the age of 16		Verify or update:	

D. Solar Hot Water Information (Inside of Building, look up tank sizes by SRCC number at https://secure.solar-rating.org/Certification/Ratings/RatingsSummaryPage.aspx?type=2)			
Ownership (Host owned, Leased, Power Purchase Agreement (PPA))		Notes:	
Drainback Tank Manufacturer (if not applicable enter "N/A")		Notes:	
Drainback Tank Model Number (if not applicable enter "N/A")		Notes:	
Drainback Tank Size (Gal) (if not applicable enter "N/A")		Verify or update:	
Storage Tank (NOT WATER HEATER) Manufacturer (if not applicable enter "N/A")		Notes:	
Storage Tank (NOT WATER HEATER) Model (if not applicable enter "N/A")		Notes:	
Storage Tank (NOT WATER HEATER) Size (Gal) (if not applicable enter "N/A")		Verify or update:	
Type of Heat Exchanger		Verify or update:	
Heat Exchanger Notes			

Stagnation Protection (Type) Note any evidence of failure in System Notes field below		Verify or update:	
Freeze Protection (Type) Note any evidence of failure in System Notes field below		Verify or update:	

Notes on System including condition of pump and its proper operation (running when it should be or when it should not be running), or any evidence of failures, and freeze protection status (see comment); for any glycol leaks a) check glycol pressure and b) check for pump failure.

E. Solar Collector Loop Information (Inside of building)			
Pipe Material (Select one or specify)		Other:	
Collector Return Line Pipe Size		Other:	
Collector Supply Line Pipe Size (Select one or specify)		Other:	
Solar Loop Pressure (if below 5psi look for failures, leaks, etc.) Drainback systems rarely have pressure.		Notes:	
Piping to Collectors Insulated (Y/N). Note condition.		Notes:	
Thickness and Type of Collector Pipe Insulation		Notes:	

F. Water Heater Information (If Single Tank System, then enter storage/water heater info here, look up tank size by SRCC number at https://secure.solar-rating.org/Certification/Ratings/RatingsSummaryPage.aspx?type=2)				
Water Heater Primary Fuel (electric/gas/propane)				
Type of Water Heater (Storage, On-Demand, Boiler)				
Maximum Water Heater Rating (kW or BTU/h)				
Manufacture Date				
Manufacturer				
Model Number				
Water Heating Tank Size (Gal) (if not applicable enter "N/A")			Verify or update:	
Tank wrapped in external insulation (Y/N) Specify thickness and type.			Thickness & type:	
Water Heater Setpoint (take picture if possible, temperature if available or low/medium/high)			Verify or update:	
Thermostatic Mixing Valve (Y/N)		Is mixing valve protected by a heat trap or drop-in hot water pipe.		
Thermostatic Mixing Relative Setting (Hot-Mid-Cold, etc)		Thermostatic Mixing Valve Set Point (in °F)		

Delivered hot water temp after stabilization. (Run nearest tap until stable and determine with Temperature Sensor)			

G. Water Pipe Info (non-solar, pipe entering from street and exiting water heating system to house)			
Pipe Material (Select one or specify)		Other:	
Cold Inlet Pipe Size (from city) (Select one or specify)		Other:	
Hot Outlet Pipe Size (to home/bus) (Select one or specify)		Other:	
Interior Piping Insulated (Y/N)		Notes:	
Interior Piping Insulation Type			
Interior Piping Insulation Thickness			
Water Recirculation Pump Present (Y/N)		Notes:	
If yes, Water Recirculation Pump control type		Make / model and notes for timer settings, dead bands.	

H. Water Heater Metering Information	
Ohm Installations ONLY [Single tank (drainback and glycol), dual tank (drainback and glycol)]	
Type of customer internet router	

Location of customer internet router and Ohm "Amber" unit (for future reference and maintenance or removal)	
Amber Serial Number (modem / data router)	
Emily Serial Number (temperature transmitter / logger)	
Ohm Sensor 1 Serial Number (Solar Tank if there is one, otherwise hot water heater)	
Ohm Sensor 1 Length (Short, Medium, Long) Water heating Tank Size (Short ~50 gal, Medium ~80 gal, Long ~ 120 gal)	
Ohm Sensor 2 Serial Number	
Ohm Sensor 2 Length (Hot Water Hear - Only if separate solar storage tank) (Short, Medium, Long) Solar Storage Tank Size (Short ~50 gal, Medium ~80 gal, Long ~ 120 gal)	
Enthalpy and temperature sensors installed on solar tank (if single tank, this is the only tank)	
Confirm Enthalpy sensor installed on backup hot water heater tank (input 2; Only for 2 Tank Systems)	
Temperature element installed on piping from the solar array on the roof to the heat exchanger inside or attached to the Hot Water Heater or Solar Storage Tank (for a two-tank system) and cable connected to the Emily / Temperature Transmitter port labelled Hx In (Yes, installation completed onsite / No)	

Temperature element installed on piping from the heat exchanger in the Hot Water Heater or Solar Storage Tank (for a two-tank system) to the solar array on the roof and cable connected to the Emily / Temperature Transmitter port labelled Hx Out (Yes, installation completed onsite / No)	
System Information Updated on Sunnovations Website (when DCF indicates in colored cells that there is only one tank or a different tank volume listed) (Yes/ No)	

I. Metering notes (problems, challenges, departures from protocol, and anything else noteworthy)

Reminder: Check to make sure all labels are in place on installed equipment and cables.

Reminder: Complete customer agreement document and obtain customer signature in CudaSign App.

APPENDIX B METERING PLAN

Draft, February 8, 2016

Estimation of program impacts and examination of system performance will rely on metered data. Those metered data will come from three sources. First, new metering installed by the impacts evaluation contractor to measure delivery of solar energy to heating loads. Second, Performance Based Incentive (PBI) metering installed at larger Multifamily and Commercial sites that measures energy delivery to the heating load. These sites are few in number and if installed to program specification, should be providing evaluation grade data. Finally, existing Consumer Performance Metering (CPM) solar system metering (installed by program participants and vendors). This first type of data is almost entirely on the solar loop and is collected by 'smart controllers'. These data, therefore, need additional information to account for standby losses to quantify savings. Plans for installation of meters, as well as acquisition and use of metered data, are summarized below.

B.1 OVERVIEW

The population of projects covered by this study is summarized in Table B-1. In this summary, projects are classified according to Budget Program and availability of data from existing solar loop metering. Projects are classified by Budget Program because that factor is important to Program Administrators for a variety of reasons, including alignment with customer types, solar technologies, and program implementation activities.

Availability of data from existing solar loop metering is included in Table B-1 because it is an important factor influencing sample design calculations and plans for installing meters for impacts evaluation purposes. These summaries of availability of data from existing metering reflect not only the presence of existing metering but also the likelihood of data being readily available. For example, large numbers of Commercial Pools are equipped with existing metering lacking remote data access capabilities. That limitation precludes reliance on data produced by those metering systems.

TABLE B-1: SUMMARY OF PROGRAM POPULATION

Budget Program	Existing Metering	N	Total Expected Savings (Therm Equivalent)
Commercial Pools	Yes—CPM	6	25,676
Commercial Pools	No	438	931,511
Commercial/Multifamily Residential	Yes—PBI	4	118,825
Commercial/Multifamily Residential	Yes—CPM	94	413,108
Commercial/Multifamily Residential	No	353	672,912
Low Income Multifamily Residential	Yes—CPM	151	494,078
Low Income Multifamily Residential	No	363	403,846
Low Income Single Family Residential	No	210	23,865
Single Family Residential	No	1,458	152,568
Grand Total		***3,077***	***3,236,388***

B.2 ANTICIPATED RELATIVE PRECISION

The allocation of new meter installs to strata is summarized in Table B-2 along with anticipated relative precision for a 90% confidence level. The assumed error ratios used in the precision calculations vary depending on several factors, including: 1) availability of solar loop data from existing CPM metering for use as the auxiliary variable in ratio analysis, 2) level of detail included in ex ante estimates of savings from the program tracking system, and 3) the incidence of existing metering systems that capture not only solar loop energy flows but also delivery of energy to heating loads.

Commercial/Multifamily provides the bulk of savings so will receive the most attention, followed by commercial pools. Commercial pools are relatively uniform in that almost all use direct, unglazed panels. Both of these have savings calculated on a per site basis using the CSI-Thermal calculator built by TESS, so we estimate an error ratio (ER) [1] of 0.6 with respect to tracking system estimates of savings. We expect that we will be able to access Consumer Performance Metering (CPM) data from Heliodyne and SunReports since both collect solar loop data from their controllers via the internet and Heliodyne has been very responsive with SunReports being somewhat responsive. Comparing these CPM data to full Load/Aux metering should give us a much better basis for estimation, so we are estimating an error ratio of just 0.2 between CPM's metered solar loop data and our metered Load/Aux data.

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[1] Error ratio is a measure of variability between the sampled data and expected results. It can be calculated as $ER = s^{(ratio)}/\bar{y}$. M. Sami Khawaja, Josh Rushton, and Josh Keeling, *The Uniform Methods Project: Methods for Determining Energy Efficiency Savings for Specific Measures*, Subcontract Report NREL/SR-7A30-53827 April 2013

TABLE B-2: STRATA-LEVEL SAMPLE DESIGN DETAIL

Budget Program	Existing Metering	Assumed Error Ratio	New Meter Installs	Anticipated Relative Precision at 0.90 Confidence[2]
Commercial Pools	Yes—CPM	0.0	0	0.00
Commercial Pools	No	0.6	30	0.18
Commercial/Multifamily Residential	Yes--PBI	0.0	0	0.00
Commercial/Multifamily Residential	Yes	0.2	12	0.10
Commercial/Multifamily Residential	No	0.6	22	0.21
Low Income Multifamily Residential	Yes	0.2	10	0.11
Low Income Multifamily Residential	No	0.6	23	0.21
Low Income Single Family Residential	No	0.8	6	0.65
Single Family Residential	No	0.8	17	0.34
Grand Total			***120***	

For small numbers of commercial pools with readily available CPM data and PBI projects we anticipate being able to use data from existing metering directly to assess energy savings. For this reason no new meter installs are planned for these projects, and these strata will be subject to no sampling error. These conditions exist for only 10 projects.

Single family systems tend to show more variability in system configurations so are allotted proportionally more meters than other sectors. Savings for these systems are calculated using the SRCC OG-300 ratings that vary by system and location, plus collector shading and orientation factors, using standard ASHRAE water heating load profiles. These water heating load profiles do not vary by occupancy, but we plan to adjust expected savings based on reported occupancy. We will further adjust this for metered sites based on data gathered on site such as actual number of occupants, use of water conservation measures like faucet aerators, and presence of washing machines, dishwashers, etc.

We previously analyzed the Florida Power and Light (FPL) Solar Hot Water Pilot Program. The residential solar FPL single family residential systems showed an error ratio of approximately 1 but the tracking system savings for that program estimates did not vary by location, system type, or occupancy. Therefore, we estimate that we will see a slightly lower error ratio of 0.8 for single family residential systems in the CSI-Thermal.

2 Precision is the relative accuracy at a particular confidence level and is a measure of the precision of a reported population level value, like annual energy savings. For example, 0.18 or 18 percent precision means that we expect to have a 0.90 or 90 percent confidence that the actual value for the population would fall with 18 percent of the reported mean value.

Summary results of the precision calculations are presented at the Budget Program level in Table B-3. A precision level of 0.08 is anticipated for the program as a whole. Precision levels for individual Budget Programs range from 0.10 to 0.65. The top 3 rows in Table B-3 correspond to 94% of expected savings and therefore are of particularly great interest. The poorer relative precision for pools reflects the lack of availability of data from existing metering. Most have CPM but use SunEarth controllers so data from those controllers can only be collected by travelling to the site and downloading the data manually. A small number of commercial pools have Heliodyne or SunReports CPM controllers for which we expect to get data.

TABLE B-3: SUMMARY OF ANTICIPATED RELATIVE PRECISION

Budget Program	New Meter Installs	Anticipated Relative Precision
Commercial Pools	30	0.18
Commercial/Multifamily Residential	32	0.13
Low Income Multifamily Residential	32	0.11
Low Income Single Family Residential	6	0.65
Single Family Residential	19	0.32
Grand Total	***119***	***0.08***

B.3 TREATMENT OF OTHER VARIABLES OF INTEREST

While sample design calculations were mainly focused on achieving a satisfactory allocation of new meter installations across Budget Programs, selection of sites for meter installations will also account for other variables of interest, including: utility company, climate zone (inland/coastal), and SWH system type. Other variables will be investigated but given the relatively small number of meters, we will only allocated meters based on the variables of interested noted previously. Meter installations were allocated within strata based on numbers of projects. A detailed list is included in Section B.5.

B.4 DISCUSSION OF KEY ASSUMPTIONS AND POSSIBLE BIAS

Precision calculations were based on assumption that solar loop data will be available for 245 projects for use as the auxiliary variable in a ratio analysis, as indicated in Table B-4. If those data are unavailable for some projects the precision actually achieved will be lower, all else equal. If the availability of those data is not random — for example if it is clustered among a subset of vendors — then bias could be introduced.

For Commercial/Multifamily Residential, 99% of savings are from indirect forced circulation systems that are simulated with the CSI-Thermal Calculator. A small number of systems representing less than 1% of savings were allowed to use SRCC OG-300 savings estimates that are likely to produce a different level of accuracy than estimates yielded by the calculator. When targeting sites for installation of metering we limited ourselves to only those projects for which simulated savings estimates from the CSI-Thermal Calculator are available. While this treatment deviates from the principles of random sampling, the benefits of having a simulation model against which to compare metered data in a consistent manner were judged to be larger than the bias risk introduced with this treatment.

B.5 NEW METER INSTALLATION TARGETS BY STRATA AND SUBPOPULATION

TABLE B-4: SINGLE FAMILY METER INSTALL TARGETS

Row Labels	Coastal	Inland
Low Income Single Family Residential		**6**
Pacific Gas and Electric		**5**
Indirect Forced Circulation (IF)		5
Southern California Gas Co		**1**
Indirect Forced Circulation (IF)		1
Single Family Residential	**4**	**15**
Pacific Gas and Electric	**2**	**4**
Indirect Forced Circulation (IF)	2	3
Indirect Thermosyphon (IT)		1
San Diego Gas and Electric		**4**
Indirect Forced Circulation (IF)		3
Indirect Thermosyphon (IT)		1
Southern California Gas Co	**2**	**7**
Direct Integral Collector Storage (DI)	1	3
Indirect Forced Circulation (IF)	1	2
Indirect Self Pumped (IS)		1
Indirect Thermosyphon (IT)		1
Grand Total	**4**	**21**

TABLE B-5: MULTIFAMILY AND COMMERCIAL METER INSTALL TARGETS

	No CPM		Expected CPM	
Strata	**Coastal**	**Inland**	**Coastal**	**Inland**
Commercial/Multifamily Residential	**11**	**10**	**9**	**2**
Pacific Gas and Electric	**7**	**3**	**6**	
Glycol				
Solar and Auxiliary Storage are the same Tank	1		1	
Solar Storage and Auxiliary Tanks are separate	6	3	4	
Solar Storage with Tankless Auxiliary Water Heater			1	
San Diego Gas and Electric	**1**	**1**	**2**	
Glycol				
Solar Storage and Auxiliary Tanks are separate	1	1	2	
Southern California Gas Co	**3**	**6**	**1**	**2**
Drainback				
Solar Storage and Auxiliary Tanks are separate	2	3		1
Glycol				
Solar Storage and Auxiliary Tanks are separate	1	3	1	1
Low Income Multifamily Residential	**9**	**13**	**6**	**4**
Pacific Gas and Electric	**6**	**1**	**3**	**1**
Drainback				
Solar and Auxiliary Storage are the same Tank	1			
Glycol				
Solar and Auxiliary Storage are the same Tank		1		
Solar Storage and Auxiliary Tanks are separate	5		3	1
San Diego Gas and Electric	**1**	**1**	**1**	
Glycol				
Solar Storage and Auxiliary Tanks are separate	1	1	1	
Southern California Gas Co	**2**	**11**	**2**	**3**
Drainback				
Solar Storage and Auxiliary Tanks are separate		2		
Glycol				
Solar Storage and Auxiliary Tanks are separate	2	9	2	3
Grand Total	**20**	**23**	**15**	**6**

TABLE B-6: COMMERCIAL POOLS METER INSTALL TARGETS

Utility	Coastal	Inland
Pacific Gas and Electric	1	1
San Diego Gas and Electric	2	3
Southern California Gas Co	5	18
Grand Total	**8**	**22**