ENERGY RESEARCH AND DEVELOPMENT DIVISION

FINAL PROJECT REPORT

Estimating Energy Savings From Community Scale Solar Water Heating in Los Angeles County

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PREFACE

The California Energy Commission's (CEC) Energy Research and Development Division manages the Gas Research and Development Program, which supports energy-related research, development, and demonstration not adequately provided by competitive and regulated markets. These natural gas research investments spur innovation in energy efficiency, renewable energy and advanced clean generation, energy-related environmental protection, energy transmission and distribution and transportation.

The Energy Research and Development Division conducts this public interest natural gas-related energy research by partnering with RD&D entities, including individuals, businesses, utilities and public and private research institutions. This program promotes greater gas reliability, lower costs and increases safety for Californians and is focused in these areas:

- Buildings End-Use Energy Efficiency
- Industrial, Agriculture and Water Efficiency
- Renewable Energy and Advanced Generation
- Natural Gas Infrastructure Safety and Integrity
- Energy-Related Environmental Research
- Natural Gas-Related Transportation

Estimation of Energy Savings From Community Scale Solar Water Heating in Los Angeles County is the final report for Contract Number PIR-16-023 conducted by the California Center for Sustainable Communities. The information from this project contributes to the Energy Research and Development Division's Gas Research and Development Program.

For more information about the Energy Research and Development Division, please visit the CEC's research website (www.energy.ca.gov/research/) or contact the Energy Research and Development Division at ERDD@energy.ca.gov.

ABSTRACT

Estimation of Energy Savings From Community Scale Solar Water Heating in Los Angeles County explores, through a series of case studies, the extent to which community scale solar water heating systems, designed for residential structures in Los Angeles County and constructed from currently available technology, can displace natural gas for domestic water heating. The effects of policy, urban form, and building characteristics on the performance of solar water heating systems, as well as community scale solar water heating's potential to reduce emissions from the residential housing sector, are discussed herein.

Three public and three private residential developments were selected as case studies for community scale solar water heating. These six cases were drawn from the approximately 19,000 "energy communities" in Los Angeles County, chosen to represent a cross-section of housing stock and development patterns common in in the county, and for different levels of suitability for solar water heating. The performance of and energy savings from solar water heating systems on each of these properties were evaluated using the National Renewable Energy Laboratory's System Advisor Model. The results of the system simulations reveal how building characteristics and hot water demand affect the performance of community scale solar water heating systems.

The case study site's system simulations show that residential developments with community scale solar water heating can reach site-wide solar fractions of 20-80 percent, depending on the characteristics of the site's residential buildings and their inhabitants. While the results of the case studies indicate that community scale solar water heating is viable as an emissions reduction technology, side-by-side comparison with other water heating technologies is necessary to determine optimality.

Keywords: solar water heating, community scale energy systems, water heating, residential energy use

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Introduction

Residential natural gas consumption represents approximately one-fifth of all natural gas deliveries in California, and water heating consumes half of all residential gas deliveries. More than 90 percent of residences are equipped with natural gas water heaters. Water heating accounts for around 25 percent of total energy end use in residential buildings, and for about 49 percent of residential natural gas consumption.

In 2016, California's residential gas consumption for water heating totaled 201,795 million cubic feet, resulting in the emission of 11 million tons of carbon dioxide. This volume of carbon dioxide is equal to that emitted annually by a United States city with a population of about 700,000. Since water heating accounts for 25 percent of residential energy consumption, substituting renewable sources for thermal energy may yield considerable energy savings for California.

It is challenging for state and local governments to develop regulations that reduce energy consumption and greenhouse gas emissions for residential buildings. To help guide these policy decisions, researchers explored community scale residential housing constructed from available solar water heating technology and evaluated how solar can displace natural gas for domestic water heating.

Project Purpose

This study examined the potential of community scale solar water heating systems to reduce natural gas consumption in Los Angeles County. Community scale describes the size of the system and an adherence to a set of system design principles and occupies an intermediate space between the domestic and utility scales.

Community-scale energy systems are intended to maximize the efficient use of local resources where possible and create a range of options for residents to contribute to its operation. Additionally, the California Energy Commission and the National Renewable Energy Laboratory suggested developing community scale energy infrastructure in a socioeconomically equitable manner, improving economies of scale and project siting, and exploring new models for service delivery and project financing.

Los Angeles County has a mild, Mediterranean climate with abundant sunshine, and the county's land use and development patterns range from densely populated urban areas to near-rural exurbs. In places where residents cannot afford to install separate domestic solar systems, or where space for system infrastructure is limited, a community scale approach offers opportunities for all participants to receive the benefits of solar water heating and support a system's operation. Residents may contribute to a system's continued operation by allowing system infrastructure to be installed on their property, or by contributing financially if they do not own property on which system infrastructure can be placed.

A community scale approach to solar water heating may be superior in economic efficiency compared to installing many smaller domestic solar water heating systems. Larger systems require larger storage tanks, which store heat more efficiently than numerous smaller tanks, thus diminishing the cost per unit of heat delivered. Furthermore, community scale systems distribute fixed costs among many users, allowing residents who do not have the financial resources to install their own solar water heating systems to enjoy low carbon hot water and reduce their consumption of natural gas.

Reducing residential natural gas consumption will reduce greenhouse gas emissions and diminish concentrations of local air pollutants, such as sulfur dioxide and oxides of nitrogen.

This study explores what role a community scale solar water heating can play in that transition, taking Los Angeles County as a geographic, policy, and climatic context. The case studies provide information about the various technologies available for community-scale solar thermal systems, the feasibility of community scale water heating, and estimates of energy savings generated by community scale solar water heating systems. The report also explores the influence of urban form (such as the shape, size, and density that constitute the physical characteristics of built-up areas) and building code on the performance of community-scale systems.

Project Process

The project team from California Center for Sustainable Communities at the University of California, Los Angeles's Institute of the Environment and Sustainability evaluated the energy-saving potential of community scale solar water heating: designing a general-purpose, scalable solar water heating system to serve as the basis for community scale solar water heating system simulations; selecting simulation methods and case study sites; and running simulations and analyzing the results.

Unlike solar photovoltaic systems, there are several varieties of solar thermal collector and heat storage technologies. Their use depends on the details of the desired application. To evaluate the energy savings of community scale solar water heating systems, it was necessary to select from among the available component technologies and create a prototypical system whose behavior could be simulated using computational methods. The prototypical system was designed with guidance from engineers who construct and operate solar thermal systems, and it complies with state and local building code requirements.

Six residential properties (102 buildings) were selected for the case studies from about 19,000 potential sites. The project team created basic feasibility criteria and a metric to measure the suitability of a given property. The cases are intended to reflect a range of different urban forms and property ownership arrangements.

Once a satisfactory prototypical solar water heating system was specified, the team determined the best methods for simulating the operation of community scale solar water heating systems. The values of simulation inputs, including hot water demand, were decided. Input from the project's technical advisory committee was invaluable for accomplishing these tasks. It was determined that the National Renewable Energy Laboratory's System Advisor Model solar water heating module was best, given the focus and requirements of the study. The volume of hot water consumed on a daily basis was calculated using a series of technical assumptions from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers and the American Society of Plumbing Engineers.

Data on the sites' buildings, the demographics of the residents, and the legal status of the site's owners/managers was collected. Based on the information collected, a characteristic daily demand schedule for hot water and the implied consumption of natural gas was constructed for each site.

Project Results

The case studies and simulation results show that community scale solar water heating is feasible for residential developments ranging in size from small, multifamily structures to large, multi-structure housing complexes. The solar fractions of the systems simulated ranged between 20 to 80 percent, indicating that community scale systems are capable, under the right conditions, of generating considerable energy savings. Solar water heating systems that met California Title 24 and incentive program requirements were designed using basic system sizing guidelines in all but one case, where an exception had to be made to meet the minimum solar fraction required under Title 24.

Interviews conducted with property owners, solar contractors, engineers and others illustrated the difficulty in programmatically estimating the cost of installing solar thermal systems. Unlike photovoltaic systems, the cost of a solar thermal retrofit depends on the condition and configuration of a building's plumbing, and whether the natural gas heaters currently installed can be used as auxiliary heaters. Engineers, owners, and contractors also stressed that qualification for incentives is essential for any solar water heating project (single-family or community scale) to be economically and practically feasible.

Finally, the case studies and simulation results made possible a detailed discussion of how the available solar thermal heating incentives affect the decision landscapes faced by different types of property owners (private/private, nonprofit/public) vis-à-vis solar water heating. A detailed review of the incentive programs and information gathered in interviews shows that it is easiest for private property owners to claim the available solar thermal incentives and thus retrofit their properties for community scale solar water heating.

All references to the California Solar Initiative's Thermal Rebates and Residential Renewable Tax Credits mentioned in the report were accurate as of December 31, 2019. However, the rebate program ended on July 31, 2020.

Technology/Knowledge Transfer

Effective knowledge transfer is critical for the ability of research to build on previous studies. As such, part of this project included involvement with solar thermal manufacturers, other colleges and universities, incubators, utilities, installers, and local city officials. This research was disseminated through publications and public webinars.

Benefits to California

Community scale solar water heating is one technological tool, among many, for reducing the residential housing sector's consumption of natural gas. Electrification, heat pump-PV systems, biomass, and other thermal generation and cogeneration technologies are also potential sources of low-carbon thermal energy for residential use. Determining which applications are best suited for a particular thermal energy technology is an essential first step in designing policy to encourage or mandate its adoption.

The results of the simulations show that the prototypical solar water heating system, for the properties selected, can provide between 20 to 80 percent of the energy required for water heating. This study's methods can be altered and scaled to provide regional estimates of the energy savings from the adoption of community scale solar water heating.

Solar water heating is not competitive with natural gas on a cost basis without incentives such as the Residential Renewable Energy Tax Credit and the California Solar Initiative's thermal performance-based rebates. Building-scale systems installed on privately owned residential properties are eligible for both the thermal rebate and the federal tax credit and would be the easiest type of building in which to install solar thermal. However, they require a solar fraction of at least 50 percent. Since no capital cost rebate is available to private nonprofits, they must be able to bear the capital costs until the system is operational, at which point they can begin receiving rebate payments. Unlike private and private nonprofit property owners, housing authorities cannot negotiate directly with solar thermal contractors. They must also pay for expensive estimates of system performance and ongoing monitoring. Combined with prevailing-wage requirements for system installation contracts, and the absence of other incentives to offset capital costs, community scale solar water heating is an expensive proposition for the public housing authorities in Los Angeles County, even if the chosen sites are well-suited for solar water heating retrofits.

The prototypical solar thermal system that emerged from this process can be used in future research projects, such as economic studies of solar thermal systems and comparisons between alternative renewable heating technologies.

CHAPTER 1:
Selection of Solar Water Heating Technologies

The fundamental elements of solar water heating (SWH) systems include solar thermal collectors, storage tanks to store the heated working fluid/heated water, and piping systems to move the heated water and working fluid between collectors, storage tanks, and buildings. Additional elements may include heat exchangers, auxiliary gas heaters, or buffer tanks. Control mechanisms for SWH systems depend on a given system's size and complexity (Fisch et al., 1998). This chapter explains how the prototypical system for community scale solar water heating emerged from a review of the available solar thermal technologies and input from local contractors and engineers.

Solar Thermal Collectors

Solar thermal collectors absorb thermal energy from incident solar radiation and transfer it to water or a working fluid. The four most common collector types are:

- Flat Plate Collectors (FPCs)
- Evacuated Tube Collectors (ETCs)
- Integrated Photovoltaic/Thermal (PV/T) Collectors

Selection of a collector type depends on the desired application and cost. The amount of useful heat a collector delivers to a given system is a function of the amount of incident solar radiation, the difference between ambient temperature and that of the unit, and the temperature of the heat transfer fluid at the collector inlet (Duffie and Beckman, 2013). Collector performance is also affected by the angle of insulation and local meteorological conditions (Duffie and Beckman, 2013). Table 1 lists the peak thermal efficiencies for different collector types measured in laboratory settings.

Table 1: Thermal Efficiency Ranges of Solar Collector Technologies

Collector Type	Peak Thermal Efficiency (T_i=T_a)
Flat Plate	70-80%*,**
Evacuated Tube	~60%**
PV/T	50-70%***
Integrated Collector Storage	Variable****

Peak thermal efficiencies shown here are based on laboratory studies measuring useful heat output obtained from a fixed amount of incident radiation and an ambient temperature equal to the collector inlet temperature (T_i = T_a).

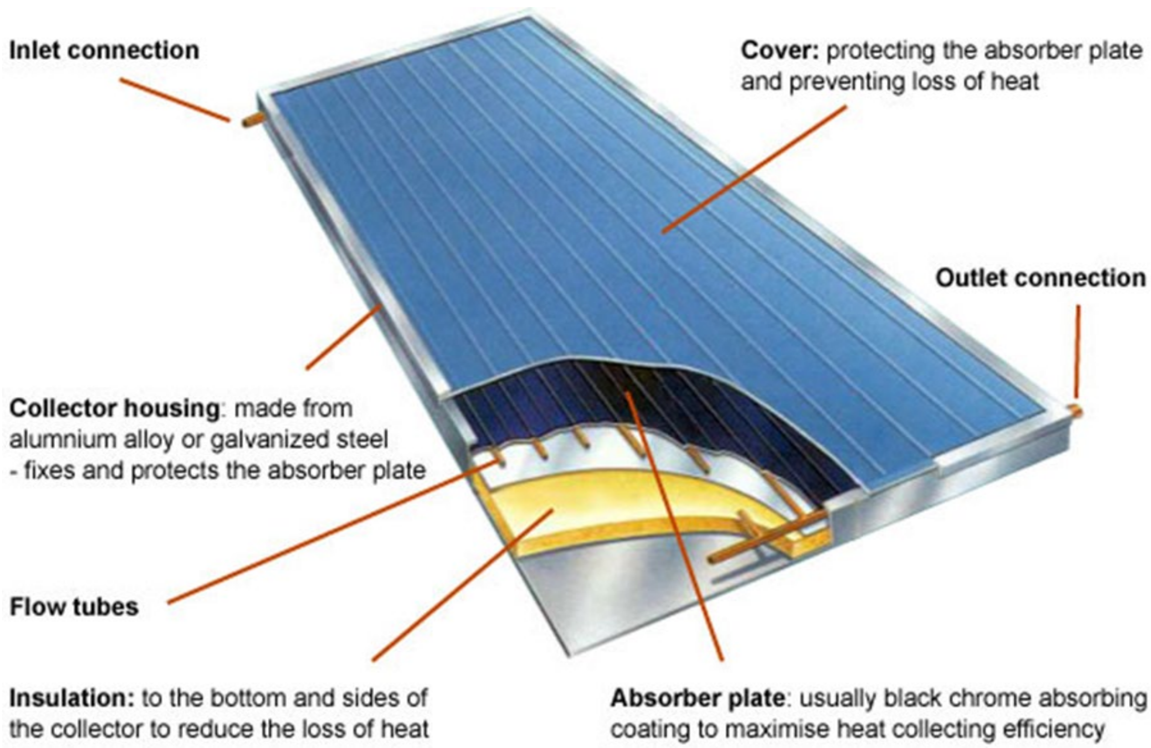
Source: *Zondag, 2008; **Avompe et al., 2011; ***Dubey and Tiwari, 2008; ****Smyth et al., 2006; California Center for Sustainable Communities at UCLA's Institute of the Environment and Sustainability.

Flat Plate Collectors (FPCs)

A flat plate collector is an insulated box containing an absorber plate and a network of flow tubes covered by a sheet of translucent glass or plastic. Most FPCs have copper flow tubes and absorber plates with selective coatings to reduce reflection (Duffie and Beckman, 2013).

FPCs transfer heat to water or a working fluid as it passes through the network of flow tubes in thermal contact with the absorber plate. The translucent cover serves to reduce heat losses from convection. Figure 1 shows a typical FPC design.

Figure 1: Flat Plate Solar Collector



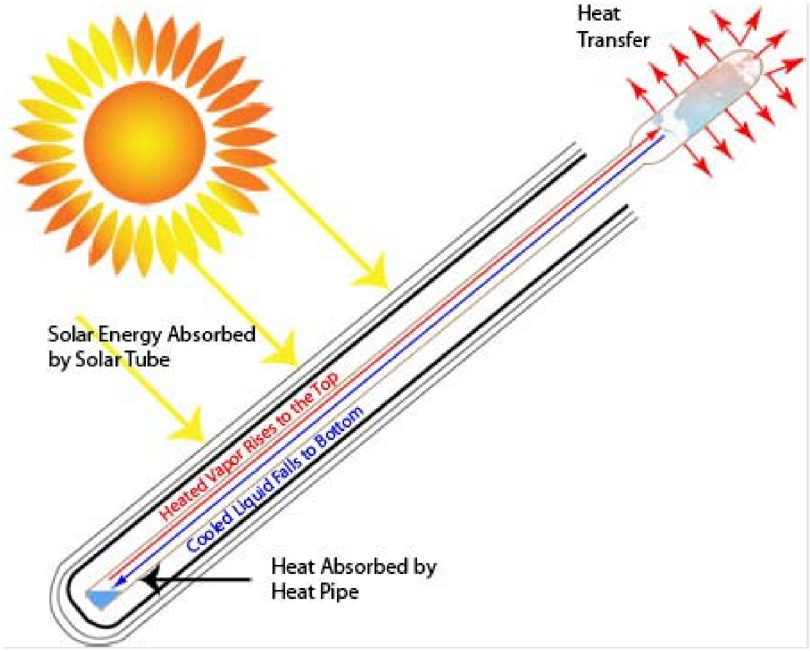
Source: 123 Zero Energy, 2024.

In controlled settings, FPCs exhibit thermal efficiencies of approximately 75 percent (Zambolin and Del Col, 2010). This should be considered an upper limit on the thermal efficiency, as the relatively low thermal mass of most flat plate collectors means their performance is sensitive to changes in ambient temperature (Zambolin and De Col, 2010). The Drake's Landing Solar Community Project, which uses an array of 800 flat plate panels to heat 52 single-family homes, has documented a thermal efficiency range for the collection system (collectors and pipes) of between 30 to 70 percent, with an average of approximately 50 percent (Sibbitt et al., 2012).

Evacuated Tube Collectors (ETCs)

Evacuated tube collectors consist of an array of evacuated glass tubes, each containing a smaller glass tube within (Figure 2). The inner glass tube houses an absorber plate in thermal contact with a flow tube. A vacuum between the two glass layers serves to thermally insulate the inner tube.

Figure 2: Evacuated Tube Solar Collector



Source: 123 Zero Energy, 2024.

There are two main types of ETC designs, but all designs employ absorptive coatings on the surface of either the inner tube wall or the absorber plate. Some evacuated tube collector designs include heat pipes that terminate in heat bulbs, around which water flows through a heat exchange manifold. Alternatively, direct circulation designs circulate a working fluid through u-shaped pipes within each of the inner tubes and return the heated fluid to a header pipe.

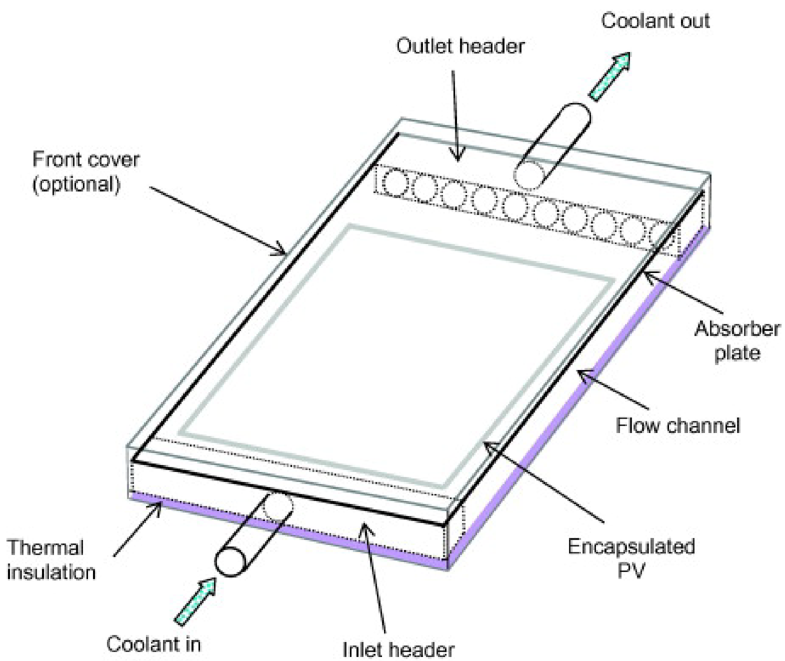
A comparison of flat plate and direct circulation ETCs' thermal efficiencies found that ETCs have slightly lower peak thermal efficiencies than FPCs (less than 60 percent) but are less sensitive to changes in ambient temperature and the direction of incident solar radiation (Zambolin and Del Col, 2010). ETCs are more efficient over a greater range of meteorological conditions and temperatures than flat plate designs (Zambolin and Del Col, 2010). The superior thermal performance of ETCs in variable weather conditions is also supported by data from a study domestic SWH systems in Dublin, Ireland, where ETC systems had greater average annual solar fractions (50.3 percent) than FPC systems (37.9 percent) (Ayompe et al., 2011).

Integrated Photovoltaic/thermal (PV/T) Collectors

Integrated PV/T collectors couple the generation of electric current from photovoltaic solar cells with the collection of thermal energy for water and space heating. The conversion of solar energy into electric current via the photoelectric effect is a process that is relatively inefficient, producing a large amount of waste heat. The collection of waste heat from PV cell arrays increases the efficiency of the cells themselves (which diminishes as their temperature increases) and provides thermal energy for space and water heating (Huang et al., 2001).

A myriad of PV/T collector designs exist, but all systems involve the circulation of a fluid coolant to collect waste heat from photovoltaic cells (Figure 3). PV/T collectors may include a translucent housing or cover to increase thermal absorptivity (Huang et al., 2001). Theoretically, PV/T technology is the most efficient method for collecting solar energy. High-performing PV/T cells could potentially obviate the need for separate photovoltaic and thermal systems. However, the lower thermal performance of PV/T systems relative to other solar thermal collectors has limited the adoption of PV/T collectors (Dupeyrat et al., 2014). PV/T systems collect solar thermal energy indirectly; only about 75 percent of incident solar energy is available in the form of heat. Maximum thermal efficiencies for PV/T solar collectors range from 50 percent to 70 percent (Chow, 2010; Dupeyrat et al., 2014). Like the other collector technologies discussed previously, the thermal efficiencies of PV/T collectors vary, depending on ambient temperature, meteorological conditions, and the angle of incident radiation (Dupeyrat et al., 2014).

Figure 3: PV/T Cell



Source: Chow, 2010.

Solar Storage Tanks

The design and use of storage tanks for water and working fluid has a significant impact on the thermal performance of SWH systems (Cruickshank and Harrison, 2010). Storage tank insulation and temperature stratification help to minimize thermal losses from solar hot water heating systems. Thermal insulation of tanks helps minimize losses to the ground and air, especially during colder months. Many domestic and community scale SWH systems take advantage of temperature stratification in their designs to increase thermal efficiency (Cruickshank and Harrison, 2010; Bauer et al., 2010; Hollands and Lightstone, 1989).

Thermal stratification refers to the tendency of hotter, less dense water to rise to the top of a column. Thermally stratified tanks are designed to preserve a temperature gradient along the axis of a storage tank. Hot water may be discharged for consumption from the hottest part of the tank, while water from the coldest part of the tank may be recirculated though the collector array or heat exchanger. Modeling and physical studies of solar hot water heating systems have found that systems employing stratified tanks can deliver approximately 30 percent more energy than systems that maintain a uniform tank temperature (Hollands and Lightstone, 1989).

Auxiliary and Backup Heating Elements

Due to economic and practical considerations, most SWH systems are not designed to meet 100 percent of their heat loads with solar energy (Duffie and Beckman, 2013). Instead, systems are designed to provide hot water at a minimum solar fraction and use an in-line auxiliary heater to ensure adequate delivery temperature. Auxiliary heaters may also be integrated into storage tanks, rather than placed in-line with the storage tank outlet pipe. At domestic scales, tankless water heating units have sufficient power to satisfy demand in the event of insufficient solar radiation or system malfunction.

For systems larger than domestic scale, it may be necessary to include back-up heating units to ensure that hot water can by supplied in the event of inclement weather or malfunction (Duffie and Beckman, 2013). A range of options for back-up heaters exists, including heat pumps, electric and gas heaters, and biomass boilers (USACE, 2011). Choice of a particular backup technology depends on application and cost.

Heat Exchange Fluids and Heat Exchangers

Closed systems with freeze resistant heat exchange fluids are required in climates that experience prolonged freezing temperatures, as most collectors are not designed to withstand such forces. Antifreeze agents are also toxic, requiring a heat exchanger to be installed between the collection and storage/delivery loops.

Common heat exchange fluids include glycol/water mixtures, hydrocarbon oils, and silicones. Choice of a heat transfer fluid depends on system design and meteorological conditions (U.S. DOE, 2017).

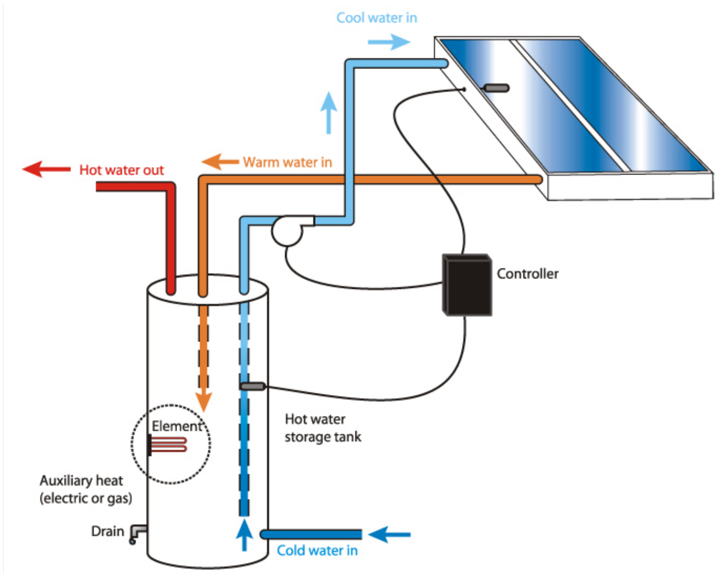
Solar Thermal System Types

Passive Versus Active Systems

The terms "passive" and "active" describe whether a solar heating system uses energy to circulate water or working fluid through the collector array. Active systems use pumps and powered control elements to circulate water or a working fluid. There are two basic active system designs: direct systems, which circulate potable water through solar thermal collectors (Figure 4), and closed systems, which use a working fluid and heat exchangers to transfer energy to stored water (Figure 5) (U.S. DOE, 2017).

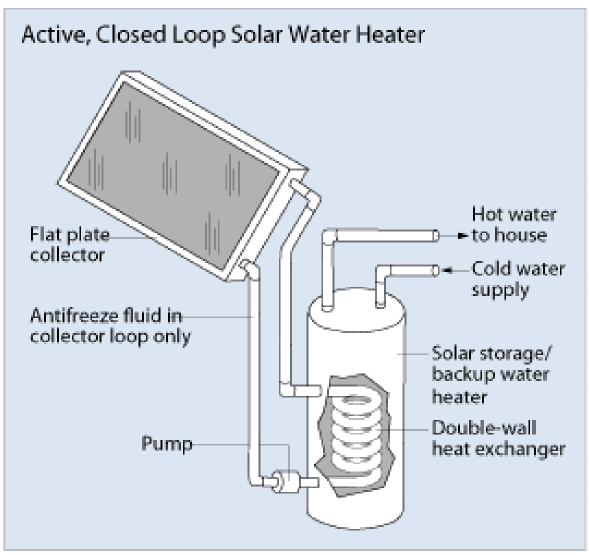
Community scale SWH systems considered in this study will be active systems. Passive systems are most common at the domestic scale. To function properly, passive systems must have collector arrays located below the storage tank, and the storage tank must be installed above the fixtures where hot water is to be used. While passive system designs are potentially sufficient for single residences, they are not practical for larger scales.

Figure 4: Schematic of an Active, Direct System



Credit: Acme Environmental, 2010.

Figure 5: Schematic of an Active Closed System



Credit: U.S. DOE, 2018.

Review of Building and Industry Codes for Community Scale Solar Water Heating

The following section reviews the building and industry codes relevant to the design and construction of community scale SWH systems. First, standards for SWH system performance and component technologies were reviewed. These standards set minimum requirements for thermal performance and durability, influencing system design and cost.

Secondly, because subsequent analyses will simulate the performance of community scale SWH systems, special attention was paid to regulations governing where system infrastructure may be installed. Rules constraining where and how collector arrays or tanks are installed informs the siting of equipment in subsequent case studies.

The design and construction of residential SWH systems are most heavily regulated by the state of California and local governments. California and Los Angeles County have specific system design and performance requirements that must be met for builders to receive construction permits and for systems to qualify for incentive programs. This section includes a summary of those regulations and explains their influence on community scale system design.

Industry Codes for Community Scale System Components

The Solar Rating and Certification Corporation (SRCC) is a nonprofit organization responsible for the testing and certification of solar thermal technologies in the United States. SRCC is a member of the International Code Council, and its testing requirements are based on the International Standardization Organization's (ISO) codes.

The SRCC has two solar thermal technology rating certifications, OG-100 and OG-300. The OG-100 certification program sets standards for the durability and thermal performance of solar thermal collectors. The OG-300 program applies to single-residence SWH systems, and it requires that systems meet an overall standard minimum thermal performance (ICC, 2015).

OG-100 Solar Collector Certification Program

While the California Solar Initiative (CSI) thermal rebate program was active, California required that all domestic and multi-family SWH systems use solar thermal collectors approved by the SRCC to be eligible for CSI thermal renewable energy credits. The SRCC's standards and test sequence for solar collectors are known as the OG-100 Minimum Standards (ICC, 2015). OG-100 makes use of ISO 9806 standards. Separate test sequences exist for FPC and ETC collectors (Table 2) (ICC, 2015).

Table 2: Minimum Solar Fraction by CEC Climate Zone

Climate Zone	Minimum Solar Fraction
1-9	20%
10-16	35%

Credit: CEC, 2015c.

The OG-100 certification process consists of laboratory test sequences for different types of thermal collectors. Solar thermal collectors that meet or exceed testing criteria are listed on the SRCC's website. Physical specification and thermal performance data are provided for each unit that receives OG-100 certification.

California State Building Code

Following is a summary of the state building codes with the greatest impact on SWH system design and siting. Other components of a SWH system, such as plumbing systems, are also subject to code requirements, but these do not affect basic system design. Code requirements that influence the selection of collection and storage technologies are discussed.

Title 24, Section 6 — Building Energy Efficiency Standards

A community scale approach to solar water heating requires the installation of systems that serve numerous residential units. Community scale systems must comply with the multi-family SWH codes of California's Title 24. The most fundamental of these requirements is that multi-family systems use SRCC OG-100 certified solar collectors and that they meet the basic eligibility requirements listed in Table 3.

Multi-family SWH systems installed in California are required to meet a minimum average annual solar fraction (CEC, 2015b). Table 4 summarizes the minimum solar fractions required for each of the California Energy Commission's (CEC) climate zones. Because the solar fraction of a system varies depending on insolation levels, meteorological conditions, and the precise details of construction and operation, system modeling methods are used to calculate an approximate value for annual solar fraction. This calculated value must meet or exceed the minimum solar fraction for the climate zone. Calculations must be performed with software approved for use by the CEC. Approved programs include both regression and simulation methods for modeling SWH system performance (Ferris et al., 2016).

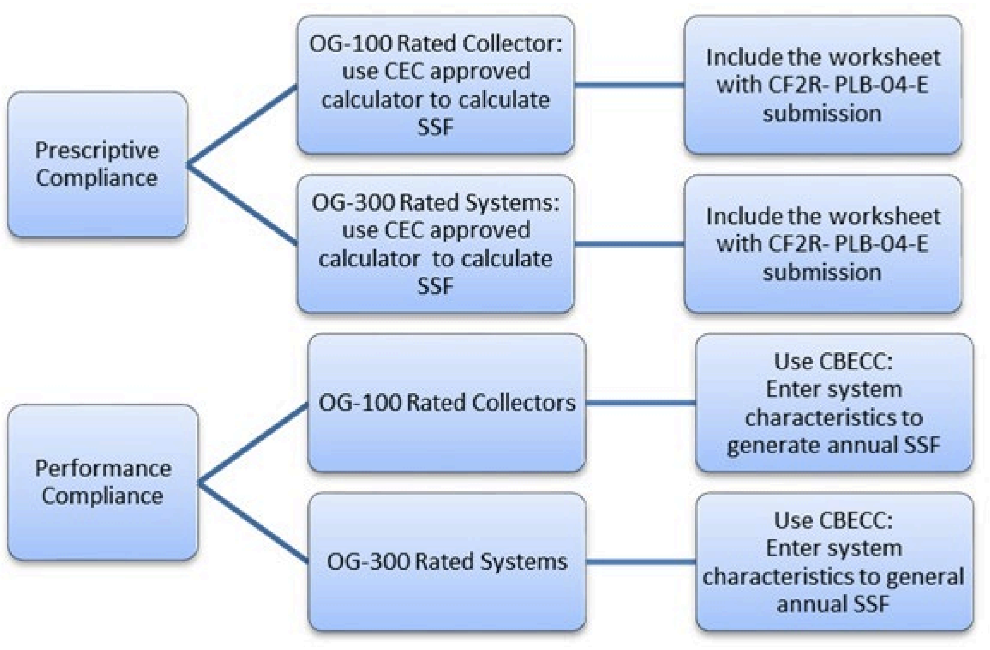
Table 3: Eligibility Criteria for Energy Efficiency Measures — SWH Systems (RA4.4.20)

System Certification Type	Eligibility Criteria
SRCC OG-100	(a) Include all features modeled and generated in the CEC-approved solar savings fraction calculation.
	(b) The collectors should be installed according to the manufacturer's instructions
	(c) The collectors shall be located in a position not shaded by adjacent buildings or trees between 9:00 AM and 3:00 PM (solar time) on December 21st.

Source: CEC, 2015b.

Figure 6 shows the process flows for prescriptive and performance compliance approaches for solar thermal systems. Selection of an appropriate code compliance approach depends on system scale and design solar fraction. In the case of community scale SWH systems intended to reduce the carbon intensity of water heating, a performance approach is most reasonable.

Figure 6: Prescriptive and Performance Compliance Pathways for SWH Systems



Credit: CEC, 2015c.

A community scale approach to solar water heating requires the installation of collector arrays on multiple residential buildings, including single and multi-family structures. This complicates the task of reaching compliance through a prescriptive approach, as those requirements assume that residential SWH systems serve only a single structure. Therefore, prior to the evaluation of energy savings from community scale SWH systems, solar fraction is estimated via simulation to ensure that minimum solar fraction requirements are met.

Los Angeles County Municipal Code

County building permits are required for solar photovoltaic or thermal systems before construction. The county's "Guidelines for Plan Check and Permit Requirements for Solar Energy Systems," effective since 2015, enumerates the municipal requirements relevant to the design and construction of community scale SWH systems (LADBS, 2023). Los Angeles County's guidelines require that SWH systems meet state energy efficiency, plumbing, and electrical codes, in addition to complying with zoning restrictions. The Los Angeles County municipal code does not contain specific SWH system design requirements beyond those in the state code (LADBS, 2023)

Past Incentive Program Eligibility Requirements

The California Solar Initiative for solar thermal water heating systems ended in July 2020. Information in this section pertains to this past program to illustrate the program requirements for solar thermal systems.

Community scale SWH systems should take advantage of incentive programs to offset the cost of installation and construction when and where and possible. The CSI was a subsidy program intended to encourage the proliferation of solar thermal technology for space and water heating (CPUC, 2019). The program included specific eligibility requirements for multi-family residential systems and systems, as summarized in Table 4.

Table 4: CSI Thermal Incentive Program Eligibility Requirements

SWH System Incentive Category	Eligibility Requirements
Multi-family < 250 kWth (kilowatt thermal), Commercial/Multi-family > 250 kWth	**Equipment** • OG-100 certified collectors • Active, indirect system type • System must include freeze and stagnation protection according to CEC climate zone. • Direct or passive systems are ineligible. • Storage tanks must have R12 insulation. • Flow meters **Installation Requirements** • Fluid collector square footage area cannot exceed 1.25 times the estimated GDP (gallon per day). • Systems with two or more tanks must have a minimum of 1 gallon of storage volume per square foot of collector. • Systems with a collector area/GPD) > 1.25 must provide justification for sizing. • R2.6 insulation on all exposed or accessible hot water piping

Source: CPUC, 2019.

Prototypical System Design for Community Scale Solar Water Heating in Los Angeles County

Specifying a prototypical community system design is necessary to simulate system performance and estimate energy savings. Any community scale system must meet the design criteria specified by the CEC, Title 24, and by Los Angeles County. Community scale SWH systems should also be eligible for rebates and/or tax credits to offset capital costs where possible, given the low cost of competing energy sources.

The following sections explain and justify the selection of component technologies and system design elements for community scale systems in Los Angeles County. Building code and rebate eligibility requirements, cost, performance, and climactic conditions are all given consideration in the design of community scale systems.

Selection of Community Scale Solar Water Heating System Components

Estimating the energy savings from community scale SWH systems requires the selection of appropriate component technologies for the given application and climate. To establish compliance with minimum solar fraction requirements, the following must be specified:

- Collector Type
- Direct/Indirect System Type
- Thermal Energy Storage Type
- Auxiliary Heat Source

Conventional Solar Thermal Collectors Versus PV/T Collectors

Based on the review of commercially available solar thermal collectors, FPCs and ETCs are potentially suitable for community scale SWH systems in Los Angeles County.

PV/T collectors are not suitable for community scale solar water heating. While PV/T collectors provide an elegant solution to the problem of PV and thermal systems competing for rooftop space, the cost and durability of existing PV/T cell technologies make them unattractive for community scale applications. PV/T panels are less thermally efficient than standard solar thermal collectors; thus, a SWH system with PV/T panels must have a larger collector area than a purely thermal system to meet an identical heat load (Dean et al., 2015). PV/T collectors are also more expensive on the basis of dollars per installed unit of collector area than either FPC or ETC technologies (Matuska, 2014). Table 5 shows a comparison in terms of dollars per square meter.

Table 5: Cost Per Square Meter of Installed Collector Area — PV/T Versus Thermal

Collector Type	$/m^2 (dollars per square meter)
PV/T	$531-$1121*
FPC or ETC	$59-$223**

Source: *Matsuka, 2014; **U.S. EPA, 2021.

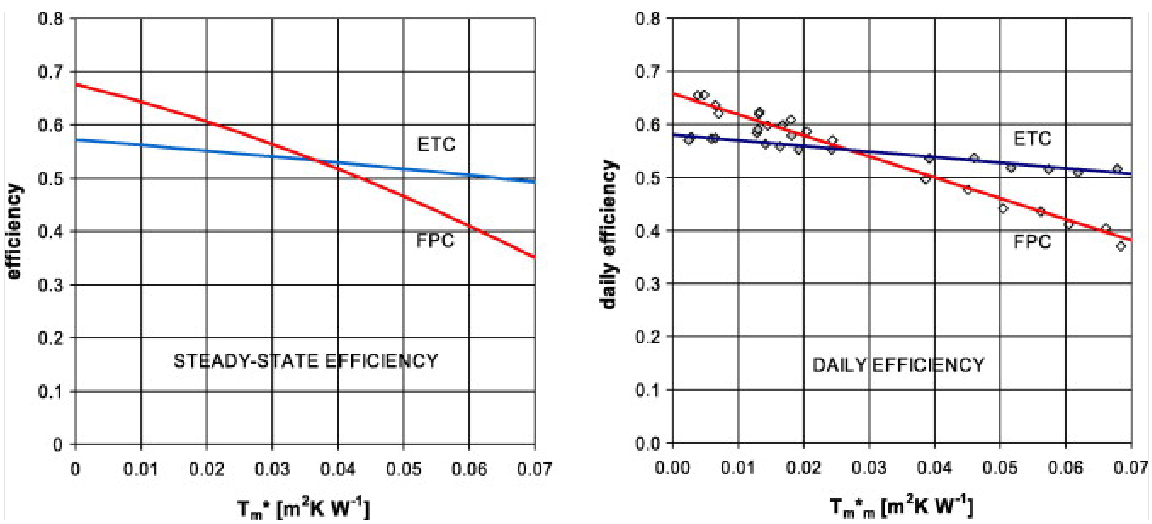
With regards to durability, the materials used to construct some PV/T collectors limit their operational temperature to between 130ºF (54°C) and 170ºF (77°C) (Zondag and Van Helden, 2002). PV/T collectors with EVA laminated PV cells may be damaged by prolonged exposure to temperatures at or above 130ºF (54ºC), as EVA thermally degrades above this temperature (Zondag and Van Helden, 2002). FPCs and ETCs have much higher stagnation temperatures, between 356ºF to 410ºF (180ºC to 210ºC) and 428ºF to 572ºF (220ºC to 300ºC), respectively (Hausner and Fink, 2002). Furthermore, SRCC OG-100 standards require that collectors be able to withstand 1000 hours of stagnation temperature per year without serious performance degradation. Thus, given the cost and accelerated timetable for performance degradation relative to thermal collectors, PV/T collectors will not be used in the community scale SWH systems proposed in this effort.

FPC Versus ETC

The choice of collector technology for community scale systems in Los Angeles County may be narrowed to FPC or ETC. The choice of the optimal collector technology may be made on the basis of climatic conditions and cost.

Climatic conditions in Los Angeles County favor FPCs over ETCs. Figure 7 shows steady-state and daily thermal efficiency curves for both evacuated tube and flat-plate collector types. Thermal efficiency is plotted as a function of the difference between ambient and fluid inlet temperature (reduced temperature) normalized by the level of incident radiation. Daily thermal efficiency measurements were made in Padova, Italy. The thermal efficiency of ETC is less sensitive to changes in ambient or inlet temperature and outperform FPCs when the difference between ambient and fluid temperatures is large (Zambolin and Del Col, 2010). However, FPCs are more efficient than ETCs when the difference is small and when weather conditions are relatively mild (Zambolin and Del Col, 2010).

Figure 7: Thermal Efficiency Versus Reduced Temperature (Ta-TI) for FPCs and ETCs



Under steady-state and field conditions in Padova, Italy. Efficiency is defined as the steady-state thermal efficiency of the collector; daily efficiency is defined as the average of efficiency measurements made in 10-minute intervals over a 24-hour period. Reduced temperature is the difference between the ambient and liquid temperatures normalized by the amount of insolation.

Source: Zambolin and Del Col, 2010.

Cost considerations also favor FPCs. FPCs are 20 percent to 40 percent cheaper than ETCs per collector unit, as they are less materially intensive to manufacture (Solartown, 2016). FPCs will be the default collector type for community scale SWH systems in Los Angeles County.

Direct/Indirect System Type

As mentioned previously, direct systems were not eligible for energy credits as per the CSI Thermal Program Handbook (CPUC, 2019). Therefore, community scale SWH systems will be indirect to take advantage of the available incentives. Community scale systems considered in this analysis may therefore be classified as “indirect forced circulation” systems. Indirect forced circulation systems use pumps to circulate a working fluid within the collector array. Thermal energy is transferred to potable water through a heat exchanger.

Thermal Energy Storage Type

The volume of thermal energy that a community scale solar thermal system must store, and the duration over which it must be stored, depend on seasonal variation in the supply of and demand for energy.

Regarding the supply of solar energy, The National Renewable Energy Laboratory (NREL) estimates that Los Angeles County receives enough sunlight for a base case SWH system (a single residence with constant load and electric auxiliary heater) to achieve an annual solar fraction greater than 80 percent (Cassard et al., 2011). This suggests that seasonal variation in the intensity and duration of incoming sunlight is not sufficient to warrant the construction of large and expensive seasonal heat stores, and that community scale systems will be able to meet and exceed minimum solar fraction requirements year round, though solar fraction may fluctuate seasonally.

Auxiliary Heat Sources

Community scale SWH systems must be able to provide hot water to the residences it serves in the event of extended inclement weather or temporary system shutdown. When possible, solar thermal contractors and heating and cooling engineers use existing natural gas heaters for solar water retrofits to minimize cost (Bavin, 2018a). This practice ensures that hot water is available for a structure’s occupants in the event of system malfunction or maintenance. For this study, existing natural gas heaters are assumed to function as auxiliary heat sources.

Prototypical System for Community Scale Solar Water Heating

Based on Los Angeles County’s regulatory environment and climate, a closed, active system with centralized storage of hot water and a flat-plate collector array is the most suitable configuration for community scale SWH systems in Los Angeles County. Such a system is easily scalable and is the prototypical SWH system type considered in this study (Chen, 2017b).

CHAPTER 2: Community Scale Solar Water Heating System Simulation Method

Chapter 2 discusses the methods used estimate putative energy savings from community scale SWH systems. The following section discusses the selection of the simulation method used to estimate system performance and potential energy savings. The section titled "Hot Water Demand Estimation Methods," on page 26, explains how hot water demand is estimated using technical assumptions.

Simulation Methods for Community Scale Solar Water Heating System Performance

Numerous methods exist for the estimation of SWH system performance and energy output. Performance calculation methods also vary widely with respect to computational complexity, underlying mathematical structure, assumptions, and flexibility. This study's choice of performance calculation method was determined by the aforementioned considerations, as well as input from the study's technical advisory committee (Anderson, 2017; Chen, 2017a).

Methods for predicting the performance of solar thermal systems may be classified as either regression or simulation methods (Duffie and Beckman, 2013). Regression methods correlate the parameters of a given system (collector area, storage volume, fluid flow rates, etc.) with thermal performance using empirical relationships derived from the performance data of existing systems (Duffie and Beckman, 2013). The f-Chart Method, approved for the estimation of minimum annual solar fraction under Title 24, is one such method (CEC, 2015c). Regression methods are computationally inexpensive compared to simulation methods, and in many instances provide accurate predictions of long-term system performance. However, regression methods like the f-Chart are not dynamical. Such methods predict only average performance over a fixed period of time. Thus, a simulation method must be used to model community scale SWH system performance.

Simulation methods model the flow of energy and mass through virtual systems at a user-specified time step (Lisboa and Fonseca, 2012). Simulation programs for modeling solar thermal systems differ with respect to their flexibility and complexity; selection of an appropriate simulation program depends on the requirements of a particular study. Because this analysis estimates hourly energy output from community scale SWH systems using a relatively small set of assumptions about system design and physical parameters, simulation programs with intermediate flexibility and computational complexity are most suitable.

This study uses NREL's System Advisor Model to calculate the hourly energy output from community scale SWH systems. The following section describes the simulation assumptions, input parameters, output, and accompanying cost calculations.

NREL System Advisor Model Software

The NREL System Advisor Model (SAM) is a free transient energy simulation program developed for modeling renewable energy systems. SAM is used to calculate the daily performance for community scale solar energy systems over the course of one year. It uses the implicit Euler method to solve a series of differential equations at each time step. SAM makes two fundamental assumptions about the design of SWH systems (DiOrio et al., 2014):

1. SWH systems are indirect. Systems have a closed collection loop through which a working fluid is circulated.
2. SWH systems use electric pumps to move fluid through the collector loop.

SAM's output variables are listed in Appendix A.

Community Scale Solar Water Heating System Siting and Design Considerations

Each case study includes the siting of SWH systems on the parcel or parcels of an energy community. Collector arrays, storage tanks, and the pipe lengths must be located in space, so that system parameters required for heat loss and other performance calculations may be entered into SAM.

Collector Array — Location, Orientation, and Simulation Parameters

Solar thermal collectors will be located on rooftops where possible to minimize shading of collector apertures and within each building rooftop's Solar Zone,[1] as defined in Section 110.10 of California's Title 24 (CEC, 2015a). All structures within an energy community's case study's parcel or parcels are considered as potential sites for collector arrays.

SAM contains a library of commercially available glazed flat-plate collectors and performance data derived from testing (DiOrio et al., 2014). This study will use the SunEarth Empire EP-40 Solar Collector as the prototypical flat plate collector. This collector model is manufactured domestically and is OG-100 certified (SunEarth, 2017). Selection of a collector model from the SAM library automatically specifies the performance parameters listed in Table 6.

Table 6: SAM Collector Performance Parameters for the SunEarth Empire EP-40 Solar Collector

Parameter	Value	
Collector Area	3.8 m^2	Gross area of one collector unit
Frta (Hottel-Whillier-Bliss Equation — Optical Gain Coefficient)	0.718	The Optical Gain Coefficient is the product of the heat removal factor and the transmittance-absorbance product, giving the maximum efficiency of the collector.

[1] Solar Zone for Low Rise and High Rise Multi-Family Buildings: "The Solar Zone shall be located on the roof or overhang of the building or on the roof or overhang of another structure located within 250 ft. of the building or on covered parking installed with the building project. The Solar Zone will have a total area no less than 15% of the total roof area of the building excluding any skylight area."

Parameter	Value	
FRUL (Hottel-Whillier-Bliss Equation — Thermal Loss Coefficient)	2.29 W/m^2 C	The Thermal Loss Coefficient is the product of the heat removal factor and the overall heat loss coefficient, giving the instantaneous heat loss per Celsius degree difference between ambient and collector temperatures.
Incidence Angle Modifier Coefficient	0.32	The Incidence Angle Modifier adjusts for changes in the angle of incoming radiation during the course of a day/year.
Test Fluid	Glycol	60-40 water-glycol mix
Test Flow	0.076	Test flow rate in kg/s (kilograms per second)

Source: California Center for Sustainable Communities at UCLA's Institute of the Environment and Sustainability

SAM uses the following parameters to simulate the collection solar thermal energy from insolation, which varies chronologically.

Solar Storage Tank — Simulation Parameters

Standby losses from solar storage tanks may be minimized by locating them within existing structures (Duffie and Beckman, 2013). SAM's Solar Water Heating model assumes a two-tank indirect system with an electric auxiliary heater, with glycol as a heat transfer fluid (NREL, 2011). These assumptions are consistent with the SWH system design details required by state and county regulatory regimes identified in Chapter 1.

SAM requires users to specify the ratio of tank height to width (Table 7). Vertically oriented and thermally stratified tanks increase the performance of SWH systems (Cruickshank and Harrison, 2010). This study assumes a height to width ratio of 2:1 for solar thermal and hot water tanks. SAM assumes two-node stratification without thermal exchange (DiOrio et al., 2014).

Table 7: Sam Storage Tank Parameters

Parameter	Description
Solar Tank Volume	Volume in cubic meters. Title 24 requires a storage volume to collector area ratio of 1.5 gallons/1 ft^2 of collector area.
Solar Tank Height to Diameter Ratio	Tank aspect ratio (2:1)
Solar Tank Heat Loss Coefficient (U-value)	W/m^2 C (watts per square meter per degree Celsius)
Solar Tank Maximum Water Temperature	Maximum allowable temperature in solar tank. Bulk tank temperature cannot exceed this value. Equivalent to the opening of a temperature-controlled relief valve.

Parameter	Description
Outlet Set Temperature	Residential hot water temperature set point (120ºF [48.89ºC])
Mechanical Room Temperature	Used to calculate tank standby loss. $Q_{Loss} = UA_{Tank}(T_{room} - T_{tank})$

In indirect SWH systems, heat exchangers transfer thermal energy from the heated working fluid in the solar tank to water for delivery to end users (Table 8). SAM requires the following parameters to model heat exchange:

Table 8: SAM Heat Exchanger Parameters

Parameter	Description/Units
Heat Exchanger Effectiveness (*e*)	$e = (T_{cold\text{-}out} - T_{cold\text{-}in}) / (T_{hot\text{-}in} - T_{cold\text{-}in})$

Source: California Center for Sustainable Communities at UCLA's Institute of the Environment and Sustainability

Collection Loop Piping and Pumps — Simulation Parameters

Indirect SWH systems have two separate piping systems. One circulates working fluid through the collection array and solar tank, and the other delivers heated water from the auxiliary tank to end users. SAM requires information about the length, diameter, and insulation of the pipes used to collect heat and distribute hot water to residential buildings to calculate heat lost from the collection loop. Collection loop pipe lengths will include the vertical and horizontal distances between collector arrays and solar storage tanks.

SAM assumes that fluid is circulated between the collector array, solar tank, and heat exchangers by an electric pump. The collector pump's peak power rating and efficiency are required to calculate solar fraction and other performance metrics (Table 9).

Table 9: SAM Pipe and Pump Parameters

Parameter	Description
Total Piping Length in System	Collection Network: vertical and horizontal distance between collector arrays (meters [m]). Transmission Network: straight line distance plus detours (m).
Pipe Diameter	Average diameter of piping (m)
Pipe insulation Conductivity	W/m^2 C (Watts per square meter per degree Celsius)
Pipe Insulation Thickness	Average insulation thickness
Pump Power	Electric pump's peak power rating (Watts [W])
Pump Efficiency	Estimated pump efficiency (0 to 1)

Source: California Center for Sustainable Communities at UCLA's Institute of the Environment and Sustainability

Auxiliary Heat Source — Simulation Parameters

All active SWH systems have auxiliary heating units to ensure that water is delivered at the appropriate temperature. SAM assumes that electric resistance supplies auxiliary heat, and it calculates the energy required to raise the temperature of water in the storage tank to the set temperature at each time step. The auxiliary energy required to reach set temperature is given by:

Equation 1: SAM Auxiliary Heat

$$Q_{aux} = m_{draw} C_P (T_{set} - T_{deliv})$$

where:

Q_{aux} = Auxiliary heat

M_{draw} = Mass of water draw

M_{draw} = Set temperature for hot water

T_{deliv} = Temperature of water delivered from solar storage

SAM includes a macro that converts kilowatt-hours of auxiliary electrical energy into volumes of gas using an estimate of the burning efficiency of a typical natural gas heater and a characteristic tank heat loss coefficient. The tank heat loss coefficient depends on a tank's shape and insulation (Table 10).

Table 10: Parameters for SAM Auxiliary Gas Heater Macro

Parameter	Description
Tank Loss Coefficient	Based on tank insulation value (0-1)
Burning Efficiency	Efficiency of auxiliary natural gas heater (0-100%)

Source: California Center for Sustainable Communities at UCLA's Institute of the Environment and Sustainability

Hot Water Demand Estimation Methods

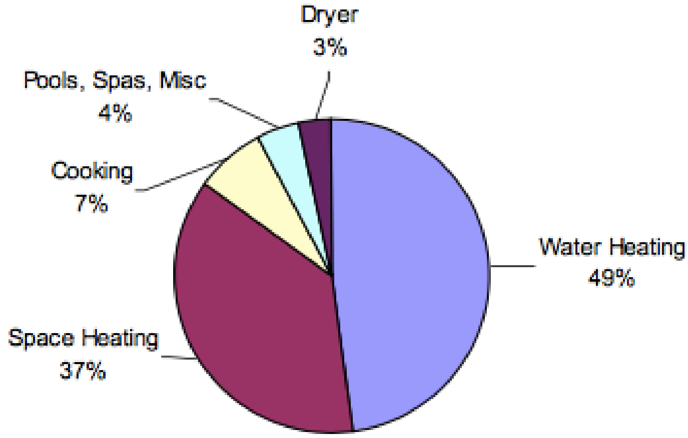
Gas Consumption for Residential Water Heating

The calculation of energy savings requires the estimation of residential gas consumption based on parcel and building-level data. This analysis develops a method to estimate the gas consumed to heat water by residential parcels on a daily basis for one year, based on ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) water consumption tables (ASHRAE, 2007). Monthly gas consumption data from the Energy Atlas was not used to estimate energy demand due to the inaccuracy inherent in disaggregating gas consumption by end uses. Daily hot water consumption calculated for the parcels in an energy community will then be used in simulations of community scale SWH system performance.

Limitations of Signal Processing Parcel-level Gas Consumption Data

This study calculates daily hot water demand based on ASHRAE guidelines instead of using consumption data from the Energy Atlas because of the difficulty of disaggregating end uses from one another. While residential appliance surveys provide estimates of gas consumption for water heating relative to total consumption, there is little data available to help decompose monthly consumption totals into separate end uses. Patterns of hot water usage and total hot water consumption also vary greatly, depending on the demographics of the people who inhabit the structures on a particular residential parcel. California's residential gas use is shown in Figure 8 (Parker et al., 2015).

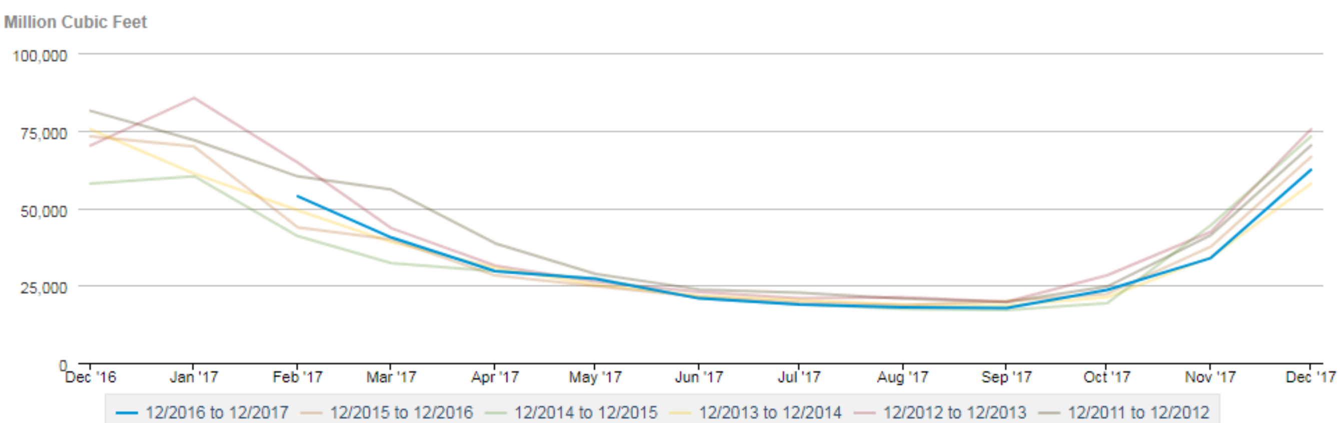
Figure 8: California Residential Gas Consumption by End Use



Source: Palmgren et al., 2010.

The focus on one end use among many complicates the estimation of energy savings. It is necessary to remove the contribution of other end uses to accurately estimate the energy consumed by water heating. Unfortunately, the structure of the available gas consumption data (monthly billing data for parcels and individual accounts) limits the potential disaggregation to seasonal and non-seasonal end uses. Residential gas consumption in California displays a strong seasonal trend due to the use of natural gas for space heating and the state's mild climate (Figure 9) (U.S. EIA, 2018).

Figure 9: 10-Year Monthly Residential Gas Consumption (2007–2017)



Source: U.S. EIA, 2018.

Hot Water Demand per Residential Unit, and Gas Consumed for Residential Water Heating

Daily hot water demand and the volume of gas required to meet it are calculated for each community scale SWH case study. These calculations use data from the Los Angeles County

Tax Assessor's Office, residential sitemaps, maximum occupancy of the residential units at each site, and daily water consumption and water heater efficiency assumptions listed in ASHRAE's *Handbook of Applications*.

Hot Water Demand per Residential Structure

Daily water demand for residential structures is calculated according to Equation 2:

Equation 2: Daily Hot Water Demand per Community Parcel (Kalogirou, 2013)

$$V_{hot} = N_{unit}V_{unit}$$

where:

V_{hot} = Volume of hot water consumed per residential structure

N_{unit} = Number of residential units per residential structure

V_{unit} = Volume of hot water consumed per residential unit per day

The volume of hot water consumed per unit per day (V_{unit}) depends on the number of units in a residential structure (CPUC, 2019). Values of V_{unit} are estimates of maximum daily hot water consumption in gallons per day (GPD) (ASHRAE, 2007). The volume of hot water is assumed to be seasonally invariant.

Energy Demand per Residential Structure

The energy demand per parcel per day is then calculated using a parcel's daily volumetric consumption (V_{hot}).

Equation 3: Daily Energy Demand per Community Parcel (Kalogirou, 2013)

$$D = V_{hot}\rho c_p(T_w - T_m)$$

where:

D = Daily energy demand per residential structure

T_w= Delivery temperature of hot water

T_m = Cold water mains temperature

This study assumes a delivery temperature of 120ºF (48.89ºC). The temperature of cold water mains varies seasonally and geographically. A mains temperature profile for Los Angeles is available in NREL SAM.

Equation 4: Daily Natural Gas Consumption per Community Parcel

$$V_{Gas} = \frac{D}{\rho_E} EF_{heater}$$

where:

V_{Gas}= Daily volume of natural gas consumed for water heating

P_E = Energy density of natural gas

EF_{heater} = Energy Factor of the extant water heater

Estimating the energy factor of the extant heater or heaters on a community parcel will require communication with building managers/property owners. Equation 3 may be modified if electric heaters are installed.

CHAPTER 3: Case Study Site Selection

Chapter 3 describes how community scale SWH case study sites were chosen from broad pools of potential candidate sites. Developing the candidate property pools, selecting case study sites, and brief descriptions of the chosen sites are included.

Practical and Technical Constraints on Community Scale Solar Water Heating

Not all residential parcels are equally suitable for a community scale approach to solar water heating. These constraints include property ownership patterns, transmission losses, available space for collector areas, and ease of permitting. The Table 11 outlines constraint categories.

Table 11: Practical and Technical Constraints for Community Scale Solar Water Heating

Constraints	Issues
Existing Infrastructure	• Heat Transmission Network • Retrofit Versus New Construction
Technical Limitations	• Transmission Losses
System and Property Ownership	• Land Use Patterns • Collective Ownership • Qualification for Incentives • Technical Limitations of Incentives

Existing Infrastructure

The greatest constraint on the development of community scale solar energy systems is the presence and state of existing infrastructure. Regardless of scale or type, all solar energy systems include energy collection and transmission infrastructure (Wiseman and Bronin, 2012). Also, virtually all solar energy systems include energy storage to match the supply of thermal or electrical energy with demand. Integration of community scale solar energy systems with existing infrastructure may reduce the cost of construction and operation, and in some cases it may increase operational scale (Wiseman and Bronin, 2012).

Heat Transmission Network

Currently, there exists no large-scale public heat transmission infrastructure in Los Angeles County. The largest central heating system in Los Angeles County belongs to the University of California, Los Angeles and supplies the Ronald Regan Medical Center as well as other campus buildings (Masunaga, 2009). Large scale cogeneration and district level heating are more economically feasible in cities with colder climates and denser urban forms, such as New York, San Francisco, and Minneapolis/St. Paul (ConEdison, 2018; SFE, 2018; District Energy St. Paul, 2018).

Retrofit Versus New Construction

As mentioned in Chapter 1, urban form impacts the feasibility of community scale SWH, and the performance of installed systems. Population density, characteristics of the building stock, and the impact of zoning rules are all potentially influential variables. Thus, in order to produce relevant and realistic estimates of energy savings, this study includes only retrofit case studies. Case studies should be representative of the urban environment in Los Angeles County as it currently exists, and they should reflect the potential community scale SWH to reduce energy consumption and emissions without additional assumptions about changes to urban form.

Technical Limitations

Unlike community scale PV systems, the physical nature of solar thermal systems limits the size of the geographies they can serve. Transmission losses from hot water distribution networks may be as large as 30 percent, even if pipes are buried and insulated according to code (Anderson, 2018). The performance of the community scale SWH systems considered in this study are more sensitive to total transmission distance than are systems with heat injection loops.

Transmission Losses

The efficiency and cost-effectiveness of central heating systems generally increase with scale, but the superior performance of large systems is due in part to how such systems store and transmit thermal energy. In district scale heating systems, heat injection loops act as thermal storage tanks, reducing the need for heated fluid to travel long distances through comparatively narrow pipes to reach users, thus minimizing transmission losses (Chen, 2018a).

Future residential construction projects may include heat storage loops, but the expense and complexity of retrofitting existing residential housing stock with central heat injection loops makes such an approach infeasible. Instead, transmission losses may be diminished by selecting residential parcels that are densely constructed and populated.

System and Property Ownership

Community scale SWH systems installed in Los Angeles County cannot take advantage of existing thermal energy infrastructure; thus, SWH system owners must bear the costs of construction and operation, offset by the applicable incentives. Land ownership patterns, utility billing practices, laws, and policies regarding SHW system financing all limit the number of candidate sites for community scale SWH that are available within Los Angeles County.

Land Use Patterns

Los Angeles County's diversity of urban forms and patchwork of single and multi-family residential buildings increases the complexity of designing and building a SWH system that serves multiple properties and residences. Land use and ownership patterns affect the size of the geographies that community scale energy systems may serve. Foremost among the factors constraining the size of community scale SWH systems is the separation of residential parcels by roadways.

The Los Angeles metropolitan area is the third most densely populated metro area in the U.S after New York and San Francisco-Oakland by average density and population-weighted density (Wilson et al., 2012). Also, Los Angeles is second to New York in metro roadway mileage (Manville and Shoup, 2005). The extension of community scale systems beyond single parcels or city blocks would require system owners to secure permission from local authorities to lay insulated pipe across roadways. In the interest of minimizing uncertainty about system costs, the community scale SWH systems considered in this study will serve either single or contiguous groups of parcels. In some cases, energy communities may be spread over multiple parcels separated by streets but, in such an instance, separate parcels will be served by separate community scale SWH systems.

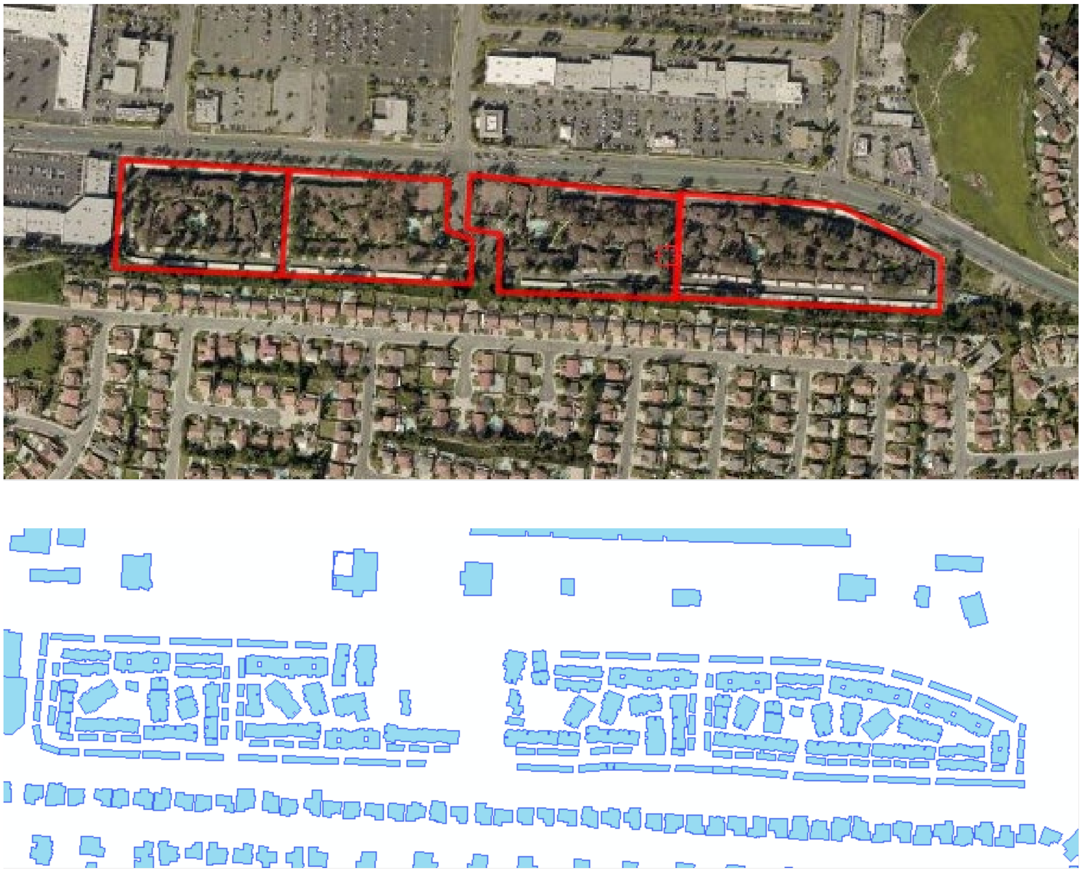
Collective Ownership

Theoretically, community scale SWH systems could be constructed and operated like thermal microgrids: with a mixture of distributed and centralized collection and storage, depending on the population density and the urban form of a given site. Such a system would need to be owned collectively by the people it serves, who pay for the cost of its construction and maintenance, some of which could perhaps be offset in part by government incentives. While it may be possible to construct and operate such a community scale SWH system, collective ownership of a community scale system is presently infeasible.

Communities intending to construct a collectively owned thermal microgrid like the one described in the previous paragraph face considerable transaction costs, and they must structure and manage relationships between users and the firms that design, build, and manage the energy infrastructure (Gui et al., 2017). This is a significant departure from how thermal energy is currently generated and distributed for residential use, and it is the primary reason why collectively owned systems are not considered in this study.

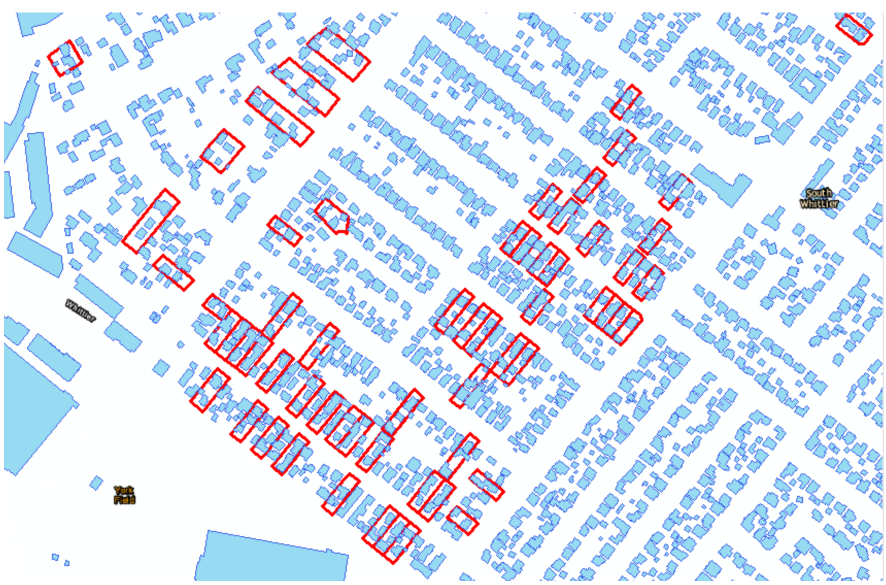
Secondly, collectively owned community scale SWH systems are ineligible for state and federal incentives (Chen, 2018b). This study considers only community scale SWH systems that were eligible for California's CSI-Thermal Multifamily Rebate and the Federal Residential Renewable Energy Tax Credit. Specific technological and property qualifications for each are discussed in the *Solar Water Heating Report*. Figures 10 and 11 show groups of parcels from the case study where collective ownership of a SWH system is possible.

Figure 10: Aerial Image With Building Outlines for the Pheasant Ridge Apartments in Rowland Heights, California



Source: LARIAC5 Orthogonal Imagery & Building Outlines Dataset

Figure 11: Adjacent Properties With 1 AIN (Single Owner) in Whittier, California



The image above (building outlines from aerial LiDAR) shows groups of adjacent residential properties (in red) where collective ownership of a SWH system is possible.

Source: LARIAC5 Orthogonal Imagery & Building Outlines Dataset

The state thermal rebate and the renewable tax credits were designed to offset the capital cost of SWH systems for the sole owner of a structure (or, more generally, a residential property) upon which the systems are installed. This is the third reason why collective ownership arrangements are considered to be outside the scope of this study. For a residential parcels to be considered a candidate energy community for solar water heating, those parcels must have a single owner to which incentive payments can be made.

Candidate Case Study Site Pools

This section explains how a programmatic and explicable case study selection method was developed from the broader constraints on community scale SWH in Los Angeles County. The first subsection describes how absolutely qualifying/disqualifying characteristics were used to select large pools of candidate energy communities from the Energy Atlas's parcel data (CCSC, 2018). The second discusses the development and application of a parcel scoring metric for community scale SWH suitability. Parcel rankings and other practical considerations were then used to select case study sites.

Development of Public and Private Residential Parcel Pools

Selection of case study sites began with the Energy Atlas's two million tax assessor's parcels (CCSC, 2018). To select the public and private residential parcels on which community scale SWH was feasible, the search filter was applied (CCSC, 2018). Table 12 summarizes the set of parcel characteristics that made community scale SWH broadly feasible.

Table 12: Public and Private Property Energy Community Filter Criteria

<table>
<tr><th>Desired Energy Community Characteristics</th><th>Filter Conditions</th></tr>
<tr><td>Energy communities may have more than one building per site.</td><td>Building Count ≥ 1</td></tr>
<tr><td rowspan="2">Energy communities must have more than one residential unit per site.</td><td>Residential Units > 1</td></tr>
<tr><td>First two digits of Los Angeles County Tax Assessor's Parcel Database Usecode indicate multi-family dwelling (02XX-05XX).</td></tr>
<tr><td>Minimize the number of parties involved in construction and operation.</td><td rowspan="2">• For Private Parcels: 1 AIN associated with a private residential parcel.
• For Public Parcels: Public parcels must have structures and facilities owned and operated by Los Angeles City or County.</td></tr>
<tr><td>Parcels must have a single owner or ownership entity to which incentive payments can be made.</td></tr>
</table>

The results of the query are shown in Table 13.

Table 13: Public and Private Parcel Counts From Community Scale SWH Filter

Private Parcels	Public Parcels
~19, 000 Multi-Family/Mixed-Use Parcels	213 City and County Public Housing Parcels

As mentioned previously, the community scale filter identified residential parcels where community scale SWH was feasible but did not include any notion of how well-suited a particular parcel was to a community scale approach to solar water heating. Selecting a specific case study site programmatically required ranking different residential parcels according to their suitability for a community scale SWH system. This study's ranking was based on the available parcel data and the geographic and building-level variables known to influence the performance of SWH systems (Dongellini et al., 2015; ASPE, 2015; Marini et al., 2015). The ranking and selection method for private and public parcels are described below.

Parcel Suitability Ranking and Selection Method

Community scale SWH case study sites were chosen according to the following criteria:

1. Parcel SWH Suitability Score
2. Number of Residential Units per Parcel
3. Urban Form and Climatic Considerations

A residential parcel's suitability score is given by the following expression:

Equation 5. Parcel Suitability Score

$$\text{Parcel Suitability Score} = \frac{\left(\frac{U_N A_B}{B_N P_B}\right)}{A_P}$$

where:

U_N = Number of residential units per parcel

A_B = Sum of building footprint areas on a parcel

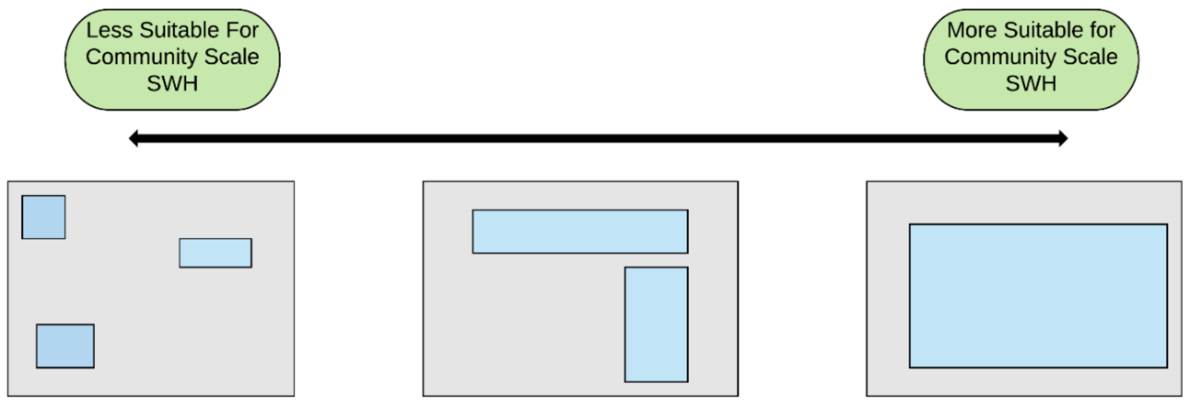
B_N = Number of buildings per parcel (with building outline ≥ 300 ft^2)

P_B = Sum of building footprint perimeters on a parcel

A_P = Area of the parcel

Parcels with higher ratios of building area to parcel area, and parcels with greater population densities (residential units/unit parcel area), score better than parcels with more numerous buildings, lower built area ratios, and fewer residential units. The relationship is illustrated in Figure 12.

Figure 12: Parcel Suitability Score



The suitability score encapsulates how a parcel's built-environment influences the performance and capital cost of a hydronic SWH system or systems. Parcels with small, distantly spaced structures may have insufficient rooftop space for collector arrays, possibly necessitating installation of collector arrays on the ground. Furthermore, long runs of insulated hot water pipe between storage tanks and residential units increase both the cost of the system (materials and trenching) as well as heat loss. By contrast, parcels with fewer, larger, and more densely populated structures may adopt SWH at a lower cost, and without installing additional heat transmission infrastructure.

Because the suitability score computes a ratio of areas weighted by residential units and the number of buildings, it is also necessary to consider the absolute number of residential units. Case studies with different numbers of residential units (between 10 and 1000 units) were chosen to elucidate the effect of population density on SWH system performance and design.

Residential Parcel Ranking and Selection — Public and Private Cases

Private Parcel Ranking and Selection Method

There were approximately 19,000 privately owned parcels in Los Angeles County for which community scale SWH is feasible. From this pool, three instructive cases were selected using the data shown in Table 14.

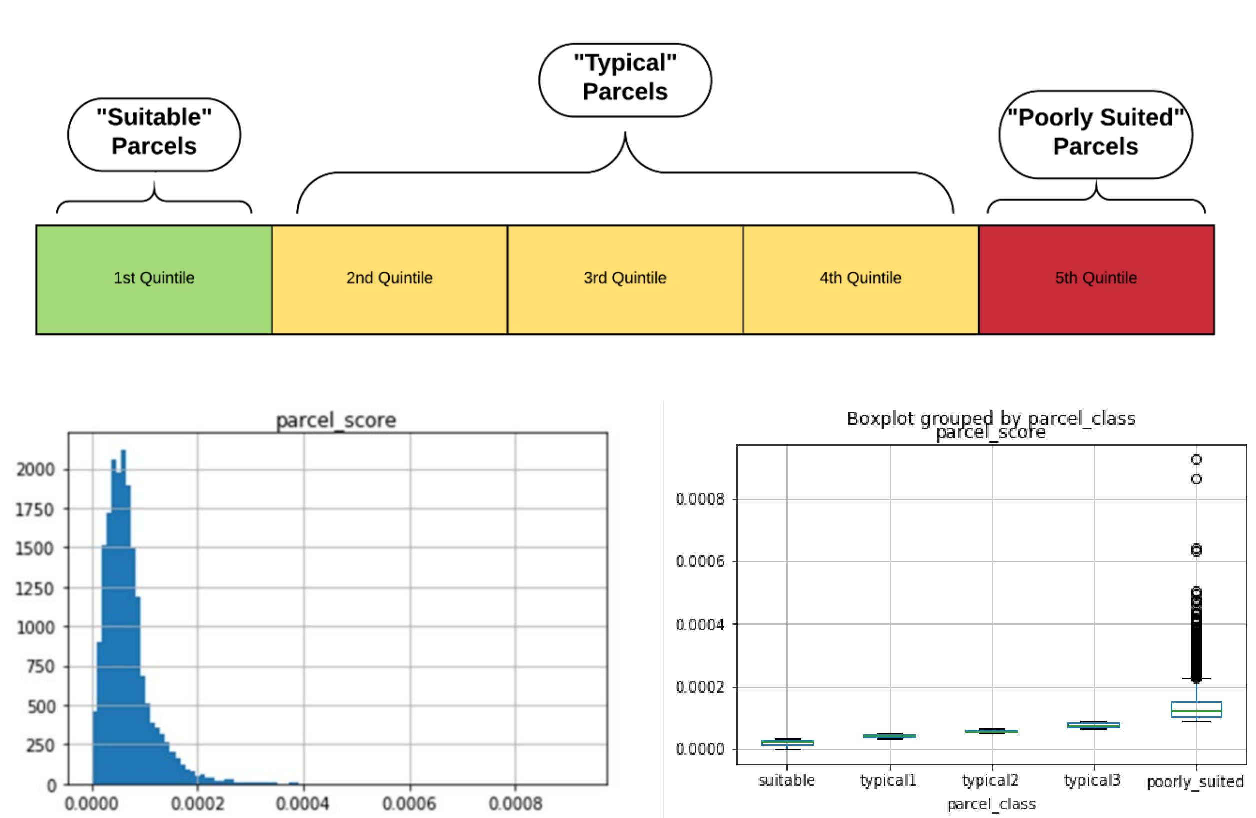
Table 14: Private Parcel Data

Variable	Description	Data Source
Building Count	Number of buildings per residential parcel with roof area ≥ 300 ft^2 (square feet)	LARIAC 4 Building Outlines
Unit Count	Number of residential units per residential parcel	Energy Atlas
Parcel Area	Parcel area in m^2 (square meters)	Energy Atlas
Parcel Perimeter	Parcel perimeter in m	Energy Atlas

Variable	Description	Data Source
Building Area	Area of the i^{th} building's outline on the j^{th} residential parcel in m^2	LARIAC 4 Building Outlines
Building Perimeter	Perimeter of the i^{th} building's outline on the j^{th} residential parcel in m	LARIAC 4 Building Outlines

The first step in selection of private cases was to compute the parcel suitability score for each of the parcels in the private pool. The parcels were then divided into quintiles (about 3,000 parcels each) and classified according to their scores. Figure 13 illustrates the suitability ranking scheme and shows the distribution of scores among the parcels:

Figure 13: Parcel Ranking Scheme and Distribution of Parcel Suitability Scores by Quintiles



After sorting each quintile by counts of residential units per parcel, a "suitable" case was selected from the first quintile, a "typical" case from the middle three quintiles, and a "poorly suited" case from the fifth quintile. These cases were selected based on their parcel score, the number of residential units in each energy community, and the presence of other potentially instructive variation in urban form. Finally, if a parcel selected was part of a larger community (specifically one parcel of an apartment complex spanning multiple parcels), the entire community was selected.

Public Parcel Ranking and Selection

Selection of publicly owned residential parcels began with the aggregation of the City and County Housing Authorities' asset portfolios. The Housing Authority of the City of Los Angeles (HACLA) and the Housing Authority of the County of Los Angeles (HACoLA) publish the addresses of the properties that they own and maintain. These properties meet the sole ownership requirement, but further information was needed from the Energy Atlas database and other sources to develop a list of feasible properties (Table 15).

Table 15: Public Property Parcel Data

Variable	Description	Data Source
Asset Location	HACLA/HACoLA Asset Portfolio addresses geocoded to tax assessor's parcel locations.	HACLA Asset Portfolio, HACoLA Asset Portfolio, Google Geocoding API, Energy Atlas
Building Count	Number of buildings per residential parcel with roof area ≥ 300 ft^2	LARIAC 4 Building Outlines
Unit Count	Number of residential units per residential parcel	CCSC Energy Atlas*, City of Los Angeles Health Atlas**
Parcel Area	Parcel area in m^2	CCSC Energy Atlas*
Parcel Perimeter	Parcel perimeter in m	CCSC Energy Atlas*
Building Area	Area of the i^{th} building's outline on the j^{th} residential parcel in m^2	LARIAC 4 Building Outlines
Building Perimeter	Perimeter of the i^{th} building's outline on the j^{th} residential parcel in m	LARIAC 4 Building Outlines

Source: *CCSC, 2020; **LACDPH, 2013.

First, the lists of addresses for properties owned by both housing authorities were geocoded to associate them with their corresponding assessor's parcels. This step was essential for scoring and selection, as the number of buildings and residential units was required. Google's Geocoding API was used to accomplish this task (Google Maps Platform, 2018).

Two-hundred and thirteen HACLA and HACoLA residential parcels met the feasibility requirements listed in the section titled Simulation Methods for Community Scale Solar Water Heating System Performance on page 21. The selection of case studies from the pool of 213 candidate parcels followed a similar procedure (scoring and sorting by number of residential units per parcel) to the private parcels. If a parcel belonging to a larger public housing site or development was selected, then the entire site was selected as a case study. Considering the smaller size of the public parcel pool, the cases in Chapter 4 were chosen to represent the diversity in public housing stock.

CHAPTER 4: Community Scale Solar Water Heating Case Studies

Community Scale SWH System Sizing and Site-Specific Hot Water Demand Calculations

The tasks of estimating the energy savings from a specific SWH system and evaluating the emissions reduction potential of community scale solar water heating in general are complicated by the lack of a standard approach to SWH system design and by the difficulty inherent in estimating domestic hot water demand from a limited set of generally publicly available building-level variables. Also, most extant community scale solar heating systems provide energy for both space and water heating and are sometimes embedded within larger district-scale heating systems (Fisch et al., 1998; Pinel et al., 2011). Thus, to evaluate the performance of community scale systems appropriate for Los Angeles County's climate and built environment, a simulation-based approach must suffice.

The following sections describe the simplifying assumptions, programmatic specification, and sizing of the 102 SWH systems simulated for this study. Simulation parameters were based on building characteristics and the occupancy limits of the residential units within them. The calculation of domestic hot water demand based on technical assumptions published by ASHRAE was also addressed (ASPE, 2015; Goldner and Price, 1996). The following sections detail the programmatic specification of the three most influential simulation parameters: collector area, storage volume, and domestic hot water demand. Other simulation parameters and their values are listed in Appendix 2.

Community Scale SWH System Design and Components

As described in Chapter 1, community scale SWH systems in Los Angeles County are hydronic, active, and closed. Regardless of scale, the SWH systems simulated in this study consist of physically separate thermal collection and potable hot water distribution loops. The collection loop is filled with a glycol-water mixture to protect against freezing and stagnation, and heat is transferred to potable water in a system's solar storage tank through an immersed load-side heat exchanger. The systems simulated in this study are consistent with the requirements listed in California's Title 24 and the CSI-Thermal Handbook (CPUC, 2019; CEC, 2015c). All systems for community scale SWH consist of the following elements shown in Table 16.

Table 16: Community Scale Solar Water Heating System Components

Component	Description
Solar Thermal Collector Panels	• Model: SunEarth EP-40 4x10 Collector Panels
Storage Tank	• 100 gallons to 2000+ gallons • Immersed load-side heat exchanger • R12 insulation

Component	Description
Insulated Copper Pipe	• 1′ copper pipe for collector and distribution loops
Control Unit	• Control and monitor flow and temperature in ***t***
Expansion Tank	• System stagnation protection
Auxiliary Heater	• Gas water heater/central boiler • Distributed or centralized depending on site
Circulation Pumps	• 40W to 100 W pumps for collector and distribution loops

Parcel-Scale Versus Structure-Scale Community Solar Water Heating

Prior to running system simulations and interrogating the results, it was necessary to determine whether it was feasible or desirable to build community scale SWH systems that serve entire residential parcels rather than separate residential structures. Studies of extant systems suggest that larger, centralized systems exhibit superior thermal efficiency than similarly designed smaller ones and, in some instances, deliver heat at a lower cost (Chen, 2018d; USACE, 2011). However, in the context of Los Angeles County, the price of natural gas, building code and rebate requirements, and the material costs of construction negate any potential benefits from the installation of a parcel-level system.

While modest economies of scale are observed for residential SWH systems (approximately \$120/ft^2 collector area for large systems versus \$160/ft^2 collector area for single-family homes), these cost savings reflect the fact that larger, more monolithically structured systems require fewer control units, pumps, and other equipment per square foot of collector area (Bavin, 2018b). Residential retrofits also typically make use of the installed gas or electric water heaters as the system's auxiliary heater to reduce capital cost (Chrisman, 2018a).

The low price of natural gas necessitates that, even in ideal retrofit cases (i.e., a building with a central water heater and adequate roof area, for which data on actual demand exists), residential SWH systems must, at a minimum, qualify for the CSI-Thermal performance-based incentive to be economically viable (Chen, 2018e). Systems that serve multiple residential structures did not qualify for the CSI-Thermal performance-based incentive or the federal Residential Renewable Energy Tax Credit (CPUC, 2019; U.S. DOE, 2018). Parcel-scale SWH systems intended to serve multiple residential structures may also require additional labor, materials, and equipment. Depending on the application, centralized, parcel-scale SWH systems serving multiple structures may require buried and insulated pipe, additional auxiliary heating equipment (such as gas-condensing boilers) and specialized control units (Bavin, 2018c).

The relationship between the scale and performance of hydronic solar thermal systems of the type described previously, and the technical challenges posed by the construction of large, centralized SWH systems, are not well understood and, thus, are considered to be outside the scope of this study. However, efforts to reduce emissions from the residential housing sector would benefit from a better understanding of the aforementioned topics.

Collector Area and Storage Volume Parameters

With component technologies for community scale SWH selected, and the question of parcel-scale versus structure-scale scale settled, the next task was to programmatically size each SWH system according to the building characteristics that were publicly available. As mentioned previously, there is no one canonical method for sizing SWH systems and predicting system performance; a variety of computational approaches can be considered as valid (Duffie and Beckman, 2013; Anderson, 2018b). System sizing is also an iterative process. In most instances, rough sizing guidelines are used as a starting point for a series of system simulations until performance targets are achieved (Table 17) (Bavin, 2018c).

This study relies on two widely used system sizing ratios to determine an initial collector area and storage volume. The collector area/storage volume ratio used in this study is also a requirement of California Title 24 (CPUC, 2019).

Table 17: Sizing Ratios for Collector Area and Solar Tank Storage Volume

Collector Area/Storage Volume	Storage Volume/Conditioned Area
1 *sqft collector area*	90 *gallons storage tank volume*
1.5-2.0 *gallons storage tank volume*	2000 *sqft conditioned area*

Thus, solar tank volume and collector area for a given SWH system are functions of the structure's *conditioned area*, or floor space.

For various reasons, exact square footage figures were not available for any of the buildings included in this study. Housing authorities and development site staff could not locate the appropriate records in most cases. In lieu of exact square footages, the conditioned area was determined using the building outline and height measurements included in the Los Angeles Regional Imagery Acquisition Consortium (LARIAC) Building Outlines shapefile (LARIAC, 2017b). The LARIAC Building Outlines shapefile contains building heights, areas, and elevations for all the structures with area ≥ 300 ft^2 in Los Angeles County. Building dimensions are estimated from aerial LiDAR data acquired by EagleView Inc. using a proprietary algorithm. The conditioned area for a building is given by the following equation:

Equation 6. Conditioned Area Formula

$$C_A = \frac{B_H}{10} * B_A$$

where:

C_A = Conditioned Area

B_H = Building Height

B_A = Building Outline

The formula above provides an estimate of floor square footage assuming 10 feet of building height per floor. The results of this calculation were checked and, in some cases, modified using LARIAC's most recent oblique aerial imagery (LARIAC, 2017a). Manual measurements were taken from orthogonal aerial imagery for buildings consisting of multiple wings with different numbers of floors.

Residential Hot Water Demand Schedule and Calculations

It is difficult to produce accurate estimates of domestic hot water consumption based a small set of building and occupant characteristics (Fuentes et al., 2018). Actual consumption of hot water has been found to vary within ±30 percent of estimates calculated from technical assumptions (Fuentes et al., 2018). Thus, for the purposes of this study, calculated hot water demand and the implied gas and water consumption per residential unit for each case study site must meet the following criteria prior to being used for simulations:

1. Calculated water and gas consumption values must fall within the distribution of actual water and gas consumption per unit from the Energy Atlas database.
2. The volume of hot water consumed per month must be more than 8 HCF (hundred cubic feet) per unit.

The volume of water consumed per month must be less than the maximum consumption for Tier 1 Los Angeles Department of Water and Power (LADWP) residential consumers (800 cubic feet per residential account per month) (LADWP, 2016). To check the robustness of the hot water demand assumptions, a comparison is made between the hot water consumption calculated from technical assumptions and actual consumption values from the CCSC Energy Atlas database.

This study uses standard technical assumptions published by ASHRAE and the American Society of Plumbing Engineers (ASPE) to calculate daily hot water demand on a per-person basis (Kalogirou, 2013; ASPE, 2015). Hot water demand on the basis of a person-day for a residential building is calculated from the following:

- **Hot Water Event Types** — Depending on what appliances and hot water fixtures are present in a residential unit, such a dishwashers or washer/dryers, the set of hot water "events" are the possible end uses of hot water.
- **Hot Water Volume per Event** — ASHRAE and ASPE list average volumes of hot water at draw-off temperature (120ºF [48.89ºC]) consumed per event type (Table 18). These volumes are different from the total volume of water (hot and cold) used per event. Total hot water consumption is assumed to be one-third to one-half of the total indoor water consumption.
- **Event Frequency per Person-Day/Person-Month** — The frequency of hot water events is determined on daily and monthly bases. Daily events are assumed to occur once or more per day, and monthly events are assumed to occur once or more per month. Event frequencies vary between cases and are listed in each case study.
- **Maximum Occupancy per Residential Unit** — Maximum allowable occupancy per unit is determined by housing authority rules, or stipulated by the owners of private residential buildings.

Table 18: Hot Water Volume per Event Type*

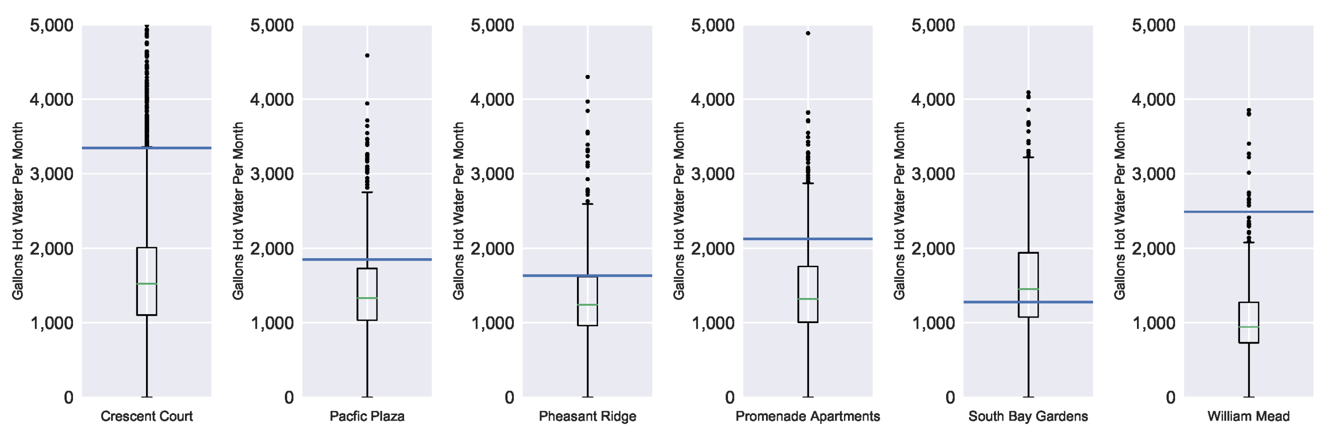
Event Type	Daily/Monthly Basis	Volume HW Consumed (gal)
Food Preparation	Daily	3.96
Manual Dishwashing	Daily	3.96
Shower	Daily	3.96
Bath	Monthly	15.85
Face and Hand Washing	Daily	2.64
Dishwasher (per wash cycle)	Monthly	6.00
Clothes Washing (per wash cycle)	Monthly	36.00

Source: *ASPE, 2015.

The CCSC Energy Atlas's historical water and gas consumption data for Los Angeles County provides the actual per unit gas and water consumption values to which calculated values are compared. To check if calculated consumption values meet the criteria above, water and gas consumption data for samples of properties similar to each case study were drawn from the database.

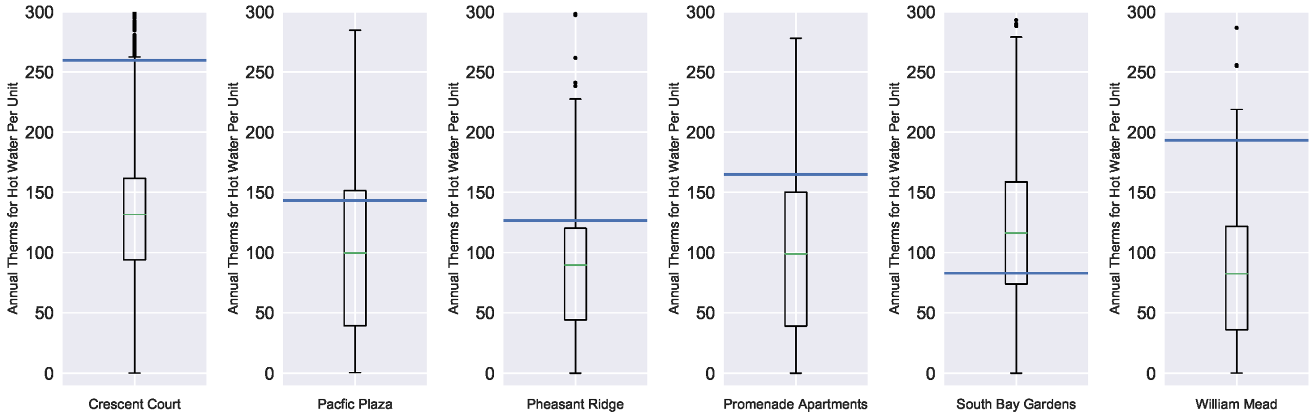
Samples of actual water and gas consumption values were selected using binned sampling to ensure an adequate number of observations and representativeness. Samples were selected based on binned vintage (year of construction), parcel square footage, and the number of residential units. Figures 14 and 15 show calculated per unit consumption values (blue horizontal lines) and distributions of actual per unit consumption values (box plots) for each case study.

Figure 14: Calculated and Actual Monthly Water Consumption per Residential Unit for Case Study Sites and Comparison Samples



Source: CCSC, 2020.

Figure 15: Calculated and Actual Annual Gas Consumption per Residential Unit for Case Study Sites and Comparison Samples



Source: CCSC, 2020.

Actual gas and water consumption meet the criterial stipulated above; however, comparison is complicated by the fact that actual consumption values are influenced by occupancy levels.

Community Scale Solar Water Heating Case Studies — Private Cases

Suitable Case — Pheasant Ridge Apartments, Rowland Heights, California

The Pheasant Ridge Apartments is a large residential complex with approximately 600 1- and 2-bedroom units on two residential parcels, divided by an entrance road. Pheasant Ridge is composed of 70 residential structures, as well as covered parking and utility and management buildings. Rowland Heights is located in the far southeastern portion of Los Angeles County (Figures 16 and 17).

Figure 16: Location of Pheasant Ridge Apartments

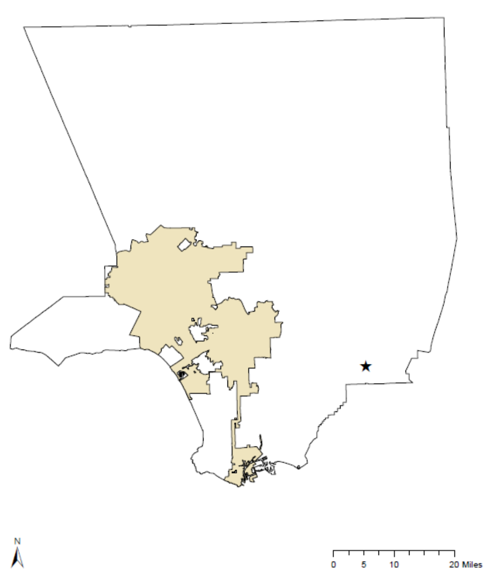
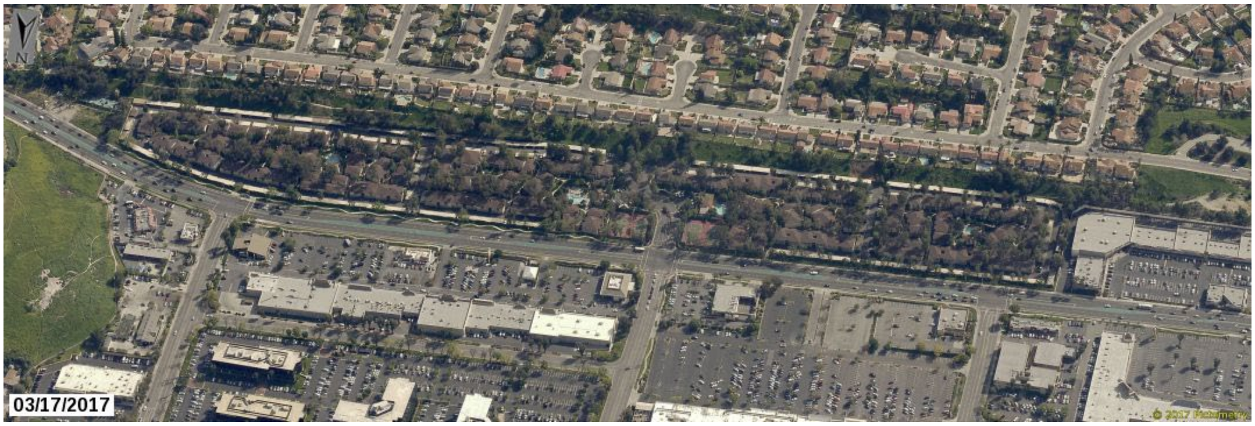
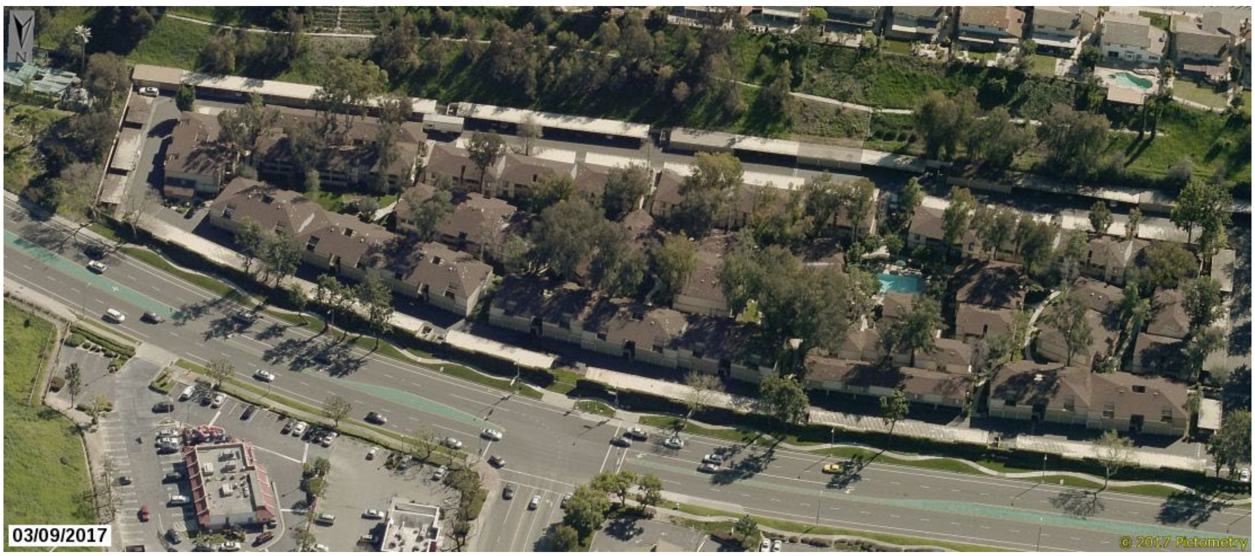


Figure 17: Aerial Images of the Pheasant Ridge Apartment Complex





Oblique aerial photographs of the Pheasant Ridge Apartment complex. The site occupies four large residential parcels near a major shopping center in the City of Rowland Heights.

Source: LARIAC/EagleView Inc.

Pheasant Ridge is well-suited to community scale SWH due to its size and density. However, the pitched roofs of the buildings, and the presence of large trees on the property, complicate installation of collector arrays, and possibly reduce the performance of systems installed on the site.

Based upon publicly available information and conversations with the complex's management company, the information shown in Table 19 was used to parameterize hot water demand schedules and the SWH system.

Table 19: Pheasant Ridge Site Data

Site Area	99,286.90 m^2
Site Perimeter	1,939.54 m
Residential Units	620
Residential Structures	71

Site Area	99,286.90 m^2
Current Water Heating Technology	Units have individual gas heaters.
Additional Information	2-bedroom units contain dishwashers, 3 shared laundry facilities.

Pheasant Ridge Apartments — Hot Water Demand and Conditioned Area Calculations

Pheasant Ridge site managers cooperated with requests for a site visit and provided a site map, unit floorplans illustrations, and an estimate of the number of 1-bedroom units with dishwashers (approximately 60 percent of 1-bedroom units have dishwashers). Based on this information, the maximum occupancies of units, the set of possible hot water events, and event frequencies were determined, as shown in Table 20.

Table 20: Pheasant Ridge — Hot Water Events and Event Frequencies

Event	Total Flow (gals, 120ºF Draw-off)	Basis and Per Person Frequency
Food Preparation	3.96	2x Daily
Manual Dish Washing	3.96	2x Daily
Shower	3.96	1x Daily
Bath	15.85	1x Monthly
Face and Hand Washing	2.64	2x Daily
Dishwasher	6.00	12x Monthly
Clothes Washing	36.00	3x Monthly

Pheasant Ridge offers 1- and 2-bedroom units for rent. Maximum occupancy for the 1-bedroom units is assumed to be two persons. Two-bedroom units are assumed to have a maximum occupancy of four persons. No manual dishwashing was assumed to occur in units with dishwashers. The conditioned areas for each of Pheasant Ridge's structures are determined according to Equation 6. The Pheasant Ridge hot water demand schedule implies the following monthly water and annual gas consumption per residential unit (Table 21).

Table 21: Pheasant Ridge — Calculated Water and Gas Consumption Values

Annual Gas Consumption per Residential Unit	3,710.86 kWh (kilowatt hours) (~126.65 therm)
Monthly Hot Water Consumption per Residential Unit	1,561.58 gal/2.46 HCF

The water and gas consumption values calculated from the Pheasant Ridge hot water demand schedule are near the third quartiles of the distributions of actual gas and water consumption (Tables 22 and 23) and meet the consumption criteria described in Chapter 4. No further adjustment of the hot water demand schedule was necessary prior to system simulations.

Distributions of actual water and gas consumption values for comparison come from properties with the characteristics shown in Table 22.

Table 22: Comparison Property Sample Characteristics

Property Characteristics	Database Query Criteria
Construction Vintage	1990 or Later
Parcel Square Footage	>50,000 ft^2
Number of Res. Units	>100 Units
Parcel Usetype	Multifamily

Pheasant Ridge Apartments — System Design and Simulation Results

Building-level system simulations for Pheasant Ridge (with the system design and hot water demand described) yield the results shown in Table 23.

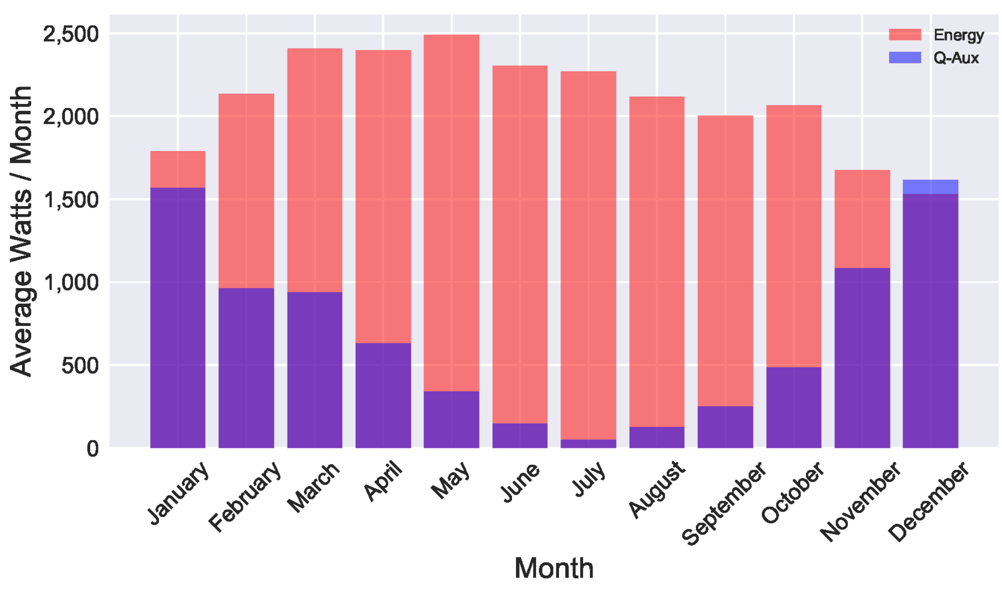
Table 23: Site Summary of Pheasant Ridge's SWH Simulation Results

Performance Metrics	Values
Average Annual System Energy	25,184.60 kWh
Average Solar Fraction	0.751 (75.1% solar energy for water heating)
Average Annual Heat Delivered	30,853.78 kWh
Average Annual Auxiliary Heat Required w/Solar	8,193.38 kWh
Average Annual Heat Delivered — Auxiliary Only	3.35e+04 kWh

Pheasant Ridge's SAM simulation results show that, with the baseline system specifications for residential SWH systems, Pheasant Ridge can displace approximately 75 percent of the gas consumed for water heating. This level of performance qualifies the site for the Residential Renewable Energy Tax Credit and the CSI-Thermal performance-based incentive.

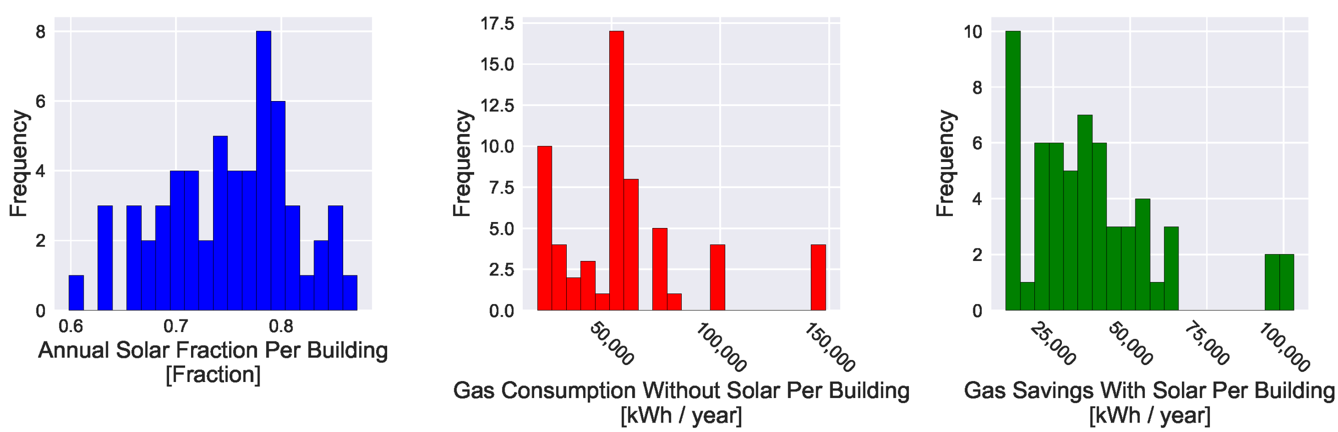
Figure 18 shows the average watts per month generated by the SWH systems installed in each building. The red in the graph shows the energy generated, and the blue shows the auxiliary energy provided. The purple in the graph is a result of the graphical overlap of the red and the blue bars. As expected, SHW systems perform best in the summer months, with site solar fraction reaching a maximum in July. The only month that auxiliary heaters provide more energy than SWH systems is December.

Figure 18: Pheasant Ridge — Average Monthly SWH System Energy and Average Auxiliary Energy per Month



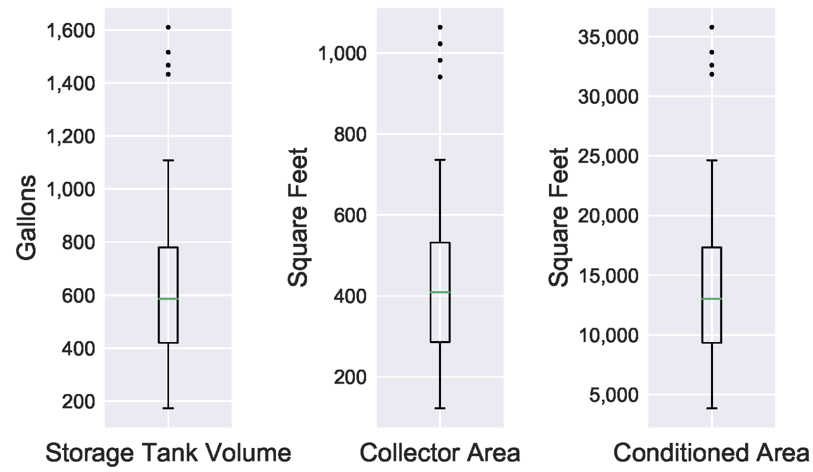
The histograms in Figure 19 show the distributions of solar fraction, gas consumption, and gas savings among Pheasant Ridge's 70 residential structures. Individual solar fractions for SWH systems range from approximately 53 percent to more than 90 percent. All of the SWH systems meet the minimum performance requirement set by Title 24 (less than 20 percent average annual solar fraction).

Figure 19: Pheasant Ridge — Distributions of Solar Fraction, Gas Consumption Without SWH, and Gas Savings for Site Buildings



The baseline assumptions for the conditioned area and system sizing for Pheasant Ridge produce the distributions of tank volume and collector area shown in Figure 20. The box-and-whisker plots show that, across Pheasant Ridge's 71 buildings, storage tanks range from 100 to 2000 gallons, and the collector area ranges from 100 to 1500 ft^2. The range of collector areas roughly corresponds to 2 to 25 individual collector panels, depending on the conditioned area of the building.

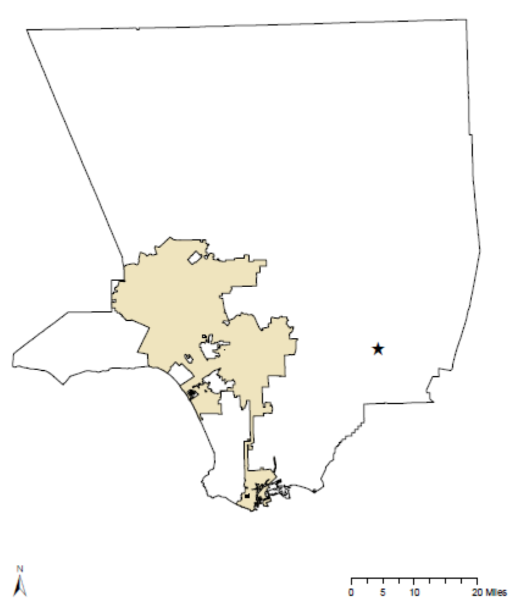
Figure 20: Pheasant Ridge — Distributions of Conditioned Areas, Collector Areas, and Tank Volumes for Pheasant Ridge Structures



Typical Case — Promenade Apartments, West Covina, California

The Promenade Apartments is a 124-unit affordable housing complex located near the I-10 Freeway in the San Gabriel Valley, east of Los Angeles (Figure 21). The complex offers studio and 1-bedroom apartments, rented preferentially to families and seniors at below-market rates (National CORE, 2018). National CORE, a non-profit housing and community outreach organization, owns and manages the property.

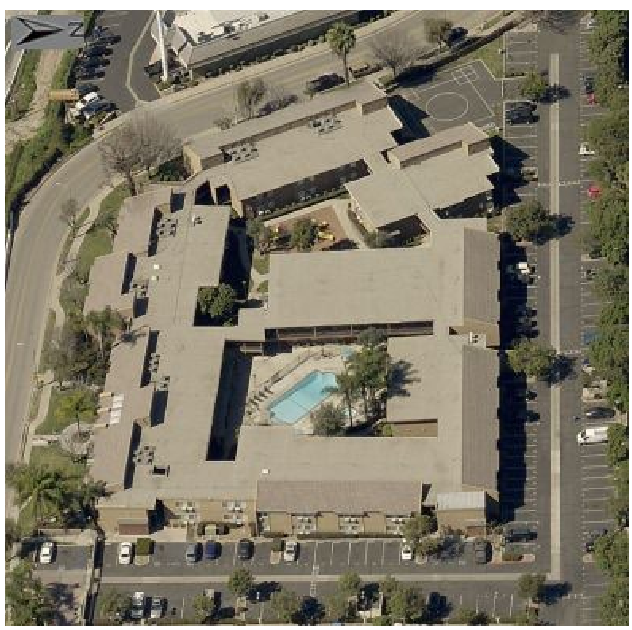
Figure 21: Location of the Promenade Apartments



The Promenade Apartments represents a type of medium-density apartment complex common in Los Angeles County (Figure 22). The property features centralized laundry facilities, but residential units contain their own storage water heating units. Despite consisting of a single building with having flat, unobstructed roof, the Promenade Apartments is rated as "typical" rather than “suitable” according to the SWH Suitability Score (Table 24). This is for two reasons. First, the parcel suitability score does not account for the degree of roof obstruction. Only parcel and building data are used to calculate suitability scores. Secondly, and more importantly, a significant proportion of Promenade Apartment’s parcel is devoted to parking and courtyards. This diminishes the building area to parcel area ratio, diminishing the site’s parcel suitability score.

Promenade Apartments are owned and managed by National Community Renaissance, a nonprofit organization that offers subsidized housing and other supportive and educational services to families (National CORE, 2018).

Figure 22: Aerial Images of the Promenade Apartments, West Covina, California



The Promenade Apartments are a private nonprofit affordable housing complex located due north of the 60 Freeway in West Covina, California.

Source: LARIAC/EagleView, Inc.

Table 24: The Promenade Apartments Site Data

Site Area	9,032.49 m^2
Site Perimeter	309.64 m
Residential Units	124
Residential Structures	1
Current Water Heating Technology	1 storage water heater per unit
Additional Information	1-bedroom units contain dishwashers, shared laundry facilities.

Pheasant Ridge Apartments — Hot Water Demand and Conditioned Area Calculations

Despite repeated attempts to contact both the Promenade Apartments site staff and National CORE, no representative from the residential complex or the nonprofit that manages operations and programs at other properties responded to requests for information. The site's hot water demand schedule was determined using the number of each unit type and the floorplans listed on the property's publicly available website (Table 25). The floorplans indicated the presence or absence of dishwashers and washer/dryer units (National CORE, 2017).

Table 25: Promenade Apartments — Hot Water Events and Event Frequencies

Event	Total Flow (gals, 120ºF Draw-off)	Basis and Per Person Frequency
Food Preparation	3.96	2x Daily
Manual Dish Washing	3.96	2x Daily
Shower	3.96	1x Daily
Bath	15.85	1x Monthly
Face and Hand Washing	2.64	2x Daily
Dishwasher	6.00	12x Monthly
Clothes Washing	36.00	3x Monthly

Promenade Apartments offers studio and 1-bedroom units for rent. Maximum occupancy for a studio unit is assumed to be two persons. One-bedroom units are assumed to have a maximum occupancy of four persons. It was assumed that no manual dishwashing occurred in units with dishwashers. The conditioned area of the Promenade Apartments complex was determined according to Equation 6.

The Promenade Apartments' hot water demand schedule implies the monthly water and annual gas consumption per residential unit shown in Table 26.

Table 26: Promenade Apartments — Calculated Water and Gas Consumption Values

Annual Gas Consumption per Residential Unit	4,839.79 kWh (~165.18 therm)
Monthly Hot Water Consumption per Residential Unit	2,126.14 gal/2.84 HCF

The water and gas consumption values calculated from the Promenade Apartments hot water demand schedule are just above the third quartiles of the distributions of actual gas and water consumption, and they meet the consumption criteria described in the section titled Auxiliary and Backup Heating Elements on page 9. No further adjustment of the hot water demand schedule was necessary prior to system simulations. Distributions of actual water and gas consumption values for comparison come from properties with the characteristics shown in Table 27.

Table 27: Promenade Apartments — Comparison Property Sample Characteristics

Property Characteristics	Database Query Criteria
Construction Vintage	1950–1978
Parcel Square Footage	10,000–20,000 ft^2
Number of Res. Units	>100 Units
Parcel Usetype	Multifamily

Promenade Apartments — System Design and Simulation Results

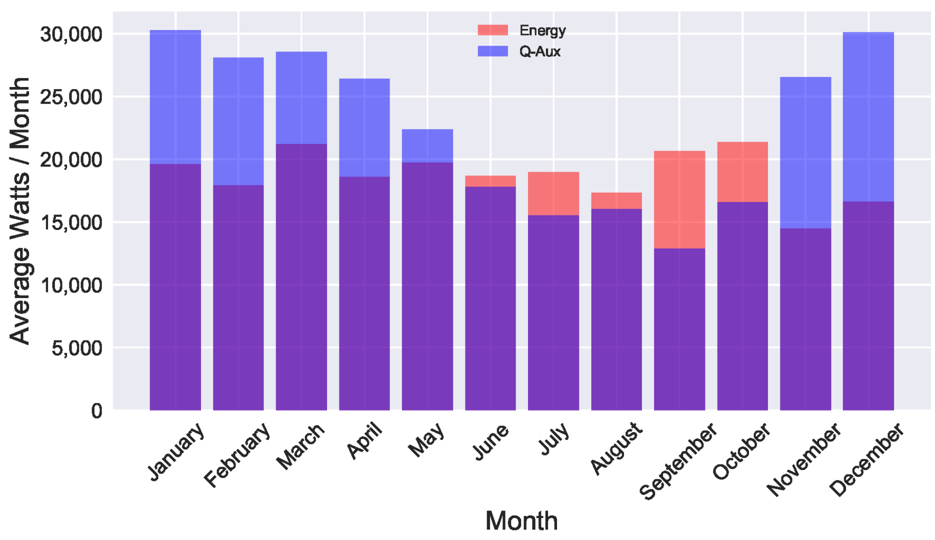
Building-level system simulations for the Promenade Apartments (with the system design and hot water demand described above) yielded the results depicted in Table 28.

Table 28: Promenade Apartments — Site Summary of SWH Simulation Results

Performance Metrics	Values
Average Annual System Energy	224,984.95 kWh
Average Solar Fraction	0.453 (45.3% solar energy for water heating)
Average Annual Heat Delivered	343,389.03 kWh
Average Annual Auxiliary Heat Required w/Solar	270,963.16 kWh
Average Annual Heat Delivered — Auxiliary Only	4.96e+05 kWh

Using the baseline system sizing assumptions, the Promenade Apartment's SWH system meets Title 24 requirements and qualifies for the CSI-Thermal performance-based incentive. The site's system also displaces approximately half of the gas consumed for water heating (Figure 23). The red in the graph shows the energy generated, and the blue shows the auxiliary energy provided. The purple in the graph is a result of the graphical overlap of the red and the blue bars.

Figure 23: Promenade Apartments — Average Monthly SWH System Energy and Average Monthly Auxiliary Energy



Unlike Pheasant Ridge, the Promenade Apartment's system energy is relatively constant between months, and considerable quantities of auxiliary energy are required to meet the demand between November and May. Table 29 shows the annual consumption of gas implied by the hot water demand schedule with and without the site's SWH system. Table 30 shows the collector area, the number of collector panels, tank volume, and the conditioned area for the site.

Table 29: Promenade Apartments — Gas Consumption Without SWH, and Gas Savings With SWH

Annual Gas Consumption w/o SWH System	826,967 kWh/year
Gas Savings w/ SWH System	418,767 kWh/year

Table 30: Promenade Apartments — Collector Area, Tank Volume, and Conditioned Area for SWH System

Collector Area	2,985.91 ft^2
Collector Panels	73
Solar Tank Volume	4,509.03 gals
Conditioned Area	100,201 ft^2

Poorly Suited Case — Pacific Plaza, Santa Monica, California

The Pacific Plaza is a mixed-use high-rise apartment building with 288 studio and 1-bedroom units located in Santa Monica, California (Figure 24).

Pacific Plaza offers very little rooftop space relative to the other sites, and it is the densest development in terms of residential units per parcel area included in this study (Figure 25, Table 31). Furthermore, it may be necessary to locate solar storage tanks in the basement of the building if the rooftop cannot accommodate them.

Figure 24: Location of the Pacific Plaza

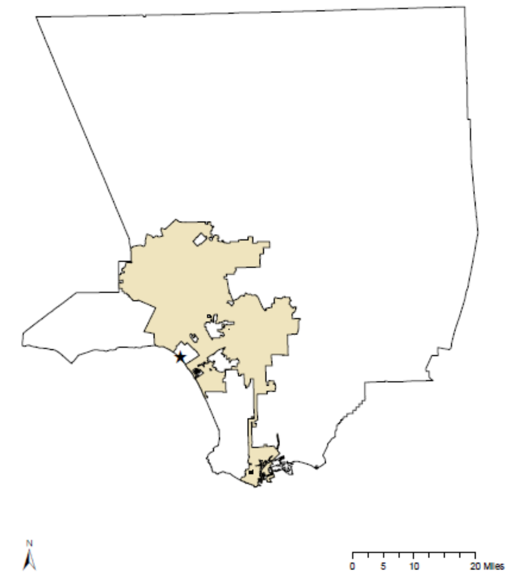


Figure 25: Aerial Images of the Pacific Plaza Building

Table 31: Pacific Plaza Site Data

Site Area	2,330.16 m^2
Site Perimeter	194.45 m
Residential Units	288
Residential Structures	1
Current Water Heating Technology	1 storage water heater per unit
Additional Information	1-bedroom units contain dishwashers, shared laundry facilities.

Pacific Plaza — Hot Water Demand and Conditioned Area Calculations

Pacific Plaza is owned and maintained by Douglas Emmett, a publicly traded real estate investment firm with a portfolio of residential and commercial properties (Douglas Emmett, 2018). Pacific Plaza offers studio and 1-bedroom units with various configurations for rent at market rates. Maximum occupancy for a studio unit is assumed to be two persons, and 1-bedroom units are assumed to have a maximum occupancy of three persons. No manual dishwashing is assumed to occur in units with dishwashers. The conditioned area of the building is determined according to Equation 6. Pacific Plaza's hot water demand schedule implies the monthly water and annual gas consumption per residential unit shown in Table 32.

Table 32: Pacific Plaza — Hot Water Events and Event Frequencies

Event	Total Flow (gals, 120ºF Draw-off)	Basis and Per Person Frequency
Food Preparation	3.96	2x Daily
Manual Dish Washing	3.96	2x Daily
Shower	3.96	1x Daily
Bath	15.85	1x Monthly
Face and Hand Washing	2.64	2x Daily
Dishwasher	6.00	12x Monthly
Clothes Washing	36.00	3x Monthly

The calculated water and gas consumption values implied by Pacific Plaza's hot water demand schedule meet the consumption criteria described in the section titled Suitable Case — Pheasant Ridge Apartments, Rowland Heights, California on page 41. Monthly water consumption per residential unit is slightly greater than the third quartile of the comparison distribution, and annual gas consumption per unit is at the upper end of the inter-quartile range (Table 33). No further adjustment of the hot water demand schedule was necessary prior to system simulations.

Table 33: Pacific Plaza — Calculated Water and Gas Consumption Values

Annual Gas Consumption per Residential Unit	4,205.58 kWh (~143.53 therm)
Monthly Hot Water Consumption per Residential Unit	1,847.69 gal/2.47 HCF

Distributions of actual water and gas consumption values for comparison come from properties with the characteristics shown in Table 34.

Table 34: Pacific Plaza — Comparison Property Sample Characteristics

Property Characteristics	Database Query Criteria
Construction Vintage	1950–1978
Parcel Square Footage	>50,000 ft^2

Property Characteristics	Database Query Criteria
Number of Res. Units	>100 Units
Parcel Usetype	Multifamily

Pacific Plaza — System Design and Simulation Results

The baseline demand and sizing assumptions produce the results for Pacific Plaza's SWH system shown in Table 35.

Table 35: Pacific Plaza — Site Summary of SWH Simulation Results

Performance Metrics	Values
Average Annual System Energy	281,267.53 kWh
Average Solar Fraction	0.281 (28.1% solar energy for water heating)
Average Annual Heat Delivered	723,295.69 kWh
Average Annual Auxiliary Heat Required w/Solar	719,816.63 kWh
Average Annual Heat Delivered — Auxiliary Only	1.00e+06 kWh

Pacific Plaza's SWH system meets the minimum requirements of Title 24, and it qualifies for the CSI-Thermal performance-based incentive. However, Pacific Plaza's relatively low annual solar fraction (more than 50 percent) means that the SWH system does not qualify for the federal Residential Renewable Rebate.

The only months for which Pacific Plaza's hot water demand is met with more solar energy than gas are those with the greatest number of daylight hours. Pacific Plaza's proximity to the ocean may also explain the low system energy relative to the other case studies. Early morning and evening clouds diminish insolation and limit the performance of the building's SWH system (Figure 26). The red in the graph shows the energy generated, and the blue shows the auxiliary energy provided. The purple in the graph is a result of the graphical overlap of the red and the blue bars.

Figure 26: Pacific Plaza — Average Monthly SWH System Energy and Average Monthly Auxiliary Energy

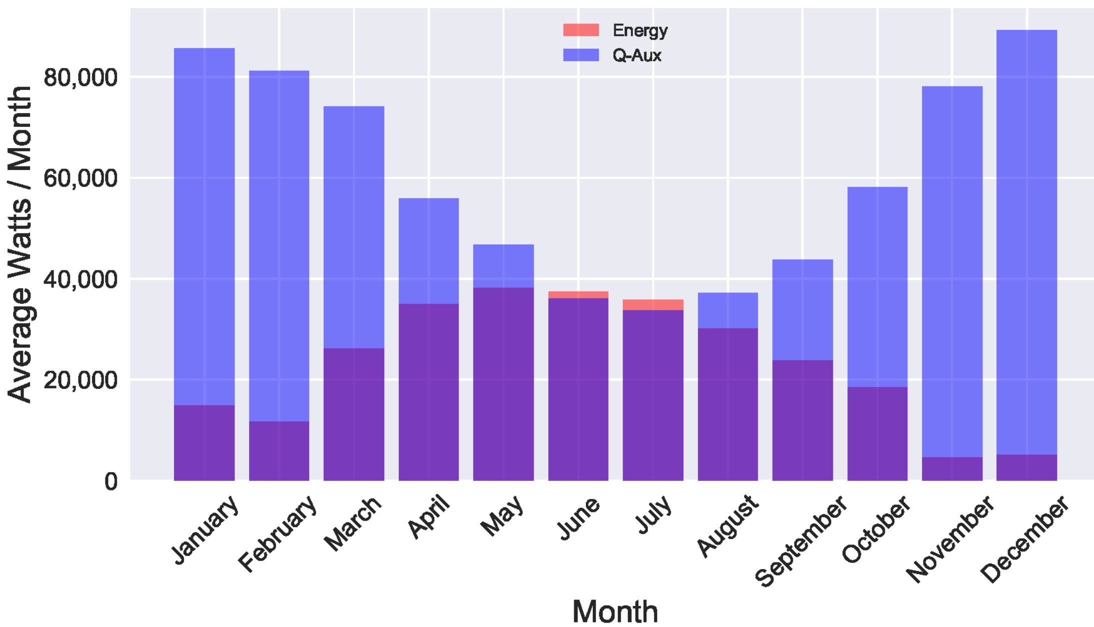


Table 36 shows the annual consumption of gas implied by the hot water demand schedule with and without the site's SWH system. Table 37 shows the collector area, the number of collector panels, tank volume, and the conditioned area for the site.

Table 36: Pacific Plaza — Gas Consumption Without SWH, and Gas Savings With SWH

Annual Gas Consumption w/o SWH System	1,668,989 kWh/year
Gas Savings w/SWH System	882,068 kWh/year

Table 37: Pacific Plaza — Collector Area, Tank Volume, and Conditioned Area for SWH System

Collector Area	9,039.53 ft^2
Collector Panels	221
Solar Tank Volume	13,532.81 gals
Conditioned Area	300,730 ft^2 (rooftop area: 16164.80 ft^2)

Community Scale Solar Water Heating Case Studies — Public Cases

Suitable Case — William Mead Homes, Los Angeles, California

The William Mead Homes are a public housing development located in the Lincoln Heights neighborhood of Los Angeles (Figure 27). The site consists of 24 2- and 3-story residential buildings and 415 units (Figure 28). HACLA manages and maintains the property, which was built by the federal government in 1945 (HACLA, 2017a). Families with children are given preference for open units.

Figure 27: Location of the William Mead Homes

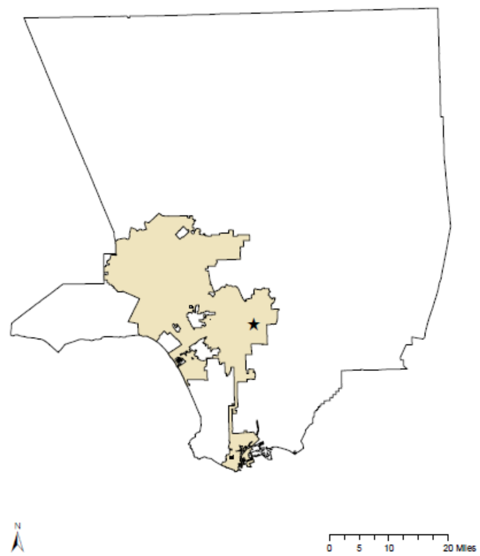


Figure 28: Aerial Images of the William Mead Homes

The William Mead Homes are high-density residential buildings with flat, unobstructed roof areas (Table 38). The style of construction is ideal for the placement of rooftop collector arrays. There is also ample room near the buildings to construct small sheds that would be needed to house SWH system storage tanks.

Table 38: William Mead Homes Site Data

Site Area	83,656.84 m^2
Site Perimeter	1,425.1 m
Residential Units	415
Residential Structures	24
Current Water Heating Technology	30-gal A.O. Smith Gas Storage WH/Unit
Additional Information	No dishwashers. About 50% of units have clothes washing machines.

William Mead Homes — Hot Water Demand and Conditioned Area Calculations

A site map, descriptions of the unit floorplans, and information about installed water heaters were obtained during a visit to the William Mead Homes. Maintenance staff and site managers cooperated with all requests for information (Santa Ana, 2018). The Housing Authority of the City of Los Angeles sets maximum occupancy limits based on a unit's number of bedrooms

(HACLA, 2017b). Based on this information, the maximum occupancies of units, the set of possible hot water events, and event frequencies were determined (Table 39).

Table 39: William Mead Hot Water Events and Event Frequencies

Event	Total Flow (gals, 120ºF Draw-off)	Basis and Per Person Frequency
Food Preparation	3.96	2x Daily
Manual Dish Washing	3.96	1x Daily
Shower	3.96	1x Daily
Bath	15.85	1x Monthly
Face and Hand Washing	2.64	2x Daily
Clothes Washing	36.00	2x Monthly

The William Mead Homes public housing complex offers units ranging in occupancy from two to eight people, based on the number of bedrooms in each unit. More than half of the units have a maximum occupancy of four. Each unit contains a washer-dryer hookup, but a washer-dryer unit is not an included amenity. The maintenance staff estimated that approximately 50 percent of the units have washer-dryers installed (Santa Ana, 2018). Washer-dryer units were assigned randomly to 50 percent of the units for demand calculations. None of the units have dishwashers; only manual dishwashing is assumed to occur.

The conditioned areas for each of William Mead's 24 structures were calculated with building outline measurements made in EagleView's CONNECTExplore aerial imagery web application and according to Equation 6. About half of the site's buildings' wings have different numbers of floors. Manual measurement of the rooftop areas of the building wings were used to calculate the conditioned area for each wing. The conditioned areas of each wing were then added to find the conditioned area of a given building.

William Mead's hot water demand schedule implies the monthly water and annual gas consumption per residential unit shown in Table 40.

Table 40: William Mead Calculated Water and Gas Consumption Values

Annual Gas Consumption per Residential Unit	3,710.86 kWh (~126.65 therm)
Monthly Hot Water Consumption per Residential Unit	2,603.22 gal/3.48 HCF

The water and gas consumption values calculated from the William Mead hot water demand schedule are at the upper ends of their respective distributions but meet the consumption criteria described in the section titled Suitable Case — Pheasant Ridge Apartments, Rowland Heights, California on page 41. William Mead's water and gas consumption per unit reflects the fact that most public housing developments are fully occupied and that larger units are frequently taken by families with children (Santa Ana, 2018). Distributions of actual water and gas consumption values for comparison come from properties with the characteristics shown in Table 41.

Table 41: Comparison Property Sample Characteristics

Property Characteristics	Database Query Criteria
Construction Vintage	Pre-1950
Parcel Square Footage	>50,000 ft^2
Number of Res. Units	>100 Units
Parcel Usetype	Multifamily

William Mead — System Design & Simulation Results

The William Mead Homes complex consists of 24 residential buildings. Each building has its own SWH system serving the units contained within. Table 42 shows the system performance metric averages across the site's 24 buildings.

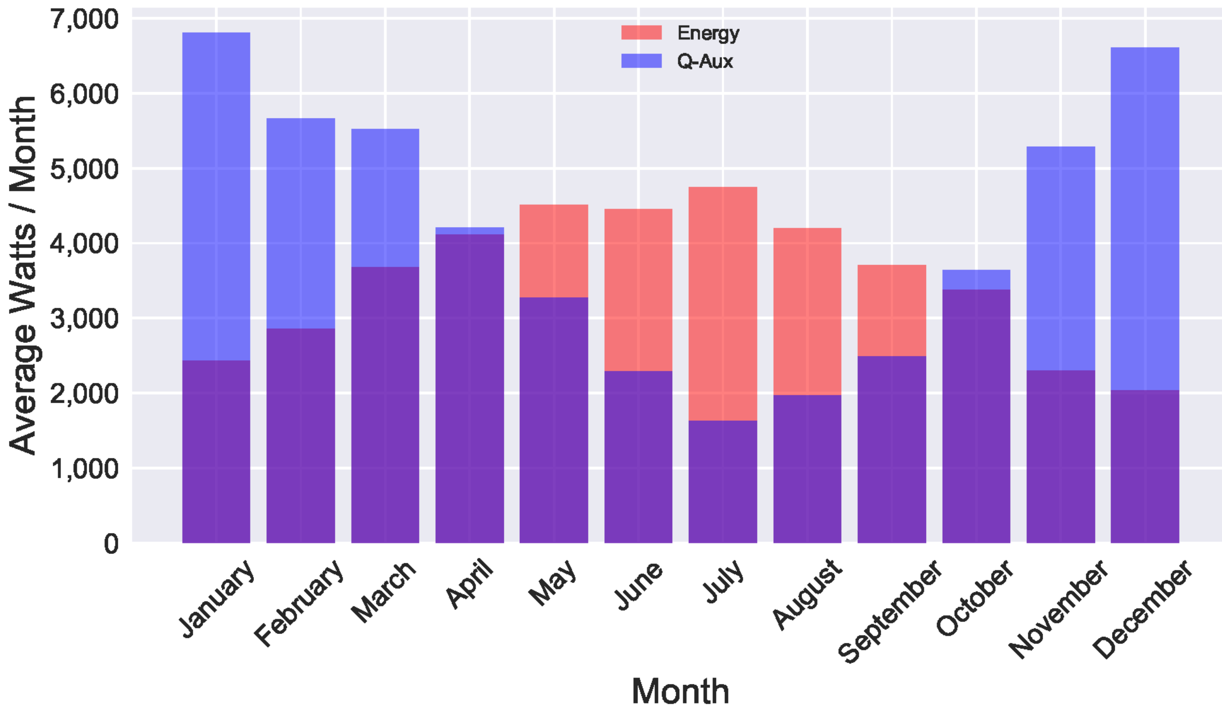
Table 42: William Mead — Site Summary and SWH Simulation Results

Performance Metrics	Values
Average Annual System Energy	42,400.77 kWh
Average Solar Fraction	0.461 (46.1% solar energy for water heating)
Average Annual Heat Delivered	49,219.69 kWh
Average Annual Auxiliary Heat Required w/Solar	49,395.83 kWh
Average Annual Heat Delivered - Auxiliary Only	9.19e+04 kWh

SAM simulation results show that William Mead's systems can displace approximately 75 percent of the gas consumed for water heating. This level of performance qualifies the site for both the Residential Renewable Energy Tax Credit and the CSI-Thermal performance-based incentive.

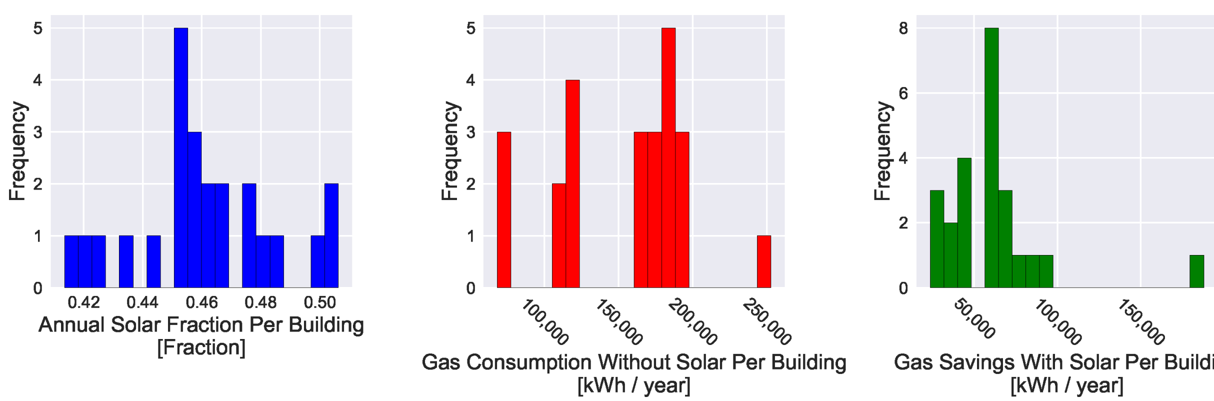
Figure 29 shows the wattage of solar energy captured by the average William Mead SWH system, and the additional energy (auxiliary energy) required by the average William Mead SWH system during one year. The red in the graph shows the energy generated, and the blue shows the auxiliary energy provided. The purple in the graph is a result of the graphical overlap of the red and the blue bars. William Mead's SWH systems perform best during the five summer months, meeting hot water demand with more solar energy than auxiliary gas. From October to April, auxiliary gas energy is required to meet hot water demand.

Figure 29: William Mead — Average Monthly SWH System Energy and Average Monthly Auxiliary Energy



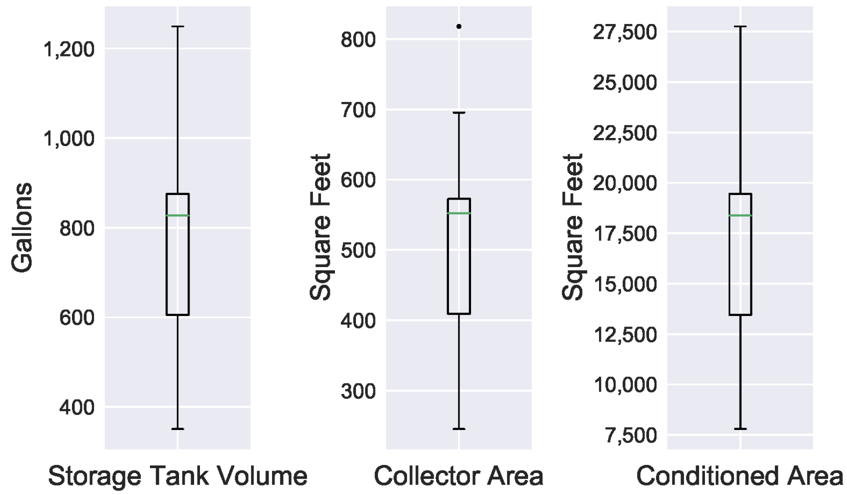
The histograms in Figure 30 show the distribution of solar fraction, gas consumption, and gas savings across the 24 structures on the 4 residential parcels that make up the William Mead Homes. Individual solar fractions for SWH systems range from approximately 30 percent to less than 90 percent. All of the SWH systems meet the minimum performance requirement set by Title 24 (more than 20 percent average annual solar fraction).

Figure 30: William Mead — Distributions of Solar Fraction, Gas Consumption Without SWH, and Gas Savings for Site Buildings



The baseline assumptions for the conditioned area and system sizing for William Mead produce the distribution of tank volume and collector area shown in Figure 31. Storage tanks range from 200 to 1600 gallons, and the collector area ranges from 250 ft^2 to 818 ft^2. The collector area translates to 6 to 20 individual collector panels per building.

Figure 31: William Mead — Distributions of Conditioned Areas, Collector Areas, and Tank Volumes for William Mead Structures



Typical Case — South Bay Gardens, Los Angeles, California

South Bay Gardens is a 124-unit senior living center located in South Los Angeles (Figure 32). The property is owned and operated by the Housing Authority of the County of Los Angeles (HACoLA) and features a centralized heating system, a community kitchen, and shared laundry facilities (Figure 33).

Figure 32: Location of South Bay Gardens Complex

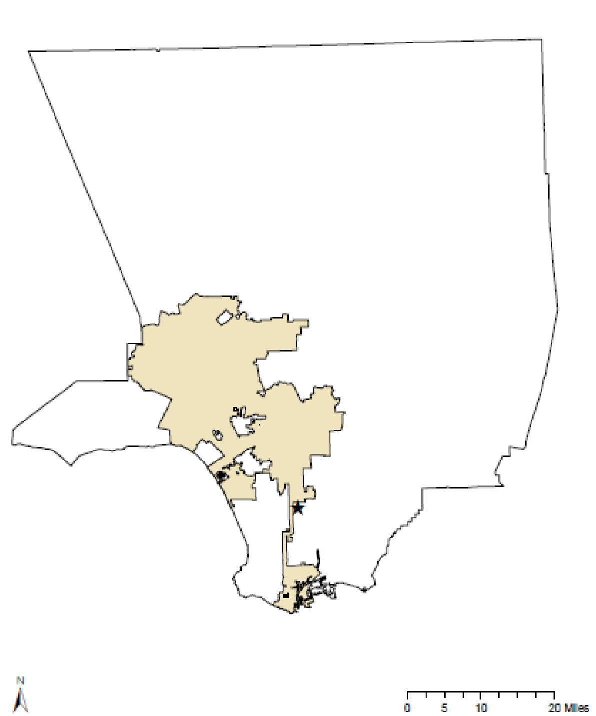
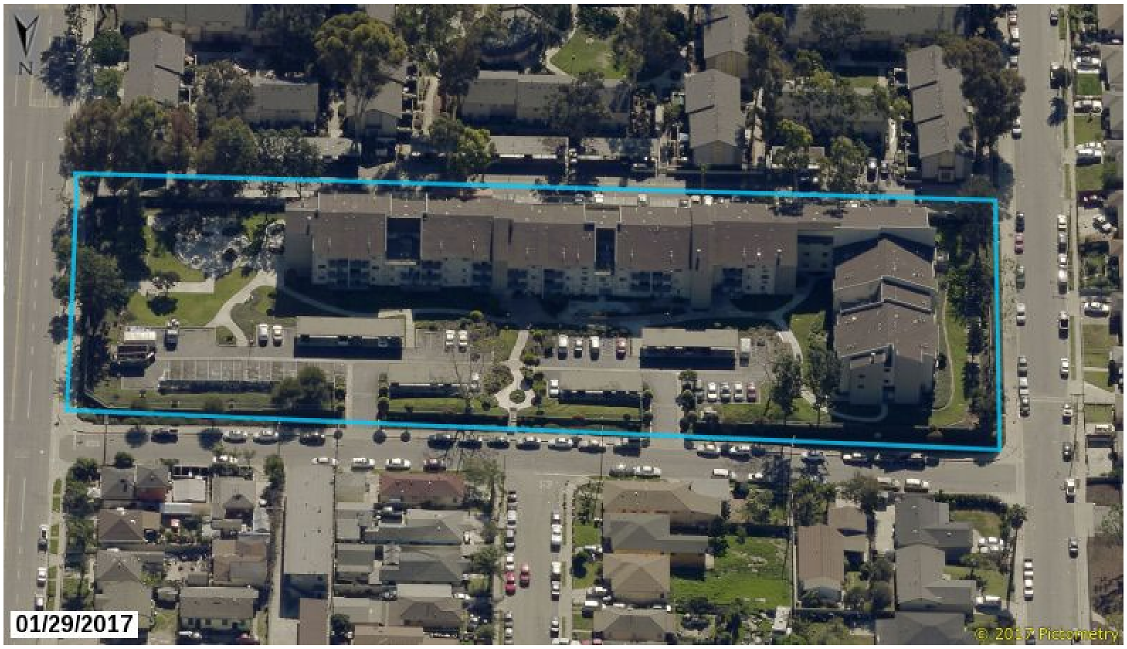


Figure 33: Aerial Images of South Bay Gardens



South Bay Gardens is located in the city of Compton, due east of the I-10 Freeway.

Source: LARIAC/EagleView, Inc.

South Bay Gardens represents a type of medium-density development well-suited to community scale SWH. The site's unobscured roof space, central boiler, and single, quasi-shared wall residential structure reduce retrofit costs (Table 43).

Table 43: South Bay Gardens Site Data

Site Area	12,920.5 m^2
Site Perimeter	506.28 m
Residential Units	124
Residential Structures	1
Current Water Heating Technology	Central Boiler
Additional Information	Senior living. Central laundry and kitchen facilities.

South Bay Gardens — Hot Water Demand and Conditioned Area Calculations

After several requests over two months, HACoLA representatives from the site and central administrative offices responded to requests for information about unit floorplans, building characteristics, and property ownership. As mentioned previously, South Bay Gardens is a senior living center that provides meals, supportive services, and other amenities to residents, and the property is owned and maintained by Los Angeles County (Clarke, 2018a).

The 124 2-bedroom residential units of South Bay Gardens are occupied by a maximum of two persons, who share a living room and kitchenette (Clarke, 2018a). Regular meals are provided in the site's cafeteria; thus, only one manual dish washing event is assumed to occur per person per day. Each resident is assumed to generate three full loads of laundry per month. The conditioned area of South Bay Gardens is determined according to Equation 6.

South Bay Gardens' hot water demand schedule implies the monthly water and annual gas consumption per residential unit shown in Table 44.

Table 44: South Bay Gardens — Hot Water Events and Event Frequencies

Event	Total Flow (gals, 120ºF Draw-off)	Basis and Per Person Frequency
Food Preparation	3.96	1x Daily
Manual Dish Washing	3.96	1x Daily
Shower	3.96	1x Daily
Bath	15.85	1x Monthly
Face and Hand Washing	2.64	2x Daily
Clothes Washing	36.00	3x Monthly

Calculated water and gas consumption values for South Bay Gardens are below the median monthly water and annual gas consumption (Table 45). However, both calculated consumption values meet the criteria listed in the section titled Auxiliary and Backup Heating Elements on page 9 and are within the interquartile ranges of their respective distributions.

Table 45: South Bay Gardens — Calculated Water and Gas Consumption Values

Annual Gas Consumption per Residential Unit	2,436.30 kWh (~83.15 therm)
Monthly Water Consumption per Residential Unit	1,279.17 gal/1.71 HCF

No further adjustment of the hot water demand schedule was necessary prior to system simulations. Distributions of actual water and gas consumption values for comparison come from properties with the characteristics shown in Table 46.

Table 46: South Bay Gardens — Comparison Property Sample Characteristics

Property Characteristics	Database Query Criteria
Construction Vintage	1950–1978
Parcel Square Footage	20,000–30,000 ft^2
Number of Res. Units	50–200 Units, Inclusive
Parcel Usetype	Multifamily

South Bay Gardens — System Design and Simulation Results

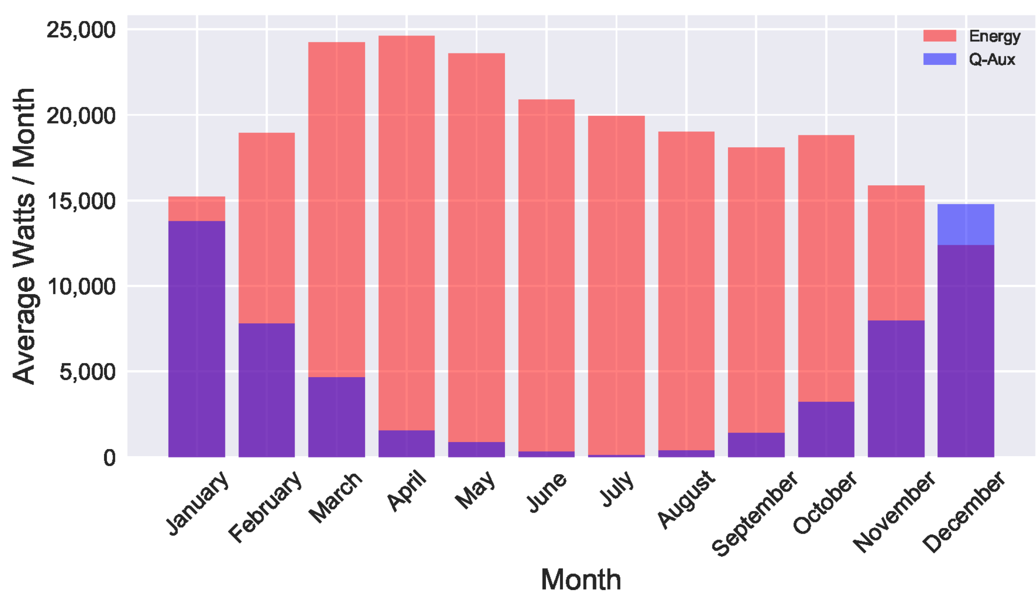
Simulation of South Bay Gardens' SWH system yields the results shown in Table 47.

Table 47: South Bay Gardens — Site Summary of SWH Simulation Results

Performance Metrics	Values
Average Annual System Energy	231,552.91 kWh
Average Solar Fraction	0.803 (80.3% solar energy for water heating
Average Annual Heat Delivered	430,885.97 kWh
Average Annual Auxiliary Heat Required w/Solar	56,885.56 kWh
Average Annual Heat Delivered — Auxiliary Only	2.87e+05 kWh

Figure 34 shows that South Bay Gardens' SWH system meets Title 24 requirements and qualifies for the CSI-Thermal performance-based incentive. The red in the graph shows the energy generated, and the blue shows the auxiliary energy provided. The purple in the graph is a result of the graphical overlap of the red and the blue bars. Due in part to its relatively low per unit hot water demand, South Bay Gardens has the highest annual solar fraction of the sites included in this study.

Figure 34: South Bay Gardens — Average Monthly SWH System Energy and Average Monthly Auxiliary Energy



According to the result of the simulation, South Bay Gardens' SWH system should be able to meet almost all of the site's hot water demand with solar energy during the months of June, July, and August.

Table 48: South Bay Gardens — Gas Consumption Without SWH, and Gas Savings per Building

Annual Gas Consumption w/o SWH System	481,035 kWh/year
Gas Savings w/ SWH System	525, 470 kWh/year

Table 48 shows the annual consumption of gas implied by the hot water demand schedule with and without the site's SWH system. Table 49 shows the collector area, the number of collector panels, tank volume, and the conditioned area for the site.

Table 49: South Bay Gardens — Collector Area, Tank Volume, and Conditioned Area for SWH System Simulation

Collector Area	1,065.63 ft^2
Collector Panels	99
Solar Tank Volume	6,078.91 gals
Conditioned Area	13,5087 ft^2

Poorly Suited Case — Crescent Court Apartments, Los Angeles, California

The Crescent Court Apartments is a multi-family HACLA property located in the MacArthur Park neighborhood of Los Angeles (Figure 35). The 2-bedroom units are designed to accommodate larger families (Figure 36).

Figure 35: Location of the Crescent Court Apartments

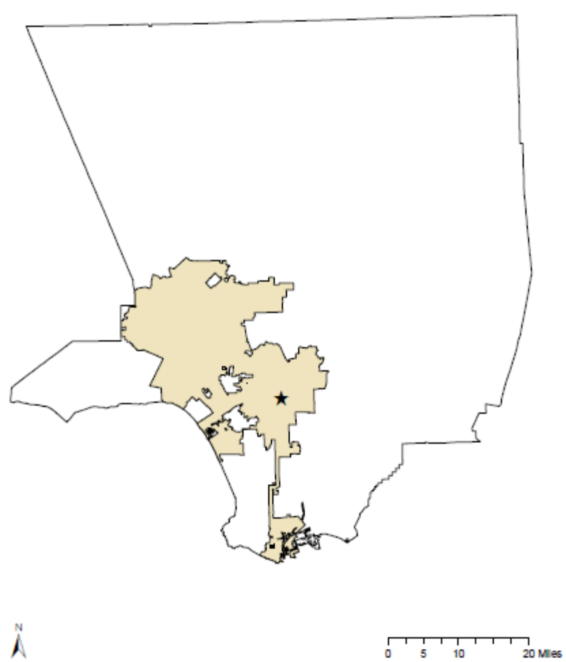


Figure 36: Aerial Images of the Crescent Court Apartments

The Crescent Court Apartments are located northwest of downtown Los Angeles.

Source: LARIAC/EagleView, Inc.

The Crescent Court Apartments are poorly suited to SWH because of the inefficient use of the available space (two units per structure), and the pitched roofs of the apartment buildings. Also, the apartment buildings are separated by paved alleyways (Table 50).

Table 50: Crescent Court Apartments Site Data

Site Area	8,153.16 m^2
Site Perimeter	363.94 m
Residential Units	32
Residential Structures	16
Current Water Heating Technology	40-gal storage WH per unit
Additional Information	Multi-family. Dishwashers in all but 2 units, washing machines in all units.

Crescent Court — Hot Water Demand and Conditioned Area Calculations

HACLA representatives from the Public Housing Department responded to requests for information about unit floorplans, building characteristics, and property ownership about one month after an initial inquiry (Maroutian, 2018). Maximum occupancy for the units, a list of hot water fixtures and appliances, and information on the current hot water heating were provided (Table 51).

Table 51: Crescent Court — Hot Water Events and Event Frequencies

Event	Total Flow (gals, 120ºF Draw-off)	Basis and Per Person Frequency
Food Preparation	3.96	1x Daily
Manual Dish Washing	3.96	1x Daily
Shower	3.96	1x Daily
Bath	15.85	1x Monthly
Face and Hand Washing	2.64	1x Daily
Dishwasher	6.00	3x Monthly
Clothes Washing	36.00	1x Monthly

Crescent Court's 32 residential duplex units are rented to families with children and have a maximum occupancy of 9 persons. All of Crescent Court's units have a full kitchen, a washer-dryer, and two bathrooms. All but two of the units come with a dishwasher. No manual dishwashing is assumed to occur in units with dishwashers

Prior to simulation, the frequency of hot water events in Crescent Court's demand schedule was altered so that monthly water consumption per unit met the more than 8 HCF per month criterion stipulated in the section titled Suitable Case — Pheasant Ridge Apartments, Rowland Heights, California on page 41. Crescent Court's units are occupied by families, and it is unlikely that members of the household undertake food preparation, clothing and dish washing separately. For those two reasons, the frequency of the daily events and clothes washing was set to 1. These changes brought down monthly per unit water consumption below the 8 HCF limit.

Following South Bay Gardens' hot water demand schedule implies the monthly water and annual gas consumption per residential unit shown in Table 52.

Table 52: Crescent Court — Calculated Water and Gas Consumption Values

Annual Gas Consumption per Residential Unit	7,612.17 kWh (~259.80 therm)
Monthly Water Consumption per Residential Unit	3,343.79 gal/4.47 HCF

Calculated water and gas consumption values for Crescent Court are very close to the 4th quartile of their respective distributions. Crescent Court's relatively high hot water demand is consonant with ASHRAE and ASPE's observations that families with children consume, on average, more hot water per person per day than other domestic arrangements (Kalogirou, 2013; ASPE, 2015). Following the frequency adjustment described above, Crescent Court's calculated consumption values met the criteria listed in the section titled Suitable Case — Pheasant Ridge Apartments, Rowland Heights, CA on page 41. Distributions of actual water and gas consumption values for comparison come from properties with the characteristics shown in Table 53.

Table 53: Crescent Court — Comparison Property Sample Characteristics

Property Characteristics	Database Query Criteria
Construction Vintage	1950 - 1978
Parcel Square Footage	10,000 – 20,000 ft^2
Number of Res. Units	20 - 50 Units, Inclusive
Parcel Usetype	Multifamily

Crescent Court — System Design and Simulation Results

Unlike the other case study sites included in this study, Crescent Court's SWH systems did not achieve the 20 percent minimum performance standard set forth in Title 24 when sized with the ratios previously listed, and they did not qualify for the CSI-Thermal performance-based incentive. Given that SWH retrofits must qualify for the CSI-Thermal PBI to make financial sense for property owners, Crescent Court's SWH system parameters had to be altered and their simulations re-run (Chen, 2018g; Clarke, 2018a).

There are numerous ways to increase the performance (specifically, solar fraction) of a SWH system. In this case, one additional collector was added to the number of panels calculated using the ratios listed. This change yielded individual solar fractions of 21 percent to 28 percent for each of the 16 buildings (Table 54).

Table 54: Crescent Court — Site Summary of SWH Simulation Results With One Additional Collector per SWH

Performance Metrics	Values
Average Annual System Energy	12,678.33 kWh
Average Solar Fraction	0.265 (26.5% solar energy for water heating)
Average Annual Heat Delivered	12,857.65 kWh
Average Annual Auxiliary Heat Required w/Solar	34,964.545 kWh
Average Annual Heat Delivered — Auxiliary Only	4.779490e+04 kWh

With the one additional collector per system, Crescent Court met Title 24 requirements and qualified for the CSI-Thermal performance-based incentive. However, Crescent Court has the lowest average annual solar fraction of any of the systems simulated in this study. The low solar fraction of Crescent Court's SWH systems is due, in part, to the high per unit hot water demand.

Like the other systems simulated in this study, Crescent Court's solar fraction is highest in the summer and lowest in the winter, varying from approximately 80 percent in July to 12 percent to 15 percent in December/January (Figure 37).

Figure 38 shows the annual consumption of gas implied by the hot water demand schedule with and without the site's SWH system. The red in the graph shows the energy generated, and the blue shows the auxiliary energy provided. The purple in the graph is a result of the graphical overlap of the red and the blue bars. Figure 39 shows the distributions of the collector area, tank volume, and conditioned areas for each of Crescent Court's buildings.

Figure 37: Crescent Court — Average Monthly SWH System Energy and Average Monthly Auxiliary Energy With One Additional Collector per System

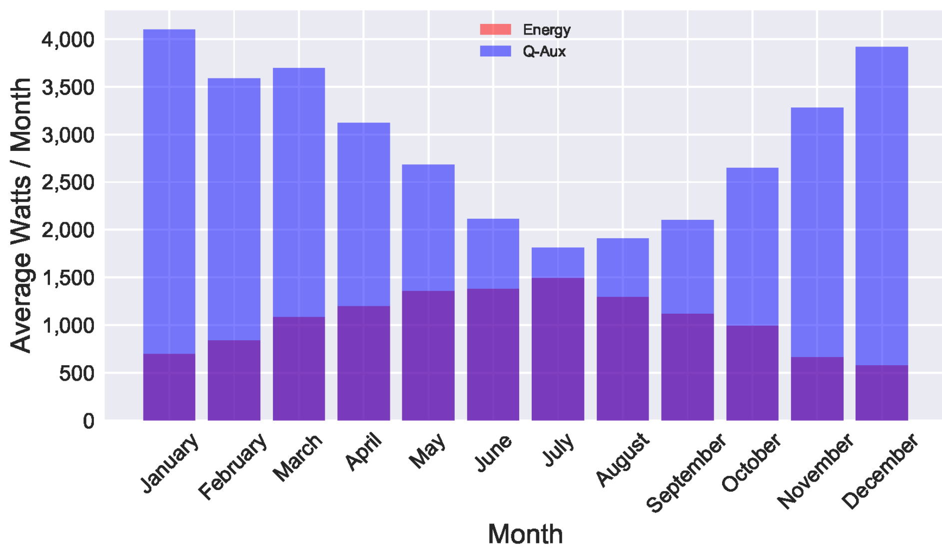


Figure 38: Crescent Court — Distributions of Solar Fraction, Gas Consumption Without SWH, and Gas Savings for Site Buildings

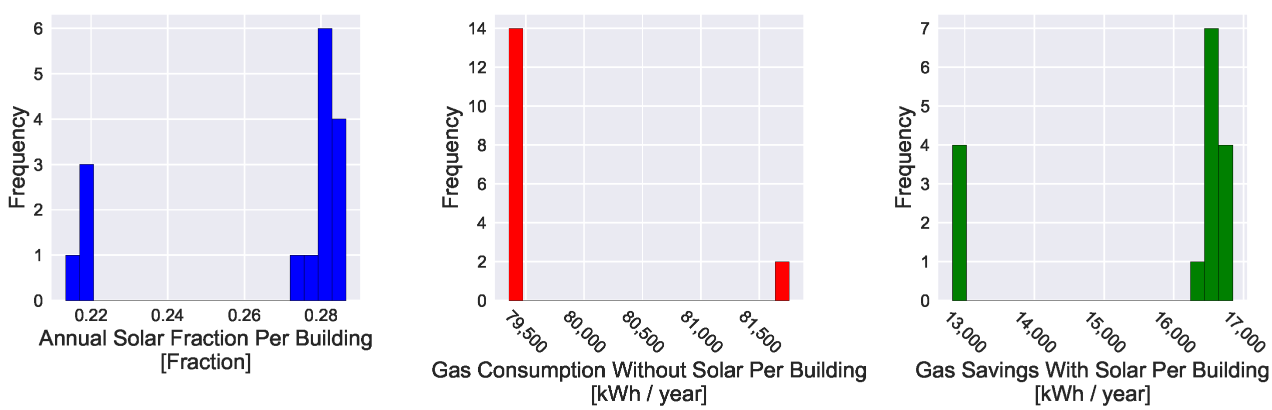
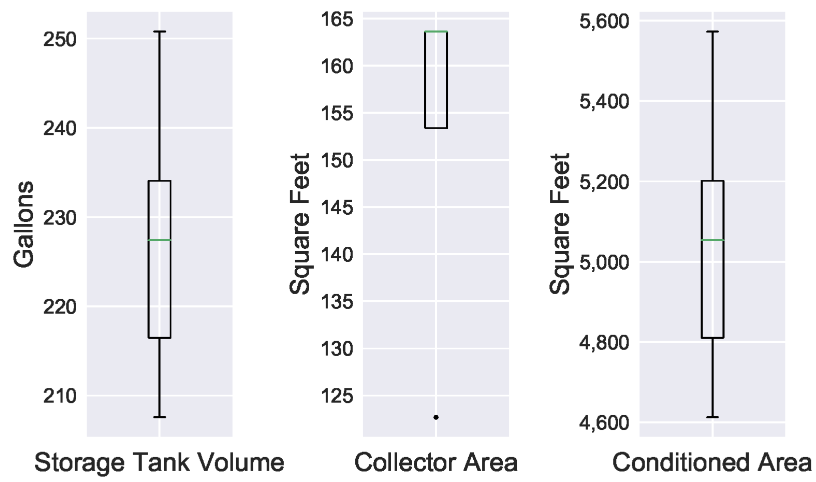


Figure 39: South Bay Gardens — Distributions of Conditioned Areas, Collector Areas, and Tank Volumes for Crescent Court Structures



CHAPTER 5: Analysis of Simulation Results and Policy Implications

Influence of Site Characteristics on System Performance

Based on the case studies, it is possible to draw conclusions about how site characteristics affect the performance of community scale SWH systems similar to those studied here (active, closed systems with flat plate collectors). It should be noted that the results of the simulations depend on the assumptions about thermal energy transfer and efficiency implicit in the SAM SWH module, and they are sensitive to changes in the assumed volume and delivery schedules of hot water demand (DiOrio et al., 2014). Therefore, relationships observed between site characteristics and system performance should be understood as preliminary findings. The relationships discussed here are suitable subjects for future modeling and simulation studies.

Roof Area to Conditioned Area Ratio

Given the value and scarcity of open space on residential parcels, SWH systems installed in Los Angeles County will, in most instances, have their collector arrays located on building rooftops. This means that residential structures for which community scale SWH is feasible must, in addition to the general feasibility criteria, have sufficient rooftop space to accommodate the system's collector array.

Pacific Plaza illustrates how some forms of residential development with low roof area to conditioned area ratios (in this case, high-rise apartment complexes) are not especially well-suited to community scale SWH. Using the Title 24 SWH system sizing ratios, the conditioned area for the site (100,201 ft^2) implies a collector area of 9,034 ft^2, or approximately 221 4' x 10' flat plate collectors. Pacific Plaza's gross rooftop space, as measured using aerial LiDAR, is 16,164 ft^2, which is apparently sufficient for the collector array (Figure 40). However, oblique aerial photos of the building's roof show that the roof space on which collector arrays could be installed is considerably less than the gross area.

Figure 40: Rooftop of Pacific Plaza Building

A low rooftop to conditioned area ratio makes the siting of collector arrays more difficult and, assuming that putative systems are similar to those considered in this study, appears to constrain the performance of SWH systems. Pacific Plaza has the lowest annual site solar fraction (28.1 percent) of the three private cases studied, and it features the second lowest performing system out of all the simulations performed (of the 102 individual buildings on the six sites). Twenty-eight percent is also likely an over-estimate of Pacific Plaza's annual solar fraction. NREL SAM's SWH simulation method does not account for the additional grid-supplied energy required to pump water against gravity to solar tanks on floors with residential units.

The Pacific Plaza case illustrates how the development of distributed solar energy systems and urban densification efforts can, in certain instances, conflict with one another. This notion was discussed in further detail in Chapter 4 but, ***for community scale solar thermal systems, the limited rooftop space of high-rise, high-density housing developments constrains the collector area, limiting system performance. Building upwards also complicates the construction of community scale SWH systems in retrofit cases, and it increases the amount of energy required to pump both potable water and heated working fluid to solar storage tanks***.

Residential Density and System Performance

Another important influence on system performance is the 'population density' of the units in a residential building and the demographics of current or putative occupants. Comparison of simulation results between the public cases shows that, for buildings with high-density units and high hot water demand demographic types (families with children, for example), the Title 24 system sizing ratios may not yield an SWH system that qualifies for the applicable incentives. Conversely, for buildings with low population densities and low hot water demand demographic types (adults without children, seniors) smaller systems may suffice, assuming they can still meet the performance requirements for incentive programs.

Crescent Courts is illustrative of a high-density, high-demand case. In this instance, the Title 24 sizing ratios do not yield systems that meet the minimum performance requirement for the CSI-Thermal incentive. According to HACLA, the Crescent Courts development is intended to house families with children, and each unit has a maximum occupancy of nine persons (the units are identical) (Maroutian, 2018; HACLA, 2018a). This is considerably higher than average occupancy per unit of the William Mead Homes (3.76 persons per unit), the other public housing site intended for families. Simulations for Crescent Court using the hot water demand schedule in Table 23 and the Title 24 system sizing ratios yielded annual solar fractions below the CSI-Thermal performance threshold for the climate zone (20 percent average annual solar fraction). In order to meet the 20 percent requirement, it was necessary to add one additional collector to each system on the Crescent Court site. In subsequent simulations with the additional collectors, each of Crescent Court's SWH systems met or exceeded the CSI-Thermal performance requirement.

South Bay Gardens, a supportive senior living center with an average per unit occupancy of two persons, represents a low-density, low-demand case. Residents do not do their laundry or prepare their own meals since the site features central laundry and kitchen facilities The average per unit occupancy is also the lowest of the three public cases. Simulations yielded an annual solar fraction of 80 percent, the highest annual solar fraction of all of the sites studied. The simulation results suggest that, for residential sites like South Bay Gardens, a smaller, less materially intensive community scale SWH system may be economically optimal. Overbuilt SWH systems use a greater portion of the site's rooftop space and, depending on the price of auxiliary energy, will in most instances have longer payback periods.

The population density of residential units and the demographic profile of their inhabitants determine the hot water demand and consumption patterns (Bertrand et al., 2017). ***To design a community scale SWH system that is optimally sized, configured, and operated, as much as possible needs to be known about the current or potential inhabitants of the building served by the system (Fuentes et al., 2018). Changes in occupancy levels or the demographics of residents can dramatically alter demands on building level SWH systems***.

Returns to Scale for SWH System Performance

One of the questions that motivated the study of community scale SWH is the possibility that larger systems may be able to achieve superior performance by virtue of their centralized design and large heat storage tanks (USACE, 2011). While the question of how the efficiency and performance of centralized, parcel-scale systems compare to structure-scale systems is not addressed here, the case studies provide some insight into how different measures of system 'size', such as building occupancy and conditioned area, affect the performance of community scale SWH systems.

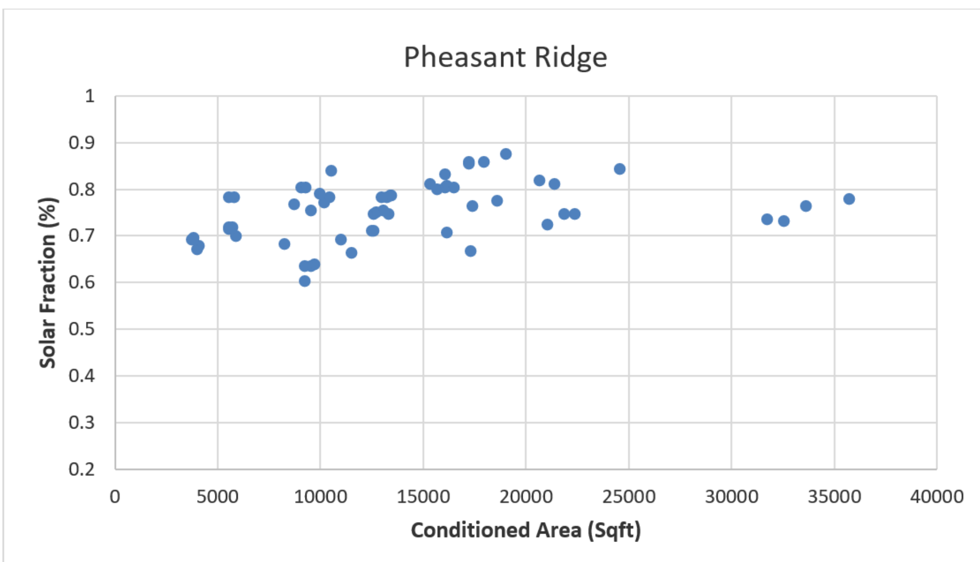
As mentioned in the section titled Evacuated Tube Collectors on page 6, the conditioned area of a building is the area of the inhabited floor space. The conditioned area is estimated from the LARIAC building outlines dataset and, in some cases, orthogonal aerial imagery of the sites (LARIAC, 2016).

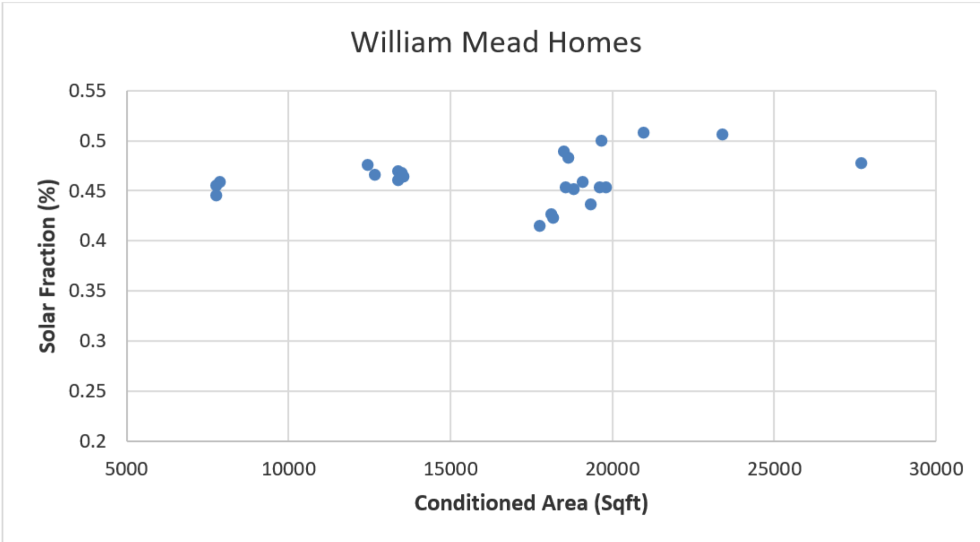
Figure 41 shows the relationship between the conditioned areas and annual solar fractions for the three sites with more than one building. For the range of conditioned areas observed (and simulation method employed) in this study, systems sized according to the Title 24 ratios display fairly consistent performance, the only exception being Crescent Courts.

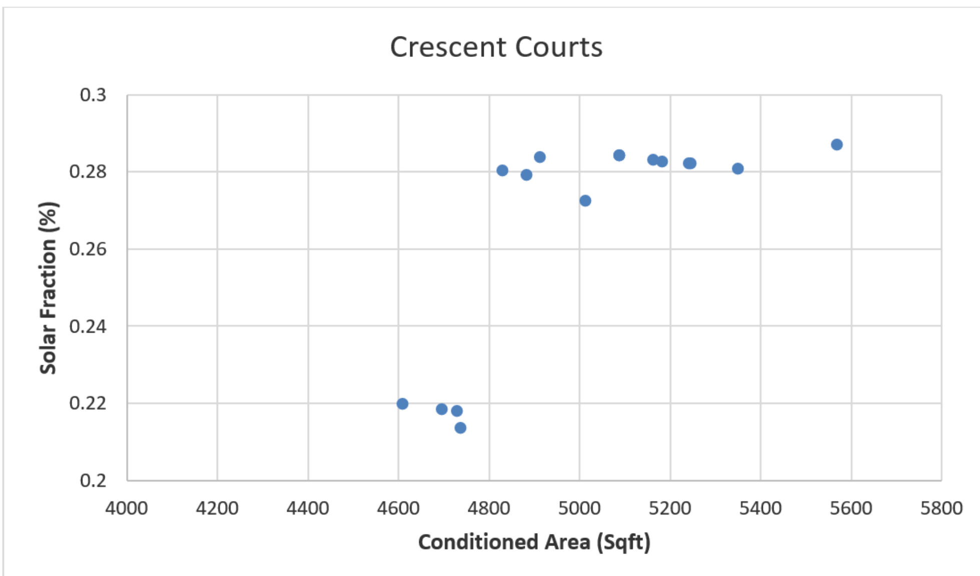
The Pheasant Ridge case has the greatest difference between the best and worst performing systems on site (27.4 percent). This range in solar fraction is attributable to the site's heterogeneous unit floorplans. The floorplans determine the maximum occupancy and the set of possible end uses for hot water for a unit, and thus the volume of demand.

The William Mead site is more homogeneous with respect to unit floorplans and displays a smaller range of annual solar fractions for its structures (10 percent). Crescent Courts, the site with the most homogeneous structures (duplexes with nearly identical layouts and amenities) is the most homogeneous of the sites with multiple structures and displays the smallest range of solar fractions (7 percent). The difference between the two distinct clusters of points in Crescent Court's scatterplot is attributable to the absence of dishwashers in two of the site's buildings.

Figure 41: Conditioned Area Versus Solar Fraction for Sites With Multiple Buildings







Conditioned area is a proxy for the population density of a residential structure, which is in turn a proxy for hot water demand. ***Situations in which the maximum occupancy to conditioned area ratio of a residential structure deviates considerably from the normal range may require special consideration. The results of the case studies show that the sizing ratios can yield systems that perform well and qualify for relevant incentives but, for large, sparsely inhabited buildings (Pacific Plaza) and small, densely inhabited buildings (Crescent Courts), sizing systems with conditioned area ratios may lead to sub-optimal system performance***.

Community Scale Solar Water Heating Suitability Criteria for Existing Residential Developments

As discussed previously, the six case study sites were selected based on their SWH suitability scores and representativeness of different residential development patterns common in Los

Angeles County (see the *Case Study Site Selection Report* for a full discussion of selection). The selection criteria used, namely the suitability scores for residential parcels, were developed based on observed, empirical relationships between urban form and SWH system performance, and they were refined with expert assistance (Chen, 2018c; Kalogirou, 2013; Anderson, 2018b). The results of the simulations show that, for the cases considered, the parcel suitability score was at least somewhat predictive of system performance. Table 55 summarizes site ranking and performance.

Table 55: Suitability Score Categories and Solar Fractions for Case Study Sites

Performance Ranking	Case Study Site	Suitability Score Quintile	Solar Fraction Mean (± σ, n = number of buildings)
1	South Bay Gardens	Typical	80.2 % (n = 1)
2	Pheasant Ridge Apartments	Well-Suited	75% ± 6% (n = 59)
3	William Mead	Well-Suited	46.1% ± 2.4% (n = 24)
4	Promenade Apartments	Typical	45.3% (n = 1)
5	Pacific Plaza	Poorly Suited	28.1% (n = 1)
6	Crescent Courts	Poorly Suited	26.5% ± 2.8% (n = 16)

The solar water heating suitability score developed for the purpose of this study awards densely constructed and populated parcels with contiguous structures with higher scores, and less dense parcels with more diffuse and irregular development patterns lower scores. Higher scores indicate greater suitability for community scale SWH. The suitability score metric was used to partition the pools of candidate parcels into categories from which individual cases were selected. ***The discrepancies between the suitability category designations and the results of the simulations suggest that a more comprehensive set of building and parcel characteristics is needed to determine the suitability of a residential structure or development for community scale SWH. The results of case study simulations indicate that densely constructed and inhabited buildings are better for community scale SWH to the extent that they have sufficient rooftop space for collector arrays, and they do not have especially high or low maximum occupancies per unit conditioned area***.

A county-wide analysis using non-linear regression methods to elucidate the relationships between resident demographics, building characteristics, and the Energy Atlas's gas consumption data would provide a ranked list of variables that influence a residential parcel's suitability for community scale SWH.

Financial Considerations for Community Scale Solar Water Heating

Interviews with solar engineers and contractors, housing authority officials, incentive program administrators, and suppliers of system components yielded a great deal of information about how building-scale solar thermal systems are financed, the cost drivers for SWH projects, and the decision landscapes facing public and private property owners. The following sections describe the decision landscapes faced by the three types of property owners (private, private nonprofit, and public), drawing upon the information gathered from the case studies and interviews. All references to the CSI Thermal Rebates and Residential Renewable Tax Credits were accurate as of December 31, 2019. However, the CSI Thermal Rebate program ended on July 31, 2020.

Financial Considerations for Privately Owned Properties

Of the three types of developments included in this report, privately owned residential properties are the easiest to retrofit with community scale SWH systems. Owners of residential developments also have the greatest incentive to install high-performing community scale systems of the three types of property owners.

Building-scale systems installed on privately owned residential properties are eligible for the CSI-Thermal rebate and the federal Residential Renewable Energy Tax Credit (CSE et al., 2020; U.S. DOE, 2018).

In practice, SWH systems installed on private properties in Los Angeles County are designed to be eligible for the CSI-Thermal Rebate and the Residential Renewable Tax Credit, as solar water heating is not competitive with natural gas on a cost basis without the incentives described in Table 56 (Bavin, 2018d; Chrisman, 2018b). Therefore, all community scale SWH systems installed on privately owned property will be designed to have solar fractions of at least 50 percent. In interviews, solar contractors, suppliers of component technologies, and engineers who design systems for residential and commercial buildings all emphasized that SWH systems of the type considered here are relatively straightforward to scale up, but that ensuring no disruption of hot water service occurs for large centralized systems (a single system serving hundreds of units in a large apartment building) in the event of malfunction can incur additional costs and complicate construction (Bavin, 2018d).

Table 56: Applicable Incentives for Community Scale SWH — Private Residential (as of 12/31/2019)

<table>
<tr><th rowspan="3">Private Residential Owners</th><th>Applicable Incentives</th><th colspan="2">Incentive Structure</th></tr>
<tr><td>CSI-Thermal — Multifamily Residential or Commercial</td><td>Performance-Based: Minimum SF = 20%</td><td>$20.19 per therm of annual energy savings</td></tr>
<tr><td>Residential Renewable Energy Tax Credit</td><td>Cost-Based:
Minimum SF = 50%</td><td>30% of qualified capital expenditures for systems installed by 12/31/2019</td></tr>
</table>

Incentives for SWH systems apply most naturally to sites with a single structure. The Residential Renewable Energy Tax Credit requires that the property owner be able to claim the property as a residence (U.S. DOE, 2018). Furthermore, qualification for the applicable incentives, and the calculations of incentive totals, are more complicated for community scale systems installed on properties with multiple residential buildings, due to the language of the eligibility requirements.

Financial Considerations for Properties Owned by Private Nonprofit Entities

Private nonprofit housing organizations, such as National CORE, the owners of Promenade Apartments, provide below-market housing and supportive services to vulnerable populations in Los Angeles County. ***Private nonprofit housing organizations own a relatively small share of the residential housing stock, but they provide vital services to their clients and advocate for affordability and environmental justice, and against discriminatory housing practices (SCANPH, 2018). Thus, consideration should be given to the ease with which private nonprofit housing organizations can realize opportunities for reducing their properties' energy consumption through the development of community scale SWH systems***.

Retrofitting buildings for community scale SWH is a more expensive proposition for housing nonprofit organizations than it is for private property owners. Nonprofits may take advantage of the CSI-Thermal incentive but not the federal Residential Renewable Energy Tax Credit (Table 57). The Residential Renewable Energy Tax Credit cannot be claimed by private housing nonprofits because of their legal status as nonprofit organizations. However, most private housing organizations that rent to low-income citizens in Los Angeles County will qualify for an increased CSI-Thermal rebate incentive rate (CSE et al., 2020).

Table 57: Applicable Incentives for Community Scale SWH — Private Nonprofit (as of 12/31/2019)

	Applicable Incentives	Incentive Structure	
Private Nonprofit Residential Housing Organizations	CSI-Thermal Rebate — Multifamily Low-Income	Performance-Based: Minimum SF = 20%	$24.98 per therm of energy savings

For example, Promenade Apartments, which is owned and managed by National CORE, requires a system with a minimum solar fraction of 20 percent to qualify for the applicable incentives. A system sized with the estimated conditioned area and Title 24 ratios yields an estimated annual solar fraction of 45.3 percent. Private nonprofit property owners therefore have an incentive to install community scale SWH systems that maximize possible solar fraction and minimize capital cost. ***Since no capital cost rebate is available to private nonprofits, they must be able to bear the capital costs until the system is operational, at which point they can begin receiving rebate payments***.

Financial Considerations for Publicly Owned and Managed Properties

HACLA and HACoLA's public housing developments are occupied by thousands of Los Angeles County residents who are unable to find suitable or affordable accommodations in the private market. The city and county housing authorities must provide safe and livable conditions for residents and ensure that their housing stock keeps pace with state and local energy efficiency goals and standards. Both organizations wish to lead by example with regard to sustainability and energy efficiency, and community scale SWH is one of a number of possible investments that the authorities could make to reduce their energy consumption.

Public housing is the most expensive type of property to retrofit with community scale SWH. There are three factors that drive up the cost of energy retrofits for public housing: Department of Housing and Urban Development rules governing the installation of renewable energy systems on properties under its jurisdiction, higher labor costs for public work contracts, and the fact that public housing does not qualify for the Residential Renewable Energy Tax Credit (Clarke, 2018b). However, public housing developments do qualify for the CSI-Thermal Low-Income rate (Table 58).

Table 58: Applicable Incentives for Community Scale SWH — Public Housing (as of 12/31/2019)

	Applicable Incentives	Incentive Structure	
Public Housing Authorities	CSI-Thermal Rebate — Multifamily Low-Income	Performance–Based: Minimum SF = 20%	$24.98 per therm of energy savings

HACoLA's installation of building-scale SWH systems at the Nueva Maravilla Housing Community illustrates how complex and expensive public SWH projects can be (Figure 42). Constructed in the 1930s and renovated in the 1970s, Nueva Maravilla is one of the largest HACoLA developments and, like William Mead and Crescent Courts, serves mostly families with children.

Figure 42. Aerial Photos of Nueva Maravilla Housing Community

Source: LARIAC/EagleView, Inc.

In 2009, HACoLA won a $5,000,000 federal grant to improve Nueva Maravilla. Between 2009 and 2013, the housing authority completed a series of site upgrades, including xeriscaping measures, energy-efficient exterior lighting, solar photovoltaic cells, and SWH systems. The entire slate of improvements cost approximately $12,000,000 and involved five private contractors in addition to the Department of Housing and Urban Development (HUD) and HACoLA (Clarke, 2018b; HACoLA, 2013).

HCLA had originally intended to retrofit all 58 buildings on the Nueva Maravilla site with SWH systems, but it ultimately decided to install systems on only 6 buildings because of provisions in HUD's Energy Performance Contracting Policy (EPC) (Clarke, 2018b). Prior to the start of the improvement project, HACoLA had determined internally that the CSI-Thermal rebate was generous enough to warrant installing solar thermal systems on all of the buildings, but it eventually abandoned this plan when confronted with the cost of the perspective studies and monitoring required by the EPC (Clarke, 2018b). HUD's EPC requires that public housing authorities pay energy consultancies selected from pre-approved lists of firms to conduct prospective studies of renewable energy projects and to file annual observation and monitoring reports for the years after the projects are completed (Clarke,2018b; U.S. HUD, various dates). In the case of Nueva Maravilla's six solar thermal water heating systems, the prospective report cost HACoLA $300,000, and the observation and monitoring reports cost an additional $30,000 per year (Clarke, 2018b). HACoLA claims that the consulting fees incurred by a site-wide retrofit would have outweighed the benefits of the estimated energy savings and rebate payments (Clarke, 2018b).

Unlike private and private nonprofit property owners, housing authorities cannot negotiate directly with solar thermal contractors. They must also pay for expensive

estimates of system performance and ongoing monitoring (Chen, 2018f). Combined with prevailing-wage requirements for system installation contracts and the absence of other incentives to offset capital costs, community scale SWH is an expensive proposition for the public housing authorities in Los Angeles County, even if the chosen sites are well-suited for SWH retrofits.

Policy Implications

The case studies demonstrate that community scale SWH can displace approximately 20 percent to 80 percent of the gas required for domestic water heating, depending on building-level characteristics and the demographics of the site's residents. Community scale systems can be constructed from the components used to build single-family and commercial scale systems and, in all but one case, the systems simulated in this study did not require exception from sizing guidelines and residential building code. Community scale SWH systems, of the kind considered in this study, can significantly reduce the amount of natural gas consumed for domestic water heating. However, the case studies also indicate that the performance of a given community scale SWH system is sensitive to the population density of the structure it serves. In extreme cases (specifically, large, sparsely populated buildings and small, densely populated ones), the conditioned area to storage volume and the collector area to storage volume ratios used to programmatically size systems may fail to yield adequate solar fraction.

Community scale SWH is a viable approach to reducing demand for natural gas, but questions remain about where the technology can be most beneficially used. To understand the role community scale solar thermal could play in reducing energy consumption and emissions from Los Angeles County's residential housing sector, it is essential to consider how this technology interacts with other sustainability initiatives.

Implications for Densification Efforts in Los Angeles County

Zoning, land use changes, and specific plans for denser residential development have been proposed by public stakeholders as a solution to Los Angeles County's housing shortage and congestion issues, and as part of broader sustainability initiatives (LADWP, 2017; Mayne et al., 2016). If densification efforts achieve their intended effect, population centers in the county would transition away from single-family homes and duplexes towards larger multi-story apartment buildings and mixed-use developments. These denser developments, to the extent that they have sufficient rooftop space, may be suitable for a community scale approach to solar water heating. Structures similar to those in the top three cases (Pheasant Ridge, South Bay Gardens, and William Mead) are examples of densely inhabited residential buildings that are suitable for community scale SWH. Buildings on these sites are 2 to 3 stories and have residential unit occupancies of 2 to 8 persons.

Pacific Plaza illustrates how densification efforts can potentially conflict with the installation and operation of solar thermal systems. Building upwards complicates the installation of solar thermal systems, while a diminishing rooftop area to conditioned area ratio constrains the performance of putative SWH systems. In Pacific Plaza's case, limited rooftop space and Title 24 building code requirements make the rooftop placement of the 221 collector panels required for the system virtually impossible. There are two possible solutions to the problem of limited rooftop space. First, systems on high-rise buildings could use collector technologies capable of delivering more energy per unit of collector area than flat-plate panels, such as evacuated tube collectors or concentrating solar collectors. Second, in cases where the vertical aspects of a structure are sufficiently exposed, collector capacity can be installed as a façade. However, both of these solutions would require special consideration under Title 24.

Implications for Proliferation Distributed Solar Energy Systems and Potential as an Emissions Reduction Technology

Community scale SWH is fundamentally different from other alternatives for reducing the carbon intensity of residential water heating (heat pumps, high-efficiency boilers, demand reduction, and appliance efficiency standards) in that it competes for rooftop space with solar PV. Rooftop space is becoming an increasingly valuable (and limited) resource in Los Angeles County; incipient building code changes will require that new residential structures under three stories install PV cells and that other classes of structure be built to accommodate PV installation in the future (CEC, 2018). The forthcoming changes to Title 24 will alter the decision landscape for property developers who may be considering SWH as a way to reduce natural gas consumption, and they will introduce logistical challenges that are not well-studied and for which ready solutions do not yet exist (Arnette, 2013). More work is necessary to establish how limited rooftop space can be best used to meet residential demand for thermal and electrical energy.

How solar thermal and photovoltaic capacity can be optimally deployed to provide the maximum amount of renewable energy (thermal and electrical) is an open question in engineering research (Awad and Gül, 2018; Assouline et al., 2018; Herrando et al., 2018). Comprehensive treatment of the thermal versus electrical rooftop space capacity problem is likely to present significant analytical challenges, particularly considering the range over which energy demand varies, and the time-dependent carbon intensity of electricity from the grid.

Progressive de-carbonization of the residential housing sector is a process fraught with difficulty: an ongoing, path-dependent set of optimization problems over which no one decision-maker exercises complete control. Frequently, different classes of decision-makers (for example, property owners and urban planners) disagree over the definition of optimality (i.e., should aesthetic appeal be a consideration in siting renewable energy capacity?). However, at its core, progressive de-carbonization involves realizing the set opportunities for substitution toward the available energy flows with the lowest embodied and emitted carbon, given resource constraints. ***The current push for proliferation of PV-ready buildings and PV capacity may yield suboptimal results, in terms of total cost per therm delivered, in instances where thermal energy could be generated most efficiently using solar thermal systems. A comparison of solar electric heating technologies with solar thermal technologies for a range of structures is necessary to answer this question.***

GLOSSARY AND LIST OF ACRONYMS

Term	Definition
$/m^2	dollars per square meter
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASPE	American Society of Plumbing Engineers
CEC	California Energy Commission
CSI	California Solar Initiative
EPC	Energy Performance Contracting
ETC	evacuated tube collector
ft^2	square feet
FPC	flat plate collector
GPD	gallons per day
HACLA	Housing Authority of the City of Los Angeles
HACoLA	Housing Authority of the County of Los Angeles
HCF	hundred cubic feet
ISO	International Standardization Organization
kg/s	kilograms per second
kWh	kilowatt hours
kWth	kilowatt thermal
LARIAC	Los Angeles Regional Imagery Acquisition Consortium
LADWP	Los Angeles Department of Water and Power
m	meters
m^2	square meters
NREL	National Renewable Energy Laboratory
NREL SAM	National Renewable Energy Laboratory's System Advisor Model
PV/T	integrated photovoltaic/thermal collector
SAM	System Advisor Model
SRCC	Solar Rating and Certification Corporation
SWH	solar water heating
W	watts
W/m^2 C	Watts per square meter per degree Celsius

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ENERGY RESEARCH AND DEVELOPMENT DIVISION

Appendix A: NREL SAM Output Variables

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APPENDIX A: NREL SAM Output Variables

Variable Name	Units	Description
Energy saved	W	Energy saved by the solar water system.
Hot water draw	kg/hr	The hourly usage of hot water specified in the draw profile on the input page.
Irradiance - Beam	W/m^2	Direct normal irradiance value from the weather file.
Irradiance - Diffuse	W/m^2	Diffuse horizontal irradiance value from the weather file.
Irradiance - Incident	W/m^2	The total hourly incident global irradiance incident on the collector.
Irradiance - Transmitted	W/m^2	The total hourly radiation that makes it into the collector. Depends on the optical properties of the collector.
Operation mode		1 – startup mode, useful energy is collected and tank temperature is somewhat stratified. 2 – mixed mode, useful energy is collected and tank temperature is fairly uniform. 3 - stratified mode, no useful energy is collected and tank temperature is very stratified.
P pump	W	Electric pump power required to drive the collector loop and heat exchanger loop.
Power generated by the system	kW	Equivalent to the energy saved by the system, expressed in kW. When you run the solar water heating model with a financial model, this is the value used by the financial model.
Q auxiliary	W	Electric power required by the auxiliary heater to raise the water temperature from the solar storage tank to the set temperature: $Q_{aux} = \dot{m}_{draw} C_p (T_{set} - T_{deliv})$, where T_{deliv} is the temperature of the water delivered from the solar tank. Because solar heat has been added to the water, $T_{deliv} > T_{mains}$, and less power is needed to bring the water to the desired set temperature than would be required without the solar water heating system.
Q auxiliary only	W	Electric power that would be required without the solar water heating system: $Q_{aux,only} = \dot{m}_{draw} C_p (T_{set} - T_{mains})$.
Q delivered	W	Thermal power delivered by the solar water heating system.
Q loss	W	Envelope loss to room: $Q_{loss} = UA_t (T_{tank} - T_{room})$.
Q saved	W	Electric energy saved by the solar water heating system: $Q_{saved} = Q_{aux,only} - Q_{aux} - P_{pump}$. This value is equivalent to the energy delivered by the solar water heating system.
Q transmitted	W	Solar irradiance transmitted through the collector glass, accounting for collector area: $Q_{transmitted} = I_{transmitted} * A_c$, where $I_{transmitted}$ is the transmitted irradiance and A_c is the total collector area.
Q useful	W	Power delivered by the collector to the solar water storage tank.
Shading losses	%	Percent loss of incident beam irradiance due to shading, determined by the shading factors that you specify on the Solar Water Heating page.

T ambient	°C	The mid-hour ambient temperature calculated by averaging the end-of-hour temperature from the previous hour with the end-of-hour temperature from the current hour in the weather file.
T cold	°C	The temperature of the cold portion of the solar storage tank volume in stratified mode. If the tank is not stratified, this value is equal to the previous hour's cold temperature.
T delivered	°C	The temperature of the water delivered from the storage tank.
T hot	°C	The temperature of the hot portion of the solar storage tank volume in stratified mode. If not stratified, this value is equal to the previous hour's hot temperature.
T mains	°C	The temperature of water incoming from the supply source.
T tank	°C	The mean temperature of the solar storage tank.
V cold	m^3	The estimated volume of the cold portion of the solar storage tank, where "cold" is with respect to the hot portion of the tank. SAM models the hot and cold portions as separate nodes. The cold volume increases as users draw water from the tank and mains water replaces it.
V hot	m^3	The estimated volume of the hot portion of the solar storage tank, where "hot" is with respect to the cold portion of the tank. SAM models the hot and cold portions as separate nodes. The hot volume increases from hour to hour as the useful energy from the collector is added until the hot volume is equal to the tank volume (and cold volume is zero).