Multifamily Central DHW and Solar Water Heating

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team October 2011

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1. Purpose

This Codes and Standards Enhancement (CASE) report regards potential changes to the 2008 California Building Energy Efficiency Standards for adoption into the 2013 Standards. It proposes changes in mandatory and prescriptive requirements for multifamily buildings with central domestic hot water features and summarizes the research supporting these proposed requirements.

2. Overview

<table>
<tr><td>a. Measure Title</td><td>Multifamily Central Domestic Hot Water (DHW) and Solar Water Heating</td></tr>
<tr><td>b. Description</td><td>This proposal adds the prescriptive requirement of demand control for DHW system serving multiple dwellings with recirculation loops and revises the existing mandatory timer control requirement. This proposal adds the prescriptive requirement on DHW system with recirculation loops serving multiple dwellings to have (at least) two separate recirculation loops, each serving a portion of the building.

This proposal adds a prescriptive requirement for multifamily buildings with central DHW systems with recirculation loops to install a solar water heating system with prescribed minimum solar savings fraction (% water heating budget) by climate zone.

The proposal adds a mandatory requirement for all multifamily buildings to be designed ready for future installation of solar water heating systems if they otherwise do not have solar water heating systems installed at the time of building design and construction.</td></tr>
<tr><td>c. Type of Change</td><td>Mandatory Measure – This proposal will add requirements in Section 150(n) for multifamily buildings to be solar water heating ready.

This proposal recommend the revision of mandatory requirement of timer control of DHW recirculation loops in Section 113(c)2.

Prescriptive Requirement – This proposal adds the following requirements to Section 151(f)8c:

Multifamily building DHW systems with recirculation loops shall have
1. demand controls, and
2. (at least) two recirculation loops, each serving half of the building, and,.
3. a solar water heating system with a minimum solar savings fraction by climate zone in the following table.

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<tr><td>CZ</td><td>1</td><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10</td><td>11</td><td>12</td><td>13</td><td>14</td><td>15</td><td>16</td></tr>
<tr><td>SSF</td><td colspan="9">0.20</td><td colspan="7">0.35</td></tr>
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Compliance Option -No change proposed. For the proposed prescriptive requirements, the CASE study demonstrates the feasibility and cost-effectiveness of alternative compliance methods.

Modeling – No change proposed by this CASE study. The Water and Space Heating CASE study proposes new algorithms for multi-family central DHW system and controls.</td></tr>
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d. Energy Benefits

The energy benefits of the measures proposed for 2013 Standards relative to 2008 Standards are presented in this section. The prototype buildings used to arrive at these energy savings are described in the following table:

Building Type		Low-rise	High-rise
Building Characteristics	Number of Floors	2	4
	Number of Units	44	88
	Conditioned Floor Area/Unit (sf)	870	
	Floor to Ceiling Height (ft)	10	

Figure 1 and Figure 2 show the per prototype energy savings resulting from proposed prescriptive measures for the low-rise and high-rise prototype buildings for each of the 16 climate zones. The last columns of the table also display the per square footage conditioned floor area (CFA) savings for the prototype buildings.

Climate Zone	Electricity Savings		Natural Gas Savings		TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	
	kwh/yr	kWh/yr per ft2 CFA	Therms /yr	Therms/ yr per ft2 CFA	TDV kBTU	TDV kBTU	PV$	PV$ per ft^2 CFA
1	(614)	(0.016)	2,271	0.059	(9,727)	356,947	$ 63,504	$ 1.66
2	(767)	(0.020)	2,230	0.058	(15,941)	350,441	$ 63,453	$ 1.66
3	(790)	(0.021)	2,229	0.058	(14,140)	349,995	$ 63,064	$ 1.65
4	(827)	(0.022)	2,213	0.058	(15,973)	348,024	$ 63,040	$ 1.65
5	(775)	(0.020)	2,311	0.060	(13,800)	364,895	$ 65,586	$ 1.71
6	(828)	(0.022)	2,165	0.057	(15,483)	341,903	$ 61,895	$ 1.62
7	(838)	(0.022)	2,173	0.057	(15,758)	343,915	$ 62,291	$ 1.63
8	(853)	(0.022)	2,170	0.057	(16,633)	342,558	$ 62,208	$ 1.63
9	(859)	(0.022)	2,161	0.056	(17,199)	341,274	$ 62,083	$ 1.62
10	(526)	(0.014)	2,758	0.072	(8,472)	435,220	$ 76,842	$ 2.01
11	(496)	(0.013)	2,812	0.073	(8,147)	438,204	$ 77,303	$ 2.02
12	(442)	(0.012)	2,838	0.074	(6,435)	440,594	$ 77,420	$ 2.02
13	(523)	(0.014)	2,753	0.072	(9,136)	428,175	$ 75,737	$ 1.98
14	(535)	(0.014)	2,802	0.073	(9,101)	442,269	$ 78,172	$ 2.04
15	(642)	(0.017)	2,566	0.067	(11,884)	406,674	$ 72,489	$ 1.89
16	(371)	(0.010)	3,016	0.079	(4,667)	470,337	$ 82,265	$ 2.15

Figure 1. Low-Rise Multifamily Prototype Energy Savings

Climate Zone	**Electricity Savings**		**Natural Gas Savings**		**TDV Electricity Savings**	**TDV Gas Savings**	**PV of Energy Cost Savings**	
	kwh/yr	kWh/yr per ft2 CFA	Therms /yr	Therms/ yr per ft2 CFA	TDV kBTU	TDV kBTU	PV$	PV$ per ft^2 CFA
1	(952)	(0.012)	3,716	0.049	(16,095)	597,949	$ 94,557	$ 1.24
2	(1,261)	(0.016)	3,635	0.047	(28,854)	584,823	$ 94,500	$ 1.23
3	(1,320)	(0.017)	3,631	0.047	(25,362)	584,013	$ 93,838	$ 1.23
4	(1,397)	(0.018)	3,599	0.047	(29,150)	580,065	$ 93,813	$ 1.23
5	(1,290)	(0.017)	3,796	0.050	(24,655)	613,756	$ 98,309	$ 1.28
6	(1,406)	(0.018)	3,503	0.046	(28,291)	568,138	$ 91,844	$ 1.20
7	(1,427)	(0.019)	3,521	0.046	(28,862)	572,158	$ 92,551	$ 1.21
8	(1,458)	(0.019)	3,513	0.046	(30,682)	569,456	$ 92,415	$ 1.21
9	(1,471)	(0.019)	3,495	0.046	(31,857)	566,890	$ 92,201	$ 1.20
10	(796)	(0.010)	4,689	0.061	(14,843)	752,548	$ 118,171	$ 1.54
11	(736)	(0.010)	4,797	0.063	(13,557)	760,336	$ 119,172	$ 1.56
12	(628)	(0.008)	4,850	0.063	(10,083)	765,126	$ 119,375	$ 1.56
13	(794)	(0.010)	4,680	0.061	(15,620)	740,320	$ 116,407	$ 1.52
14	(812)	(0.011)	4,778	0.062	(16,059)	766,547	$ 120,514	$ 1.57
15	(1,031)	(0.013)	4,305	0.056	(21,630)	695,762	$ 110,471	$ 1.44
16	(483)	(0.006)	5,206	0.068	(6,498)	824,555	$ 127,974	$ 1.67

Figure 2. High-Rise Multifamily Prototype Energy Savings

The Time Dependent Valuation (TDV) method emphasizes the energy savings benefits during peak demands, especially electricity peak demands. The application of a demand control system reduces the pump electric energy use by eliminating the constant pump operation throughout the day. Optimal recirculation loop design, solar water heating, and solar water heating *ready* all generate natural gas savings, not electric energy savings. There is actually increased electric energy consumption due to pumps for the solar water heating system operation, as indicated by the negative electric savings.

The assumptions and calculations used to derive the energy and demand savings for prototype buildings are documented in Section 2 “Methodology” and Section 3 “Analysis and Results.”

The annual statewide energy savings from the proposed measures are displayed in Figure 3 below.

Building Type	Electric Savings	Gas Savings	TDV Energy Savings
	(GWh/yr)	(MMT/yr)	(MBtu/yr)
Low-Rise MF	(0.23)	0.87	132,299
High-Rise MF	(0.20)	0.60	92,570
Hotel/Motel	(0.16)	0.52	78,816
Total	**(0.59)**	**1.98**	**303,685**

Figure 3. Annual Statewide Energy Savings

e. Non-Energy Benefits

The solar water heating ready measures would substantially reduce the cost of future installation of solar hot water heating systems. Prescriptive requirements for installing solar water heating with minimum solar savings fraction and making buildings solar water heating *ready* could potentially result in increased property valuation. These could seem attractive to building owners/operators and tenants interested in utilizing renewable energy sources.

f. Environ-mental Impact

Material use impact from the proposed measures are summarized below. Detailed calculation can be found in Section 7.11.

	Mercury (lb)	Lead (lb)	Copper (lb)	Steel (lb)	Plastic (lb)	Glass (lb)	Aluminum (lb)
per low-rise building	0.01	0.05	272	1922	99	708	191
per high-rise building	0.01	0.05	583	3842	185	1356	366
Statewide	10	48	353,356	2,411,079	120,287	869,882	234,645

Water Consumption:

	On-Site (Not at the Power plant) Water Savings (or Increase) (Gallons/Year)
Per Prototype Building	NC

1. For description of prototype buildings refer to Section 3.2.2 below.

Water Quality Impacts: NA

g. Technology Measures

Measure Availability:

Demand control products for DHW recirculation are widely available in the market and ready to meet the increased demand generated by the proposed code change. Manufacturers include Enovative Group, Taco, Uponor and Advanced Conservation Technology Distribution.

Design and implementation of optimal recirculation systems for at least two recirculation loops in a building is common practice, so the proposed requirement will not result in significant change in market practice.

Solar water heating is a mature technology with established product availability and distribution channels. Since its inception in 1980, the Sola Ratings and Certification Corporation now has over 400 collector products rated from 155 manufacturers in its OG-100 collector database. The Energy Information Administration (EIA) Solar Thermal Collector Manufacturers Report shows that California accounts for over a quarter of domestic solar thermal collectors (3.5 million sqft) shipped in 2009. Further, the five largest manufacturers account for 79% of market share.

Industry stakeholders have suggested that there is room for improvement in terms of consistent design strategy for multifamily solar water heating systems. They also identified lack of trained installers as one of the major market barriers. However, both these issues are expected to be addressed with the recently started California Solar Initiative (CSI)-Thermal incentive program. By 2014, this program will greatly increase solar industry design experiences and work force to ensure successful implementation of the proposed code changes.

Useful Life, Persistence, and Maintenance:

Demand control equipment is assumed to have a useful life of 15 year with no maintenance needs.

Useful life of Optimal design is assumed to be 30 years as energy savings benefits associated will persist through the entire building life.

The solar water heating system components and maintenance/replacement schedule are shown below.

Component	Life Expectancy (yr)	Implementations during 30 year Building Life
Collector	20	1.5
Solar Tank	15	2
Motor and Pump	10	3
Controller	20	1.5
Heat Transfer Fluid Check	1	20
Heat Transfer Fluid Check & Replacement	3	10

h. Performance Verification of the Proposed Measure

Field verification of the installation of demand control equipment, implementation of optimal design and installation of solar water heating systems will be required during building inspection by building officials. Performance verification of solar water heating system installation is a more specialized task and shall be performed by system design/contractors.

i. **Cost Effectiveness**

Climate Zone	Measure Life	Additional Costs1– Current Measure Costs (Relative to Basecase)	PV of Additional Maintenance Costs (Savings) (Relative to Basecase)	PV of Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building	Solar Savings Fraction
	(Years)	($)	(PV$)	(PV$)	($)	(%)
1	30	$ 43,072	$ 12,792	$ 63,504	$ (7,639)	20%
2	30	$ 35,428	$ 11,109	$ 63,453	$ (16,916)	20%
3	30	$ 30,775	$ 5,496	$ 63,064	$ (22,205)	20%
4	30	$ 29,736	$ 5,350	$ 63,040	$ (23,447)	20%
5	30	$ 30,775	$ 5,496	$ 65,586	$ (24,726)	20%
6	30	$ 26,579	$ 4,907	$ 61,895	$ (26,156)	20%
7	30	$ 26,579	$ 4,907	$ 62,291	$ (26,552)	20%
8	30	$ 27,106	$ 4,981	$ 62,208	$ (25,825)	20%
9	30	$ 27,104	$ 4,981	$ 62,083	$ (25,702)	20%
10	30	$ 42,179	$ 7,096	$ 76,842	$ (22,068)	35%
11	30	$ 47,588	$ 7,856	$ 77,303	$ (15,929)	35%
12	30	$ 48,600	$ 7,998	$ 77,420	$ (14,811)	35%
13	30	$ 48,595	$ 7,997	$ 75,737	$ (13,134)	35%
14	30	$ 40,780	$ 6,900	$ 78,172	$ (25,104)	35%
15	30	$ 38,599	$ 6,594	$ 72,489	$ (22,082)	35%
16	30	$ 49,629	$ 8,142	$ 82,265	$ (18,400)	35%

Figure 4. Low-rise Building Prototype LCC Results

Climat e Zone	Measure Life (Year)	Additional Costs1– Current Measure Costs (Relative to Basecase)	PV of Additional Maintenance Costs (Savings) (Relative to Basecase)	PV of Energy Cost Savings – Per Proto Building (PV$)	LCC Per Prototype Building	Solar Savings Fraction
1	30	$ 83,202	$ 26,222	$ 94,557	$ 14,868	20%
2	30	$ 67,797	$ 22,881	$ 94,500	$ (3,822)	20%
3	30	$ 57,497	$ 10,400	$ 93,838	$ (15,693)	20%
4	30	$ 55,419	$ 10,080	$ 93,813	$ (18,198)	20%
5	30	$ 57,497	$ 10,400	$ 98,309	$ (20,165)	20%
6	30	$ 48,397	$ 9,000	$ 91,844	$ (24,774)	20%

7	30	$ 48,397	$ 9,000	$ 92,551	$ (25,481)	20%
8	30	$ 49,488	$ 9,168	$ 92,415	$ (24,018)	20%
9	30	$ 49,484	$ 9,167	$ 92,201	$ (23,808)	20%
10	30	$ 79,935	$ 13,851	$ 118,171	$ (12,722)	35%
11	30	$ 90,972	$ 15,548	$ 119,172	$ (292)	35%
12	30	$ 92,961	$ 15,854	$ 119,375	$ 1,926	35%
13	30	$ 92,953	$ 15,853	$ 116,407	$ 4,882	35%
14	30	$ 77,111	$ 13,416	$ 120,514	$ (18,501)	35%
15	30	$ 72,775	$ 12,749	$ 110,471	$ (13,735)	35%
16	30	$ 94,984	$ 16,165	$ 127,974	$ (4,212)	35%

Figure 5. High-rise Building Prototype LCC Results

j. Analysis Tools

The current Title 24 ACM and building simulation tools does not include the necessary algorithms to model demand control and recirculation loop designs of multi-family DHW systems. This CASE study used a recirculation loop model, which was developed based on the PIER studies on multi-family DHW distribution system and was validated by field monitoring data, to analyze energy savings by control technologies and optimal recirculation loop designs.

CEC's version of F-chart can be used to quantify energy savings in terms of solar savings fractions resulting from the installation of solar water heating systems. The CEC is in the process of adding hourly calculation capability to the tool to enable more accurate assessment of potential gas (and electric) energy reduction. TRNSYS can provide the most accurate models of solar water heating systems. F-chart was developed using a curve fitting method based on extensive TRNSYS simulation study results. For this study, the team utilized TRNSYS to assess the performance benefits from installation of a solar water heating system.

k. Relationship to Other Measures

This CASE proposes minimum solar savings fractions and solar water heating readiness requirements for buildings. There are three related measures:

1. The single family Solar Ready Homes and Solar Oriented Developments CASE proposes PV and SWH readiness and orienting developments for optimal solar energy harvest and minimal building energy gain.
2. The cross-cutting Solar Water Heating CASE proposes to increase the existing solar fraction requirement for single family residential buildings with electric water heating, and to add a new solar fraction requirement for restaurants with both electric and natural gas water heating above a certain sqft.
3. The Commercial Solar Ready CASE proposes solar ready requirements for PV systems in *commercial* buildings. These CASEs were developed collaboratively, with each CASE addressing distinct areas of the code.

Specifically, this CASE collaborated the Single Family and Specialty Commercial Solar Water Heating CASE (Water Heating #2) in cost collection and TRNSYS

	simulation efforts. The teams continue to assist CEC in developing necessary software capabilities, such as hourly calculation in f-Chart. There are currently no PV or skylight requirements in the 2008 or proposed for the 2013 Title 24 regulations for multifamily buildings. There was not enough information nor existing studies available to determine the impact. Therefore, the team did not evaluate how the proposed requirement on solar water heating would affect the design and incorporation of PV or skylights in MF buildings.

3. Methodology

This section describes the methodology and approach used to develop the recommendations for the various measures being considered for multifamily DHW systems. As the methodology used for the two parts of the study – MF DHW improvements and Solar Water Heating– have distinct data collection processes and analysis approaches, they will each be addressed separately in this methodology section. The key elements of each part of the methodology are as follow:

- Data Collection
- Energy Savings Modeling
- Cost Analysis
- Cost-effectiveness Analysis
- Stakeholder Meeting Process

3.1 Methodology for Multifamily DHW Improvements

3.1.1 Data Collection

This CASE proposal is based on a Public Interest Energy Research (PIER) project on Central Domestic Hot Water (DHW) Distribution System conducted from 2008 to 2010 by the Heschong Mahone Group (HMG). This PIER research investigated performance of multi-family central DHW distribution systems through extensive field monitoring, performance analysis, and heat transfer model development. It sought to get an in-depth understanding of recirculation loop heat loss mechanisms and assess effectiveness of different control technologies. The PIER study provided extensive field measurement data, DHW system performance characteristics, recirculation loop designs, and control technology performance characteristics. This CASE study further funded the HMG team to develop and validate a multi-family DHW system recirculation loop model based on the PIER research results.

The PIER project surveyed more than 50 multifamily buildings and performed DHW systems monitoring in 32 buildings with various building sizes, DHW system designs, recirculation loop configurations, and occupancy types throughout California. The field monitoring studies measured hot water supply and return temperatures, cold water temperatures, hot water draw flows, recirculation flows, and natural gas input to the boiler. Measurements were logged with a 30 second time interval to get enough granularity of DHW system dynamics. Information on the building characteristics (size, number of units and such) and recirculation loop designs (pipe lengths, pipe diameters, insulation among others) were also collected. For nine of these 32 buildings, relative performance of various recirculation loop controls, including timer control, temperature modulation, and demand controls, was studied. The monitoring study collected data for more than one year for those buildings to get a comprehensive system performance at various climate and operational conditions.

DHW system performance and control technology savings were assessed using an energy flow analysis method, which allowed major energy loss components to be quantified using field monitoring data. As shown in Figure 6, the energy flow analysis method breaks down overall DHW system energy consumption into three components: water heater loss, distribution loss, and end-use energy.

The distribution loss is further separated into recirculation loop loss and branch loss. Based on performance analysis results of all 32 multifamily buildings monitored, the PIER study found that on average only thirty-five percent (35%) of the energy input in central DHW system was reaching the end-user, as much as that is lost in the distribution system (33% in the recirculation loop, and 1% in the branch pipes) and about 31% was lost at the water heater.

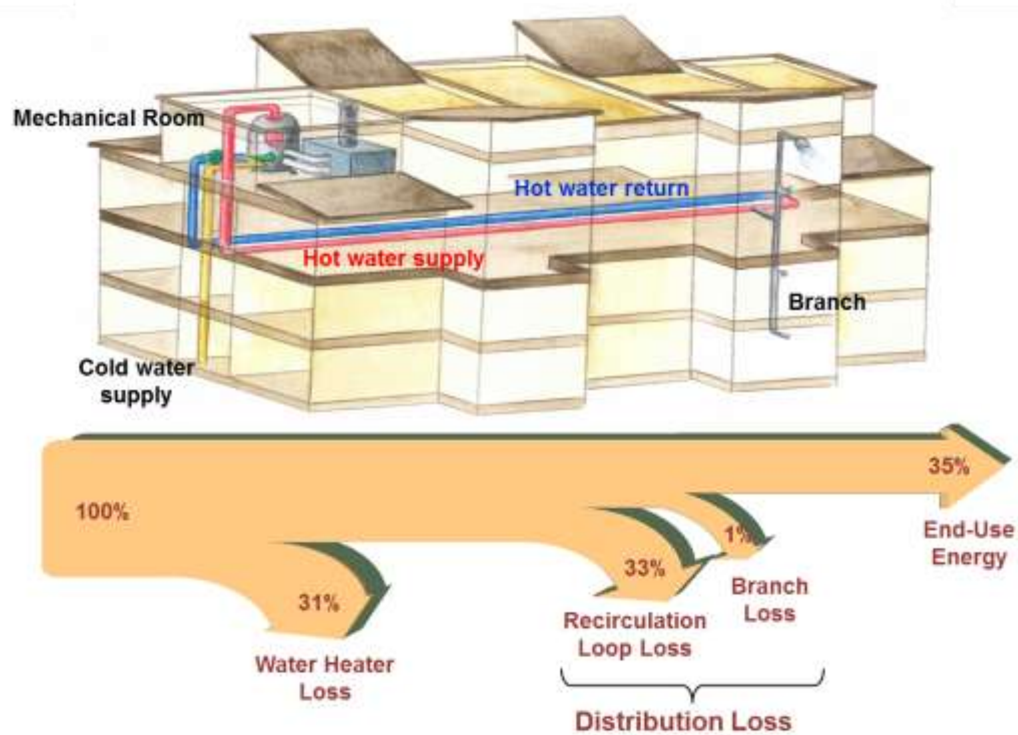

Figure 6. Central DHW System Energy Performance

Performance of three recirculation loop control technologies – timer control, temperature modulation, and demand control – were investigated through field monitoring studies. The PIER study revealed that simple comparison of system gas consumption with and without controls is not a reliable approach to quantify energy savings by controls, as hot water usage variations may offset control savings. A recirculation loop model was developed to provide better understanding of control mechanisms and estimation of energy savings. The model included the consideration of heat transfer modes under different control operation conditions, as well as detailed recirculation loop plumbing designs. This model was successfully validated by field performance monitoring data collected from buildings representing a wide range of buildings size, recirculation loop design, ambient conditions, and hot water usage patterns. The Water and Space Heating CASE study, presented separately, provides detailed model validation results and presents the ACM algorithms developed based on the validated recirculation loop model.

In addition to highlighting control savings potential, both the PIER research and this CASE effort emphasize the influence of distribution system layout (location, pipe diameter and insulation) on the system performance. The PIER research collected detailed recirculation loop design information of buildings where recirculation performance was monitored. The CASE study reviewed more recirculation loop designs available from building plans collected by utility multifamily incentive programs. The recirculation loop model developed by the joint efforts of PIER study and CASE studies (this study and the Water and Space Heating CASE study) was validated based on actual recirculation loop designs and their corresponding performance. Therefore, this model is capable of assessing performance of different recirculation loop designs.

3.1.2 Energy Savings Modeling

The energy savings were evaluated using the validated DHW recirculation model, which is implemented using EXCEL (screenshots of the model are provided in Appendix 7.2). The Water and Space Heating CASE study report provides detailed description of approaches used in the model to pipe heat transfer modes, piping configurations, and controls. That report also provides model validation results for four different recirculation loop configurations and for three control technologies: timer control, temperature modulation, and demand control. Modeling results of impacts by controls were compared to field measurement results. In all cases, the difference between modeled impact and measured impact were less than 3%. Model validation results are summarized in Appendix 7.1.

Energy savings from controls and recommend recirculation loop designs were assessed using the recirculation loop model based on a low-rise and a high-rise multifamily building prototypes (described in the immediately following paragraphs). Continuous pumping was used as the baseline for control energy savings assessment. The PIER multi-family DHW system field studies found that almost all systems used continuous pumping. Even through timer controls is required by 2008 Title 24 as a minimum compliance option, it does not practically provide any savings since multifamily buildings have scattered hot water usage patterns and recirculation pump cannot be turned off for extended periods of time, as indicated by the PIER multi-family DHW system field studies and feedback from stakeholders. In addition to the two control technologies, temperature modulation and demand control, energy savings by continuous monitoring technology was also assessed. It is assumed that a continuous monitoring system can keep building operators well informed of potential operation issues so that they won't resolve performance issues by simply increasing supply temperature. This study assumes continuous monitoring would reduce supply temperature by 5^{o}F. For each building prototype, annual DHW system energy savings were assessed for all sixteen (16) climate zones.

Performance of two types of recirculation loop designs was compared. One represents the typical design, while the other represents an optimized design.

Building Prototype Development

The energy savings were calculated using two building prototypes: a low-rise multifamily building, and a high-rise multifamily building. The two buildings are rectangular shape, with 22 units per floor, organized along a central corridor. The two building prototypes were originally developed for the 2005 Title 24 code changes based on market studies of California multi-family buildings. The prototype building characteristics and DHW system characteristics are summarized in Figure 7 below.

Building Type		**Low-rise**	**High-rise**
Building Characteristics	**Number of Floors**	2	4
	Number of Units	44	88
	Conditioned Floor Area/Unit (sf)	870	
	Floor to Ceiling Height (ft)	10	
DHW System Characteristics	**Hot water Temperature Supply (°F)**	135	
	Water Heater Thermal Efficiency (%)	80	
	Recirculation Pump Power (hp)	1/4	1/2
	Recirculation Pump Flow Rate (gpm)	6	8

Figure 7. Building Prototype Characteristics

The hot water temperature setting reflects Title 24 code assumptions, although hot water is usually set to a lower temperature according to the PIER research. Overall water heater efficiency corresponds to the minimum thermal efficiency required by Title 24. Recirculation pump power as well as recirculation pump flow rate reflect typical values observed in the field.

For each prototype, a default domestic hot water distribution network was developed, following the default design assumptions proposed to be implemented in the ACM by the Water and Space Heating CASE. It assumes that the recirculation pipe system is made of a single loop located in the ceiling space of the corridor of a specific floor, and that the mechanical room is located in one corner of the building on the first floor. In the low-rise building, the recirculation loop is located on the first floor (Figure 8). In high-rise building, the recirculation loop is located in the middle floor of the building. Additional lengths of recirculation piping connect the recirculation loop to the mechanical room which houses the water heater or boiler and the recirculation pump (Figure 9).

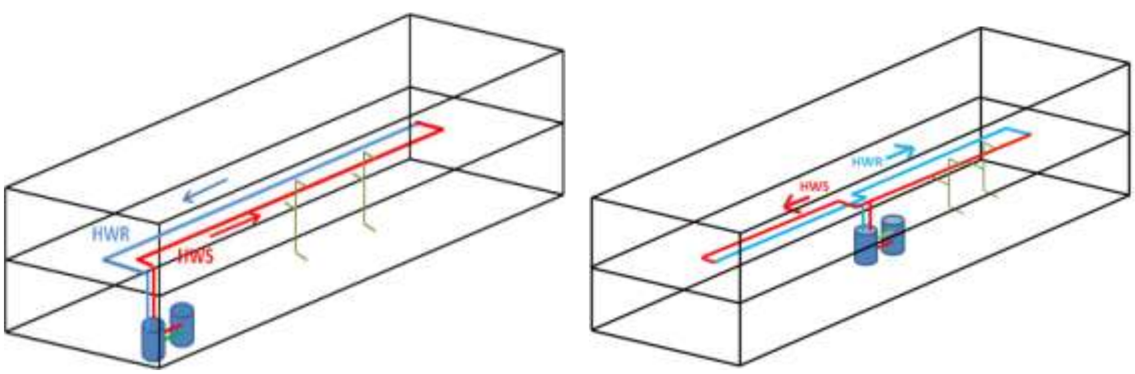

Figure 8. Low-rise Prototype Recirculation Piping

Default (Left) and Optimized (Right) Configurations

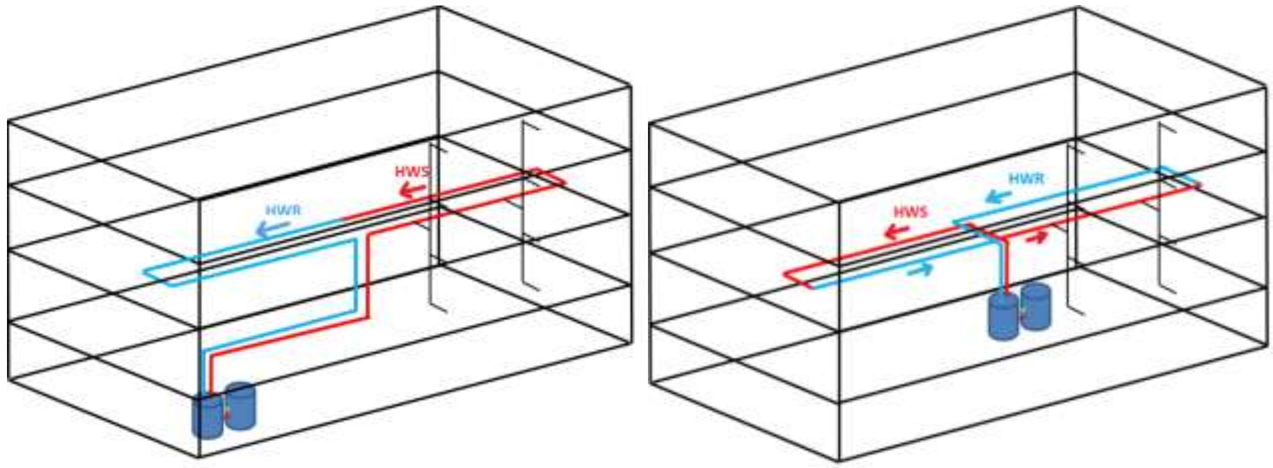

Figure 9. High-rise Prototype Recirculation Piping

Default (Left) and Optimized (Right) Configuration

Following findings of the PIER report, an optimized DHW distribution network was designed. The length of the recirculation loop and piping is minimized by splitting the single loop into two and by locating the mechanical room closer to the loop. The optimized layout still assumes that the recirculation loop is located in the ceiling of a specific floor, which is conditioned. The mechanical room is now assumed to be located in the middle of the building, one floor away from the recirculation loop.

Information on default and optimized domestic hot water distribution networks is summarized in Figure 10.

Recirculation Layout Characteristics	Low-rise		High-rise	
	Default Layout	Optimized Layout	Default Layout	Optimized Layout
Mechanical Room Location	First floor, corner of the building	Middle of the building	First floor, corner of the building	Middle of the building
Pipe Length from Mechanical Room to Recirculation loop (ft)	25	25	116	25
Recirculation Loop Location	First floor central corridor ceiling	First floor central corridor ceiling	Middle floor central corridor ceiling	Middle floor central corridor ceiling
Number of Loops	1	2	1	2
Pipe Length/loop (ft)	324	162	324	162

Figure 10. Distribution Network Characteristics

Based on the building dimension (unit area of 870 sf and floor to ceiling height of 10 ft) and configuration (building 11 units long), the recirculation piping length was calculated for each design. The recirculation loop was further broken down into sections according to the number of units served by the loop at specific points. Breakpoints are defined by branches providing water to the units. Based on this information, each pipe section diameter was evaluated using IAPMO guidelines. Detailed calculation of the pipe sizing can be found in Appendix 0. As the modeling tool requires modeling each loop as a succession of three (3) pipe supply sections followed by three (3) pipe return sections. Within each section, pipes with different diameters could exist. Averaged section pipe diameters were calculated by averaging pipe diameters weighted by corresponding pipe lengths. Section heat transfer coefficients were calculated through weighted averaging in the same way. The return pipe diameter is usually constant and was calculated based on the recirculation flow rate. The piping lengths presented in Figure 11 and Figure 12 include the pipes connecting the recirculation loop length to the mechanical loop.

	Section Type	**Supply 1**	**Supply 2**	**Supply 3**	**Return 1**	**Return 2**	**Return 3**
Default Design	**Section Length (ft)**	113	103	133	133	103	113
	Average section pipe diameter (inch)	2.67	2.43	1.75	1	1	1
Optimized Design	**Section Length (ft)**	57	59	59	59	59	57
	Average section pipe diameter (inch)	2.35	2.00	1.44	0.75	0.75	0.75

Figure 11. Recirculation Loop Layout – Low-rise

	Section Type	**Supply 1**	**Supply 2**	**Supply 3**	**Return 1**	**Return 2**	**Return 3**
Default Design	**Section Length (ft)**	204	103	133	133	103	204.3
	Average section pipe diameter (inch)	3.50	2.93	2.14	1	1	1
Optimized Design	**Section Length (ft)**	56.6	59.0	59.0	59.0	59.0	56.6
	Average section pipe diameter (inch)	2.85	2.38	1.81	0.75	0.75	0.75

Figure 12. Recirculation Loop Pipe Layout – High-rise

3.1.3 Cost Analysis

Cost information was collected through manufacturers interviews and online product and pricing research. Specifically, prices of different diameter copper pipes per linear foot were collected on the Internet in order to assess the incremental cost of better recirculation piping layout design. Control device prices were gathered through interviews of the control manufacturers as well as internet research.

3.1.4 Cost-Effectiveness Analysis

The CASE team calculated lifecycle cost analysis using methodology explained in the California Energy Commission report *Life Cycle Cost Methodology 2013 California Building Energy Efficiency Standards*, written by Architectural Energy Corporation, using the following equation:

$$\Delta LCC = Cost\ Premium - Present\ Value\ of\ Energy\ Savings$$ [1]

$$\Delta LCC = \Delta C - (PV_{TDV\text{-}E} * \Delta TDV_E + PV_{TDV\text{-}G} * \Delta TDV_G)$$

Where:

ΔLCC	change in life-cycle cost
ΔC	cost premium associated with the measure, relative to the base case
$PV_{TDV\text{-}E}$	present value of a TDV unit of electricity
$PV_{TDV\text{-}G}$	present value of a TDV unit of gas
ΔTDV_E	TDV of electricity
ΔTDV_G	TDV of gas

A 30-year lifecycle was used as per the LCC methodology for residential and non-residential hot water system measures. LCC calculations were completed for two building prototypes (low-rise and high-rise multifamily buildings), in all sixteen (16) climate zones.

3.1.5 Statewide Savings Estimates

The statewide energy savings associated with the proposed measures will be calculated by multiplying the per dwelling unit estimate with the statewide estimate of new construction in 2014. Since the low-rise and high-rise multifamily prototype buildings have 44 and 88 units respectively, per building energy savings are first converted to per unit energy savings, then applied to the respective statewide construction estimate. 82% of low-rise multifamily buildings are assumed to have central water-heating feature, and 100% for high-rise multifamily buildings. Details on the method and data source of the residential construction forecast are in 7.8.

For stateside savings associated with motels and hotels, the team averaged of the per unit energy savings from low- and high-rise prototype buildings, and adjusted for the average sf of motel/hotel room (since the average motel/hotel room is 350sf, the ratio of 350/780 was applied). Details on the method and data source of the nonresidential construction forecast are in 7.9.

3.1.6 Stakeholder Meeting Process

All of the main approaches, assumptions and methods of analysis used in this proposal were presented at the Residential Stakeholder Meetings held on April 12th and May 13th, 2011, at the UC Davis Beuhler Alumni and Visitor Center, in Davis, CA.

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[1] The Commission uses a 3% discount rate for determining present values for Standards purposes.

At the meetings, the CASE team presented the methodology and analysis and asks for feedback on the proposed language and analysis thus far. Presentation materials and meeting notes, along with a summary of outstanding questions and issues are distributed using MyEmma meeting planning services.

In addition to the Stakeholder Meeting, two Stakeholder Work Sessions covering specific technical issues related to domestic hot water in multifamily building were held on October 13th, 2010, and January 13th, 2011.

A record of the Stakeholder Meeting presentations, summaries and other supporting documents can be found at www.calcodesgroup.com.

3.2 Methodology for Multifamily Solar Water Heating

3.2.1 Data Collection

The purpose of the data collection efforts was to gather supporting information on the following aspects of solar water heating application for multifamily buildings:

- Solar water heating technologies and market conditions
- System performance simulation tools and simulation inputs
- Installed system costs and maintenance assumptions
- Solar water heating *ready* components

Literature Review

To understand where California stands in terms of multifamily buildings solar water heating installations, HMG conducted literature review to collect data on available solar water heating system types and current market conditions. Detailed market condition include current practices, prevalent system types, installed system costs, and potential market barriers. Resources reviewed included the latest CEUS data, incentive program documents, and literature available from various domestic and international organizations. Resources reviewed are described in detail in Section 4.2.3 with citations in the Bibliography section.

HMG carried out research to select an appropriate modeling method and software tool for evaluating solar water heating performance. The software tools examined spanned across research-level physical-principle based modeling tools, highly specialized tools for system design purposes and comprehensive tools used to assess comparative performance between energy efficiency measures.

To identify components of making multifamily building solar water heating ready, HMG then reviewed existing guidelines and languages established in other jurisdictions and other interested agencies to promote the deployment of solar water heating technology. These included criteria/checklists from various green building rating systems and various established ordinances or guidelines developed by industry groups.

Industry Surveys and Interviews

In addition to data collected through literature review, HMG conducted targeted surveys to solicit further inputs from solar water heating equipment manufacturers, system designers and installers with multifamily system experience. An online survey tool was developed with questions regarding market conditions, tools utilized for system performance assessment and sizing, designs considerations and market barriers (A copy of the survey tool is provided in Appendix 7.3).

Following the survey efforts, HMG conducted pointed phone interviews with a selective number of survey participants, mostly solar water heating system designers and installers, to seek inputs regarding components of making multifamily buildings solar water heating *ready* to substantially reduce the future cost of installing a solar water heating system. Interviewees were also asked to provide information on installed system cost estimates and cost breakdown for new construction, current typical retrofit (without *ready* measure) and retrofit with *ready* measures scenarios to help assess cost benefits that were possible due to implementation of *ready* measures.

3.2.2 Energy Savings Simulation

To quantify the amount of energy savings from a solar water heating system, the team simulated the performance of typical solar water heating system configurations with the appropriate energy simulation software. Decisions on solar water heating system configurations and an appropriate simulation software were based on the results from the data collection process.

Selection of Simulation Software

To assess the potential energy savings possible with the installation of solar water heating systems, the team needed to first review the wide variety of software tools available for the purpose. For Title 24 compliance purpose, buildings presently can demonstrate compliance with the code through performance path by using a spreadsheet based solar fraction calculator if an SRCC (Solar Ratings Certification Corporation) OG-300 rated *system* is installed, or CEC's version of f-Chart if SRCC OG-100 rated *collectors* are installed.

The spreadsheet calculator for OG-300 systems uses a set of pre-defined inputs to calculate an annual solar fraction based on the building conditioned floor area, solar energy factor provided by the SRCC directory and a solar radiation table by the 16 California climate zones. However, this is not suitable for use on most multifamily buildings, as the largest rated systems in SRCC's OG-300 directory with gas auxiliary has collector area of less than 250 ft^2. The two prototype buildings used for the analysis have collector areas larger than 250 ft^2. Therefore, CEC's version of f-Chart can be used to calculate an annual solar fraction, which then can be used as an input into calculation of water heating budget (Equation 1 and Equation 2).

In addition to what is currently used for demonstrating Title 24 compliance, the team also investigated the following tools: RETScreen, Solar Analysis Modeling (SAM) tool, TRNSYS, f-chart, PolySun and T-Sol. RETscreen developed by Natural Resource Canada, and SAM developed by National Renewable Energy Lab (NREL) are similar because they were both developed to help inform and prioritize between technology options. While RETScreen included both energy efficiency and renewable energy options, SAM features only renewable energy generation options. Although they are helpful in comparing various technology options in terms of energy performance and financial impact, they were not appropriate for our purpose because of their limited energy simulation capability.

Almost all survey respondents identified using design tools such as PolySun and T-Sol (and other similar proprietary customized tools) for system sizing, performance and cost savings estimate purposes. These tools were not suitable for our analysis because they were not designed to provide accurate hourly energy performance of systems with different configurations and operational inputs.

The team explored TRNSYS and TRNSYS-based tools and decided that TRNSYS was the best fit for this study. Although requiring lots of modeling expertise and resources, TRNSYS would provide accurate hourly modeling results for specific inputs in regards to weather file, water draw, and a wide range of design parameters.

Figure 13 compares the various TRNSYS based tools used for evaluation of solar water heating systems.

	TRNSYS based		
Tool	**SDHW**	**f-Chart**	**SAM**
Purpose	Energy savings estimation	Solar fraction for systems with OG-100 collectors	Cost implication
Application Type	Res single family	Res and Commercial	Res and Commercial
Input			
Weather	pre-defined US stations	2008 version CA climate zones	tmy2, tmy3 & epw files
Water Draw Profile	pre and user-defined	built-in (no shown through interface)	pre and user-defined
System Information			
Type	ICS and active glycol (area only)	OG 100 certified collectors	glazed flat plate (HWB eqn)
Orientation	√	√	√
Piping	√	--	--
Layout	√	--	--
HX & Pump	√	--	HX only
Storage Tank	√	√	√
Auxiliary	√	--	√
Output			
System E Output & Savings	√	Solar Fraction only	√
Feature			
Parametric	√	--	√
Sensitivity	--	--	√

Figure 13. Comparison between Various TRNSYS-based Tools

Building Prototype Development

The two building prototypes, a low-rise and a high-rise multifamily building, are the same as those two used for recirculation loop improvement investigation as described in 3.1.2 previously.

Standard Base Case

The standard base case used as the baseline for energy use comparison was a domestic hot water system, as defined in 2008 Title 24 rules, with a recirculation loop and gas water heaters. The daily building hot water draw schedules were calculated according to Appendix E of the 2008 Residential ACM Manual. The principle equation used to calculate the hourly adjusted recovery load seen by the water heater is (2008 Residential ACM RE-1):

$$HARL = HSEU \times DLM \times SSM + HRDL + \sum HJL$$

Equation 1

Where

HARL = hourly adjusted recovery load (Btu)

HSEU = hourly standard end use (Btu)

DLM = Distribution loss multiplier (unitless)

SSM = Solar Savings Multiplier (unitless), it is defined as the amount of the total hot water load that is not provided by solar hot water heating. Therefore, SSM = 1- SSF (2008 Residential ACM RE-1), where SSF is solar savings fraction and is the amount of total hot water load provided by solar hot water heating.

HRDL = Hourly recirculation distribution loss (Btu)

HJL = the tank surface losses of the unfired tank (Btu)

In these base cases, the solar savings multiplier assumed the value of one, as all of the hourly standard end use (Btu) would have to be met by the gas water heater, in absence of a solar water heating system. Distribution loss multiplier (DLM) specifies distribution heat loss associated with pipes within dwelling units. It equals to one (1) in the standard base case and, therefore, it has no impact to system load. According to 2008 Title 24, the recirculation loop standard design includes a timer control. As proposed by this CASE study, the recirculation loop standard design should include a demand control and a dual-loop design. It should be noted that assumptions of recirculation controls and designs have little impact to solar savings multiplier (SSM). This is because the proposed solar water heating systems are designed to only meet system load associated with hot water draws, but not recirculation loop loss and the 2008 Title 24 ACM defines the SSM in the same way.

Proposed Case

Results obtained from the TRNSYS simulation runs were used to calculate the amount of energy harvested from the sun from a solar water heating system. The solar savings fraction (SSF) is calculated following the same equations as presented in the Standard Base Case section. Both the standard base case and proposed cases have the same hourly standard end use (HSEU) determined by draw schedule, supply temperature, and ground water temperature defined in the 2008 T24 Residential ACM Manual.

However, note that because solar water heaters are configured to only meet hot water draw loads, distribution system heat loss is not affected by solar water heaters. With $SSM = 1 - SSF$ and isolating the effect of distribution loss from solar water energy gain, Equation 1 becomes,

$$HARL = (HSEU \times DLM - HSEU \times SSF) + HRDL + \sum HJL$$

Equation 2

Difference in system gas energy consumption between the standard and proposed case (ΔE_{gas}) can be calculated from the solar energy gain from the solar water heating system (Q_{solar}). The team assumed a hot water boiler thermal efficiency (η_{WH}) of 0.8.

$$\Delta E_{gas} = \frac{Q_{solar}}{\eta_{WH}} = \frac{Q_{WH,std} - Q_{WH,proposed\_with\_solar}}{\eta_{WH}}$$

It is related to solar savings fraction as:

$$SSF = 1 - \frac{\sum Q_{solar}}{\sum HSEU}$$

Knowledge gained from the data collection process of the study (through incentive program resources and online survey) helped us narrow down to a handful of typical system types (and their common configurations) and select the most fitting simulation tool. Detailed information on assumptions of the modeled system configurations which are not addressed in this section can be found in Appendix 0. With the expertise of our subcontractor, Thermal Energy System Specialists (TESS), the team defined three simulation input sets explained in the next section, Section 3.2.3. These simulation sets were crafted to map solar water heating system performance under different design conditions so that cost effective and technically feasible system design solutions can be identified.

- Performance Base Simulation: Four System Configurations in All Climate Zones
    1. Active Glycol with External Heat Exchanger
    2. Active Glycol with Immersed Heat Exchanger
    3. Water Drainback
    4. Forced Circulation (Open Loop)
- Permutation Simulation Phase I: Design Component Sizing
- Permutation Simulation Phase II: Collector Area Optimization

3.2.3 Simulation Approaches

This section explains the three different simulation input sets used to assess the energy performance of solar water heating systems of various configurations and under different design parameters.

Performance Base Simulation – System Configurations in All Climate Zones

To assess performance differences between the defined system configurations, we modeled the solar water heating system performance for two building prototypes in all 16 of California's climate zones under a set of "default" design parameter values. There are three principal system design parameters considered in this study:

1. Collector sizing ratio: in unit of square footage collector area to the gallons per day daily demand of the building as calculated per Title 24 rules.
2. Solar tank sizing ratio: in unit of gallons of storage capacity per sq. ft. collector area , and
3. Auxiliary tank sizing ratio: also in unit of gallons of storage capacity per sq. ft. collector area.

More detailed assumptions and descriptions of the modeled systems can be found in Appendix 0, in addition to the following highlights:

- Pumping power based on 15 W/gpm representative of a standard pump (90% motor and 60% overall efficiency) pumping a 60/40 mixture of water/propylene glycol.
- Double-wall heat exchanger with 0.4 effectiveness for water/glycol systems and single-wall heat exchanger with 0.5 for water/water systems.

Inputs defined for the performance base case simulations are shown in Figure 14. With the exception of the collector sizing ratio, the quantities depicted in the input table represent those of a typical multifamily sized solar water heating system. (The team later learned that collector size ratio of 1 is larger than physically feasible due to overheating issues). The team then utilized the comparative performance results between the different system configurations and climate zones as comparison basis to help process results obtained from the permutation phases to follow.

TRNSYS System Configuration	Solar Collector Type	# Tanks	Aux. Type	Climate Zone	Bldg Proto-type	Collector Size (sq ft per gal/day)	Orient-ation	Tilt Angle (deg from horizontal)	Solar Tank Size (gal/ sq ft collector)	Auxiliary Tank Size (gal/ sq ft collector)
All 4	Flat Plate	2	Gas Storage	1~16	LR, HR	1	due south	18.4°	1	1

Figure 14. Performance Base Simluation Inputs

Permutation Simulation Phase I - Design Component Sizing

After establishing the performance base case for the four system configurations, the team investigated the effects that each of the above-mentioned sizing parameters has on system performance in terms of auxiliary water heater gas energy saved. Therefore, one system configuration (active glycol with external heat exchanger) in one climate zone for one building prototype was chosen, and a set of permutation runs were defined with various collector, solar tank and auxiliary tank sizing, as shown in Figure 15. The ranges of design sizing parameters were determined based on review of data collected and the stakeholder meeting process which are explained later in the report. Specifically, the collector sizing range of 0.05, 0.1 and 0.3 was chosen initially as a result of literature review and feedback received from stakeholders.

TRNSYS System Configuration	Solar Collector Type	# Tanks	Aux. Type	CZ	Bldg Proto-type	Collector Size (sq ft per gal/day)	Orient-ation	Tilt Angle (deg from horizontal)	Solar Tank Size (gal/ sq ft collector)	Auxiliary Tank Size (gal/ sq ft collector)
Active Glycol (external HX)	Flat Plate	2	Gas Storage	10	LR	0.05, 0.1, 0.3, 1	due south	18.4°	1,1.5,2	0.5,1,1.5

Figure 15. Permutation Simulation Phase I Inputs

Permutation Simulation Phase II - Collector Area Sizing Optimization

After review results from the first phase of permutation efforts, the team determined that it was necessary to further investigate the effect that collector sizing has on energy production of solar water heating system. Therefore, phase II of the permutation simulation runs were conducted with much of the same assumptions as were made in Phase I, with the exception of finer collector sizing increments to help discover the optimal collector sizing that will result in the most energy savings benefits on a per unit cost basis.

TRNSYS System Configuration	Solar Collector Type	# Tanks	Aux. Type	Climat e Zone	Bldg Proto-type	Collector Size (sq ft per gal/day)	Orient-ation	Tilt Angle (deg from horizontal)	Solar Tank Size (gal/ sq ft collector)	Auxiliary Tank Size (gal/ sq ft collector)
Active Glycol (external HX)	Flat Plate	2	Gas Storage	1,3,7, 10,12	LR, HR	0.1 -0.8 in 0.1 increment	due south	18.4°	1	1

Figure 16. Permutation Simulation Phase II Inputs

3.2.4 Cost Analysis

On the other side of the cost-effectiveness equation to the potential energy savings are the cost premiums associated with solar water heating systems. To facilitate the cost effectiveness analysis, the team generated cost estimates for

- Installed System Cost, and
- Maintenance Costs

This section lays out the resources considered and assumptions used to perform these cost estimates. The results of the analysis are provided in Section 4.2.6.

Installed System Costs

Installed system costs of solar water heating systems should include solar equipment, labor and profit margin costs. However, this level of cost breakdown was not available or accessible in most of the resources the team identified. The three sources from which most cost data was gathered were: program data, RS Means cost book and stakeholder input. The team ultimately collected installed system costs as aggregate cost numbers, instead of costs by components (ex. equipment vs. labor vs. markup).

First, the team collected data from available solar water heating incentive program databases in California. The two sources of actual project data with installed system costs are the Solar Water

Heating Pilot Program (Pilot Program) administered by the California Center for Sustainable Energy and the newly implemented California Solar Initiative – Thermal (CSI-Thermal) program for multifamily and commercial projects. Solar water heating system cost data is also available in RS Means cost data books. In addition, as points of reference, stakeholders provided high-level estimate on installed system cost estimate through the stakeholder meeting process and various interview efforts.

Maintenance Costs

To estimate general realistic maintenance costs, we needed both realistic maintenance schedules and costs associated with equipment-specific maintenance tasks.

Maintenance schedules are closely tied to equipment life, as equipment-specific maintenance tasks are performed at the end of equipment life. Stakeholder inputs and warranty requirements for EnergyStar residential solar water heating program were included and examined for the consideration of equipment life assumptions.

For cost associated with various maintenance tasks, RS Means cost book was again utilized for labor cost estimate and industry stakeholders inputs were used for the number of hours and relevant equipment/material costs needed.

3.2.5 Cost Effectiveness Analysis

Two methods of LCC are presented below, as the solar water heating codes change proposals *with* and *without* energy savings should be evaluated on very different basis.

LCC of Prescriptive Minimum Solar Fraction Requirement

The same lifecycle costing methodology described previously in Section 3.1.4 is used for the evaluation of the solar water heating portion of the study. A 30-year lifecycle was assumed for both the low-rise and high-rise prototype buildings, with the 30-yr Residential and 30-yr Non Residential TDV multipliers and present value factors used respectively.

Cost Effectiveness of* Ready *Measures

The basic idea of making a building solar water heating *ready* is based on the assumption that it would reduce cost of future installation while adding relatively little cost during the time of new construction if a building was designed with retrofitting of a solar water heating system in mind. Therefore, in addition to the potential energy cost savings benefits, there are also direct cost savings expected from the *Ready* portion of the solar water heating measure.

To be prudent and avoid over-estimate of benefits resulting from the measure, the team decided to not account for the energy cost savings benefits in the cost-effectiveness calculation approach. The universal lifecycle cost methodology developed by the CEC for evaluation all codes and standards enhancement topics was thus not suitable for evaluation of the solar water heating *ready* measure.

Instead, we proceeded to estimate the first costs needed to make a building solar water heating *ready* during the design phase and compare this with the potential cost savings possible when it comes the time for retrofitting for a solar water heating system. Naturally, not all buildings which are made solar water heating ready will decide to retrofit for it later. Therefore, it is crucial to determine what market penetration rate solar water heating may achieve within the measure life of 30 years.

This is the main difference between the evaluation of other measure and this *ready* measure. While other measure with energy cost savings can be evaluated on a per building basis, the cost-effectiveness of this ready measure highly depends on just how much of the housing stock will decide to retrofit for solar water heating systems.

$$Additional\_Cost\_Now = Cost_{ready} \times (MF_{total} - MF_{newinstall})$$

$$Cost\_Savings\_Later = \Delta Cost_{retrofit} \times FVM_{n\,years} \times MF_{retrofit}$$

Equation 3

where

$Cost_{ready}$ = additional cost to be *ready*, per building

MF_{total} = total building stock in 2013

$\Delta Cost_{retrofit}$ = cost savings when retrofitting a *ready* building (vs. a regular building), per building

$MF_{retrofit}$ = number of buildings that will retrofit for solar water heating → the only unknown

$MF_{install}$ = number of buildings that will install solar water heating during new construction; this number is neglected, since it is currently accounts for less than 1% of total MF housing stock.

$FVM_{n\,year}$ = future value multiplier n years between the solar ready home built and when solar is added later on. Based on the future value of money at a 3% real discount rate.

Given the per building additional cost and the per building cost savings possible, we can calculate the minimum adoption rate ($MF_{retrofit}$) required at the end of the measure life to allow positive cost-effectiveness but equating the additional cost now to the cost savings later. The team intended to collect these figures through the literature review and stakeholder interview/meeting process.

After finding this minimum cost-effective adoption rate, comparing this with various projected future penetration rates predicted by different resources will help the team assess whether making the building solar water heating ready is feasible or not depending on how closely the minimum adoption rate aligns with these projected penetration rates.

3.2.6 Statewide Savings Estimates

Please see Section 3.1.5.

3.2.7 Stakeholder Meeting Process

Approaches, assumptions and methods of analysis used for this portion of the study were again vetted via the previously mentioned stakeholder meeting process sponsored by the IOUs.

At each of the meeting, the utilities' CASE team presented the progress of analysis completed thus far, actively sought stakeholders inputs and feedbacks and compiled and distributed summary of discussion during the meeting, along with outstanding questions and issues.

A record of the stakeholder meeting and related supporting documents can be found at www.calcodes.com. Stakeholder meetings were held at the following locations and dates:

- First Solar Topic Stakeholder Meeting: April 2010, San Ramon Valley Conference Center, San Ramon, CA

- Second Solar Topic Stakeholder Meeting: November 2010, San Ramon Valley Conference Center, San Ramon, CA
- Third Solar Topic Stakeholder Meeting: April 2011, via webinar

An additional follow-up discussion was held via webinar on January 11, 2011 to facilitate more in-depth discussion and solicit feedbacks.

4. Analysis and Results

This section presents the analysis performed and results obtained using the methodologies described previously. Similar to the methodology section, presentation of the data collection results, energy savings and cost analysis for the DHW and Solar Water Heating parts of the study are presented separately. The major components include:

MF DHW Improvements:

- DHW Recirculation Loop Controls
- DHW System Configuration
- Energy Savings Analysis
- Cost Analysis

Solar Water Heating:

- Solar Water Heating Technology
- Market Penetration of Solar Water Heating
- Existing Solar *Ready* Regulations
- Energy Savings Analysis
- Cost Analysis

Cost effectiveness results combining elements of all these considered measures are presented in a single LCC results section to demonstrate and compare the combined energy and cost savings implications of all the related multifamily DHW measures.

4.1 Analysis and Results for Recirculation Loop Improvements

This section provides detailed market study and analysis results for DHW recirculation loop improvements.

4.1.1 Data Collection/Market Study

This CASE was developed based on the PIER multifamily DHW system study, which provided the following data sets to support the development of the proposed changes:

- General central DHW system configurations, recirculation loop designs, and controls collected through on-site DHW system inspection of 50 multi-family buildings.
- DHW system performance monitoring and analysis data, along with general building characteristics, from 32 multi-family building. The field monitoring studies measured cold water supply temperature and flow, hot water supply temperature and flow, and hot water return temperature and flow. Monitoring periods vary from one month to more than one year based on permission by the building owners and operators. Performance data were logged in 30-second intervals.
- Detailed on-site monitoring and analysis of recirculation control technology performance in 9 multi-family buildings. Timer control, demand control, and temperature modulation control

were installed and study. In addition to water temperatures and flows measurements, natural gas consumptions were monitored. Detailed recirculation loop designs were obtained from the building plans as well on-site inspection. Monitoring periods lasted for more than one year at each site. Performance data were logged in 30-second intervals. Performance monitoring results and detailed recirculation loop designs from four (4) building sites were used to validate the DHW recirculation loop model.

- Multi-year DHW system continuous monitoring data collection by the EDC Technology from 50 multi-family buildings. All of these systems have a combined temperature modulation control and remote continuous monitoring.

The PIER multifamily DHW system study developed an energy flow analysis method, which calculates major DHW system energy flow components using field measurement data. Figure 6 presents the average DWH system energy flow breakdown based on field performance study results of all buildings studied by the PIER research. DHW system performance in different buildings vary drastically from building to building. As shown in Figure 17. Recirculation loop heat loss can represent from 9% to 63% of the total system gas energy input.

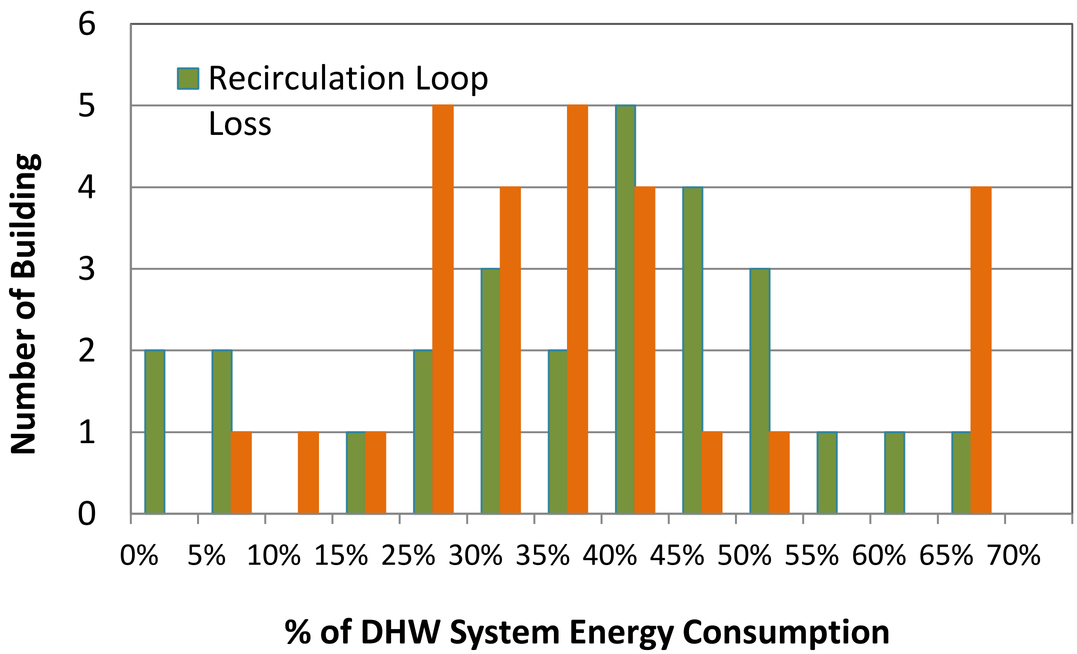

Figure 17. Multifamily DHW System Performance Statistics

DHW system overall energy consumption strongly depends on the distribution network configurations, and is also influenced by different operational parameters, including hot water draw patterns, ambient temperatures and supply temperatures. The former parameters keep changing throughout the year, while the latter may vary due to building manager behavior.

DHW Recirculation Loop Controls

Several control technologies can be used to reduce recirculation loop heat loss in central DHW systems without sacrificing hot water delivery services. These technologies either control recirculation pump operation or modulate hot water supply temperatures. This study focuses on the demand control and temperature modulation control. The PIER study investigated energy savings potential of time controls, but the field results indicated that timer control with recirculation pump being turned off for extended period of time is not suitable for multifamily buildings, since hot water demand can be expected throughout the day in multi-family buildings.

Temperature modulation devices lower the temperature at times when hot water demand is expected to be low. Recirculation pumps are not controlled by temperature modulation controls. Some versions of temperature modulation devices use fixed temperature control schedules, while others can automatically adjust control schedules based on measured draw patterns. Manufacturers of temperature modulation technologies include:

- EDC Technology
- Pro-Temp Controls
- Heat-Timer Corporation

Figure 18 depicts the temperature pattern of a combined temperature modulation with monitoring control. In this particular example, the supply temperature was allowed to drop by 15˚F at night when the demand was low, compared to its setting during high demand hours. In practical applications, temperature modulation settings depend on specific temperature modulation technology and building operation requirements. This control does not change recirculation pump operation.

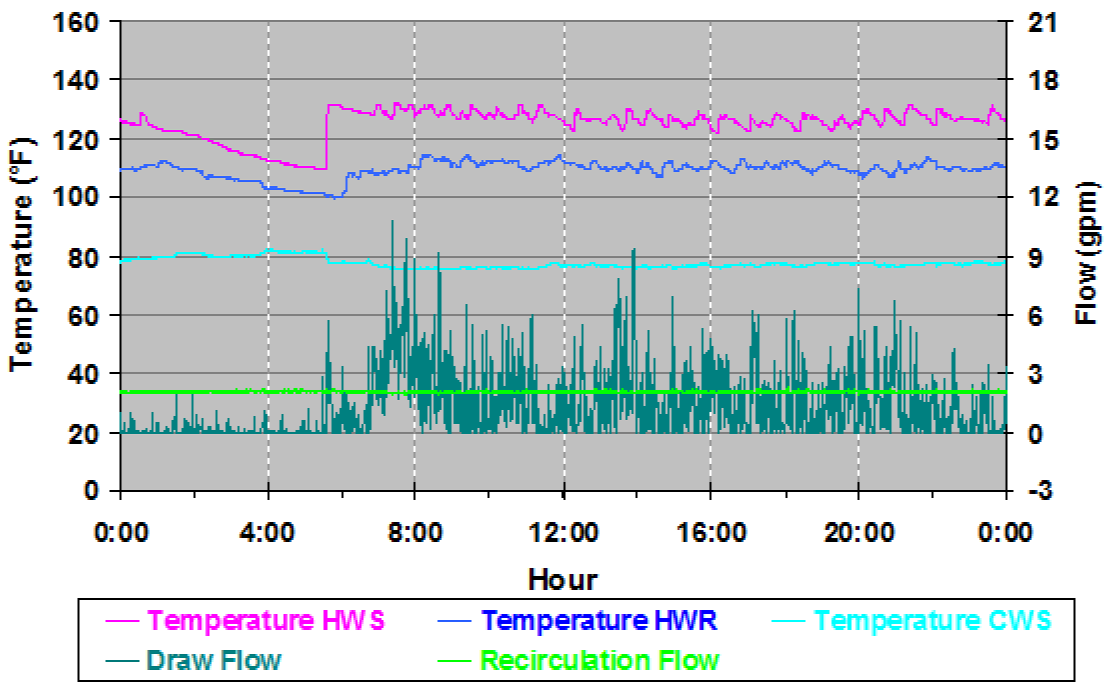

Figure 18. Example of Monitored Temperature Modulation Operation

Demand control technologies control recirculation pump operation based on hot water demand. Some demand control technologies also incorporate recirculation pump controls based on hot water return temperature measurement. These controls only switch the recirculation pump on when hot water demand is detected and the hot water return temperature is below a threshold. In other words, the recirculation pump is kept off if there is no hot water demand or the water temperature in the hot water pipes is deemed to be warm enough (above a threshold value set by the control). In recirculation systems, hot water demand is usually detected by a flow sensor installed on the cold water supply pipe. Manufacturers of demand control technologies include:

- Enovative Group
- Taco
- Uponor
- Advanced Conservation Technology Distribution

Figure 19 shows the temperature and water flow profiles under demand control. Since hot water demand exists throughout the day, the pump operation is determined by return temperature (Temperature HWR). The measurement shows the control threshold setting was slightly below 100˚F. The figure also shows the effect of pipe cool down after recirculation pump was turned off (reflected by the measurement of recirculation flow, the bright green curve).

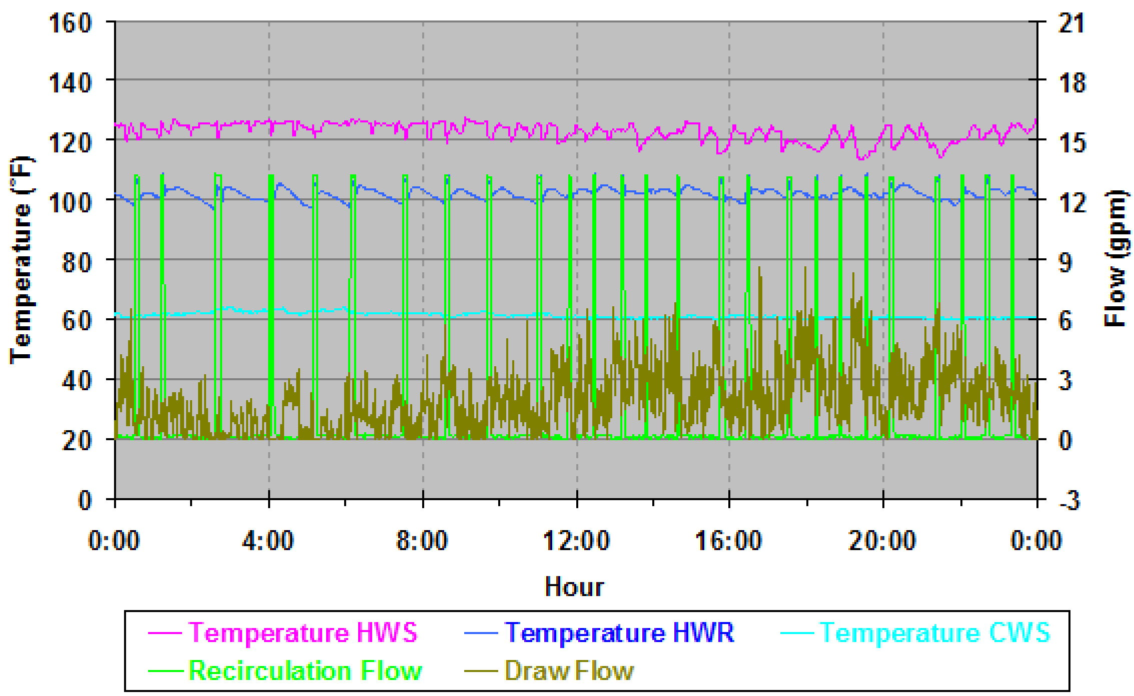

Figure 19. Example of Monitored Demand Control Operation

Recirculation control technologies save energy by reducing recirculation pipe heat loss, either by reducing temperatures of water flow in the loop (temperature modulation) or by letting recirculation pipes to cool down without water flow (demand control). Demand controls also provide pump energy savings. The PIER research indicated that energy savings could be accurately assessed through heat transfer analysis instead of through simple comparison of system gas consumption with and without controls, because large variations in daily hot water usages often offset impact by controls.

A continuous monitoring system monitors different operation parameters of the DHW system and automatically provides system operation status and malfunction updates to system operators. Although it does not actively control DHW system operations, it can help building maintenance personal to properly operate the DHW system without potentially using excessively high supply temperatures, which is a common way used by building operators to solve DHW system performance issues without knowing system operation details.

Despite promotion of recirculation system controls by utility incentive programs, market penetrations of demand control and temperature modulation technologies are still very low. Out of the total 50 buildings visited by the PIER field study, only one building had a temperature modulation control and five buildings had a demand control and all six buildings were built before 1985.

Since 2005, Title 24 standards mandate recirculation systems to have a control capable of automatically turning off the recirculation pump. The residential ACM Appendix E- Water Heating Calculation Method provides energy savings credit for timer control based on the assumption that timer controls turn off recirculation pumps from 10 PM to 5 AM everyday. As indicated above, PIER field studies and stakeholder feedbacks indicated that this assumption was not valid. The existing Title 24 requirements do not recognize energy savings by demand controls and temperature modulation controls.

DHW System Configurations

In addition to system performance monitoring, the PIER study investigated multifamily building recirculation system designs. For each building, where DHW system field performance monitoring was conducted, the project team gathered information on water heating systems, recirculation loop configuration, and pipe insulation. For buildings, where recirculation controls were studied, they carefully studied recirculation loop configurations in terms of pipe locations, lengths, diameters, and insulation levels according to both building plans and site inspection. The CASE study further investigated general recirculation loop design practices by reviewing building plans available from utility multifamily programs.

In general, both the PIER study and further CASE study efforts found that multifamily DHW distribution network can have various configurations. Although building shape determines the general locations of the recirculation loop, the pipe routes had a wide range of variation even with similar building shapes. The CASE study interviewed several mechanical system designers who designed the building DHW systems, which were investigated by the CASE study. The CASE team found that there is no industry guideline on DHW distribution system designs. Most of those systems were designed based on designers’ experience and some of those were based on hydronic heating distribution designs.

As pipe heating loss is directly correlated with pipe surface areas, detailed recirculation configurations have to be considered in understanding DHW distribution system performance. The PIER study conducted in-depth performance analysis and modeling using field monitoring data from four buildings, whose recirculation loop configurations were also carefully examined. The four buildings had very different recirculation loop designs and drastically different measured performance. The building performance data were used to test the general principle and accuracy of the recirculation loop performance model so that it can be applied to a broad range of designs. Figure 20 summarized recirculation loop configurations of the four buildings and Figure 21 to Figure 24 illustrate the corresponding loop structures.

Site 1 has a relatively complex recirculation layout. The mechanical room is located in the garage and the recirculation loop was split to serve two parts of the building. The recirculation loop serves the front of the building (part on the right in the figure), while the other serves the part located on top of the garage (left part on the figure). The first loop is routed through the second floor, and the fourth floor. The second loop is routed through garage ceiling, the second floor, and the fourth floor.

Site 2 shows an example of a simple recirculation loop. The mechanical room is located on the third floor (top floor) and the loop piping is routed through the second floor ceiling. This configuration reduces the length of the unit distribution branches, the longest one being two floors long. The hot water supply main line branches right after the mechanical room and serves all of one side of the building, which is centered, around a courtyard. When the hot water supply lines reach the opposite side of the building, they become hot water return lines, which merge before returning to the mechanical room.

Site 3 has the recirculation loop located in the garage ceiling space with long branches going from the recirculation loop to dwelling units above. Site 4 has a very similar arrangement but with several secondary loops.

Site ID	Recirculation Loop Location	Total Loop Length (ft)	Insulation	Supply		Return	
				Length (ft)	Diameter (inch)	Length (ft)	Diameter (inch)
Site 1-SFD	Garage (ground floor), second and third floor	1009	Fiber glass 1 inch	516	2.	493	1
Site 2-SAM	Ceiling of second floor	897	Fiber glass 1 inch	575	2	322	0.75
Site 3-SFF	Garage	437	Fiber glass 1 inch	218	2	219	1
Site 4-SFH	Garage	1391	Fiber glass 1 inch	678	2	713	0.75

Figure 20. Summary of Recirculation Loop Systems

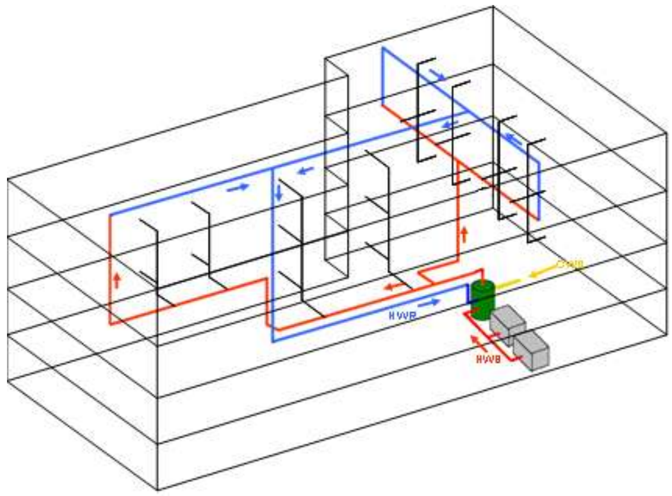

Figure 21. Site 1 - SFD

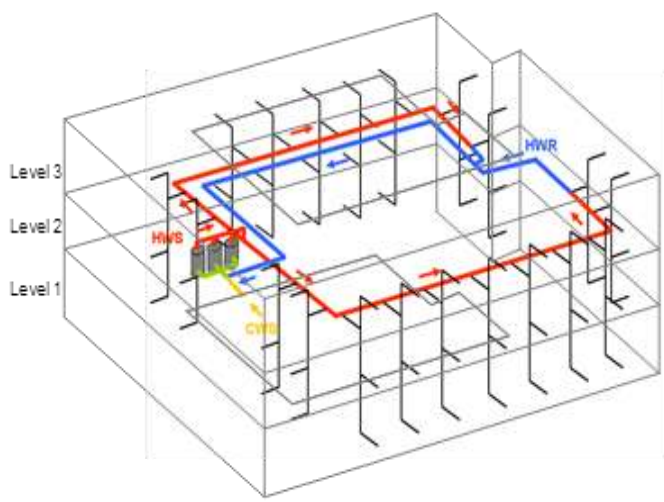

Figure 22. Site 2 - SAM

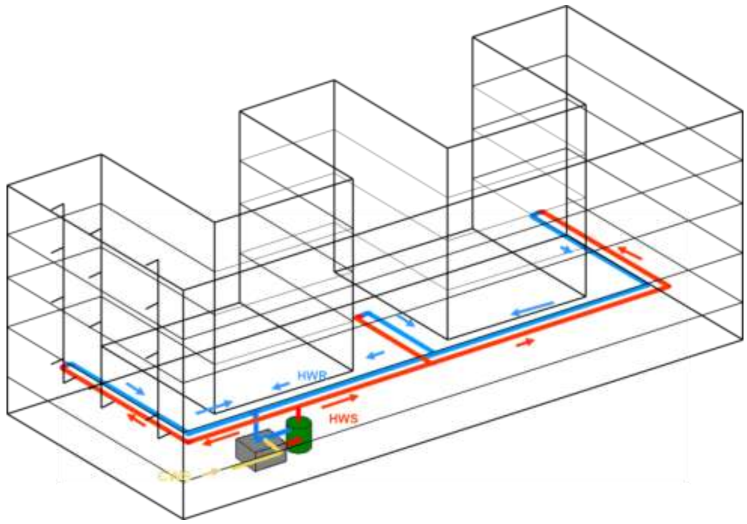

Figure 23. Site 3 - SFF

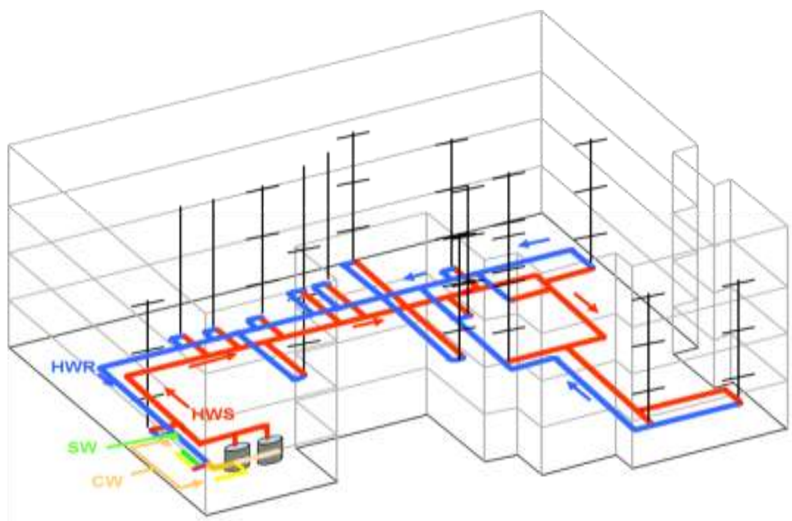

Figure 24. Site 4 - SFH

4.1.2 Energy Savings Analysis

Energy savings from control technologies and recirculation loop design improvement were evaluated using a multifamily DHW recirculation loop performance model developed by the PIER research and validated by the CASE study.

PIER Multi-family DHW System Recirculation Loop Performance Model

The PIER Multifamily DHW System Recirculation Loop Performance Model was developed to assess the recirculation system performance under different control schedules and operating conditions. It allows users to provide specific custom recirculation loop designs, including those with split-loop configurations. The Water and Space Heating CASE study provides a detailed description of the modeling method and the associated proposed ACM algorithms. In general, the model assesses heat loss of each pipe section along the recirculation loop. Pipe heat losses are modeled in two different modes, pipe with water flow and pipe without water flow, which represent two different heat transfer processes. In the first mode, water flow in the pipe maintains pipe temperature at a relatively stable level so that the heat loss is also stable. The exact pipe temperature and heat loss are modeled using heat transfer principles with consideration of pipe section supply temperature, flow rate, pipe diameter, ambient temperature, and insulation conditions. In the second mode, without water flows, pipe heat loss leads to steady reduction of water and pipe temperature so that pipe heat loss gradually slows down. The long the water flow is stopped, the lower the pipe temperature will be, and the less the pipe heat loss would be. Heat loss rate is a time-dependent value and is modeled based on the lump-capacitance heat transfer method. Heat transfer mode for each pipe section depends on hot water draw schedule, control schedule, and relative location of pipe section in the loop. The relative locations of pipe sections are used by the model pass flow and temperature information between connected pipe sections. The PIER model assesses overall system performance through model integration of all pipe sections.

This model was successfully validated with field measurement data for all control scenarios. As shown in appendix 6.3, for four significantly different buildings and recirculation loop designs, the modeled and measured values of recirculation loop heat loss and total system energy consumptions were very close to each other.

The model is implemented as an EXCEL tool. Some screenshots of the tool are shown in in appendix 6.4. The first step is to specify the central DHW system designs including recirculation loop pipe sections (pipe length, diameter, insulation thickness, and location), recirculation flow rate, pump power, and water heater efficiency. System operation schedule is then specified from a list of default choices or from a customer schedule. The operation schedule includes specifications of hot water supply temperature and pump status (on or off) for each time step. For the demand control, in order to model the intermittent pump operation, each hour is broken down into two uneven time steps. The pump is on during the first time step, which is usually short. The exact duration of the time step depends on return pipe volume and recirculation flow rate. The second time step lasts the remaining of the hour when the pump is off. The model incorporate Title 24 ACM draw schedule and weather data and can also use customer draw schedule and weather data. For model validation, we used field measured hot water draw patterns and operation schedules.

The model produces detailed hourly system performance data, such as hot water temperatures of each pipe sections and system energy (natural gas and electricity) consumptions. TDV energy consumptions are calculated accordingly using the new TDV values for 2013 Title 24 development.

Energy Analysis Assumptions

The Water and Space heating CASE study developed a set ACM algorithms based on the PIER recirculation loop model. In order to make the compliance process more practical, the proposed ACM algorithm only requires the recirculation loop to be modeled as six pipe sections, with three hot water supply sections and three hot water return sections. This CASE study followed the proposed ACM algorithms by using a six-section recirculation model to estimate energy savings.

General DHW system operation conditions are based on the Title 24 residential ACM Appendix E, including hot water draw schedule, ground water temperature (cold water supply temperature), and hot water supply temperature (135°F). Indoor temperature was assumed to be 72°F.

Control schedule assumptions are shown in Figure 25 through Figure 28. Each day were broken into forty-eight (48) time intervals (two per hour). For temperature modulation and continuous monitoring, time intervals are uniform with each at 30 minutes. Temperature modulation control was assumed to reduce the supply temperature by 10°F from 1 am to 5 am to with one-hour transitions at 12pm and 6am. Continuous monitoring benefits were modeled by lowering the supply temperature by 5°F, as explained in the previous section. The combined temperature modulation and continuous monitoring control were assumed to achieve the effects of both controls as shown in Figure 25 and Figure 26.

As explained above, demand controls have varying time step intervals, with successive pump on/pump off sequences. Figure 27 and Figure 28. present the pump operation schedule for the low-rise and high-rise prototype buildings used in CASE study.

Step Index	Time Interval (min)	Pump On/Off	How Water Supply Temperature (°F)		
			Temperature Modulation	Continuous Monitoring	Temperature Modulation + Continuous Monitoring
1	30	On	125	130	120
2	30	On	125	130	120
3	30	On	125	130	120
4	30	On	125	130	120
5	30	On	125	130	120
6	30	On	125	130	120
7	30	On	125	130	120
8	30	On	125	130	120
9	30	On	125	130	120
10	30	On	125	130	120
11	30	On	130	130	125
12	30	On	130	130	125
13	30	On	135	130	130
14	30	On	135	130	130
15	30	On	135	130	130
16	30	On	135	130	130
17	30	On	135	130	130
18	30	On	135	130	130
19	30	On	135	130	130
20	30	On	135	130	130
21	30	On	135	130	130
22	30	On	135	130	130
23	30	On	135	130	130
24	30	On	135	130	130

Figure 25. Control Schedule for Temperature Modulation and Continuous Monitoring (Part 1)

Step Index	Time Interval (min)	Pump On/Off	How Water Supply Temperature (°F)		
			Temperature Modulation	Continuous Monitoring	Temperature Modulation + Continuous Monitoring
25	30	On	135	130	130
26	30	On	135	130	130
27	30	On	135	130	130
28	30	On	135	130	130
29	30	On	135	130	130
30	30	On	135	130	130
31	30	On	135	130	130
32	30	On	135	130	130
33	30	On	135	130	130
34	30	On	135	130	130
35	30	On	135	130	130
36	30	On	135	130	130
37	30	On	135	130	130
38	30	On	135	130	130
39	30	On	135	130	130
40	30	On	135	130	130
41	30	On	135	130	130
42	30	On	135	130	130
43	30	On	135	130	130
44	30	On	135	130	130
45	30	On	135	130	130
46	30	On	135	130	130
47	30	On	130	130	125
48	30	On	130	130	125

Figure 26. Control Schedule for Temperature Modulation and Continuous Monitoring (Part 2)

Step Index	Pump On/Off	Hot Water Supply Temperature (°F)	Time Interval (min)			
			Low-rise		High-rise	
			Demand Control (Default Design)	Demand Control (Optimized Design)	Demand Control (Default Design)	Demand Control (Optimized Design)
1	On	135	14.8	7.4	22.6	11.3
2	Off	135	45.2	52.6	37.4	48.7
3	On	135	14.8	7.4	22.6	11.3
4	Off	135	45.2	52.6	37.4	48.7
5	On	135	14.8	7.4	22.6	11.3
6	Off	135	45.2	52.6	37.4	48.7
7	On	135	14.8	7.4	22.6	11.3
8	Off	135	45.2	52.6	37.4	48.7
9	On	135	14.8	7.4	22.6	11.3
10	Off	135	45.2	52.6	37.4	48.7
11	On	135	14.8	7.4	22.6	11.3
12	Off	135	45.2	52.6	37.4	48.7
13	On	135	14.8	7.4	22.6	11.3
14	Off	135	45.2	52.6	37.4	48.7
15	On	135	14.8	7.4	22.6	11.3
16	Off	135	45.2	52.6	37.4	48.7
17	On	135	14.8	7.4	22.6	11.3
18	Off	135	45.2	52.6	37.4	48.7
19	On	135	14.8	7.4	22.6	11.3
20	Off	135	45.2	52.6	37.4	48.7
21	On	135	14.8	7.4	22.6	11.3
22	Off	135	45.2	52.6	37.4	48.7
23	On	135	14.8	7.4	22.6	11.3
24	Off	135	45.2	52.6	37.4	48.7

Figure 27. Control Schedule for Demand Control (Part 1)

Step Index	Pump On/Off	Hot Water Supply Temperature (°F)	Time Interval (min)			
			Low-rise		High-rise	
			Demand Control (Default Design)	Demand Control (Optimized Design)	Demand Control (Default Design)	Demand Control (Optimized Design)
25	On	135	14.8	7.4	22.6	11.3
26	Off	135	45.2	52.6	37.4	48.7
27	On	135	14.8	7.4	22.6	11.3
28	Off	135	45.2	52.6	37.4	48.7
29	On	135	14.8	7.4	22.6	11.3
30	Off	135	45.2	52.6	37.4	48.7
31	On	135	14.8	7.4	22.6	11.3
32	Off	135	45.2	52.6	37.4	48.7
33	On	135	14.8	7.4	22.6	11.3
34	Off	135	45.2	52.6	37.4	48.7
35	On	135	14.8	7.4	22.6	11.3
36	Off	135	45.2	52.6	37.4	48.7
37	On	135	14.8	7.4	22.6	11.3
38	Off	135	45.2	52.6	37.4	48.7
39	On	135	14.8	7.4	22.6	11.3
40	Off	135	45.2	52.6	37.4	48.7
41	On	135	14.8	7.4	22.6	11.3
42	Off	135	45.2	52.6	37.4	48.7
43	On	135	14.8	7.4	22.6	11.3
44	Off	135	45.2	52.6	37.4	48.7
45	On	135	14.8	7.4	22.6	11.3
46	Off	135	45.2	52.6	37.4	48.7
47	On	135	14.8	7.4	22.6	11.3
48	Off	135	45.2	52.6	37.4	48.7

Figure 28. Control Schedule for Demand Control (Part 2)

4.1.3 Energy Savings Results

Figure 29 presents the energy savings from different recirculation loop control technologies. Since recirculation loops are mostly located in conditioned spaces, energy savings are not sensitive climate zones. Electricity consumption reductions are due to decreased pump operation, and hence only occur with demand controls. The electricity savings are not climate-zone sensitive. The natural gas savings show little sensitivity to the different climate zones, as most of the distribution network is assumed to be located in conditioned spaces.

The combination of temperature modulation and continuous monitoring yields twice as much gas savings than temperature modulation only or continuous monitoring only, while demand control savings yields two and a half times more savings than temperature modulation only. Demand savings estimates are based on the average pump time off during an hour under demand control scheme.

Control Technology	Low-rise			High-rise		
	Electricity Savings (kWh)	Demand Savings (kW)	Natural Gas Savings (Therms)	Electricity Savings (kWh)	Demand Savings (kW)	Natural Gas Savings (Therms)
Temperature Modulation	0	0	405	0	0	535
Continuous Monitoring	0	0	461	0	0	771
Temperature Modulation + Continuous Monitoring	0	0	785	0	0	1199
Demand Control	1228	0.140	1014	2035	0.233	1255

Figure 29. Control Energy Savings

4.1.4 Cost Analysis

This CASE study proposes the prescriptive requirements of installation of demand controls. Based on interview with manufacturers, demand control equipment cost about $1000 for each recirculation loop system and installation cost is about $200. The lifetime for demand control is about 15 years. As a result, for the 30-year LCC analysis, a demand control is assumed to be installed twice, one in the first year and one in the sixteenth year.

Both optimized design and default design recirculation loop piping material cost were calculated using detailed recirculation system design, which breaks the piping into different sections depending on pipe diameter, which decrease along the recirculation loop (and is related to the number of units by section). Each section cost was estimated using copper pipe type L price per linear foot summarized in Figure 30. Neither incremental installation nor maintenance costs were considered, as the total length of piping is similar in both cases, leading to similar labor cost, and usually no maintenance is performed after installation. The cost of each design, as well as the incremental cost of the design improvement is shown in Figure 31. For both low-rise and high-rise building, this incremental cost is significant.

Pipe Diameter	Price ($/ft)
0.75	3.65
1	5.40
1.25	7.78
1.5	9.85
2	19.08
2.5	29.84
3	34.43
3.5	49.95

Figure 30. Copper Piping Type L Cost ($/ft) for different pipe diameter

Recirculation System Configuration	Low-rise	High-rise
Default	$9,785	$18,300
Optimized	$7,625	$10,407
Optimized Incremental Cost	$(2,159)	$(7,892)

Figure 31. Recirculation Configuration Cost

4.2 Analysis and Results for Solar Water Heating

This section presents results from our data collection efforts and savings analysis for multi-family solar water heating.

4.2.1 Solar Water Heating Technology

Solar water heating systems are made up of components which collector solar heat, store solar heat, delivers hot water, control the operation and protect the system again freezing. Understanding in basic system components, their functions and how system performances are currently evaluated helps the team make informed decision on the simulation software and ultimately define system configurations and inputs for the simulation runs.

For harvesting solar energy, various types of collectors are available on the market. The most common types of collectors are flat plate collectors. Collectors are rated by the Solar Ratings Certification Corporation (SRCC), and included in SRCC's OG-100 database. Technical specifications included in the database include daily energy harvesting potential of the given panel at various inlet and outlet working fluid temperature differences, the dimension of the collectors, pressure drop across the collectors and collector efficiency as a function of collector temperature amongst other technical quantities.

For the storage of solar energy, unheated solar water tanks or electric or gas water heating tanks can be employed. To deliver the collected and stored energy where it is needed, components such as heat transfer fluid (water vs. glycol or air), pumps, pipes and heat exchangers are necessary. Control equipment driven by temperature differential, PV or time is needed to determine when sufficient solar energy is available to be transferred into the domestic water heating system, .

Lastly, for prevention of fluid freezing and resulting damage to the collector, various strategies can be applied. These include the use drainback tanks, continuous water flow, freeze prevention valves (mostly in colder weather than California) or recirculation of working fluid with lower freeze point such as propylene glycol. More detailed descriptions and schematics of freeze protection strategies are included in the market condition section of the report.

Inter-related to the system components, solar water heating systems may be categorized in many different ways, in additional to the type of collectors used. Some common distinctions include:

- Unglazed liquid, glazed liquid vs. air collector types, depend on the collector work fluid
- Open vs. close system type, depending on whether the collector loop and the water heater loop are the same where the working water also is served to the end user
- Active vs. passive system types, depending on the pumping method
  - Active systems are those with active pumping for circulation and/or freeze protection
  - Passive systems include: thermosyphon and integrated collector storage (ICS)
- Freeze protection: automatic mechanism (automatic draining, antifreeze fluids, thermal mass, sometimes with manual draining capability or recirculation loop)

Besides satisfying the domestic hot water use, solar water heating system, especially the larger multifamily sized systems, are often coupled with hydronic space heating as well. The study only considered solar water heating for offsetting the domestic water heating budget, not space heating.

4.2.2 Current Title 24 Requirements

There are currently no requirements for installing solar water heating systems for multifamily buildings in California. However, solar water heating is required for new state buildings and residential buildings with certain features.

In terms of requiring solar water heating installation for larger buildings, the state set a precedent by adding the mandatory requirement in Section 113(c)6, which requires that new state buildings to provides at least 60 % of the water heating energy from site solar energy or recovered energy. To satisfy this requirement, systems and/or collectors must be certified by the Solar Rating and Certification Corporation (SRCC). This section of the code also states that the requirement may be omitted when deemed economically or physical infeasible, which left much of the requirement up to interpretation.

Furthermore, for single family buildings that wish to demonstrate compliance using Component Package C (for buildings with electric-resistance space heating), Title 24 requires that the primary water heating may be electric-resistance only if the water heater is located within the building envelope, and a minimum of 25% of water heating energy is provided by a solar system. However, since this minimum solar water heating requirement appears only as a footnote to the Component Package table, the team suspects and it is confirmed via the Residential Appliance Saturation Study (RASS) database, that there is relatively low compliance in the market. Another CASE topic, Single-Family and Specialty Commercial Solar Water Heating, explores the opportunity of requiring a higher solar fraction requirement for electric resistance water heating in low-rise residential buildings and possibility of clarifying this minimum requirement in the code to increase the installation of solar systems.

4.2.3 Market Condition of Solar Water Heating Systems

National

There are a wide variety of solar collectors available on the market today. US Energy Information Administration's annual report on the manufacturing activities provides a snapshot of the domestic distribution of solar thermal collectors. The more-relevant collector type here is the "Medium-Temperature" type, which the EIA defines as having working fluid temperature of 140-180°F. Within medium-temperature collector types, flat-plate collectors are over 75% of the market share.

Market Sector/ End Use	**Type**						
	Low-Temperature	**Medium-Temperature**					**High-Temperature**
	Liquid/Air		**Liquid**				
	Metallic and Nonmetallic	**Air**	**ICS/ Thermo-siphon**	**Flat-Plate (Pumped)**	**Evacuated Tube**	**Concen-trator**	**Parabolic Dish/ Trough**
Market Sector							
Residential	8,423	17	134	1,466	199	-	-
Commercial	526	4	7	278	123	26	10
Industrial	11	-	-	27	1	-	594
Electric Power	-	-	-	-	-	-	374
Transportation	-	-	-	-	-	-	-
U.S. Total	**8,959**	**21**	**141**	**1,771**	**324**	**26**	**978**
End Use							
Pool Heating	8,882	-	-	47	5	-	-
Hot Water	7	5	141	1,553	286	-	-
Space Heating	61	14	-	70	5	-	-
Space Cooling	-	s	-	-	-	-	10
Combined Space and Water Heating	9	2	-	100	27	-	-
Process Heating	-	-	-	2	-	11	594
Electricity Generation	-	-	-	-	-	15	374
U.S. Total	**8,959**	**21**	**141**	**1,771**	**324**	**26**	**978**

Figure 32. Domestic Shipment of Solar Thermal Collectors in 2009 (in 1000s of ft^2)

Figure 32 also sheds light on market condition in terms of market sector and end use. The upper portion of the table shows that by market sector, residential uses account for 83% of the flat-plate collectors. By end use, approximately 87% of flat plate collectors are used for domestic water heating purposes. Low temperature collectors are typically used for swimming pools and approximately 5 times as much area is sold. High temperature collectors are typically used for making steam for electricity production or industrial uses and the market share is approximately half that of medium temperature collectors.

Aligned with the trend of renewed interest in solar water heating applications, the federal government enacted a capped Federal investment tax credit of 30% in 2005, and extending this to an uncapped version in 2008 and lasting until 2016 to encourage the use of solar water heating in residential buildings[1].

California

There are a number of resources the team examined to study the solar water heating market for multifamily buildings in California. The 2009 Residential Appliance Saturation Study (RASS) conducted by KEMA indicates that current market penetration of solar water heating in multifamily buildings is just below 1% (Figure 33).

Building Population	Year	Building Population	Solar Water Heating	Solar Space Heating	Total Solar
Apt Condo 2-4 Units	2009	872,492	7,939	30,223	38,162
			0.9%	3.5%	4.37%
Apt Condo 5+ Units	2009	2,007,514	16,814	21,537	38,351
			0.8%	1.1%	1.91%

Figure 33. Solar Water Heating Penetration Rate in Apartments/Condos

In terms of program resources, there have been two major incentive programs in California to stimulate the wide adaptation of solar water heating systems in buildings. Namely, they are the Solar Water Heating Pilot Program and its successor, the California Solar Initiate- Solar Water Heating Program (CSI-Thermal), an incentive program with dedicated funding specifically for single family, multifamily and commercial buildings.

Available program resources were invaluable to help paint a picture of the solar water heating market in California, as they offered various reports and databases of participating projects with information on market condition, penetration, costs and barriers.

The Pilot Program was an 18-month incentive program implemented in the Sempra territory and administered by the California Center for Sustainable Energy. It started in July 2007 and California Public Utilities Commission intended to use the Pilot Program to inform the creation of the $250 million statewide CSI-Thermal in accordance with provisions established by Assembly Bill 1470.

Shortly after the Pilot Program and upon CPUC's review and approval of the cost-effectiveness pilot program, CSI-Thermal program was created and started in 2010. The program goal states that 64% of the incentive amount would be allocated for gas-displacing solar water heating systems, and 60% of the total incentive amount would be for multifamily/commercial projects. Much of the decision on this study's simulation efforts presented in the rest of the results and analysis section was based on data from these two programs. For our CASE analysis we utilized data from the two incentive

[1] Federal Residential Renewable Energy Tax Credit: http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US37F

programs. We consulted the program handbook and calculation tool for simulation efforts, we utilized the database for system cost info and stakeholder recruitment and engagement process.

In addition to reviewing data available from the programs, we also developed a survey tool targeting solar equipment manufacturers, designers and installers to collector information on market condition. The online survey questions (Appendix 7.3) spanned across prevalent system configurations, design (sizing and economic analysis) tool selection, breakdown between single vs. multifamily, new vs. retrofit projects, design consideration for different climate zones and specific to multifamily sized projects and market barriers.

Market Breakdown

The team aimed to determine prevalent solar system configurations in California to focus the simulation efforts. The program data and our survey results provided consistent information on system type (Figure 34).

While only residents in Sempra Utilities service area were eligible to participate in the Pilot Program and there were only fifteen multifamily/commercial projects, the applicant system type breakdown chart below showed that water drainback was the dominant system types installed. In contrast, both responses to our survey tool and the CSI-Thermal database indicated that active glycol was the most popular, followed by water drainback, and there were few installations of forced circulation (water) systems. We suspect that differences between the two data sources stem from the fact that the Pilot Program covered only the southernmost part of the state with lesser degree of need for freeze protection. The few installations reported for forced circulation systems in the survey is reflective of the exclusion of forced circulation system type in the newly implemented CSI-Thermal program.

Data Source	Survey Participants (Sample Population)	System Type		
		Water Drainback	Active Glycol	Forced Circulation
Online Survey	Solar equipment manufacturers, designers and installers (10)	20%	78%	< 1%
CCSE Pilot Program	MF projects in Sempra service territory (20)	11	3	6
CSI-Thermal	MF projects in the entire state (~40)	~ 10%	> 90%	Not allowed

Figure 34. System Configuration Breakcdown

- Survey Results and Program Resources

Based on the data collected via reviewing program resources, results from our survey efforts and to continue the synergy between the CSI-Thermal program's and our simulation work, the team narrowed our simulation and cost-effectiveness analysis down to these four system configurations:

1. Active Glycol with External Heat Exchanger
2. Active Glycol with Immersed Heat Exchanger
3. Water Drainback
4. Forced Circulation (Open Loop)

It should be noted that the last system configuration, forced circulation, is not allowed in the CSI-Thermal program due to possible freezing issues, pending conclusion drawn from further technical assessment. The decision of including this system type in our study was based on its possibly sizable market share in the southern, warmer part of the state and the consideration of its possible inclusion in incentive programs in the future.

Market Barriers

The most informative resource in terms of identifying major market barriers to solar water heating technology in California is the interim evaluation report to the Pilot Program, authored by Itron. The major market barriers included large upfront installation cost, general lack of both public knowledge and experience in solar water heating installers.

These findings were confirmed by our survey results as well. When asked to rank a number of possible market barriers, the overall economics (high first cost, long payback) of solar water heating was overwhelmingly identified as the number one barrier, followed by lack of knowledge in technology in general public.

	Market Barrier Ranking Options			
	Lack of knowledge on technology in general public	Equipment availability	Lack of trained installers	Overall economics (long payback period, low life-cycle cost savings, etc.)
Average Ranking	1.89	4.00	2.56	1.56

Figure 35. Online Survey Results: Market Barriers Ranking

Out of the nine responses received, four of them also identified the lack of space in the mechanical room for solar equipment as a common issue encountered with multifamily sized solar water heating projects. The competition on roof space with photovoltaic was mentioned by one respondent.

4.2.4 Existing Solar Ready Regulations and Voluntary Codes

Recognizing that solar water heating has been adopted more widely in some parts of the world, the team started researching for relevant solar ready measures by reviewing literatures from organizations such as the Intelligent Energy, Europe and Solar Thermal Ordinances website by Solar Thermal Industry Federation (ESTIF) and Natural Resources Canada (NR Canada). Each of these organization had documents with recommendations on how to approach and construct the solar thermal ready ordinances and examples. A few common ideas mentioned included linking solar installation requirement to solar savings fraction (% heating budget). However, lining solar installation requirement to minimum collector area was not recommended in generally because it may adversely encourage lower performance collectors.

The team also examined the rating criteria of GreenPoint Rated for Multifamily buildings and LEED 2009 for new and retrofit. Out of the 100 points possible for the GreenPoint Rated scale, 4 possible points are allocated for installation of solar hot water system to preheat domestic hot water to satisfy at least 40% of the water heating load. There was also once a point given for pre-plumbing for solar water heating. Proposed update to ASHRAE 189.1 Renewable sections were reviewed as well. However, while considering requirement on renewable electric generation in terms of generation density (kWh/m^2) and total roof area (m^2), the version of ASHRAE 189.1 proposal last reviewed did not include any provision on solar water heating. LEED 2009 criteria yielded a similar story. The 7 points available (out of 100 total) in the renewable energy section were all given for installation of renewable electricity generation depending on the percentage of load satisfied by the installed PV system.

On a domestic level, NREL developed a Solar Ready Planning Guide to provide guidance, including a check list (ref appendix) on items to pay special attention to when designing solar ready requirements. On the safety side, the team, along with the other photovoltaic-related topic authors reviewed the Roof Fire Access document by California Department of Forestry and Fire Protection, Office of the State Fire Marshal. (ref appendix) The team considered local ordinances from cities such as Portland, San Rafael and Chula Vista. While these local ordinances were useful in identifying the type of measures and language structure of making building solar water heating ready, almost all the specifications of these requirements were specific to single family buildings.

Industry stakeholders were asked to provide ideas on solar ready measures and possible sizing rules and guidance through direct phone interviews and the codes and standards enhancement stakeholder meeting process. Combining the results of the literature review and feedbacks received from industry stakeholders, here is a summary list of possible solar ready measures, roughly in the order of importance noted:

- Roof space reservation
- Room in/around boiler room for solar storage tank
- Pre-plumbing of water piping
- Pre conduit for electrical connections for controller and pumps
- Roof truss load

The team, along with the rest of the solar topic CASE authors, investigated the feasibility of each of the measures, and the development of each of the measure is discussed below to support the decision of inclusion/exclusion into the suite of solar water heating measures proposed.

Adequate Roof Space for Collectors

Adequate roof space for both solar thermal collectors and photovoltaic panels is one of the first things system designers advocate for when considering making a building ready, there was little hesitation on including this measure. The main task in crafting this measure is in regards to specifying and quantifying the requirement. The requirement could be defined in a number of ways

- Specifying the collector sizing ratio according to the daily hot water demand, in ft^2 area per gal/day demand, calculated from a targeted solar savings ratio, OR
- Specifying the percentage of total roof area, again calculated from a targeted solar savings ratio

Specifying the collector area percentage directly may be desirable because it is more easily verified by building officials during inspection. However, this approach does not account for the variation of collector area need with number of stories and thus building footprint and roof area available. The team decided to pursue the route of defining solar water heating ready by specifying the percentage of total roof area needed to be reserved. The team would also largely adopt requirements regarding shading and orientation from the existing CSI-Thermal program guidelines/calculation rules, as much resources and thoughts were invested and there is great synergy between our efforts.

Adequate Space for Solar Water Heating Equipment

The concern regarding adequate space for future installation of solar water heating system is mainly on the room for the solar tank, as it is the equipment with the largest footprint within the system. Many of the solar water heating system designers pointed this out during our interviews as a major difficulty. While it is not essential to have the solar tank located within the boiler room, it is greatly helpful to plan out and reserve the space for the solar tank within or near the boiler room where the auxiliary heater or system is located. If located outside of the boiler room, it was suggested that a requirement for an external concrete pad to be installed. The team estimated the cost associated with housing the solar tank inside the boiler room in the Energy Savings section because this is likely to be the more cost option.

Pre-Plumbing and Pre-Conduit for SWH System

As mentioned earlier, almost all of the literature sources reviewed included specific (though different) requirements on how to pre-plumb and install pre-conduit or chase to facilitate future electric needs associated with solar water heating systems. However, major challenges exist on the development of general, easily followed and verified yet still useful requirements for this purpose. after surveying the various techniques and existing requirements and communication with industry stakeholders, the team decided to pursue this idea by requiring the pre-plumbing and pre-conduit routes to be specified and market on the plans instead of requiring actual installation. This decision is mainly based on feedback from stakeholders concerns over incompatible pre-pluming and conduit being installed, since future technology development is difficult to predict. In addition, mapping out the plumbing and conduit route accomplishes the goal of avoiding inefficient or difficult plumbing and conduit paths in the future without risking the danger of installing infrastructure which may be technology specific.

Sufficient Roof Truss Load

Various literature sources cited roof truss load requirement of additional capacity of approximately 5 lb/ft^2 (to mainly account for load from a solar tank) and occasionally requirement for wind load analysis. The team determined that most multifamily buildings in compliance of the building structural code already have sufficient roof truss capacity to withstand resulting loads from solar water heating equipment. In addition, a more appropriate place for design guidelines such as this one would be the Title 24 residential manual instead of the code language itself.

4.2.5 Energy Savings

This section presents simulation results, in terms of annual gas and electric savings, time dependent valued (TDV) kBtu savings and their corresponding present value energy cost savings.

Performance Base Simulation

The purpose of this part of the simulation results was to differentiate between the performance of various SHW system configurations, and the California climate zones while keeping all SHW system sizing parameters constant. Trends observed from these performance base results was applied to simulation results obtained in the permutation runs described in Sections “Permutation Simulation Phase I - Design Component Sizing” and “Permutation Simulation Phase II - Collector Area Sizing Optimization.”

Comparison of a Single System Type across Climate Zones

Figure 36 presents energy savings results for the low-rise prototype with an active glycol (external heat exchanger) solar water heating system using design inputs presented in Figure 14. Results for all system configurations for both low-rise and high-rise prototypes are presented in appendix 7.5.

Climate Zone/ City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms /yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	2,383	2,889	(57,767)	447,379	67,476	59%
2. Santa Rosa	2,329	3,440	(48,075)	533,121	84,004	73%
3. Oakland	2,415	3,448	(51,104)	535,599	83,909	73%
4. San Jose Reid	2,348	3,510	(46,651)	547,500	86,741	76%
5. Santa Maria	2,470	3,778	(52,199)	596,723	94,305	81%
6. Torrance	2,520	3,616	(52,423)	572,753	90,115	81%
7. San Diego	2,476	3,656	(51,428)	582,160	91,916	83%
8. Fullerton	2,369	3,556	(47,370)	562,747	89,257	81%
9. Burbank-Glendale	2,345	3,517	(45,363)	556,915	88,595	81%
10. Riverside	2,309	3,550	(44,796)	563,239	89,788	82%
11. Red Bluff	2,191	3,305	(42,013)	513,793	81,707	74%
12. Sacramento	2,272	3,299	(44,458)	508,971	80,448	72%
13. Fresno	2,086	3,109	(39,362)	480,431	76,388	72%
14. Palmdale	2,361	3,786	(44,891)	601,538	96,405	85%
15. Palm Springs	2,189	3,341	(40,975)	533,930	85,374	90%
16. Blue Canyon	2,390	3,625	(46,903)	565,860	89,877	71%

Figure 36. Energy Savings and Solar Fractions of Base Performance Runs - Low-Rise Multifamily Prototype, Active Glycol with External HX System

A few observations can be made when examining these energy savings and solar savings fraction results. First, when we convert the electricity use from the solar pumps from kWh to therms for comparison purpose, the electricity use negates roughly 5% of the natural gas savings across the climate zones. However, after converting the raw energy savings to TDV kBtu saving, the TDV electricity savings (negative denotes increase in usage) becomes nearly 20% of the TDV gas savings since electricity usage during the day when solar water heating systems would be active is largely penalized when evaluated on the TDV basis. The present value of energy cost savings column (second to last) is simply the sum of the TDV electricity and gas savings figures multiplied by a $/TDV kBtu scalar number.

In terms of solar savings fractions, climate zones 7,10,14 and 15 exhibited the highest values while climate zone 1 yielded a substantially lower savings fraction. This trend in CZ 10, 14, 15 and CZ 1 appeared logical, as the first three climate zones have very high solar insolation levels , and CZ 1 has a relatively low solar insolation level. However, it may be surprising to some that other zones with high insolation level as well, such as CZ 12 and 13 (Fresno and Sacramento), did not display higher solar fraction savings. This may be explained by examining the Title 24 monthly cold water inlet temperatures for these climate zones (Figure 37).

The cold water inlet temperature values are colored to visually highlight the temperature variations between months within each climate zone. As evident in the table, CZ 11 and 12 both exhibit large temperature variations between the winter and summer months. Physically, this implies that with the same amount of collector areas, during the summer months when the most solar insolation level is available, the end use water heating energy budget (which is proportional to the temperature difference between the fixed hot water supply temperature of 135°F and the cold water inlet temperature) is also the lowest. The opposite is also true, during the winter months, the low insolation level and the high end use water heating energy demand also coincide. This mismatch between the solar resources availability and the end use water heating energy demand is the reason behind the relatively low solar savings fraction for climate zones with large cold water temperature variations between months.

Climate Zone	City	Jan 1	Feb 2	Mar 3	Apr 4	May 5	Jun 6	Jul 7	Aug 8	Sep 9	Oct 10	Nov 11	Dec 12
1	Arcada	52.2	51.5	51.4	51.8	53.1	54.5	55.6	56.4	56.4	55.8	54.7	53.4
3	Oakland	55.1	54.1	54	54.5	56.5	58.5	60.3	61.4	61.5	60.6	58.9	56.9
7	SD Coastal	60.1	59.1	59	59.5	61.5	63.4	65.2	66.2	66.3	65.5	63.8	61.9
10	Riverside	59.4	57.6	57.4	58.3	61.8	65.2	68.2	70.1	70.2	68.7	65.8	62.4
11	Fresno	54.9	52.4	52.2	53.4	58.2	63	67.2	69.8	70	67.9	63.8	59.2
12	Sacramento	54.6	52.5	52.3	53.3	57.3	61.3	64.8	67	67.2	65.4	62	58.1

Figure 37. Cold Water Inlet Tempratures by Climate Zone

Comparison across System Configurations in a Single Climate Zone

Compiling and plotting the solar savings fractions for each prototype building and all climate zones (Low-rise results are shown in Figure 38; high-rise results in Appendix 7.5.1), it is clear that for the input parameters defined, water drainback configuration produces the highest solar savings fractions, followed by forced circulation and active glycol (with both external and immersed HX) configurations in general. Simulation results for a system with evacuated tube type collectors are also plotted below for comparison. With the same sizing criteria, evacuated tube system exhibits performance similar to that of a water drainback system and forced circulation system.

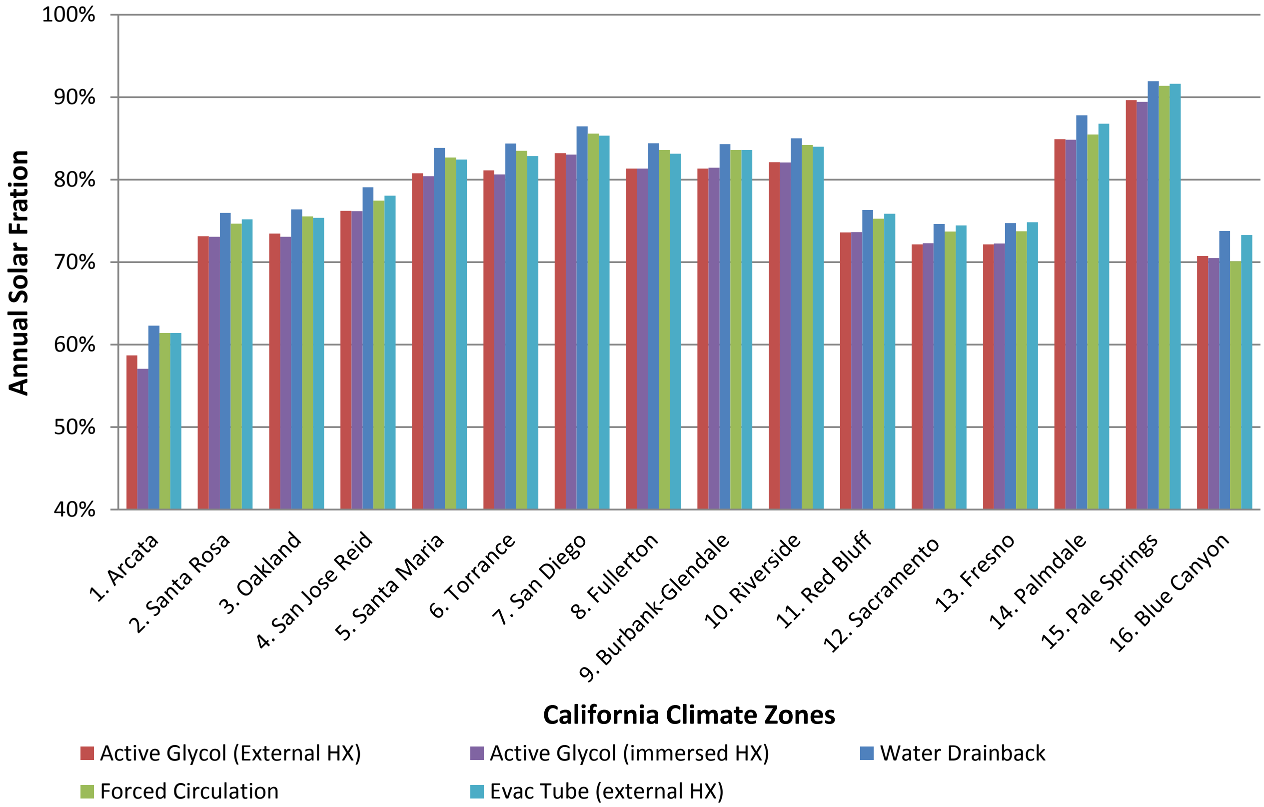

Figure 38. Solar Savings Fractions for Various Configurations

- Low-rise Multifamily Prototype, All Climate Zones

Figure 39 displays the performance differences between the system configurations in terms of percentage difference from solar savings fraction of the active glycol (external HX) configuration. For the system sizing and prototype building defined, water drainback systems had solar fractions almost 4% higher than their active glycol (external HX) counterparts. As this CASE study aims to investigate the feasibility of solar water heating technology for use in multifamily buildings and establish a bottom line in terms of minimum solar savings fractions, we decided to use the active glycol (external HX) as the default baseline system, while keeping in mind that systems with higher performance in terms of solar savings fractions are certainly achievable. Note that although the modeled active glycol (immersed HX) exhibits slightly lower performance than the chosen default baseline, active glycol (external HX), it is much less common for multifamily-sized systems because immersed type heat exchange built in the storage heaters become less practical for solar water heating systems of large sizes.

Climate Zone/ City	Active Glycol (immersed HX)	Water Drainback	Forced Circulation
1. Arcata	-2.7%	6.1%	4.6%
2. Santa Rosa	-0.1%	3.8%	2.1%
3. Oakland	-0.5%	4.0%	2.8%
4. San Jose Reid	-0.1%	3.7%	1.6%
5. Santa Maria	-0.4%	3.8%	2.4%
6. Torrance	-0.6%	4.0%	2.9%
7. San Diego	-0.2%	3.9%	2.9%
8. Fullerton	0.0%	3.8%	2.8%
9. Burbank-Glendale	0.1%	3.6%	2.8%
10. Riverside	-0.1%	3.5%	2.5%
11. Red Bluff	0.0%	3.7%	2.2%
12. Sacramento	0.2%	3.4%	2.2%
13. Fresno	0.1%	3.5%	2.2%
14. Palmdale	-0.1%	3.4%	0.7%
15. Palm Springs	-0.2%	2.6%	2.0%
16. Blue Canyon	-0.3%	4.3%	-0.9%
Average	-0.3%	3.8%	2.2%

Figure 39. Percentage Differences in Solar Savings Fractions

Relative to Active Glycol System (external HX)

- Low-rise Prototypes, All Climate Zones

Permutation Simulation Phase I

This phase of the simulation effort focuses on investigating the performance differences with varying combination of design parameter sizing. Again, the three sizing parameters identified by the team are collector sizing, solar tank sizing and the auxiliary tank water heating sizing. We will also provide an overview on the effect that collector tilt and orientation have on solar water heating system performance. The following equation is used for calculation of daily hot water consumption for each dwelling unit:

$$GPD = 21.5 + 0.014 \times CFA$$

Where

GPD = average daily hot water consumption, gallons

CFA = conditioned floor area of the dwelling unit, sqft

Solar Water Tank and Auxiliary Tank Sizing

The results from the permutation runs defined by input set Figure 15 are displayed below. We performed permutation runs with four collector sizing, three solar tank sizing and three auxiliary tank gas heater sizing – for a total of thirty-six runs.

All runs for this and the next permutation phases of the analysis were conducted with one system configuration in the same climate zone and for one prototype building. Active glycol system configuration, Climate Zone 10 and low-rise prototype was chosen because active glycol was the configuration with the highest market penetration rate while the highest number of low-rise buildings are expected to be built in climate zone 10 in year 2013. Keeping all other variables but the design parameters constant is essential for discerning these performance differences.

	Input			Results					
	Collector Sizing	Solar Tank Sizing	Aux Tank Sizing	Increased Electricity Consump-tion	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
Run Index	sf per gal/day	gal per gal/day	gal per gal/day	(kwh/yr)	(Therms /yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
#1	0.05	1	0.5	171	121	(4,167)	17,417	$2,295	3.04%
#2	0.05	1	1	174	124	(4,260)	17,778	$2,341	3.10%
#3	0.05	1	1.5	175	122	(4,292)	17,537	$2,294	3.07%
#4	0.05	1.5	0.5	170	123	(4,138)	17,810	$2,368	3.10%
#5	0.05	1.5	1	173	125	(4,216)	18,035	$2,393	3.14%
#6	0.05	1.5	1.5	174	124	(4,249)	17,769	$2,341	3.10%
#7	0.05	2	0.5	171	126	(4,138)	18,214	$2,438	3.16%
#8	0.05	2	1	173	127	(4,205)	18,321	$2,445	3.19%
#9	0.05	2	1.5	174	125	(4,237)	18,019	$2,387	3.14%
#10	0.1	1	0.5	330	425	(7,966)	64,730	$9,831	10.67%
#11	0.1	1	1	332	428	(8,041)	65,123	$9,886	10.74%
#12	0.1	1	1.5	333	424	(8,066)	64,574	$9,787	10.66%
#13	0.1	1.5	0.5	331	436	(7,972)	66,499	$10,136	10.95%
#14	0.1	1.5	1	333	437	(8,030)	66,616	$10,147	10.98%
#15	0.1	1.5	1.5	333	433	(8,050)	65,971	$10,031	10.88%
#16	0.1	2	0.5	333	446	(8,012)	68,082	$10,403	11.20%
#17	0.1	2	1	334	446	(8,059)	67,985	$10,378	11.19%
#18	0.1	2	1.5	335	442	(8,078)	67,324	$10,261	11.09%
#19	0.3	1	0.5	936	1,467	(22,307)	227,367	$35,514	36.84%
#20	0.3	1	1	937	1,448	(22,314)	224,269	$34,976	36.36%
#21	0.3	1	1.5	937	1,435	(22,327)	222,151	$34,607	36.04%

#22	0.3	1.5	0.5	948	1,560	(22,683)	241,999	$37,983	39.20%
#23	0.3	1.5	1	948	1,539	(22,685)	238,593	$37,393	38.66%
#24	0.3	1.5	1.5	948	1,525	(22,691)	236,309	$36,996	38.31%
#25	0.3	2	0.5	950	1,598	(22,840)	248,167	$39,024	40.15%
#26	0.3	2	1	950	1,578	(22,845)	244,870	$38,452	39.63%
#27	0.3	2	1.5	951	1,564	(22,860)	242,666	$38,068	39.30%
#28	1	1	0.5	2,109	3,274	(41,887)	519,895	$82,785	82.25%
#29	1	1	1	2,127	3,269	(42,313)	518,651	$82,496	82.11%
#30	1	1	1.5	2,139	3,264	(42,661)	517,534	$82,242	81.99%
#31	1	1.5	0.5	2,031	3,364	(47,350)	533,960	$84,275	84.51%
#32	1	1.5	1	2,035	3,358	(46,114)	532,502	$84,237	84.35%
#33	1	1.5	1.5	2,046	3,350	(46,278)	530,868	$83,925	84.16%
#34	1	2	0.5	2,035	3,346	(44,661)	531,466	$84,309	84.05%
#35	1	2	1	2,047	3,331	(45,180)	528,657	$83,732	83.66%
#36	1	2	1.5	2,059	3,322	(45,681)	526,905	$83,342	83.45%

Figure 40. Energy Savings and Solar Savings Fractions with Varying Parameter Sizings - Active Glycol (external HX), CZ 10, Low-rise Prototype

Figure 40 illustrates that by solar savings fractions, there is natural grouping at each of the collector sizing values, 0.05, 0.1, 0.3 and 1 ft^2 per gal/day (think bordered). While solar tank and auxiliary tank sizing contribute to slight variations (within 2%) in the resulting solar savings fractions, collector sizing has by far the most impact on the performance of solar water heating systems. Within each collector sizing ratio group , the highest solar savings fractions (pink highlighted) occurred with

- Solar tank sizing of 1.5 gal per gal/day demand and
- Auxiliary tank sizing of 0.5-1 gal per gal/day demand: 1for the lower collector sizing ratio range and 0.5 for the higher collector ratio.

Plotting the runs with fixed solar tank and auxiliary tank ratios of 1 (yellow highlighted rows in Figure 41), we observed in Figure 41 that the solar savings fractions are largely proportional to the collector sizing ratio. Furthermore, there appeared to be a tapering effect with increasing collector sizing ratio, implying diminishing returns in terms of solar savings fractions towards larger collector sizing ratio. Accounting for installed system costs, the asymptotic curve suggests that a cost effective collector sizing ratio range may exist for each system configuration. These preliminary results prompted the team to carry out further permutation runs in the next simulation phase to explore the complete effects of collector sizing ratio on solar savings fractions and ultimately determine cost-effective solar water heating system configurations and sizing.

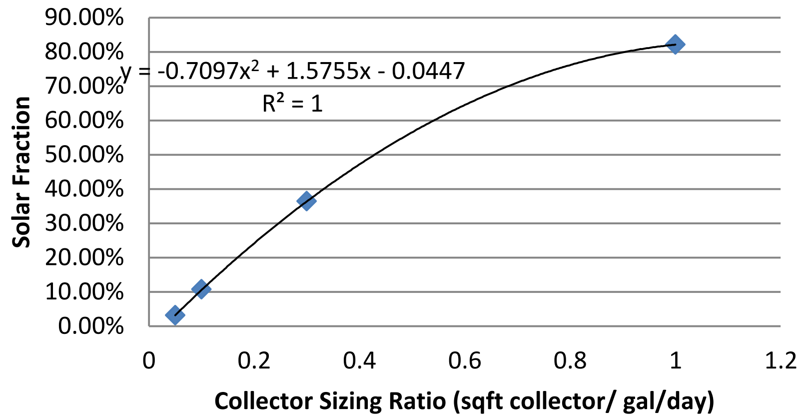

Figure 41. Solar Savings Fractions vs. Collector Sizing Ratio

- Active Glycol (external HX), CZ10, Low-rise Prototype

Collector Tilt and Orientation Effects

Similar to solar tank and auxiliary tank sizing ratio, the tilt and orientation of collectors also have secondary effects on the performance of solar water heating systems. Since, all of the simulation runs conducted for this study had the default 4:12 (18.4°) tilt and 180° (due south) orientation, we utilized simulation results from another CASE proposal efforts, *Solar Ready Homes and Solar Oriented Development*, to demonstrate collector tilt and orientation effects.

Figure 42 displays the solar orientation factors (in percentages of maximum solar water heating system energy output) variation with collector tilt range between 0:12 to 8:12 (33.7° from horizontal) and orientation of 90° (due East) to 180° (due West). Although these simulations results were obtained using single family homes assumptions, the relative effects on performance of solar water heating system remain applicable..

Not surprisingly, optimal orientation occurs at 180° (due South) with 10% performance degradation limits at 120° and 150°. Also, examining across each row in Figure 42, performance differences on the order of magnitude of 12% are possible between a 3:12 (14.0° from horizontal) to 8:12 collector tilt. However, it is important to remember that optimal collector tilt for solar water heating systems will vary depending on the latitude of the climate zone; the higher the latitude, the higher the optimal collector tilt.

Orientation	Collector Tilt			
	0:12	**3:12**	**5:12**	**8:12**
90 (E)	70%	71%	72%	72%
120	70%	80%	85%	89%
150	70%	85%	91%	95%
165	70%	87%	94%	99%
180 (S)	70%	87%	85%	100%
195	70%	87%	94%	100%
210	70%	86%	82%	98%
240	70%	80%	85%	89%
270 (W)	70%	71%	72%	72%

Figure 42. Solar Orientation Factors vs. Collector Tilt and Orientation - CZ 1, Single Family House

Permutation Simulation Phase II

The last part of the permutation runs were conducted with the goal of determining cost-effective solar water heating collector sizing ratio range. Five representative climate zones were targeted to capture the range of weather conditions present across the state. CZ 3,12,7,10 represent respectively the northern coastal, northern inland, southern coastal and southern inland areas of the state geography. CZ 1(Arcata) was also included to represent a worst-case scenario in terms of solar radiation level.

For each of the climate zones, solar water heating systems with collector sizing range between 0.1 and 0.8 (inputs in Figure 16) yielded the energy savings and solar savings fractions results plotted in Figure 43 and Figure 44 below. As expected, CZ 1 consistently has the lowest solar savings fractions of all five zones over the entire collector size range. The two northern zones, CZ 3 and 12, exhibit lower solar savings fractions than the two southern zones, CZ 7 and 10. Most interestingly, within each of the geographic groups (northern and southern), the inland climate zones, CZ 12 and 10, illustrate trends which are much curvier while the values at the lowest and highest collector sizing ratio remain roughly the same as their coastal counterparts. This “curvy” behavior is again a manifestation of the law of diminishing returns, and the effects are more pronounced in climate zones with higher solar insolation levels (Inland area, typically). The reverse can be observed, as the increase in solar savings fraction for CZ 1 (the most bottom curve) appears almost linear with increasing collector sizing ratio.

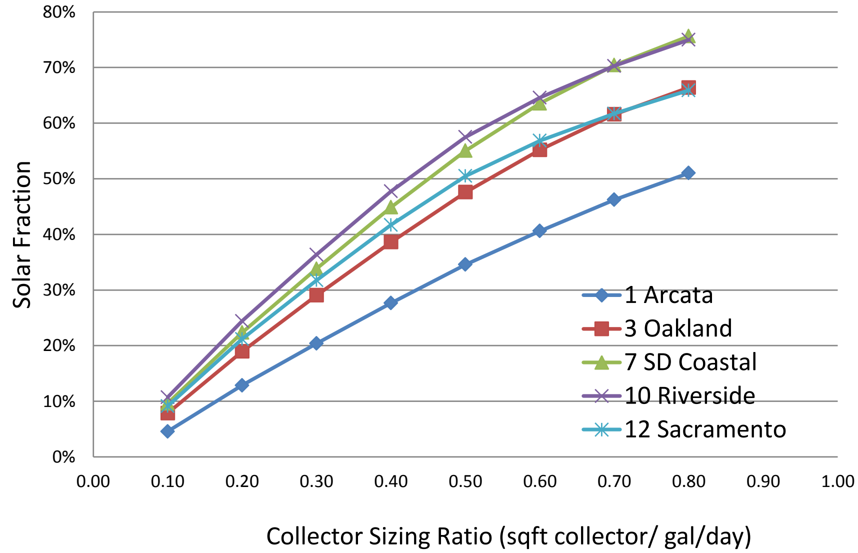

Figure 43. Solar Savings Fractions over a Completel Range of Collector Sizing Ratio - Various Climate Zones, Low-rise Prototype

Building Prototype	Collector Sizing (sf/daily hot water draw in gallons)	Electricity Savings (kwh/yr)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings (TDV kBTU)	TDV Gas Savings (TDV kBTU)	Base Code: PV of Energy Cost Savings	Reach Code: PV of Energy Cost Savings
Low-rise	0.1	(332)	428	(8,041)	65,123	$9,886	$13,258
Low-rise	0.2	(638)	973	(15,303)	149,953	$23,320	$31,230
Low-rise	0.3	(937)	1,448	(22,314)	224,269	$34,976	$46,832
Low-rise	0.4	(1,223)	1,901	(29,077)	295,379	$46,120	$61,749
Low-rise	0.5	(1,460)	2,290	(33,437)	357,064	$56,048	$75,017
Low-rise	0.6	(1,642)	2,571	(35,936)	402,648	$63,510	$84,980
Low-rise	0.7	(1,783)	2,798	(37,233)	437,951	$69,400	$92,835
Low-rise	0.8	(1,909)	2,985	(39,157)	468,788	$74,407	$99,524
High-rise	0.1	(596)	645	(14,377)	96,682	$12,674	$17,347
High-rise	0.2	(1,219)	1,774	(28,884)	271,480	$37,357	$50,956
High-rise	0.3	(1,828)	2,744	(42,896)	422,325	$58,428	$79,667
High-rise	0.4	(2,411)	3,684	(56,207)	568,988	$78,963	$107,643
High-rise	0.5	(2,901)	4,486	(65,356)	695,300	$97,005	$132,190
High-rise	0.6	(3,265)	5,090	(70,288)	792,726	$111,248	$151,540
High-rise	0.7	(3,564)	5,553	(74,347)	868,633	$122,312	$166,572
High-rise	0.8	(3,831)	5,931	(78,722)	930,930	$131,232	$178,706

Figure 44. Energy Savings vs. Collector Sizing Ratio w/ Base and Reach TDV - CZ 10, Low-rise and High-rise Prototypes

the simulated solar savings fraction curve for CZ 10 (Riverside) for a low-rise prototype building is shown in Figure 45. The graph allows us to more closely examine the relationship between solar savings fraction as a function of collector sizing ratio in climate zones with higher solar insolation level. Judging from the curve, the most drastic slope change occurs between collector sizing ratio of 0.5 to 0.6. This suggests that from a purely performance point of view (that is, if installation and maintenance costs of a solar water heating system remain linear to the collector square footage), a solar water heating system in the specified climate zone and size should be designed with an optimal solar savings fraction of 0.5 and 0.6.

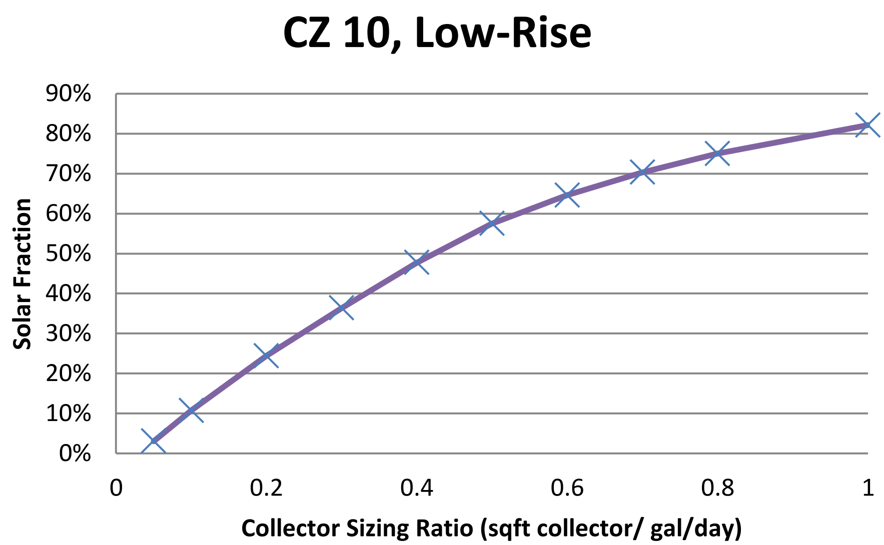

Figure 45. Solar Savings Fraction vs. Collector Sizing Ratio - High Solar Insolation case: CZ 10, Low-rise Prototype

4.2.6 Cost and Cost Savings

This section presents findings on cost figures needed to conduct life cycle cost analysis for the proposed measures. These include installed system costs for solar water heating systems, associated maintenance and replacement costs and costs associated with implementing solar *ready* measures.

Installed System Costs

The team tried three sources for gathering installed system cost numbers: RS Means, industry stakeholder input and incentive program data. RS Means Costworks 2010 provides installed system costs of solar water heating systems with detailed cost component break down, including material and labor costs associated with each of the system components. The RS Means estimates were only available for systems with up to four 3’x7’ collectors, well below what is needed for the multifamily building prototypes defined in this study. Therefore, this data source is deemed not suitable for multi-family solar water heating applications. For reference, a 4-collector system with black chrome collectors was estimated to cost around $12,000 to install based on the selection of system components included.

The team conducted a number of phone interviews to solicit information on cost and cost structure breakdown from individual solar water heating system designers/installers. However, this method was proven not to be effective, since in addition to a general lack of willingness to disclose sales-related figures, interviewees also pointed out that it is difficult to provide generalized estimates when many variables could come into play.

During the stakeholder meeting process, it was agreed upon that even though there exists a wide variety of solar water heating system possibilities, defining installed system cost as a function of collector area makes the most sense, as collector area dictates the energy harvesting potential of a system. Some stakeholders suggested that $150/ ft^2 of collector area was a reasonable rule of thumb for estimating installed system costs. This relatively conservative figure (on the high end) includes overhead and profit on top of material and labor costs. .

The third channel of installed system cost numbers came from available applicant data from the Solar Water Heating Pilot Program (Pilot Program) and the newly implemented California Solar Initiative – Thermal (CSI-Thermal) program for multifamily and commercial projects (previously described in 4.2.3). The CSI-Thermal program provided the most comprehensive and latest solar water heating system costs based on actual multi-family/commercial projects. Over 103 participating projects across these programs were plotted to generate the cost trend lines depicted in Figure 46. These projects include a wide range of multi-family buildings with different building sizes. The solar system costs largely correlate with collector area, but can have large variations. The \$150/ ft^2 of collector area, as suggested by some stakeholders, represents the up bound of the cost range. The average cost, as shown by the trend line in Figure 1, was used for the CASE study analysis. The team decided to, with stakeholder consensus, break up the data sets into two brackets: projects with below and above 700 ft^2 of collector area sizing. The main reason for such a division was to reflect the economy of scale effect in that some equipment and overhead cost are not sensitive to system costs. The break point, 700 ft^2, was determined by conducting trend line analysis and determining the division value yielded the highest R^2 numbers. The slopes of the trend lines for systems with collector area below and above 700 ft^2 are 112 and 107 respectively, demonstrating the effect of economy of scale at larger system sizes.

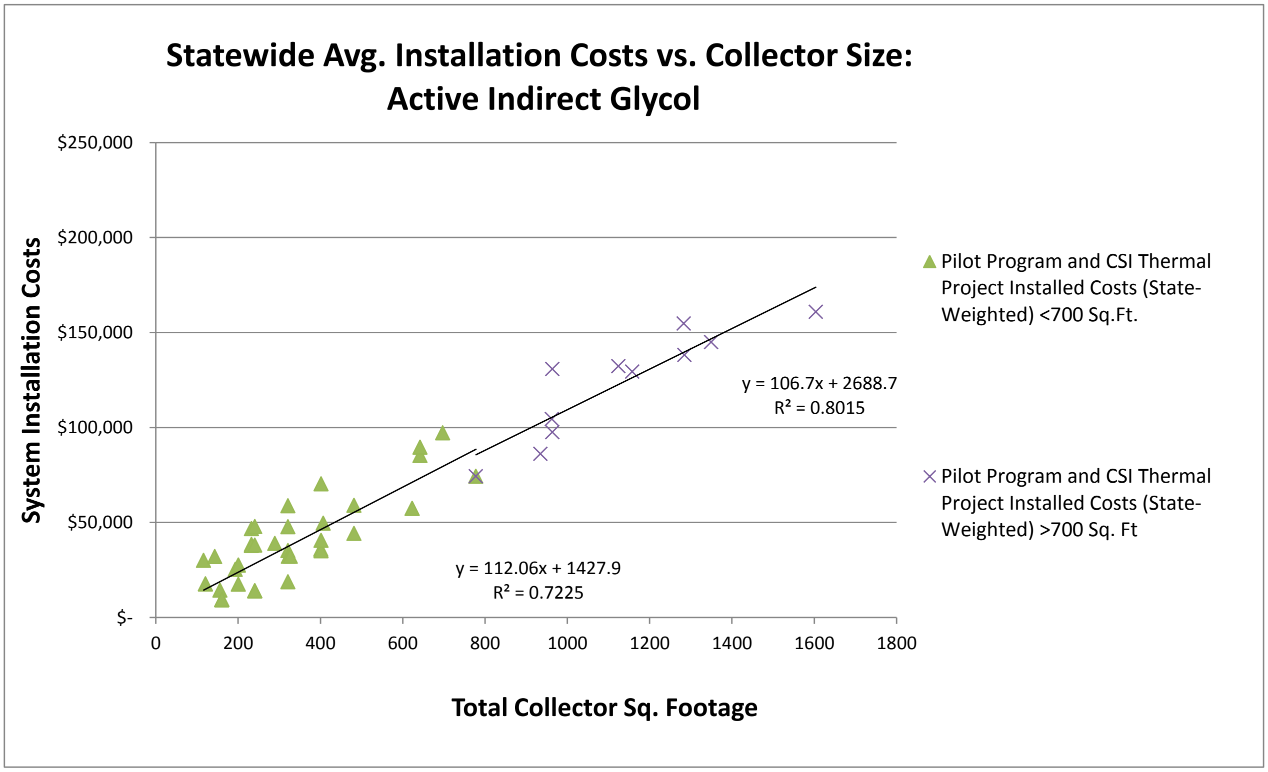

Figure 46. Installed System Costs vs. Collector Area

Maintenance Costs

The team interviewed a number of solar water heating system designers/installers for typical assumptions on maintenance schedule and labor hours needed. For costs associated with various maintenance tasks, RS Means cost book was utilized for labor cost estimates and interview results were used for the number of labor hours and relevant equipment/material costs needed.

These interview results, vetted through our stakeholder meeting process, formed the basis for the component life expectancy assumptions shown in Figure 47 that were used for generating cost figures associated with maintenance in our cost effectiveness study. During one of the IOU stakeholder meetings (presentation and notes are available on http://www.h-m-g.com/T24/Solar/solar.htm), a representative from California Solar Energy Industries Society (CalSEIA) expressed the opinion that these life expectancy assumptions seem to be on the conservative side from industry standpoint.

Component	Life Expectancy (yr)	Replacement Schedule during 30 yr
Collector	20	Once at yr 21st, include 50% of replacement cost
Solar Tank	15	Once at yr 16th
Motor and Pump	10	Twice at yr 11th, 21st
Controller	20	Once at 21st
Heat Transfer Fluid Check	1	21 times at all other yrs when fluid check & replacement is not performed
Heat Transfer Fluid Check & Replacement	3	9 times at yr 4th,7th,10th, 13th, 16th, 19th, 22nd, 25th and 28th

Figure 47. Component Life Expectancy

During each component replacement, a full replacement cost was included, not just maintenance cost (as in fixing existing equipment). The team's assumption on cost figures was conservative (on the high end) as well. No likely future reductions in cost were factored into our analysis. In other words, we assumed the same costs will be paid in 10 or 20 years from now as someone is paying now for equipment replacement

The issue of warranty versus measure life was raised during the CEC pre-rulemaking workshop. As suggested during the workshop, the team further investigated typical equipment warranties. However, warranties were not used for the measure life assumptions. Equipment warranty denotes the amount of time manufacturers are legally responsible for the operation of equipment sold, whereas measure life assumptions for lifecycle cost considerations represent realistic useful equipment life instead. The two concepts are different and should not be mixed.

To earn EnergyStar's new residential solar water heating program label, solar water heating systems must be SRCC OC-300 certified, achieve minimum solar savings fraction of 0.5, and have the following warranties: 10 years on solar collector, 6 years on storage tank, 2 years on controls and 1 year for piping and parts. Solar designers/installers interviewed by the team said that the industry standard for solar collectors is a 10 year warranty (consistent with CSI-Thermal program requirement), and 1-3 year warranties for the rest of the system components.

The resulting present value maintenance costs for solar water heating for our defined low-rise and high-rise building prototypes with various collector sizing ratios are shown in Figure 48.

Building Prototype	Measure Life (years)	Collector Sizing (sf/daily hot water draw in gallons)	Collector Area (sf)	PV of Additional Maintenance Costs
Low-Rise	30 Res	0.1	148	$6,551
Low-Rise	30 Res	0.2	296	$9,756
Low-Rise	30 Res	0.3	445	$12,962
Low-Rise	30 Res	0.4	593	$16,167
Low-Rise	30 Res	0.5	741	$19,372
Low-Rise	30 Res	0.6	889	$22,578
Low-Rise	30 Res	0.7	1,037	$25,783
Low-Rise	30 Res	0.8	1,186	$28,989
High-Rise	30 NR	0.1	296	$12,393
High-Rise	30 NR	0.2	593	$18,804
High-Rise	30 NR	0.3	889	$25,215
High-Rise	30 NR	0.4	1,186	$31,626
High-Rise	30 NR	0.5	1,482	$38,037
High-Rise	30 NR	0.6	1,778	$44,448
High-Rise	30 NR	0.7	2,075	$50,859
High-Rise	30 NR	0.8	2,371	$57,270

Figure 48. PV of Maintenance Costs at Various Collector Sizing Ratios - Low-rise and High-rise Prototypes

Cost and Cost Savings Associated with Solar Water Heating* Ready *Measures

As described in Section 4.2.4, the team narrowed the proposed solar water heating ready requirements down to three components: adequate roof space, adequate space for solar related equipment (tank especially) and specifying plumbing and conduit routes.

Figure 49 below shows the estimated additional cost and potential cost savings of making MF buildings solar water heating *ready*. As displayed, the only measure that was assumed to incur additional cost is requiring adequate space for solar related equipment. For estimating the additional cost of housing a solar tank inside the boiler room, collector sizing ratio and solar tank sizing ratio of 0.4 ft^2 per gal/day demand (corresponding to solar savings fraction of ~ 50%) and 1 gal per gal/day demand were assumed respectively. Also, the team obtained the cost per sqft of building area using RS Means online database calculation tool. The footprint of a vertical solar tank was calculated, and the corresponding cost of reserving that area for the tank, leaving a 2ft clearance on one side of the tank, was calculated.

The team's attempt to estimate the potential cost savings from industry stakeholder online surveys and phone interviews was unsuccessful, as these were just as difficult to obtain as the installed cost system numbers were. Ultimately, it was agreed upon during stakeholder discussions collectively that cost savings on the order of 10-15% total installed system costs was entirely possible with the combination of these *ready* measures considered.

Additional Costs			
Adequate roof space for collectors	Soft design cost		
Specified plumbing and conduit routes on plans	Soft design cost		
Adequate space/access for solar related equipment (solar tank in particular)		Low-Rise	High-Rise
daily hot water demand	gal/day	1,347	2,896
cost of construction per foot print	$\$/ft^2$	$ 145	$ 173
volume of solar tank	gal	539	1159
	ft^3	72	155
radius of vertical tank	ft	1.75	2.5
resulting height of tank	ft	7.49	7.89
required sq ft foot print	ft^2	19	35
Total Additional Cost	$/bldg	$ 2,782	$6,047
Potential Cost Savings (first year of adoption)			
total installed cost	$/bldg	$57,656	$121,830
10% of installed system cost	$/bldg	$ 5,766	$ 12,183
15% of installed system cost	$/bldg	$ 8,648	$ 18,275

Figure 49. Solar Water Heating Ready Cost and Cost Savings per Building - Low-rise and High-rise

4.3 Cost-Effectiveness Analysis

This section presents cost-effectiveness results associated with the following three levels of proposed requirements:

1. Demand Control alone
2. Demand Control + Optimal Design
3. Demand Control + Optimal Design + Solar Water Heating

To translate the LCC results to code requirement, the resulting highest cost-effective solar savings fractions are also presented.

4.3.1 LCC Results of Demand Control and Optimal Design Implementation (Level 1 and 2)

Energy savings and cost analysis were combined to produce LCC following the method described in section 3.1.4. For both building prototypes, the level 1 improvement option, demand control along, was cost effective (indicated by the red negative quantities under LCC column). The level 2 improvement option, demand control combined with optimal recirculation loop design, is even more cost effective as there was not only an increase in energy cost savings, but further a reduction in measure incremental cost due to piping material reduction.

	Building Prototype	Measure Life (Year)	Additional Costs– Current Measure Costs ($)	PV of Add'l Maintenance Costs ($)	PV of Energy Cost Savings ($)	LCC Per Prototype Building ($)
Level 1: Demand Control	Low-Rise MF	Res 30	$2,000	$0	$29,083	($27,083)
Level 2: Demand Control + Optimal Design	Low-Rise MF	Res 30	($159)	$0	$38,409	($38,568)
Level 1: Demand Control	High-Rise MF	NonRes 30	$2,000	$0	$39,765	($37,765)
Level 2: Demand Control + Optimal Design	High-Rise MF	NonRes 30	($5,892)	$0	$58,785	($64,677)

Figure 50. Level 1 and Level 2 LCC – Average Over All Climate Zones

4.3.2 LCC Results of the Combined Package (Level 3)

Since implementation of both demand control along (level 1) and demand control + optimal design (level 2) were shown to be highly cost-effective, we proceed to determine the cost effective size of solar water heating system when all three measures are combined (level 3).

Figure 51 follows the same format as the energy savings table presented previously and displays the LCC results of combining demand control, optimal design and solar water heating with collector sizing ratios 0.1-0.8 sqft per gal/day demand. It shows that when combined with demand control and optimal design, solar water heating systems with collector sizing up to 0.5 and 0.3 are cost effective for low-rise and high-rise prototypes respectively, in climate zone 10 (Riverside), using base code TDV multipliers and conversion factors. These collector sizing values corresponds to 58% and 34% solar savings fraction for the low-rise and high-rise prototype buildings. Figure 52 displays the same results while putting the LCC results of all three levels of proposed requirements side by side for comparison.

Collector Sizing (sf/daily hot water draw in gallons)	Prototype	Measure Life (Year)	Additional Costs– Current Measure Costs (Relative to Basecase)	PV of Additional Maintenance Costs (Savings) (Relative to Basecase)	PV of Energy Cost Savings	LCC Per Prototype Building	Solar Savings Fraction
0.1	Low-Rise	Res 30	$14,921	$6,551	$ 47,114	($31,811)	10.7%
0.2			$29,481	$9,756	$ 55,945	($27,479)	24.4%
0.3			$44,041	$12,962	$ 63,925	($21,370)	36.4%
0.4			$58,601	$16,167	$ 71,622	($14,749)	47.8%
0.5			$73,161	$19,372	$ 78,975	($6,912)	57.5%
0.6			$87,720	$22,578	$ 85,314	$3,391	64.6%
0.7			$102,280	$25,783	$ 91,296	$15,267	70.3%
0.8			$116,840	$28,989	$ 96,434	$28,025	75.0%
0.1	High-Rise	NonRes 30	$25,372	$12,393	$ 61,556	($39,627)	8.1%
0.2			$54,931	$18,804	$ 78,023	($28,340)	22.3%
0.3			$84,490	$25,215	$ 92,311	($13,441)	34.5%
0.4			$114,050	$31,626	$ 106,605	$1,994	46.3%
0.5			$143,609	$38,037	$ 119,962	$19,922	56.3%
0.6			$173,168	$44,448	$ 132,137	$41,649	64.0%
0.7			$202,727	$50,859	$ 142,772	$66,555	69.7%
0.8			$232,286	$57,270	$ 151,883	$93,606	74.5%

Figure 51. Level 3 Improvement LCC - CZ 10

It is important to point out that although this exercise helped us determine the cost-effective collector sizing/solar savings fraction for a given building type and climate zone, the *most* cost effective solar savings fraction occurred at a lower collector sizing/solar savings fraction value. For example, a solar water heating system is the most cost effective at collector sizing of 0.1 for both low- and high-rise with basecase criteria.

As the additional costs of solar water heating system was assumed to be the same across the climate zones, and the present value (PV) of energy cost savings were different for each climate zone (weather dependent), a table such as Figure 51 could be generated for each of the 16 climate zones. Because this table is for climate zone 10 (Riverside), the cost-effective collector sizings and solar savings fractions are on the higher end of the spectrum in comparison to results from other climate zones. Also, the team is aware that this cost effective calculation showed the highest system sizing for having a net negative LCC, it had not taken into consideration of physical feasibility (overheating from oversizing, for example) of such collector sizing/solar savings fractions.

	Building Proto-type	**Measure Life (Years)**	**Additional Costs– Current Measure Costs (Relative to Basecase)**	**PV of Add'l Maintenance Costs (Savings)**	**PV of Energy Cost Savings**	**LCC Per Prototype Building**	
Demand Control	Low-Rise	Res 30	$2,000	$0	$5,245	($26,562)	
Demand Control + Optimal Design			($159)	$0	$37,707	($37,866)	
Demand Control + Optimal Design + Solar Water Heating			$73,161	$19,372	$78,975	($6,912)	Solar Fraction: 57.5%
Demand Control	High-Rise	NonRes 30	$2,000	$0	$3,871	($36,948)	
Demand Control + Optimal Design			($5,892)	$0	$57,487	($63,380)	
Demand Control + Optimal Design + Solar Water Heating			$84,490	$25,215	$93,311	($13,441)	Solar Fraction: 34.5%

Figure 52. LCC of All Three Proposed Requirement Levels - CZ 10

4.3.3 Cost Effective Solar Savings Fractions

Carrying out the same LCC analysis as presented in the previous section, converting the collector sizing to solar savings fraction and interpolating between results, we calculated the highest cost-effective values for the rest of the climate zones displayed in Figure 53.

	BASE TDV Value: Demand Control + Optimal design + Cost Effective Solar Fraction		**REACH TDV Value: Demand Control + Optimal design + Cost Effective Solar Fraction**	
Climate Zone	Low-Rise	High-Rise	Low-Rise	High-Rise
1. Arcata	26%	15%	51%	47%
2. Santa Rosa	39%	22%	64%	63%
3. Oakland	47%	29%	66%	66%
4. San Jose Reid	50%	31%	69%	68%
5. Santa Maria	52%	33%	66%	66%
6. Torrance	58%	38%	76%	75%
7. San Diego	59%	39%	76%	75%
8. Fullerton	56%	37%	74%	73%
9. Burbank-Glendale	56%	36%	74%	73%
10. Riverside	62%	45%	75%	74%
11. Red Bluff	52%	35%	67%	67%
12. Sacramento	51%	34%	66%	65%
13. Fresno	49%	32%	66%	65%
14. Palmdale	67%	50%	78%	77%
15. Palm Springs	66%	46%	82%	81%
16. Blue Canyon	54%	38%	65%	64%

Figure 53. Highest Cost Effective Solar Savings Fractions

The figures displayed here are the highest solar savings fractions proven cost effective in combination with the demand control recirculation strategy and optimal design of distribution layout. Our calculation so far had only taken into consideration the energy savings potential and associated costs (additional system cost and maintenance cost). In order to determine the minimum solar fraction requirements, the following three factors are further evaluated.

- Alternative compliance options
- Availability of roof space
- Avoidance of solar water heating system overheat

Alternative Compliance Options

Even though the solar water heating market is gaining momentum to satisfy the growing market demand, it is possible that builders want to use alternative ways to achieve energy savings without installing solar water heating systems. As the CASE study intends to propose prescriptive requirements on solar water heating, the minimum solar fraction requirements were determined to make sure the TDV energy savings from the solar water heating requirements can be achieved by other cost-effective means, if builders decided to demonstrate compliance via the performance route.

While there are many different alternative compliance approaches, the CASE study analyzed the alternative option of using high efficiency water heater and HVAC components, including:

- Using condensing water heaters with thermal efficiency of 96%, as compared to a standard design water heater with thermal efficiency of 80%
- Using condensing gas furnaces with AFUE of 95%, as compared to a standard design gas furnace with AFUE of 80%
- Using SEER 15 air conditioners, as compared to a standard design SEER 13 air conditioner

Since buildings located in different climate zones have different heating and cooling loads, different combinations of the above three equipment were investigated for each climate zone to find the cost effective solutions with maximum energy savings. Energy savings were assessed based on building energy simulation studies. Cost of high efficiency equipment, as shown in Figure 54, were obtained from market data collected by other CASE studies. The energy savings and cost effectiveness analysis results are shown in Figure 55. The results show that the alternative compliance packages, varying by climate zones, are cost effective (negative LCC). The TDV energy savings from the alternative compliance method were calculated and expressed as fractions of solar water heating TDV energy savings, based on the proposed SSFs. The results indicate that the alternative compliance method can provide equivalent TDV energy savings as the proposed solar water heating requirement. The original proposal provided tailored SSF recommendation for each climate zone to make sure they can be completely replaced with the alternative compliance packages listed in Figure 55. Upon stakeholder suggestion, we decided to use only two levels of SSFs (0.20 and 0.35) for code simplification purpose. For some climate zone, the proposed alternative packages generate savings less than the proposed solar water heating requirements. Other efficiency measures need to be included if solar water heating is not used.

	Incremental Cost Compared to Standard Design Equipment	**Number of Equipment**
Condensing Water Heater	$3000	Two per building
Condensing Furnace	$500	One per dwelling unit
SEER 15 Air Conditioner	$1100	One per dwelling unit

Figure 54. Costs for Alternative Compliance Equipment

Climate Zone	Solar Water Heating		Alternative Compliance Method							
	Proposed SFF	TDV Energy Savings-kBtu/sqft	Efficiency Measures			TDV Energy Savings		PV Energy Savings ($/sqft)	Incremental Cost ($/sqft)	LCC ($/sqft)
			HE Water Heater	HE Furnace	HE AC	kBtu/sqft	Percent of Solar Water TDV Energy Savings			
1	0.20	6.3	Yes	Yes		7.5	**119%**	$1.29	$0.73	-$0.56
2	0.20	6.1	Yes	Yes		8.3	**135%**	$1.43	$0.73	-$0.70
3	0.20	6.1	Yes	Yes		6.5	**107%**	$1.13	$0.73	-$0.40
4	0.20	6.0	Yes	Yes		7.1	**117%**	$1.23	$0.73	-$0.50
5	0.20	6.1	Yes	Yes		6.7	**110%**	$1.16	$0.73	-$0.43
6	0.20	5.9	Yes	Yes		5.4	**92%**	$0.94	$0.73	-$0.21
7	0.20	5.9	Yes	Yes		5.3	**90%**	$0.92	$0.73	-$0.18
8	0.20	5.9	Yes	Yes		5.5	**94%**	$0.96	$0.73	-$0.22
9	0.20	5.8	Yes	Yes		5.5	**94%**	$0.95	$0.73	-$0.21
10	0.35	10.2	Yes		Yes	9.7	**95%**	$1.67	$1.42	-$0.25
11	0.35	10.4	Yes	Yes	Yes	13.8	**132%**	$2.39	$2.00	-$0.39
12	0.35	10.5	Yes	Yes		7.6	**72%**	$1.31	$0.73	-$0.58
13	0.35	10.2	Yes	Yes	Yes	13.7	**135%**	$2.38	$2.00	-$0.38
14	0.35	10.4	Yes	Yes	Yes	14.6	**140%**	$2.53	$2.00	-$0.53
15	0.35	9.4	Yes	Yes	Yes	18.0	**191%**	$3.12	$2.00	-$1.12
16	0.35	11.3	Yes	Yes	Yes	13.9	**123%**	$2.41	$2.00	-$0.41

Figure 55. Alternative Compliance Method to Installing Solar Water Heating

Roof Space for Solar Water Heating

There had been concerns regarding the amount of roof space needed to achieve a specified minimum solar savings fraction requirement, especially high density multifamily buildings with smaller footprint, therefore relatively small roof areas. Furthermore, roof space set aside for the installation of solar thermal collectors (and photovoltaic panels) would also compete with existing mechanical systems installed on the roof. To ensure our proposed minimum solar savings fractions were feasible in terms of roof space constraint, the team calculated the amount of roof space needed to satisfy the requirement and compare that to the total roof space, which is effectively the footprint of a multi-story building.

As shown in Figure 56, with a solar savings fraction level of 50% (the highest proposed level is 35% for climate zones 10-15), the corresponding collector sizing ratio is approximately 0.4 ft^2 per gal/day hot water demand. The resulting collector area needed for the low-rise and high-rise building prototypes respectively accounts for 3% and 6% of the building footprints, which are roughly the amount of roof space theoretically available. Furthermore, with fixed daily hot water demand numbers, we calculated the collector area in percentage building footprint for buildings with different number of stories. With a 20-story multifamily building with the same daily hot water demand (the same number of units with the same CFA each), the collector area necessary to achieve a solar savings fraction of 50% would only account for 28% of the total available roof space (Figure 57).

Building Prototype	Unit	low-rise	high-rise
Daily hot water demand	gal/day	1,347	
Building footprint	ft^2	19,140	19,140
Number of stories		2	4
Solar savings fraction		50%	50%
corresponding collector sizing ratio	ft^2/ gal/day	0.4	0.4
Resulting collector area	ft^2	539	1,159
% of building footprint	% total	3%	6%

Figure 56. Collector Area in % Total of Building Footprint Calculation (SSF = 50%)

Number of Stories	% of building footprint
2	3%
3	4%
4	6%
5	7%
10	14%
20	28%

Figure 57. Roof Area for Solar Collectors (SSF = 50%)

Overheating Issue due to Oversizing

Industry stakeholders reflected that while the issue of freeze protection has been widely explored (the development of various solar water heating system types is a reflection of this evolution), the issue of overheating is often not considered as seriously as it should be, especially for climate conditions with relatively high solar insolation level such as California. When a solar water heating system is designed with a relatively high annual solar savings fraction, the monthly solar fractions during the summer months are maxed out to 100%, and the unintended consequence of overheating occurs. To be conservative, stakeholders have suggested for the team to cap out the solar savings fraction requirement at 50%. This suggestion was followed as the highest solar fraction requirement the team is proposing (for CZ 15) is 35%.

4.3.4 Solar Water Heating Ready Measure Cost Effective Adoption Rates

Costs, potential cost savings and estimated minimum cost effective adoption rates for solar water heating ready buildings are displayed in Figure 58. Although the construction start estimates for low and high-rise multifamily buildings in 2013 are included in this calculation, these numbers do not change the resulting adoption rates, as the adoption rates are mathematically the ratio between these two terms described in Section 3.2.5:

$$Additional\_Cost\_Now = Cost_{ready} \times (MF_{total} - MF_{newinstall})$$

$$Cost\_Savings\_Later = \Delta Cost_{retrofit} \times FVM_{n\ years} \times (MF_{retrofit})$$

Calculations show that in order for the solar water heating ready measure to be cost effective, at least half of the buildings would have to retrofit for solar water heating systems during the 30 years measure life length (from 2013-2043), assuming a 15% cost savings and a linear adoption curve.

Building Prototype	Low-rise	Hig hrise
# new buildings in 2013	272	202
Installation at new const	1%	1%
Remaining bldg w/t installation at new const	269	200
per bldg "ready" cost	$2,782	$6,047
Ready Costs associated	$749,562	$ 1,208,671
Minimum Cost Effective Adoption Rate		
with 10% cost savings	73%	75%
with 15% cost savings	49%	50%

Figure 58. Cost Effective Adoption Rates for *Ready* Measure

We explored a few sources of future market penetration for solar water heating systems to determine the likelihood of such adoption rates. We reviewed the same literature and followed a similar logic as the Solar Ready Homes and Solar Oriented Development CASE topic (for single family homes), There are three major sources of future market penetration rates:

- California Statewide Residential Appliance Saturation Study (RASS) 2009

- California Statewide Residential Sector Energy Efficiency Potential Study
- CSI-Thermal program energy savings goals
- CPUC's California Long Term Energy Efficiency Strategic Plan

The 2009 RASS database provided a current market penetration of ~ 1% (Figure 33), and the Energy Efficiency Potential Study established the upper bound of penetration rate (close to 100%). Unfortunately, it is challenging to extract the number of multifamily building solar water heating installations expected from the CSI-thermal program energy savings goals[2], due to the difficulty in defining an average sized building and system and that the goal is a combined goal for single-family, multifamily and commercial buildings within the state.

The last identified source of future market penetration rate, California's Long Term EE Strategic Plan, calls for

- All new residential construction in California be zero net energy by 2020,
- 25% of existing homes will achieve 70% decrease in purchased energy, relative to 2008 levels
- 75% of existing homes will achieve 30% decrease in purchased energy, relative to 2008 levels

To accomplish the goal of being zero net energy, it is reasonable to expect that t solar water heating systems will be installed in all new constructions. For the 25% of existing buildings that would need to achieve 70% reduction in purchase energy, the installation of renewable technology is inevitable. Therefore, if this level of solar water heating penetration is needed to achieve the state's grand vision of energy efficiency, an equivalent housing stock (both new construction and existing buildings) adoption rate would be higher than 25% by 2020.

Furthermore, our calculation assumed that the solar tank space reservation is inside, rather than outside the building. If the space reserved for future solar equipment (tank) is outside, the ready measure would imply merely installing a concrete pad at the time of new construction. The calculation of the minimum cost effective adoption rates for solar water heating ready measure did not factor in the probable reduction in installed system pricing due to various program efforts. Another conservative assumption built into the calculation is the exclusion of any energy savings benefits as the results of the installation of solar water heating system, promoted by the *ready* measures. Accounting for the above-mentioned references and reasons, the team concluded the proposed solar water heating *ready* measure cost effective. The space reserved for potential solar collectors shall be roof space equivalent to solar savings fraction of 50%, marginally exceeding the highest solar savings fractions requirement (45%) across climate zones. This calculation of the reserved space needed will be a function of the number of the story of the building to account for decreasing building footprint with increasing number of story.

[2] Program goal includes "achieving the installation of natural gas-displaying systems that displace 585 million therms over the 25-year life of the systems."

4.4 Statewide Savings Estimates

The statewide energy savings from the proposed combined package (Level 3), with demand control, optimal recirculation loop design and cost effective solar savings fractions, are presented in Figure 59, Figure 60 and Figure 61 for low-rise, high-rise multifamily buildings and motels/hotels. Figure 62 shows the total annual statewide energy savings.

Climate Zone	Electric Savings (kWh/yr)	Gas Savings (Therm/yr)	TDV savings (TDV kBtu/yr)
1	(1,076)	3,979	608,265
2	(9,778)	28,432	4,263,968
3	(12,704)	35,844	5,401,624
4	(9,495)	25,401	3,811,951
5	(3,887)	11,587	1,760,100
6	(19,316)	50,512	7,616,270
7	(29,868)	77,447	11,693,099
8	(25,896)	65,867	9,894,636
9	(31,791)	79,973	11,994,593
10	(25,928)	135,941	21,035,775
11	(7,579)	42,965	6,572,053
12	(17,854)	114,510	17,517,304
13	(17,113)	90,038	13,705,405
14	(7,238)	37,911	5,860,754
15	(8,955)	35,768	5,503,370
16	(4,028)	32,770	5,059,499
total	(232,506)	868,945	132,298,667

Figure 59. Statewide Energy Savings: Low-rise MF prototype

Climate Zone	Electric Savings (kWh/yr)	Gas Savings (Therm/yr)	TDV savings (TDV kBtu/yr)
1	-	-	-
2	(2,006)	5,782	884,497
3	(21,127)	58,094	8,938,415
4	(25,124)	64,738	9,910,210
5	(2,316)	6,816	1,057,705
6	(25,449)	63,417	9,772,452
7	(16,691)	41,166	6,352,857
8	(37,268)	89,777	13,769,339
9	(44,001)	104,574	16,008,448
10	(9,306)	54,835	8,626,114
11	(678)	4,415	687,376
12	(12,146)	93,750	14,594,648
13	(2,156)	12,710	1,968,220
14	-	-	-
15	-	-	-
16	-	-	-
total	(198,268)	600,074	92,570,282

Figure 60. Statewide Energy Savings: High-rise MF prototype

Climate Zone	Electric Savings (kWh/yr)	Gas Savings (Therm/yr)	TDV savings (TDV kBtu/yr)
1	(491)	1,859	287,304
2	(5,288)	15,317	2,317,729
3	(14,986)	41,793	6,357,494
4	(15,331)	40,320	6,105,366
5	(2,771)	8,214	1,259,852
6	(10,005)	25,597	3,897,493
7	(13,619)	34,520	5,263,535
8	(19,488)	48,359	7,332,795
9	(45,624)	111,846	16,930,053
10	(3,987)	22,021	3,433,582
11	(1,869)	11,268	1,737,749
12	(13,219)	91,946	14,179,873
13	(5,930)	32,821	5,035,742
14	(2,330)	12,853	2,001,586
15	(660)	2,689	417,138
16	(1,581)	14,510	2,258,644
total	(157,179)	515,934	78,815,933

Figure 61. Statewide Energy Savings: Motels/Hotels

Building Type	Electric Savings (GWh/yr)	Gas Savings (MMT/yr)	TDV savings (TDV MBtu/yr)
Low-Rise MF	(0.23)	0.87	132,299
High-Rise MF	(0.20)	0.60	92,570
Hotel/Motel	(0.16)	0.52	78,816
Total	**(0.59)**	**1.98**	**303,685**

Figure 62. Total Statewide Energy Savings

5. Recommended Language for the Standards Document, ACM Manuals, and the Reference Appendices

The recommended code language below incorporates inputs from various stakeholders and CEC staff, received throughout the IOUs stakeholder meetings and CEC's pre-rulemaking processes. For a complete evolution of changes in recommended language, please refer to Appendix 7.7.

The original proposal recommended different levels of solar savings fractions (SSF) according to measure cost-effective characteristics in each climate. During the pre-rulemaking workshop, industry stakeholders suggested that the number to SSFs be reduced for easy implementation. Upon discussion with CEC staff, we recommend that only two levels of SSFs be used, 0.2 (for CZ1-9) and 0.35 (CZ10-16). This simplification is based on the originally proposed SSF. The proposed SSFs are slightly increased for some climates and reduced for others. The averaged SSF overall all 16 climate zones stay the same at 0.27.

5.1 Section 101(b)

DEMAND CONTROL (for central water heating) is an automatic control system that controls the recirculation pump operation based on measurement of hot water demand and hot water return temperature.

SOLAR SAVINGS FRACTION (SSF) is the fraction of domestic hot water demand provided by solar hot water heating, according to Residential ACM Appendix E equation RE-1. The value of SSF shall be determined using the approved solar water heating calculations methods based on results from the OC-100 and OG-300 test procedure.

TEMPERATURE MODEULATION CONTROL (for central water heating) is an automatic control system that reduced hot water supply temperature when hot water demand is expected to be low.

5.2 Section 151(f) 8C

C. For systems serving multiple dwelling units, ~~with~~ a central water heating system that includes the following components shall be installed:

1. ~~g~~Gas or propane water heaters, boilers or other water heating equipment that meet the minimum efficiency requirements of Sections 111 and 113~~.~~, and
2. A water heating recirculation loop system that meets the requirements of Section 113(c)2 and Section 113(c)5 and is equipped with a demand control and has two recirculation loops each serving half of the building, and

   EXCEPTION 1 to Section 151(f)8c 2: Buildings with eight or few units are exempt from the requirements on having two recirculation loops.
3. A solar water heating system with a minimum solar savings fraction of 0.20 for climate zones 1 through 9 and 0.35 climate zones 10 through 16.

5.3 Section 113(c)2

2. **Controls for hot water distribution systems**. Service hot water systems with circulating pumps or with electrical heat trace systems shall be capable of automatically turning off the system.

   EXCEPTION 1 to Section 113(c)2: Water heating systems serving a single dwelling unit.
   EXCEPTION 2 to Section 113(c)2: Recirculation systems serving multiple dwelling units and equipped with temperature modulation control.

5.4 Section 150(n)

~~*(n) Water Heating Recirculation Loops Serving Multiple Dwelling Units. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.*~~

(n) **Water Heating System Serving Multiple Dwelling Units.**

1. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.
2. The following items shall be clearly shown and labeled on building plans/drawings submitted for building permit:
   A. Marked solar zone on the roof and/or structures attached to the building:
      1. The solar zone shall be at least 1.5 % of building conditioned floor area or 30% of the total available roof area whichever is smaller and be oriented between 90° and 270°.
         - Exception 1 to Section 150(n)2A1: The area of roof shaded from existing trees, utility poles, other buildings, and other non-building sources are exempted from the available roof area requirement.
      2. The solar zone shall be minimally shaded by vents, chimneys, architectural features, mechanical equipment or other obstructions that are on the roof or any other part of the building. Any vent, chimney, or other architectural feature shall be a minimum distance of twice the height from the solar zone(s).
         - Exception 1 to Section 150(n)2A2: Any vent, chimney, or other architectural feature to the north of the solar zone(s) shall be exempt from the minimum shading requirement.
      3. The solar zone may be comprised of smaller sub-areas. No sub-area shall be smaller than 33% of the total solar zone or smaller than 80 sqft. All sub-areas must be at least 5 feet wide in the narrowest dimension.
      4. The solar zone shall be sited in compliance with Section 2 of the California Department of Forestry and Fire Protection Office of the State Fire Marshal Solar Photovoltaic Installation Guideline.

B. Marked solar tank area with a minimum area in sqft determined by:
0.0004 x building CFA + 13.
The area must be at least 4 feet wide in the narrowest dimension.

C. Marked plumbing and conduit paths between the solar zone and the solar tank area.

D. Marked plumbing and conduit paths between the solar tank area and the water heater(s)/boiler(s).

EXCEPTION 1 to Section 150(n)2: Buildings with an installed solar water heating system that meets Section 151(f) 8C iii.

5.5 Reference Appendix 9.1.1

For the Joint Appendix, the team recommends the following organization and language:

9 Solar Energy Systems

9.1 Solar Thermal Systems

9.1.1 Solar Water Heating Systems

Solar water heating systems ~~for individual dwellings shall be rated with the OG 300 procedures.~~ shall satisfy the following eligibility criteria:

~~In order to use the OG-300 method, the system must satisfy the following eligibility criteria:~~

1. The system shall be SRCC certified using the OG-100 or OG-300 procedures. Systems used for individual residential dwellings shall be certified using the OG-300 procedure.
2. The collectors ~~must~~ shall face within 35 degrees of south and be tilted at a slope of at least 3:12
   ~~The system shall be SRCC certified.~~
3. ~~The system must~~ Systems using OG-300 certification shall be installed in the exact configuration for which it was rated, e.g. the system must have the same collectors, pumps, controls, storage tank and backup water heater fuel type as the rated condition.
4. The system ~~must~~ shall be installed according to manufacturer's instructions.
5. The collectors shall be located in a position that is not shaded by adjacent buildings or trees between 9:00 AM and 3:00 PM (solar time) on December 21.

9.1.2 Solar Space Heating Systems

9.2 Photovoltaic Systems

6. Bibliography and Other Research

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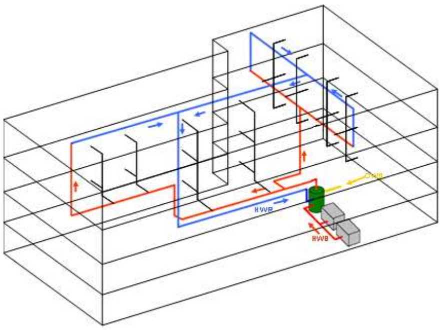
7. Appendices

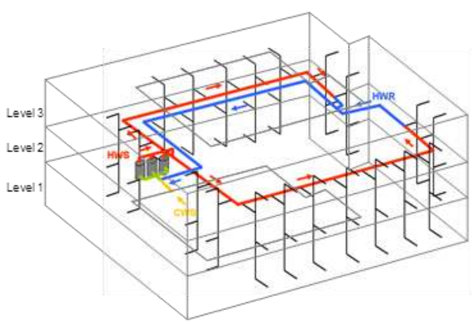
7.1 Recirculation Loop Model Validation Results

Building 1. Recirculation loop loss represent 34% Total hot water energy



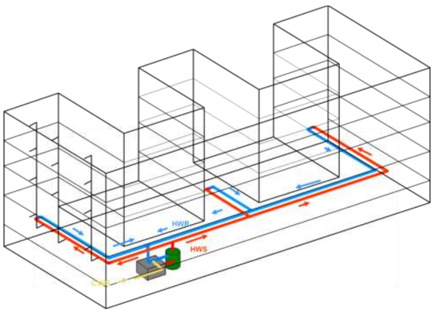
	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
SFD	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)
CONT Pump	608,711	608,711	-	-	639,732	643,487	-	-	1,875,663	1,879,417	-	-
Temp Mod	600,697	582,695	1.3%	4.3%	633,433	616,266	1.0%	4.2%	1,958,764	1,941,597	-4.4%	-3.3%
Timer	507,048	461,656	17%	24%	600,803	562,822	6.1%	13%	1,732,428	1,694,446	7.6%	10%
Demand	215,483	191,328	65%	69%	411,903	453,556	36%	30%	1,423,628	1,465,281	24%	22%

Building 2. Recirculation loop loss represent 42% Total hot water energy



	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
SAM	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)	Measured (Btu/day)	Modeled (Btu/day)	Measured reduction (%)	Modeled reduction (%)
CONT Pump	368,536	368,536	-	-	443,280	456,190	-	-	1,030,479	1,043,388	-	-
Temp Mod	362,987	355,698	1.5%	3.5%	442,840	435,949	0.1%	4.4%	1,030,039	1,023,148	0.0%	1.9%
Timer	265,214	279,559	28%	24%	421,494	419,521	5%	8%	1,008,693	1,006,720	2.1%	3.5%
Demand												

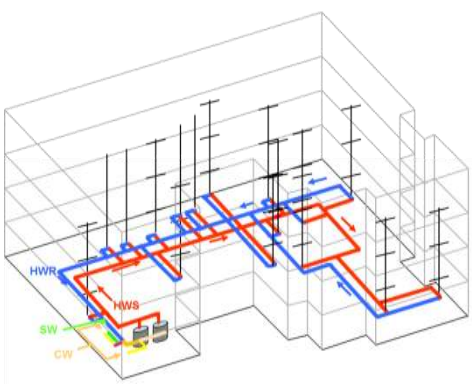
Building 3. Recirculation loop loss represent 7% Total hot water energy



Comparison to measured results

	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
SFF	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**
CONT Pump	176,588	176,588	-	-	221,165	228,267	-	-	3,116,211	3,123,313	-	-
Temp Mod	157,692	159,541	11%	10%	204,820	204,057	7%	11%	2,564,910	2,564,146	18%	18%
Timer	151,829	147,709	14%	16%	220,452	228,777	0.3%	-0.2%	3,443,807	3,452,131	-11%	-11%
Demand	48,168	78,002	73%	56%	178,093	179,729	19%	21%	2,784,551	2,786,187	11%	11%

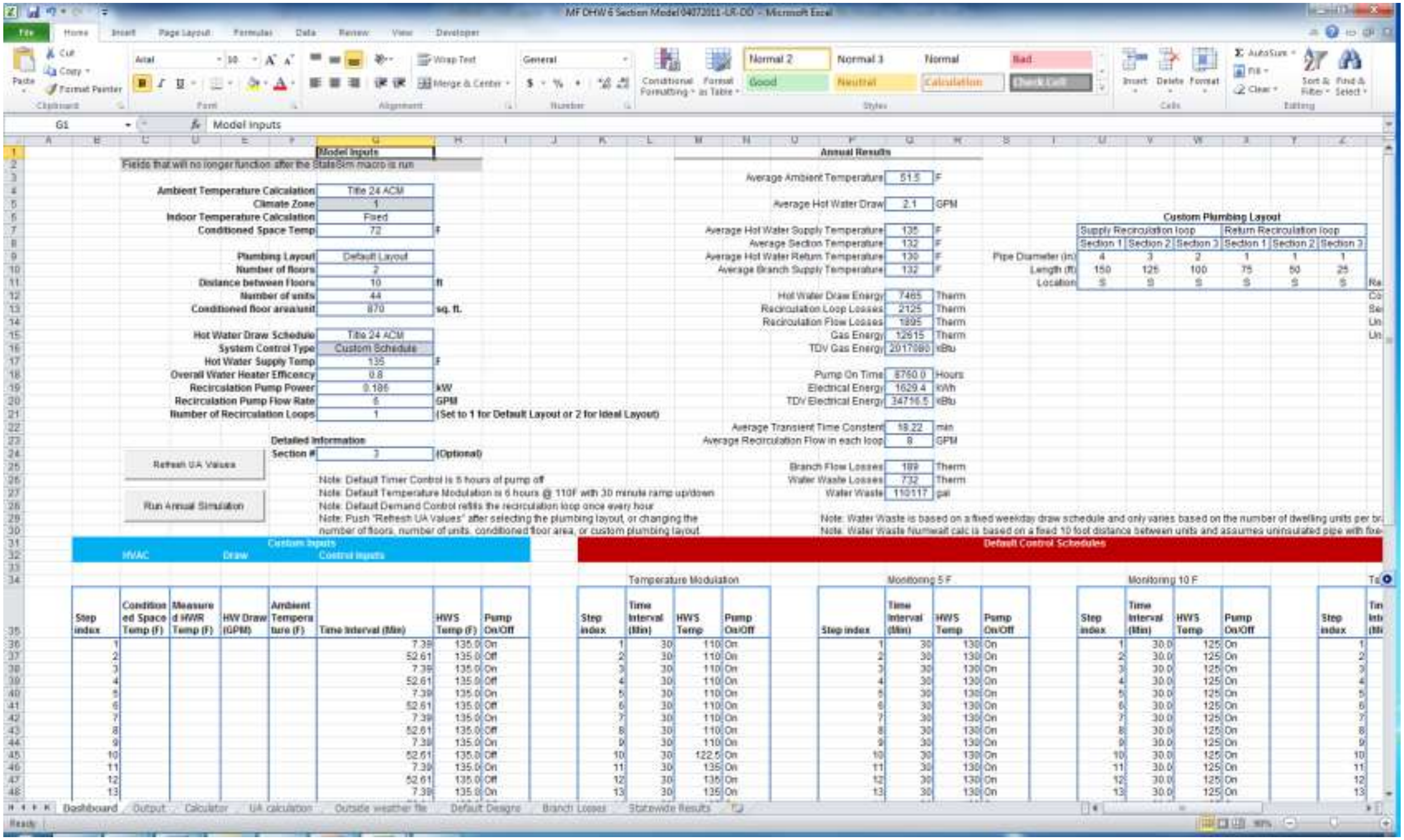
Building 4. Recirculation loop loss represent 14% Total hot water energy

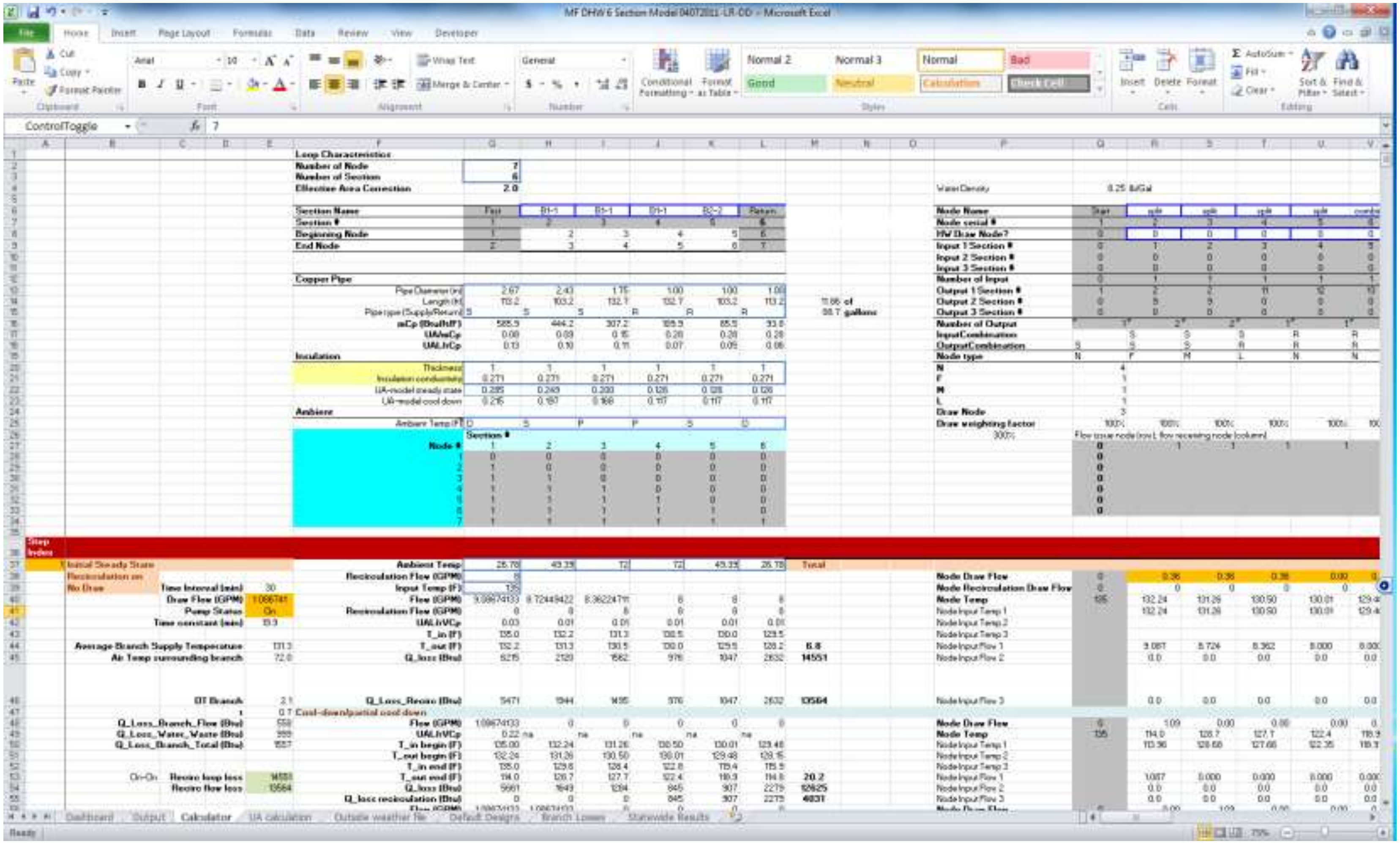


Comparison to measured results

	Recirculation Flow Heat Loss				Recirculation Loop Heat Loss				Total Hot Water Energy			
SFH	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**	**Measured (Btu/day)**	**Modeled (Btu/day)**	**Measured reduction (%)**	**Modeled reduction (%)**
CONT Pump	177,796	177,796	-	-	201,589	207,200	-	-	1,094,813	1,100,423	-	-
Temp Mod			-	-			-	-	-	-	-	-
Timer	143,549	145,345	19%	18%	187,240	194,233	7%	6%	942,592	949,586	14%	14%
Demand	90,349	82,244	49%	54%	180,478	173,723	10%	16%	742,710	735,955	32%	33%

7.2 *Screenshots of the Recirculation Model*




MF DHW 6 Section Model 04072011-LR-DD - Microsoft Excel
ControlToggle
Dashboard
Output
Calculator
UA calculation
Outside weather file
Default Designs
Branch Losses
Statewide Results

7.3 Solar Water Heating Online Survey Instrument

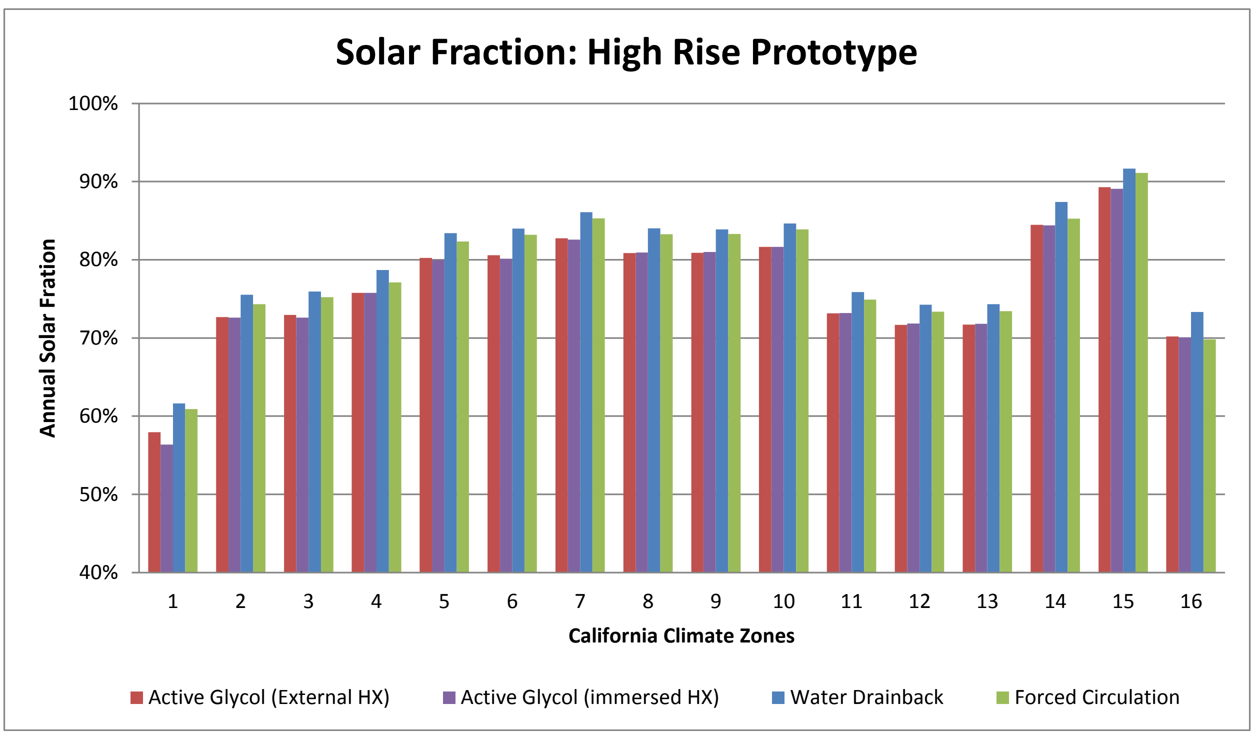
Acrobat Document

7.4 Example of Solar Water Heating Ready Ordinances

Acrobat Document

7.5 Energy Saving: Solar Water Heating Simulation Results

7.5.1 Comparison between Climate Zones (high-rise prototype)



7.5.2 Comparison between Various Configurations

Low-rise Prototype

Active Glycol (External HX)

Climate Zone City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	2,194	2,660	(54,648)	409,985	61,540	59%
2. Santa Rosa	2,145	3,167	(47,481)	488,551	76,388	73%
3. Oakland	2,223	3,175	(50,665)	490,789	76,224	73%
4. San Jose Reid	2,162	3,232	(47,029)	501,627	78,731	76%
5. Santa Maria	2,274	3,479	(51,366)	546,500	85,751	81%
6. Torrance	2,320	3,330	(51,665)	524,495	81,888	81%
7. San Diego	2,280	3,366	(50,857)	533,019	83,505	83%
8. Fullerton	2,181	3,274	(47,130)	515,347	81,090	81%
9. Burbank-Glendale	2,159	3,239	(45,653)	509,998	80,419	81%
10. Riverside	2,126	3,269	(45,102)	515,756	81,512	82%
11. Red Bluff	2,018	3,043	(42,816)	470,790	74,120	74%
12. Sacramento	2,092	3,038	(44,886)	466,491	73,017	72%
13. Fresno	1,921	2,863	(40,138)	440,304	69,304	72%
14. Palmdale	2,174	3,487	(45,305)	550,798	87,545	85%
15. Palm Springs	2,016	3,076	(40,952)	488,795	77,561	90%
16. Blue Canyon	2,201	3,338	(47,464)	518,440	81,567	71%

Active Glycol (Immersed HX)

Climate Zone City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	6,345	2,587	(140,325)	397,837	44,598	57%
2. Santa Rosa	6,224	3,163	(134,268)	486,176	60,946	73%
3. Oakland	6,300	3,158	(136,753)	486,355	60,547	73%
4. San Jose Reid	6,227	3,230	(133,698)	499,297	63,317	76%
5. Santa Maria	6,332	3,465	(137,255)	542,275	70,145	80%
6. Torrance	6,370	3,310	(137,834)	519,421	66,086	81%
7. San Diego	6,348	3,359	(137,286)	530,030	68,019	83%
8. Fullerton	6,261	3,275	(134,158)	513,498	65,697	81%
9. Burbank-Glendale	6,211	3,242	(132,462)	508,623	65,147	81%
10. Riverside	6,187	3,267	(132,015)	513,636	66,092	82%
11. Red Bluff	6,111	3,045	(130,425)	469,119	58,658	74%
12. Sacramento	6,162	3,043	(131,944)	465,561	57,779	72%
13. Fresno	6,050	2,866	(128,688)	439,257	53,787	72%
14. Palmdale	6,176	3,485	(131,308)	548,183	72,198	85%
15. Palm Springs	6,026	3,070	(127,926)	486,493	62,099	89%
16. Blue Canyon	6,235	3,327	(133,829)	514,503	65,928	71%

Forced Circulation

Climate Zone / City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	5,444	2,783	(117,683)	429,637	54,027	61%
2. Santa Rosa	5,534	3,233	(118,204)	499,482	66,033	75%
3. Oakland	5,528	3,265	(118,292)	506,108	67,165	76%
4. San Jose Reid	5,534	3,285	(117,980)	510,289	67,943	77%
5. Santa Maria	5,602	3,561	(119,886)	560,789	76,359	83%
6. Torrance	5,553	3,428	(118,638)	541,186	73,180	83%
7. San Diego	5,561	3,462	(118,710)	549,427	74,595	86%
8. Fullerton	5,546	3,365	(118,153)	530,974	71,496	84%
9. Burbank-Glendale	5,534	3,328	(117,651)	525,340	70,607	84%
10. Riverside	5,551	3,352	(117,957)	530,087	71,376	84%
11. Red Bluff	5,495	3,111	(116,794)	482,286	63,299	75%
12. Sacramento	5,485	3,104	(116,761)	477,564	62,487	74%
13. Fresno	5,465	2,925	(115,995)	450,957	58,011	74%
14. Palmdale	5,574	3,510	(118,091)	554,433	75,569	85%
15. Palm Springs	5,497	3,136	(116,281)	499,486	66,366	91%
16. Blue Canyon	5,660	3,308	(120,082)	512,623	67,983	70%

Evacuated Tube (External HX)

Climate Zone City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	4,477	5,486	(113,352)	847,381	127,125	61%
2. Santa Rosa	4,362	6,417	(99,172)	991,663	154,569	75%
3. Oakland	4,500	6,418	(105,070)	993,579	153,879	75%
4. San Jose Reid	4,368	6,523	(97,482)	1,013,541	158,651	78%
5. Santa Maria	4,631	6,997	(107,506)	1,099,606	171,820	82%
6. Torrance	4,702	6,703	(107,918)	1,055,982	164,193	83%
7. San Diego	4,627	6,802	(106,348)	1,077,026	168,110	85%
8. Fullerton	4,426	6,598	(98,065)	1,038,470	162,867	83%
9. Burbank-Glendale	4,364	6,559	(94,674)	1,033,575	162,606	84%
10. Riverside	4,304	6,588	(93,571)	1,039,973	163,906	84%
11. Red Bluff	4,104	6,182	(88,983)	958,384	150,570	76%
12. Sacramento	4,244	6,177	(93,359)	950,982	148,530	74%
13. Fresno	3,929	5,851	(83,796)	902,936	141,865	75%
14. Palmdale	4,380	7,024	(93,100)	1,110,821	176,257	87%
15. Palm Springs	3,994	6,198	(82,581)	986,351	156,522	92%
16. Blue Canyon	4,488	6,815	(99,750)	1,059,949	166,295	73%

High-rise Prototype

Active Glycol (External HX)

Climate Zone City	**Electricity Use**	**Natural Gas Savings**	**TDV Electricity Savings**	**TDV Gas Savings**	**PV of Energy Cost Savings**	**Solar Savings Fraction**
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	4,411	5,254	(110,212)	809,132	121,045	58%
2. Santa Rosa	4,314	6,294	(95,933)	970,135	151,401	73%
3. Oakland	4,477	6,307	(102,462)	974,233	150,980	73%
4. San Jose Reid	4,348	6,427	(94,942)	996,699	156,174	76%
5. Santa Maria	4,579	6,916	(103,843)	1,085,785	170,061	80%
6. Torrance	4,671	6,619	(104,400)	1,041,922	162,368	81%
7. San Diego	4,591	6,698	(102,863)	1,060,034	165,771	83%
8. Fullerton	4,386	6,511	(95,057)	1,024,264	160,928	81%
9. Burbank-Glendale	4,342	6,443	(92,130)	1,014,028	159,662	81%
10. Riverside	4,278	6,502	(91,017)	1,025,348	161,815	82%
11. Red Bluff	4,061	6,050	(86,492)	935,186	146,984	73%
12. Sacramento	4,198	6,037	(90,464)	926,162	144,733	72%
13. Fresno	3,863	5,690	(81,012)	874,316	137,391	72%
14. Palmdale	4,383	6,940	(91,549)	1,095,555	173,882	84%
15. Palm Springs	4,055	6,130	(82,582)	973,543	154,304	89%
16. Blue Canyon	4,424	6,628	(95,816)	1,028,517	161,533	70%

Active Glycol (Immersed HX)

Climate Zone City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	12,737	5,112	(281,822)	785,536	87,237	56%
2. Santa Rosa	12,494	6,290	(270,069)	966,033	120,533	73%
3. Oakland	12,648	6,275	(274,939)	965,733	119,637	73%
4. San Jose Reid	12,498	6,427	(268,783)	992,699	125,374	76%
5. Santa Maria	12,716	6,891	(276,009)	1,077,945	138,886	80%
6. Torrance	12,790	6,581	(277,193)	1,031,955	130,716	80%
7. San Diego	12,747	6,684	(276,257)	1,054,241	134,738	83%
8. Fullerton	12,566	6,517	(269,645)	1,021,330	130,183	81%
9. Burbank-Glendale	12,463	6,452	(266,101)	1,011,623	129,115	81%
10. Riverside	12,413	6,502	(265,227)	1,021,556	130,987	82%
11. Red Bluff	12,255	6,054	(261,881)	932,069	116,069	73%
12. Sacramento	12,359	6,052	(265,081)	924,911	114,275	72%
13. Fresno	12,130	5,698	(258,371)	872,442	106,350	72%
14. Palmdale	12,387	6,936	(263,641)	1,090,426	143,189	84%
15. Palm Springs	12,081	6,116	(256,874)	968,577	123,258	89%
16. Blue Canyon	12,509	6,613	(268,954)	1,021,737	130,373	70%

Forced Circulation

Climate Zone City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	10,914	5,523	(236,049)	851,855	106,650	61%
2. Santa Rosa	11,087	6,437	(236,826)	993,932	131,122	74%
3. Oakland	11,082	6,501	(237,295)	1,007,100	133,321	75%
4. San Jose Reid	11,098	6,543	(236,618)	1,015,912	134,964	77%
5. Santa Maria	11,235	7,095	(240,495)	1,116,724	151,752	82%
6. Torrance	11,128	6,834	(237,826)	1,078,427	145,582	83%
7. San Diego	11,148	6,902	(238,107)	1,094,946	148,394	85%
8. Fullerton	11,121	6,707	(237,000)	1,057,689	142,134	83%
9. Burbank-Glendale	11,096	6,634	(235,976)	1,046,553	140,382	83%
10. Riverside	11,128	6,681	(236,601)	1,056,067	141,922	84%
11. Red Bluff	11,015	6,196	(234,092)	959,787	125,682	75%
12. Sacramento	10,990	6,178	(233,947)	949,760	123,970	73%
13. Fresno	10,953	5,826	(232,610)	897,555	115,161	73%
14. Palmdale	11,178	7,005	(236,903)	1,105,928	150,505	85%
15. Palm Springs	11,018	6,257	(233,022)	996,093	132,155	91%
16. Blue Canyon	11,337	6,591	(240,565)	1,020,851	135,136	70%

Water Drainback

Climate Zone City	Electricity Use	Natural Gas Savings	TDV Electricity Savings	TDV Gas Savings	PV of Energy Cost Savings	Solar Savings Fraction
	(kwh/yr)	(Therms/yr)	(TDV kBTU)	(TDV kBTU)	(PV$)	(%)
1. Arcata	10,966	5,590	(237,654)	862,456	108,208	62%
2. Santa Rosa	11,157	6,543	(238,680)	1,010,873	133,735	76%
3. Oakland	11,150	6,566	(238,958)	1,016,552	134,670	76%
4. San Jose Reid	11,176	6,675	(238,606)	1,037,893	138,427	79%
5. Santa Maria	11,299	7,187	(242,229)	1,131,060	153,935	83%
6. Torrance	11,218	6,898	(239,764)	1,087,995	146,904	84%
7. San Diego	11,229	6,968	(239,875)	1,104,851	149,804	86%
8. Fullerton	11,191	6,768	(238,709)	1,066,766	143,410	84%
9. Burbank-Glendale	11,166	6,683	(237,574)	1,053,857	141,371	84%
10. Riverside	11,188	6,741	(237,950)	1,065,284	143,284	85%
11. Red Bluff	11,087	6,275	(235,840)	972,411	127,565	76%
12. Sacramento	11,066	6,254	(235,864)	961,826	125,728	74%
13. Fresno	11,023	5,900	(234,152)	908,924	116,862	74%
14. Palmdale	11,249	7,182	(238,532)	1,136,413	155,502	87%
15. Palm Springs	11,090	6,295	(234,516)	1,001,875	132,897	92%
16. Blue Canyon	11,166	6,922	(238,054)	1,076,977	145,292	73%

7.6 System Assumptions from CSI-Thermal Incentive Calculator Documentation

Acrobat Document

7.7 Evolution of Recommended Code Language

This section documents the versions of proposed language produced by the CASE team for the combined Multi-Family Domestic Hot Water and Solar Water Heating topic. Changes occurred between the versions are shown in red to help accentuate the differences. The evolution of the versions is summarized below:

1. First version: HMG's version presented in the CEC pre-rulemaking workshop on 6/9/2011
2. Second version: Revised HMG version based on comments collected during the CEC pre-rulemaking workshop
3. CalSEIA's recommendation
4. Third version: Revised HMG version based on consideration of CalSEIA input.

7.7.1 First Version

Section 151(f) 8C

C. For systems serving multiple dwelling units, a central water heating system that includes the following components shall be installed:~~ that has~~

   1. ~~g~~Gas or propane water heaters, boilers or other water heating equipment that meet the minimum efficiency requirements of Sections 111 and 113~~.~~, and

   2. A solar water heating system with solar fraction specified in Table 151-C, and

   ~~3. and a~~A water heating recirculation ~~loop~~ system that meets the requirements of Section 113(c)2 and Section 113(c)5 and is equipped with a demand control and has two recirculation loops each serving half of the building. ~~shall be installed.~~

Table 151-C

	Climate Zone															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

(requirements for other building components and systems – no change)																	
WATER-HEATING	**General**	**System shall meet Section 151(f)8 or Section 151(b)1**															
	Solar Savings Fraction for multifamily buildings	**0.2**	**0.25**	**0.2**	**0.2**	**0.2**	**0.15**	**0.15**	**0.15**	**0.15**	**0.3**	**0.40**	**0.25**	**0.35**	**0.45**	**0.50**	**0.4**

Section 113(c)2

2. **Controls for hot water distribution systems**. Service hot water systems ~~with circulating pumps or~~ with electrical heat trace systems shall be capable of automatically turning off the system.

   EXCEPTION to Section 113(c)2: Water heating systems serving a single dwelling unit.

Section 150(n)

~~*(n) Water Heating Recirculation Loops Serving Multiple Dwelling Units. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.*~~

(n) **Water Heating System Serving Multiple Dwelling Units.**

1. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.
2. The following items shall be clearly shown and labeled on building plans/drawings submitted for building permit:
   A. Marked solar zone for potential future solar collectors on the roof or other available space on the building site
      1. The solar zone shall be at least 1.5 % of building conditioned floor area or 30% of the total available roof area whichever is smaller and be oriented between 90° and 270°.

         - Exception 1 to Section 150(n)2A1: The area of roof shaded from existing trees, utility poles, other buildings, and other non-building sources are exempted from the available roof area requirement.
      2. The solar zone shall be minimally shaded by vents, chimneys, architectural features, mechanical equipment or other obstructions that are on the roof or any other part of the building. Any vent, chimney, or other architectural feature shall be a minimum distance of twice the height from the reserved area(s).

         - Exception 1 to Section 150(n)2A2: Any vent, chimney, or other architectural feature to the north of the reserved roof area(s) shall be exempt from the minimum shading requirement.

3. The solar zone shall be sited in compliance with Section 2 of the California Department of Forestry and Fire Protection Office of the State Fire Marshal Solar Photovoltaic Installation Guideline

B. Marked solar tank area for potential solar water heating storage tank installation of a minimum X sf or X% of conditioned floor area

C. Marked plumbing and conduit paths between the solar zone and the solar tank area

D. Marked plumbing and conduit paths between the solar tank area and the water heater(s)/boiler(s)

EXCEPTION to Section 150(n)2: Buildings with an installed solar water heating system that meets Section 151(f) 8C ii**.**

7.7.2 Second Version

Section 151(f) 8C

D. For systems serving multiple dwelling units, a central water heating system that includes the following components shall be installed:

1. ~~g~~Gas or propane water heaters, boilers or other water heating equipment that meet the minimum efficiency requirements of Sections 111 and 113~~.~~, and

2. A solar water heating system with solar savings fraction specified in Table 151-C, and

~~3. and a~~A water heating recirculation loop system that meets the requirements of Section 113(c)2 and Section 113(c)5 and is equipped with a demand control and has two recirculation loops each serving half of the building. ~~shall be installed~~

Table 151-C

		Climate Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(requirements for other building components and systems – no change)																	
WATER-HEATING	**General**	**System shall meet Section 151(f)8 or Section 151(b)1**															
	Solar Savings Fraction for multifamily buildings	**0.2**	**0.25**	**0.2**	**0.2**	**0.2**	**0.15**	**0.15**	**0.15**	**0.15**	**0.3**	**0.40**	**0.25**	**0.35**	**0.45**	**0.45**	**0.4**

Section 113(c)2

3. **Controls for hot water distribution systems**. Service hot water systems ~~with circulating pumps or~~ with electrical heat trace systems shall be capable of automatically turning off the system.

   EXCEPTION to Section 113(c)2: Water heating systems serving a single dwelling unit.

Section 150(n)

~~*(n) Water Heating Recirculation Loops Serving Multiple Dwelling Units. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.*~~

(n) **Water Heating System Serving Multiple Dwelling Units.**

1. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.
2. The following items shall be clearly shown and labeled on building plans/drawings submitted for building permit:

   A. Marked solar zone on the roof and/or structures attached to the building:

      1. The solar zone shall be at least 1.5 % of building conditioned floor area or 30% of the total available roof area whichever is smaller and be oriented between 90° and 270°.

         - Exception 1 to Section 150(n)2A1: The area of roof shaded from existing trees, utility poles, other buildings, and other non-building sources are exempted from the available roof area requirement.

      2. The solar zone shall be minimally shaded by vents, chimneys, architectural features, mechanical equipment or other obstructions that are on the roof or any other part of the building. Any vent, chimney, or other architectural feature shall be a minimum distance of twice the height from the reserved area(s).

         - Exception 1 to Section 150(n)2A2: Any vent, chimney, or other architectural feature to the north of the reserved roof area(s) shall be exempt from the minimum shading requirement.

      3. The solar zone may be comprised of smaller sub-areas. No sub-area shall be smaller than 80 sqft, and all areas must be at least 5 feet wide in the narrowest dimension.

      4. The solar zone shall be sited in compliance with Section 2 of the California Department of Forestry and Fire Protection Office of the State Fire Marshal Solar Photovoltaic Installation Guideline

   B. Marked solar tank area with a minimum area in sqft determined by:
   0.0004 x building CFA + 13
   The area must be at least 4 ft wide in the narrowest dimension.

C. Marked plumbing and conduit paths between the solar zone and the solar tank area

D. Marked plumbing and conduit paths between the solar tank area and the water heater(s)/boiler(s)

EXCEPTION to Section 150(n)2: Buildings with an installed solar water heating system that meets Section 151(f) 8C ii are exempt from the solar water heating ready requirements**.**

7.7.3 CalSEIA's Written Comment

Section 150(n)

(n) **Water Heating System Serving Multiple Dwelling Units.**

2. The following items shall be clearly shown and labeled on building plans/drawings submitted for building permit:

    A. Marked solar zone on the roof and/or structures attached to the building:

        3. The solar zone may be comprised of smaller sub-areas. No sub-area shall be smaller than 33 percent of the total area of the solar zone, and all areas must be at least 18 feet wide in the east-west dimension, and 15 feet wide in the north-south dimension.

    B. Marked solar storage tank area (marked area) with a minimum area in square feet equivalent to no less than 1.6 square feet of flat, structurally adequate area for each 10 square feet of solar collector area. The marked area must be at least 10 feet wide in the narrowest dimension

        1. The marked area may be inside or outside the structure upon which the solar collectors are mounted.

        2. There must be sufficient access to accommodate the movement of a solar storage tank with dimensions six feet in height by eight feet in width into and out of the marked storage tank area, and the marked area must be structurally capable of supporting a live load of 180 pounds per square foot.

        3. If the marked area is outside the structure, the marked area shall be 100 feet or less from the conventional water heating equipment, and shall have a marked plumbing path(s) to the conventional water heating equipment.

7.7.4 Third Version

Section 151(f) 8C

D. For systems serving multiple dwelling units, ~~with~~ a central water heating system that includes the following components shall be installed:

    4. ~~g~~Gas or propane water heaters, boilers or other water heating equipment that meet the minimum efficiency requirements of Sections 111 and 113~~.~~, and

5. A water heating recirculation loop system that meets the requirements of Section 113(c)2 and Section 113(c)5 and is equipped with a demand control and has two recirculation loops each serving half of the building, and

   EXCEPTION 1 to Section 151(f)8c 2: Buildings with eight or few units are exempt from the requirements on having two recirculation loops.

6. A solar water heating system with solar savings fraction specified in Table 151-C.

Table 151-C

		Climate Zone															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
(requirements for other building components and systems – no change)																	
WATER-HEATING	**General**	**System shall meet Section 151(f)8 or Section 151(b)1**															
	Solar Savings Fraction for multifamily buildings	**0.2**	**0.25**	**0.2**	**0.2**	**0.2**	**0.15**	**0.15**	**0.15**	**0.15**	**0.3**	**0.40**	**0.25**	**0.35**	**0.45**	**0.45**	**0.4**

Section 113(c)2

4. **Controls for hot water distribution systems**. Service hot water systems with circulating pumps or with electrical heat trace systems shall be capable of automatically turning off the system.

   EXCEPTION 1 to Section 113(c)2: Water heating systems serving a single dwelling unit.
   EXCEPTION 2 to Section 113(c)2: Recirculation systems serving multiple dwelling units and equipped with temperature modulation control.

Section 150(n)

~~*(n) Water Heating Recirculation Loops Serving Multiple Dwelling Units. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.*~~

(n) **Water Heating System Serving Multiple Dwelling Units.**

3. Water heating recirculation loops serving multiple dwelling units shall meet the requirements of Section 113(c)5.

4. The following items shall be clearly shown and labeled on building plans/drawings submitted for building permit:

   E. Marked solar zone on the roof and/or structures attached to the building:

      5. The solar zone shall be at least 1.5 % of building conditioned floor area or 30% of the total available roof area whichever is smaller and be oriented between 90° and 270°.
         - Exception 1 to Section 150(n)2A1: The area of roof shaded from existing trees, utility poles, other buildings, and other non-building sources are exempted from the available roof area requirement.

      6. The solar zone shall be minimally shaded by vents, chimneys, architectural features, mechanical equipment or other obstructions that are on the roof or any other part of the building. Any vent, chimney, or other architectural feature shall be a minimum distance of twice the height from the solar zone(s).
         - Exception 1 to Section 150(n)2A2: Any vent, chimney, or other architectural feature to the north of the solar zone(s) shall be exempt from the minimum shading requirement.

      7. The solar zone may be comprised of smaller sub-areas. No sub-area shall be smaller than 33% of the total solar zone or smaller than 80 sqft. All sub-areas must be at least 5 feet wide in the narrowest dimension.

      8. The solar zone shall be sited in compliance with Section 2 of the California Department of Forestry and Fire Protection Office of the State Fire Marshal Solar Photovoltaic Installation Guideline.

   F. Marked solar tank area with a minimum area in sqft determined by:
      0.0004 x building CFA + 13.
      The area must be at least 4 feet wide in the narrowest dimension.

   G. Marked plumbing and conduit paths between the solar zone and the solar tank area.

   H. Marked plumbing and conduit paths between the solar tank area and the water heater(s)/boiler(s).

EXCEPTION 1 to Section 150(n)2: Buildings with an installed solar water heating system that meets Section 151(f) 8C iii.

7.8 Residential Construction Forecast Details

The Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from the California Department of Finance and California

Construction Industry Research Board (CIRB) building permits. The Department of Finance uses census years as independent data and interpolates the intermediate years using CIRB permits.

CASE stakeholders expressed concern that the Residential forecast was inaccurate compared with other available data (in 2010 CEC forecast estimate is 97,610 new units for single family and the CIRB estimate is 25,526 new units). In response to this discrepancy, HMG revised the CEC construction forecast estimates. The CIRB data projects an upward trend in construction activity for 2010-2011 and again from 2011-2012. HMG used the improvement from 2011-2012 and extrapolated the trend out to 2014. The improvement from 2011-2012 is projected to be 37%. Instead of using the percent improvement year on year to generate the 2014 estimate, HMG used the conservative value of the total units projected to be built in 2011-2012 and added this total to each subsequent year. This is the more conservative estimate and is appropriate for the statewide savings estimates. Based on this trend, the new construction activity is on pace to regain all ground lost by the recession by 2021. The multi-family construction forecasts are consistent between CEC and CIRB and no changes were made to the multi-family data.

Residential New Construction Estimate (2014)			
	Single Family	Multi-family Low Rise	Multi-family High Rise
CZ 1	378	94	-
CZ 2	1,175	684	140
CZ 3	1,224	863	1,408
CZ 4	2,688	616	1,583
CZ 5	522	269	158
CZ 6	1,188	1,252	1,593
CZ 7	2,158	1,912	1,029
CZ 8	1,966	1,629	2,249
CZ 9	2,269	1,986	2,633
CZ 10	8,848	2,645	1,029
CZ 11	3,228	820	81
CZ 12	9,777	2,165	1,701
CZ 13	6,917	1,755	239
CZ 14	1,639	726	-
CZ 15	1,925	748	-
CZ 16	1,500	583	-
Total	47,400	18,748	13,845

Residential construction forecast for 2014, in total dwelling units

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ). These 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). HMG has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and decay rate. Total construction is the sum of all existing dwelling units in a given category (Single family, Multi-family low rise and Multi-family high rise). Decay rate is the number of units that were assumed to be retrofitted, renovated or demolished. The difference in total construction between consecutive years (including each year’s decay rate) approximates the new construction estimate for a given year.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has segmented all multi-family buildings into low rise and high rise space (where high rise is defined as buildings 4 stories and higher). This calculation is based on data collected by HMG through program implementation over the past 10 years. Though this sample is relatively small (711), it is the best available source of data to calculate the relative population of high rise and low rise units in a given FCZ.

Most years show close alignment between CIRB and CEC total construction estimates, however the CEC demand forecast models are a long-term projection of utility demand. The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022, and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure), however to estimate next year's construction, CIRB is a more reliable data set.

"Res Construction Forecast by BCZ v4"; Developed by Heschong Mahone Group with data sourced September, 2010 from Sharp, Gary at the California Energy Commission (CEC)

7.9 Non-Residential Construction Forecast details

The Non-Residential construction forecast dataset is data that is published by the California Energy Commission's (CEC) demand forecast office. This demand forecast office is charged with calculating the required electricity and natural gas supply centers that need to be built in order to meet the new construction utility loads. Data is sourced from Dodge construction database, the demand forecast office future generation facility planning data, and building permit office data.

All CASE reports should use the statewide construction forecast for 2014. The TDV savings analysis is calculated on a 15 or 30 year net present value, so it is correct to use the 2014 construction forecast as the basis for CASE savings.

The demand generation office publishes this dataset and categorizes the data by demand forecast climate zones (FCZ) as well as building type (based on NAICS codes). The 16 climate zones are organized by the generation facility locations throughout California, and differ from the Title 24 building climate zones (BCZ). HMG has reorganized the demand forecast office data using 2000 Census data (population weighted by zip code) and mapped FCZ and BCZ to a given zip code. The construction forecast data is provided to CASE authors in BCZ in order to calculate Title 24 statewide energy savings impacts. Though the individual climate zone categories differ between the demand forecast published by the CEC and the construction forecast, the total construction estimates are consistent; in other words, HMG has not added to or subtracted from total construction area.

The demand forecast office provides two (2) independent data sets: total construction and additional construction. Total construction is the sum of all existing floor space in a given category (Small office, large office, restaurant, etc.). Additional construction is floor space area constructed in a given year (new construction); this data is derived from the sources mentioned above (Dodge, Demand forecast office, building permits).

Additional construction is an independent dataset from total construction. The difference between two consecutive years of total construction is not necessarily the additional construction for the year because this difference does not take into consideration floor space that was renovated, or repurposed.

In order to further specify the construction forecast for the purpose of statewide energy savings calculation for Title 24 compliance, HMG has provided CASE authors with the ability to aggregate across multiple building types. This tool is useful for measures that apply to a portion of various building types' floor space (e.g. skylight requirements might apply to 20% of offices, 50% of warehouses and 25% of college floor space).

The main purpose of the CEC demand forecast is to estimate electricity and natural gas needs in 2022 (or 10-12 years in the future), and this dataset is much less concerned about the inaccuracy at 12 or 24 month timeframe.

It is appropriate to use the CEC demand forecast construction data as an estimate of future years construction (over the life of the measure). The CEC non-residential construction forecast is the best publicly available data to estimate statewide energy savings.

7.9.1 Citation

"NonRes Construction Forecast by BCZ v7"; Developed by Heschong Mahone Group with data sourced August, 2010 from Abrishami, Moshen at the California Energy Commission (CEC)

7.10 Pipe Sizing Calculation

The following section describes the methodology used to create the pipe sizing table.

First, we take the user inputs and determine the allowable pressure loss per 100 ft. of pipe using UPC methodology and ASHRAE guidance for estimating total developed length.

Assume that,
Building water supply pressure = P_{supply} = 55 psi
Minimum residual pressure = $P_{residual}$ = 15 psi
Developed Length Multiplier = 1.75 = $L_{multiplier}$
Mechanical Room to Recirculation Loop Adder = L_{adder}
where,
L_{adder} for Low-rise:

$$L_{adder} = h_{floor} + \frac{L_{unit}}{2}$$

L_{adder} for High-rise:

$$L_{adder} = h_{floor} \times \#of\ Floors\ between\ mech\ room\ and\ recirc\ loop + \frac{L_{unit}}{2} + \frac{TRLS}{4}$$

$$Vertical\ Rise = h_{floor} \times \#\ of\ Floors = L_{vertical}$$

$$Total\ Developed\ Length = \frac{L_{supply}}{\#\ of\ Loops} + L_{adder} \cdot L_{multiplier} = L_{developed}$$

$$Total\ Allowable\ Pressure\ Loss = P_{supply} - P_{residual} + L_{vertical} \times 0.43 = P_{allow}$$

$$Allowable\ Pressure\ Loss\ per\ 100ft.of\ pipe = \frac{100 \cdot P_{allow}}{L_{developed}} = P_{allow,100}$$

The UPC uses an iterative approach to determine pipe sizes. When sizing each section of pipe in the building, the allowable pressure loss per 100ft. of pipe calculation is used, but the total demand in gallons per minute (GPM) is determined separately for each section of pipe starting at the whole building level and working down to the dwelling unit level. Charts A-4 through A-7 in the UPC is used to convert the demand and pressure loss values into a pipe size for each section.

In the UPC, demand flow is determined using charts A-2 and A-3. These Hunter's Curve charts convert Water Supply Fixture Units (WSFU) into total demand in GPM. WSFU are values assigned to each type of appliance, appurtenance, or fixture by table A-2 in the UPC. In other words, to properly determine the demand for the building, we must first assume what combination of fixtures and appliances exist in each dwelling unit. For the default assumption, each dwelling unit has:

- Kitchen sink
- Bathroom sink
- Dish Washer
- Combination Bath/Shower

A table based version of Hunter's Curve was used to determine demand. Simple linear interpolation was used to find any intermediate values

UPC charts A-4 through A-7 were replaced with 2005 ASHRAE Fundamentals Handbook derived equivalent calculations that take the demand values in GPM and determined the velocity in ft/s and pressure loss per 100ft. of pipe for each size of pipe.

Flow velocity [ft/s] in a pipe was calculated by:

$$Velocity = \frac{C_1 \cdot V}{C_2 \cdot \frac{1}{4} \cdot \pi \cdot d_i^2}$$

where,
C_1 = conversion factor: 1 GPM = 0.13368/60 [ft^3/s]
V = Flow Rate [GPM]
C_2 = conversion factor: 1 in^2 = 1/144 [ft^2]
d_i = inner pipe diameter [in]

The pressure drop [psi] in 100 feet of pipe was calculated by:

$$Pressure\,Loss = (H_L \cdot C_2 \cdot \rho)$$

where,
C_2 = conversion factor: 1 in^2 = 1/144 [ft^2]
ρ = density of water @ 120 degF = 62.3 [lb/ft^3]
H_L = Total Head Loss from 100 feet of straight pipe

Straight pipe Head Loss [ft] was calculated by:

$$Head\ Loss = f \cdot \left(\frac{L}{d_i}\right) \cdot \left(\frac{v^2}{2g}\right)$$

where,
f = friction factor
d_i = inner pipe diameter [ft]
ρ = density of water @ 120 degF = 62.3 [lb/ft^3]
v = velocity of water flow [ft/s]
L = total length of straight pipe [ft]
g = gravity = 32.174 [ft/s^2]

Friction Factor was calculated by:

$$f = 8\left[\left(\frac{8}{Re_{D_h}}\right)^{12} + \frac{1}{(A+B)^{1.5}}\right]^{1/12}$$

where,

$$A = \left[2.457 \cdot \ln\left(\frac{1}{\left(\frac{7}{\mathrm{Re}_{D_h}}\right)^{0.9} + \left(\frac{0.27\varepsilon}{D_h}\right)} \right) \right]^{16}$$

$$B = \left(\frac{37530}{\mathrm{Re}_{D_h}} \right)^{16}$$

and,
ε = roughness height of the wall surface = 0.06 μin. for commercially smooth brass, lead, copper, or plastic pipe
Re_{Dh} = Reynolds number

The Reynolds number was calculated by:

$$\mathrm{Re}_{D_h} = \frac{v \cdot D_h}{\upsilon}$$

where,
v = velocity of water flow [ft/s]
D_h = hydraulic diameter = inner pipe diameter [ft]
υ = kinematic viscosity of water @ 120 degF = 0.607×10^{-5} [ft^2/s]

An example table of the ASHRAE calculation results is given in the table below. The table below represents the calculations for sizing 88 dwelling units in a 4 story building. The value of $P_{allow,100}$ for this example is 5.98 psi.

Pipe pressure loss calculation					
Nominal Size [in]	Length of pipe [ft]	Flow Rate [GPM]	Head Loss [ft]	Pressure Loss [psi]	Flow Velocity [ft/s]
0.25	100	129.41	170466	73750.2	532.75
0.375	100	129.41	37778	16344.1	285.89
0.5	100	129.41	12003	5193.0	177.97
0.75	100	129.41	2057	890.1	85.78
1	100	129.41	567	245.5	50.31
1.25	100	129.41	206	89.0	33.03
1.5	100	129.41	89	38.5	23.34
2	100	129.41	23	10.1	13.42
2.5	100	129.41	8	3.6	8.70
3	100	129.41	4	1.5	6.09
3.5	100	129.41	2	0.7	4.51
4	100	129.41	1	0.4	3.47

As can be seen, the limiting factor in this case is velocity. The UPC limits the hot water velocity to 5 ft/s and results in a 3.5 inch pipe size selection. If the value for $P_{allow,100}$ alone was the determining factor a 2.5 inch pipe would have been sufficient.

After performing several more calculations with a different number of dwelling units and number of floors, it became apparent that, using all previously stated assumptions, the pipe size of each section could be determined based on the 5 ft/s velocity limit when considering groups of dwelling units. The allowable pressure drop only becomes limiting for high-rise buildings and these buildings will already have a booster pump installed to ensure that adequate pressure exists to push water up to the highest floors. The end result of the pressure and flow loss calculations is a table that converts the number of dwelling units served by a pipe section into an equivalent pipe size.

7.11 Environmental Impact

Environmental impact associated with the proposed measures is consisted of three components: impact resulting from installation of demand control, optimal design and solar water heating systems. Material use increases associated with the installation of a pump controller (for recirculation pump control and solar pump control) and the copper piping increase from having an optimal design is summarized in the table below. Note that the copper piping net increase shown here considered the reduced piping from optimal design and the increased piping from running the water between the collector area back and the solar tank/boiler room area associated with the solar water heating system.

	Mercury (lb)	**Lead (lb)**	**Copper (lb)**	**Steel (lb)**	**Plastic (lb)**	**Glass (lb)**	**Aluminum (lb)**
per Controller	0.005	0.025	1.5	1	2.5		
Plumbing: per low-rise bldg			6.0				
Plumbing: per high-rise bldg			76.0				

The team also studied the environmental impact of installing solar water heating systems per the SSF levels recommended in Section 5.2. Namely, the impact is in terms of additional collector copper absorbers, glass glazing, aluminum frame and steel for solar tank.

Out of the ~ 900 SRCC OG-100 collectors[3], 90% of them reported having copper absorber material. Since copper weight content is not typically report in collector manufacturer published specification sheets, the team estimated the length and weight of copper absorber in flat-plate collectors using collector specifications available via SRCC OG-100's online database.

[3]Online database available via http://www.solar-rating.org/ratings/og100.html, accessed on 10/28/2011.

The team estimated the weight density of copper, plastic, glass and aluminum of "typical" flat-plate solar thermal collectors with data from manufacturers with representative products (through CalSEIA). These weight components include

- Copper: for collector absorbers
- Plastic: for insulation material inside collectors
- Glass: for collector glazing
- Aluminum: for collector frames. For framing, 84% of flat-plate collectors in SRCC's OG-100 database reported having aluminum based framing.

The team estimated the weight of steel associated with addition of the solar water tank by extrapolating and interpolating from the data point that a 1000-gal steel tank with shipping weight of 3200 lb. Material use increases associated with solar water heating systems are summarized below:

	Mercury (lb)	**Lead (lb)**	**Copper (lb)**	**Steel (lb)**	**Plastic (lb)**	**Glass (lb)**	**Aluminum (lb)**
Per SF collector area			0.725		0.259	1.95	0.526
Solar tank: per low-rise bldg				1,920			
Solar tank: per low-rise bldg				3,840			

Combining the results from all three components of the proposal, the total environmental impact is summarized in the following table:

	Applicable Equipment Unit	**Mercury (lb)**	**Lead (lb)**	**Copper (lb)**	**Steel (lb)**	**Plastic (lb)**	**Glass (lb)**	**Aluminum (lb)**
Low-rise Prototype								
Controller	2	0.01	0.05	3	2	5		
Plumbing				6				
Solar Tank					1920			
Solar Collector	363 SF			263		94	708	191
Total		0.01	0.05	272	1922	99	708	191
High-rise Prototype								
Controller	2	0.01	0.05	3	2	5		
Plumbing				76				
Solar Tank					3840			
Solar Collector	695 SF			504		180	1356	366
Total		0.01	0.05	583	3842	185	1356	366
Statewide		10	48	353,356	2,411,079	120,287	869,882	234,645