EVALUATING ENERGY SAVINGS FROM COMMUNITY SCALE SOLAR WATER HEATING (CSSWH) IN LOS ANGELES COUNTY

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ABSTRACT

This paper examines the potential of community scale solar water heating (CSSWH) to reduce natural gas consumption in Los Angeles County via geospatial analysis and system simulations. Properties suitable for CSSWH were identified using a set of criteria developed using data from UCLA's Energy Atlas. Performance of these case study properties were then simulated using RETSCREEN Clean Energy Management Software. The cost of energy provided by community scale was then calculated using a cost-benefit framework to assess the feasibility of CSSWH in Los Angeles County and the potential to reduce emissions from the residential building sector.

Keywords: Modeling, simulation, sustainability, energy, decision.

INTRODUCTION

The current research is a study of community-scale solar water heating (CSSWH) in Los Angeles County, the purpose of which is to estimate the technology's potential to reduce gas consumption and the carbon-intensity of residential water heating. Reducing carbon emissions from existing residential structures is a major component of state and local climate change mitigation efforts in California. While considerable time and energy have been spent studying residential electricity consumption, residential efficiency measures, and creating feasible de-carbonization pathways for electrical generation, less attention has been paid to residential use of thermal energy. In addition to the generation of renewable electricity, deep de-carbonization of the residential building sector also requires reducing the share of thermal energy from fossil fuel sources. This is especially important California, where most of the energy for space and water heating comes from natural gas. Solar thermal in the sector of urban and regional planning has been implemented at many levels. The recent study of [1] highlights the use of geographic information system (GIS) based_modeling to assess building energy consumption and suitability for solar energy usage. A geographic information system (GIS) is a framework for gathering, managing & analyzing data The work of [2] offers a study on enhancing the social awareness and acceptability of solar energy in urban planning. The research of [3] provides an urban planning study for solar energy implementation. In the area of community based solar energy application, the research of [4] gives a techno-economic optimization and analysis of a solar district heating system with seasonal storage taking into account different community sizes. The work of [5] compares community solar initiatives in the USA to those of the UK and other European countries. The study of [6] discusses a hybrid solar thermal power system with thermoelectric generator for desalination and power production, while the work of [7] provides techno-economic analysis of innovative production and application of solar thermal chilled water for agricultural soil cooling. The work of [8] gives results for a photovoltaic thermal hybrid solar collector and district heating configurations for a Central European multi-family house. The study of [9] provides a review of solar energy based heat and power generation systems. The future forecast of solar thermal applications is vast as outlined in [10], where perspectives for solar thermal applications in Taiwan are presented. In the study of [11], modelling and control of solar thermal system with borehole seasonal storage is presented. The work of [12] gives a recent review of the progress in building-integrated solar thermal systems. The study of [13] outlines the promotion of renewable energy in Germany, including a section on solar thermal applications. Thus, we see from the literature search that the application of solar thermal energy at the community level is an on-going area of research. To this end, the remaining sections of this manuscript outline the candidate CSSWH site selection process, the modeling of CSSWH using RETSCREEN software, followed by a discussion of results and wrapping up with a summary and conclusions section.

CANDIDATE CSSWH SITE SELECTION

The feasibility of CSSWH is dictated by site location, urban and regional planning, and community engagement and awareness. Candidate site location is a critical step in the whole process. To this end, the following criterion were applied to filter the possible site selection of the CSSWH

- The site must be large scale public and/or private housing communities
- The case studies shall focus on financial constraints
- Adherence to building codes and practical considerations must be considered
- The research team will conduct stakeholder interviews with contractors, county housing officials, and private property developers

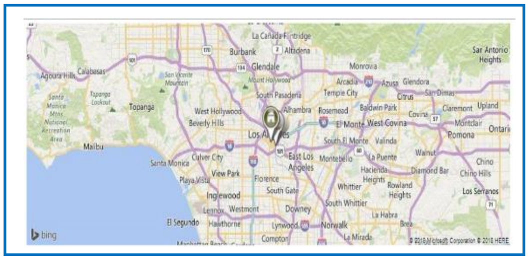
By applying the above filtering criteria to several sites, a few candidate sites were selected using geospatial analysis. Two of these sites are shown below in Figure 1 and Figure 2. William Mead Homes is a public housing development located in Chinatown, a neighborhood of the city of Los Angeles. It was built in 1941-1942 and contains 449 units in 24 buildings occupying 15.2 acres. Pheasant Ridge is a 620-unit, multi-building apartment complex, with over 1,000 residents, situated on 20.59 acres in Rowland Heights, CA 23 miles east of downtown Los Angeles in the San Gabriel Valley. Both candidate sites were based upon the filtering criteria outlined above.

Figure 1 – William Mead Homes, Los Angeles, CA

Figure 2 – Pheasant Ridge Apartments, Rowland Heights, CA

RETSCREEN CSSWH SYSTEM SIMULATION METHODOLOGY

Simulations of system performances conducted using RETSCREEN [14]. Financial analyses include benefits to site residents, system owners, and the general public (reduction in carbon emissions). The software tool RETSCREEN (aka RETSCREEN Clean Energy Management Software) was used to analyze the systems. RETSCREEN is a renewable energy modeling software developed and provided by the Canadian government [14]. RETSCREEN is a Clean Energy Management Software system for energy efficiency, renewable energy and cogeneration project feasibility analysis as well as ongoing energy performance analysis. RETSSCREEN allows professionals and decision-makers to rapidly identify, assess and optimize the technical and financial viability of potential clean energy projects. This decision intelligence software platform also allows managers to easily measure and verify the actual performance of their facilities and helps find additional energy savings/production opportunities [14]. The RETSCREEN software has experience proliferate application in the renewable energy sector to model renewable energy systems of many types. Previous studies [15,16] have benchmarked the RETSCREEN software. The study of [17] presents RETSCREEN based modeling of building integration of solar thermal systems-example of a refurbishment of a church rectory. The work of [18] a case study in Finland using solar water heating for aquaculture applications in cold climates is discussed. The work of [19] outlines the use of RETSCREEN for a techno-economıc analysıs of evacuated tube solar water heating usıng the f-chart method. The study of [20] gives results for a comparative study of solar-powered underfloor heating system performance in distinctive climates using RETSCREEN. The research of [21] outlines the preliminary determination of optimal size for renewable energy resources in buildings using RETSCREEN. The case study of [22] presents the analysis of a solar water heating initiative in Oman and subsequent carbon footprint impact. The following is a walk-through of how the Graphical User Interface (GUI) of RETSCREEN functions used for simulating the CSSWH candidate sites herein. Figure 3 shows the weather data used at the site.



	Unit	Climate data location	Facility location	Source
Latitude		34.0	34.1	
Longitude		-118.2	-118.2	
Climate zone		3B - Warm - Dry		NASA
Elevation	m	82	0	Ground – Ground
Heating design temperature	°C	2.3		NASA
Cooling design temperature	°C	33.2		NASA
Earth temperature amplitude	°C	22.8		NASA

Figure 3 – Candidate Site Weather Data

Figure 4 shows the climatology data for the candidate site locations.

Month	Air temperature	Relative humidity	Precipitation	Daily solar radiation - horizontal	Atmospheric pressure	Wind speed	Earth temperature	Heating degree-days 18 °C	Cooling degree-days 10 °C
	°C	%	mm	kWh/m²/d	kPa	m/s	°C	°C-d	°C-d
January	9.1	52.5%	65.02	2.91	95.1	4.5	9.1	276	0
February	10.1	53.6%	92.47	3.37	94.9	4.6	10.8	221	3
March	12.6	48.3%	36.27	4.95	94.8	4.7	14.5	167	81
April	15.9	38.6%	24.73	6.22	94.7	4.7	19.1	63	177
May	19.6	36.0%	12.89	6.70	94.5	4.9	23.9	0	298
June	23.2	31.7%	2.30	7.04	94.5	4.7	28.5	0	396
July	25.9	29.7%	2.13	7.38	94.6	4.3	31.2	0	493
August	26.0	29.9%	1.82	6.87	94.6	3.9	30.4	0	496
September	23.3	33.8%	6.00	5.53	94.5	3.9	26.9	0	399
October	18.7	36.7%	15.90	4.19	94.7	3.8	20.9	0	270
November	12.6	42.7%	25.63	3.36	95.0	4.4	13.4	162	78
December	8.9	48.4%	45.96	2.74	95.1	4.5	8.9	282	0
Annual	**17.2**	**40.1%**	**331.12**	**5.11**	**94.7**	**4.4**	**19.8**	**1,172**	**2,690**
Source	NASA	NASA	NASA	Ground	NASA	NASA	NASA	NASA	NASA
Measured at					m	10	0		

Figure 4– Candidate Site Climatology Data

Figure 5 shows the solar insolation data for the candidate site locations.

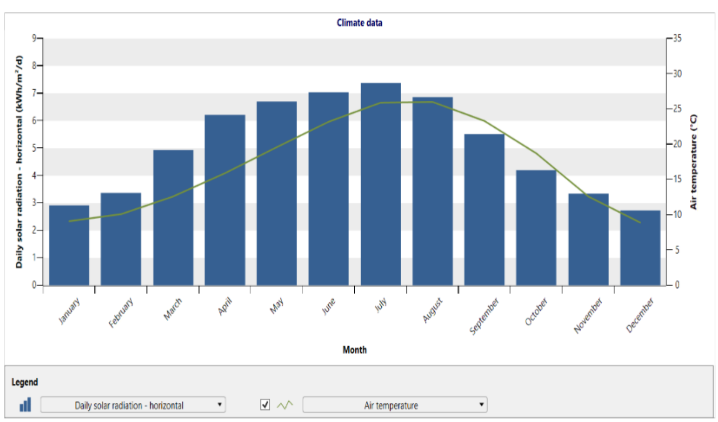


Figure 5– Site Location Solar Insolation Data

Figure 6 includes a description of the candidate site's facility data as well as fuel consumption data

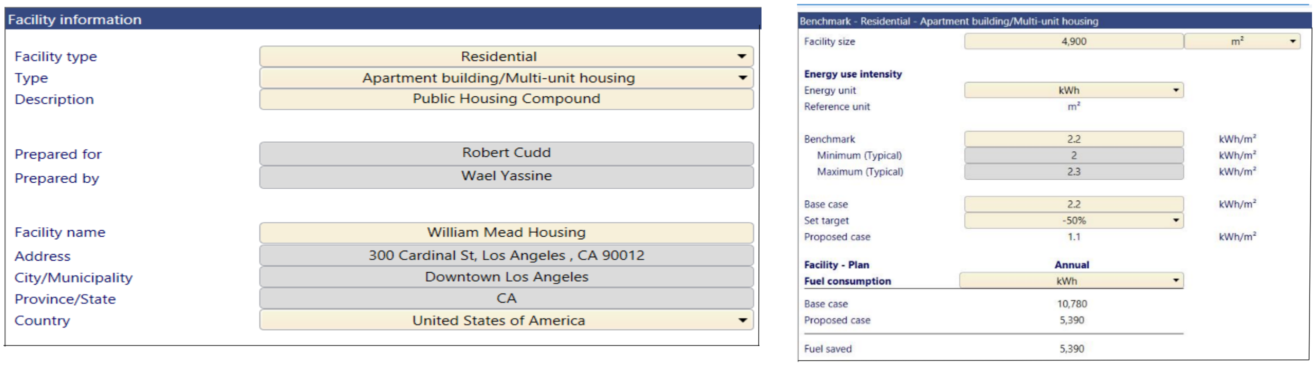


Figure 6– Site Location Facility Data

Figure 7 shows the energy savings goal of the project.

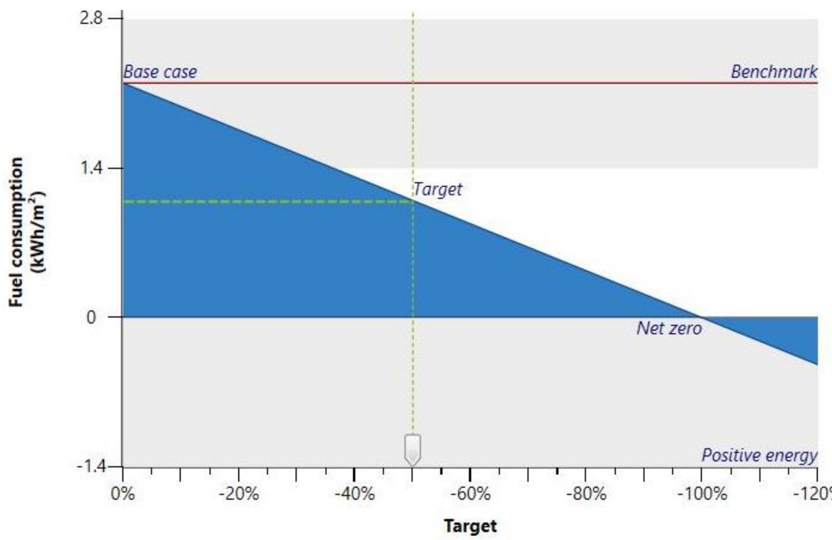


Figure 7– Energy Savings Goals

Figure 7 shows the current base case which is used as the benchmark in RETSCREEN. Figure 7 also shows the target case, which here is a 50% reduction of energy. The point of solution is shown by the intersection of the two dashed green lines in Figure 7, where the amount of fuel consumption (kWh/m^2) is shown to be approximately 1.2 kWh/m^2 for the target of 50% reduction. Figure 8 shows the input dialog of the rate of fuel and electricity consumption.

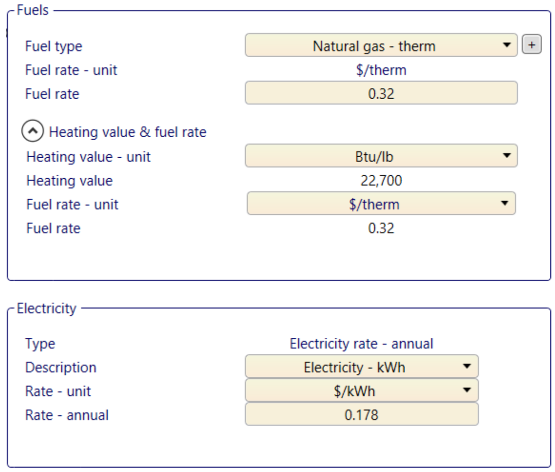


Figure 8 – Energy Savings

Figure 8 shows that the fuel rate of 32 ¢/therm is applied to the natural gas, while the rate of 17.8 ¢/kWh for electricity is applied. These values are typical of Southern California. Recall 1 therm = 99976.1 BTU, 1 BTU = 1055.06 J). Next, natural gas heating is considered as shown in Figure 9.

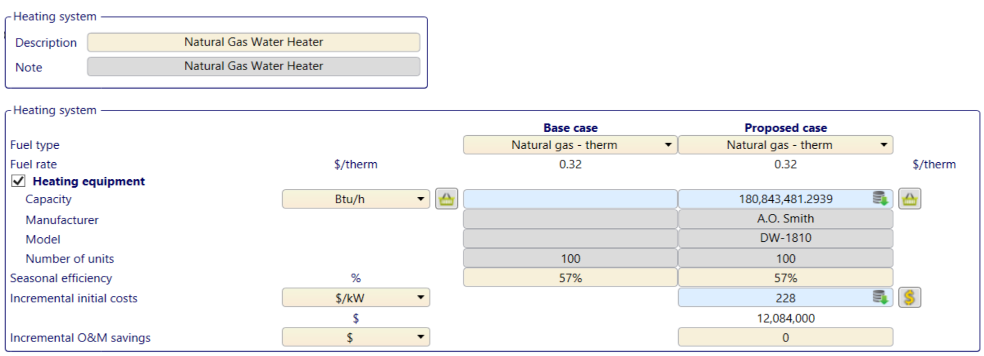


Figure 9– Gas Heating

From Figure 9, we see that gas heating for the proposed case translates into a reduction 228 $/kW if the 50% proposed energy reduction is met. Figure 10 summarizes the overall energy savings as completed by the project.

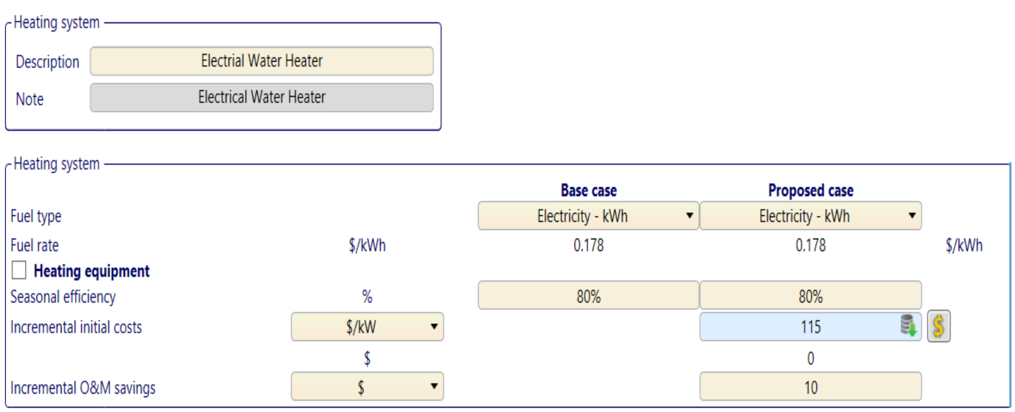


Figure 10– Energy Savings Retrofit vs. As-Is

Figure 10 shows that a savings of 115 $/kW is realizable if the proposed 50% reduction case were to be implemented.

RETSCREEN CSSWH SYSTEM SIMULATION RESULTS

The input above can be used to shed light on the design on the CSP power plant design. Figure 11 shows the dialog from RETSCREEN for the design of the how water supply based upon the hot water demand schedule input by the modeler. Figure 11 details the hot water demand schedule of a typical apartment located in one of the candidate sites. The value of 4476 gal/day is based on national average numbers.

Hot water - Method 1

		Base case	Proposed case	Energy saved
☑ **Load type - calculator**		Apartment		
Number of units	Unit	100		
Occupancy rate	%	100%		
Daily hot water use - estimated	US gal/d	4,476		
Hot water use	US gal/d	6,420	6,420	
Temperature	°F	131	131	
Supply temperature method		Formula		
Water temperature - minimum	°F	57.7		
Water temperature - maximum	°F	68.5		
Operating hours	h/d	8	8	
Heat recovery efficiency	%	50%	50%	

Figure 11– Hot Water System Design

Figure 12 shows the hot water demand schedule.

☑ **Percent of month used**				
January		100%	100%	
February		100%	100%	
March		100%	100%	
April		100%	100%	
May		100%	100%	
June		100%	100%	
July		100%	100%	
August		100%	100%	
September		100%	100%	
October		100%	100%	
November		100%	100%	
December		100%	100%	
Incremental initial costs	$		1,208	
Incremental initial costs - other	$			
Incremental initial costs - total	$		1,208	
Incremental O&M savings	$			
Heating system		Natural Gas Water Heater	Natural Gas Water Heater	
Heating	kWh	65,197	65,197	0
				0%

Figure 12– Hot Water Useage Schedule

Figure 12 computes the natural gas cost associated with heating the given water useage schedule. The solar hot water system design from RETSCREEN is shown in Figure 13, while Figure 14 shows the monthly heating load (BTU) delivered by the solar hot water system.

Solar water heater		
Load characteristics		
Hot water		Hot Water Consumption
Temperature	°F	131
Heating	Btu	222,462,024
Resource assessment		
Solar tracking mode		Fixed
Slope	°	34
Azimuth	°	0

Figure 13– Solar Hot Water System Design

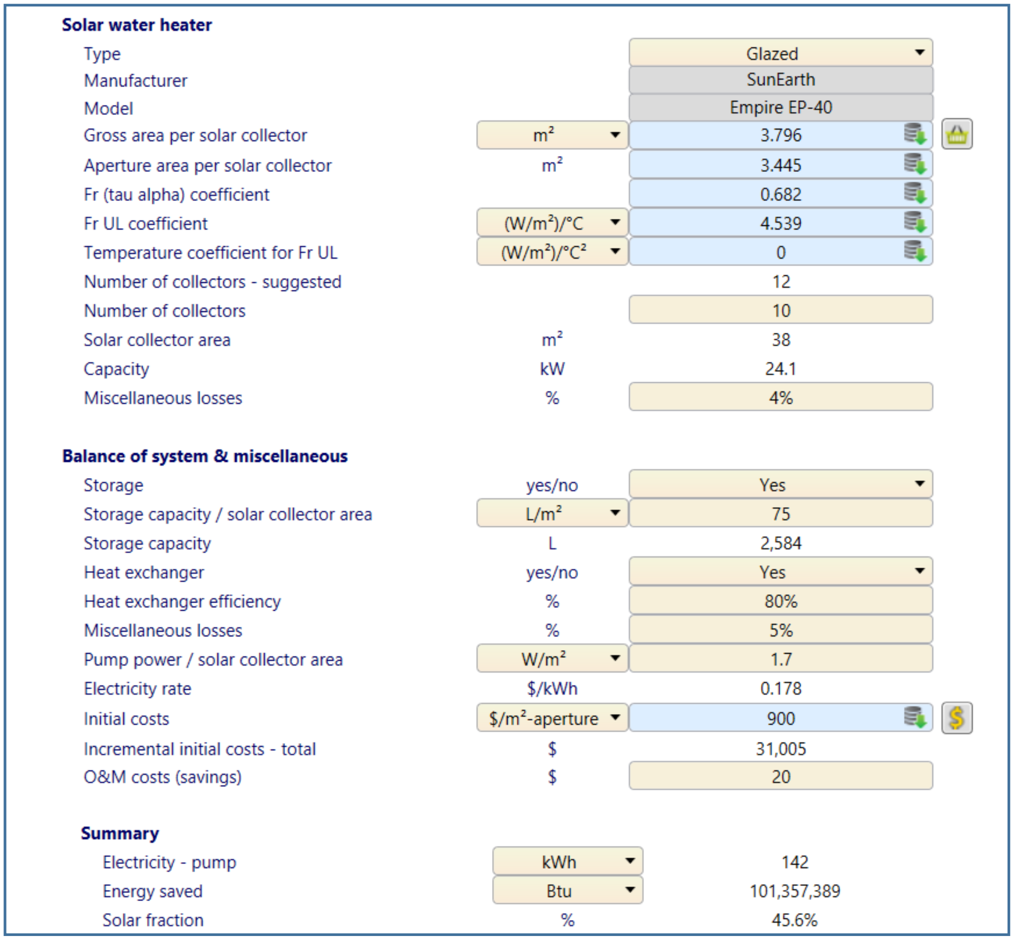
Month	Percent of month used - base case %	Percent of month used - proposed case %	Daily solar radiation - horizontal kWh/m²/d	Daily solar radiation - tilted kWh/m²/d	Heating delivered Btu
January	100%	100%	2.91	4.41	6,499,392.815
February	100%	100%	3.37	4.37	5,841,990.770
March	100%	100%	4.95	5.73	8,945,797.170
April	100%	100%	6.22	6.32	9,663,261.002
May	100%	100%	6.70	6.16	9,749,544.971
June	100%	100%	7.04	6.18	9,484,002.385
July	100%	100%	7.38	6.59	10,378,493.215
August	100%	100%	6.87	6.69	10,383,795.258
September	100%	100%	5.53	6.09	9,018,759.720
October	100%	100%	4.19	5.33	7,997,495.134
November	100%	100%	3.36	5.02	7,130,883.945
December	100%	100%	2.74	4.37	6,263,972.324
Annual	**100%**	**100%**	**5.11**	**5.61**	**101,357,388.709**

Annual solar radiation - horizontal	MWh/m²	1.87
Annual solar radiation - tilted	MWh/m²	2.05

Figure 14– Solar Hot Water System

Figure 15 summarizes the hardware used to construct the solar hot water system. Figure 15 tabulates the energy saved and solar fraction needed to accomplish that goal. Here, for the 50% reduction of energy case of Figure 7, the energy saved using solar thermal is 101.35 MBTU =1013.5 therms (1 therm = 1.055e+8 Joules= 29.3 kW-hr), corresponding to a solar thermal system having a solar fraction of f = 45.6% (i.e. the solar thermal energy system provides 45.6% of the needed energy to heat the hot water).

Figure 16 shows the corresponding emission report. Figure 16 states that there is a 45% gross annual Greenhouse Gas (GHG) emission reduction associated with the proposed system. This is associated with the reduction of natural gas needed to heat the hot water, which has now been offset by the solar thermal hot water system.



Solar water heater		
Type		Glazed
Manufacturer		SunEarth
Model		Empire EP-40
Gross area per solar collector	m^2	3.796
Aperture area per solar collector	m^2	3.445
Fr (tau alpha) coefficient		0.682
Fr UL coefficient	$(W/m^2)/°C$	4.539
Temperature coefficient for Fr UL	$(W/m^2)/°C^2$	0
Number of collectors - suggested		12
Number of collectors		10
Solar collector area	m^2	38
Capacity	kW	24.1
Miscellaneous losses	%	4%
Balance of system & miscellaneous		
Storage	yes/no	Yes
Storage capacity / solar collector area	L/m^2	75
Storage capacity	L	2,584
Heat exchanger	yes/no	Yes
Heat exchanger efficiency	%	80%
Miscellaneous losses	%	5%
Pump power / solar collector area	W/m^2	1.7
Electricity rate	$/kWh	0.178
Initial costs	$\$/m^2$-aperture	900
Incremental initial costs - total	$	31,005
O&M costs (savings)	$	20
Summary		
Electricity - pump	kWh	142
Energy saved	Btu	101,357,389
Solar fraction	%	45.6%

Figure 15– Solar Hot Water System Hardware

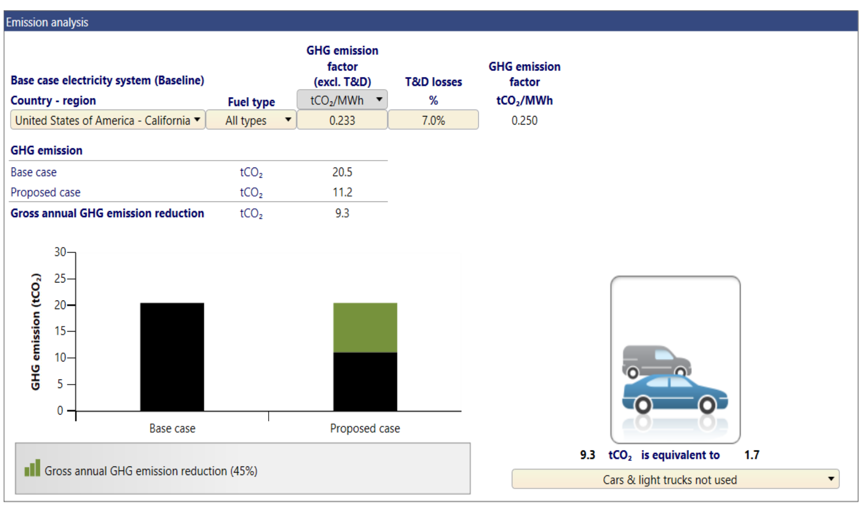


Figure 16– Emissions report

CONCLUSIONS

This paper has presented the analysis of community scale solar water heating (CSSWH) to reduce natural gas consumption in Los Angeles County via geospatial analysis and system simulations. The geospatial analysis used a set of filtering criteria in order to identify candidate sites for the implementation of CSSWH. The simulation tool RETSCREEN was then used to determine the natural gas footprint offset by using solar thermal hot water heating in a typical candidate site. The results show that a typical installation site can afford a 45% gross annual reduction of greenhouse gas emission by using a solar thermal system rated at a solar fraction of 45.5% having an associated energy reduction of 101.35 MBTU. Future work will quantify the pump, flow rate and solar thermal panels and storage tanks needed to realize the installation of an actual system.

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