Renewable Energy Project

Economic Analysis Report
Implementation of the SuperSurya Cogeneration System

December 13, 2019

MCAD Student: Thongminh Nguyen
Project Advisor: Mithra Sankrithi
Practicum Advisor: Denise Deluca

Table of Content

1. Introduction

Sunlight energy is ‘free’ and available year round in most places in the world. The SuperSurya is a new technology that harvests sunlight energy. While solar panels convert sunlight into electricity, the SuperSurya converts a large portion of sunlight into usable heat in addition to converting a concentrating photovoltaic portion of sunlight into electricity. Additionally, the SuperSurya is installed with a 2-axis tracking that allows for maximum energy collection throughout the day. Collecting sunlight energy as usable heat provides some advantages to the SuperSurya because many home appliances and equipment produce heat as their output hence can benefit from the utilization of “waste heat” from a CPV cogeneration system such as SuperSurya, rather than expensive energy conversion from electricity to heat. The big three equipment areas that use heat are home home heating, ventilation and cooling (HVAC) system, water heaters, and pool heaters. Among other home appliances, stoves, microwaves, grills, and irons also use heat. This project provides an overview on the overall cost of the SuperSurya low-concentration CPV cogeneration system along with a comparison between the implementation of the SuperSurya and solar panels.

2. Purpose and Objectives

The purpose and outcome of the project is an economic analysis of a new solar cogeneration collector, the SuperSurya. There are four main objectives in the project. The first objective is to analyze five main scenarios for providing energy to residential homes in five cities from five different states in the U.S. The second objective is to provide a pre-assessment for installing the SuperSurya on rooftop of a few homes in the selected cities. The third objective is to include a start-up cost and long term cost of the SuperSurya. The fourth objective is to include a preliminary assessment of the materials that are used in making the SuperSurya.

The five main scenarios for providing energy to residential homes are:

1. All electric
2. All electric with installation of solar panel
3. All electric with installation of solar panels with net metering
4. All electric with installation of the SuperSurya collector
5. All electric with installation of the Super Surya with net metering.

The five selected cities are:

1. Boston, Suffolk County, Massachusetts
2. Houston, Harris County, Texas
3. Los Angeles, Los Angeles County, California
4. Minneapolis, Hennepin County, Minnesota
5. Salt Lake City, Salt Lake City County, Utah

3. Data Collection Structure, Method, and Validation

Various types of data are collected for verification, correlation, and calculation purposes. The data is divided into two three main categories: weather and solar collector capability, energy needs in a home with all electric appliances, and cost of energy with the installation of solar collectors.

Data about weather includes average temperature, heating degree days, cooling degree days, hours of sunlight, percent of possible sunlight, and solar radiation with or without heliostatic tracking. Data about weather are crucial for verification of energy needs and calculating the output power of energy generator/collector systems. Heating degree days (HDD) are the days that a home/building requires heating. Cooling degree days (CDD) are the days that a home/building requires cooling. HDD and CDD are directly related to the energy used for home heating and home cooling. Heaters and air conditioners are only used when the temperature falls below or rises above certain thresholds hence HDD and CDD are relative parameters and are different from home to home. For a generic analysis, the base temperature for HDD is set at 68^{o}F and the base temperature for CDD is set at 75^{o}F.

Hours of sunlight, percent of possible sunlight, and solar radiation are directly related to the amount of energy that solar panels and the SuperSurya are able to provide. Percent of possible sunlight accounts for cloud cover and the fact that sunlight might not reach earth's ground during day time. All three parameters vary from month to month but have a strong correlation with one another. For the project, the combination of the number of hours of sunlight and the percent of possible will be used for energy generation calculations.

Energy need is divided into three categories: low demand, medium demand, and high demand. The low o basic demand category covers the basic energy needs such as water heating, cooking, refrigerator, space cooling, space heating, lightning, and TV and entertainment. The medium demand category adds the usage of a second refrigerator, a large screen TV, and a spa or hot tub. The high demand category adds pool heating. All energy needs are recorded in or converted to US dollars.

All collected and generated data for each city are presented in the format below. *Refer to the Excel files for the five selected cities in the Works Cited section.* The data is divided into two main groups. Groups with the asterisk (*) use the available raw data that are unique to each city or climate region where the city is located. Groups without the asterisk (*) use computed data that are estimates calculated from raw data. Further explanation for how the data is used is provided below.

A1*	Weather, Heating Degree Days, and Cooling Degree Days	This data is used to validate the monthly home energy cost. Energy use for space heating and space cooling correlates with regional temperatures.
A2*	Monthly Solar Radiation in kWh / sq ft / day	This data is used to calculate available solar income.
A3*	Energy Usage in Mix-Dry/Hot-Dry Regions	This data is used to determine the percent of the total energy used for space heating, space cooling, and water heating.

A4	Effective Roof Area for Solar Panel Installation in sq ft based on Home Square Footage in sq ft	This calculation determines the number of solar panels that can be installed on a roof.
A5	Effective Ridge Length for SuperSurya Installation in ft based on Home Square Footage in sq ft	This calculation determines the number of SuperSurya that can be installed on a ridge.
A6	Dimensions and Ratings of Solar Panels and SuperSurya	This calculation shows the comparison of all parameters of solar panels and SuperSurya.
A7	Maximum Energy Received from the Sun in kWh based on Home Base Area in sq ft	This calculation shows solar income for a 1000 square foot home and a 3000 square foot home.
A8	Monthly Energy Generation in kWh	This calculation shows the amount of energy that can be collected from solar panels and SuperSurya for a 1000 square foot home and a 3000 square foot home.
A9*	Average Residential Electricity Rates in c/kWh	This data contains the local electricity rates in cents per kWh.
A10	Monthly Cost Reduction in $	This calculation shows the amount of money that solar panels and SuperSurya can save for homeowners.
B1*	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Low Demand	Calculations B1* through B6* show the monthly energy cost of a 1000 square foot home and a 3000 square foot home with all electric appliances and four household members with low, medium, and high energy demand. All energy comes from the grid.
B2*	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Medium Demand	
B3*	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, High Demand	
B4*	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Low Demand	
B5*	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Medium Demand	
B6*	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, High Demand	
C1	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Low Demand, Local Cost	Calculations C1 through C6 account for the local cost into calculations B1* through B6*.
C2	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost	
C3	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town	

	Home, 4 People, High Demand, Local Cost	
C4	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Low Demand, Local Cost	
C5	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost	
C6	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, High Demand, Local Cost	
D1	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, Solar Panel	Calculations D1 through D6 account for the energy saving from installing solar panels into calculations C1 through C6.
D2	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, Solar Panel	
D3	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, High Demand, Local Cost, Solar Panel	
D4	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, Solar Panel	
D5	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, Solar Panel	
D6	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, High Demand, Local Cost, Solar Panel	
E1	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, Solar Panel, Net Meter	Calculations E1 through E6 account for energy saving from installing solar panels plus net metering into calculations D1 through D6.
E2	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, Solar Panel, Net Meter	
E3	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, High Demand, Local Cost, Solar Panel, Net Meter	
E4	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, Solar Panel, Net Meter	
E5	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, Solar Panel, Net Meter	
E6	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, High Demand, Local Cost, Solar Panel, Net Meter	
F1	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, SuperSurya	Calculations F1 through F6 account for the energy saving from installing SuperSurya into calculations C1 through C6.
F2	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, SuperSurya	
F3	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, High Demand, Local Cost, SuperSurya	
F4	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, SuperSurya	
F5	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, SuperSurya	
F6	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, High Demand, Local Cost, SuperSurya	
G1	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town	Calculations G1 through G6

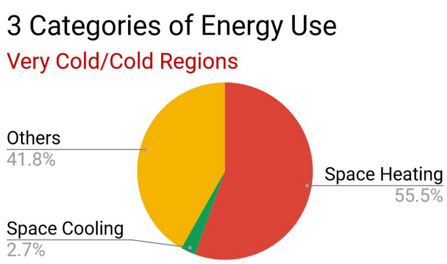
	Home, 4 People, Low Demand, Local Cost, SuperSurya, Net Meter	account for the energy saving from installing SuperSurya plus net metering into calculations F1 through F6.
G2	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, SuperSurya, Net Meter	
G3	Estimated Monthly Home Energy Cost in $ - All Electric, 1000 Square Foot, Town Home, 4 People, High Demand, Local Cost, SuperSurya, Net Meter	
G4	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Low Demand, Local Cost, SuperSurya, Net Meter	
G5	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, Medium Demand, Local Cost, SuperSurya, Net Meter	
G6	Estimated Monthly Home Energy Cost in $ - All Electric, 3000 Square Foot, Town Home, 4 People, High Demand, Local Cost, SuperSurya, Net Meter	
H1	Monthly Home Energy Cost Comparison, 1000 Square Foot, Town Home, 4 People, Low Demand	This section summarizes and compares the monthly energy cost of a home with all electric appliances, the same home with solar panels installed, and the same home with SuperSurya installed.
H2	Monthly Home Energy Cost Comparison, 1000 Square Foot, Town Home, 4 People, Medium Demand	
H3	Monthly Home Energy Cost Comparison, 1000 Square Foot, Town Home, 4 People, High Demand	
H4	Monthly Home Energy Cost Comparison, 3000 Square Foot, Town Home, 4 People, Low Demand	
H5	Monthly Home Energy Cost Comparison, 3000 Square Foot, Town Home, 4 People, Medium Demand	
H6	Monthly Home Energy Cost Comparison, 3000 Square Foot, Town Home, 4 People, High Demand	
I1	Annual Home Energy Cost Comparison, 1000 Square Foot, Town Home, 4 People, Low Demand	This section summarizes and compares the annual energy cost of a home with all electric appliances, the same home with solar panels installed, and the same home with SuperSurya installed.
I2	Annual Home Energy Cost Comparison, 1000 Square Foot, Town Home, 4 People, Medium Demand	
I3	Annual Home Energy Cost Comparison, 1000 Square Foot, Town Home, 4 People, High Demand	
I4	Annual Home Energy Cost Comparison, 3000 Square Foot, Town Home, 4 People, Low Demand	
I5	Annual Home Energy Cost Comparison, 3000 Square Foot, Town Home, 4 People, Medium Demand	
I6	Annual Home Energy Cost Comparison, 3000 Square Foot, Town Home, 4 People, High Demand	

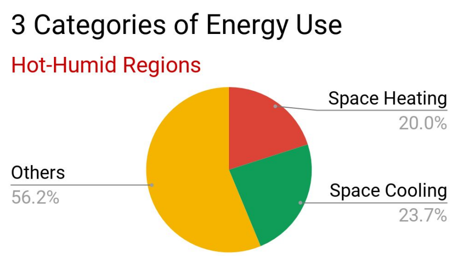
4. End Use Consumption: Electric & Heat

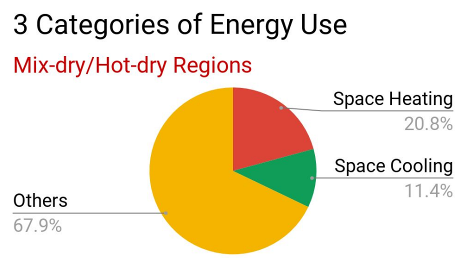
Because the SuperSurya generates electricity and usable heat, this section explores the end use consumption of energy by various categories. Homes that are in the same climate region are likely to have similar energy footprint. For example heaters are unlikely to be turned on when the outdoor temperature is above 80ºF and air conditioners are unlikely to be turned on when the outdoor temperature is below 50ºF.

Energy usage is investigated in three different climate regions of the five cities. Boston, Minneapolis, and Salt Lake City are in the Very Cold/Cold region. Houston is in the Hot-humid region. Los Angeles is in Hot-dry region. The energy usage data in kWh is obtained from the U.S. Energy Information Administration and is converted into percentages that are shown below. This section assumes that usable heat generated by the SuperSurya can be used for all specified categories; more details on the technical advances will be included in Section 10.

In the first comparison, energy consumption is divided into three categories: space heating, space cooling, and others. Space heating regions is expected to be the highest in the Very Cold/Cold region due to the fact that the Very Cold/Cold region has the lowest temperature during winter time among all climate regions. Space cooling is expected to be the highest in Hot-humid region due to the fact that Hot-humid region has the highest temperature during summer time among all climate regions.

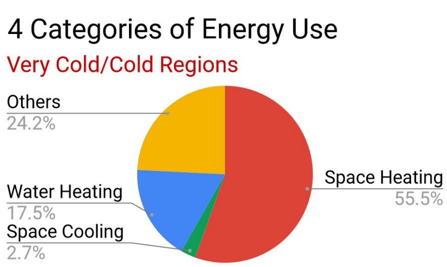


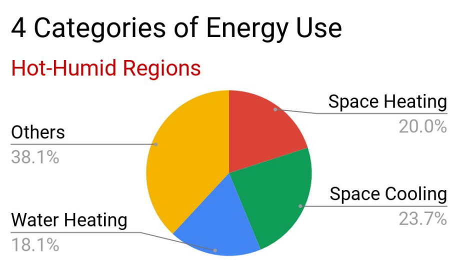


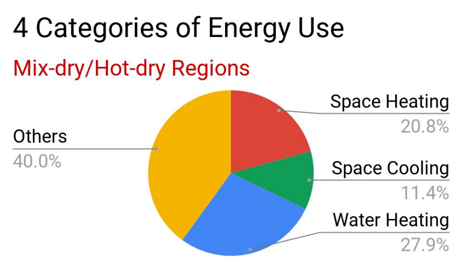


(Data source: U.S. Energy Information Administration)

The second comparison separates water heating from the ‘others’ category. In all three climate regions, space heating, space cooling, and water heating account for 50% or more of the total energy usage. The percentages from the 4 Categories of Heating will be used for latter sections.





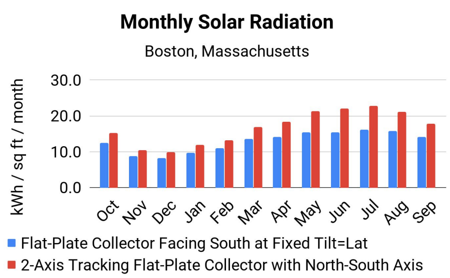


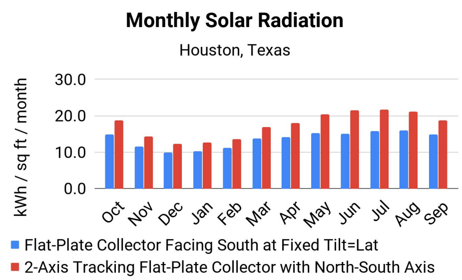
(Data source: U.S. Energy Information Administration)

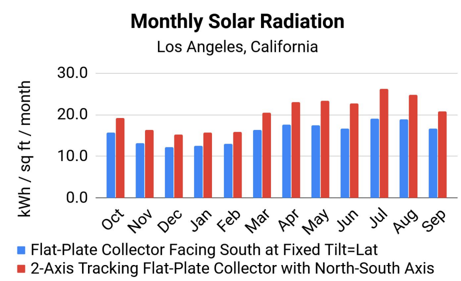
The conclusion is that the majority of home appliances use heat not electricity. The next section shows how the SuperSurya is the better fit when energy demand is heat rather than electricity.

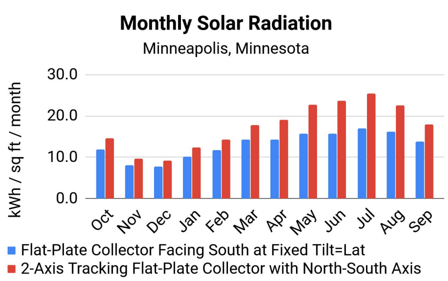
5. Input Power and Output Power

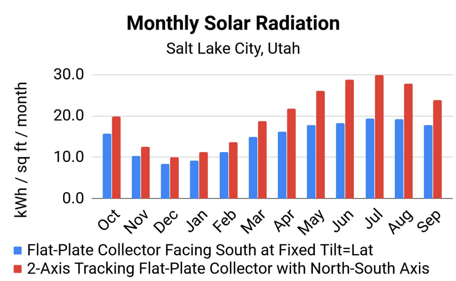
Solar panels and the SuperSurya converts sunlight into electricity, while SuperSurya harvests additional solar energy that is converted into usable heat. The graphs below show the Monthly Solar Radiation (in kWh / ft / month) in the five selected cities. The two most effective solar energy collection methods shown are ‘Flat-Plate Collector Facing South at Fixed Tilt=Lat’ and the ‘2-Axis Tracking Flat-Plate Collector with North-South Axis’. The Solar Radiation data in kWh / ft^2 is converted from the original Solar Radiation data in kWh / m^2 / day. The ‘Flat-Plate Collector Facing South at Fixed Tilt=Lat’ data shows the available solar energy per square foot per month if solar collectors are positioned on the rooftop area facing South at a fixed latitude. The ‘2-Axis Tracking Flat-Plate Collector with North-South Axis’ shows the available solar energy per square foot per month if solar collectors can track the sun and are able to receive the most sunlight throughout the day. Since the SuperSurya uses the 2-axis tracking method, it is able to collect more sunlight than solar panels, approximately 4.6 kWh more per square foot per month.





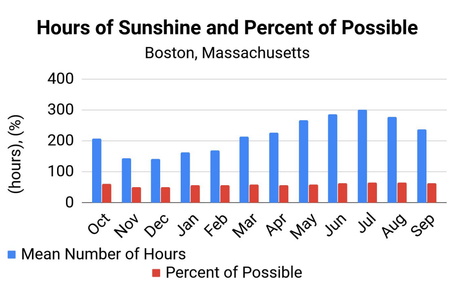


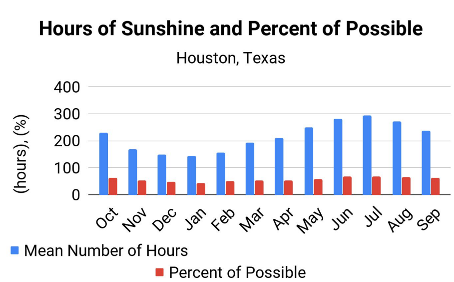


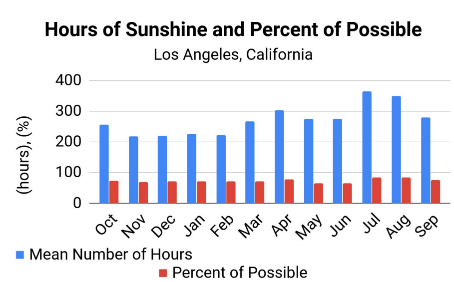


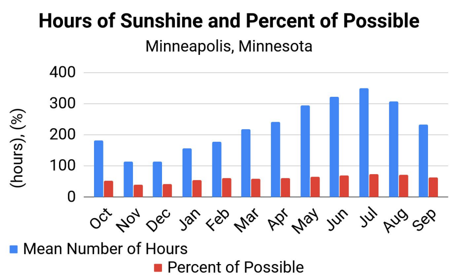
(Data source: www.nrel.gov)

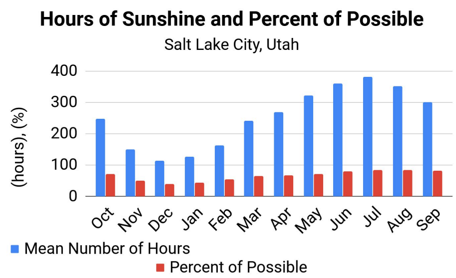
In order to calculate the energy collected by solar panels and the SuperSurya, the monthly sunshine hours and percent of possible are required. The sunshine hours are the number of daylight hours. The percent of possible includes other factors that prevent sunlight from reaching earth’s ground hence effectively reduce the sunshine hours. These other factors include cloud coverage, moisture, etc. Among the five selected cities, Los Angeles has the most sunshine hours as well as the highest and most consistent percent of possible throughout the year.





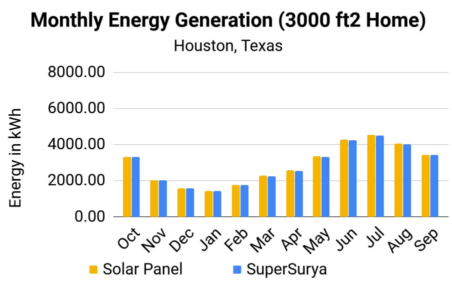


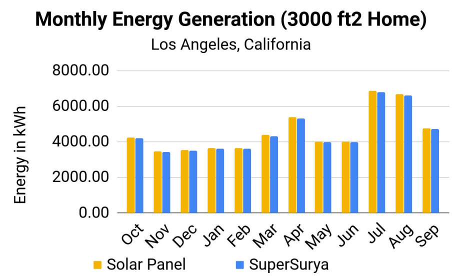


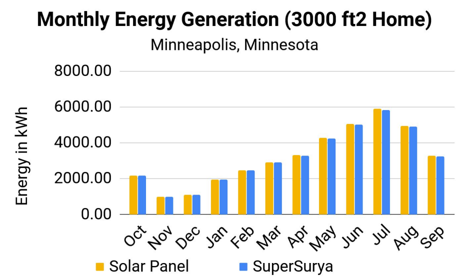


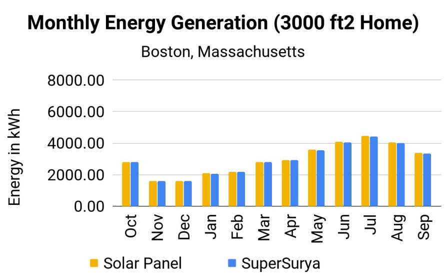
(Data source: data.un.org)

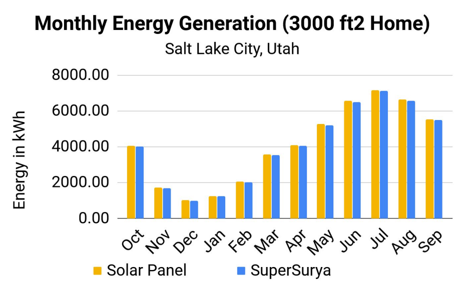
The energy collected or the power output of the solar panels and the SuperSurya is calculated by multiplying their output power rating (in W or kW) by the number of sunshine hours and the percent of possible per month.







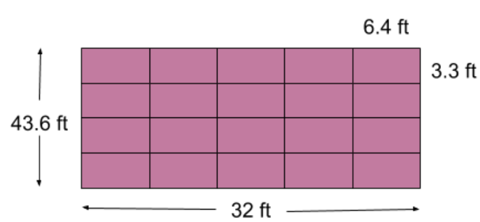
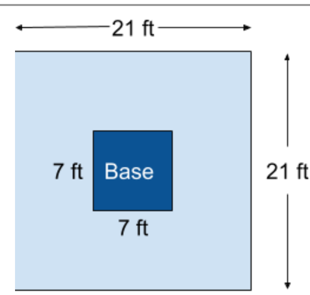




The result shows that both solar panels and the SuperSurya have not maximized all available sunlight energy. The power density (output power in a given area) of the solar panels is approximately equal to that of the SuperSurya.

6. Comparison: Ease of Installation, Occupied Area, and Power Generation

This section shows the installation and compare power generation of solar panels and the SuperSurya. To maximize energy collection, solar panels are installed on South facing roofs. Due to the shape of rooftops being trapezoidal and the shape of solar panels being rectangular, not all areas of the roof can be used to install solar panels. The total occupied area of solar panels are always smaller than the area of the roof. On the contrary, the SuperSurya is installed on horizontal or slightly slanted ridges. The mounting base of the SuperSurya is approximately a third of the total length, which can allow for more SuperSurya to be installed on one ridge. The table below compares the characteristics between the SuperSurya and the 'Trina Solar 370Watts Tallmax Plus'. The SuperSurya is comparable to solar panels in both power density and cost.

Comparison Criteria	Trina Solar 370 Watts Tallmax Plus 72-Cell Monocrystalline Solar Module (1500V) TSM-DE14A(II)	SuperSurya Cogeneration System
Installation	On roof	On ridges
Mounting Base	Occupy as much space as the solar panel.	Base is approximately ⅓ of the SuperSurya, possible for more units to be installed.
Power per Unit	370W	7.5 kW (1.6 kWe + 5.9 kWt)
Size	77.2 in. x 39.1 in. (6.4 ft. x 3.3 ft.)	21 ft. x 21 ft.
Unit Area	21.0 ft^2	441 ft^2
Power Density	17.6 W / ft^2	17.0 W / ft^2
Unit Cost	$230	
Price per Watt	$0.62	
Unit Cost + Installation	$1,235.80	$27,000.00
Price per Watt + installation	$3.34	$3.60
Quantity for Equal Power	20	1
Drawing		

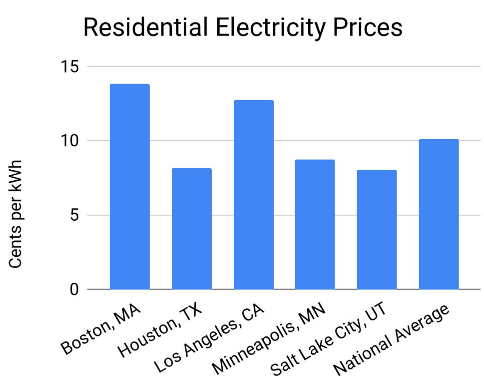
7. Annual Energy Cost Comparison: All Electric vs. Solar Panel vs. SuperSurya

This section shows a general analysis, comparing the following scenarios:

1. The cost of electricity in a two houses when all home appliances are electric.
2. The cost of electricity of the same houses with solar panels installed.
3. The cost of electricity of the same houses with solar panels installed with net-metering.
4. The cost of electricity of the same houses with the SuperSurya installed.
5. The cost of electricity of the same houses with the SuperSurya installed with net-metering.

In the scenarios with the solar panels and the SuperSurya, energy collected during the day is assumed to be stored for use during the night. Leakage and efficiency of such storage is unaccounted in this analysis.

For the first scenario, data on the cost of electricity in an all electric home is collected via Home Energy Solutions website. The two example houses will be a 1000 ft^2 home with a low demand of energy use and a 3000 ft^2 with a high demand of energy use. Neither home requires pool heating. Both homes have four occupants, an average heating setting of 68°F, an average cooling setting of 75°F, townhome style, 5 to 15 years old, average insulation, and average weatherization. A home with a higher energy demand include, in addition to the previous list, a second refrigerator/freezer, a large screen TV, and a spa or hot tub. All costs on Home Energy Solutions are normalized to 10 cents per kWh. To account a more realistic cost, electricity cost per city is obtained from the Electricity Local website. A graph of electricity cost across the five selected cities and the national average is shown below. Electricity cost in Boston, MA and Los Angeles, CA are higher than the national average by two to three cents per kWh.



(Data source: www.electricitylocal.com)

To calculate the cost of electricity for the second scenario, a typical solar panel is used. The solar panel is 17.6 ft^2 in size and is capable of 320W under Standard Test Conditions. The energy (in kWh) that is generated by the solar panels is calculated by multiplying the following parameters: the output power per solar panels, the number of solar panels, sunshine hours, and percent of possible. The cost reduction is calculated by multiple the previously calculated energy by the electricity cost per city. For the second scenario, if the cost reduction is greater than the cost of electricity, the home owner pays zero in electricity. For the third scenario where net-metering is available, the cost reduction is subtracted from the cost of electricity, which allows homeowners to earn some income by selling electricity to local electric company.

General equations describing second and third scenarios are shown below:

EQ1. *(Cost Reduction) = (Power per Solar Panel) x (# of Solar Panels) x (Sunshine Hours) x (% of Possible) x (Unit Cost of Energy)*

EQ2. *(Electricity Cost) = (Cost of All Electric) - (Cost Reduction from Solar Panels)*

In the fourth scenario, calculating the cost of electricity with the SuperSurya installed is slightly different to that of the second scenario. The SuperSurya generates two types of energy: heat and electricity. Both heat and electricity are converted to an equivalent cost reduction. The cost of electricity from the all electric scenario (scenario 1) is also divided into two categories, heat and electricity, by the percentages from Section 4. The analysis assumes that heat generated by the SuperSurya will first be used for heat demand in the home, and the rest of energy need will be covered by either electricity generated by the SuperSurya or by the grid. In the fifth scenario (SuperSurya with net-metering), excess electricity generated by the SuperSurya is sold to the local electric company.

General equations describing fourth and fifth scenarios are shown below:

EQ3. *(Cost Reduction) = (Power per SuperSurya) x (# of SuperSurya) x (Sunshine Hours) x (%of Possible) x (Unit Cost of Energy)*
EQ4. *(Electricity Cost) = (Cost of All Electric) x (Percentage of Heat As End Use) - (Cost Reduction from Heat Generated by the SuperSurya) + (Cost of All Electric) x (Percentage of Electricity as End Use) - (Cost Reduction from Electricity Generated by the Super Surya)*

The number of solar panels and the SuperSurya vary according the shape and sizes of the home and its roof. For the analysis in this section, the number of solar panels is calculated with a pitch-to-depth ratio of 1:4 and a setback area percentage of 25%. The area of the roof varies with the pitch of the roof. Due to the shape of the roof being non-rectangular, solar panels cannot fully cover the entire roof hence accounted for by the setback area percentage. The effective roof area for solar panel installation based on home area is calculated according to the equation below:

EQ5. *(Area for Solar Panel) =* $\sqrt{(1/4 + (\text{pitch-to-depth ratio})^2)}$ *x (home area) x (1 - setback area percentage)*

Assuming the roof having only one ridge and that the shape of the house is a square, the ridge length in which the SuperSurya can be installed is calculated by the equation below:

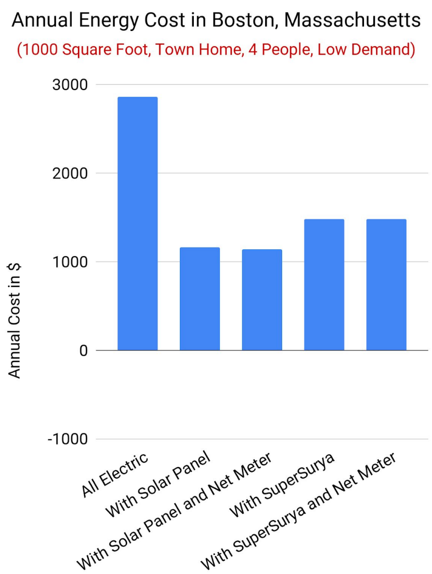
EQ6. *(Ridge Length for SuperSurya) =* $\sqrt{(\text{home area})}$

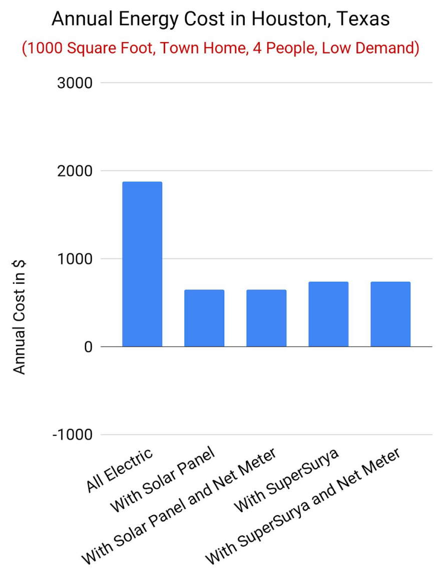
The number of solar panels that can fit on the rooftop and the number of SuperSurya that can fit the ridge are calculated as follows:

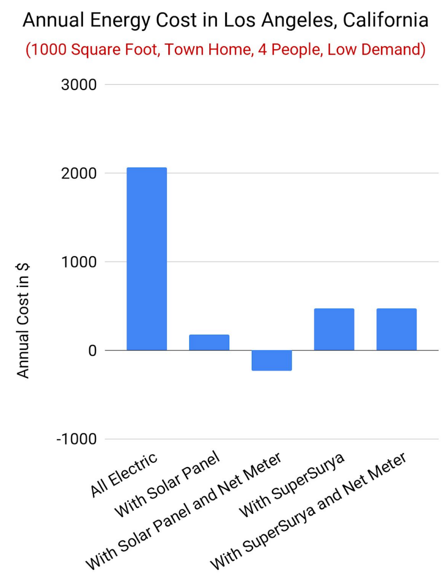
EQ7. *(Number of Solar Panels) = (Area for Solar Panel) / (Unit Area of Solar Panel)*
EQ8. *(Number of SuperSurya) = (Ridge Length for SuperSurya) / (Unit Length of SuperSurya)*

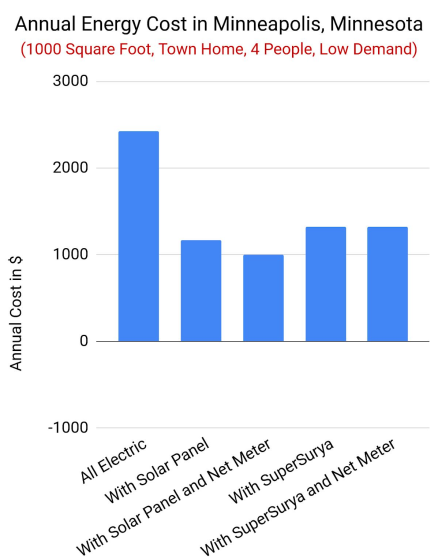
As a general trend from this calculation, the number of SuperSurya that can be installed increases with the square footage of the home by the ratio of one SuperSurya per 1000 ft^2. This trend will be further investigated in Section 9.

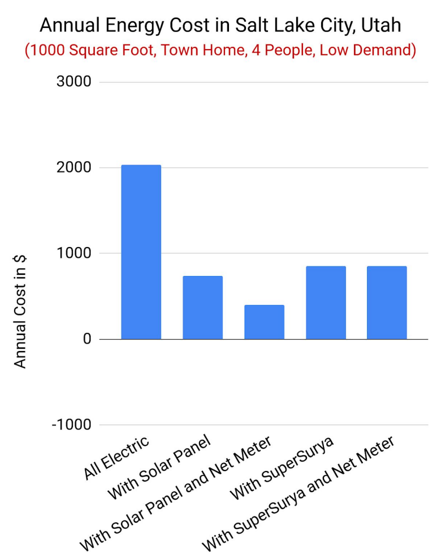
Below are the annual cost of electricity in a 1000 ft^2 home with low demand of energy across the five scenarios and the five selected cities. In all selected cities, the solar panels and the SuperSurya lower the annual electricity cost by more than half. The net metered scenarios result in a lower cost than the scenarios without net-metering as expected. More specifically in Los Angeles in California, the cost of electricity with solar panels and net metering is negative. This is due to relatively high sunshine hours and percent of possible compared to other cities. In the examples of Boston, Minneapolis, and Salt Lake City, the energy cost using the SuperSurya is lower than that of the solar panels because the effective area of the SuperSurya is larger than that of solar panels.





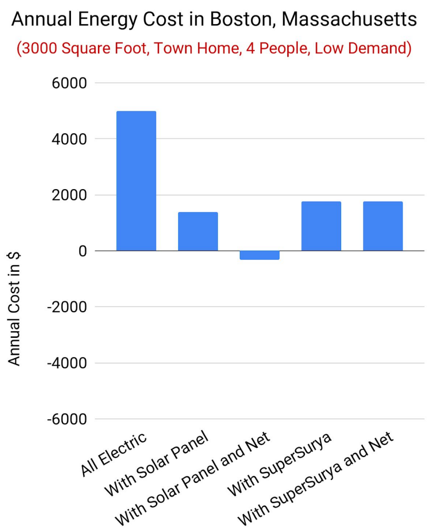


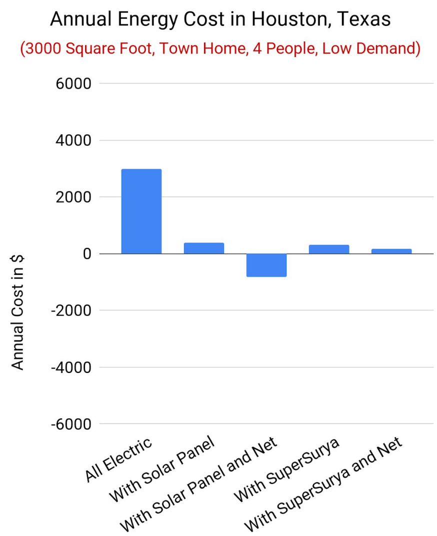


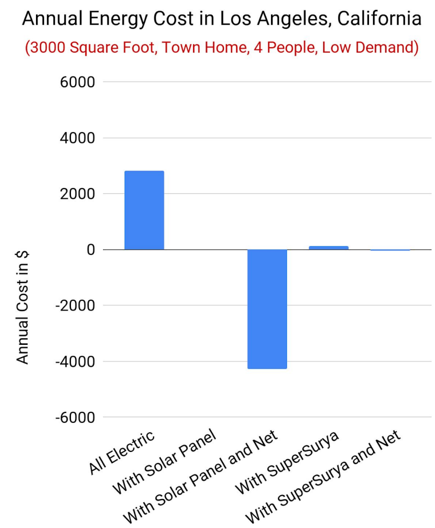


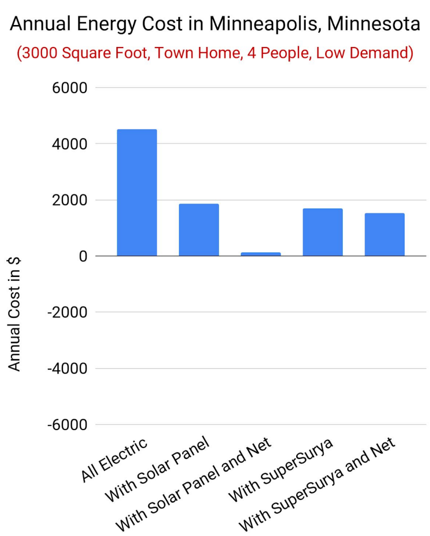
(Data source: members.questline.com)

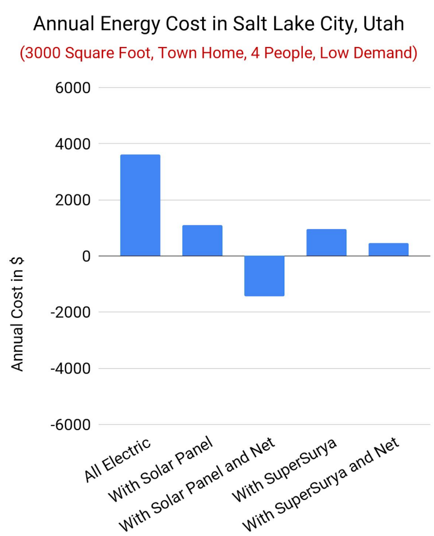
As the house grows in size, from 1000 ft^2 to 3000 ft^2, the effective area of solar panels is larger than that of the SuperSurya. The assumption remains that the roof shape is similar to the box gable style and that the roof faces South. The graphs below show the annual cost of a 3000 square foot home with low demand of energy. The electricity cost of having solar panels is tentatively lower than the electricity cost of having the SuperSurya.





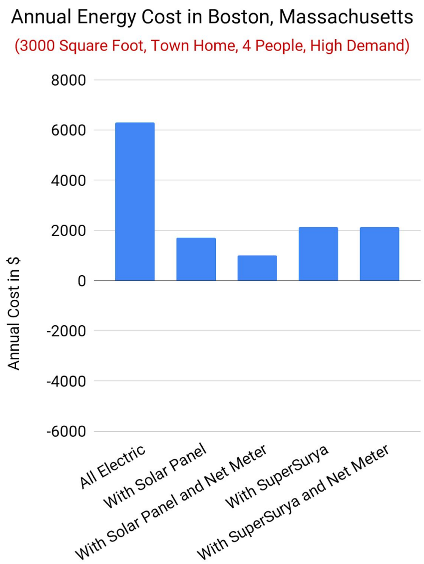


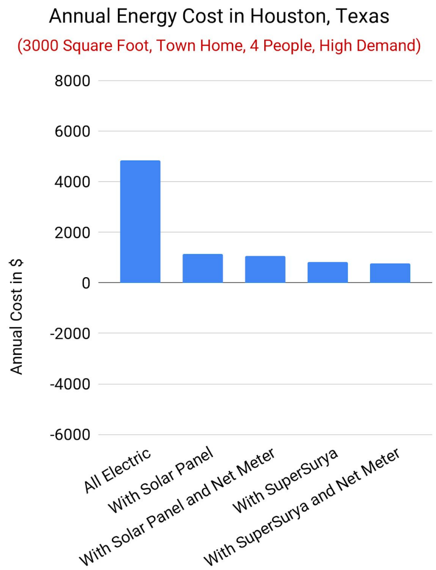


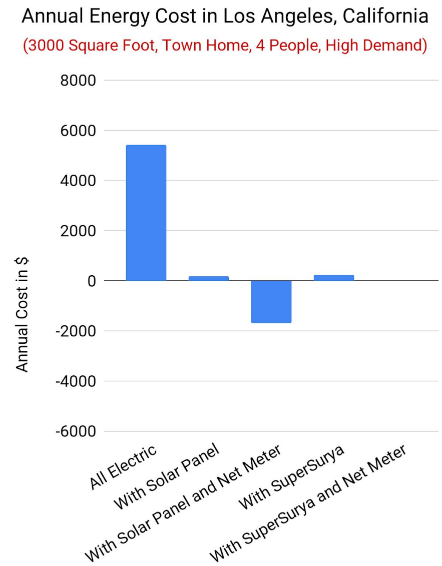


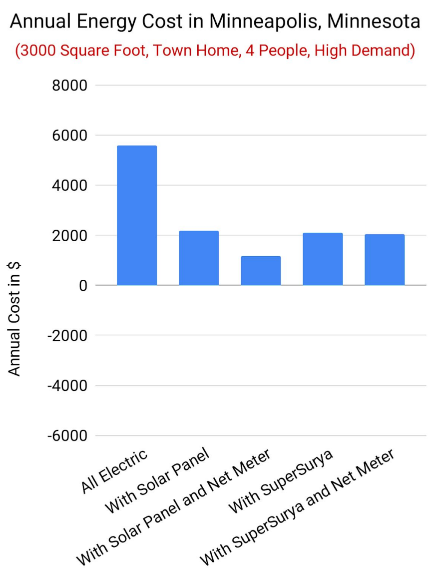
(Data source: members.questline.com)

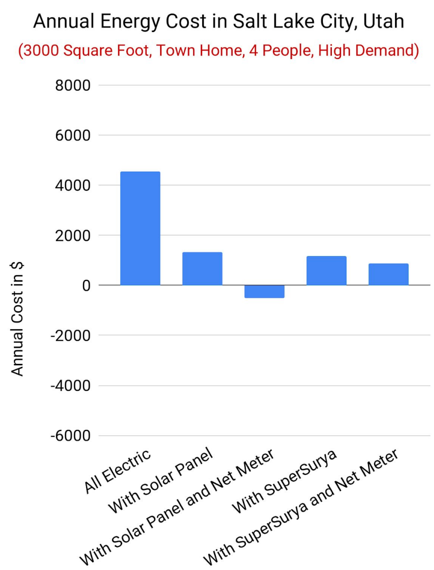
Pool heating adds approximately between $1,000 to $2,000 to the total annual cost. In this example, the size of the pool is constant. There are some variations in pool usage across the five cities, depending on monthly average temperature.







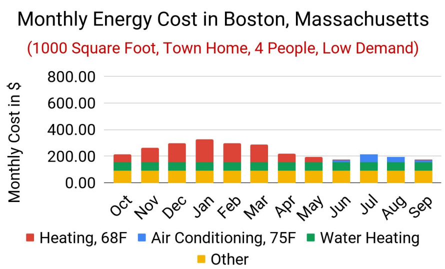


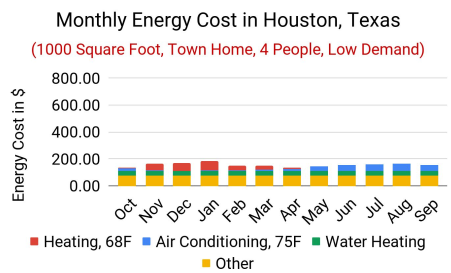


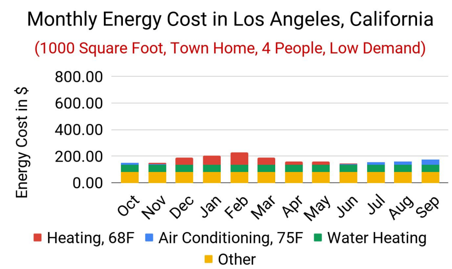
(Data source: members.questline.com)

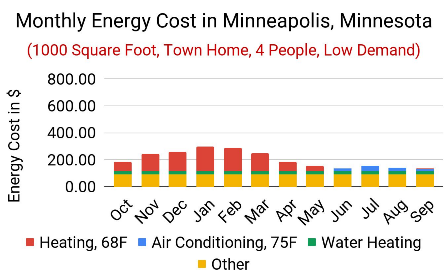
8. Monthly Energy Cost Comparison: All Electric vs. Solar Panel vs. SuperSurya

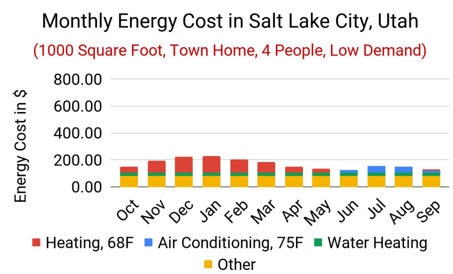
This section shows the monthly energy cost and the energy usage composition of the five selected cities. As a general trend, energy cost is at the highest during winter time when space heating is most required. Sunshine hours and percent of possible are also lowest during winter time which means that the energy collected by solar panels or the SuperSurya is at minimum hence the peak energy cost in the graphs. The graphs also use the energy usage percentages from Section 4 to show the energy usage composition of each month. The energy costs in 'Water Heating' and 'Other' categories vary slightly across the five cities.





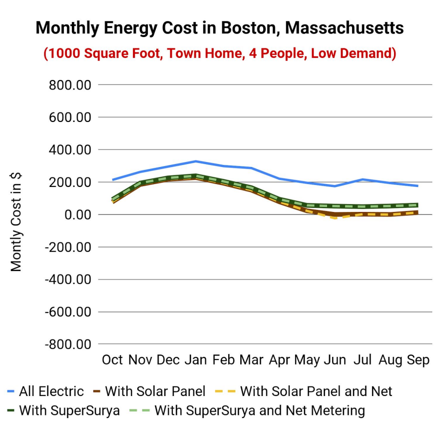


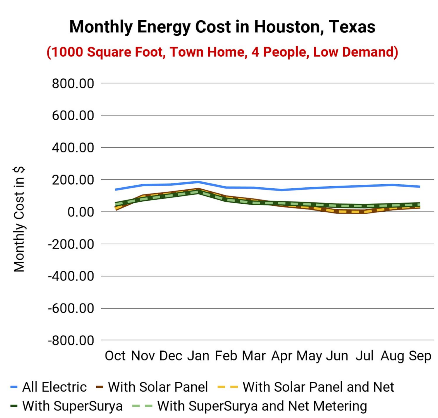


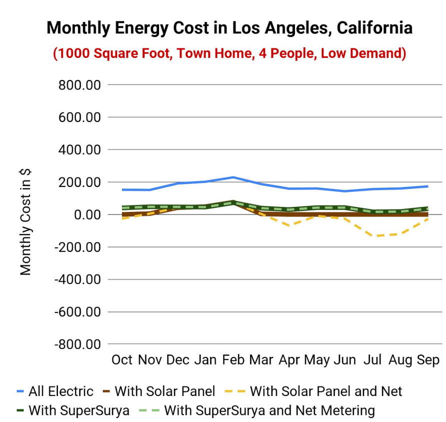


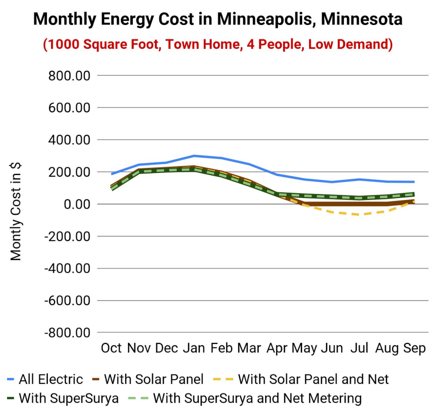
(Data source: members.questline.com)

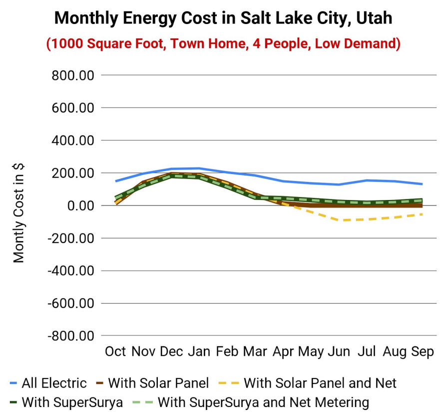
Each graph below compares the energy cost across five categories: a 1,000 square foot home with four people and a low energy consumption with all electric appliances (solid, blue), the same home with solar panels installed (solid, dark yellow), the same home with solar panels and net-metering (dash, yellow), the same home with the SuperSurya installed (solid, dark green), the same home with the SuperSurya and net-metering (dash, green). For the 1000 ft^2 home, the SuperSurya performs just as well as the solar panels.





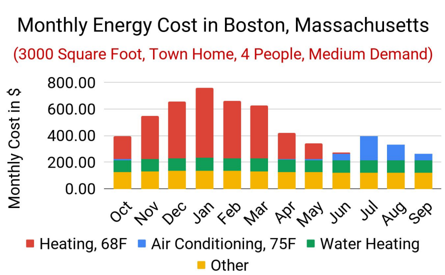


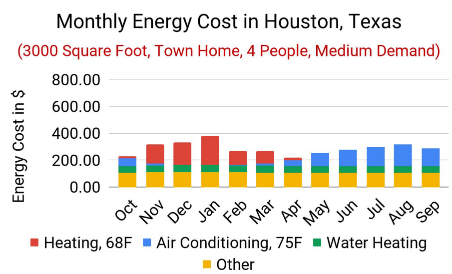


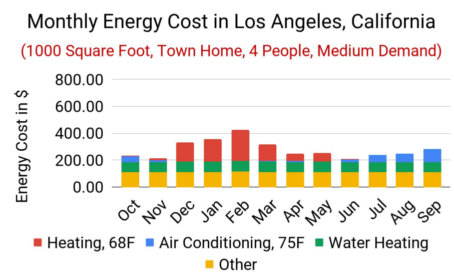


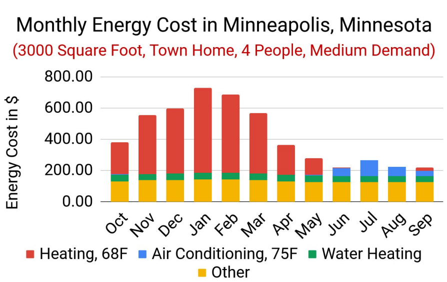
(Data source: members.questline.com)

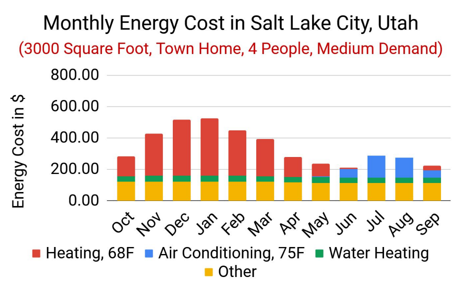
Below are the energy usage composition for a 3000 square foot home with a medium demand of energy. Compared to the 1000 square foot home with low demand of energy, the cost of space heating and space cooling increases as the size of the home increases





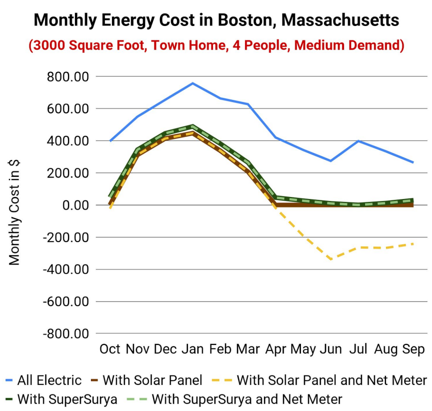


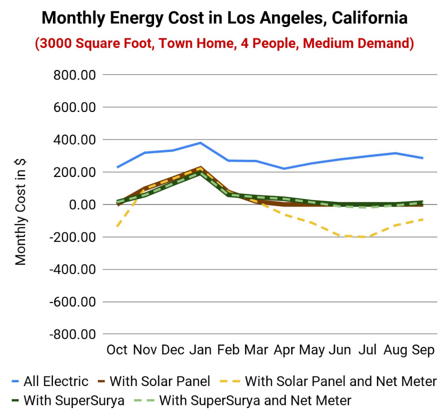


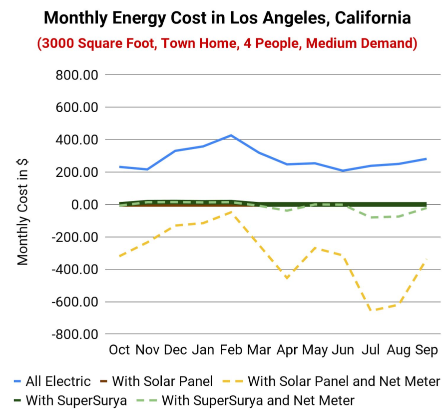


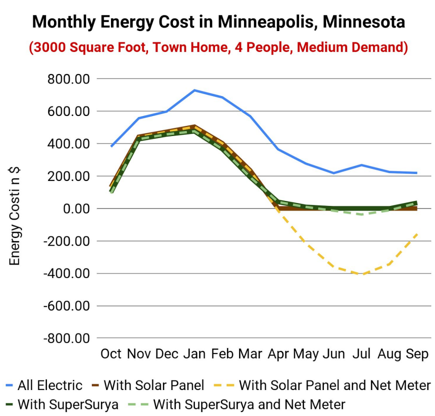
(Data source: members.questline.com)

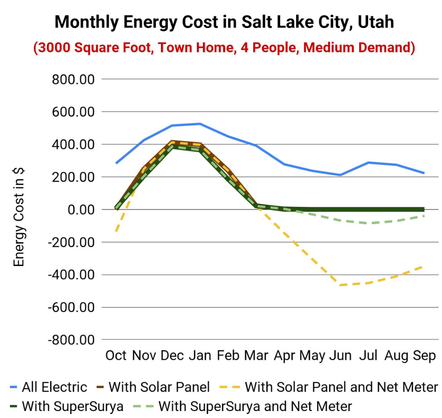
As the home grows in size, more solar panels and SuperSurya can be installed. This is clearly shown in most summer months when the energy cost becomes negative for net meter option. The negative cost means that homeowners gain an income from putting power back to the grid.





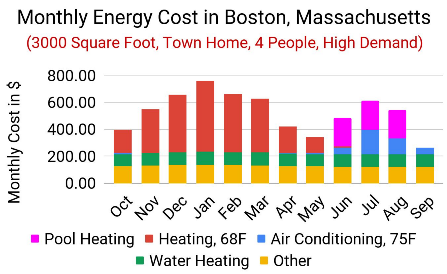


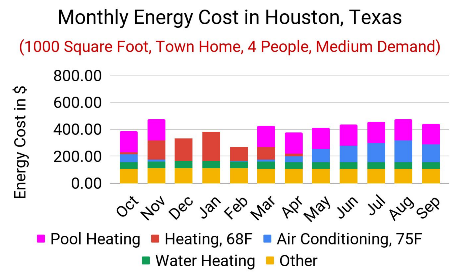


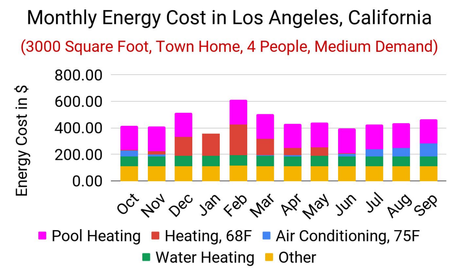


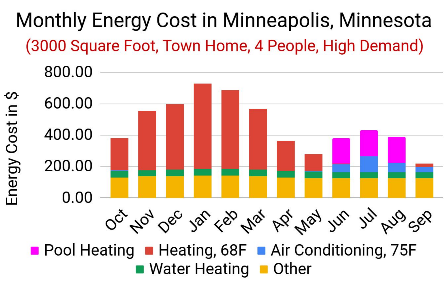
(Data source: members.questline.com)

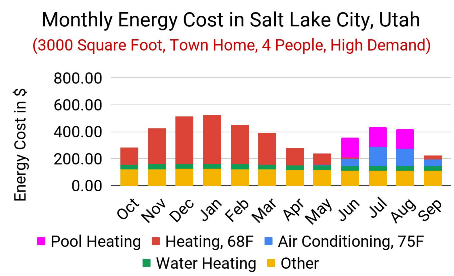
Pool heating does not add to the total energy cost of every month. Pool usage depends on the average outdoor temperature. If the temperature is too low for swimming or for heating the pool, then the pool is not used hence no additional cost. In the cold months in Boston, Minneapolis, and Salt Lake City when the temperature is very low (reflected by the high cost of space heating), the pool is not used at all. On the contrary, Los Angeles does not have temperature extremes like that of Boston, Minneapolis, and Salt Lake City, and pool usage is more common, 11 of 12 months.





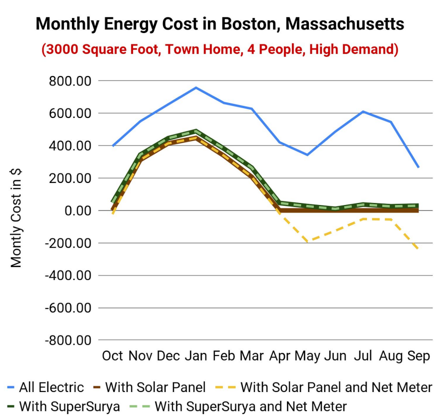


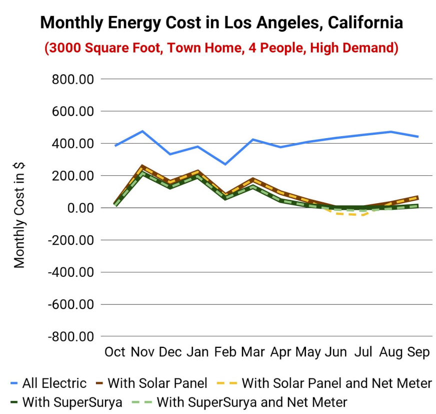


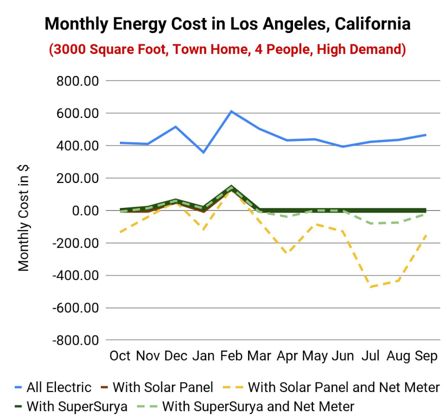


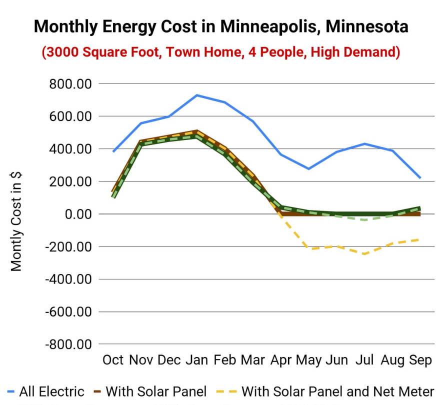
(Data source: members.questline.com)

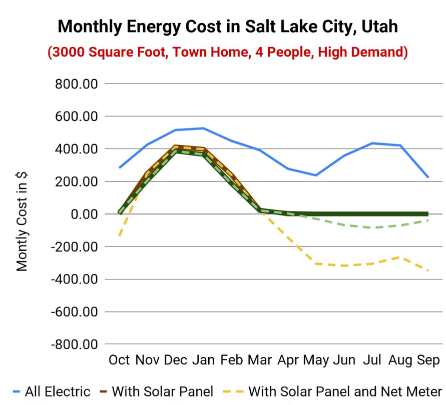
The additional cost of pool heating is covered by both the solar panel and the SuperSurya.











(Data source: members.questline.com)

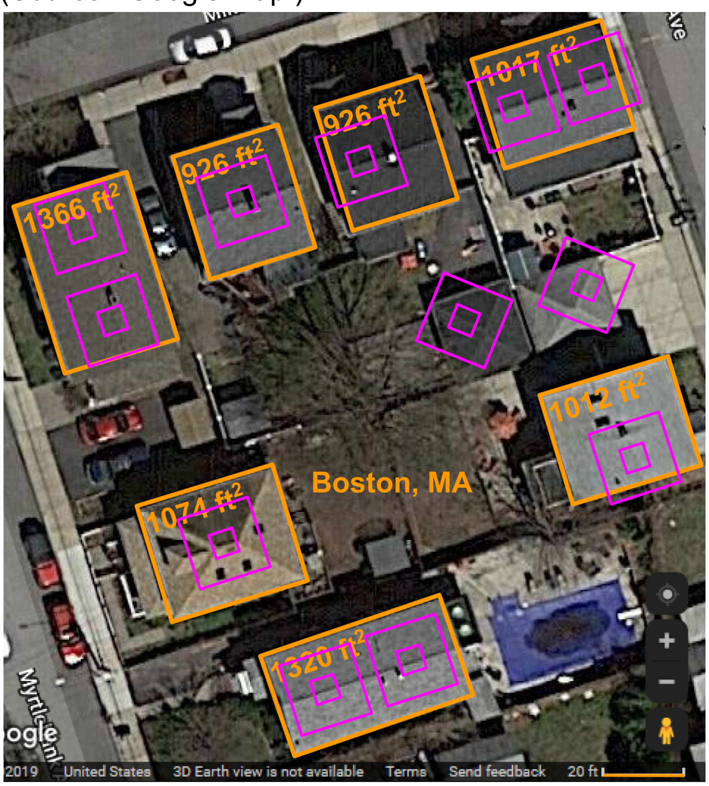
9. Pre-Assessment

This section assesses the installation of solar panels and the SuperSurya on sample houses found on Google Map. The assessment assumes a top view of the roof. In the images below, the roofs and the SuperSurya are relative in size. The size of the SuperSurya is 21 ft by 21 ft; Google Map is zoomed to 20 ft proportion for a one-to-one comparison. The SuperSurya is represented by a ‘pink’ square with a smaller ‘pink’ square showing the base.

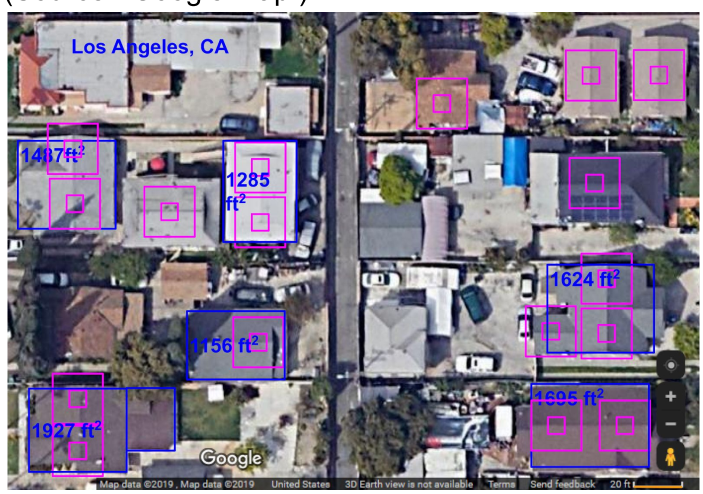
The solar panels have limited practical installation due to not having South-facing roofs. As consistently shown in random houses in the five selected cities, some houses only have West-facing or East-facing roofs. Other houses have roofs that face South-East or South-West directions. Solar panels that are installed on these roofs will have a reduced efficiency, in which case more solar panels have to be installed to generate energy equivalent to solar panels that only face South direction.

The SuperSurya uses two-axis tracking which enables it to be installed on any ridges. The two-axis tracking also allows the SuperSurya to be installed in any orientation or rotation and still maintain its efficiency. As shown below, the SuperSurya can have flexible installations despite various directions of roofs and ridges. The SuperSurya also has an advantage when being installed on roofs that have multiple ridges (shown in the image “Houston, TX”) where very few solar panels could be installed.

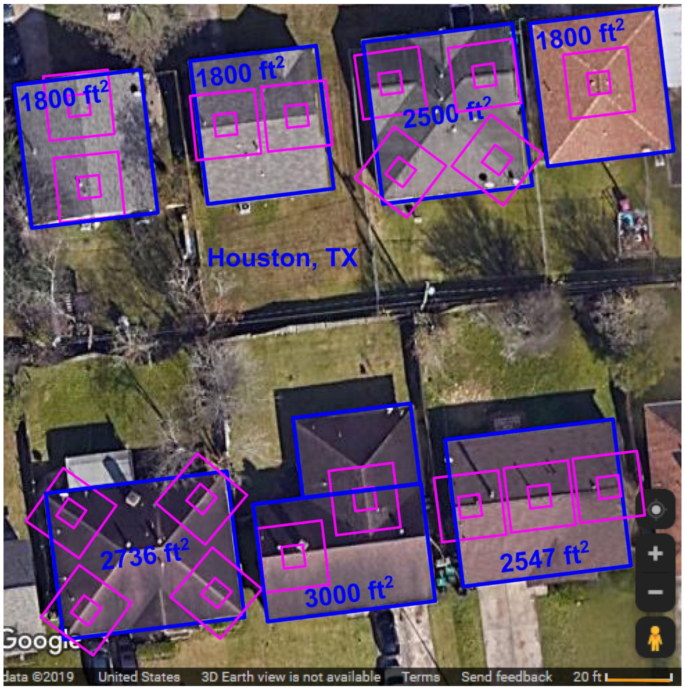
Boston, Massachusetts
(Source: Google Map.)



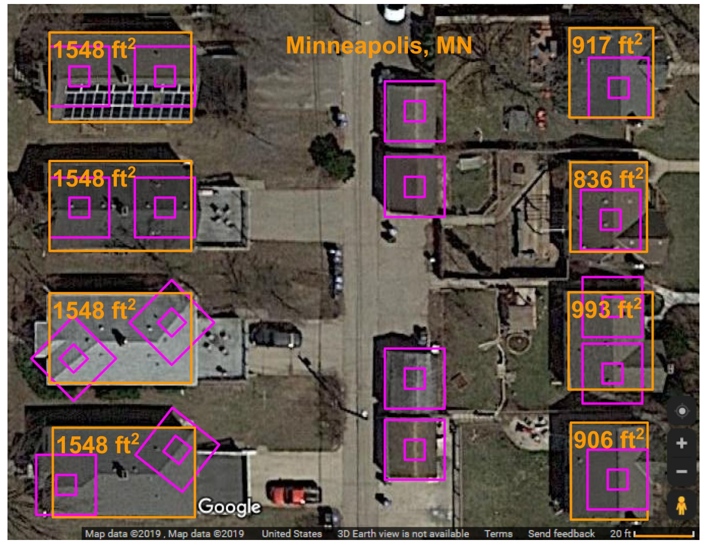
Los Angeles, California
(Source: Google Map.)



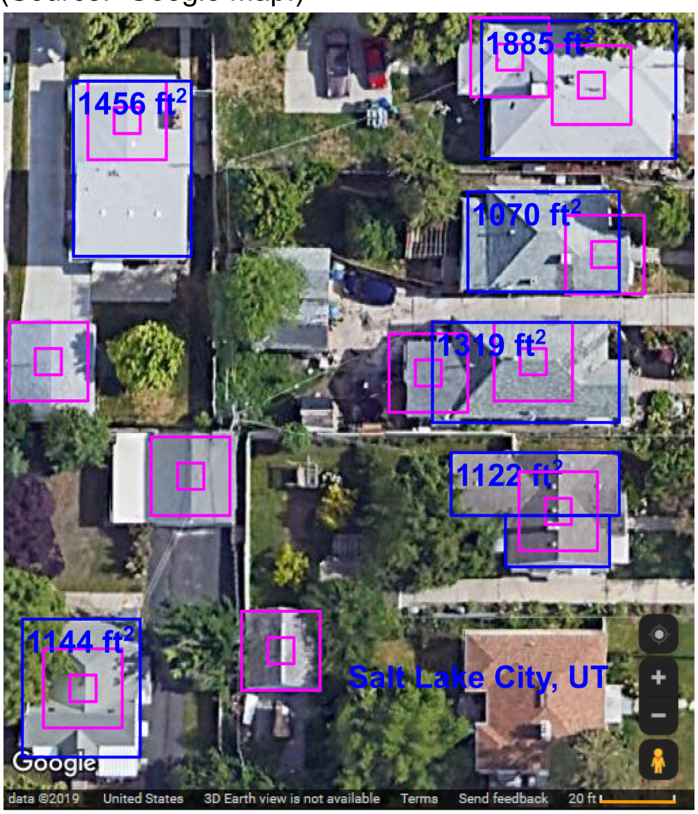
Houston, Texas
(Source: Google Map.)



Minneapolis, Minnesota
(Source: Google Map.)



Salt Lake City, Utah
(Source: Google Map.)



The conclusion from the pre-assessment is that the SuperSurya can be installed more easily on existing houses where many houses have West-facing and East-facing roofs as well as roofs with many ridges that can greatly reduce roof areas necessary for solar panels to be installed.

10. Levelized Cost Comparison

In order to calculate the cost of the SuperSurya over a 20-year period, a Levelized Cost of Energy Calculator National Renewable Energy Laboratory is used. The calculator accounts for the period in which the technology is used, the discount rate, the capital cost, capacity factor, fixed annual operation and maintenance cost, variable annual operation and maintenance cost, the heat rate (amount of fossil fuel burned to produce electricity), the fuel cost (upkeep costs such as transport of oil from extraction site to utility site), the local electricity price, and the cost escalation rate over time. Of all the parameters, only the discount rate, the capacity factor, the electricity price, and the cost escalation rate vary across the five selected cities. The SuperSurya costs approximately $27,000 and produces 7.5kW of energy, hence its capital cost is $27,000 / 7.5kW, or 3600 $/kW. The SuperSurya receives all its energy from the sun, the capacity factor is calculated by dividing the 'mean hours of sunshine in a year' by the 'total hours in a year' multiplied by the 'mean percent of possible' in a year'. For this analysis, all maintenance costs are assumed to be zero. The results are imported from the NREL website and tabulated below.

Simple Levelized Cost of Energy Calculator					
Location					
City, State	Boston, MA	Houston, TX	Los Angeles, CA	Minneapolis, MN	Salt Lake City, UT
Financial					
Periods (Years)	20	20	20	20	20
Discount Rate (%)	2.5	2.5	2.5	2.5	2.5
Renewable Energy System Cost and Performance					
Capital Cost ($/kW)	3600	3600	3600	3600	3600
Capacity Factor (%):	17.6	16.9	27.1	18.3	22.8
Fixed O&M Cost ($/kW-yr)	0.00	0.00	0.00	0.00	0.00
Variable O&M Cost ($/kWh)	0.00	0.00	0.00	0.00	0.00
Heat Rate (Btu/kWh)	0.00	0.00	0.00	0.00	0.00
Fuel Cost ($/MMBtu)	0.00	0.00	0.00	0.00	0.00
Today's Utility Electricity Cost					
Electricity Price (cents/kWh)	14.91	10.98	13.03	11.48	10.31
Cost Escalation Rate (%)	2.73	2.59	2.53	2.82	2.73
Results					
Levelized Cost of Utility Electricity (cents/kWh)	19.5	14.2	16.7	15.2	13.5
Simple Levelized Cost of Renewable Energy (cents/kWh)	14.9	15.6	9.7	14.4	11.5
(Source: www.nrel.com)					

The result shows that the cost of the SuperSurya over a 20-year period is cheaper than the cost of utility electricity in four of five selected cities. The reason for the cost of utility being higher than the cost of the SuperSurya in Houston, Texas is that the local electricity price is the second lowest and the percent of possible is the lowest among the five cities.

There are other start-up costs to fully implement the SuperSurya. Like solar panels, the SuperSurya produces DC electricity which means that an inverter (converting DC power to AC power) is required to provide power to common electrical appliances such as TV and refrigerator. Unlike solar panels, the SuperSurya produces usable heat which can not be used to power equipment that require AC power input, hence new equipment that can operate by inputting heat are required. Examples of such equipment are heat radiator (replacing or supplementing distributing heat inside the home), an absorption chiller or an adsorption chiller (replacing air conditioner, producing and distributing cool air), a solar water heater, and a solar oven/cooker. These equipment have a wide range of prices depending on household needs.

11. Environmental Impact

Preliminary environmental impact is assessed using Okala Impact Assessment Forms. Each form gives an impact score based on a list of materials and processes that are involved in making the SuperSurya. For simplicity, cost of transportation and energy usage are not included in the assessment. Information regarding the manufacturing process of dynalene bioglycol is unavailable, hence a key component of this material is used to represent the impact of the entire material. The impact of each material in the product composition is assessed over the product's 20-year lifespan, shown in Form 1A. In Form 2A, two materials are swapped: virgin aluminum is replaced by recycled aluminum and potato starch is replaced by cornstarch. These simple swaps reduce the environmental impact of the SuperSurya by a factor of 8 or 87.8%, from 12,950 impact points per lifetime to 1,585 impact points per lifetime. The major impact reduction is achieved by replacing virgin aluminum with recycled aluminum.

Okala Impact Assessment Form (1A)

date: November 9, 2019
designers: Mithra Sankriti, Thongminh Nguyen
product lifetime: 20 years
product concept name: SuperSurya
system boundaries:
functional unit (default: impacts/ hour): 0.074

BILL-OF-MATERIALS	AMOUNT	UNIT x	OKALA FACTOR POINTS	UNIT =	OKALA IMPACT POINTS
Aluminum, primary	900	lbs.	13	/lb.	11700
Steel, low alloy, pri.	150	lbs.	3.5	/lb.	525
Polyurethane foam (PU, flexible)	150	lbs.	3.1	/lb.	465
Heat transfer fluid (Dynalene BioGlycol)	100	lbs.		/lb.	0
Miscellaneous	100	lbs.		/lb.	0
Dynalene BioGlycol (potato starch)	100	lbs.	2.6	/lb.	260
				Total impact / lifetime	12950

Impacts / product lifetime 12950 / lifetime hours 175200 = Impact / hour 0.074

Okala Impact Assessment Form (2A)

date: November 9, 2019
designers: Mithra Sankriti, Thongminh Nguyen
product lifetime: 20 years
product concept name: SuperSurya
system boundaries:
functional unit (default: impacts/ hour): 0.0090

BILL-OF-MATERIALS	AMOUNT	UNIT x	OKALA FACTOR POINTS	UNIT =	OKALA IMPACT POINTS
Aluminum, sec.	900	lbs.	0.55	/lb.	495
Steel, low alloy, sec.	150	lbs.	3.3	/lb.	495
Polyurethane foam (PU, flexible)	150	lbs.	3.1	/lb.	465
Heat transfer fluid (Dynalene BioGlycol)	100	lbs.		/lb.	0
Miscellaneous	100	lbs.		/lb.	0
Dynalene BioGlycol (cornstarch)	100	lbs.	1.3	/lb.	130
				Total impact / lifetime	1585

Impacts / product lifetime 1585 / lifetime hours 175200 = Impact / hour 0.0090

The carbon footprint of product is calculated using CO_2 equivalent in pounds. Using the strategy of swapping material described above, the carbon footprint of the SuperSurya reduces from 11,892 lbs of CO_2 to 1,755 lbs of CO_2, or a factor of 6.8.

Okala Impact Assessment Form (1B)

date: November 9, 2019
designers: Mithra Sankriti, Thongminh Nguyen
product lifetime: 20 years
product concept name: SuperSurya
system boundaries:
functional unit (default: impacts/ hour): 0.068

BILL-OF-MATERIALS	AMOUNT	UNIT x	CO2 EQ.	UNIT =	CO2 POINTS
Aluminum, primary	900	lbs.	12	/lb.	10800
Steel, low alloy, pri.	150	lbs.	2.0	/lb.	300
Polyurethane foam (PU, flexible)	150	lbs.	4.8	/lb.	720
Heat transfer fluid (Dynalene BioGlycol)	100	lbs.		/lb.	0
Miscellaneous	100	lbs.		/lb.	0
Dynalene BioGlycol (potato starch)	100	lbs.	0.72	/lb.	72
				Total impact / lifetime	11892

Impacts / product lifetime 11892 / lifetime hours 175200 = Impact / hour 0.068

Okala Impact Assessment Form (2B)

date: November 9, 2019
designers: Mithra Sankriti, Thongminh Nguyen
product lifetime: 20 years
product concept name: SuperSurya
system boundaries:
functional unit (default: impacts/ hour): 0.010

BILL-OF-MATERIALS	AMOUNT	UNIT x	CO2 EQ.	UNIT =	CO2 POINTS
Aluminum, sec.	900	lbs.	0.5	/lb.	450
Steel, low alloy, sec.	150	lbs.	3.1	/lb.	465
Polyurethane foam (PU, flexible)	150	lbs.	4.8	/lb.	720
Heat transfer fluid (Dynalene BioGlycol)	100	lbs.		/lb.	0
Miscellaneous	100	lbs.		/lb.	0
Dynalene BioGlycol (cornstarch)	100	lbs.	1.2	/lb.	120
				Total impact / lifetime	1755

Impacts / product lifetime 1755 / lifetime hours 175200 = Impact / hour 0.010

If an average household uses 11,000 kWh of energy (which is approximately the energy that can be generated by one SuperSurya in a year), the same household will consume 220,000 kWh over a 20-year period. If the home is powered by 115V (imported electricity), then the total impact score per lifetime will be 242,000 and the total carbon footprint will be 396,000 lbs of CO_2. Installing the SuperSurya compared to using 115V (imported electricity) reduces the environmental impact by 99.3% and the carbon footprint by 99.6%.

Okala Impact Assessment Form (1A)

date: November 9, 2019

designers: Mithra Sankriti, Thongminh Nguyen

product lifetime: 20 years

system boundaries:

functional unit (default: impacts/ hour): 1.381

product concept name: SuperSurya

BILL-OF-MATERIALS	AMOUNT	UNIT x	OKALA FACTOR POINTS	UNIT =	OKALA IMPACT POINTS
Electricity (US low V.)	220000	kWh	1.1	/kWh	242000

Total impact / lifetime: **242000**

$$\frac{\text{Impacts / product lifetime: } 242000}{\text{lifetime hours: } 175200} = \text{Impact / hour: } \mathbf{1.381}$$

Okala Impact Assessment Form (1B)

date: November 9, 2019

designers: Mithra Sankriti, Thongminh Nguyen

product lifetime: 20 years

system boundaries:

functional unit (default: impacts/ hour): 2.260

product concept name: Imported Electricity

BILL-OF-MATERIALS	AMOUNT	UNIT x	CO2 EQ.	UNIT =	CO2 POINTS
Electricity (US low V.)	220000	kWh	1.8	/kWh	396000

Total impact / lifetime: **396000**

$$\frac{\text{Impacts / product lifetime: } 396000}{\text{lifetime hours: } 175200} = \text{Impact / hour: } \mathbf{2.260}$$

12. Works Cited

1. Boston, MA Electricity Statistics. Electricity Local. Last modified 2019. Accessed August 10, 2019. https://www.electricitylocal.com/states/massachusetts/boston/.
2. Climate Boston - Massachusetts. U.S. Climate Data: Temperature - Precipitation - Sunshine - Snowfall. Last modified 2019. Accessed August 9, 2019. https://www.usclimatedata.com/climate/boston/massachusetts/united-states/usma0046.
3. Climate Houston - Texas. U.S. Climate Data: Temperature - Precipitation - Sunshine - Snowfall. Last modified 2019. Accessed August 9, 2019. https://www.usclimatedata.com/climate/houston/texas/united-states/ustx0617.
4. Climate Los Angeles - California. U.S. Climate Data: Temperature - Precipitation - Sunshine - Snowfall. Last modified 2019. Accessed August 9, 2019. https://www.usclimatedata.com/climate/los-angeles/california/united-states/usca1339.
5. Climate Minneapolis - Minnesota. U.S. Climate Data: Temperature - Precipitation - Sunshine - Snowfall. Last modified 2019. Accessed August 9, 2019. https://www.usclimatedata.com/climate/minneapolis/minnesota/united-states/usmn1524.
6. Climate Salt Lake City - Utah. U.S. Climate Data: Temperature - Precipitation - Sunshine - Snowfall. Last modified 2019. Accessed August 9, 2019. https://www.usclimatedata.com/climate/salt-lake-city/utah/united-states/usut0225.
7. Degree Days.net - Custom Degree Day Data. BizEE Degree Days. Last modified nd. Accessed August 9, 2019. https://www.degreedays.net/.
8. Home Energy Analyzer. Energy Solutions. Last modified 2019. Accessed August 9, 2019. http://members.questline.com/calcHomeEnergy.aspx?accountID=2558&nl=15750.
9. Houston, TX Electricity Statistics. Electricity Local. Last modified 2019. Accessed August 10, 2019. https://www.electricitylocal.com/states/texas/houston/.
10. How Many Solar Panels Do You Need to Power Your House?. Solar Power Rocks. Last modified nd. Accessed August 10, 2019. https://www.solarpowerrocks.com/square-feet-solar-roof/.
11. Kroposki, Benjamin. Average of Solar Radiation For Each of 360 Months, 1961-1990. National Renewable Energy Laboratory. Last modified nd. Accessed August 10, 2019. https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/mon2/14739.txt.
12. Kroposki, Benjamin. Average of Solar Radiation For Each of 360 Months, 1961-1990. National Renewable Energy Laboratory. Last modified nd. Accessed August 10, 2019. https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/mon2/12960.txt.
13. Kroposki, Benjamin. Average of Solar Radiation For Each of 360 Months, 1961-1990. National Renewable Energy Laboratory. Last modified nd. Accessed August 10, 2019. https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/mon2/23174.txt.
14. Kroposki, Benjamin. Average of Solar Radiation For Each of 360 Months, 1961-1990. National Renewable Energy Laboratory. Last modified nd. Accessed August 10, 2019. https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/mon2/14922.txt.
15. Kroposki, Benjamin. Average of Solar Radiation For Each of 360 Months, 1961-1990. National Renewable Energy Laboratory. Last modified nd. Accessed August 10, 2019. https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/redbook/mon2/24127.txt.
16. Levelized Cost of Energy Calculator. National Renewable Energy Laboratory. Last modified nd. Accessed November 10, 2019. https://www.nrel.gov/analysis/tech-lcoe.html
17. Los Angeles, CA Electricity Statistics. Electricity Local. Last modified 2019. Accessed August 10, 2019. https://www.electricitylocal.com/states/california/los-angeles/.
18. Minneapolis, MN Electricity Statistics. Electricity Local. Last modified 2019. Accessed August 10, 2019. https://www.electricitylocal.com/states/minnesota/minneapolis/.
19. Nguyen, Thongminh. Data and Calculations. Boston, Suffolk, Massachusetts V2. Last modified November 7, 2019. Accessed November 7, 2019. https://docs.google.com/spreadsheets/d/1joRTNwjf2cYMGZxaOhEKXqplAQPV-Dr5AftuEGL_Ki8/edit#gid=1407722603.

20. Nguyen, Thongminh. Data and Calculations. Houston, Harris, Texas V2. Last modified November 7, 2019. Accessed November 7, 2019. https://docs.google.com/spreadsheets/d/1joRTNwjf2cYMGZxaOhEKXqplAQPV-Dr5AftuEGL_Ki8/edit#gid=1407722603.
21. Nguyen, Thongminh. Data and Calculations. Los Angeles, Los Angeles, California V2. Last modified November 7, 2019. Accessed November 7, 2019. https://docs.google.com/spreadsheets/d/1joRTNwjf2cYMGZxaOhEKXqplAQPV-Dr5AftuEGL_Ki8/edit#gid=1407722603.
22. Nguyen, Thongminh. Data and Calculations. Minneapolis, Hennepin, Minnesota V2. Last modified November 7, 2019. Accessed November 7, 2019. https://docs.google.com/spreadsheets/d/1joRTNwjf2cYMGZxaOhEKXqplAQPV-Dr5AftuEGL_Ki8/edit#gid=1407722603.
23. Nguyen, Thongminh. Data and Calculations. Salt Lake City, Salt Lake City, Utah V2. Last modified November 7, 2019. Accessed November 7, 2019. https://docs.google.com/spreadsheets/d/1joRTNwjf2cYMGZxaOhEKXqplAQPV-Dr5AftuEGL_Ki8/edit#gid=1407722603.
24. Roof Assemblies and Rooftop Structures. Common Wealth of Massachusetts. Last modified 2019. Accessed August 10, 2019. https://www.mass.gov/files/documents/2016/09/wo/780015.pdf.
25. Salt Lake City, UT Electricity Statistics. Electricity Local. Last modified 2019. Accessed August 10, 2019. https://www.electricitylocal.com/states/utah/salt-lake-city/.
26. Statistics - Sunshine. UN Data - A World of Information. Last modified July 14, 2010. Accessed August 9, 2019. http://data.un.org/Data.aspx?q=Korea&d=CLINO&f=ElementCode%3A15%3BCountryCode%3AKO.
27. White, Philip, Louise St. Pierre, and Steve Belletire. Okala Practitioner - Integrating Ecological Design. Phoenix: Okala, 2003.