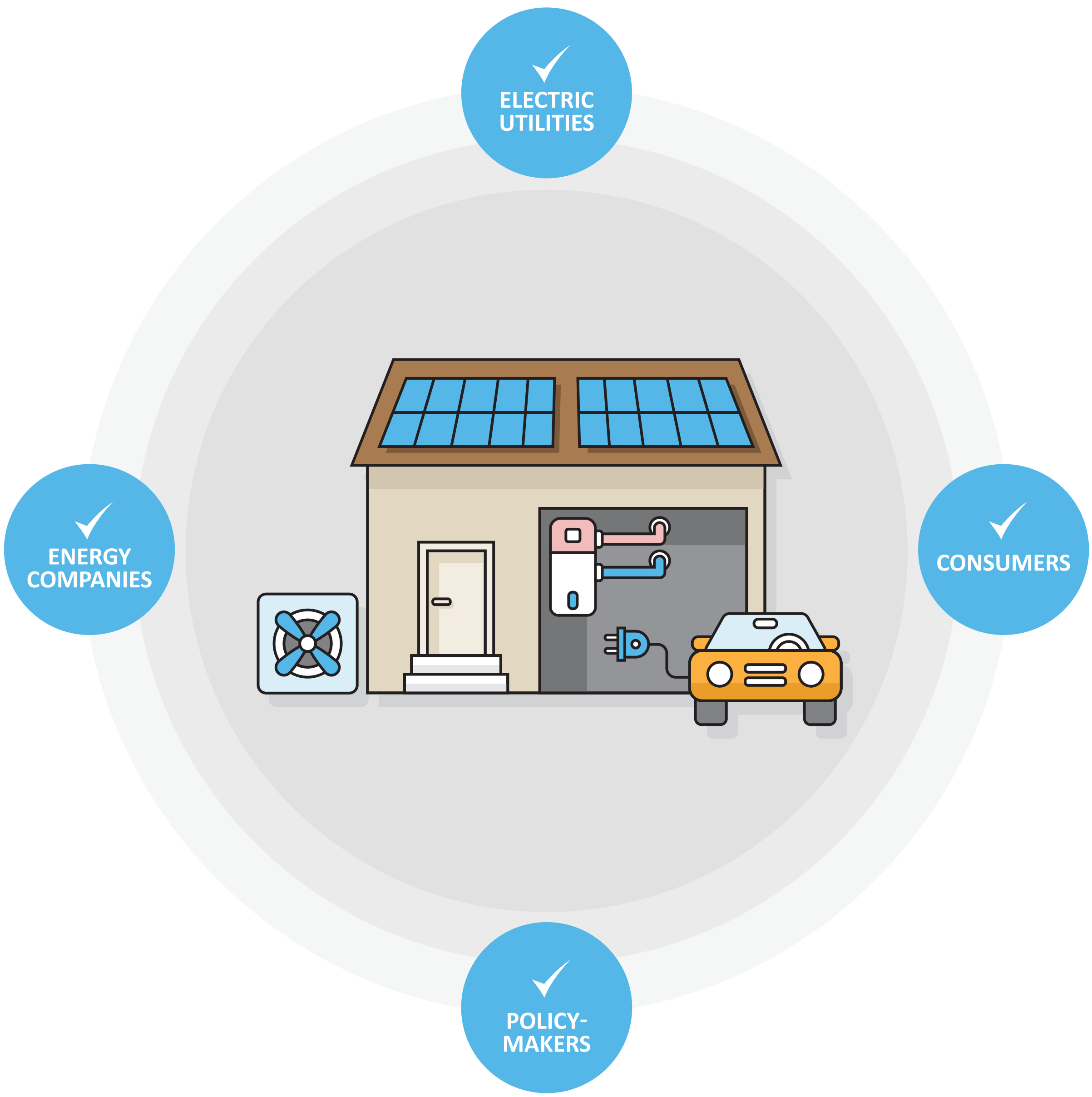
Shaping the New Energy Future Today

# DRIVING STRATEGIC TECHNOLOGY ADOPTION

## WITH SOLAR+ HOMES




Clean Power Research®

# Shaping the New Energy Future Today:

## Driving Strategic Technology Adoption with Solar+ Homes

### Executive Summary

We are in the early stage of one of the most significant energy transformations in nearly a century. Major trends include increased electrification, greater intelligence at the grid edge, a move from centralized to distributed energy resources, fundamental shifts in energy generation technology and dramatic increases in the use of energy storage. This is a transformation that will not be isolated to traditional uses of electricity, but will spill over into all areas of energy, including transportation, heating and cooling of buildings, and water heating.

In the recent report, "New Energy Outlook 2016," Bloomberg New Energy Finance forecasted dramatic changes in the way we generate, distribute and use energy:

- Wind and solar will account for 64% of new generation over the next 25 years, with a third of this capacity coming from small scale solar. They will be the two least cost generating technologies in most developed economies.
- Electric vehicles will make up 35% of new passenger vehicles solar by 2040, and 25% of the total fleet—increasing electricity consumption by 8%.
- Small scale solar will reach socket parity (retail price parity) across all major developed economies by 2020.
- Continuous pressure on the price of storage, mainly from electric vehicles, will make small-scale and grid-scale storage competitive in many applications during the next 25 years.

The energy transformation is fundamentally technology driven. Concerns about global climate change and high energy prices in the first part of the 21st century spurred significant investment in energy technology. The dramatic improvements in solar and wind technology received the greatest attention, but technology improvements in storage, vehicles, and heating and cooling technologies were also substantial.

Technology changes have substantially expanded the choices available to homeowners. Previously simple choices such as which internal combustion engine vehicle to buy, which gas furnace to purchase or which day to pay the electric bill have been replaced by a range of energy decisions. This range of choices is often baffling to the homeowner.

The complex choices of the energy transformation offer an enormous economic opportunity. Electric utilities, the new energy industry, consumers and policymakers all have a role to play in the energy transformation, and all four can be winners

- Electric utilities win by increasing electricity consumption from 30-50%, and having flexible loads that reduce costs and facilitate high penetration renewables.
- The new energy industry wins as they sell new products and services to consumers.
- Consumers win by reducing and stabilizing their total energy bill and having more comfortable homes.
- Policymakers win by creating a policy environment that reduces site energy consumption from 60-80% percent, and supports financially healthy utilities and a cleaner environment.

Homeowners cannot take advantage of the energy transformation unless they can make sense of it. The Solar+ homes concept allows homeowners to follow three easy steps to transform their energy consumption and production. As outlined in this paper, the homeowner should:

- Reduce energy leaks
- Switch to efficient devices (electric vehicles, heat pumps and LED lighting)
- Offset consumption with PV (rooftop, community solar or utility-sited solar)

This paper provides a path for homeowners to follow these three steps to reduce site energy consumption by 60-80% and offset the remainder with solar. This allows homeowners to reduce their carbon footprint, achieve significant savings and have more comfortable homes.

### About the Author

*Tom Hoff is a pioneer in the science of valuing distributed solar generation, and holds a number of patents in the area of PV fleet power estimation. Tom's research is proving vital to utilities and ISOs faced with the challenge of maintaining reliability while integrating ever-increasing levels of PV generation on the grid. In performing his research, Tom has been known to test hypotheses using the PV and electrical systems in his own home.*

*Tom is the founder and President of Clean Power Research. He began his career at Pacific Gas and Electric Company. He holds a Ph.D. in Engineering-Economic Systems from Stanford University's School of Engineering.*

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# PV as the Foundation of the Energy Transformation

Solar photovoltaics (PV) was a research novelty when I began my career at Pacific Gas and Electric Company (PG&E) in the early 1980's. The first 15 years of my work focused on publishing highly technical research papers. In the late 1990's, people like my neighbor began asking the question: What's the value of solar for me? PV was still in its infancy when Clean Power Research was founded in 1998 to help answer this question.

We spent the next 15 years building tools at Clean Power Research to help organizations address challenges and seize opportunities around solar. We wanted to inform consumers, streamline business processes and support energy-related decisions. Our goal was to produce superior software services based on cutting-edge research. The tools were the result of answering questions. They formalized the algorithms, analytics and approaches, and made them widely and inexpensively accessible.

We began to think about the next set of questions that people would ask. Our thinking was stimulated by California's goal that all new homes needed to be zero net energy (ZNE) by 2020. This prompted the questions:

- *Can ZNE be cost-effectively applied to* **existing** *homes?*
- *Can ZNE be extended to included* **personal transportation***?*

These questions were different because they required a holistic approach to the problem. It included PV and non-PV technologies.

It has become clear that PV is at the heart of the worldwide energy transformation. To be at the cutting edge, we at Clean Power Research think of the energy transformation in terms of How, Where, When, What and Who. We have spent years thinking about the How, Where and Who. More specifically, we found that:

- How electricity is generated is transitioning from fossil-fueled to renewable generation, especially solar.
- Where electricity is produced is changing as represented by a growing interest in distributed systems.
- Who can generate power is changing from a few producers to many consumers.

We are now adding the What and When. What electricity is used for is increasing, especially with electric vehicles and other appliance electrification. When electricity is used is shifting as solar penetration increases.

## What Is a Solar+ Home?

This energy transformation has set the stage for Solar+ homes. A Solar+ home is one that is fully powered by solar electricity, including water heating, space conditioning and transportation. Fully powered is defined to be on an annual site energy basis.

Existing homes can be converted to Solar+ homes in three steps:

- Reduce leaks
- Switch to efficient devices
- Offset consumption with PV.

More specifically, Solar+ homes combine simple energy efficiency measures, PV, electric vehicles (EVs) and appliance electrification to create households that are fully powered by solar electricity. They have substantial economic and environmental savings over conventional approaches. Solar+ homes address the What question and have the potential to address the When question.

People are intrigued by the idea of a Solar+ home. The reality of having their own Solar+ home, however, eludes them. Reasons for this include:

- A confusing array of choices about energy-saving devices.
- The incorrect belief that technological breakthroughs are required before Solar+ is cost-effective.
- A faulty assumption that costly "deep retrofits" are required to achieve Solar+.

The result is that people assume that Solar+ can only be a reality in a new home or an expensive retrofit.

## Why Focus on Existing Homes?

The research highlighted in this whitepaper focuses on existing homes. As shown in Figure 1a, residential homes (including personal transportation) account for more than one-third of primary energy consumption in the United States (Figure 1a). Demonstrating the feasibility of Solar+ homes in the residential retrofit market could have major benefits for consumers, utilities and energy service companies alike.

This whitepaper describes why **YES** is the answer to the question: Can existing homes cost-effectively be made into Solar+ homes? It's organized around the topics that we at Clean Power Research have researched and tested over the past several years.

The research that forms the core of this paper mixes the professional with the personal. On the one hand, it has been conducted as a high quality research project including implementation in a prototype house with detailed, circuit-level load (Figure 1b) and temperature monitoring (Figure 1c) that is controlled using smart thermostats (Figure 1d). On the other hand, it's personal: the prototype Solar+ house is my own home (Figure 1e).

*Our desire is that this series will help the average homeowner as well as energy professionals develop a vision that existing homes—including the personal transportation of their occupants—can be cost-effectively converted to Solar+ homes to support a renewable energy future.*

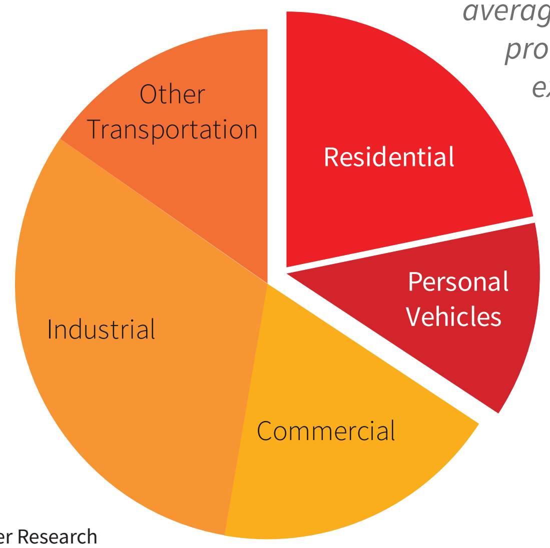



**Figure 1a.** More than one-third of primary energy consumption in the United States is from the residential sector and personal vehicles.[1]



[1] Data sources: www.eia.gov/totalenergy/data/annual/#consumption, www.eia.gov/todayinenergy/detail.cfm?id=17171, www.americanenergyindependence.com/fuels.aspx

**Figure 1b.** eGauge system monitors a dozen end-use loads every second.

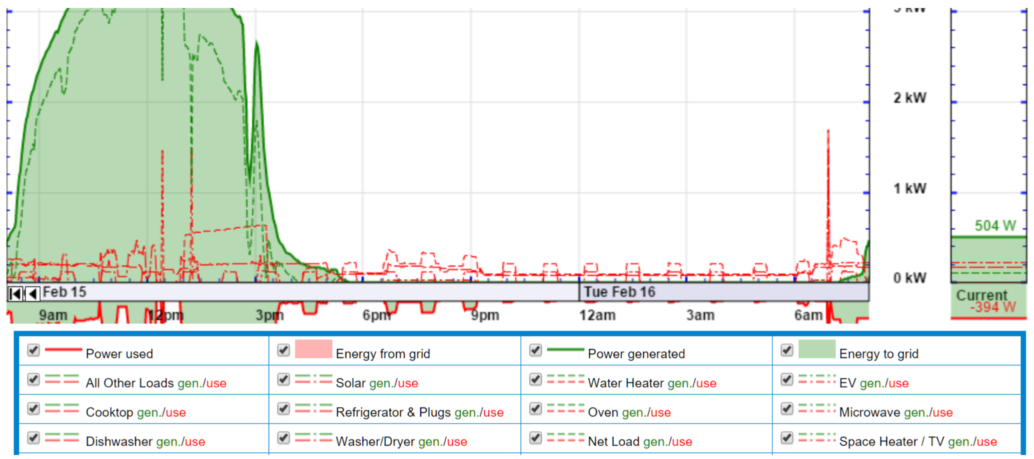



**Figure 1c.** Netatmo devices record temperature in five locations.

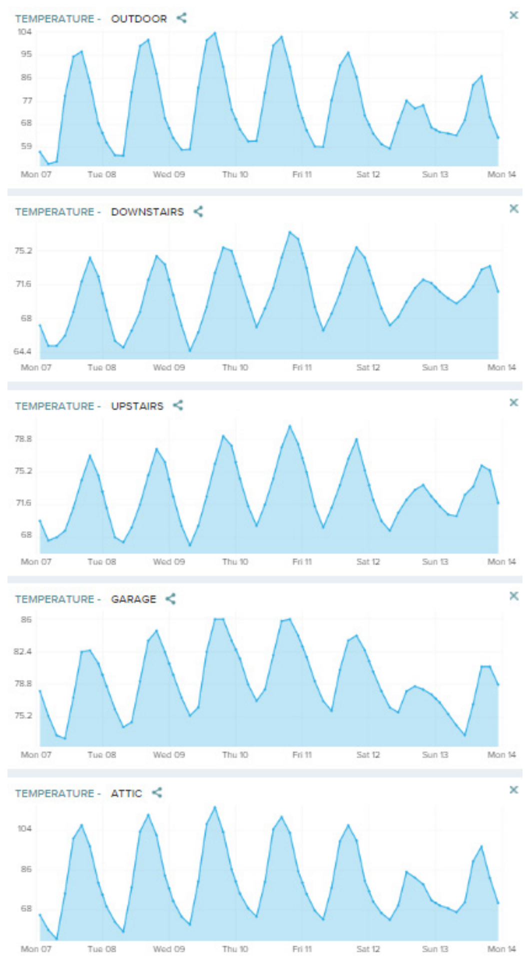



**Figure 1d.** NEST thermostats are combined with circuit switches to control the water heater (listed as Basement), heater (listed as Downstairs) and whole house ventilation (listed as Upstairs).

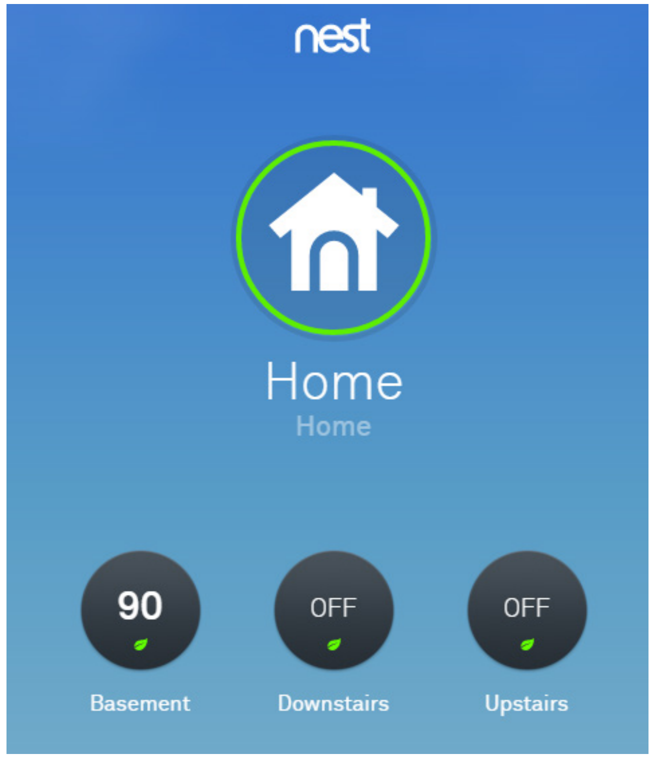



**Figure 1e.** House with SunPower 5.9 kW-DC PV System.

# Defining a Solar+ Home

Existing clean energy technologies can be cost-effectively combined to result in a Solar+ home that offers strong economic and environmental benefits. The approach is to combine PV power, an EV, simple energy efficiency measures and appliance electrification. Benefits are maximized when the various technologies are sized, installed and operated within the context of the house as an integrated system.

The specific technologies are:

- Solar power, where PV is located either on the customer's home or as community solar.
- Personal transportation electrification that shifts from gas-powered vehicles to EVs.
- Simple energy efficiency measures, including phantom (or plug) load reduction and conversion to LED lighting.
- Appliance electrification, including conversion of water and space heating from natural gas to electric heat pump technologies.
- Basic building shell improvements including caulking, targeted insulation and ventilation.

## Conceptual Example of a Solar+ Home

Figure 2a illustrates how to convert a typical home to a Solar+ home. The size of the rectangles represent the amount of site energy consumed, normalized into units of kWh. The left graph is the existing situation. The middle graph corresponds to the amount of energy consumed after efficiency, an EV and electrification. The right graph shows how the electricity consumption is satisfied using PV.

The large rectangle in the left graph (Existing situation) corresponds to the total amount of site energy required before conversion. The four inset boxes represent the sources of consumption including: Personal Transportation, Water Heating, Space Heating and Other Electricity. The relative sizes of the rectangles are drawn to scale and correspond to site energy. The colors correspond to the fuel sources including: electricity (blue), natural gas (orange) and gasoline (gray).

The middle graph shows how site energy is reduced by:

- implementing efficiency and switching gasoline-powered vehicles to a hybrid and an electric vehicle; and
- switching natural gas-powered water and space heating to electric-powered appliances.

The right graph shows how electricity consumption can be supplied using PV power. That is, the PV production (green) is overlaid on top of the electricity consumption (blue) so that net electricity consumption is zero.

There are a few things to notice:

- Personal Transportation in the Existing graph accounts for more than half of the energy consumption.
- Other Electricity in the Existing graph (and the typical target for a PV system) only represents one-seventh of the total site energy consumption.
- Consumption is greatly reduced using basic efficiency measures, an EV and appliance electrification (middle graph).
- Consumption can be met by a moderately sized PV system (right graph) to almost eliminate site energy consumption.

Some gasoline consumption remains because only one of the household's two vehicles is electrified. If carbon dioxide (CO2) emissions were used instead of site energy consumption in the graphs, the only remaining emissions would be those associated with the gasoline used by the gas-powered vehicle. There would be about a 90 percent reduction in emissions.

## Actual Example of Solar+ Home

Conceptual diagrams are interesting but what people really care about is whether or not Solar+ homes are feasible in practice.

Clean Power Research has had a multi-year research effort focused on Solar+ homes. Part of the effort was to cost-effectively implement Solar+ in an existing, fully occupied house using off-the-shelf technology without a deep retrofit. The prototype house has been operated since May 2014.

**Figure 2a.** Conceptual example of how to achieve Solar+ on a relative site energy basis.

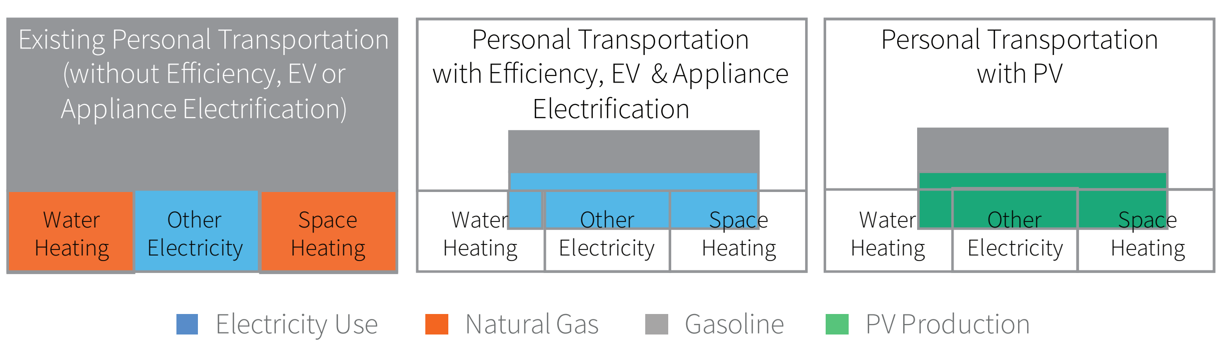





**Figure 2b.** Measured data for existing home.

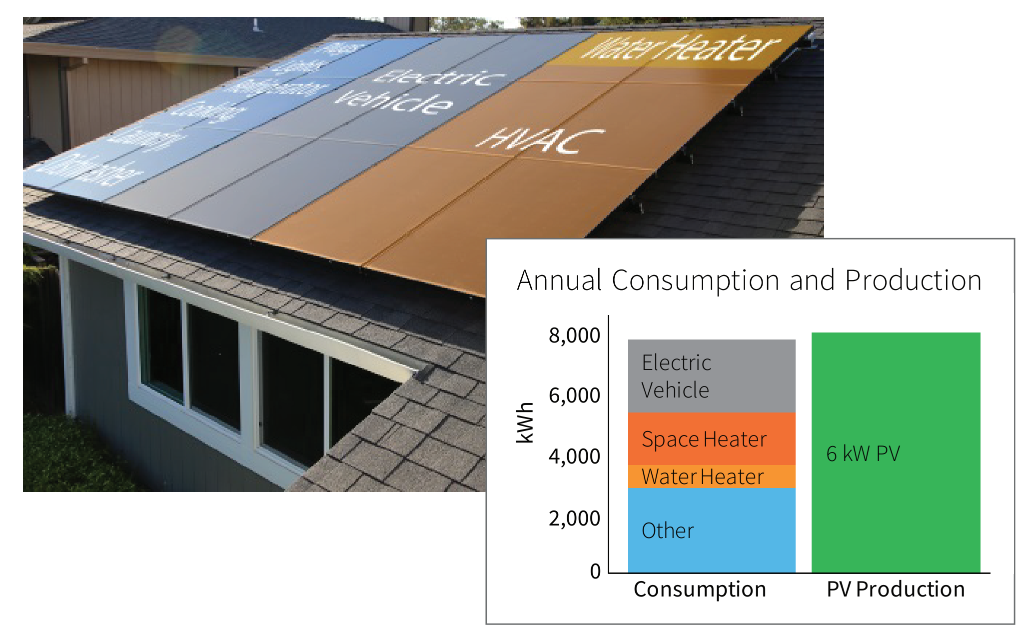


Figure 2b presents one-year's worth of measured results. Net site energy consumption has been reduced by 85 percent by combining efficiency investments, appliance electrification and powering electricity consumption with a 5.9 kW PV system. Annual end-use consumption is graphically overlaid on the PV panels to illustrate how much energy each end-use consumed relative to the amount of energy produced by the PV.

Figures 2c, 2d and 2e present average daily energy consumption by month for the last six years. The figures show that:

- Other electricity consumption has declined with phantom load reduction and LED lights.
- Water and space heating consumption has declined with the switch to efficient electric appliances and building shell improvements.
- Transportation consumption has declined with the switch to an EV and a hybrid—even with a 50 percent increase in mileage.

The only remaining non-solar consumption is 200 gallons of gasoline for the gas-powered (hybrid, but not plug-in hybrid) vehicle, and 30 therms of natural gas for clothes drying. Since the home uses electric resistance heating, the final step will be to convert the resistance heating to a mini-split heat pump and purchase an electric dryer. This would save enough electricity that could then be used to fully power a second EV, making the home 100% renewable powered if this were done today. That is, the PV system is already sized sufficiently large enough to reach a fully Solar+ home given the energy savings with a heat pump and the energy consumption associated with a second EV.

**Figure 2c.** Electricity consumption has declined with phantom load reduction and LED lights.

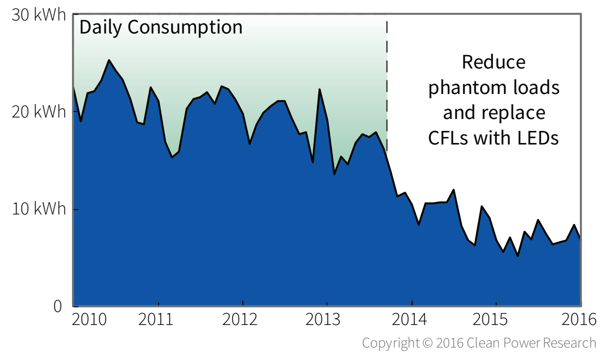



**Figure 2d.** Water and space heating consumption has declined with the switch to efficient electric appliances and building shell improvements.

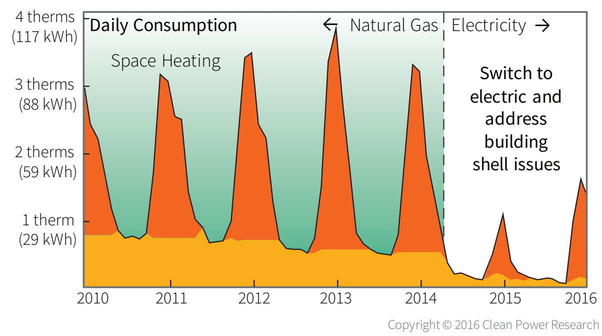
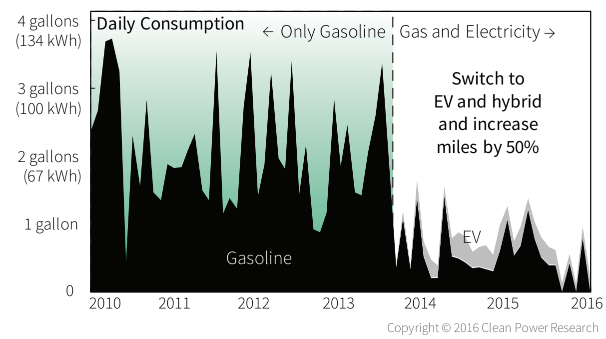



**Figure 2e.** Gasoline consumption has declined with the switch to EV and hybrid vehicles even with an increase in mileage.



# A Friendship Between Solar+ Homes and Utilities

One investment approach that is gaining traction among consumers is to buy an EV, and then size the PV system to meet existing consumption plus the extra consumption required by the EV.

Figure 3a presents electric load on a typical summer day after consumers have taken this approach. The graphs on the right present end-use consumption and PV production. The graphs on the left present consumption minus production, or net consumption. The dashed line corresponds to net consumption before any investments. The figure shows that this would have required a 6.8 kW PV system in the case of the prototype house. There is sufficient production to satisfy consumption on an annual basis.

The problem is that net consumption has steep peaks and troughs, and rapid ramp rates. This is a costly load for utilities to serve.

## But What About Violation of the "Efficiency First" Mantra?

Energy experts might be tempted to wring their hands because the "efficiency first" mantra has been violated. Consumers are buying what is attractive to them (an EV + PV combination), and they have missed the opportunity for efficiency investments.

Fortunately, this is not the case. Figure 3b presents the electric load for a home after all Solar+ home investments have been made. In addition, the loads are controlled to match PV production. One thing to notice is that the PV system is nearly the same size for the Solar+ home and EV + PV only home. In fact, the Solar+ home PV system size is slightly smaller.

This initially appears to be magic. It's not. It has been accomplished by implementing basic efficiency investments *after* the PV was installed, and using the electricity savings to fuel-switch appliances (water and space heating). The basic efficiency investments include phantom load reduction, LED lights and building sealing. More advanced investments include targeted insulation. Nighttime ventilation would further reduce consumption.

A second thing to notice is that net load is fairly flat. This has been accomplished by controlling three key loads: HVAC, water heater and EV. The result is that this load is a low-cost load to serve. The load would be flat if the new net load was added to the old net load. This suggests that the residential load would be flat if half of all residential customers had Solar+ homes, and half did not.

A third thing to notice is what is absent from the figure. Every device in the house does not need to be controlled if the correct efficiency investments have been made. It's sufficient to focus only on EV, HVAC and water heating consumption.



## How to Get There

Clean Power Research has developed algorithms that leverage the existing thermal mass of a building to shift HVAC load and to control the water heater. Thermal storage is similar in many ways to electrical storage, but with the added benefit that there are no capital or operational costs. There are only moderate additional energy losses.

Figure 3c illustrates how the thermal capacity in a heat pump water heater has been implemented to match PV production in the prototype house. The result even works in the winter months.

## What This Means for Utilities

Energy experts need not fret that consumers are purchasing an EV + PV combination and skipping efficiency. These households can still be converted to 100% solar to achieve a Solar+ home after the PV investment. In fact, they may be excellent candidates because they have expressed interest in their energy consumption. It will be feasible in many cases to achieve Solar+ homes without additional PV being required. It can be accomplished by combining efficiency actions with appliance electrification.

Because Solar+ homes can have profiles that are low-cost for utilities to serve, utilities and Solar+ homes should be close friends. Utilities simply need to take actions that encourage HVAC, EV and water heater electricity consumption to occur at specific times.

**Figure 3a.** Electric load on average summer day after purchasing EV and PV bundle.

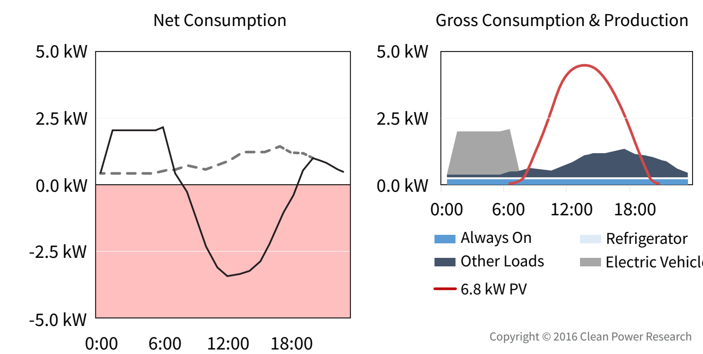



**Figure 3b.** Homes can be made Solar+ after the PV-EV combination has been purchased. Loads can be flattened using control.

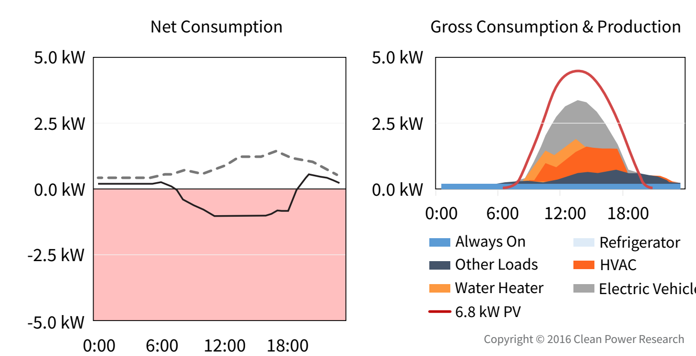
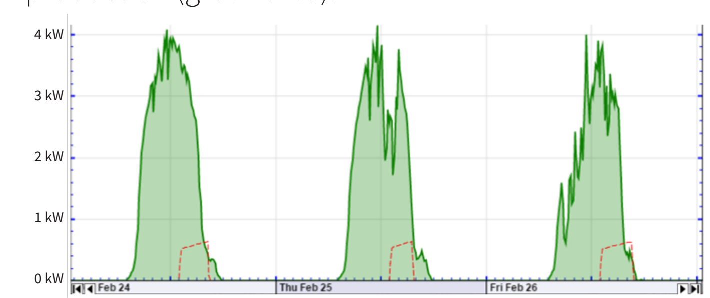



**Figure 3c.** Heat pump water heater consumption (red dashed line) can be controlled to match PV production (green area).



I've had many conversations with people on airplanes over the past several years about Solar+ homes. Everyone is interested because they all have homes, and they want to know what they can do.

The conversation inevitably moves to the question: where should I start? I typically give them specific suggestions based on what they have told me about their home.

The more I think about it, however, the more I believe the question they should be asking is where they want to finish, rather than where they should start. Investment order is not important if you know what the end result looks like. There are multiple places to start as long as you have the end result in mind.

## What About The "Efficiency First" Mantra?

Energy experts have a mantra: "efficiency first." They argue that it's important to implement efficiency measures before investing in renewables.

Consumers, however, don't tend to listen to the chant of the experts. They purchase what is attractive to them. A particularly attractive combination is an EV and a PV system. Energy efficiency experts fear that consumers miss the opportunity for efficiency investments when they take such an approach.

If the PV system is correctly sized with the end result in mind, then the order does not matter. The key is to have a plan before you begin. The most important part of the plan is to correctly size the PV system at the outset.

## EV + PV Can Be a Fine Initial Purchase Given Proper Planning

Solar and an electric vehicle are the two most important Solar+ home investments a typical homeowner will make. Combining an electric vehicle with solar has obvious appeal for the following reasons:

- Vehicles can be "fueled" at home with sunshine instead of going to the corner station and pumping gas.
- Consumers have certainty about how much fuel will cost in the future.
- Individuals are taking actions to personally reduce environmental emissions.

It's analytically complex to correctly combine these two investments. Important factors include:

- Which EV to choose.
- How to correctly size the PV system.
- When to charge the vehicle.
- How much public charging will cost.
- How the price of gas affects the decision.
- Which is the optimal electric rate structure.
- How to pay for the investments (cash, loan, or lease).

While we won't be discussing each of these factors in this whitepaper, our experience has shown that making an incorrect choice for any one of these factors can substantially reduce the financial benefits of a combined EV + PV investment.

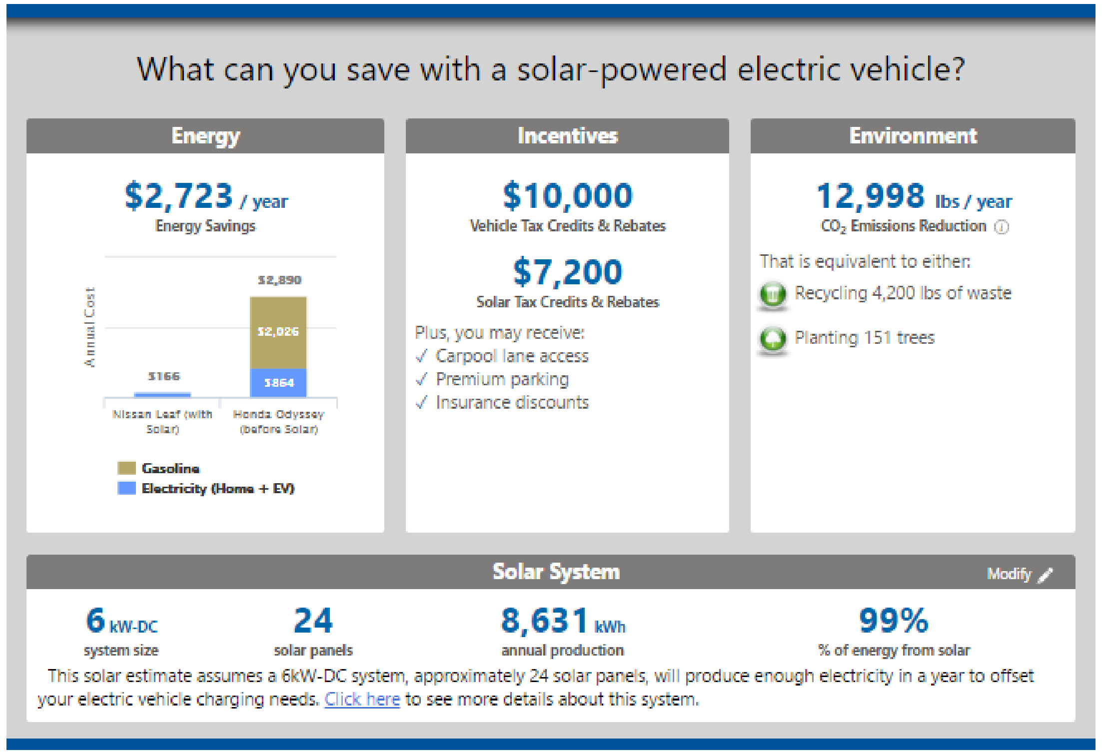
## Making Complex Analysis Simple with Online Tools

Today there is an online tool available that can answer all of the questions listed above. It can even allow users to input their own detailed consumption data that is available from their utility website. The tool is called WattPlan® (see Figure 4a), and it's available to PG&E, SCE and SDG&E customers at csi.wattplan.com (through September 2016), and to customers in New York at https://nyserda.wattplan.com/.

The WattPlan EV + solar tool is a major step toward evaluating a Solar+ home. In the future, expect to see key Solar+ home investments integrated into a Solar+ Home version of WattPlan.

An EV + PV combination is a fine place to start on the path to a Solar+ home. There will be additional investments that can be made in the future as long as the PV is sized with the final goal in mind.

**Figure 4a.** Solar-powered vehicle calculator (WattPlan).



# Unmask Phantom Loads and Don't Worry About Reminding the Kids to Turn Off the Lights

Simple efficiency measures represent one of the easiest and least expensive steps toward achieving a Solar+ home. Two of the simplest measures are reducing phantom loads and installing LEDs.

## Phantom Loads

The first simple efficiency measure is phantom load reduction. Phantom loads are so-called because most electrical appliances and electronic devices such as TVs continue to draw power even when they are turned off. Phantom loads are also referred to as "vampire" or "plug" loads.

Phantom loads are sneaky little parasites. It seems like a load as small as 10 Watts is irrelevant; however:

1. The loads are always on.
2. A house can have a lot of phantom loads.
3. A lot of small loads add up to a large load.

Consider an example. Suppose a home has 170 Watts of phantom loads. These phantom loads consume 1,500 kWh per year. This is because 170 Watts x 1 kW/1,000 Watts x 24 hours/day x 365 days per year equals nearly 1,500 kWh. To put this in perspective, it would require the amount of energy produced by 1 kW of PV in a location like California to satisfy this wasted energy.

How do you know if you have substantial phantom loads? While the research is sparse on this topic, we have found that a rough rule-of-thumb is that a house may have addressable phantom loads if its baseload consumption exceeds 250 Watts. Clean Power Research has developed methods to calculate baseload consumption by examining historical load data such as Green Button data or other hourly load or "interval" data that may come directly from the utility.

The solution is two-fold: (1) Unplug unused items that provide no benefit, such as old phones, routers or an old UPS; and (2) Use smart power strips for devices such as TVs, and power conserving switches for items that are occasionally used.

**Figure 5a.** Example of smart power strip.


## LED Lights

The second simple efficiency measure is converting to LED lights. "Turn off the lights" was a phrase I often heard when I was growing up. It was not surprising to hear this admonishment when all lights were incandescent and running them could have a noticeable impact on one's electric bill.

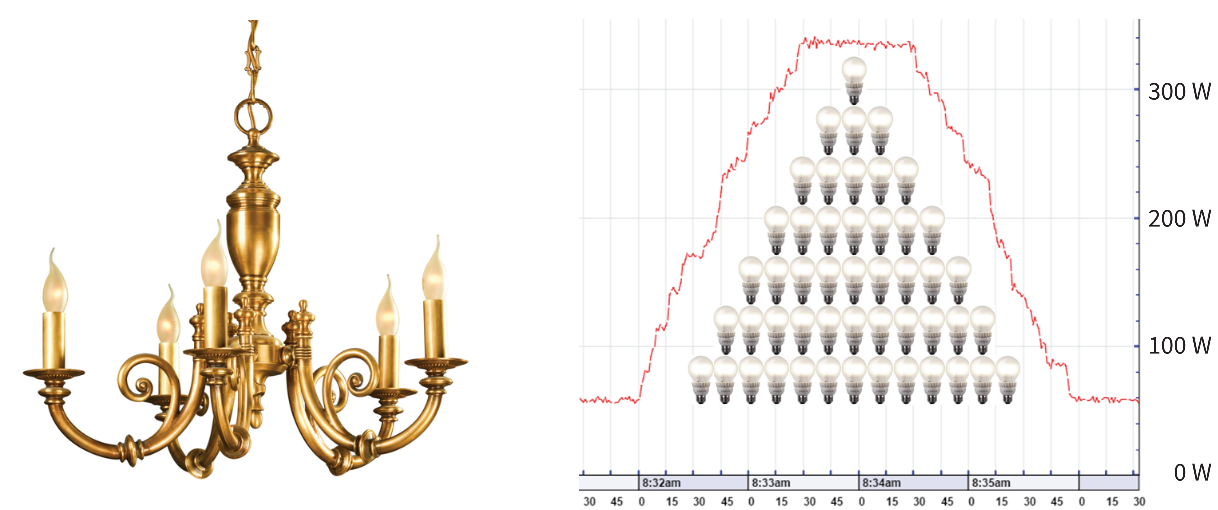
Today, however, while my dad would still encourage me to turn off the lights, the efficiency of modern lighting technologies is dramatically reducing their energy and cost footprint. The introduction of compact fluorescents (CFLs) cut energy use by 75 percent compared to incandescent lights, and LEDs have reduced consumption by another half to two-thirds. The result is that ten LEDs now produce about as much light as one incandescent light using the same amount of energy.

One way to think about this is in terms of what you can do with a dollar. Suppose you want to operate lights 4 hours per day for a week, and that electricity costs $0.12 per kWh. Figure 5b shows that for one dollar, you can operate one incandescent fixture, or you can turn on all of the LED lights in the house. The graph in Figure 5b was created by turning on and off all 49 LED lights in the prototype house.

The solution is obvious. Replace lights, particularly incandescent ones, with LEDs. This can be done either all at one time or incrementally as bulbs wear out and need to be replaced.

**Figure 5b.** How many lights can you turn on 4 hours a day for a week with $1?

One Incandescent Fixture | Every LED Light in the House




(5) 60-Watt Incandescent candelabra bulbs

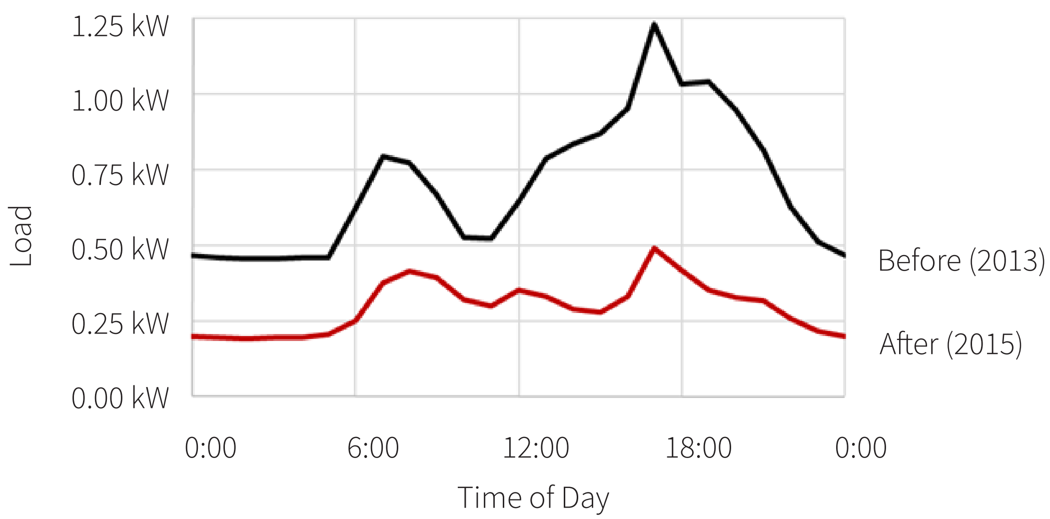
(49) "40-Watt equivalent" LED bulbs (avg. power of a 6-Watt bulb)

## Does This Work?

The effectiveness of simple energy efficiency measures can be seen by examining measured data for the prototype house. Figure 5b presents electricity consumption before and after the Solar+ home investments were made at the prototype house. The figure excludes PV production and electricity consumption associated with fuel switching (i.e., electric vehicle, heat pump water heater and electric heating) in order to provide an apples-to-apples comparison. The figure shows that simple energy efficiency measures reduced consumption by over 50 percent in the prototype house.

Large electric energy savings are often feasible using simple efficiency measures. Two of the simplest measures are reducing phantom loads and installing LEDs. Electricity consumption at the prototype house was cut in half using these two measures alone.

**Figure 5c.** Simple energy efficiency measures reduced consumption by more than 50 percent in the prototype house.



# Next Generation Solar-powered Water Heating

Solar domestic water heating systems have been around for decades. There are a variety of types of collectors and circulation systems. Their common element, however, is that they directly use the sun to heat water (or a fluid that then heats water).

This direct heating approach has limitations:

1. Water (or fluid) needs to be transported to the roof of a house. Pipes and fittings that contain water or other liquids tend to leak over time.
2. It's not economical to transport hot water from a single system more than a few hundred yards.
3. Hot water heating systems degrade over time and are unattractive after a period of neglect, as shown in Figure 6a.

Some people even claim that solar thermal water heaters no longer make sense in many situations.

These limitations can be overcome by indirectly using the sun to heat water. More specifically,

**Figure 6a.** Solar hot water heating system in need of repair.


PV can generate electricity and electricity can heat water using an electric resistance water heater. Better yet, electricity can heat water using a highly efficient heat pump water heater (HPWH).

There are a number of benefits to this approach:

- There is no need to transport water to or from the roof, so there is no risk of leakage in walls, through the roof or in other hard-to-detect places.
- PV can generate electricity hundreds or thousands of miles away to produce solar-powered hot water.
- PV systems do not have pipes and other water handling components that wear out like solar water heating systems.

Both the direct and indirect approaches provide solar-powered water heating, but the indirect approach is preferable for the reasons described above. The indirect approach also costs less than the direct approach.

## What Is a Heat Pump Water Heater?

People are familiar with PV and water heaters, but they may not have heard of heat pump water heaters. Natural gas and electric resistance water heaters look similar to HPWHs, but they operate on completely different principles. The first two consume fuel to heat water. HPWHs move heat from one location to another as the primary method of heating water.

Heat pumps sound unfamiliar or even exotic to many consumers. In fact, most consumers have at least two types of heat pumps in their homes: a refrigerator and an air conditioner (A/C). Heat pumps move heat from one location to another. A refrigerator moves heat from inside its contained space to outside that space. An A/C moves heat from inside to outside a house.

One way to think of a heat pump water heater is that it's basically like a room A/C unit attached to the top of a water tank with the

**Figure 6b.** Tank-based water heaters look similar (they may vary in size based on capacity).

waste heat transferred to the water rather than the outside air (see Figure 6c).

HPWHs are particularly impressive in terms of their performance. As shown in Figure 5d, the EnergyGuide estimates that a typical natural gas water heater consumes 240 therms per year (this is equivalent to 7,032 kWh). This compares well to the 230 therms (6,746 kWh) of natural gas actually consumed per year at the prototype house from 2010 to mid-2014.

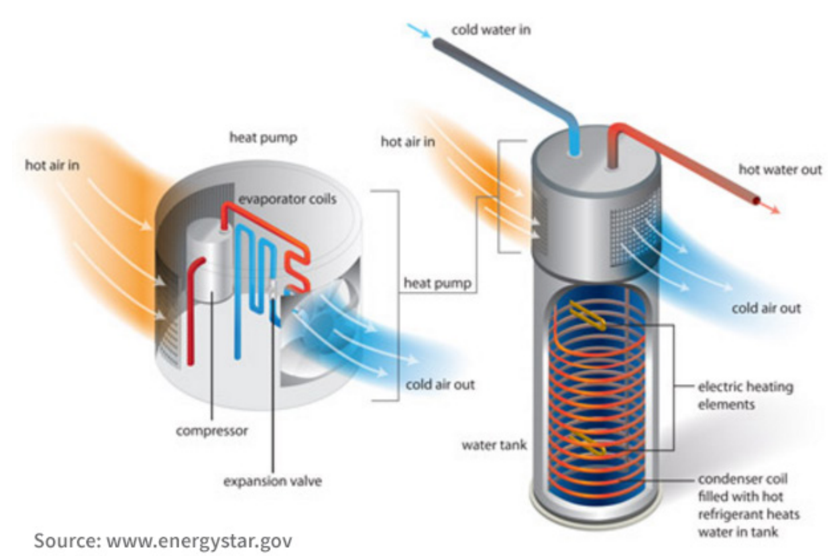
The EnergyGuide estimates that a typical electric resistance water heater consumes 4,600 kWh and that a Stiebel-Eltron HPWH uses 1,400 kWh per year. The Stiebel-Eltron HPWH installed at the prototype house in mid-2014 actually used 700 kWh in its first year.

Thus, the HPWH used only half as much energy as predicted by the EnergyGuide, and only one-tenth as much as a typical natural gas unit. Consumption was lower than predicted, most likely as a result of installation factors and mode of operation.

HPWHs are unlike traditional water heaters in that their performance can be exceptional. Also unlike traditional water heaters, HPHWs require that attention be given to how and where the unit is installed, as well as when it's operated, to achieve optimal and efficient operation.

For example, remember that an HPWH is like an A/C unit joined with a water tank. Few people would think that it's a good idea to turn on the A/C the middle of the winter while the heater is running. Likewise, using heated indoor air as the source of heat for the HPWH will have negative implications for performance during the winter. The home's heating system would have to replace the heat taken by the HPWH, thereby effectively reducing the efficiency of the HPWH to be equivalent to that of the heating system.

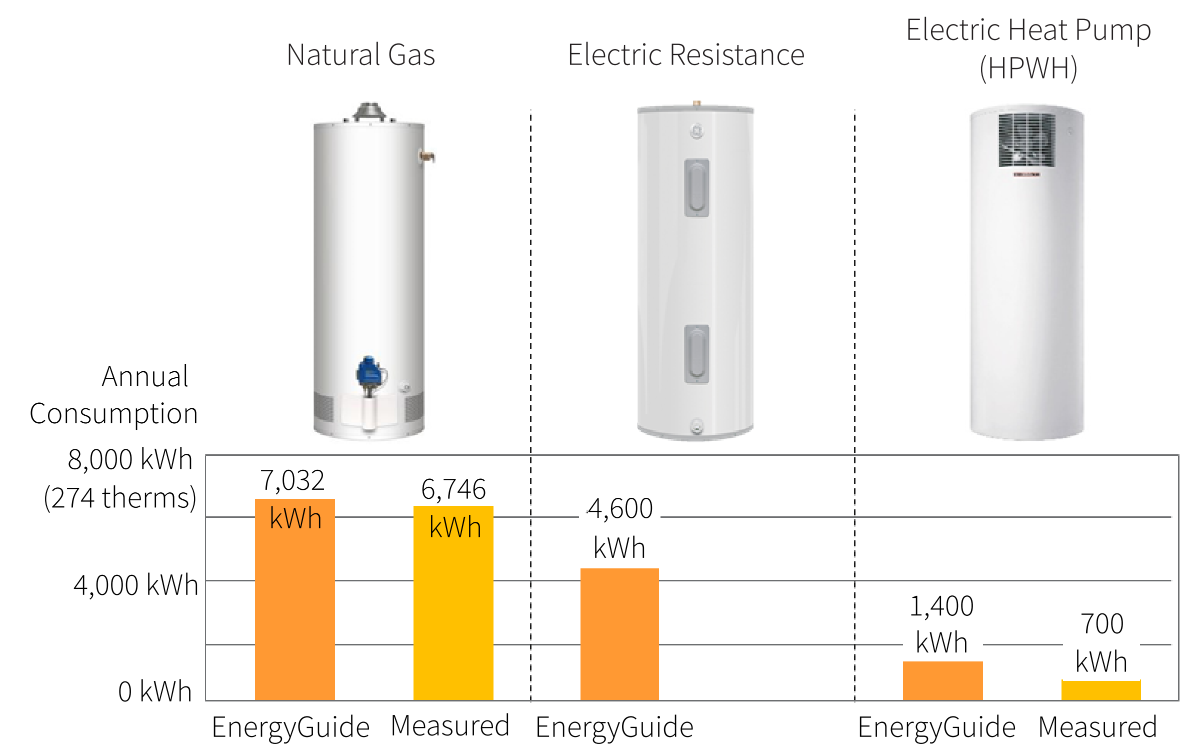
**Figure 6c.** Combine an A/C unit with a water tank to get an HPWH.




There are other details that need to be considered as well, including the time of day the unit is operated, and where the waste cold air goes.

Water heaters consume a lot of energy. For example, a house that uses 6,500 kWh of energy as electricity will consume more energy for water heating using natural gas (on a site energy basis). An indirect approach may be preferable to a direct approach to solar water heating. The indirect approach combines PV with an electric HPWH. The prototype house used one-tenth as much energy using this indirect approach as compared to the energy consumed using a natural gas water heater.

**Figure 6d.** Natural gas, electric resistance and electric heat pump water heaters look similar but consume different amounts of energy.




Measured natural gas from Jan. '10 to Apr. '14. Measured HPWH is from May '14 to Dec. '15.

# Staying Warm in Winter

Conversations about energy efficiency elicit images of caulking and weather-stripping in many people's minds. However, we've focused on basic electrical efficiency and fuel switching in this research. There are several reasons for this approach:

1. Evaluating building energy investments is complicated because there are many options, including: smart thermostats; new windows; insulation; caulking; weather sealing; various types of HVAC equipment; etc.
2. The widely-used heating and cooling degree day approaches make it challenging to isolate the effect of different types of investments.
3. Home-heating in moderate climates such as California consumes less energy than vehicles, and is comparable to water heating energy consumption.
4. Heating and cooling needs should be treated differently from an analytical perspective.

## Energy Balance Approach

It's useful to take an energy balance approach to evaluate building energy consumption. A building is in balance if indoor temperatures at the beginning and ending of the time period are the same. As one can imagine, it's simple to satisfy this condition, particularly when the analysis is performed over a season. An energy balance is achieved by setting heat gain equal to heat loss. The additional parameter that describes comfort is the average temperature over the time period.

A building's indoor temperature changes based on the amount of heat gained or lost and the building's thermal mass. Only three sources provide heat gain (occupancy, internal electric and solar), and two sources provide either heat gain or heat loss, depending on the season (HVAC and envelope).

Occupancy is the heat given off by people. Internal electric is the heat given off by devices such as lights and TVs. Solar is the heat gained due to the sun through windows and the sun's heating of exterior building surfaces.

HVAC is a gain in the winter when the heater is operated, and envelope is a gain in the summer when it's warmer outside than inside. HVAC is a loss in the summer when the A/C is operated, and envelope is a loss in the winter when it's colder outside than inside. Envelope loss can also occur in the summer when it's colder outside than inside at night.

The energy balance approach in the winter requires that heat gain—which is the sum of occupancy, internal electric, solar and HVAC (heater) gains—equals envelope heat loss. The energy balance approach in the summer requires that heat gain—which is the sum of occupancy, internal electric, solar and envelope gains—equals heat extracted by the HVAC system (A/C). HVAC fuel requirements are calculated by incorporating HVAC efficiency (or coefficient of performance for A/C or heat pumps).

The energy balance approach can be used to assess the effect of investments on fuel consumption. Investment effects depend upon the initial situation of the building. Buildings are challenging in that the needs can differ significantly between various buildings. Once a building has been quantified, however, investments can be evaluated. Later in this paper we'll describe how to use Virtual and Lean Energy Audits to quantify the initial situation.

## Heating Investment Analysis

Consider an application of the energy balance approach in the winter. Figure 7a assesses the combined effect of four possible investments/actions. The investments/actions include:

(1) A smart thermostat that will save fuel by reducing average indoor temperature.

(2) Reduction of window obstructions such as trimming trees and removing window screens in order to increase solar gain.

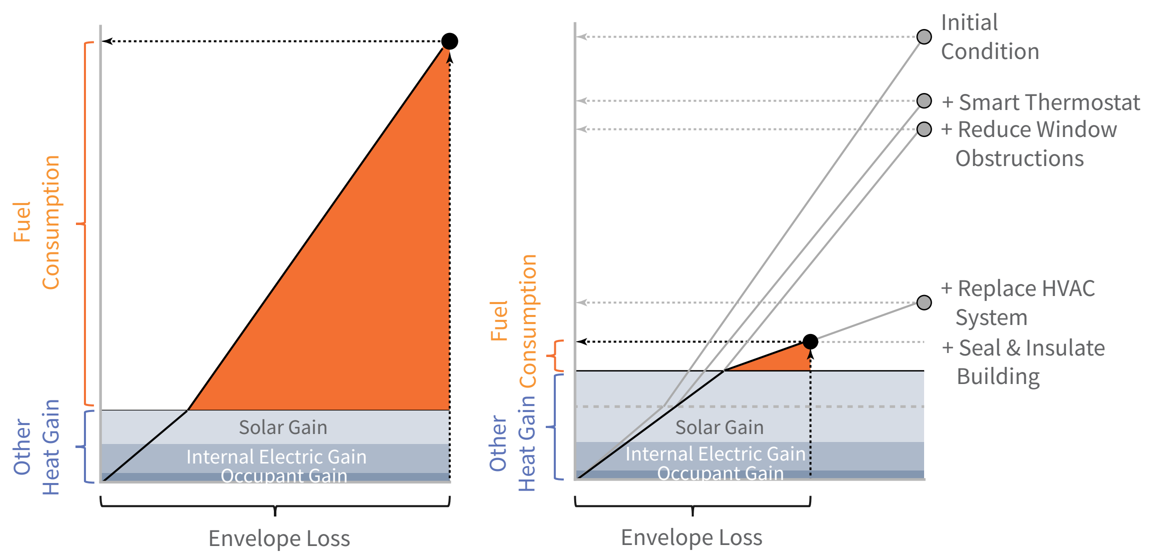
(3) Replacing the natural gas HVAC system with an electric mini-split heat pump in order to improve overall HVAC system efficiency.

(4) Sealing and insulating the building to reduce air and heat leakage.

The blue areas of the graphs in Figure 7a correspond to heat gain from occupancy, internal electric and solar gains. The orange area corresponds to HVAC fuel consumption. The x-axis relates heat gain to envelope loss. HVAC fuel consumption is plotted versus envelope loss.

The left side of Figure 7a is the initial condition, and the right side is the result after all investments. The right side of the figure illustrates how each investment/action changes HVAC fuel consumption including the interaction between the various investments. The figure shows that investments can be combined in such a way as to substantially reduce heating fuel consumption.

**Figure 7a.** Illustration of fuel savings associated with four investments.




² Tests for the house shows that transmissivity was 32 percent for the window alone vs. 18 percent for the window including the screen.

# The Power of Thermal Mass to Stay Cool in Summer

We've discussed how an energy balance approach can be used to analyze investments that reduce building energy consumption in winter. A slightly revised approach can be used to analyze investments in the summer. The energy balance in the summer requires that heat gain—which is the sum of occupancy, internal electric, solar and envelope gains—equals heat extracted from air conditioning.

There is an increasing desire to match consumption to PV production on a temporal basis. One approach is to assume that A/C loads should not be altered. This results in a mismatch between PV production and consumption, however, because A/C loads extend into the evening. Electric storage can be used to address this mismatch by transferring excess PV production from daytime to evening. Storage can be a costly alternative because it requires capital expenditures, variable operation costs and energy losses.

Another option is to use a home's thermal mass to shift unmet A/C consumption from evening to daytime. This does not undermine the energy balance approach because it satisfies the requirement that indoor temperatures are the same at the beginning and end of the time period.

This can be a low cost alternative because every building is a thermal battery (see Figure 8a). The thermal mass is free (it's already part of the home), and the approach may only involve moderate additional energy losses.

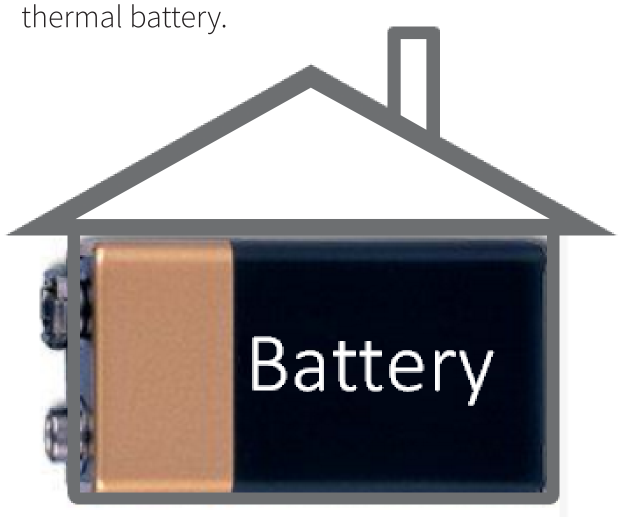
The question is: How good of a thermal battery is the house? How does shifting consumption affect consumer comfort? Consumer comfort will be determined by how the temperature varies over time.

## Eliminating Air Conditioning Needs

A building's thermal mass can be used in several ways. One approach is to shift A/C consumption from evening to earlier in the day by pre-cooling the building. This might be done to match A/C consumption to PV production. A more aggressive approach is to eliminate A/C consumption. This is accomplished by shifting free cool air from the night to the day using the building's thermal mass and an efficient building shell.

Buildings can be operated using either a passive or an active approach. A passive approach maintains constant building shell efficiency throughout the day. Envelope gains will occur on hot summer days when outdoor temperatures exceed indoor temperatures. Envelope losses will occur on cool summer nights when indoor temperatures exceed outdoor temperatures. The losses will offset gains to some degree. The remainder of the gain needs to be satisfied using A/C.

**Figure 8a.** Every house can be viewed as a thermal battery.




An active approach is to temporarily change building shell efficiency throughout the day. In particular, reducing efficiency during the nighttime in order to increase envelope losses. This will cool the building at a faster rate.

The two thermal conductivity components that determine building shell efficiency are infiltration and conduction. The infiltration rate can be temporarily increased by opening windows or operating a whole house ventilation fan.

## Demonstrating Effectiveness During the Hottest Week of the Year

Consider a simple example. Assume that outdoor temperatures exceed indoor temperatures for half of the day. Assume also that the outdoor temperatures average 20˚ F higher than indoor temperatures during the day, and the outdoor temperatures average 5˚ F lower than indoor temperatures during the night. Reducing building shell efficiency by a factor of four during the night would offset daytime heat gain with nighttime heat loss.

This, in fact, is exactly what happened on the hottest week of the year (2015) for the prototype house. Figure 8b presents measured data at two houses in Napa, Calif., throughout this hottest week of 2015 (September 7th through 11th). The graphs on the left are for a poorly insulated, 3,500 ft2 house that required A/C. The graphs on the right are for a well-insulated, 3,000 ft2 prototype house. The top graphs present indoor and outdoor temperatures. The bottom graphs present electricity consumption.

There are several things to notice:

1) The two houses have similar indoor and outdoor temperatures.

2) There is a large difference in energy consumption between the two houses.

The inefficient house required 57 kWh per day compared to the prototype house that required 9 kWh per day to maintain a comfortable indoor temperature. The inefficient house regularly had 10 kW of peak A/C demand to keep it cool, while the prototype house required no A/C to keep it cool; cooling was entirely accomplished using nighttime ventilation and the building's thermal mass.

The hottest day of the year illustrates the details of what happened. Consider the temperatures at the prototype house over the 24-hour period starting at 9 p.m. on September 9th:

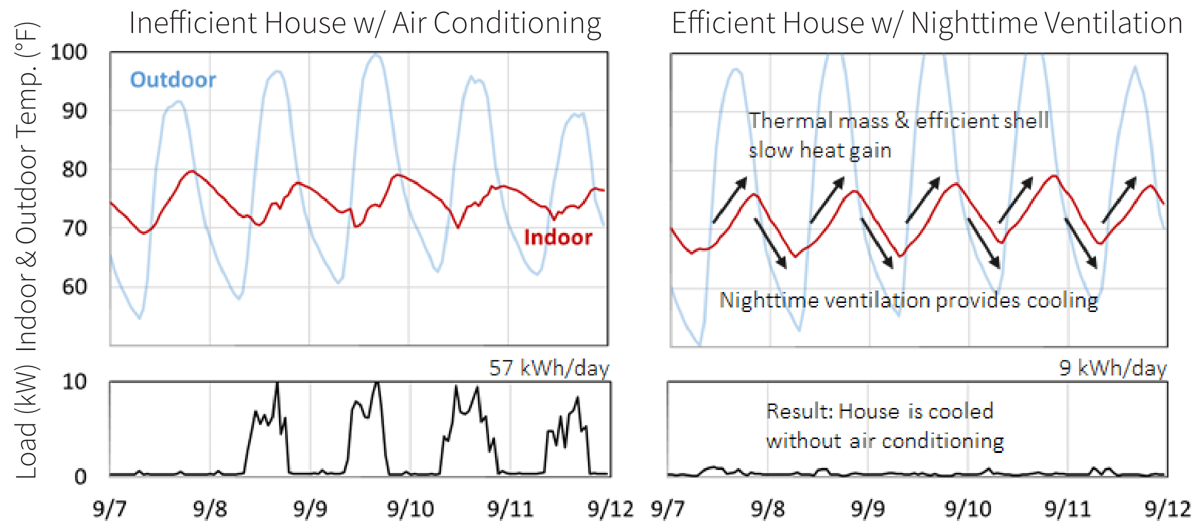
Sept. 9, 9:00 p.m.: Indoor and outdoor temperatures started at 78˚ F. The ventilation strategy was started.

Sept. 10, 8:00 a.m.: The house cooled by 10˚ F down to 68˚ F. This was accomplished even though the outdoor temperature only averaged 6˚ F below the indoor temperature.

> Sept. 10, daytime: Temperatures reached 105° F—the hottest day of the year—and averaged 20° F above the indoor temperature.
>
> Sept. 10, 9:00 p.m.: It took 12 hours for the indoor temperature to reach 79° F.

Building mass represents free thermal storage. Cooling at the prototype house was accomplished using no A/C at all during the entire period. It was accomplished by combining the building's thermal mass, an efficient shell and cool air from the nighttime. The extreme case of eliminating A/C consumption used thermal mass and an efficient building shell. The easier case of shifting A/C consumption should be broadly applicable.

**Figure 8b.** Measured indoor and outdoor temperatures and load at two houses on hottest work week of the year in Napa, Calif.



# Is Your House Leaky?

We know that the five sources of heat gain or loss in a building include: occupancy, internal electric, solar, HVAC and envelope. Two of these five sources are associated with building shell efficiency. They are solar gain and envelope gain (or loss).

Solar heat gain is caused by the sun shining through windows and heating exterior building surfaces. Envelope is the gain (or loss) due to the indoor/outdoor temperature differential and the building's thermal conductivity. A building's thermal conductivity is determined by the rate of infiltration and conduction.

Building shells are inefficient because they "leak" in three ways:

1. Buildings with infiltration issues have too much air leakage.
2. Buildings with conductivity problems have too much heat leakage.
3. Buildings that allow unwanted solar gain have solar leakage.

## Conquering Challenging Attics

Attics are a particularly interesting part of homes because they can be affected by all three types of leakage. As a result, they present an opportunity to discuss all three components of building shell efficiency. Consider how each type of leakage can influence building performance within attics.

### Heat Leakage (Conduction)

Conduction is the first issue that consumers think about. Conduction problems occur because there is insufficient insulation to limit heat leaking into the house through the attic in summer, or out of the attic in winter.

### Air Leakage (Infiltration)

Infiltration can be an issue in several ways. The stack effect can occur in the winter where cold air enters the home through holes and gaps near the floor, and hot air rises and leaks through holes and gaps in the ceiling. Mechanical ventilation such as attic fans in the summer can create low pressure in the attic if there is inadequate intake air ventilation. This creates the situation where the fan pulls cool air from inside the house through holes in the ceiling.

Holes in the ceiling include gaps around light fixtures, poorly sealed attic hatches, and improper sealing around plumbing and HVAC exhaust pipes.

### Solar Leakage (Solar Gain)

Solar gain is an indirect issue that needs to be considered. It's of particular concern in the summer. The sun heats the roof, which then heats the attic. The temperature will increase if there is inadequate attic ventilation. The insulation has to work harder to stop heat from "leaking" into the house as attic temperatures increase.

## Solutions

The solutions to these issues are to seal holes, have adequate insulation and/or prevent unwanted solar gain. Conduction issues are solved by adding attic insulation. Infiltration issues are solved by plugging ceiling holes. Solar gain can be prevented in one of three ways:

(1) Block the sun by shading the building with trees or an on-roof structure like a PV system.

(2) Reflect the sun using reflective material.

(3) Ventilate to prevent heat buildup.

These are the same methods one would use to keep a car cool when parked outside on hot days:

(1) Block the sun by parking the car under a structure.

(2) Reflect the sun by purchasing a white car and windshield shades.

(3) Ventilate the car by opening windows.

## Prototype House

The attic issues were addressed in the prototype house in a number of ways. One portion of the black roof was well insulated but not shaded. This portion only experienced solar gains. A PV system was situated over this part of the roof. It served the dual purpose of producing power and acting as a shade structure, thus cooling the roof.

The other portion of the roof had all three issues. Infiltration losses were reduced by sealing around light fixtures and other penetrations in the ceiling, and tightly shutting attic hatches. Conduction losses were addressed by adding attic insulation and providing insulation to

**Figure 9a.** Passive attic ventilation system keeps attic cool while PV system shades roof.

uninsulated areas. Solar gains were prevented by using a passive ventilation system. The system had unobstructed intake air vents under the eaves that allowed the air to have a clear path to exit a ridge vent and remove hot air trapped by a radiant barrier (Figure 9a).

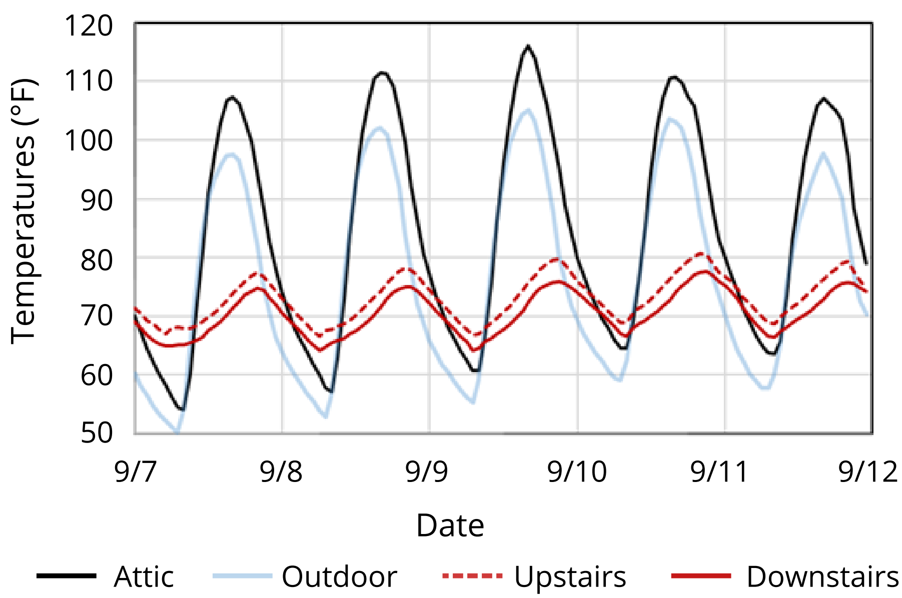
As a result of these investments, the attic was only 10˚ F above the outdoor temperature even on the hottest week of 2015 (Figure 9b). Put another way, the solar gain for the 900 ft2 attic area was reduced to the equivalent gain associated with a 2 ft2 clear window.

A key lesson learned was that attic ventilation components must be treated as a system. The technologies were installed and tested in this order: radiant barrier, ridge vent and then intake vents (including a clear path to the ridge vent).

The radiant barrier had almost no effect by itself. Temperatures reduced by half when the ridge vent was added. The intake vents, which were sized to avoid low pressure in the attic, completed the ventilation system and provided adequate ventilation. Keep in mind that this passive system even worked for a house with a black roof on hot days.

Any building surface or portion of a building can be inefficient because it "leaks" in three ways: air leakage, heat leakage and solar leakage. Some surfaces have only one problem, while others, such as attics, can leak in all three ways. The solution is to seal holes, have adequate insulation and prevent unwanted solar gain. Each of these solutions is additive.

**Figure 9b.** Attic temperature remains cool at 10˚ F above outdoor temperature.



# The Energy Detective and His Muscleman Friend

We've described how HVAC fuel consumption is related to envelope gain. Now we'll describe a simple, inexpensive method for measuring the effectiveness of your home's thermal conductivity.

As we've learned, envelope gain is based on thermal conductivity, and thermal conductivity is defined by conduction and infiltration rates. Conduction and infiltration are typically estimated using an on-site home energy audit. In traditional energy audits, conduction is estimated by measuring surface areas and estimating R-values for each surface. Infiltration is estimated using a blower door test and estimating building volume.

Home energy audits yield valuable information about the efficiency of a house. Traditional energy audits, however, are expensive, time-consuming and intrusive. Consider, for example, the challenges with the blower door test:

- The test requires specialized equipment and trained personnel.
- The test is intrusive to consumers: Trained personnel must come to the consumer's home, open a door for an extended period of time, go throughout the home and place airtight covers over all the HVAC vents, and run a noisy fan.
- It's easy to make calibration errors that invalidate the test.
- It can cost several hundred dollars to perform the test.

Finally, results from traditional energy audits need to be translated from high pressure conditions to actual operating conditions using an approximation to estimate actual infiltration losses. That is, the results are still just estimates even after all the work has been performed because they need to be converted to actual conditions.

## An Empirical, Non-Invasive, Low-Cost Approach to Energy Audits

At Clean Power Research, we've developed an alternative to the traditional home energy audit. It's an empirical, non-invasive, low-cost approach that consists of two steps:

1. A Virtual Energy Audit
2. A Lean Energy Audit

This audit method is empirical because it's based on measured data versus estimating results. It's non-invasive because the first step requires no onsite measurements, and the second step only requires a small, unobtrusive device. It's low-cost because the device required in the second step is inexpensive.

The two-step approach directly measures conduction and infiltration. The Virtual Energy Audit measures the combined effects of infiltration and conduction. The Lean Energy Audit measures infiltration. Measured conduction is obtained by subtracting measured infiltration (Lean Energy Audit results) from measured infiltration plus conduction (Virtual Energy Audit results).

## The Virtual Energy Audit

The Virtual Energy Audit is performed using measured energy consumption data and weather data. The energy consumption data is obtained from customer utility bills, and the weather data is available at SolarAnywhere.com. Assumptions or inferred values include:

- Average number of occupants
- Average indoor temperature
- Effective window area and HVAC efficiency

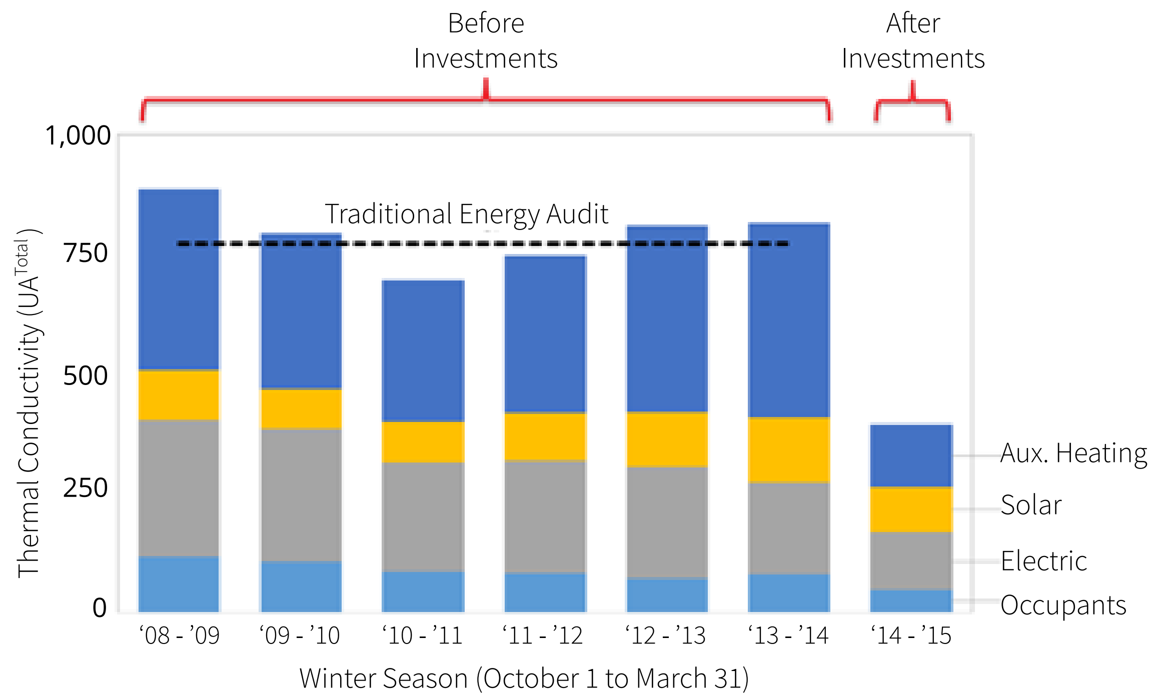
The data can be combined to assess the overall performance of the house. Figure 10a shows the results of the Virtual Energy Audit that was performed at the prototype house. Results from a traditional energy audit that was also conducted on the prototype house are included for comparison purposes.

The figure shows that results from the Virtual Energy Audit and traditional energy audit are comparable. The figure also shows that the effectiveness of the Solar+ home building shell investments can be verified.

## The Lean Energy Audit

The Lean Energy Audit is based on measured data from a simple, unobtrusive device placed in the home. Infiltration is the amount of air flowing through the house. It equals the number of air changes per hour times the volume of the house. The device measures infiltration

**Figure 10a.** Virtual Energy Audit compared with traditional energy audit.



based on carbon dioxide concentration using an "Empty Building" test. Results can be validated using an "Equilibrium" test.

The Empty Building test requires people to leave for a short period of time. Figure 10b presents carbon dioxide concentration data on a day when the home was vacated. The home had 0.06 air changes per hour, making this a very efficient home. Note that the test can actually be performed in about an hour even though the plot presents 24 hours. The Equilibrium test is based on long-term, steady-state conditions. Figure 10c validates the accuracy of the Empty Building test results.

In addition, a few short-duration tests can be run to verify effective window area, HVAC efficiency and thermal mass. Longer-term data from the device can be used to calculate average indoor temperature and occupancy over a season.

**Figure 10b.** Empty Building test translates to 0.06 air changes per hour (December 10, 2015).

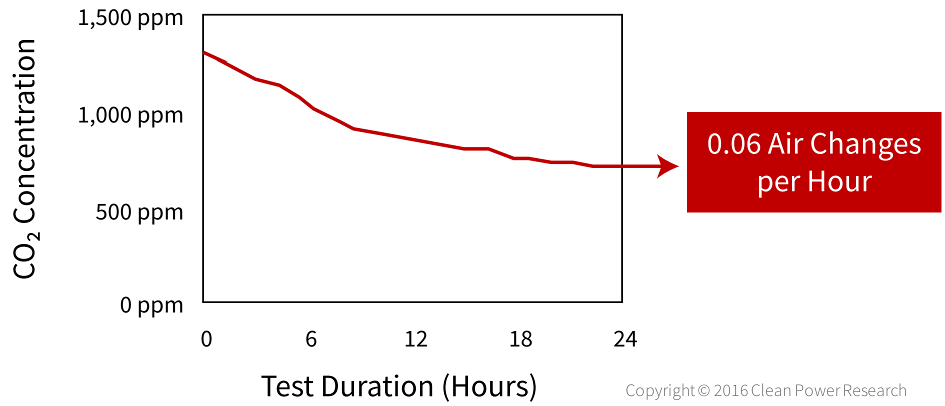
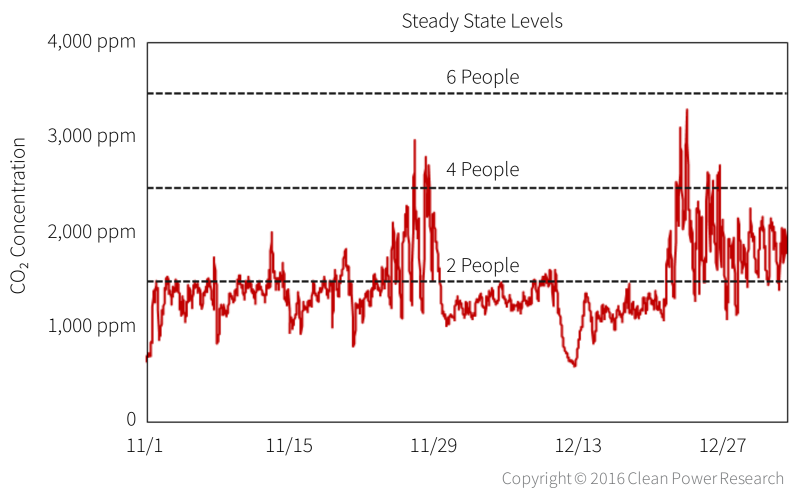



**Figure 10c.** Equilibrium test validates 0.06 air changes per hour.



# Conclusion

The Solar+ homes concept can help homeowners win from the energy transformation. By following three steps, homeowners can reduce their carbon footprint, achieve significant savings and have more comfortable homes—all using commercially-available technologies. These steps are:

- Reduce energy leaks
- Switch to efficient devices (electric vehicles, heat pumps and LED lighting)
- Offset consumption with PV (rooftop, community solar or utility-sited solar)

The paper has also shown that the energy transformation, as enabled by Solar+ homes, can benefit electric utilities, new energy technology companies, utility customers and regulators.

- Electric utilities may see the largest benefits as Solar+ homes allow for significant growth in electric load, while simultaneously adding flexible loads that can either be controlled directly, or induced to consume at favorable times through pricing mechanisms.
- The new energy industry benefits by selling their equipment (PV, EVs, heat pumps and the like).
- Consumers benefit with lower, more predictable energy bills, a cleaner environment and more comfortable homes.
- Policymakers, including utility regulators, win by having financially stronger utilities and a healthier environment.

An opportunity as big as Solar+ homes needs an action plan to match. Electric utilities, consumers and policy makers each need a plan to make the energy transformation a reality.

Electric utilities can start by changing their thinking around energy efficiency. In the old paradigm, energy efficiency meant electric efficiency. In the new paradigm, energy efficiency means that the utility looks at consumers' total energy usage and finds ways to reduce that usage, even if that means increasing electricity consumption.

Electric utilities must facilitate the energy transformation through policies, rates and incentives that encourage the smart use of energy. These policies will encourage the most energy efficient appliances and transportation. They will also encourage flexible loads that consume at times of lowest cost.

Finally, the electric utility should venture far down the path of becoming the trusted energy advisor and provide information and analysis for their customers to help them make decisions about new technologies. Tools such as WattPlan® from Clean Power Research can help electric utilities become the true trusted energy advisor.

For energy consumers, it's time to start planning for the energy transformation. Very few consumers will follow the path of our test home and implement multiple technologies in less than two years. Instead, the transition will be gradual. An EV will be purchased or leased when it is time to replace an old vehicle. A PV system might go on the house right away, or it might wait until after the roof is replaced. A heat pump water heater could replace an old water heater when the warranty expires in 2 or 3 years.

All these efforts take planning and coordination. For instance, a homeowner might size a PV system and storage for a higher future load—that includes charging an EV, and powering a heat pump water heater—rather than today's load. To facilitate this planning, WattPlan is evolving to model more energy technologies. Just as importantly, long term planning tools are on the roadmap.

Policymakers have an important role to play as well. First, they need to make sure that their utilities are sending the right price signals to customers. Smart meter technology that is becoming increasingly ubiquitous allows for rates and tariffs that reflect underlying costs in ways that were never possible before. This means that low price signals can induce consumers to consume electricity at preferred times.

Policymakers also need to eliminate restrictions that keep electric utilities from encouraging energy efficiency. For example, regulated utilities in some states cannot encourage their customers to switch from gasoline vehicles to electric vehicles or from natural gas to electric heating or water heating. These laws stand in the way of the utility being the trusted energy advisor.

Finally, policymakers should encourage the new paradigm of energy efficiency and transition away from the old paradigm of electricity efficiency.

Everyone has a role to play in the new energy transformation. The Solar+ homes concept can make the energy transformation straightforward for energy consumers. Tools like WattPlan that embody these concepts can help the consumer engage, plan and implement their own personal energy transformation.

# Appendix: Long-term Performance of Solar+ Homes

We've described how to transform an existing home into a Solar+ home by combining off-the-shelf technologies to make a house fully solar powered. The specific technologies are:

- Solar power, with PV located either on the customer's home or as community solar.
- Transportation electrification that shifts from gas-powered vehicles to electric vehicles.
- Simple energy efficiency measures, including phantom (or plug) load reduction and LED lighting conversion.
- Appliance electrification, including conversion of water and space heating from natural gas to electric heat pump technologies.
- Basic building shell improvements, including caulking, targeted insulation and ventilation.

Most aspects of a Solar+ home should not require much attention once the investments have been completed. However, there are two caveats to this:

1) Homeowners should ensure that their PV system is operating correctly.
2) Homeowners should be on guard to catch phantom loads that try to sneak back into the house (e.g., a new cable box with a DVR, chargers, etc.).

Let's take a look at the performance of the prototype house.

Looking through the Rearview Mirror

We've used a prototype house throughout this series to illustrate the feasibility of the Solar+ home concept. Nearly all investments were completed by mid-2014. This article summarizes performance from June 1, 2014 to May 31, 2015.

Figure a1 presents annual electricity consumption and PV production. Annual consumption and PV production were equal. Consumption was divided into thirds, with one-third for the electric vehicle, one-third for space and water heating, and one-third for other electricity consumption. Note that this does not include 30 therms of natural gas for laundry drying, and about 200 gallons for gasoline consumption in the second vehicle. This is equivalent to 900 kWh and 6,700 kWh, respectively.

Figure a2 presents details of other electricity consumption and electric water heating from Figure 11a. It also includes natural gas consumption for the clothes dryer, as this is the only remaining natural gas consumption after switching both space and water heating to electric. What is particularly interesting about the figure is that six groups of end-uses have approximately similar amounts of annual energy consumption:

- Baseload
- Lights & miscellaneous
- Refrigeration
- Cooking and dishwashing
- Laundry
- Water heating

It's expected that switching the electric resistance space heater to a heat pump would also have about the same annual consumption. The savings would be enough to purchase a second EV and make this a 100 percent Solar+ home.

Of particular interest is what not to focus on for this house. For example, high efficiency inductive alternatives exist for stovetop cooking, but the electric resistance cooktop only uses a few hundred kWh per year. It's probably not worth the additional investment for this house.

**Figure a1.** Annual consumption equals PV production in first year (June 1, 2014 to May 31, 2015).

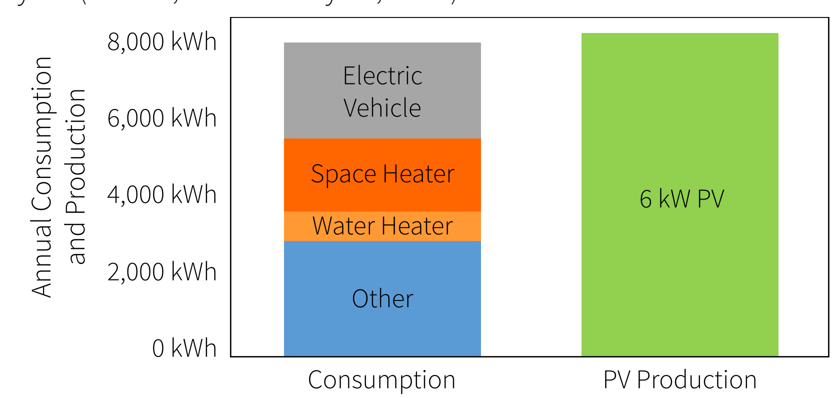
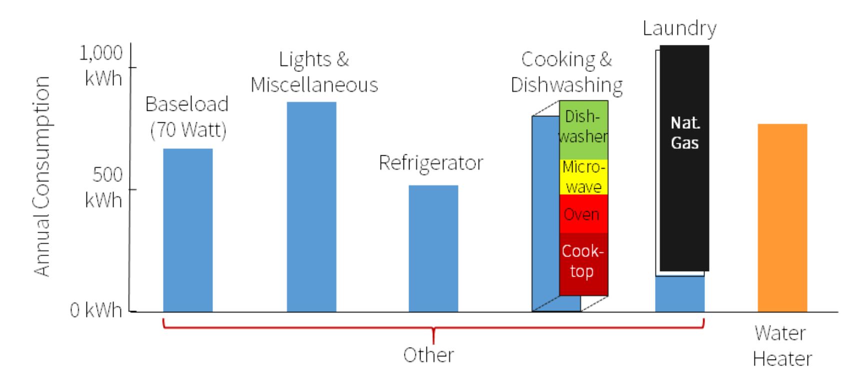





**Figure a2.** Details of Other, Laundry (incl. natural gas for dryer) and Water Heater (electric). Cooking & Dishwashing details are also included.

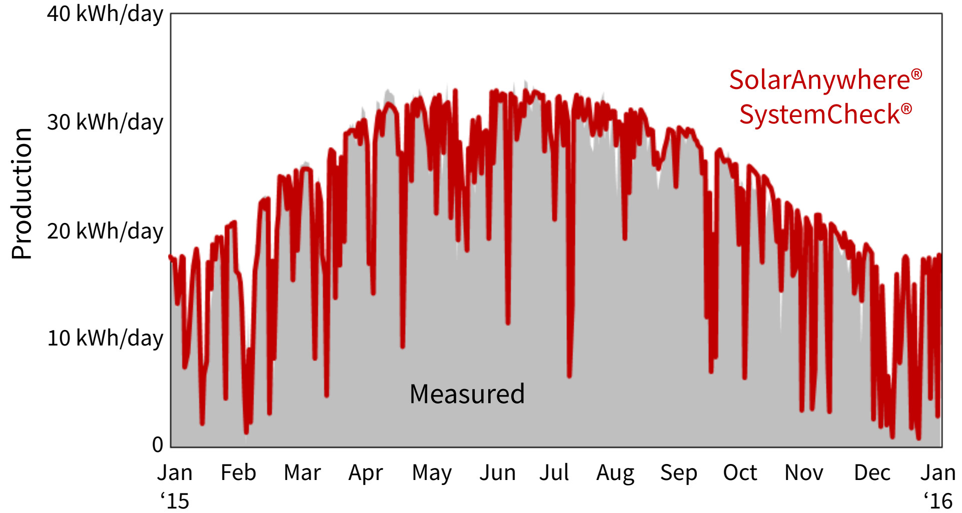


## Verify PV Is Working Correctly

PV is an ideal technology because it's a silent energy producer. One drawback, however, is that most consumers only know that their PV system is working by viewing some sort of monitoring equipment. Even then, they do not know if it's operating at full capacity. This makes it important to regularly verify PV system operation once Solar+ home investments have been made. While PV systems are highly reliable, it's important to keep track of performance.

One way to accomplish this is using SolarAnywhere® SystemCheck®. SystemCheck combines PV system specifications with solar resource data derived from satellite datasets to simulate PV power production. This can then be compared to actual performance to verify correct PV performance (see Figure a3). Many PV manufacturers and third-party ownership companies (e.g., companies that lease PV systems to residential and commercial customers) have built this capability directly into their monitoring systems.

**Figure a3.** Validate that a PV system is operating correctly using SolarAnywhere® SystemCheck®.






## Prevent Growing Phantom Loads

Phantom loads have the tendency to increase over time. People plug devices in the wall and then forget that they are plugged in, or they might upgrade an electronic component or computer in their house that increases standby power consumption. There will be a growing waste of energy if these loads remain undetected. These loads can be monitored using a method developed by Clean Power Research.

Clean Power Research's prototype Solar+ home has performed as expected for two years. To ensure optimal performance over the long-term, consumers should monitor two things after their Solar+ home investments have been completed. First, verify that the PV system continues to perform as expected. Second, keep an eye on phantom loads because they have the tendency to increase over time.

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