Applications for Large Residential Communities: What is Net-zero Energy?

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ABSTRACT

In the building industry, the term zero energy home (ZEH) or building can be interpreted in a variety of ways. And it is not simply a semantic argument; targeting one definition versus another can have significant impacts on building practices, utility demand profiles, and construction programs and policies. Therefore, it is important to review the different definitions of "zero" and the relevant benefits and shortcomings of each. This article will review three primary "ZEH" definitions—zero peak, zero net-electricity, and zero net-energy—and how community-scale implementations of these strategies can improve cost effectiveness while enhancing zero energy and zero peak benefits.

ZERO PEAK, ZERO NET-ELECTRICITY, ZERO NET-ENERGY, COMMUNITY SCALE

The zero peak (ZP) strategy is based on the fact that the worst time to consume electricity is during peak hours. The problem with consumption at peak is three-fold: increased pollution, highest costs, and decreased utility grid stability. First, large peak loads require the construction and use of throttleable generation sources known as "peaker plants"; these plants, which are only turned on to meet peak demand, tend to be less efficient and higher polluting compared to base-load plants. Reducing peak demand would reduce the need for these plants, saving energy and reducing pollution. The impacts of high peak demand on grid stability have been demonstrated by the blackouts and brownouts that have occurred on both coasts during particularly intense summers; if this demand (attributed to air conditioning) had been reduced or spread out to other parts of the day, then the grid capacity would have been sufficient to prevent these power outages. Therefore, the goal of the zero peak strategy is to flatten the load on the grid during peak hours while keeping the overall load low.

The next step beyond peak is to reduce the entire annual net-electricity use (not just the load at peak) to zero. This strategy is called **zero net-electricity** (ZNEl). The important part of this term is "net-electricity." ZNEl homes will continue to consume electricity for the foreseeable future, so the attachment to the grid and electricity demand from ZNEl homes cannot be completely eliminated. However, their electricity needs will be reduced through high efficiency design and construction, coupled with on-site photovoltaics (PVs) that will generate enough electricity to equal the annual electricity use (i.e., zero annual net-electricity use). In other words, via net-metering, the electricity pulled from the grid (when demand exceeds renewable generation) over the course of the year will be offset by at least the same amount of excess renewable generation being provided back to the grid (when generation exceeds demand), and therefore the home will be considered to have consumed zero net-electricity. ZNEl homes may still use natural gas for space heating, water heating, cooking, and/or clothes drying. However, this strategy does not deal with gas, because, at present, electricity generated cannot be exchanged (net-metered) for natural gas.

The apex of the ZEH design strategies is **zero net-energy** (ZNEn). Like the ZNEl strategy, the ZNEn goal is to balance out annual consumption and annual generation. However, this time consumption includes all energy used by the home, both electricity and gas. If the home is all-electric (i.e., it uses only electricity), then ZNEl and ZNEn are equivalent strategies. For dual-fuel homes with gas and electricity, ZNEn is achieved by increasing the energy efficiency and renewable generation capacity beyond that of ZNEl by an amount equivalent to the energy associated with the gas usage. Of course, a dual-fuel home design can also be converted to all-electric, in which case the PV array would need to be sized to meet the increased electric usage.

The implementation of ZEH strategies can also be categorized into two larger strategies: **individual homes** and **community-scale**. Meeting your "zero" goal on a home-by-home basis (e.g., for ZNEl, each home must generate as much electricity as it consumes) is a fairly straightforward concept, but it can be difficult and costly to achieve. For example, the efficiency design/features and the renewable system(s) will have to be designed, sized, and priced for each unique home design.

Therefore, expanding the scale of the strategy to the entire community as a whole (e.g. for ZNEl, the entire community must generate as much electricity as it consumes) can open additional opportunities that reduce costs and increase efficiencies through the economy of scale, particularly for renewable generation. For instance, instead of placing large, custom-sized PV systems on each home to produce a community of ZNEn homes, the community can instead be ZNEn using consistently-sized, smaller, home-mounted PV systems that will fit on any and all roofs, and large-scale PV systems designed to balance the remaining electricity demand of the community. These large-scale PV systems can be installed anywhere within the community: on the roofs of local schools and commercial buildings, in parking lots, and/or ground-mounted on remote areas of the property. Additionally, there may be new opportunities to employ other types of renewable generation, depending on the local resources of the community, for instance: nearby wind farms, methane-capture at adjacent farms, low-head hydroelectric power, geothermal generation, and gas or energy from agricultural processes (dairies, canneries, food processing facilities), and waste sites.

The path toward a sustainable energy infrastructure through zero energy homes will likely experience each of the three main zero energy strategies, and the logical progression is to start with zero peak and eventually get to zero net-energy. Similarly, the focus will generally start on individual homes, but as the industry matures, the concepts will most likely begin to be applied on a community scale.

CURRENT STATE OF THE PRACTICE

Premier Gardens

Premier Gardens was the Sacramento area's first "near zero energy home" community, defined as a community of homes with homes designed to cut energy bills by at least 50 percent compared to a home just built to code (see photo). While the Premier Gardens development started later than a comparable but non-ZEH neighboring development, it actually sold before this development. This is a significant indication of a strong market desire for this type of product. This project was a

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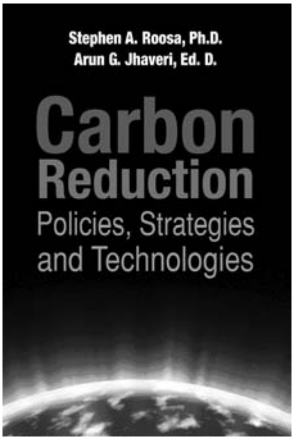

Stephen A. Roosa, Ph.D. and Arun G. Jhaveri, Ed.D.

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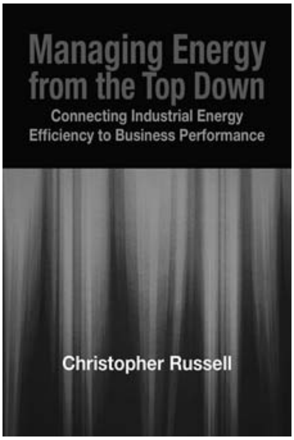

Christopher Russell

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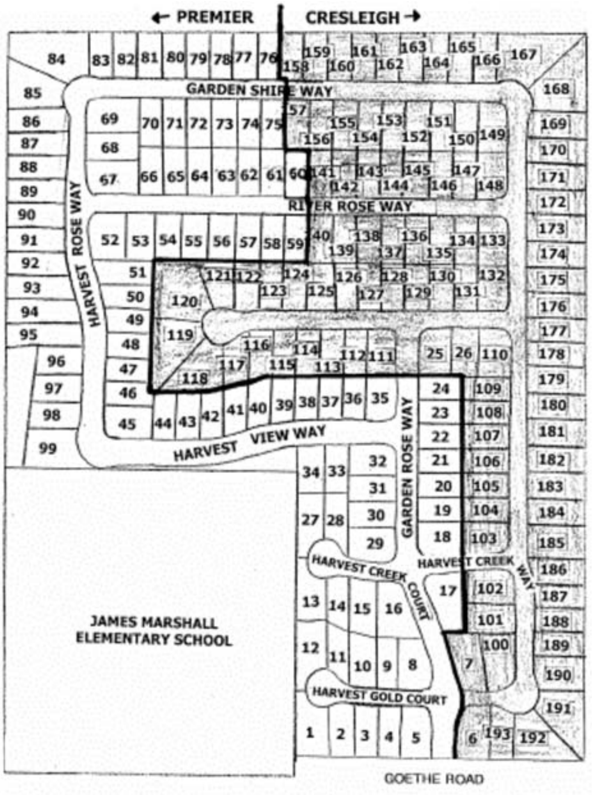
partnership between the Sacramento Municipal Utility District (SMUD), ConSol, the U.S. Department of Energy ("DOE") Building America Program, and Premier Homes.

Premier Homes built the 95 entry-level and first move-up homes in Rancho Cordova, near Sacramento, in 2004. In the same in-fill community, during the same period, 98 similarly sized homes were built by another builder, competing for the same market segments (see community site-map). The homes are nearly identical in size and price, but the Premier Homes are "near zero energy homes," with more energy-saving features and a 2.4-kW DC photovoltaic system on every roof. When Premier Gardens homeowners started moving into their homes in fall 2004, the Premier Homes September electric bills averaged $20, while their neighbors were paying around $70.

The neighboring houses provided an opportunity to monitor and analyze the energy use of the two sets of homes. While the initial interest was marketability of near-ZEH homes, SMUD's focus quickly changed to examining the opportunity to decrease peak-energy demand, specifically the demand caused by air conditioning. While the non-ZEH development was designed to surpass California's strict energy code by reducing cooling energy use by 30 percent, the Premier Gardens near-ZEH homes saved an additional 44 percent over the non-ZEH homes. More importantly, the average demand reduction for the Premier homes during the peak month of July 2005 was 55 percent, despite a quarter of the PV arrays facing east (see Figure 1). This peak reduction is attributable to both the energy efficiency features (including low SHGC windows and high SEER & EER air conditioners) and the PV generation, even though it peaks much earlier in the day (see Figure 1).



Community Site Map—Premier Gardens

In addition, an analysis was done on the impact of different PV orientations. PV systems were roof integrated, and the PV roof orientation for Premier Gardens was 57 percent south, 18 percent west, 24 percent east, and 1 percent southwest. The difference in annual energy production for different orientations was not more than 5 percent (decrease from latitude tilt—south). With the late afternoon peak, the west orientation provided an additional 42 percent demand reduction, for a resulting overall average peak reduction of nearly 80 percent (or 1.3 kW). To assess the impact of the east-facing arrays on peak reduction, the PV-generation data were subtracted from each home data set, leaving the gross electricity usage; then the generation from a representative west-facing array was added back into the gross electricity usage to obtain the net-electricity usage. The results, in Figure 2, show that the peak was reduced another 12 percentage points to a 67 percent

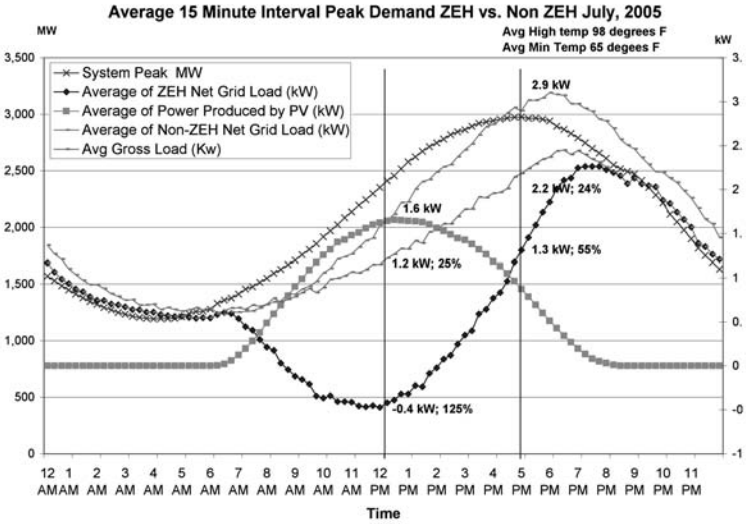


Figure 1. Peak Demand for Premier Gardens vs. Non-ZEH

reduction compared to the control group. Note that the control group had energy efficiency features designed to reduce cooling energy by 30 percent, so the peak reduction compared to a home just built to code is likely much greater than the measured 67 percent.

Treasure Homes—Fallen Leaf at Riverbend

Fallen Leaf at Riverbend, by Roseville-based Treasure Homes, was designed to save homeowners approximately 60 percent on their utility costs. While this was a small step up from Premier Gardens, it included a strategy that employed the most available, practical, cost effective energy efficiency features. The community of 32 homes was constructed to further our understanding of the technical and market challenges that a builder faces when attempting to build super-efficient homes, with PVs, on the path to true zero energy homes. This project was a partnership of SMUD, ConSol, the DOE Building America Program, and Treasure Homes.

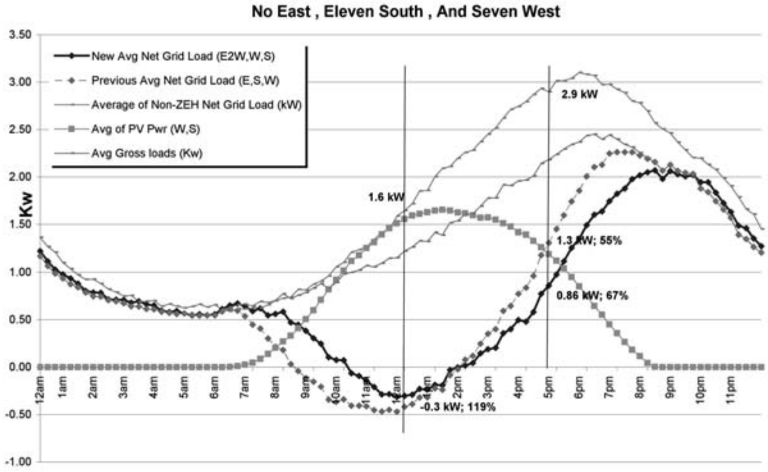


Figure 2. Impact of Premier Gardens Orientation on Peak Demand

Fallen Leaf at Riverbend includes 32 homes, with four floor plans, ranging in size from 1,026 to 2,271 square feet of living space.

This community achieves a near zero energy level of performance, with solar power and many other energy-saving components included as standard features. Every home includes a mechanically designed heating and air conditioning system, spectrally selective glass windows, fluorescent lighting, and tightly sealed air ducts. The 2.4 kW DC photovoltaic integrated roofing system, coupled with other energy efficient features, will produce almost as much electricity as it needs to offset the electricity use in the house on an annual basis. The homes are connected to the local grid so homeowners can draw electricity when they need it, and any excess energy produced by the zero net-electricity (ZNEl) home is fed back to the utility for credit and distribution to other customers.

As with Premier Gardens, SMUD monitored power consumption from these homes. As expected, the Treasure homes produced a peak savings similar to that found in the Premier homes. The Treasure homes had higher energy efficiency air conditioning features, which resulted in improved peak reduction in the Treasure homes compared to Premier homes (see Figure 3). Premier data are shown by the diamond line, Treasure by the X line. The control, triangle line, is the same 98 home control group built with Premier. This finding confirmed the findings at Premier Gardens that highly energy efficient homes with PVs provide significant peak reduction resulting from both the energy efficiency and PV features, and it showed that increased efficiency in the air conditioning equipment will provide additional reduction in the afternoon electricity peak.

These two projects, Premier Gardens and Treasure Fallen Leaf, provide examples of homes designed to have nearly net-zero electric use (ZNEl), as well as the impact of such homes on peak loads.

As previously mentioned, the Treasure homes at *Fallen Leaf* were designed to produce a 60 percent reduction in energy cost to the consumer. Figure 4 shows the reduction in each end use based on computer simulations.

Pinnacle Homes—The Vinings

In 2005, Pinnacle Homes built two directly adjacent model homes in Las Vegas, Nevada. Side-by-side, they appear similar but are actually very different. One was built using conventional methods to exceed the local energy code by 15 percent; the other incorporated a range of innovative energy efficiency technologies plus a large roof-mounted PV array, with a goal of net-zero annual energy use. The prototype home was designed to save 92 percent on utility costs compared to a house built to just meet code. This project was a joint effort by the Univer-

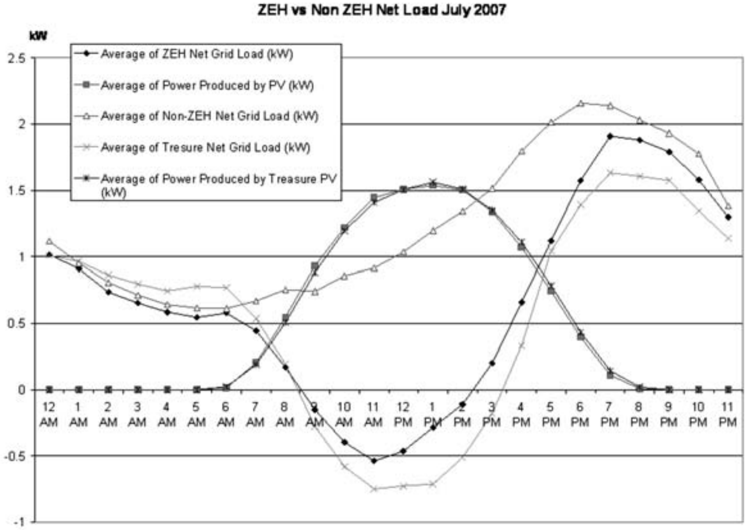


Figure 3. Fallen Leaf at Riverbend Impact on Peak

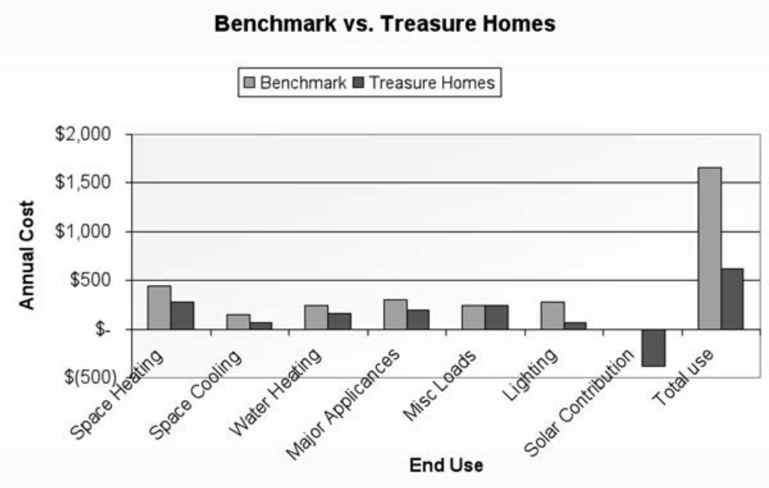


Figure 4. Benchmark vs. Fallen Leaf Annual Cost by End-use

sity of Nevada Las Vegas (UNLV), ConSol, Building America, Nevada Power, and Pinnacle Homes. It provides a basis for the technology and cost issues associated with net-zero energy homes (ZNEn).

The Pinnacle ZNEn home (pictured in Figure 5) was designed to minimize energy consumption and generate electricity through the use of the following features/design elements:

- "T-Mass" insulated concrete exterior wall system
- Hydronic space heating system
- Solar water pre-heating system for space and water heating
- Tankless water heater for hot water backup
- Roof-mounted, building-integrated photovoltaic panels rated at 5.28kW DC
- Water-cooled air conditioning condensing unit rated at 19 SEER
- Ducts in conditioned space
- Vinyl framed windows with low SHGC glass
- Radiant barrier roof deck
- ENERGY STAR® rated light fixtures and fluorescent lamps

The performance of the Pinnacle ZNEn, compared to a code home in terms of energy bills, is displayed in Figure 6.

Figure 5. Pinnacle Homes—The Vinings

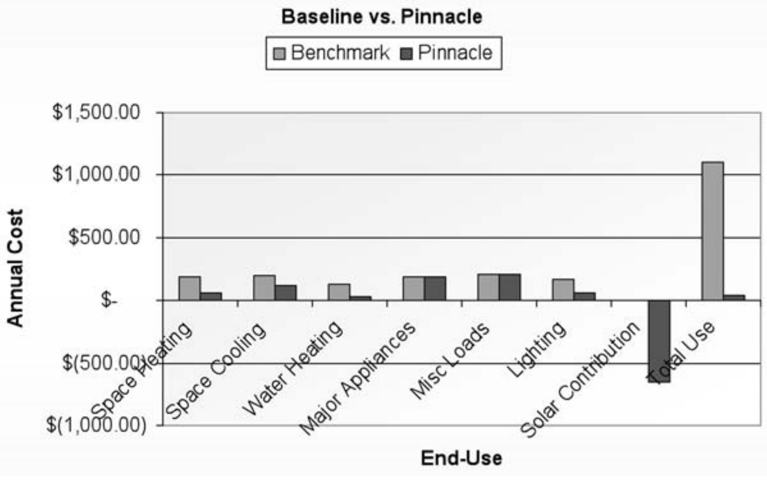


Figure 6. Baseline (code) vs. Pinnacle The Vinings Annual Cost by End-Use

Summary: State-of-the-practice

These project summaries are useful to compare costs, marketability, and energy and demand impacts of the different approaches. While both Premier and Treasure employed features to reduce both electric and gas use, the focus was on electricity use and peak demand. The

PV system size was designed to fit on all roofs and generate as much electricity as was predicted to be used by the occupants. Thus, Premier and Treasure are examples of zero-net electricity homes (ZNEl), and they provide some information regarding zero peak communities, which are discussed in a later section.

The Pinnacle home is an example of a zero-net energy strategy (ZNEn) where, on an annual basis, the total net-energy use is zero. For Pinnacle, net-energy use was estimated to be a just a small percentage of typical usage, rather than actually net-zero. This was achieved by more/higher energy efficiency features and over twice as much PV.

As is shown in Table 1, the energy use predicted for Pinnacle is 33 percentage points lower than for Treasure, at a cost increment of 240 percent. A complicating factor for this comparison is that these homes were built in different locations and climates (Treasure in Sacramento, CA; Pinnacle in Las Vegas, NV). Both climates have similar heating requirements, but Las Vegas requires approximately twice the cooling. Nonetheless, in comparing predicted energy bill savings, the Treasure home saves the occupants just under $1,000 annually, and the Pinnacle ZNEn saves the occupants just over $1,500 annually when compared to a code home, using the same utility costs for each ($0.11/kWh and $1/therm). Therefore, under these conditions, Treasure's ZNEl strategy appeared more cost effective than Pinnacle's ZNEn strategy. As technology and strategies improve over time, so will the cost effectiveness of ZNEn strategies.

Table 1. Comparison of Costs vs. Energy Savings

Treasure Homes (ZNEl)	*Pinnacle (ZNEn)*	
Simulated Energy Savings Compared to Baseline	61%	94%
PV System Size (DC)	2.4 kW	5.3 kW
PV System Cost	$ 16,397	$ 35,908
Total Incremental Cost	$ 22,006	$ 53,856

HOW DO WE GET TO ZERO? STRATEGIES

Zero Peak

Definition and Interpretations: Zero Peak

As described in the introduction, the zero peak (ZP) strategy is to eliminate the large increase in load during peak hours. So what we are really trying to do with this strategy is to reduce the summer electricity peak to near baseline electricity use. Two questions immediately arise from this strategy, however: Which energy loads are the major contributors to the peaking? and What are "peak hours?" For the first question, in this analysis, the strategy focuses on the electricity peak, specifically the summer electricity peak due to air conditioning, particularly residential A/C. As for peak hours, they depend on location and the markets being served, but the summer electricity peak in the southwest typically occurs between 4PM and 7PM. The duration of the critical peak period, when electricity supply can become critical, can range from one to four hours. Based on these factors, it would be desirable for a zero peak home to dramatically reduce or eliminate afternoon air conditioning from about 4PM to 7PM such that summer afternoon electricity demand from the home is approximately the same as it is in the mid to late morning hours. Construction and control strategies to achieve this are discussed later in this section.

Benefits and Shortcomings: Zero Peak

Peak demand presents unique problems as compared to general electricity demand. Servicing peak demand requires the use of peaker plants that provide additional electricity capacity when the baseline power plants cannot meet the system needs. These peaker plants are generally only run hours at a time, sometimes as little as a few hours per year. Therefore, it is not economically reasonable for these plants to be as efficient as the plants that serve the base load. Because they are intermittent and less efficient (and also higher polluting), the electricity generated by peaker plants during peak hours is "dirtier" and more costly. The zero peak strategy is therefore targeting, in some ways, the worst of the worst.

Peak demand, especially that driven by air conditioning during summer heat storms, can lead to demand nearing or exceeding total grid capacity in some locations. Overloading the grid can result in large-scale power outages. A system operator strategy to reduce the risk of blackouts is to selectively turn off the power for parts of the grid, sometimes moving from one location to the next (called "rolling blackouts"). Another option is to drop the voltage supplied to parts of the grid, causing lights to dim (hence the name "brownouts") and some appliances to turn off in those areas. These, however, are simply treating the symptoms. To treat the cause, the generation and transmission infrastructure needs to be expanded (including the construction of additional peaker plants) or peak demand needs to be reduced. Masses of zero peak homes could be a very cost effective solution to this growing problem.

One of the main problems with the zero peak strategy is that, in addition to requiring a properly designed and built home/building, it requires building occupants to use air conditioning control strategies that will result in flat load profiles. For instance, this strategy may utilize relatively complex peak-shifting techniques, including pre-cooling of thermal mass so that the cooled mass can absorb heat later in the day, reducing or eliminating the need for peak-hour air conditioning. In addition to thermal mass, this strategy requires both a more complicated thermostat and proper programming of thermostat controls. This requires homeowner education and some considerable motivation for the consumer to go to this effort.

Consumer willingness to employ the necessary control strategies depends heavily on a financial motivation, typically an electricity tariff that strongly discourages heavy electricity use during peak and/or critical peak periods. These are often called time-of-use (TOU) rates.

Current Home Strategies: Zero Peak

There are three main methods that can be used to eliminate peak demand: energy efficiency, peak-demand shifting, and renewable generation. General energy efficiency (for example, installing an energy efficient refrigerator that runs all day) will reduce loads not just on peak but also off peak. The more direct approach with energy efficiency is to incorporate efficiency measures that focus on features having a more direct impact on peak; typically these will be measures that reduce cooling loads and increase cooling efficiency, including improved envelope insulation and sealing, higher efficiency A/C equipment, and properly installed and sealed ducts. Also, passive design elements like building orientation, location and amount of glazing, and use of overhangs and shading elements can provide considerable peak savings.

These first methods can help to reduce peak, but they cannot eliminate it. One option to eliminate peak cooling is to shift the load off-peak and spread it over a longer period. This is generally done by pre-cooling thermal mass in the house prior to peak hours and then "coasting" through the peak. Through peak hours, the house will continue to accumulate heat, but this will be absorbed by the cool thermal mass instead of heating up the indoor air; this is similar to radiant floor heating, except in this case the mass in the floor (or elsewhere) is maintaining home temperature within an acceptable range by absorbing the unwanted heat accumulating in the house. With sufficient thermal mass, home comfort can be maintained while requiring zero additional AC load during peak hours. Figure 7 shows temperatures and air conditioning electricity draw in a ZP house with high-mass walls and floor in the Borrego Desert of southern California. On a hot summer day the home was pre-cooled to 72°F, and at noon the thermostat was raised to 80°F. Over the next 12 hours, the air conditioner did not run and the temperature went up only 3°F. This home demonstrated that ZP homes are buildable and can produce a relatively flat load profile*. If less mass is available, the peak demand can still be reduced through this method, though it would require the HVAC system to cycle (but run less than a typical home during peak hours) to sustain an acceptable indoor air temperature.

The critical design issues for zero peak homes are proper combinations of overall energy efficiency features and substantial thermal mass (probably distributed throughout the home in order to provide sufficient comfort), coupled with appropriate thermostat controls that will allow pre-cooling and peak-coasting and are simple enough to be used and maintained by the homeowner.

The final method to reduce peak—renewable generation—can be used to eliminate any remaining load not taken care of by the other methods. This typically comes in the form of roof-mounted photovoltaic (PV) solar panels. While expensive compared to most efficiency features, it can be a key component to completely eliminating peak load. An issue with this approach is that roof-mounted PV will typically provide maximum output earlier in the day than the peak electricity demand.

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*Reports on the Borrego Springs ZEH homes are available on both the ConSol.ws and BIRA.ws websites. This project was supported by DOE Building America and the builder was Clarum Homes.

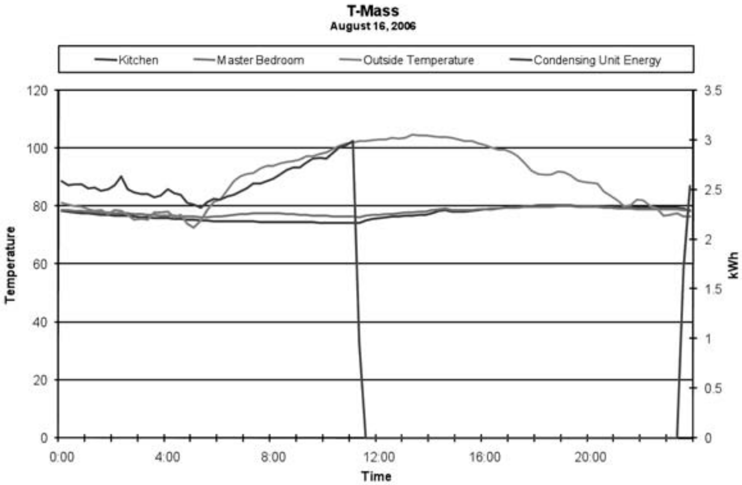

Figure 7. Zero afternoon air conditioning on a summer day in the desert ("coasting")

Also, PV systems will provide maximum output at somewhat different times of the day, depending upon the orientation of the panels. East-facing panels, for example, will produce nearly as much annual electricity as south-facing panels, but they will not significantly contribute during peak hours; alternatively, west-facing panels will provide a little less annual generation than south-facing, but they will out perform a south-facing system during the peak periods. See Figure 8.

Thus, for a home with a peak-reduction tariff, west-facing PV panels may provide the best economic benefit, depending upon the tariff. Regardless of orientation, the peak output of a roof-mounted PV system will likely peak prior to the electric utility peak, so use of any excess electricity generated to perform pre-cooling of the thermal mass is important to obtaining a flat load profile.

Gaps and Needed Research: Zero Peak

The following is a short list of construction issues and changes needed to go from current practices (code homes) to ZP homes and ZP communities:

- Improved envelopes
- Thermal mass and controls for pre-cooling the mass and possibly night cooling

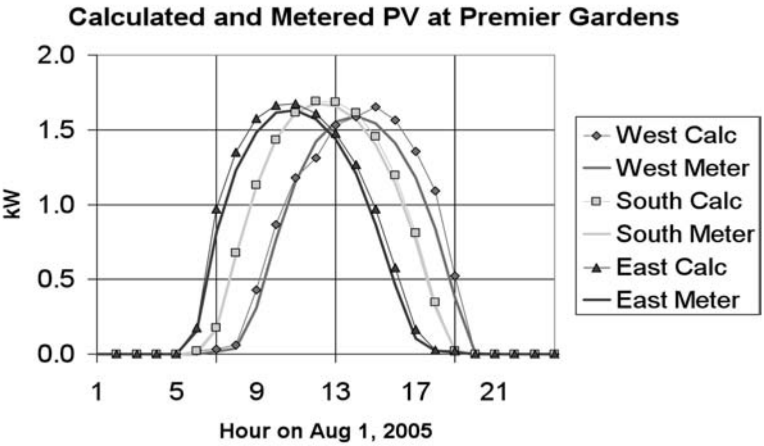

Figure 8: Effect of orientation on PV generation on a summer peak day. ***Courtesy California Energy Commission, New Solar Homes Partnership.***

- Alternative cooling systems that would reduce (peak) electricity demands
- More efficient lighting and lighting controls
- Reduced MELs (miscellaneous electric loads)
- Improved PV integration
- Electricity tariffs that reward peak reduction and/or flat load profiles
- Net-metering rules that allow excess generation to be credited and/or shared within the ZP community

The ZP target depends heavily on measures impacting the performance of and load on the A/C system. This means improvement to the envelope (walls, windows, roof systems, infiltration, etc.), along with the A/C equipment itself, including improvements to duct sealing and insulation (such as can be provided by ducts in conditioned space) or the use of ductless systems. Window performance continues to improve, and a number of advanced wall systems, some of which provide very tight homes, are making it into the production market. These include structurally insulated panels (SIPs), optimally valued engineering (OVE*), and insulated concrete forms (ICFs). Radiant barriers are already common in many markets, but other improvements to

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*Also called "resource-efficient framing."

the roof deck (including "cool roof" products, continuous deck insulation, counter roof battens, and indirectly conditioned attics) are gaining traction in some areas. HVAC equipment continues to become more efficient, and high-efficiency alternatives (such as ductless mini-split systems, ground-source heat pumps, and ducts in conditioned space) are finding their way into more homes each year.

Another important factor for the ZP target is the mechanism of shifting the peak load. Beyond the efficiency measures listed above, which will help improve the effectiveness of the shift, there are two main factors that affect the ability of a home to shift load: thermal mass and automation/controls (e.g. thermostats). Without significant mass, after pre-cooling the home and turning off the A/C, the home will quickly begin to warm up again and require active cooling to maintain comfort. Thermal mass, in effect, acts as a "cooling battery." You charge it up (cool the mass) with your air conditioning system and then let the thermal mass take over for passive peak cooling (allow the mass to absorb heat). An added benefit of this approach is that the air conditioner is going to be working to cool the mass at night or in the morning hours, when the outdoor temperatures are lower than during the peak hours when air conditioners typically run. This adds efficiency to the equation, because the outdoor compressor is more efficient at the cooler outdoor temperatures as compared to running during the hot, peak summer hours. The mass also needs to be properly insulated from the outdoors (so that its "charge" doesn't dissipate too quickly) and sufficiently distributed throughout the house (so that the home is kept evenly cool)*. New slab foundation insulation systems continue to make this issue less of a problem for slab mass.

While everything in the home will to some extent act as thermal mass, the best forms have high heat capacities and high densities. These include (uncovered) concrete slab or slab with tile floors, high-mass walls (such as concrete, brick, or adobe walls; concrete SIPs (CSIPs) and ICFs), and even items like stone countertops. Another advanced "cooling storage" technology is phase change materials (PCMs); during the pre-cooling phase they will solidify, and during the coasting phase at peak they will absorb heat and melt. Whatever the type of mass, if this storage is concentrated in one location, such as the kitchen, keep-

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*An alternative is a large mass with a ventilation system that brings the heat from all areas of the home to the mass; this is more energy intensive and likely more expensive.

ing the bedrooms comfortable would require a complicated ventilation system; so design, building integration, and installation need to be well planned and executed. Finally, thermal mass is only useful if you use it properly. Like a cell phone, if you don't fully charge it daily, it may do you little good when you need it. Therefore, it is critical to have proper thermostat controls that can be easily maintained by the occupants. During pre-cooling, "undercharging" the thermal mass can be as wasteful as "overcharging" it. In addition, the time it will take to fully charge the thermal mass may change, depending on a variety of conditions. Therefore, these controls will optimally both have access to weather forecast information and "learn" over time the conditions preferred by the occupants and how to optimize charging and coasting.

There are also some "all-in-one" air conditioning systems that shift peak without the use of building-integrated thermal mass. Instead, they cool or freeze water during off-peak hours and then use that to cool the house during peak. Early demonstrations of these systems, however, have not proven to be nearly as cost effective as building-integrated thermal mass (i.e., mass walls, floors, etc.).

Miscellaneous electric loads (MELs)—also known as plug loads—can also contribute a significant amount to peak demand. Just as when we come home from work we turn on the air conditioning, so will we turn on lights, televisions, and other plug-in devices. As regulations for the other major loads in the home (space cooling, space heating, and water heating) continue to tighten, energy use by the increasing variety of relatively under-regulated MELs are on the rise. In a super-efficient home fitting any of the categories in this article, MELs will account for approximately half of the total energy use in the home. This issue needs to be addressed in two ways: regulating the electronics installed in the home such that they are more energy efficient, and providing convenient control systems to make sure they are turned off when not in use. To address the latter point, more and more automation and control devices are coming to the market. They come in a variety of shapes and sizes, anything from power strips and timers to integrated home automation systems. As the other major loads in the home get smaller and smaller, research into MELs reduction will grow evermore important.

Finally, to make a significant impact on peak will require a large number of homes to be built as ZP homes. For this to occur, utility tariffs are needed that both reflect the value to the utility of a flattened load profile and provide motivation to buyers who want to own them, which will in turn encourage builders to build them. Research needs to be done to determine the structure of such ZP utility tariffs.

Summary: Zero Peak

Zero peak homes are likely the most financially attractive major step toward zero net-energy homes. This is because there should be financial benefits to utilities for having ZP homes with flattened load profiles on their system, in contrast to either code homes or zero net-energy homes that are not designed to maximize load flattening. In addition, ZP homes have substantially lower additional construction costs than ZNEl or ZNEn homes, because they can have substantially smaller PV systems (or none at all!), the single most expensive feature on any of the variety of ZEHs.

Unfortunately, this strategy can be the most complex to understand and the most difficult to properly design. In addition, it requires cooperation from the home's occupants to properly use and control the thermal mass and air conditioning systems.

Well planned ZP communities would be more reliable and possibly more cost effective than accumulations of ZP homes. In ZP communities, assuming friendly net-metering rules and corresponding tariffs, PV arrays on big-box rooftops can be oversized to provide excess generation. This excess can be managed by a smart grid system for distribution to buildings doing pre-cooling and possibly stored in electric vehicles for use if/when needed to offset unexpected peaks. Such peaks can also be mitigated by demand-response technologies in the homes managed by the smart grid.

Zero Net-electricity

Definition and Interpretation: Zero Net-electricity

The zero net-electricity (ZNEl) strategy is a lot more self-explanatory than the zero peak strategy. It's exactly how it sounds: produce at least as much electricity as is consumed. This does, however, bring up the question of timescale. Is the "net" calculated daily? Monthly? Annually? Over the life of the home? The most common definition uses the annual definition: over the course of each year, produce at least as much electricity as is consumed. ZNEl homes are generally still connected with the electricity grid, which acts as a battery. Absent local electric storage of some type, this excess generation is actually used by others on the grid in real time, but net-metering allows the home owner/rate payer to receive credit for excess electricity that is put back in the grid (which is counted against electricity use during some other time period).

The time of day at which excess generation or excess use occurs can be economically important. For instance, under a TOU electricity rate structure, it would be most beneficial to the homeowner to be a net-generator on peak, when the electricity rate is high (and be credited at this high rate), and a net consumer off peak, when the electricity rate is low. In other words, this ZNEl strategy incorporating a TOU tariff may also encourage utilization of the methods used in the ZP strategy. Thus, as previously stated, the zero peak strategy can be a stepping stone to zero net-electricity and zero net-energy homes.

Benefits and Shortcomings: Zero Net-electricity

For the electricity grid, the ZNEl homes would have no impact *on an annual scale*. When designing ZNEl homes, it may be important to simulate the load profile of the homes at peak. Because the peaks for PV generation and air conditioning are out of phase (without employing peak-shifting techniques, per the ZP strategy), it is actually possible to make the utility load profile *worse* than that from a code home. See Figure 3. Compare peak-to-trough height for Premier and Treasure versus Control; the disparity between minimum load and maximum load for the ZNEl homes is greater than for the control homes, even though the ZNEl homes' peaks are lower. In volume, this would be a problem for utilities and could strongly discourage ZNEl homes as a result. With this in mind, ZNEl homes could also be designed to be zero or net-generators on peak, when generation is most needed, thus becoming both ZP *and* ZNEl homes. Therefore, on a day-to-day scale, ZP-designed ZNEl homes could help "flatten" the load profile on the electricity grid.

While the ZNEl strategy focuses on electricity usage, many of the measures and techniques that are implemented will also improve gas efficiency. For example, low U-value walls and high-efficiency ductwork will benefit both space cooling and space heating. On the other hand, certain electricity efficiency measures will have a negative effect on gas efficiency. Both cool roof products and low solar heat gain coefficient (SHGC) windows can significantly reduce cooling loads for the home during the summer, but both will increase the heating loads during the winter. Another interesting example of this is that compact fluorescent lights (CFLs) can actually increase the annual space heating for a home. Part of the inefficiency of incandescent lights is that the majority of their energy use is radiating heat; CFLs, on the other hand, do not provide significant amounts of radiant heat. So while switching to CFLs saves electricity (especially during the summer, where incandescents would require additional space cooling), their lack of radiant heat will slightly increase winter heating costs.

Current Home Strategies: Zero Net-electricity

ZNEl homes will generally utilize three of the four load reduction methods from the ZP strategy, namely general energy efficiency, peak efficiency, and solar PV. Peak shifting may be used in ZNEl homes, but that would be for utility bill savings purposes, not annual electricity use reduction. Peak shifting may actually result in slightly higher net-electricity use, due to efficiency losses related to charging and discharging the mass so that comfort is maintained; however, most if not all of those losses can be mitigated by charging the mass during the coolest hours when the air conditioner will run at its highest efficiency. Because lowering peak demand is not the focus, most current ZNEl homes have lower peak demands than code homes but larger than ZP homes.

One of the main questions in designing ZNEl homes is: At what point should one shift from upgrading efficiency measures to installing solar PV? As the individual electricity loads in a home are decreased through efficiency measures, it becomes harder (and more costly) to reduce those loads further. At some point in this iterative process, a tipping point will be reached where it is more cost effective to reduce grid-supplied electricity loads through solar electricity generation. An additional consideration is the amount of available, un-shaded roof space in a desirable orientation.

Gaps and Needed Research: Zero Net-electricity

The technology advances and research needed to achieve a cost effective ZNEl community rather than a community of ZNEl homes are similar to those for the community ZP strategy. The most challenging is tariff related:

- Improved envelopes
- Alternative cooling systems that have reduced electricity demands
- More efficient lighting and lighting controls

- Reduced MELs (miscellaneous electric loads)
- Improved PV integration
- Electricity tariffs that reward zero-net electricity—possibly as a result of peak reduction and/or grid stabilization
- Net-metering rules that allow excess generation to be credited and/or shared within the ZNEl community

Summary: Zero Net-electricity

The ZNEl strategy can either be achieved by skipping over the ZP target or by standing on its shoulders. The differences between a ZNEl house and a ZP house are that the ZNEl house will likely be more efficient with more PV, and it will likely not incorporate any significant thermal mass. One advantage of ZNEl designs over ZP designs is that there is no need to use complicated load-shifting schemes and the accompanying control systems; however, ZP homes that emphasize peak reduction may find greater popularity, especially to utilities, because they provide benefits to the power grid and they are *not* net-zero energy. However, ZNEl homes will provide very low utility costs compared to typical homes, regardless of current electricity rate structures, though tiered or TOU tariffs could offer the greatest benefit; therefore, ZNEl homes may be more appealing to home buyers.

The last question left unanswered by ZNEl is what to do about the gas use. ZNEl homes will typically have smaller gas use than their non-ZNEl counterparts, but there may be little to no conscious design effort to address gas consumption.

Zero Net-energy

Definition and Interpretations: Zero Net-energy

Zero net-energy (ZNEn) homes are sought after as the true "zero" milestone. The Department of Energy's Building America Program has set its goal as practical, marketable ZNEn homes by 2020. The California Energy Commission and California Public Utilities Commission jointly agree that their strategic goal is that all new homes in California should be ZNEn by 2020. Similar to the ZNEl strategy, this requires annual energy production to meet or exceed annual energy consumption—but for all energy used by the home, not just electricity. Theoretically, this can be done by achieving both zero annual net-electricity use and zero annual net-natural gas use. Because natural gas generation is not readily available for homes, however, the ZNEn criterion is simply zero net-energy use. The tricky point can be converting the different energy sources (i.e., gas and electric) to a common unit to determine net-energy use. Typically, this is done by converting both to a common energy unit, namely BTUs. However, there are disagreements as to conversion factors, including whether and how much to account for generation and transmission losses. Given an industry solution to this problem, excess PV generation could go to offset gas consumption.

The other option to achieve ZNEn is to convert any gas loads to electric loads—in other words, all-electric homes where any and all gas appliances (for space heating, water heating, cooking and clothes drying) are replaced by efficient electric counterparts. This method will also be useful for those locations where no gas hook-up is available. However, this ZNEn method will likely be less cost effective than methods using gas appliances.

Benefits and Shortcomings: Zero Net-energy

This strategy provides significant utility bill savings to the homeowner while providing net-electricity generation to the grid in areas that use gas. As with ZNEl homes, ZP strategies can be employed with ZNEn homes, providing value to the electric utility. (See *Benefits and Shortcomings* in previous ZP and ZNEl sections.) The three major problems with the ZNEn goal are:

1. Currently, to achieve ZNEn requires a substantial amount of PVs, making this goal the most costly of the three strategies discussed herein. (For comparisons, see Table 1.) In addition, some homes will not have sufficient roof area to accommodate the amount of PVs necessary to reach zero annual net-energy.

2. In many markets, consumers prefer gas for heating, water heating, cooking, and clothes drying. If the ZNEn design incorporates gas, then it will require a PV system that generates more electricity (but not more energy) than it consumes. Most net-metering policies do not pay the consumer for excess generation, so new tariffs, and likely new utility business models, would be required to make this economically feasible to both the utilities and the consumers.

3. Currently, there is no method for utilities to recover costs to serve electricity to homes that net-meter at the retail rate and which,

on an annual basis, produce as much electricity as they consume. Exacerbating this problem is that ZNEn homes that are not also ZP homes will likely have worse load profiles than code homes. Therefore, it is likely that, without a dramatically different tariff than is currently available, utilities may refuse to hook up to or otherwise discourage building ZNEn homes.

Current Home Strategies: Zero Net-energy

This strategy will copy the strategy from ZNEl and then increase PV generation while adding more efficiency measures, especially on the gas side, which is ignored in ZNEl. If there is a significant winter heating load, measures like cool roofs and low SHGC windows might be best avoided; in fact, passive solar heating could be a critical component of ZNEn. Additionally, improvements to the hot water system will be added, such as tankless water heaters, heat pump water heaters, and ground-source heat-pump and solar hot water systems. The space heating system will be a high-efficiency furnace or heat pump, or hydronic with solar. Gas appliances (e.g., stove, oven, and clothes drier) will also need to be taken into account.

Gaps and Needed Research: Zero Net-energy

The ZNEn goal requires highly-efficient homes and large PV arrays. This will be "pushing the envelope" well beyond the previous two strategies. Therefore, it will be the most difficult to cost effectively achieve for the production market and will require additional research into advanced efficiency technologies and techniques. As the numbers of these homes increase, new technologies will be proven and additional gaps and opportunities realized and solved. In addition, costs will decrease, both of the high-efficiency features and the PVs.

Substantial work with utilities and tariffs is also required. Currently, electric and gas bills are based primarily on usage; if the net usage is zero, then the utility is going to be reluctant to hook up a lot of these homes. As previously discussed, peak reduction and load flattening (but not necessarily elimination) may provide opportunities for new business models and tariffs that support these super-efficient homes with solar, especially given that they will be vastly outnumbered on the larger grid by existing homes that not only use gas and electricity but also produce peak-usage periods that make utility service more challenging and costly than it would if the load profile were flat. With research and experience, builders will find innovative ways to reduce costs, and utilities will find value from having ZP, ZNEl, and/or ZNEn homes and communities within their service territory.

Summary: Zero Net-energy

True zero net-energy homes currently require virtually all readily available energy efficiency features plus a large PV array. To move builders and consumers in this direction, it will be helpful to take the steps ZP, then ZNEl to finally get to ZNEn. Taking this route will likely result in more attention to the resulting electricity load profile, which will probably make it more attractive to utilities. Substantial research and building of ZNEn homes will be required to drive down costs and to ensure that all the needed technologies are available for all climate areas. Included in these efforts should be ZNEn communities, because, as discussed in the next section, there are opportunities for more energy efficiency and for simpler, less expensive PVs in community-scale projects.

Utility research and innovative tariffs are necessary for widespread adoption of ZNEn homes, because there is no net-energy for which to charge, coupled with grid benefits due to reduced peak and possibly a flat load profile. Utilities will need very different tariffs if ZNEn homes become widespread, as is intended in California.

Community-scale Advantages

As with most industries, the economies of scale can help the housing industry, in this case in its move towards "zero." This does, however, require a little flexibility with the definition of zero, whether peak or net-electricity or net-energy. Instead of requiring that each home in the community meet the particular zero design goal, the community as a whole meets the ZP, ZNEl or ZNEn goal. This allows for opportunities that wouldn't otherwise be available—opportunities that may make reaching "zero" a bit more feasible.

As noted previously, solar PV is relatively expensive compared to most energy efficiency options. The higher cost of PV is exacerbated in community settings by the need to install systems on each home, increasing the cost of labor and the balance of systems (e.g., inverter and wiring) compared to a large-scale system, such as on the roof of a big-box retail store. Further, it may be difficult to place a PV system on each home due to limited availability of unshaded roof space with proper orientation. A more cost effective alternative is to determine the amount of PV desired for the entire community to achieve desired generation needs, and then install as many larger arrays as possible to achieve the desired generation. A recent survey of PV costs found that roof-mounted systems on homes can cost 15 to over 30 percent more per kW than a large array on a big-box building*. Large arrays can also take advantage of remote open spaces in the community for ground-mounted systems, as well as roof space on local commercial and/or public buildings. This approach may require innovative tariffs or PV ownership that equably spreads the (value of) generation across the community to get the full impact of load-flattening (zero peaking) from the community as a whole.

There are also some efficiency options that can be more feasible on the community-scale. For example, a ground source heat pump (GSHP, a.k.a. a geothermal heat pump) can provide high-efficiency heating and cooling to the home, but it generally requires a large length of pipes to be buried, either vertically or horizontally, in the ground. Vertical installation requires deep holes to be bored into the ground, an expensive process. Installing them horizontally, a few feet below the surface, is much easier to do but requires a large plot of land. In either case, large, costly machinery is involved. If these costs can be amortized over a number of homes, each installation will be more cost effective. When installing GSHP systems, in some cases the vertical option would be cost-prohibitive, and there wouldn't be sufficient area for the footprint of a horizontal system. However, a community-scale system could provide plenty of area for the horizontal system while providing additional savings from the economies of scale.

Community-scale implementations also open opportunities for other, larger systems that are impractical at the individual home level. Such things include community-scale combined heat and power, community geo-exchange loops, smart grid demand-response systems, and local electricity storage (including electric vehicles).

Another opportunity offered at the community-scale is the possibility of nearby natural gas generation, including at waste dumps and agricultural areas or farmland. Therefore, while individual homes may not be zero net-electricity and zero net-natural gas, a community

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*CBIA, private communication

(depending on local resources) may be able to make that claim.

In summary, community-scale implementation provides the opportunity for greater innovation and amortization of some costs. However, they also require innovation in net-metering rules and tariff structures.

CONCLUSIONS

The U.S. Department of Energy and California share the goal of practical, marketable, net-zero energy homes by 2020 (and in California net-zero buildings by 2030)—defining a net-zero energy home as one that, on an annual basis, produces as much energy as it consumes. In this article we make the case that, from a holistic viewpoint, the more practical and more cost effective approach to large-scale implementation of net-zero energy homes (and commercial buildings) is net-zero energy communities, as a stepping stone, and later integration of zero-peak communities into the final net-zero energy communities solution. A net-zero energy community would consist of very energy efficient homes with roof-mounted PVs (though the homes are likely not net-zero energy), very efficient commercial buildings with renewable energy (some of which could produce more energy than the building consumes), and other renewable generation resources either co-located or distant from the community. From the perspective of net energy used and net-greenhouse gases produced, it is irrelevant whether the community is an assemblage of net-zero energy homes and commercial buildings, or a net-zero energy community. However, the technological costs to achieve these two goals are very different, with net-zero energy communities being more achievable in the near term, and at a lower cost. The main caveat is that community implementation requires significant changes in both net-metering rules and tariffs.

This article also concludes that zero-net energy buildings research should include development of zero peak homes, buildings, and communities. A zero peak community in the southwest, for example, where summer electric peaks prevail, would have dramatically reduced electric peaks (primarily due to cooling) by shifting them from late afternoon to evening, night, and early morning; they would also have local electric storage for excess solar generation for later local use, further flattening the load curve and reducing utility costs. Zero peak buildings would include both energy efficiency and thermal storage features in both residential and commercial buildings to reduce peak and then shift the remaining, smaller peak to different parts of the day. Due to relatively flat and low electric-load profiles, zero peak communities should be financially advantageous to electric utilities, and these benefits could be used to offset the additional construction costs of zero peak homes and buildings, as compared to current practice. Additional research is needed to quantify the benefits of zero peak communities and to develop new utility business models and tariffs that would support development of such communities.

We show that:

- Zero peak communities are a more near-term possibility than net-zero energy communities, based on available technologies and costs;

- The building attributes that will produce low, flat electric load profiles are beneficial to development of net-zero energy communities, and therefore:

- A broader research focus on net-zero energy communities, including zero peak elements, is a recommeπnded, as well as complementary addition to the current research that focuses on individual net-zero energy homes and net-zero energy commercial buildings. A dual, coordinated approach will result in faster market adoption of large volumes of net-zero energy homes and commercial buildings.

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