Zero Peak Homes: A Sustainable Step

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ABSTRACT

Zero Peak ("ZP") homes and communities have a relatively small and constant power draw from the grid including during times of peak system-wide demand. Taking all stakeholders into account, ZP homes are the most attractive next step in moving toward zero net-energy homes. Utilities are the primary beneficiaries of the ZP home's flattened load profiles and could derive a net financial benefit from ZP homes and communities. In contrast, code-homes or even Zero Net-Energy ("ZNE") homes have peaking profiles that account for significant utility costs. ZP homes have substantially lower additional construction costs than either Zero Net Electricity or true ZNE homes because ZP homes can have substantially smaller PV systems, which is the single most expensive feature of ZNE homes.

Designing and building communities of ZP homes is complex. In addition to highly efficient systems, and good solar exposure, ZP homes require sophisticated HVAC controls to properly manage the homes' thermal mass, as well as a Smart Grid to manage the flow of electricity to/from the grid and local storage systems.

Details are provided on evaluation of different energy-efficiency design approaches for ZP homes, and how these different energy features contribute to achieving a low, flat load-profiles for ZP homes and communities. In addition the utility benefits of a ZP home/community are estimated. From this data, we propose how utility support could make these communities cost-competitive today, and the policies crucial to development of ZP communities, including net metering, tariffs, thermal and electricity storage, and Smart Grid implementation.

Background

The first goal of the California Energy Efficiency Strategic Plan (CPUC, 2008) is to deliver zero net energy (ZNE) new homes by 2020. This is a stretch-goal and some steps will need to be taken to get there. Zero Peak homes are a likely first and major step as has been discussed elsewhere (Hammon, 2009, Anderson, 2009). ZP homes are a likely first step because of the major impact they can have on electricity use and demand. The California Energy Commission states the following regarding the difficulties due to and importance of electricity demand (CEC Staff):

> *For a small number of hours, the generation capacity that sits idle for most of the year is needed to meet peak demand. Electricity use varies widely over the time of day and time of year. On a typical day, demand increases 60 percent from the midnight low to the afternoon high. Because air conditioning loads drive peak demand, California sees its greatest demand spikes during the summer months (June, July, August, and September).*
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> *On a hot summer day, this swing can be 85 - 90 percent. The difference in demand between an average summer day and a very hot peak day is 6 percent. This difference is equivalent to three years' average growth in statewide*

> *electricity demand. This variable demand trend requires a generation system that is extremely flexible. The full available capacity of the system needs to be dispatched only to meet a few hours of pead demand each summer.*

Managing residential air conditioning could have a major impact on the need for new generation as well as on the need for substantial enlargement of distribution infrastructure, potentially placing great value on developing and building ZP communities. Towards the ZNE goal, this research shows that there may be a straightforward way to build new ZP homes that have low, flat load profiles, eliminating summer afternoon peak demand.

Methods

This study was performed using EnergyGauge USA (v2.8) simulations of a typical production home – represented by one of the models built at the Premier Gardens community in Rancho Cordova, CA, a suburb of Sacramento. This Premier Gardens home was employed because there is substantial monitored data from this community that can be compared to the baseline predictions to evaluate the predictive quality of the simulation.

The test home is a single story with a concrete-slab foundation, 1846sq.ft. living area, and 16.7% glazing area (as a percentage of floor area). The baseline features for the test home ("Baseline," consistent with current good quality energy-efficiency features in CA) were R-38 in the attic, standard 2x4, 16"oc wood framing with R-13 batts (insulation quality 3rd party inspected) with R-4 EPS foam sheathing on the exterior of the framing, low-e windows with U-factor of 0.37 and SHGC (solar heat gain coefficient) of 0.32, 14 SEER air conditioner (A/C) and 91% AFUE furnace, R-13 sealed ducts in the attic (buried in the insulation; duct leakage less than 6% of airflow), 3.5 SLA (standardized leakage area), and a 0.82EF tankless water heater with hot-water piping insulated. The homes were simulated with 100% fluorescent lighting and Energy Star dishwasher and refrigerator and for the Baseline, 90% carpeted slab.

The home was also simulated with as-built Premier Gardens features for direct comparison to the measured data. The actual homes were built in 2003 and substantially exceeded the requirements of the 2001 Title 24 code; the efficiency features that were different from the Baseline are window U-factor 0.4 and SHGC 0.4 windows and an 80 AFUE furnace. The 95 homes built also all had 2kWac building integrated photovoltaic (PV) systems with three different orientations: 28% of those in the measured sample of 18 homes were facing east, 11% facing west and the remainder facing south.

The test home was simulated with the following improvements to determine their impacts on both the electricity peak demand, and the relative flatness of the demand curve for the peak day. Features were added in the following order, cumulatively (except as noted):

- 100% wood covering the slab
- 20% tile 80% carpet covering the slab (not cumulative)
- 40% tile 60% carpet covering the slab (not cumulative)
- 60% tile 40% carpet covering the slab (not cumulative)
- 80% tile 20% carpet covering the slab (not cumulative)
- 100% tile covering the slab (not cumulative); all subsequent simulations included 100% tile floors
- 5/8" drywall ceilings (increased from ½")

- 5/8” drywall walls
- 5/8” drywall ceilings and walls
- SIPs (structural insulated panel) exterior walls (with ½” drywall ceiling and walls)
- SIPs with 5/8” drywall ceilings
- SIPs with 5/8” drywall walls
- SIPs with 5/8” drywall ceilings and walls
- CSIPs (SIPs panels with cementitous structural panels
- CSIPs with 5/8” drywall ceilings
- CSIPs with 5/8” drywall walls
- CSIPs with 5/8” drywall ceilings and walls
- CSIPs with 20 SEER A/C(with ½” drywall throughout)
- CSIPs with 20 SEER A/C and 2kWac PV system

The simulations were done with Sacramento weather files, and the test day used for all comparisons was July 19.

Results and Discussion

To evaluate the accuracy of the peak-day hourly kWh demand, the as-built and Baseline cases (see Methods for a list of Baseline energy-efficiency features and differences for the as-built) were compared with the measured results for the actual community.[1] Figure 1 provides a comparison of the actual 15-minute measured data from the Premier Gardens homes and the hourly simulation results for the as-built features.

Two sets of comparisons are shown in Figure 1, simulations of home with the as-built features, with and without PVs, to the measured loads, with and without PVs. There are two main differences between the simulated data and the actual data: the height of the peaks and troughs (kW draw and generation extremes), and the widths of the peaks (durations). While we have no direct method to determine the source of these differences, the lower peak-kW demand and the wider duration of the demand peak in the measured data may be explained due to community diversity in A/C-cycling and in thermostat set-points: the measured data comes from monitoring energy use and generation at 15 minute intervals from 18 different homes with their different families; there are also differences in the homes (multiple models and orientations), as well as weather differences between the actual and simulated days, although both were the summer peak day. The differences in kW production may be a function of panel orientation (modeled as south facing, actual homes have east, west, and south facing arrays – see Methods) and perhaps also the impact of temperature on the BIPV systems. In addition, the simulations are not perfect models of the homes or the PVs. However, the simulations appear to provide a reasonable representation of the loads and their shapes.

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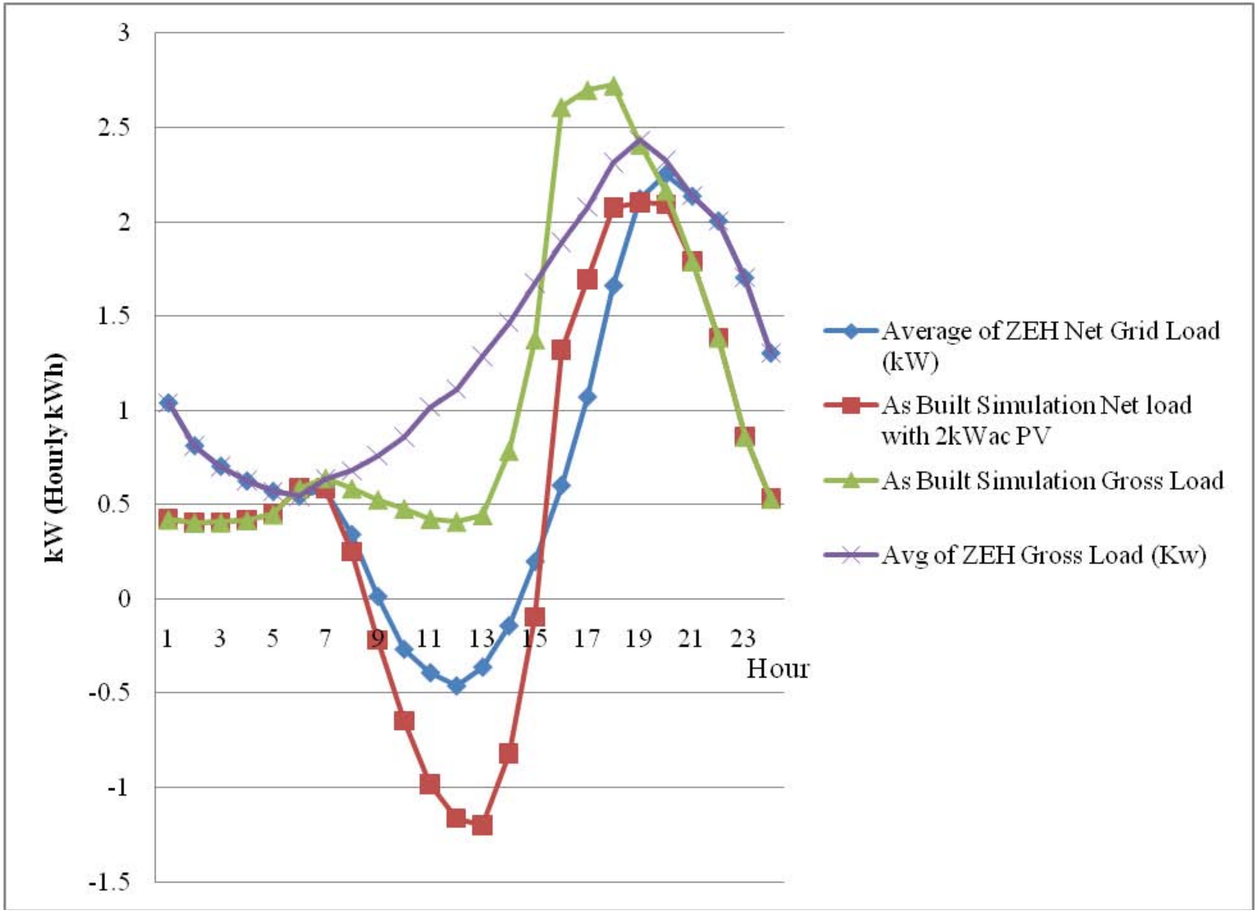
[1] Premier Gardens was a joint effort of Premier Homes, SMUD (the Sacramento Municipal Utilities District), and ConSol, as members of the BIRA Building America Consortium. Energy use and energy bill data was graciously provided by SMUD to ConSol as part of this on-going Building America effort.

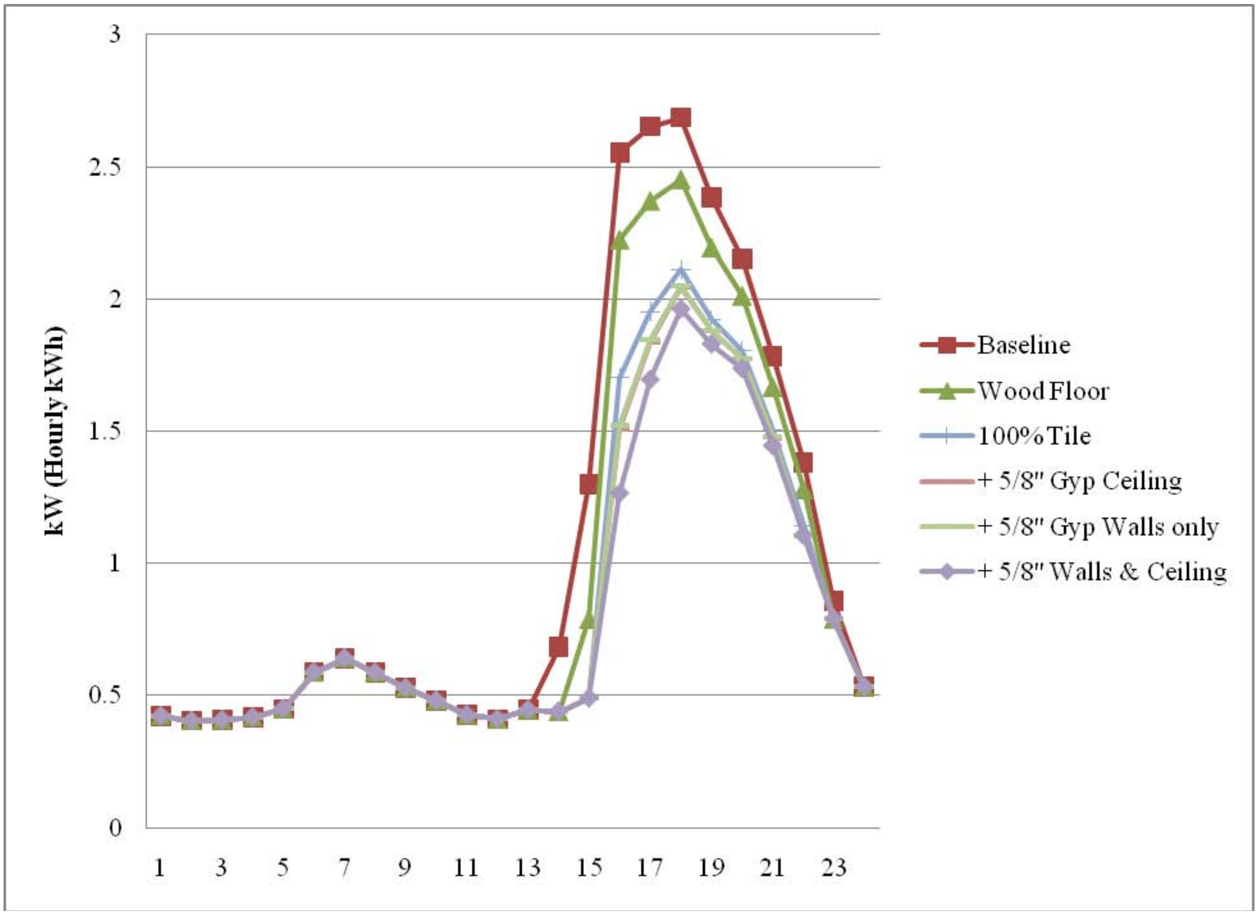
Figure 1. Comparisons of Simulation Results and Actual Measurements from Premier Gardens Homes, With and Without PVs



A range of envelope measures, mainly focusing on architectural-design neutral features to provide both a good envelope and improved thermal mass, were explored to examine their impacts on reducing and/or flattening the summer cooling peak. Carpet, wood, and tile floor coverings were examined, with the amount of tile coverage ranging from 20% to 100% in 20% intervals. Not surprisingly, 100% tile floor covering provided the largest reduction in peak, about 20%, at the peak hour of 6PM. All subsequent simulations included 100% tile floors.

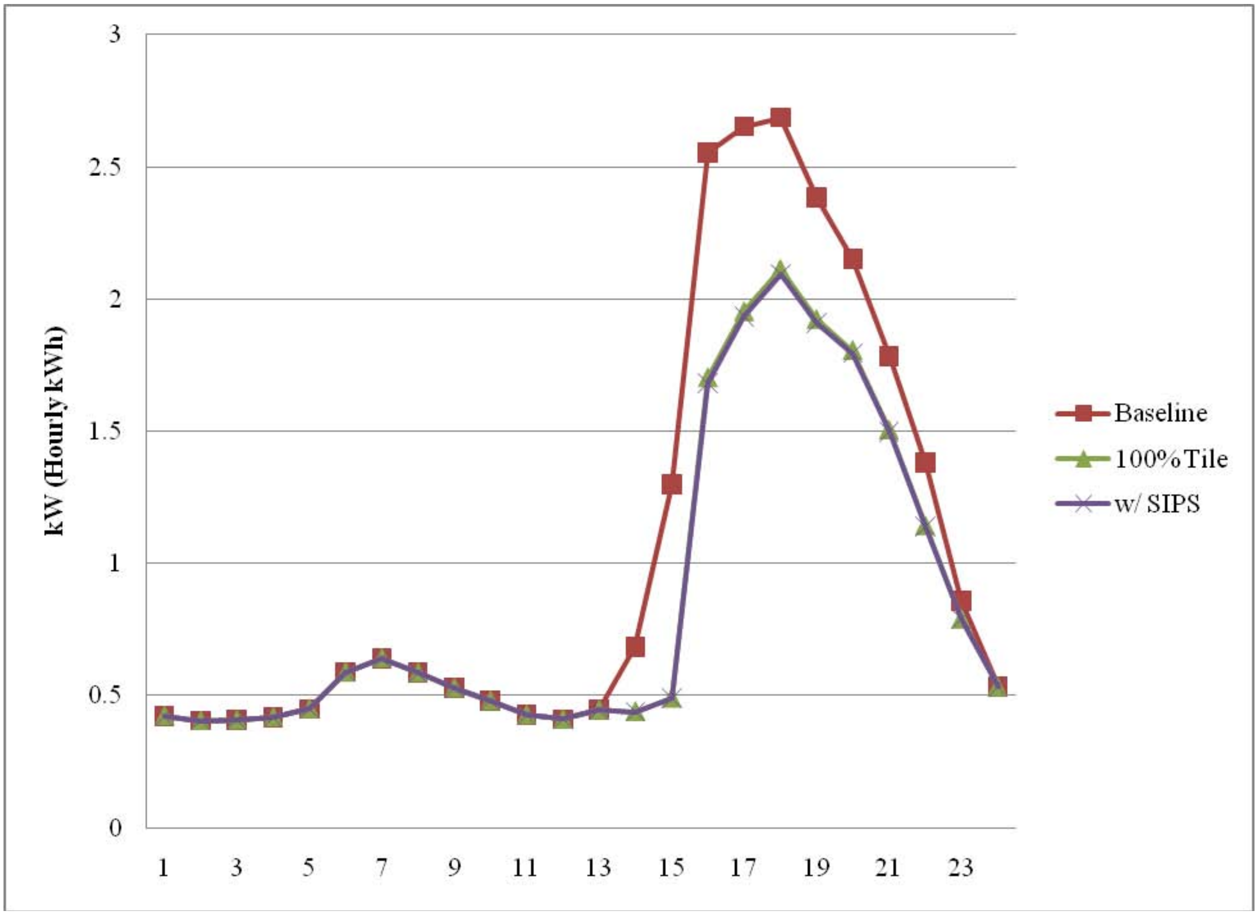
In addition to the tile floors, drywall ("gyp" in Figure 2) thickness was increased from ½" to 5/8" for ceilings, walls, and both ceilings and walls in discrete simulations. As shown in Figure 2, the added mass from the thicker drywall did reduce the peak, but the impacts were substantially smaller than for tile, which is often offered as an optional upgrade from carpet, indicating that homebuyers see tile floors as an upgrade or preference whereas the thicker drywall has no aesthetic value and increases construction costs and difficulty both due to materials and non-standard door-sets.

Figure 2. Simulation Results: Baseline Compared with Wood and Tile Floors, and Tile with Different Amounts of Wallboard Mass



Next the walls were thermally improved, changing from the Baseline 2x4", 16"oc wood framing with R-13 batt insulation (3rd-party verified to have minimal installation defects) plus 1" EPS foam external insulation with elastomeric stucco exterior (commonly referred to as "1-coat"), to 4" SIPs wall panels. The SIPs walls are pre-manufactured wall panels that sandwich EPS foam between two OSB (oriented-strand board) panels. As Figure 3 shows, the SIPs had almost no impact on the peak (approximately 1% improvement) presumably due to the exterior foam sheathing in the Baseline. Although not shown in this figure, thicker drywall was also added providing similar incremental peak reduction as is shown in Figure 2.

Figure 3. Simulation Results: Baseline Compared with Tile Floors and Tile Floors with SIPs Walls



The SIPs panels were then replaced with CSIPs panels, which substitute cementitous panels for the OSB panels on standard SIPs. The results are illustrated in Figure 4; the added mass of the CSIPs reduced the peak by an additional 18% to the tile alone, the two features producing almost 40% peak reduction compared with the baseline. Additional wallboard was again simulated, producing small impacts, so for clarity they are not shown in Figure 4. The last major efficiency feature added was a 20 SEER[2] air conditioner. This was simulated along with the tile floor, and CSIPs walls. This 20 SEER A/C, simulated with the tile floors and CSIPs walls produced an additional 8% reduction in peak, for a total peak reduction of almost 50% from the Baseline.

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[2] EER was not modeled because it is not an input for EnergyGauge. Nonetheless, for reference, in previous studies at Borrego Springs performed by BIRA, DEG and NREL, NREL calculated EERs of several systems, including the Lennox 21 SEER air conditioner. They found that the EER ranged from over 18 at 80°F outdoor temperature to about 13 at over 105°F outdoor temperature (Springer, et.al, 2008).

Figure 4. Simulation Results: Baseline Compared with Tile Floors Plus SIPs or CSIPs Walls or CSIPs Walls and 20 SEER A/C

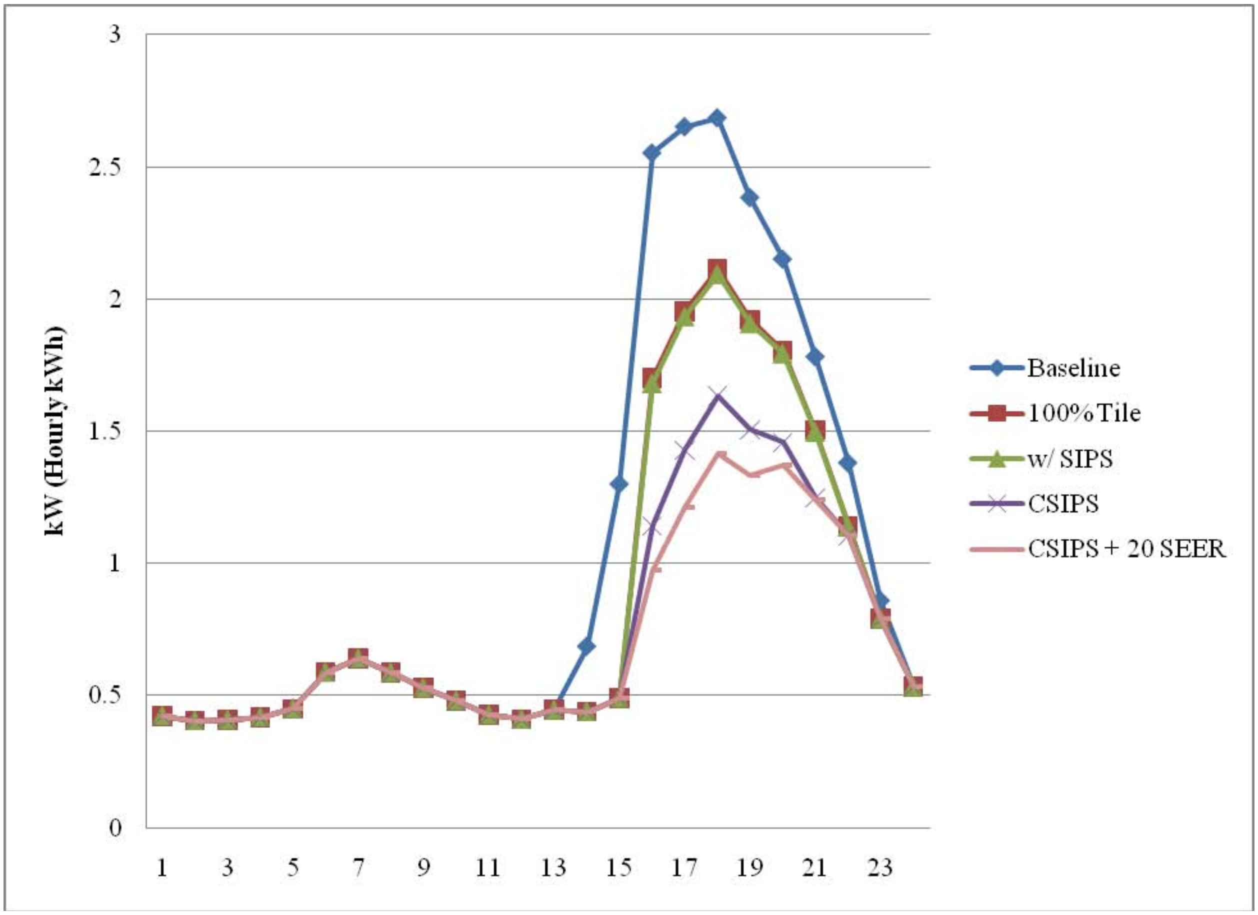
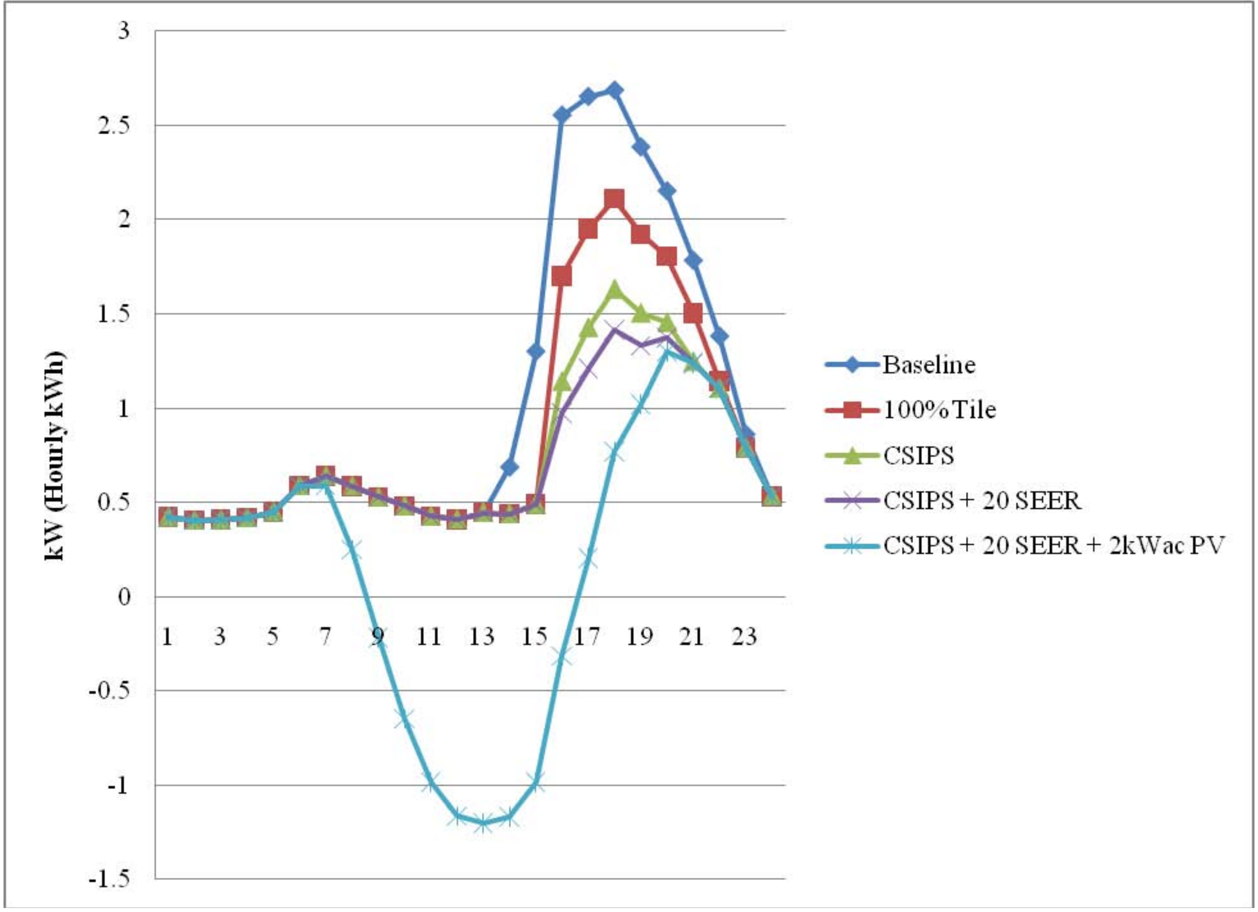


Figure 5 provides the simulation results when 2kWac of PV was added to the tile floor, CSIPs wall, 20 SEER air conditioner case. This combination of mass and generation reduces the 6PM electricity demand by over 70% and pushes the peak back 2 hrs to 8PM, beyond the current Sacramento CA peak and super-peak periods. In addition, at 8PM the demand is still 40% below the Baseline-home demand at that hour.

Figure 5. Simulation Results with Tile Floors and CSIPs Walls or CSIPs Walls with 20 SEER A/C or CSIPS Walls with 20 SEER A/C and 2kWac PV System



Other than the addition of PVs, none of the features modeled shifted the peak from the initial baseline peak at 6PM. Previous experimental results from the BIRA Building America team's "prototype" or "laboratory" homes built in Borrego Springs CA, showed that homes with mass floors, significant overhangs, and SIPs or high-mass insulated walls could be pre-cooled and float through the afternoon peak with acceptable or negligible (for the high-mass walls) temperature climb (Cubano, et.al). Several pre-cooling thermostat strategies were simulated with this 1864 sqft home in Sacramento with the tile floors and CSIPs walls. None of the EnergyGauge simulations from the various pre-cooling thermostat-control strategies tested resulted in a spread out and thereby reduced peak; rather, they simply shifting it to a slightly earlier or later time without producing a significant reduction at the peak. These results, combined with the fact that thermostat control strategies require occupants to properly manage them resulted in their rejection from this study as a long-term strategy to produce the desired load flattening and peak reduction required for ZP communities.

This is not to say that time-based thermostat control strategies are not promising; however, to be effective they need appropriate rate structures, such as well-designed time-of-use, or critical-peak pricing, and/or demand-responsive tariffs. These require substantial policy and regulatory changes which take time. Here we explore approaches that do not require substantial policy, regulatory, or occupant-behavioral changes, and that can be done today.

Compressor-less cooling technologies such as evaporative cooling (of any variety) were also not employed because in large areas of the Southwest and all of the Southeast, the outdoor humidity is too high for these technologies to be practical for the entire summer, requiring compressor-cooling for some or all of the cooling season. Therefore our strategy was to employ a very good envelope with integrated mass, and a small, high-efficiency air conditioner.

Up to the addition of the PV system, all of the measures served to reduce the peak without increasing (or decreasing) loads at other times of the day, moving toward a flat load profile. The PV system dramatically lowered and shifted the peak, in the same way as it did in the actual measured results, as are illustrated in Figure 1 ("Average of ZEH Net Grid Load"). However, due to the time differences between the peak PV generation (mid-day) and the peak air conditioning demand (6PM in Sacramento, which is later than the Southern California peak), there is actually an increase in the disparity between the lowest and highest demands for the efficient home with PVs: 1.8kW peak-to-trough for the Baseline, and 2.5kW for the case including PVs. This larger disparity in large-scale implementation could result in new distribution issues for electric grids. Therefore it may be beneficial to store the excess generation and use it to reduce or possibly eliminate the peak, producing a ZP home.

In the simulation with PVs in Figure 5, there is excess generation past 4PM (hour 16), when the demand starts to climb due to the air conditioning load. With the proper use of battery storage and smart meters coupled to a smart grid, this excess generation during the middle of the day could be stored and used to bring the peak down to a day-long flat load of about 0.5kW, based on simulation results. The average demand from 1AM to 3PM is 0.55kW for the Baseline home, thus any generation in excess of 0.55kW could be stored in batteries, either locally or in battery banks elsewhere in the smart grid, and could be used to flatten the profile during the afternoon, eliminating the peak. Applying this strategy to the simulation results provides a total of 6.2kWh excess generation available from 6AM to 9PM, determined by summing the generation in excess of 0.55kW over that period. Simulated load curves for the Baseline home and the home with Tile + CSIPs + 20 SEER + 2kWac PVs, with and without battery storage used to flatten the load are shown in Figure 6.

The energy required to reduce the simulation with Tile + CSIPs + 20 SEER + 2kWac PV to a maximum of 0.55kW is 5.1kWh. Battery storage efficiency ranges from a low of around 50% for lead-acid batteries to a high of around 85% for some uses of lead-acid and for lithium-based batteries. Based on the results of these simulations, the battery and control system to store and release energy throughout the day to maintain the home load at 0.5kWh/hr or less, the system would need to be 82% efficient for the charge/discharge cycles, which is in the high range for both lead-acid systems and lithium-battery systems (Burke & Miller, 2009; Stevens and Corey). This system efficiency is based on a 2kWac PV system; the required battery system efficiency could be reduced by installing a larger PV system.

The incremental costs for this flat-load solution are high today. Estimates for the additional features are in Table 1, and total approximately $45,000 at current prices. The major costs, for the PV system and the smart battery system should both go down in coming years due to increased market demand, and improved product manufacturing and installation procedures.

Figure 6. Simulation Results with Tile Floors, CSIPS Walls with 20 SEER A/C and 2kWac PV System, With and Without Battery Storage

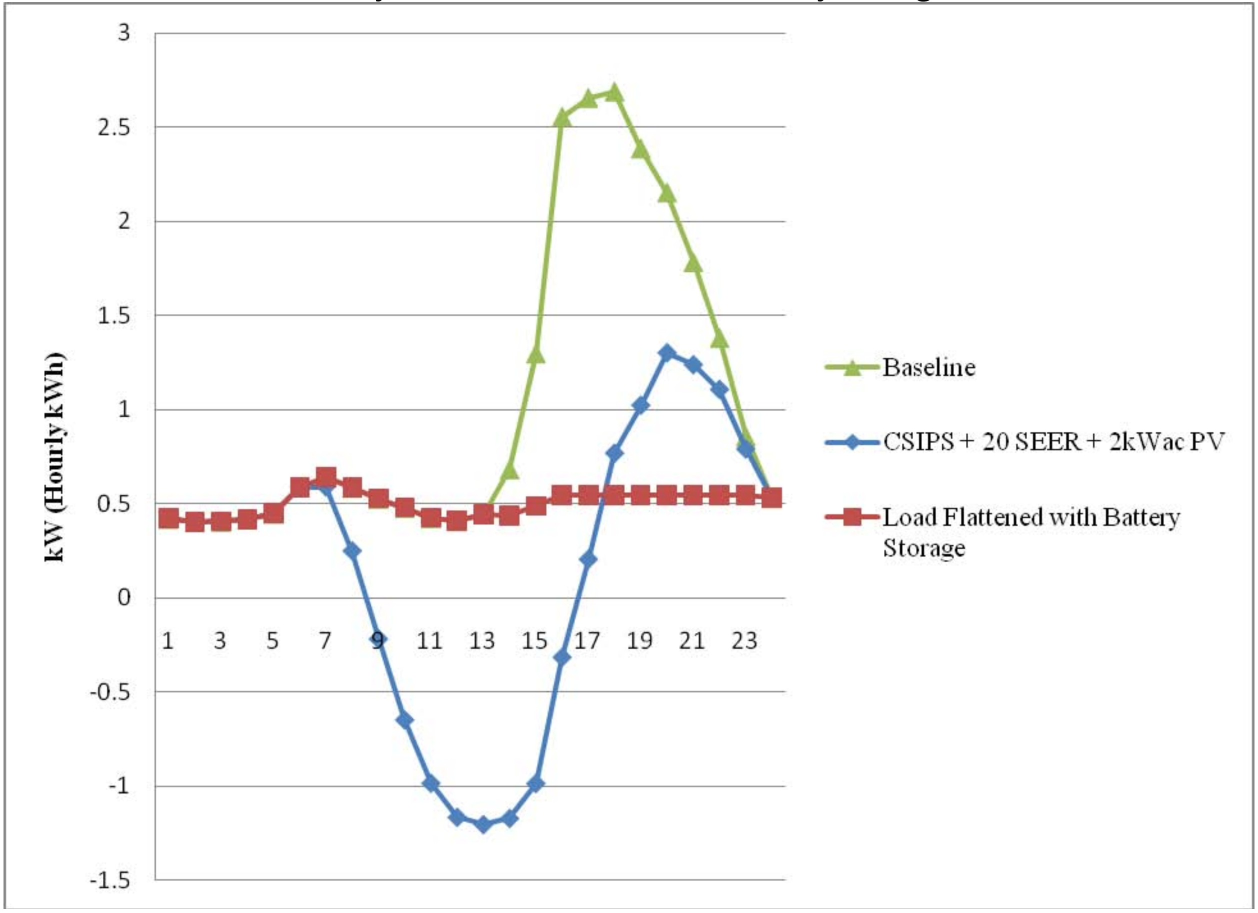


Table 1. Incremental Cost Estimates

Feature	Incremental Cost
Tile	$0
CSIPS	$15,000
20 SEER	$1,400
2kWac PV	$18,000
Battery	$10,750
Total	$45,150

Utilities would benefit from having communities of homes with low, flat load curves. The homes would both save significant kWh and would not require any peak power nor require construction of “peaker” plants – generation plants that produce electricity only during peak or extreme peak periods. The community electricity distribution costs would also be substantially less due to smaller distribution wiring, and either smaller substation transformers or more homes per substation. In addition, as was found at SMUD (Keesee, 2006) the lower loads on the substation transformers allow them to run cooler and last longer.

While we do not have access to the value of these utility savings, at a minimum ZP homes should be eligible for current utility program incentives as detailed in Table 2. There are two incentive levels for kW savings in Table 2: incentives from the CA statewide residential new construction program, and a much higher value paid for some commercial demand response (DR) programs. The kW savings in Table 2 are based on reductions compared to a typical new home in SMUD territory (Pratsch, 2008) rather than the Baseline for this study, which is more efficient than required by code and therefore has a lower peak demand than a typical new home.

Table 2. CA Utility Incentives Estimates

	Savings Compared to Typical New Home	Incentive / Unit Energy or Demand	Incentive to Builder
Therms	108	$6.88	$743
kWh	1,040	$1.72	$1,789
kW[1]	4	$150.00	$600
kW[2]	4	$1,500.00	$6,000
PV Incentive (per Watt)		$2.60	$5,200
[1] Current Res New Construction			$8,332
[2] With Max Value for kW per some			$13,732

Even the most optimistic incentive, nearly $14,000, is far from the incremental cost of over $45,000. However these incentives do not capture the total value of ZP communities where the demand curve is not only flat, but also quite low, at about 0.5kW throughout the day.

Conclusions

This study has shown that changes to home construction features and materials, including PVs and battery storage can result in homes with low, flat load profiles (ZP homes) without requiring any changes to architecture or occupant behavior, which, if required, could make them less desirable to builders and buyers.

The features employed to obtain this result – 100% tile flooring over concrete slab, CSIPs walls, 20 SEER A/C, PVs with smart batteries connected to a smart grid via a smart meter – are not the only set of features that could produce such a result, nor are they necessarily the optimal set. Nonetheless, they do produce the desired ZP result in simulations, and testing this concept would be straightforward through programs such as Building America, CA PIER, or utility programs such as Emerging Technologies. In addition, the battery systems could be located either in the homes or in community electricity substations, and the substation approach would likely be more cost-effective and better maintained.

To determine actual cost-effectiveness of this approach and of ZP communities in general, more research is required to determine the incremental construction costs in a mature market, and the total value to consumers and utilities of building communities of ZP homes. It is likely that the value of ZP communities to electric utilities is substantially higher than the estimated incentives currently available through California investor-owned utilities, especially in areas with limited distribution infrastructure. The good news is that in simulations, the approach works and the simulated technologies are readily available. Efforts should be made to test this concept as soon as possible.

References

Anderson, Ren, 2009. (Personal Correspondence/Draft Paper) *Impact of efficiency, residential PV, and temperature control on peak demand savings in Sacramento homes*. Golden, CO: National Renewable Energy Laboratory.

Burke, Andrew, and Marshall Miller, 2009. *The UC Davis Emerging Lithium Battery Test Project*. U.C. Davis, Davis, CA

Cubano, Abe, Faith Shimamoto, Michael Lubliner, David Hales and Bruce Baccei. 2008. *Final Report: Results of Research Systems for Prototype Homes.* BIRA Building America Report, Stockton, CA

CEC Staff Report. 2009. *Summer 2009 Electricity Supply And Demand Outlook.* CEC Publication 200-2009-007, May 2009. Sacramento, CA

CPUC. 2009. *Long Term Energy Efficiency Strategic Plan.* September 2008. San Francisco, CA

Hammon, Robert, Adam Neugebauer, and Faith Shimamoto. 2009. "Applications for Large Residential Communities." In *West Coast Energy Management Congress 2009 Proceedings*. Long Beach, CA.

Keesee, Mike. 2006. *Private communication.* Sacramento, CA.

Pratsch, Lew. 2008. *ZEH Presentation to Santa Fe Area Home Builders Association.* Santa Fe, NM.

Springer, David, Mark Eastment, Willard Dakin, Leo Rainer, Ed Hancock. 2008. **"**Comparative performance of four prototype mechanical systems in a desert climate." In *ASHRAE Transactions, July 2008.*

Stevens, John and Garth Corey. *A Study of Lead-Acid Battery Efficiency Near Top-of-Charge and the Impact on PV System Design.* Sandia National Laboratory, Albuquerque, NM