Lessons Learned from a Zero Net Energy Production Builder Demonstration

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ABSTRACT

In support of California's goal for all new residential buildings to be zero net energy (ZNE) by 2020, Pacific Gas and Electric Company (PG&E) is running a ZNE Builder Demonstration project. The participating builders receive help from start to finish to upgrade one of their existing prototypes to ZNE in a way that is broadly applicable to future homes that they will build. Design consultants provide advice on energy efficiency measures for the builder's standard design based on performance modeling and substantial past experience with zero-energy and energy-efficient homes. They also visit the site during construction to ensure that the measures are being properly installed. PG&E buys down up to $15,000 in incremental cost of the energy efficiency measures; experience shows that the incremental costs will drop in subsequent projects. Finally, monitoring consultants track the end-use energy consumption of the completed home for a year to determine whether the occupied prototype is performing as designed and to diagnose operational issues.

This paper presents results from this first phase of this demonstration project with six builders' homes at various stages of completion. It addresses the following questions:

- What obstacles and opportunities do production builders face in building ZNE homes?
- What are the drivers of builders' decision making?
- How might building subsequent ZNE homes be different from the first one?
- What are the challenges in modeling the performance of ZNE homes?
- How can modeled performance be evaluated, especially across projects?
- How can occupied performance be monitored and what design changes are needed to do so?

Introduction

ZNE Production Builder Demonstration Overview and Goals

In California's Long Term Energy Efficiency Strategic Plan, the California Public Utility Commission (CPUC) defined four "Big Bold Energy Efficiency Strategies." One key goal is for all new residential construction in California to be Zero Net Energy (ZNE) by 2020, and the building code requirements are moving in this direction. Pacific Gas and Electric Company (PG&E) is working with a number of production builders in California to help them move toward offering ZNE homes ahead of this deadline.

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[1] The BIRAenergy team also includes Rob Hammon.
[2] The Design AVEnues LLC team also includes Rick Chitwood (Chitwood Energy) and Steve Easley (Steve Easley and Associates).

This paper refers to three definitions of ZNE buildings:

- Zero Net Site Energy: All energy consumed on site over a year (e.g. electricity, natural gas, etc.) is offset by renewable energy produced on site during that same year.
- Zero Net Source Energy: Site-source multipliers are applied to the annual site energy consumption and production based on the energy type to account for efficiencies in energy conversion, transmission, and distribution.[3]
- Zero Net Time Dependent Valuation (TDV) Energy: Energy has different value to society based on its source and on when and where it is consumed or produced. Climate-dependent multipliers are applied to simulated hourly annual energy consumption and production data to calculate the time dependent valuation of the energy (CEC 2013; Price et al. 2011). This is the definition that is used in the California Building Energy Efficiency Standards (Title 24) and in this demonstration.

Because peak electricity during hot summer afternoons is the most costly energy for the grid operators to produce, procure, and deliver, it is weighted the most in terms of TDV. Electricity production from photovoltaic (PV) panels is often greatest during these peak periods, so PV production from a given array can offset a higher proportion of TDV consumption than basic energy consumption. This results in a smaller array being needed to reach TDV zero than site zero.

In early 2015, PG&E selected seven production builders[4] to participate in a ZNE Production Builder Demonstration and began providing assistance in designing, building, and monitoring a ZNE prototype based on one of the builders' existing models while preserving the look, feel, characteristics and amenities of the builder product type for the development or sub-division. PG&E focused on production builders to help address some of their specific challenges for shifting their practices: they have established, vetted home designs; they have established subcontractor and supply chain relationships; and there is significant concern about cost and performance issues when trying new designs and equipment at a large scale. However, because production builders construct a high volume of homes and reuse the same plans, achieving a successful ZNE prototype could have a broad influence in the types of homes built by that builder in the future, and potentially at a large scale. The goal of the ZNE Production Builder Demonstration is to achieve an integrated, whole building approach to achieving ZNE. However, because the builder designs are generally established, some of the performance gains and costs are calculated incrementally per measure or improvement.

Each builder team is matched with a consultant team that is expert in energy efficient and ZNE design and has experience working with builders' design and construction teams to ensure the prototypes are built as designed. The builders also work with a separate monitoring team. The consultant teams guide the builders through the four main components of the offering:

1. Design Development. Beginning with a target of ZNE, the design consultants and builder team tailor the prototype based on parameters like climate zone, customer base, and supply chain. Design consultants perform energy modeling to determine final building

[3] The electricity multipliers depend on the generation technology and fuel mix of the grid, so they are not static or identical everywhere.
[4] As of March 2016, one of these projects has been significantly delayed. This paper will discuss the other six builders.

systems and equipment for inclusion in the prototype and to estimate energy performance. To date, design changes have typically included energy efficiency measures such as increasing insulation in the walls, reducing thermal bridging, moving ducts into conditioned space, and increasing water heater and HVAC equipment efficiency.

2. Construction and Construction Review. Consultants work with the builder team and subcontractors to ensure careful installation of energy efficient and ZNE systems and equipment. This includes testing and commissioning of building components and equipment to ensure that systems perform as designed.
3. Equipment and System Buydown. The builder carefully documents the cost of their standard model and the cost of the ZNE prototype, and PG&E reimburses up to $15,000 of incremental cost of energy efficiency measures. This buydown is strictly targeted at the energy efficiency measures; it does not go towards PV. For the five projects with detailed budget numbers, the calculated incremental cost for the energy efficiency approach is less than the maximum PG&E reimbursement.
4. Ongoing Energy Performance Monitoring. Monitoring consultants work with the builder team and design consultants to integrate monitoring equipment from the early stages of design. Once construction is completed and the home is occupied, the monitoring team tracks energy consumption by end use and PV production to determine whether the occupied prototype is performing as designed and to diagnose any operational issues.

PG&E believes this offering benefits both the participating builders and PG&E.

Builder Benefits include:

- Develop and test a replicable ZNE prototype ahead of competition and code
- Demonstrate proof of concept of ZNE in a production environment
- Test market acceptance
- In depth training on ZNE design
- Construction review together with education of tradespeople
- Assistance with incremental cost of ZNE prototype construction
- Feedback on performance of occupied prototype
- Assistance with cost reduction techniques and practices
- Publicity through case studies and public events

PG&E Benefits and Goals include:

- Move toward a building code that supports California's ZNE goals and PG&E's efforts to support the California Energy Commission around these goals
- Demonstrate proof of concept of ZNE in a production builder environment
- Gather information on any challenges of building ZNE homes in a production environment
- Gather information about the current cost implications of ZNE for builders, the cost of ZNE homes, and where these costs can be driven down
- Develop relationships with proactive builders
- Gather information about the performance of occupied ZNE homes
- Develop case studies for builder education

In addition to these benefits to the builders and PG&E, the homeowners get a high-performance house with minimal energy use and expenses.

Participants

PG&E is working with several organizations to develop and implement this Demonstration. On the consultant and project management side:

- Resource Refocus LLC – demonstration development, oversight, coordination, and energy modeling
- Design AVEnues[5] – design & technical assistance
- BIRAenergy – design & technical assistance, energy modeling
- Davis Energy Group – performance monitoring

The participating builders:

- Pulte Home Corporation
- Meritage Homes
- Blu Homes
- De Young Properties
- Community Housing Improvement Systems and Planning Association, Inc. (CHISPA)
- Habitat for Humanity Greater San Francisco[6]
- Habitat for Humanity of San Joaquin County, Inc. (SJC Habitat)

These builders vary in size, targeted market segment, and process. De Young, Meritage, and Pulte all build market rate homes, but Meritage and Pulte are national while De Young is a regional builder in the Fresno area. Blu Homes, on the other hand, builds custom homes made of modules in their factory before trucking them to the site. SJC Habitat and CHISPA both serve lower income populations. Habitat for Humanity has affiliates all over the world that use volunteer labor and often donated materials, while CHISPA builds in the Salinas area using a more standard process. PG&E and the consultants tailored their approach to the ZNE prototype to fit the process and circumstances of each builder.

Project Status

Table 1 summarizes the location, primary characteristics, and construction status of the active projects. Five of the six projects are in hot-dry climates (CA climate zones 11-13), and the sixth is in a marine climate (climate zone 3). Where possible, PG&E targeted prototypes located in climate zones where a significant cooling load would be required, as this posed additional challenges for getting to ZNE. The active projects are in all stages from permitting to complete and being monitored.

[5] Team includes Ann Edminster, Rick Chitwood, and Steve Easley.
[6] This project has been significantly delayed.

Table 1. Project characteristics and status[7]

Builder	Location	CA Climate Zone	Floor Area (sf)	Bed-rooms	Status	Estimated Completion
Pulte	Brentwood	12	2,359	4	Finish work	May 2016
Meritage	Hayward	3	2,047	4	Site work	Nov 2016
Blu Homes	Loomis	11	1,877	3	Modules installed; finish work	Nov 2016
De Young	Clovis	13	2,024	3	Permitting	Nov 2016
CHISPA	Greenfield	12	1,167	3	Site work	Fall 2016
SJC Habitat	Stockton	12	1,229	3	Monitoring underway	Completed Apr 2016

Opportunities and Obstacles

Synergies

There are a few ways that increasing energy performance can save materials and cost. Framing members create thermal bridges and are also more expensive than insulation. By increasing the spacing from 16” to 24”, the R-value of the assembly increases and the material cost goes down by saving lumber. Sizing and placing windows to fit in the 24” module can further reduce the lumber required. Using these strategies, one builder has managed to adjust their home design to remove one-third of the lumber previously used. Similarly, long hot water pipe runs waste energy by trapping unused hot water in the lines. Grouping the hot water draws in a central location not only saves energy but also saves pipe and money and reduces the time it takes for hot water to arrive at the fixture.

When considered as a whole system, a measure that initially appears to be an incremental cost can sometimes end up saving money. One builder moved their ceiling insulation to directly under the roof deck in order to put the ducts in conditioned space. Although this increased the cost of the roof insulation because the installation process is more labor intensive, it also allowed them to remove the radiant barrier and roof vents and downsize the HVAC system.

Product Availability

One of the energy efficiency measures that has been surprisingly difficult to achieve is 100% LED lighting. While there are many choices for LED lamps and fixtures for generic uses, several builders have reported that they are having a hard time finding LED replacements for specialty fixtures including ceiling fan light kits and bathroom strip lights. Even when options exist, they are sometimes rejected due to the required color rendering index (CRI) requirements of a California utility incentive program[8] or to aesthetic concerns from the interior design teams.

Builders have strict requirements for roof materials. Roof color can influence people’s first impressions as well as the architectural street scape, so the builder’s aesthetics team sometimes has strict color requirements that cannot be met with cool roof products. Other times, it is the permitting authority that imposes the restriction.

[7] As of May 2016.
[8] California Advanced Homes Program (CAHP)

Constructing well insulated, tight building envelopes can reduce heating and cooling loads so much that some equipment is not available in small enough sizes. Because oversized equipment performs less efficiently, provides comfort less effectively, and has a reduced life, it is important to correctly size equipment to match the loads. The lack of furnaces with small enough capacity is one of the reasons that one builder replaced the furnace in their standard package with a heat pump for the ZNE home.

Another complicating factor around product availability is that builders frequently want to maintain existing relationships with particular suppliers. While a particular product may be available in the larger market, if it is not available from one of their established suppliers, builders are less likely to choose it. One builder chose to move their ducts to conditioned space with blown fiberglass held in place with boxed netting instead of spray foam explicitly because that was what they could get from their regular supplier. The two solutions have similar costs, with the boxed netting perhaps being slightly higher. Another builder wanted to keep the exterior rigid insulation to a maximum of 1” because otherwise they would not be able to get windows with large enough flanges from their regular supplier.

One unique aspect of Habitat affiliates’ supply chains is that they receive many gifts in kind. SJC Habitat routinely receives donations of denim insulation, so that is what they use in their walls.[9]

Bidding and Construction Process

The builders that serve low-income populations in the demonstration have specific constraints around the bidding and construction process. One builder receives significant financial support from donors and other funding organizations, some of which require that they get three bids on construction packages. Because of the extra time and work required, they prefer to make changes early in the design process and all at once instead of iteratively or making equipment changes late in the process.

Habitat for Humanity has a unique model in that they rely on volunteers for most of their labor. Because of this, SJC Habitat is more open to energy efficiency improvements that can be labor intensive such as very tight air sealing and careful installation of insulation. However, it also guides them away from other measures that may be more technically challenging to build. For example, they prefer raised floor foundations to slab on grade, even though they are more labor intensive, because they can be built with volunteers instead of requiring subcontractors to do the work. Similarly, Habitat for Humanity Greater San Francisco uses fiber cement siding instead of stucco because the volunteers can install it. They also cap the size of their windows to something that two volunteers can easily carry.

Drivers of Decision Making

We will use the examples related to water heaters and upcoming energy code changes to discuss some of the drivers of decision making that came up while working with the builders and consultant teams.

[9] Other products that do not fit their specifications as well can be sold at a ReStores, so the donation is valuable even if it does not directly end up in one of their projects.

Upcoming Code Changes

One of the goals of the builder demonstration is to help builders get ahead on anticipated changes in Title 24 building energy code in the next cycle. Many of the builders are participating in the Demonstration because of this, but it also has driven some of the decisions about individual energy efficiency measures. The next code cycle is anticipated to include higher R-value wall requirements. One builder explicitly told us that they want to build 2x6 walls to get experience before the code change, and another builder decided to use closed cell spray foam insulation because it would allow them to meet the anticipated code with 2x4 walls.

One anticipated change that can be challenging for builders is the requirement for ducts to be in conditioned space. All six builders are meeting this requirement, with four of them using the extra design, technical, and financial support provided in the demonstration to do so for the first time. The six builders are using five different solutions. One is building the roof with structural insulated panels (SIPs) and two have dropped the ceiling in the hallways to run ducts under the attic floor. The three others are putting insulation directly under the roof deck but in different ways: spray foam, fiberglass batts glued and wired in place, and blown fiberglass held in place with boxed netting. Figure 1 shows cavities formed by boxed netting in the process of being filled with blown-in fiberglass insulation.

Figure 1. Installing insulation under roof deck with boxed netting solution. *Source*: Can Anbarlilar, PG&E.

Site Conditions

A common recommendation was for the builders to upgrade to condensing gas tankless water heaters. One builder chose not to use a tankless water heater because the water in the area is hard, so the appliance would require frequent maintenance. Given the site-specific condition, this builder is upgrading their standard gas tank water heater to a condensing one to increase efficiency without imposing a maintenance burden on the low-income homeowner.

ZNE Metric

The ZNE metric that is being used affects whether gas or electric appliances are favored. From a site energy perspective, heat pump water heaters (HPWHs) are the clear winners because they are 2-3 times more efficient than the best gas-fired water heaters. However, because of the relative weights that the TDV factors give to gas and electricity consumption, gas-fired water heaters are preferable from a TDV perspective. For example as shown in Table 2, for a 3 bedroom house in CA climate zone 12, a HPWH would consume about 45% less site energy but 103% more TDV energy than a condensing gas tankless water heater. Gas-fired water heaters are also preferable from a source energy perspective; a HPWH would consume about 60% more source energy than a condensing gas tankless water heater in the same house. Because this demonstration program is using a TDV-based definition of ZNE, a consultant team considered but did not recommend a HPWH to one of the builders.[10]

Table 2. Comparison of energy consumed by condensing gas tankless and heat pump water heaters – 3 bedroom house in CA climate zone 12

Water Heater	Site Energy (MMBtu/yr)	Source Energy[11] (MMBtu/yr)	TDV[12] (MMBtu TDV/yr)
Gas tankless 0.96 EF	8.9	9.7	14.4
HPWH 2.4 COP	4.9	15.5	29.3

Subsequent ZNE Homes

One of the ideas behind the Demonstration is that once production builders have built one ZNE home, subsequent ones will be easier and less costly. There is some work that only has to be done once and then can be reused in future projects, such as:

- Finding LED alternatives for lamps and fixtures
- Revising drawings, for example to raise the top plate from 8’ to 9’ in order to accommodate a dropped ceiling for locating ducts in conditioned space
- Assessing the structural strength of 24” on center studs for transport by truck and revising drawings to include them
- Rearranging the floor plan to group hot water draws and shorten pipe runs
- Training subcontractors on new installation techniques

Under the auspices of the demonstration, builders are able to try novel solutions and assess their performance before using them more widely. For instance to locate ducts in conditioned space, one builder is moving the attic insulation from the attic floor to directly under the roof deck by gluing and wiring the fiberglass batts to the underside of the roof. However, this builder has some concerns about moisture in the unvented attic and the length of the installation process.

[10] This analysis is based on current TDV factors and site-source multipliers, which may change in the future.
[11] Department of Energy national site-source multipliers (National Institute of Building Sciences 2015).
[12] 2013 factors.

Building a ZNE house once also allows builders to better assess any cost differences. Labor, in particular, is difficult to estimate, and one builder has included a contingency figure into their budget around the air sealing goal. Next time, the contractors will not only have experience with the level of detail that is required but the builder will be more confident about the budget.

Time is of the essence in construction, and getting plans approved can be a lengthy process. With standard models and plans that already been approved, builders can get their permits faster. Once they have gone through the process with a ZNE house, those plans can also be permitted more quickly.

Modeling Challenges

Both BIRAenergy and Resource Refocus used BEopt v2.3 running the EnergyPlus simulation engine for modeling the performance of the houses (NREL 2014). While this is an excellent tool, there are still some limitations that make modeling some features considered during the design process challenging.

Hot Water Distribution

Energy for heating water is a large fraction of total consumption in ZNE homes in California, often 25-35%, especially in small houses.[13] Because of this, details of the distribution system can make a noticeable impact. One builder carefully grouped the hot water use points very close together in order to minimize pipe runs, but there is not a built-in way to model compact design. Instead a 10% reduction in hot water consumption was assumed based on a study about water savings from short pipe runs (Kosar, Glanville, and Vadnal 2012).

Hydronic Heating

A homebuyer requested radiant floor heating, which cannot be directly modeled in BEopt. Modeling the system directly in EnergyPlus proved difficult because of the complicated control sequence that was proposed to link one HPWH used for both water and space heating and an air source heat pump for backup space heating. Although the final design solution was to use dedicated space and water HPWHs, the final modeling solution was to calculate an upper bound on heating consumption using an air source heat pump to cover the whole heating load. This value was used to size the PV array.

Unusual Constructions

In order to allow larger rooms than are otherwise possible in buildings that are trucked to site, the modular builder has developed hinged floor and wall constructions. Such unusual constructions cannot be modeled directly in BEopt, but there was concern that the metal hinge was a significant enough thermal bridge to affect performance. We therefore used the two-dimensional heat transfer software THERM to calculate the assembly R-value to input into BEopt (LBNL 2015). When we discovered that the hinge was reducing the floor performance from R-25 to R-17, we modeled several possible options for breaking the thermal bridge before settling on a layer of polyisocyanurate around the hinges to bring the assembly back to R-23.

[13] Based on modeling the homes and some variants for this demonstration project.

TDV

BEopt can directly calculate TDV consumption for simulations using the California weather files, but the latest version of BEopt automatically uses the 2008 TDV factors and weather files instead of the 2013 versions that are currently used for code compliance[14]. The weather file year used for analysis is not stated in the BEopt documentation and must be double checked manually, which can potentially lead to confusion and errors. In order to use the up-to-date weather and TDV values, the simulated hourly energy consumption output has to be manually post-processed to multiply by the appropriate hourly TDV values.

The weather files and TDV factors that are used have a surprisingly large impact. The same generic house with a gas furnace and water heater modeled in CA climate zone 3 required a PV array almost 20% smaller using the 2013 TDV values compared to the 2008 ones.

Evaluating Modeled Energy Performance

Energy Use Intensity (EUI) is one of the standard metrics of building energy performance because it allows comparison across different building sizes. This works well for buildings like offices where the end uses are mostly proportional to floor area, but in houses there are several important end uses that depend strongly on the number of occupants. For modeling purposes, the number of bedrooms serves as a proxy. The number of showers or loads of laundry per house, for example, do not depend on the floor area of the house. This means that comparing the EUI of the small houses built by low-income builders to the EUI of larger houses with the same number of bedrooms gives a misleading picture of their relative efficiency.

Figure 2 shows the modeled performance of the six builders' houses per floor area (EUI) and per bedroom. "Exemplar" houses with 3 bedrooms and 2,100 sf were developed in multiple climate zones by Arup as a proof of ZNE design (Arup 2012). Their modeled energy performance is shown below for comparison. While houses D and E have higher EUIs than their corresponding exemplars, they have lower consumption per bedroom. The change in relative efficiency is dramatic when comparing the builders with the two metrics; D and E had among the highest consumption on a per-area basis and the lowest consumption on a per-bedroom basis.

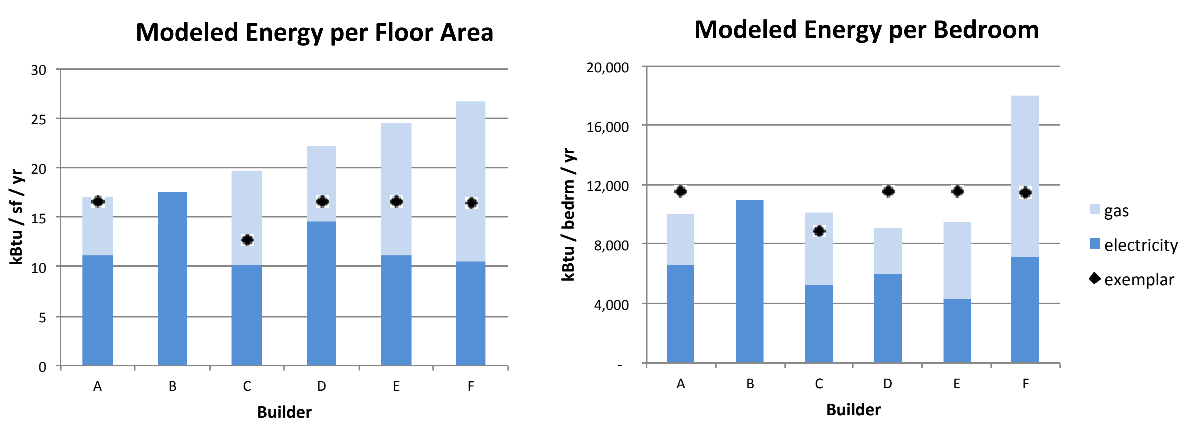

Figure 2. Modeled energy consumption per floor area and per bedroom. "Exemplar" performance shown for the same climate zone as the modeled home (Arup 2012).

[14] As of May 2016 writing.

Energy Performance Monitoring

Energy consumption in each of the prototype homes will be monitored for one year once all systems are installed and operational and the house is occupied. Total building electricity and gas use, along with disaggregated electrical and gas end uses will be collected using Powerwise SiteSage dataloggers. The datalogging equipment will be connected to the home network either through hardwired Ethernet or Wi-Fi, or use cell modem to communicate directly to a cloud-based portal. Electrical end uses will be measured using power monitors located at the main service panel or subpanel. The performance monitoring team coordinated with the builders and electrical contractors to separate the end uses in the panel, especially lighting and plug loads since they are often grouped together, so that they can be individually measured. Temperature sensors and gas meters are wired directly to measure indoor zone temperatures and gas appliance energy use, respectively. The dataloggers will upload data to the portal at one minute intervals and will log and report sums and averages at one hour intervals. Additionally, on-board memory is sufficient to store three weeks of data, so that loss of power or communications will not interrupt the stream of data.

The SiteSage portal also provides an online dashboard, allowing the occupants to see how much energy they are using, how much energy the PV system is producing, and overall how well the house is performing from a ZNE standpoint.

Conclusions

One of the biggest opportunities for builders designing for ZNE is to exploit synergies where energy efficiency and cost savings go hand in hand. Some of these are a result of the ways that individual building components interact with each other when considering the house as a whole system.

Choices that seem to be simple, like choosing a water heater, can be complex when weighing multiple factors. Local conditions, cost to the builder and to the homeowner, upcoming code changes, product availability, and bidding and construction systems all make an impact.

The ZNE metric that is chosen has a significant impact on design decisions. In general, with the current TDV factors, fuel switching from gas to electricity is often beneficial from a site energy perspective but counterproductive from a TDV perspective. In terms of PV sizing, the TDV metric requires a smaller array than the site metric to get to zero.

When comparing the energy performance of houses, it is useful to consider both EUI and energy per bedroom because the major end uses are split between ones that vary with floor area and ones that vary with the number of bedrooms. Small houses that look comparatively inefficient with the EUI metric can be the most efficient with a per-bedroom metric.

Building subsequent ZNE homes is expected to be easier and cheaper for the builders because they can reuse some of their design work and research into and sourcing of replacement technologies. Builders and contractors are also more confident in processes and technologies they have already tried. Of the builders we’re working with, all six have indicated that they plan to continue applying a number of ZNE design strategies and iterating the ZNE prototypes.

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