Pacific Gas and Electric Company Zero Net Energy Production Builder Demonstration
Habitat for Humanity of San Joaquin County
Dream Creek Subdivision, Stockton, California

Figure 1. Completed Demonstration Home (Chitwood Energy Management)

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Acknowledgements

This project was conducted as part of Pacific Gas and Electric Company's Zero Net Energy Production Builder Demonstration. It was led by Ann Edminster (Design AVEnues) in collaboration with Rick Chitwood (Chitwood Energy Management) and Steve Easley (Steve Easley & Associates Inc.). Peter Turnbull, Conrad Asper, and Can Anbarlilar (PG&E) as well as Anna LaRue and Margaret Pigman (Resource Refocus LLC) provided general oversight. Bill Dakin, Daniel Stuart, and James Haile (Davis Energy Group) are monitoring the energy performance of the occupied home. George Koertzen and Mike Huber led the project for Habitat for Humanity of San Joaquin County.

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EXECUTIVE SUMMARY

California's strategic energy plans call for all new California homes to be designed for zero net energy (ZNE) by 2020. Pacific Gas and Electric Company (PG&E) developed a consultant-based assistance demonstration effort to identify and showcase cost-effective ways to incorporate ZNE processes and techniques into production home-building.

Habitat for Humanity of San Joaquin County ("SJC Habitat") partnered with PG&E in the ZNE Production Builder Demonstration ("Demonstration") beginning in 2015, assisted by the Design AVEnues consulting team (Ann Edminster, Design AVEnues LLC; Rick Chitwood, Chitwood Energy Management; and Steve Easley, Steve Easley & Associates, "Consultants"). PG&E funded the Consultants' contributions and provided the builder with a cost reimbursement of up to $15,000 to offset the cost of upgraded equipment and some learning curve costs associated with design and drawing changes.

The Demonstration home is House 10 in the Dream Creek subdivision of Stockton, California (Climate Zone 12). It is a one-story, 1,200 square foot, 3-bedroom, 2-bath single-family house. With the implemented energy efficiency measures, the project is anticipated to achieve an energy use intensity (EUI) of 21.8 kBtu/sf/yr and ZNE[1] on an annual basis with the installed 3.36 kW photovoltaic system.

This project is somewhat unusual in that the construction manager had already been working towards the ZNE goal, having built several homes in the subdivision with successive energy efficiency improvements incorporated in each one. Thus, modeling showed relatively small performance gains during the formal Demonstration project. However, in order to accurately represent the net effect of SJC Habitat's progressive approach to ZNE, this report documents the changes made, and the performance outcomes, from House 1 to House 10 in the subdivision.

The ZNE measures, in aggregate, *reduced* the net cost of the home by nearly $3,000. This unexpected outcome was the result of a holistic, highly integrated approach that involved greater investment in some aspects of labor, materials, and equipment, more than offset by savings in labor, materials, and equipment from key efficiency strategies. **SJC Habitat has determined that all future homes in this and other subdivisions will include all the energy features implemented in House 10.**

> ***This project demonstrates that ZNE can be highly affordable even on a limited budget; projects with more generous budgets should have no difficulty achieving ZNE provided they approach that goal with the same attention to detail shown by SJC Habitat.***

[1] "ZNE" here refers to the California code definitions provided below, under "Demonstration Background."

Some of the major improvements include:

- Wall framing changed from 2x4 @ 16" o.c. to 2x6 @ 24" o.c.
- Wall cavity insulation increased from R-11 to R-21
- R-5 exterior wall insulation added
- Air sealing focus increased, with envelope leakage rate reduced by two-thirds
- Gas furnace and air conditioner replaced by a ¾-ton mini-split heat pump
- Both the duct system and the hot water fixture layout designed to be very compact
- Lighting improved from a combination of compact fluorescent and incandescent fixtures to all light-emitting diode (LED) fixtures

However, many other, more innovative measures also contributed significantly to the success of the project. *Table 1* provides a comprehensive, detailed list of the measures employed. That list along with cost data can be found in Appendix 1.

The SJC Habitat example outstandingly demonstrates the cost-effectiveness of cross-trade synergies, which – despite their benefits – are seldom captured in mainstream construction projects. These synergies require collaboration *during design*, when the design team works with the trades to identify design changes that meet the overall project goals. An example is creating space for mechanical systems inside the enclosure, an important measure that is nearly impossible to accomplish without early collaboration.

Several other important lessons emerged from the realization that nearly all the energy efficiencies and cost benefits achieved on this project derive from the unusual level of motivation, knowledge, and capabilities of SJC Habitat and its construction manager:

1. Top-level organization commitment and consistent, conscientious attention to details – in design, construction, and commissioning – is instrumental to success in achieving high performance goals.
2. Training in energy-efficient design and construction is effective, and enables a trainee (who is experienced, innovative, and efficiency-minded) to achieve very high performance results when given the opportunity to iteratively incorporate improvements in a series of homes.
3. Targeted education for building professionals allows them to achieve ZNE with almost zero reliance on either unproven technologies or even on expert consulting support. While the Consultants did suggest beneficial refinements to the design, those interventions accounted for only a 5% reduction in modeled energy use as compared to the original design – or far less than the equivalent of one solar panel.

These findings are of great relevance to the future development of ZNE programs in and beyond California. To the degree that mainstream production builders can receive targeted, comprehensive, effective ZNE education (both classroom-based and onsite), are otherwise well-equipped to implement the principles, and receive adequate organizational support for implementation, California's goal for all new residential construction to be ZNE by 2020 will be easily achieved.

Table 1. Detailed Specifications (a blank cell indicates no change, bold indicates final package)

STOCKTON DREAM CREEK ZNE DEMONSTRATION PROJECT SPECIFICATIONS		House 1 (before EE iteration)	House 8 (ZNE features, pre-demo)	House 10 (ZNE Demo)
Envelope				
Exterior Walls	cavity R value, insulation type	R-11 Fiberglass	**R-21 denim**	
	framing type, spacing	2x4 16" oc .35 framing factor	**2x6, 24"oc, 0.13 framing factor**	
	continuous insulation type, R value	none	**R-5 XPS**	
Glazing	U / SHGC	.5 U/ .25 SHGC	**0.27 U / 0.24 SHGC**	
	WWR	13.2% WWR	**6.4% WWR**	
	shading	**1' eaves**		
	skylights	**no skylights**		
Roof	insulation type, R value	**R-42 cellulose**		
	insulation location	**attic floor**		
	vented/unvented attic	**vented attic**		
	radiant barrier?	**radiant barrier**		
	roof material	**Composition**		
	reflectance / emittance	**0.25**		
Foundation	type	slab	vented crawlspace	**reduced ventilation crawlspace (0.5 ACH)**
	insulation		**R-21 denim**	
	framing type, spacing	NA	**4x6, 32" oc**	
Air leakage	ACH50	4.75 ACH50	1.8 ACH50	**1.5 ACH50**
HVAC System				
Ventilation	type	balanced, 2 ERVs		
Heating & Cooling	heating system type	3-ton split gas furnace	**ducted mini split**	
	heating efficiency	80%	10 HSPF	**12.5 HSPF**
	heating capacity	60,000 Btuh	10,900 Btuh	**12,000 Btuh**
	cooling system type	conventional a/c	**ducted mini split**	
	cooling efficiency	13 SEER	15.3 SEER	**24.5 SEER**
	cooling capacity	3 tons	1.5 ton	**3/4 ton**
	equipment location	attic	**cond. space (hall soffit)**	
	switching			**heat pump off switch**
	thermostat	code-compliant setback	**wired web-enabled**	
Ducts	location	attic	**dropped ceiling - conditioned space**	
	insulation	**R8**		
	change in duct length?	250 ft	50 ft	**slightly shorter ducts**
Water Heating				
Water Heater	water heater type, efficiency	**tankless gas, 0.82 EF**		
	equipment location	garage		**interior wall**
DHW distribution	insulation, pipe material	**Pex in conditioned space**		
	recirculation system	**no recirculation**		
	low flow fixtures	**low flow fixtures**		
	change in pipe length	WH to last fixture 60'	WH to last fixture 50', avg fixture run 25'	**WH to last fixture 12' (moved from garage to center of house), avg fixture run 8'**
Electric Loads				
Lighting	100% LED	50% CFL, 50% incandescent	**100% LED**	
	controls			
Appliances	fridge	fridge	**EnergyStar fridge**	
	cooking	**electric cooking**		
	dishwasher, washer, dryer	**not provided, assumed inefficient electric**		
Other	Home energy management (HEM)			**HEM system added**
	Light "on" indicators, garage & porch lights			**lights on switch panels to indicate they're on**
	Power disconnects, mini-split & water heater			**Added disconnects**
	EV charging			**EV-adaptable circuit in garage**

DEMONSTRATION BACKGROUND

PG&E launched the Demonstration in 2014, offering design assistance to selected production builders to help them in achieving significant energy demand reductions for residential projects with ZNE goals. The homes built during the Demonstration are intended to inform PG&E's future program offerings and provide insight into ways to reduce barriers to the design, construction, and operation of ZNE buildings in California.

For purposes of the Demonstration, PG&E used the California Energy Commission's 2013[2] definition of a ZNE home:

> *A zero-net-energy code building is one where the net amount of energy produced by on-site renewable energy resources is equal to the value of the energy consumed annually by the building, at the level of a single "project" seeking development entitlements and building code permits, measured using the California Energy Commission's Time Dependent Valuation [TDV] metric.* [This is referred to as ZNE-TDV; henceforth in this report, "ZNE" is used to represent ZNE-TDV.]
>
> *A zero-net-energy code building meets an energy use intensity value designated in the Building Energy Efficiency Standards by building type and climate zone that reflects best practices for highly efficient buildings.*

PG&E contracted with the Consultants to work with several builders, starting by performing initial assessments of builder-selected candidate home plans and, based on those plans, proposing a detailed work scope designed to enable the homes to achieve ZNE.

The second phase of work involved the Consultants working with each participating builder to design, construct, evaluate, and document a single home to achieve ZNE. This entailed adjusting a current, above-code design to achieve ZNE, while meeting both the builder's objectives and the objectives of the Demonstration. Resource Refocus LLC collaborated with the Consultants to provide energy modeling results for the base case and for potential energy savings packages the team wished to evaluate.

A monitoring consultant team, Davis Energy Group, was also active from the early stages of design to integrate monitoring equipment. After occupancy, the end use energy consumption of each Demonstration home will be tracked over the course of a year to evaluate whether the occupied prototype is performing as designed and to diagnose any adjustments that may be indicated.

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[2] CEC (California Energy Commission). 2013. *Integrated Energy Policy Report: 2013 IEPR*. http://www.energy.ca.gov/2013publications/CEC-100-2013-001/CEC-100-2013-001-CMF-small.pdf

DESCRIPTION OF HOUSE/PROJECT

In this case study, the Consultants worked with SJC Habitat, a non-profit developer that serves a low-income population, providing affordable housing using a combination of donations, student trainee labor, and sweat equity on the part of future homeowners. (It is important to note that the participation of unskilled workers and trainees was a factor in several design decisions that might have been approached differently with a more typical labor force.) The family that now owns the home comprises two adults and two young children.

The primary SJC Habitat contacts were George Koertzen, construction manager, and Mike Huber, executive director.

The home is a one-story, three-bedroom, two-bath unit, with 1,200 square feet of occupied space. There is a two-car attached garage. It is a mixed-fuel home, with natural gas used for water heating and all other energy end uses served by electricity.

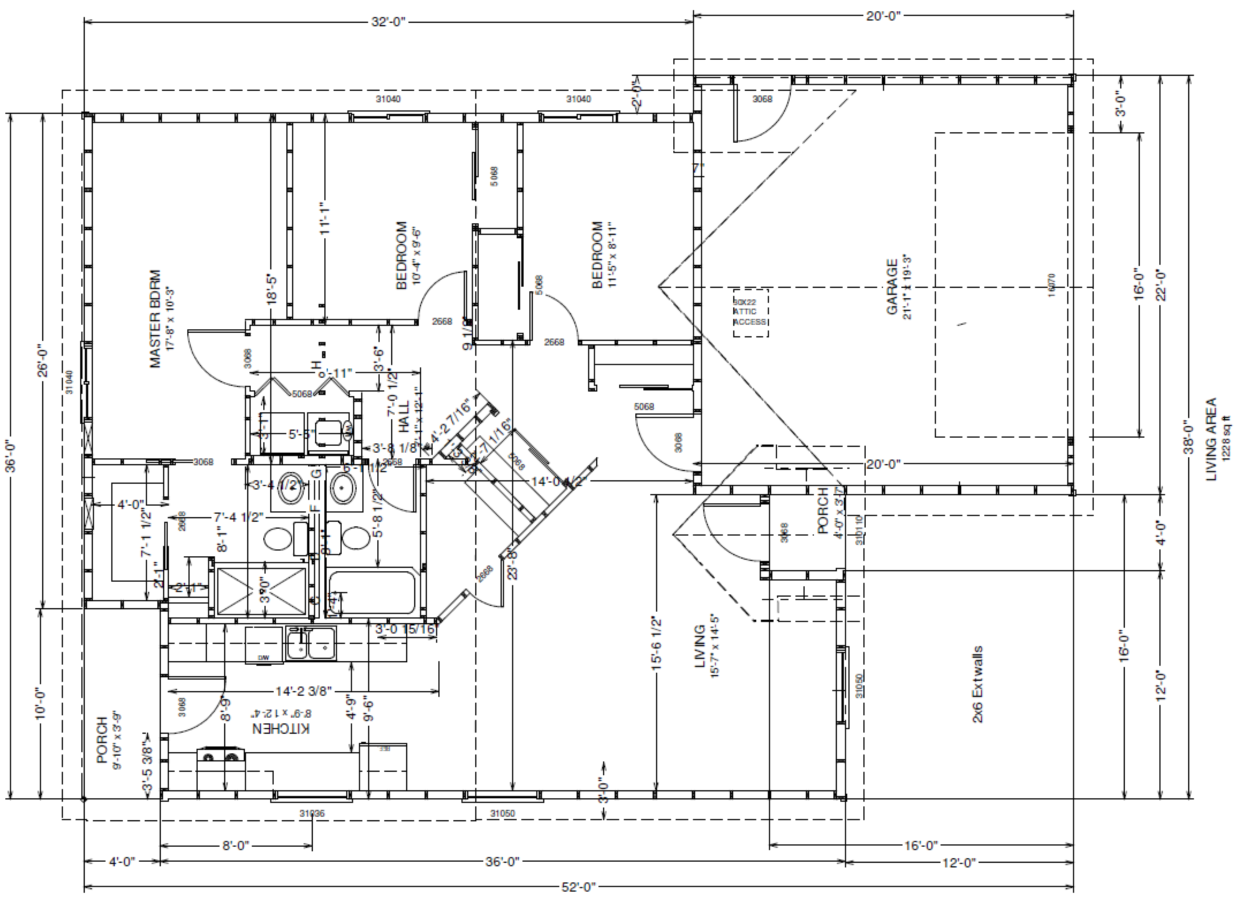

Figure 2. Demonstration Home Floor Plan (SJC Habitat)

Figure 3. Demonstration Home Southwest Elevation (SJC Habitat)

SJC Habitat's interest in participating in the pilot arose primarily due to Mr. Koertzen's personal dedication to resource efficiency and housing affordability, including ensuring extremely low utility costs for the eventual homeowners. Mr. Koertzen has a background in production building; he served for seven years as the production manager for a modular manufacturer and owned a panel plant for two years. In a sense, PG&E's "technical assistance" role in the project began three years earlier, in 2013, when Mr. Koertzen attended a series of six full-day classes on ZNE New Homes at PG&E's Energy Training Center in Stockton.[3]

In the three years following Mr. Koertzen's attendance, he continued a casual dialogue with Chitwood, Edminster, and other consultants while integrating more advanced energy features into the Dream Creek subdivision. By the time of building the eighth home ("House 8") in the subdivision, not only had Mr. Koertzen integrated most of the advanced energy features covered in the classes into his standard construction practices, he had further refined nearly every feature. With input from the Consultants, a few additional refinements were incorporated into the Demonstration home ("House 10"). This report, therefore, reflects the net effect of the improvements incorporated in the subdivision as a whole, not exclusively those in House 10.

The heating/cooling equipment sizing provides one striking example of the improvements made. The first house in Dream Creek has a 3-ton air conditioner and a 60,000 Btu/hr furnace. House 10 has a ¾-ton air conditioner (a 75% reduction in system capacity) and a 12,000 Btu/hr heating system (an 80% reduction in capacity). More carefully matching the system heating/cooling capacities with the enclosure losses increases occupant comfort while reducing demands on the electric grid and gas pipeline infrastructure. It will also extend the lifespan of the HVAC equipment, which will experience less frequent cycling with capacities better matched to the loads.

[3] The ZNE New Homes class series Mr. Koertzen attended was developed in 2011 by consultants Ann Edminster and Rick Chitwood and a team of additional instructors (including Steve Easley), with funding from the PG&E ZNE Pilot Program.

ENERGY EFFICIENCY IMPROVEMENTS

Implemented Measures

Highlights of the Dream Creek ZNE homes include advanced framing measures to reduce thermal bridging. Specific advanced framing features include 24" o.c. framing throughout, single top plates, engineered wood headers, windows sized and located to fit framing layout, and numerous other efficient details. This package of measures, many of them quite innovative, has yielded the exceptionally low framing factor of 12.5%, which is between one-third and one-half the state average. Appendix 3 has more information about how this was achieved.

Other measures were focused on achieving the outstandingly low infiltration rate of 1.5 ACH_{50}. These included a suite of cost-effective air sealing details, blower door testing on every home, fixed windows at appropriate locations, no recessed lights, attic and crawlspace access hatches that do not penetrate insulated assemblies, raised-heel trusses, and other details, also shown in Appendix 3.

Table 2 lists measures implemented in House 8, the first home to incorporate a comprehensive set of ZNE measures (and prior to the Consultants' direct involvement).

Table 2. House 8 ZNE Improvements

	Item	**House 8 Improvements**
Enclosure	Insulation	Above-code insulation in walls (R-21) and attic (R-42) plus continuous exterior wall insulation (R-5)
	Windows	Improved windows (0.27 U vs. 0.5 on earlier homes)
	Framing	Innovative advanced framing strategies, resulting in a framing factor of 12.5%
	Foundation	Ventilated crawl space (vs. slab in House 1)
	Air Sealing	Air leakage rate of 1.8 ACH50
Mechanical	Hot Water Distribution	Compact hot water fixture layout adopted
	HVAC Equipment	1.5-ton ducted mini-split, HSPF 10, SEER 15.3 (vs. 3-ton gas furnace and conventional a/c in House 1)
	Ducts	Moved from attic to conditioned space
Elec	Lighting	100% LED (vs. 50% CFL, 50% incandescent in House 1)
	Appliances	Energy Star fridge provided

With the Consultants' input, the additional items shown in *Table 3* were implemented in House 10.

Table 3. House 10 ZNE Improvements

	Item	Improvement, House 10
Enclosure	Foundation	Reduced ventilation crawl space
	Air Sealing	Improved air sealing (reduced from 1.8 to 1.5 ACH50)
	Doors	Half-glazed kitchen back door for better daylighting and eyes on the back yard
Mechanical	Water Heating	Relocated tankless water heater to laundry area to move it into conditioned space and minimize hot water piping runs
	HVAC	¾-ton ducted mini-split, HSPF 12.5, SEER 24.5
	Ventilation	ERVs relocated to shorten duct runs
	Controls	Power disconnect (double-pole light switch) for mini-split in hallway next to thermostat; also for water heater
Electric	Energy Management	Home energy management system (HEMS) added
	EV Charging	EV-adaptable circuit in garage
	Lighting Controls	Vacancy sensors in baths
	Indicators	Indicator lights on switch plates for outdoor and garage lights to show when they're on

Non-adopted Measures

A few measures that were recommended were not adopted, for the reasons indicated in *Table 4* below.

Table 4. ZNE Improvements Not Adopted

Recommendation	Reason for Non-adoption
QII-compliant installation of cotton batt insulation in walls	Insulation is installed by volunteer unskilled labor, so QII-compliant installation is sometimes hard to achieve
Solar tubes for daylight in interior baths and hallways	Running LEDs for estimated hours of use each year is less costly than installation of solar tubes, and reduces roof penetrations that compromise the thermal enclosure
Landscaping on west property line for shading	Insufficient space; close neighbor also shades structure
Best-in-class appliances (e.g., rating of 90+ on Enervee.org)	Appliances that are provided are donated so model choices are limited; others are purchased by the homeowner

PERFORMANCE MODELING

In order to assess the effects of energy efficiency measures and to size the PV system to achieve ZNE-TDV, the house was modeled in BEopt version 2.3, using both SJC Habitat's standard design[4] and the proposed energy efficiency measures.[5] The performance was evaluated using site energy, which can be measured and thus will be used for comparison with monitoring data, and TDV energy. The State of California uses TDV to account for the different values of energy to society based on its source and on when and where it is consumed or produced. TDV energy is calculated using the simulated hourly site energy consumption and climate-dependent hourly TDV factors for gas and electricity. These factors weight electricity more than gas and electricity produced or consumed during hot summer afternoons much more heavily.

Site Energy Simulation

The modeled site energy use intensity (EUI) of House 10 is 21.8 kBtu/sf/yr, 6% lower than the baseline EUI, as shown in Figure 4 and *Table 5*. This slim margin of improvement reflects the fact that numerous efficiency measures, as mentioned above, had already been incorporated into the design. More than half of the modeled savings came from water heating, where the savings were achieved by moving the water heater into conditioned space and shortening the hot water pipe runs.

Modeling also indicates that water heating is the largest consumer of site energy, followed by appliances and plug loads (Figure 4 and *Table 5*). Because hot water consumption depends on the number of occupants, rather than on the size of the house, it is not surprising that a high proportion of the energy use in this small (1,229-sf) three-bedroom house is for water heating.

SJC Habitat provides an Energy Star refrigerator but does not provide a dishwasher, clothes washer, or dryer; homeowners may purchase these independently. These appliances therefore were modeled using low values for efficiency, accounting for high energy consumption in the model. As it turned out, the homeowners did not install a dishwasher but did install an inefficient washer and dryer.

[4] House 8 is considered here to be SJC Habitat's standard or baseline package.

[5] The California Energy Commission's 2013 weather files and TDV factors for climate zone 12 were used for the modeling.

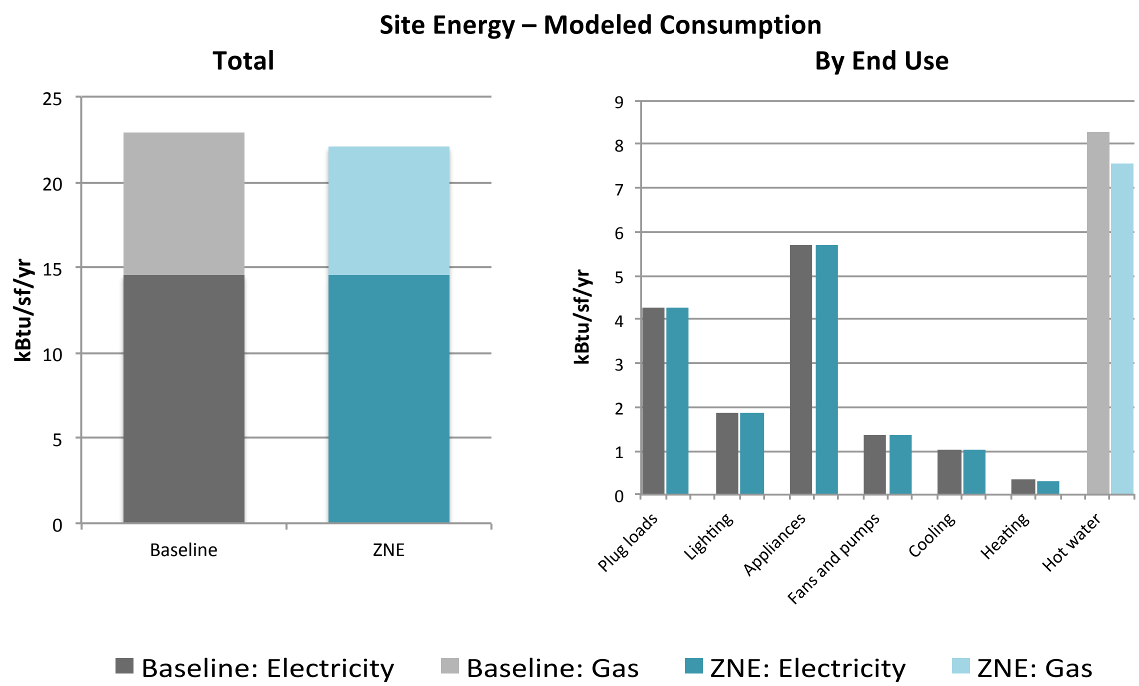

Figure 4. Modeled Site Energy Consumption (Resource Refocus LLC)

Table 5. Modeled Site Energy Consumption (Resource Refocus LLC)

	Site Energy - Modeled Annual Consumption								
	Baseline				ZNE				Savings
	Electricity kWh	Gas therms	Total kBtu	EUI kBtu/sf	Electricity kWh	Gas therms	Total kBtu	EUI kBtu/sf	kBtu
Plug loads	1,530	-	5,220	4.3	1,530	-	5,220	4.3	-
Lighting	674	-	2,300	1.9	2,052	-	2,300	1.9	-
Appliances	2,052	-	7,000	5.7	2,052	-	7,000	5.7	-
Fans and pumps	487	-	1,660	1.4	487	-	1,660	1.4	-
Cooling	369	-	1,260	1.0	223	-	760	0.6	500
Heating	129	-	440	0.4	141	-	480	0.4	- 40
Hot water	-	101	10,130	8.3	-	93	9,250	7.6	880
Total	5,240	101	28,010	22.9	6,483	93	26,670	21.8	1,340

TDV Energy Simulation

In terms of TDV, the difference in modeled consumption between the baseline and House 10 is only 1% (Figure 5 and *Table 6*). As was true for the site energy modeling, water heating represented the biggest difference between the two models. However, because the water heating is gas, which has relatively low TDV multipliers, this change did not have as large an impact on overall TDV consumption as it did on overall site energy consumption, and accounts for a much smaller proportion of modeled consumption – 11% TDV vs. 34% site energy (Figure 5 and *Table 6*).

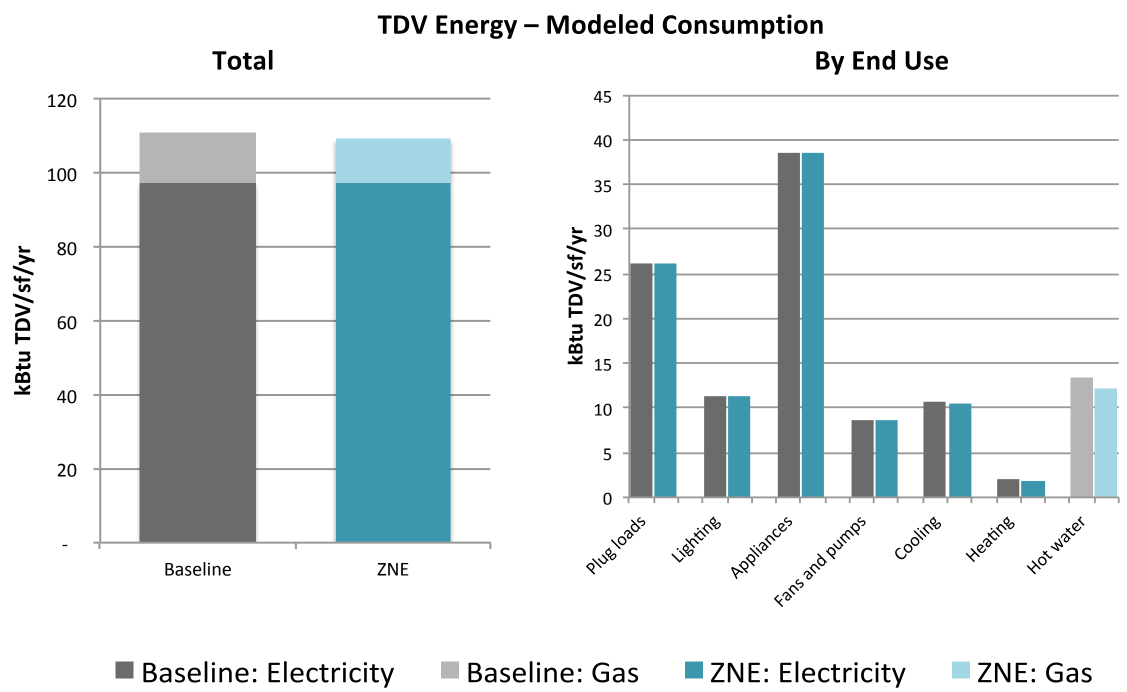

Figure 5. Modeled TDV Energy Consumption (Resource Refocus LLC)

Table 6. Modeled TDV Energy Consumption (Resource Refocus LLC)

	TDV Energy - Modeled Annual Consumption								
	Baseline				ZNE				Savings
	Electricity kBtu TDV	Gas kBtu TDV	Total kBtu TDV	Total kBtu TDV/sf	Electricity kBtu TDV	Gas kBtu TDV	Total kBtu TDV	EUI kBtu TDV/sf	kBtu TDV
Plug loads	32,156	-	32,156	26.25	32,156	-	32,156	26.25	-
Lighting	13,950	-	13,950	11.39	13,950	-	13,950	11.39	-
Appliances	47,161	-	47,161	38.50	47,161	-	47,161	38.50	-
Fans and pumps	10,670	-	10,670	8.71	10,660	-	10,660	8.70	10
Cooling	12,997	-	12,997	10.61	12,856	-	12,856	10.49	141
Heating	2,503	-	2,503	2.04	2,180	-	2,180	1.78	324
Hot water	-	16,421	16,421	13.40	-	14,988	14,988	12.24	1,433
Total	119,438	16,421	135,859	111	118,963	14,988	133,951	109	1,907

Comparison to Exemplar

In order to place these modeling results in a larger context, they were compared to exemplar performance of a house in California Climate Zone 12, as reported in *The Technical Feasibility of Zero Net Energy Buildings in California*.[6] Modeling of the SJC Habitat house shows a higher EUI than the exemplar (Figure 6). However, while both are three-bedroom homes, the SJC Habitat house is much

[6] "Exemplar" performance is taken from "The Technical Feasibility of Zero Net Energy Buildings in California" conducted on behalf of the California Investor-Owned Utilities by Arup, 2012. http://calmac.org/publications/California_ZNE_Technical_Feasibility_Report_CALMAC_PGE0326.01.pdf

smaller than the exemplar – 1,229 sf vs. 2,100 sf. Some loads, such as heating and cooling, vary depending on floor area, but others, such as water heating, appliances, and plug loads, vary depending on the number of occupants. Comparing to the performance of the exemplar using the number of bedrooms plus one as a proxy for number of occupants, the SJC Habitat house is modeled to consume 23% less per person than the exemplar (Figure 6).[7]

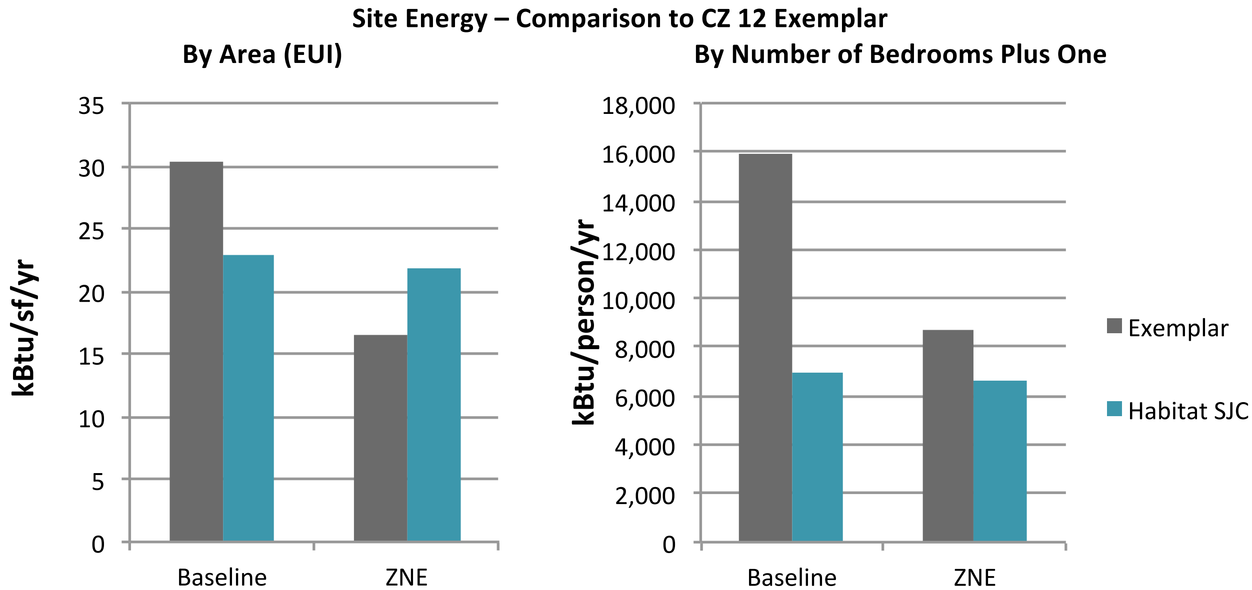

Figure 6. Comparison of Modeled Site Energy Consumption to Exemplar (Resource Refocus LLC)

Site vs. TDV

Figure 7 shows the modeled monthly consumption of the Demonstration house for both site and TDV energy throughout the course of a year. In terms of site energy, appliance and fans and pumps consumption remain relatively constant throughout the year, while lights, plug loads, and hot water consumption are higher in winter than in summer.

These differences combine to create the U-shaped consumption trend for the whole year (Figure 8). In terms of TDV energy, consumption in the winter is also higher than in the swing seasons, but the electric end uses spike from July through September, when the TDV multipliers for electricity are the highest. When considering all the end uses together, the consumption pattern is a W-shape with the summer values being highest overall (Figure 9).

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[7] This follows Building America assumptions and ASHRAE Standard 62.2, which both use the number of bedrooms plus one as a proxy for the number of occupants.

For both site and TDV energy, PV production follows an inverted U-shape, with production peaking in the summer months. For site energy, PV production is less than consumption every month (Figure 8). For TDV energy, PV production is more than consumption from May through September, which allows the house to achieve annual zero net energy performance even though consumption exceeds production for 7 months (Figure 9). Once again, the effect of the large TDV multipliers for electricity consumed or produced during summer afternoons accounts for the difference between the two metrics.

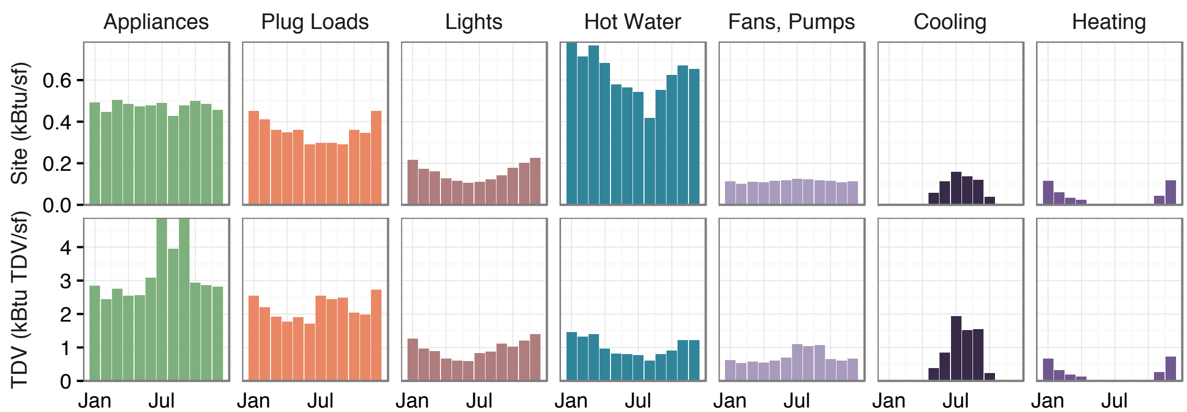

Figure 7. Monthly Modeled End Use Consumption – Site and TDV Energy (Resource Refocus LLC).

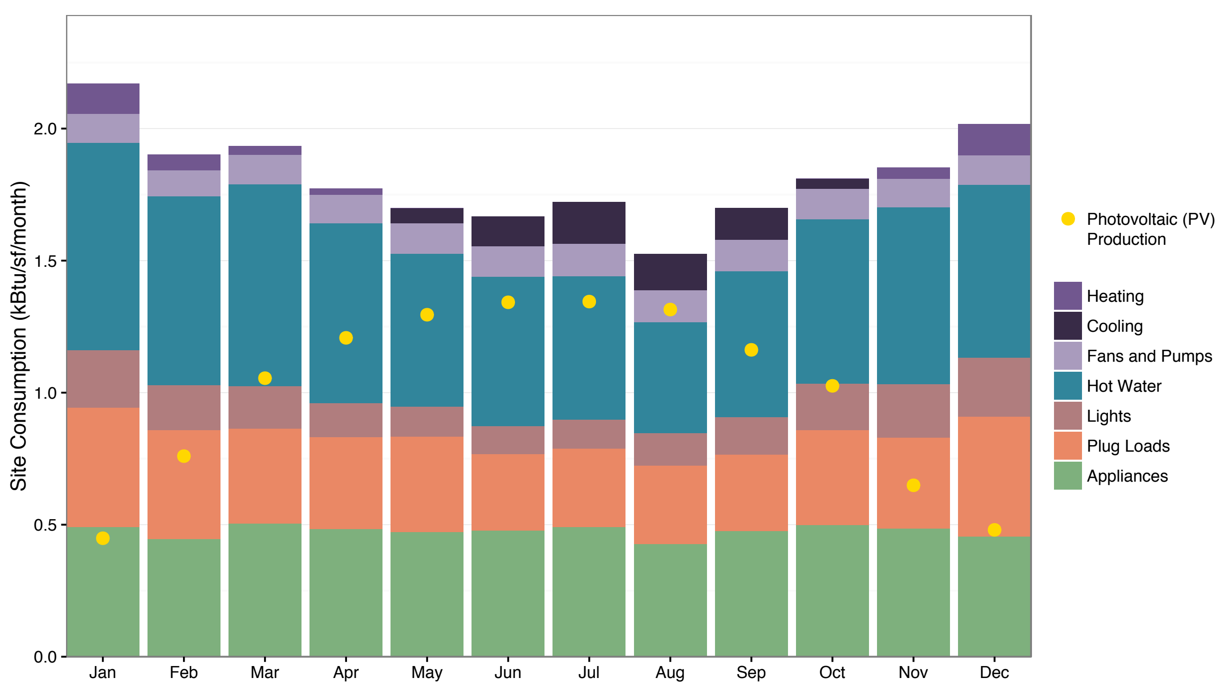

Figure 8. Modeled Monthly Performance of ZNE House – Site Energy (Resource Refocus LLC)

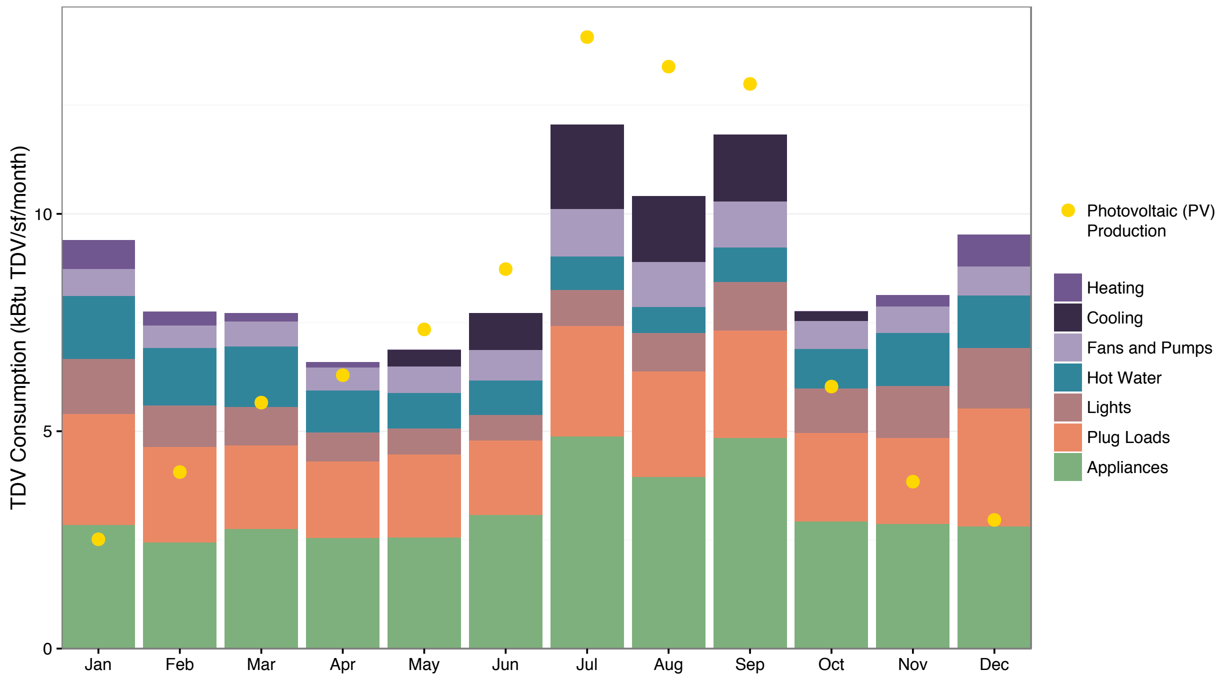

Figure 9. Modeled Monthly Performance of ZNE House – TDV (Resource Refocus LLC)

Based on the current feature set, energy modeling indicates that the project will be able to achieve ZNE-TDV with a PV array of approximately 3.2 kW. A 3.36 kW array was installed.

CONSTRUCTION PROCESS

The construction process for this Demonstration house, as with any project, begins with design and planning. The seeds for the many energy feature upgrades were planted when Mr. Koertzen attended a series of classes on ZNE New Homes at the PG&E Energy Training Center in Stockton three years earlier. Mr. Koertzen, with his decades of residential construction experience, understood the benefit of virtually every energy efficiency measure covered in these six days and how well they all matched the goals of his project – affordable zero net energy.

New production homes in California are typically built in 60 to 90 days. Because SJC Habitat's homes are built by students and volunteers, their process may take as much as ten months. This longer construction period provides many more opportunities for consultant site visits to refine efficiency measures.

The consulting team field specialist Rick Chitwood visited the construction site on ten occasions, to provide performance input on equipment installation details and to document all energy features photographically. These site visits have yielded improvements in the installed performance of the two energy recovery ventilators (ERVs), the bathroom exhaust fans, and the heat pump. On one visit, the infiltration rates on two earlier houses in the subdivision were measured and air leakage sites were identified using a smoke generator. These findings were used to reduce air infiltration in the Demonstration house.

The home was completed in March 2016. The homeowners took occupancy in late May 2016.

Planning Stage Site Visits

Three site visits were made during the planning stage of the Demonstration. These visits benchmarked the current construction process and current performance levels. During these visits air infiltration measurements (blower door tests) were made on the two previous houses (Houses 8 and 9) and a smoke test was performed on House 9 to identify air leakage sites (Figure 10). These tests identified air leakage sites that otherwise would have gone undetected, reinforcing the need to perform diagnostic testing on every high-performance home.

Figure 10. Smoke Test in House 9 (Chitwood Energy Management)

The blower door test on house 8 showed leakage at 572 CFM_{50}, or 3.6 ACH_{50}. At house 9 the leakage was 469 CFM_{50}, or 2.9 ACH_{50}. These air leakage numbers are much better than the state average for new homes of 5.5 ACH_{50}, but higher than the target for the Demonstration home. The Demonstration home had a final blower door test result of 250 CFM_{50}, or 1.53 ACH_{50}, about one-quarter of the state average for new homes.

Also at these planning visits, the heating/cooling system sizing was reviewed, leading to a capacity reduction of 50 percent – from 1.5 tons on House 8 to ¾-ton on Houses 9 and 10. The Consultants' deep experience in HVAC field testing has proven that for a small home in this relatively mild climate, with a high-performance, field-tested enclosure, every piece of heating/cooling equipment manufactured is too large. The Consultants therefore advised SJC Habitat to install the smallest available equipment, as oversizing makes it difficult to provide comfort. Further, a smaller system is less expensive, easier to install, and slightly more energy efficient.

This home is sized at 1,600 square feet of conditioned floor space per ton of cooling. Industry standard new homes are typically sized between 500 and 800 sf/ton, even though computer modeling has shown an 85 percent reduction in cooling loads in the last 35 years. A larger PG&E project home in Redding (a hotter climate), currently under construction, is being sized at 2,400 sf/ton.

Framing Stage Site Visits

Three site visits were made during the framing stage. These visits were used to provide guidance on the sizing and installation of the mechanical systems. Mr. Koertzen, with his decades of framing and construction experience, needed no consulting expertise implementing his innovative energy-efficient advanced framing details, which he had been refining since the ZNE New Homes classes three years before. However, these site visits also afforded the opportunity to document the construction process with dozens of photos, from which other builders can learn about the innovative and resource-efficient techniques and details that Mr. Koertzen has developed. His truss assembly detail shown below, for example, significantly reduces the need for blocking, thereby also reducing thermal bridging.

Many additional details are shown in Appendix 3.

Figure 11. Truss Assembly (Chitwood Energy Management)

Mr. Koertzen does not have significant experience with mechanical system design and installation. Duct sizing guidance was provided for all five pieces of the ducted mechanical equipment on these visits. Since all of the ducted equipment – two bathroom exhaust fans, two ERVs, and the heat pump air handler – have high-efficiency, electronically commutated motors (ECMs), there is a significant opportunity for fan energy saving by keeping the external static pressure low. Undersized ducts or air filters can actually cause these high-efficiency ECMs to use more fan energy than conventional fan motors due to high external static pressure. Ducting and filters were all sized to take full advantage of these advanced fan motors. For example, the return air filter grille installed on the ¾-ton ducted mini-split heat pump is as large as a grille often used on a 4-ton HVAC system – 20” x 30” and 2” thick. This oversized filter has three main advantages: 1) it greatly reduces fan energy, 2) it enables the use of high-efficiency air filtration, and 3) it reduces filter change intervals to once or twice a year. The measured static pressures are shown in the commissioning report (Appendix 2).

Finish Stage Site Visits

Three site visits were made during the finish stage. These visits included the following tasks:

1. Preliminary air infiltration (blower door) testing with only the ceiling dry-walled, so leaks were not yet covered by insulation and drywall. This test showed a very tight shell, 162 CFM_{50}, or 1.0 ACH_{50}. This test yielded a tighter result than the final test, since several penetrations were sealed, e.g., all three temporary exterior doors.
2. Mechanical equipment startup was performed. The ¾-ton split system heat pump outdoor unit is shown in Figure 12.
3. Further photo documentation was acquired.
4. Mechanical equipment commissioning was begun.

Figure 12. Installed Heat Pump (Chitwood Energy Management)

Several recommendations were made for further improvements to mechanical equipment, most focusing on installation practices and standardization of installation practices. Some of the recommendations include:

1. Install the heat pump farther above the ground to make it easier to work on and keep it out of the weeds.
2. Install the heat pump electrical service a little lower to minimize wire on the outside of the house.
3. Run a mini-split power/control wire with the refrigerant line set, which will eliminate one penetration on the outside of the house.

4. Replace current 110 CFM bathroom exhaust fans with 80 CFM units to reduce house depressurization.
5. To improve aesthetics in the living area, where framing limits grille space, use matching square supply grilles (probably 6” x 6”). (Current grilles are 10” x 4” and 4” x 8”.)
6. Include condensate piping (¾” PVC) for the ducted mini-split air handler in the rough framing.
7. Create a set of installation schematics for all mechanical equipment.

Commissioning Site Visit

Only one site visit was made to complete the equipment and enclosure commissioning. The commissioning process confirmed proper design and installation in accordance with the manufacturers’ instructions; this finding is notable in that California Energy Commission-funded research of 240 new HVAC systems found that 100 percent failed to meet manufacturers’ static pressure requirements. Commissioning would have identified this failure, but the industry standard is ***no commissioning***. See the full commissioning report in Appendix 2.

FINANCIAL FINDINGS

> ***The ZNE measures at Dream Creek REDUCED building costs by almost $3,000.***

The net effect of the ZNE measures implemented in the SJC Habitat Dream Creek subdivision has been to reduce the overall cost of building, factoring in both materials and labor. The total financial impact was a cost reduction of roughly $6,585 from House 1 to House 8, the first home that included a comprehensive set of ZNE measures. However, $3,650 of that total resulted from switching from a slab to an insulated, vented crawlspace, a change that was not driven by the ZNE goal.[8] The cost reduction from House 1 to House 10 attributable to the ZNE measures totals $2,862. The changes from House 8 to House 10, while achieving significant performance gains (e.g., equipment efficiencies, reduction in air leakage from 1.8 to 1.5 ACH50, and other improvements detailed in Appendix 1) increased costs by only $73.

Notable cost findings are listed below:

1. Changing the wall framing from 2x4 @ 16” o.c. to 2x6 @ 24” o.c. resulted in no significant net change in material costs, but reduced framing time by 12 hours, saving $300.
2. Improving the wall insulation from R-11 to R-21 caused no change in material cost but yielded a 4-hour reduction in installation time, saving $100.
3. The reduction in air leakage from 4.75 ACH_{50} to 1.5 ACH_{50} was achieved with an investment of both materials ($400) and 32 labor hours ($800), increasing the cost by $1,200.
4. Switching from a conventional gas furnace and air conditioner to a ¾-ton mini-split heat pump saved $2,000 and will provide improved comfort in addition to lower space conditioning costs.

[8] Two related factors drove the change from a slab to a crawlspace: slab installation requires skilled labor and therefore had to be done by a subcontractor, at relatively high cost; whereas building a vented crawlspace and a raised floor was within the capabilities of the SJC Habitat laborers.

5. A compact duct system reduced both materials and labor, saving $600.
6. A compact hot water distribution system reduced both materials and labor, saving $470.
7. Improving the lighting from a 50-50 mix of CFL and incandescent to 100% LEDs entailed a cost increase of $390.

Labor costs were based on a rate of $25 per hour; where labor rates are higher, changes such as items 1, 2, 5, and 6 would be likely to yield even greater savings. Conversely, the improved air sealing (item 3) – which relies on labor – might result in a cost increase for builders whose crews are not well-versed in the process. However, Mr. Koertzen believes that the time required for air sealing can be reduced considerably: "When it becomes something that is done as part of the normal process and has specific jobs to be done and trained people it might come down to 8 hours."

The saving due to the mini-split (item 4) results solely from an equipment change and thus will not be affected by different labor rates.

The change in lighting is also due solely to equipment; however, as 100% LED lighting is rapidly achieving greater market penetration, prices are dropping accordingly.

The detailed specifications and cost effects are shown in Appendix 1. Note that the reported costs and savings are approximate.

LESSONS LEARNED

The ZNE approach adopted by SJC Habitat was two-pronged – first, reevaluate every detail, and then identify and capture cross-trade synergies.

This approach is reflected in the enclosure in numerous advanced framing measures, both tried-and-true (albeit rarely implemented) strategies, as well as innovations unique to this project. Several of each type are shown in Appendix 3. Examples include locating wires only along the studs and bottom and top plates to minimize insulation obstructions (the bottoms of the studs were notched to facilitate this); ordering windows to fit within the 24-inch stud framing intervals; and, to assure that no extra framing lumber is used, showing every allowable stud on the plans.

The degree to which resource efficiency was integrated throughout this project is truly exceptional, and the details in Appendices 1 and 3 warrant close study by builders wishing to achieve ZNE cost-effectively.

Over the course of building and thoroughly commissioning ten homes in this subdivision, the outcomes in House 10 included reducing lumber use by more than 50%, with thermal bridging (and lumber costs) decreased accordingly; and air leakage measured at 1.5 ACH_{50}, less than one-third of the average for new California homes. As a result, the Demonstration house uses smaller, more efficient mechanical equipment: system capacities have been reduced by 85% for heating and 75% for cooling.

The SJC Habitat Demonstration was highly unusual in several respects:

1. The construction manager had proactively participated in numerous PG&E-sponsored efficiency and ZNE training classes;
2. The construction manager competently fulfilled several roles that are more typically fulfilled by multiple parties with varying levels of knowledge, commitment to energy goals, and competency in implementing high-performance building strategies (this reinforces the value of education for everyone in the design and construction process);
3. SJC Habitat remained extraordinarily committed and attentive to the ZNE goals throughout design and construction;
4. That commitment was exhibited in willingness to adapt the pre-existing home plans, taking an integrated approach to translating performance goals into design solutions, and engaging in an extremely collaborative work process with the Consultants.

These conditions were conducive to very positive outcomes: the SJC Habitat Dream Creek subdivision demonstrates that affordable ZNE is highly achievable. A common fear expressed within the mainstream construction industry relative is that meeting the 2020 ZNE goal will require adding costly features such as ultra-high R-value insulation, triple-pane windows, very expensive HVAC equipment, and large numbers of expensive solar panels, driving home prices beyond the reach of many buyers.

The SJC Habitat experience illustrates another path: a highly-integrated approach to efficiency that yields savings due to reduced quantities of framing lumber, drywall[9], ducting, and piping, along with lower-capacity HVAC equipment. These savings offset modest cost increases for selected higher-efficiency equipment items, such as the ERVs and the water heater. Labor was increased for some tasks and reduced for others, with no net change in labor hours (except for the foundation change, which was a decision made independent of the ZNE goal). The number one Habitat for Humanity goal of affordability was never compromised; in fact, it was exceeded.

Some of the lessons learned from this project are:

1. Top-level organizational commitment is an excellent foundation for success;
2. A prior introduction of energy efficiency principles and practices to key construction team members in an instructional setting is extremely helpful;
3. The opportunity to evolve solutions in response to a specific project context (workforce, budget, climate, etc.) yields increasing benefits with iteration from home to home;
4. A high level of quality control fosters performance improvements;
5. Training needs vary as a function of the knowledge and experience of the workforce; and
6. Some specialized tasks are likely to require more support than others – e.g., mechanical system design, layout, and commissioning;

[9] An innovative drywall splicing technique was used; see Appendix 5 (Section A3.16) for details.

7. Tried-and-true efficiency improvements – advanced framing, above-code insulation, compact layouts, and high-performance equipment – are essentials in the ZNE toolkit;
8. Significant further performance gains can be made via a holistic, integrated, and innovative approach.

CONCLUSIONS AND RECOMMENDATIONS

The clearly defined goals of SJC Habitat were: 1) affordability; and 2) achieve ZNE in homes built today. These goals differ little from those of the mainstream construction industry: 1) affordability; and 2) achieve mandatory TDV-ZNE on the homes they will be building in 2020. There are important innovations and outcomes from this project that can be profitably adopted in the mainstream construction industry, enumerated below.

This project demonstrates that ZNE can be highly affordable even on a limited budget; projects with more generous budgets should have no difficulty achieving ZNE provided they approach that goal with the same attention to detail shown by SJC Habitat.

Cross-trade synergies are seldom captured in the mainstream construction process, yet yield significant benefits. These synergies are captured at the design stage, when the design team collaborates with the trades to identify design changes that meet the overall design goals. An example is creating space for mechanical systems inside the enclosure, an important measure that is nearly impossible to accomplish without early collaboration.

Reevaluating every construction detail to meet the affordable ZNE goal resulted in adaptation and refinement of lessons from previous energy efficiency efforts – many dating back to the Arab oil embargo of almost 40 years ago. SJC Habitat showed that synergistic implementation of these features into the construction process can be not only affordable, but often less expensive than current practice, as well as more energy-efficient.

Research consistently shows that there is a large opportunity for heating/cooling system efficiency improvements, that most new systems are oversized, and that full system commissioning is necessary to capture the maximum energy efficiency opportunity.

After energy loads have been minimized by a well-insulated enclosure with low air leakage, the biggest mechanical challenge is selecting heating/cooling equipment that is small enough. Matching equipment capacity with the enclosure loads is important for many reasons:

- It is difficult to provide good comfort levels with oversized equipment;
- Smaller equipment is more affordable and easier to install;
- Smaller equipment is easier to locate inside conditioned space;

- Smaller equipment is quieter; and
- Correctly sized systems will cycle less and should last longer and require less maintenance.

Based on the Demonstration project experience, which – apart from the slightly smaller photovoltaic array – completely met the goals of affordable ZNE, SJC Habitat has determined that all future homes in this and other subdivisions will include all the energy features implemented in House 10. All nine of the remaining homes in the subdivision are expected to be completed by the end of 2018. In addition, because of the success of this project, the Housing Authority of San Joaquin County has approached SJC Habitat and requested that they build out another 40 homes in an adjoining subdivision, adopting the same efficiency measures.

The basic high-performance concepts incorporated in the Demonstration home are not new, having been time-tested for decades:

1. Project participants chosen to have the requisite knowledge and skills, and/or provided with training when needed to supplement their prior experience;
2. ZNE principles integrated throughout design and construction;
3. Simplified framing and other details;
4. Heating/cooling equipment capacity matched to enclosure loads; and
5. Vigilant quality management and performance measurement to assure fully delivered performance of each energy feature.

However, the degree to which these approaches were implemented and the care taken in their execution were highly unusual (see comprehensive list of adopted measures in Appendix 1). The outcomes were equally unusual, as detailed in the prior sections.

Key recommendations parallel the lessons learned identified above:

1. Ensure top-level organizational commitment to ZNE goals;
2. Provide instruction on energy efficiency principles and practices – both theoretical and hands-on – to key construction team members before undertaking a ZNE project;
3. Plan to refine the development of ZNE solutions over a series of homes;
4. Incorporate comprehensive quality management processes;
5. Offer training appropriate to the knowledge and experience of the workforce; and
6. Provide design and field support, as needed, for specialized tasks such as mechanical system design, layout, and commissioning.

Appendix 1. DETAILED SPECIFICATIONS & COSTS

Table A1-1. Detailed Specifications & Costs (a blank cell indicates no change, bold indicates final package)

STOCKTON DREAM CREEK ZNE DEMONSTRATION PROJECT SPECIFICATIONS & COST DATA		House 1 (before EE iteration)	House 8 (ZNE features, pre-demo)	Cost Difference, House 1 to House 8		House 10 (ZNE Demo)	Cost Difference, House 8 to House 10	
				$ -2,935	Excluding foundation		$ 73	Excluding foundation
				$ -6,585	All features		$ 73	All features
Envelope								
Exterior Walls	cavity R value, insulation type	R-11 Fiberglass	**R-21 denim**	$ -100	no change in materials cost (R21 @ 24" < per sf than R11 @ 16"), labor -4 hrs			
	framing type, spacing	2x4 16" oc .35 framing factor	**2x6, 24"oc, 0.13 framing factor**	$ -300	no change in cost of materials, labor -12 hrs			
	continuous insulation	none	**R-5 XPS**	$ 600	labor +24 hrs, material donated			
Glazing	U / SHGC	.5 U/ .25 SHGC	**0.27 U / 0.24 SHGC**	$ -1,505	fewer windows			
	WWR	13.2% WWR	**6.4% WWR**		50% less glass			
	shading	**1' eaves**						
	skylights	**no skylights**						
Roof	insulation type, R value	**R-42 cellulose**						
	insulation location	**attic floor**						
	vented/unvented attic	**vented attic**						
	radiant barrier?	**radiant barrier**						
	roof material	**Composition**						
	reflectance / emittance	**0.25**						
Foundation	type	slab	vented crawlspace	$-11,800	materials: 2" rat slab + 10 mil visqueen ($1,200 for materials +8 hrs) vs. slab ($13,000 for materials +132 hrs)	**reduced ventilation crawlspace (0.5 ACH)**		negligible cost impact
	insulation	NA	R-21 denim	$ 200	installation +8 hrs			
	framing type, spacing	NA	4x6, 32" oc	$ 7,950	$6,000 materials +78 hrs labor @ $25			
Air leakage	ACH50	4.75 ACH50	1.8 ACH50	$ 1,200	Foam and caulking to seal walls and attic (materials +32 hours)	**1.5 ACH50**		
HVAC System								
Ventilation	type		**balanced, 2 ERVs**					
	air flow							
Heating & Cooling	heating system type	3-ton split gas furnace	**3/4-ton ducted mini split**	$ -2,000	smaller, less expensive unit, no labor change			unit donated, no cost difference
	heating efficiency	80%	10 HSPF			**12.5 HSPF**		
	heating capacity	60000 Btuh	10,900 Btuh			**12,000 Btuh**		
	cooling system type	conventional a/c	**3/4-ton ducted mini split**					
	cooling efficiency	13 SEER	15.3 SEER			**24.5 SEER**		
	cooling capacity	3 tons	1.5 ton			**3/4 ton**		
	equipment location	attic	**cond. space (hall soffit)**	$ -150	Removing furnace from attic allowed for simpler, less expensive truss design with raised			
	switching					**heat pump off switch**	$ 5.00	donated; appx value
	thermostat	code-compliant setback	**wired web-enabled**		negligible cost impact			
Ducts	location	attic	**dropped ceiling - conditioned space**		negligible cost impact			
	insulation	**R8**						
	leakage							
	change in duct length?	250 ft	50 ft	$ -600	materials + labor savings (-24 hrs)	**slightly shorter ducts**		negligible cost impact

Table A1-1 continued. Detailed Specifications & Costs (a blank cell indicates no change, bold indicates final package)

STOCKTON DREAM CREEK ZNE DEMONSTRATION PROJECT SPECIFICATIONS & COST DATA		House 1 (before EE iteration)	House 8 (ZNE features, pre-demo)	Cost Difference, House 1 to House 8		House 10 (ZNE Demo)	Cost Difference, House 8 to House 10	
					Notes			Notes
Water Heating								
Water Heater	water heater type, efficiency equipment location	**tankless gas, 0.82 EF** garage				**interior wall**		no net diff (less piping between WH & manifold but added 2-pipe flue through roof)
DHW distribution	insulation, pipe material recirculation system low flow fixtures change in pipe length	**Pex in conditioned space** **no recirculation** **low flow fixtures** WH to last fixture 60'	WH to last fixture 50', avg fixture run 25'	$ -470	materials and -16 hrs	**WH to last fixture 12' (moved from garage to center of house), avg fixture run 8'**		see note above
Electric Loads								
Lighting	100% LED controls	50% CFL, 50% incandescent	**100% LED**	$ 390	CFL/LED cost $30 ea. more than incandescent			
Appliances	fridge cooking dishwasher, washer, dryer	fridge **electric cooking** **not provided, assumed inefficient electric**	**EnergyStar fridge**	$ -	fridge donated			
Other	Home energy management (HEM) Light "on" indicators, garage & porch lights Power disconnects, mini-split & water heater EV charging	NA				**HEM system added** **lights on switch panels to indicate they're on** **Added disconnects** **EV-adaptable circuit in garage**	$ - $ 8 $ 10 $ 50	negligible labor, materials supplied by PG&E estimated cost of special plug, wire, breaker

Appendix 2: MECHANICAL AND ENCLOSURE COMMISSIONING REPORT

Mini-split

Daikin heat pump model RXS09LVJU, ¾ ton, SEER 24.5, HSPF 12.5 Daikin ducted air handler FDXS09V95, 30’ line set (no refrigerant adjustment required) Wired thermostat Daikin ENVi, web-enabled	
Duct leakage	13 CFM_{25} (hard to seal return)
Duct leakage to the outside	0 (not measurable, less than 9 CFM_{25})
Check for refrigerant leaks	450 psi overnight test, 92-micron evacuation
Static pressure	+7.7 Pa (hard to measure, poor plenum access)
Fan watt draw	50 watts (high fan speed, 10-watt resolution)
Total air flow	378 CFM (high fan speed, sum of the supplies)
room air flows (CFM) • Living • Kitchen • Master bedroom • Bedroom 2 • Bedroom 3	 104 51 95 56 72
bedroom pressurization with air handler fan on high • Master bedroom • Bedroom 2 • Bedroom 3	 +2.5 Pa +1.8 Pa +2.8 Pa

Energy Recovery Ventilators (ERVs)

Panasonic FV-04VE1 (2 units, each rated 40 CFM exhaust, 30 CFM supply, continuous operation)		
	Hall ERV	Living Room ERV
Static pressure	-21.0 Pa/+11.3 Pa	30.9 Pa/+9.6 Pa
Fan Watt draw	2A3.3 Watts	22.2 Watts

Bathroom Exhaust Fans

Panasonic FV-11VQC5		
	Master Bath	Hall Bath
rated fan speed (not selectable)	110 CFM	110 CFM
humidity set-point	70% RH	70% RH
occupancy timer setup	turn off 5 minutes after occupant leaves	turn off 5 minutes after occupant leaves
Standby Watt draw	0.6 Watts	0.7 Watts
Watt draw when operating	22.2 Watts	22.4 Watts
Static pressure	+19.3 Pa	+17.1 Pa
Measured air flow	111 CFM	109 CFM

Enclosure

Duct leakage	13 CFM_{25} (hard to seal return)
Air infiltration	330 CFM_{50}
Air infiltration, ventilation system sealed	250 CFM_{50}, 1.53 ACH_{50}
House pressures when exhaust fans are on: • Single bathroom fan • Both bathroom fans • Both bathrooms + kitchen range hood	 -12.8Pa -30.6 Pa -36.2Pa
No combustion appliances in conditioned spaces	

Measurement Equipment

- Fan Wattage – Kill-A-Watt P3 installed at electrical panel
- Air handler Wattage – Extech 380940 clamp-on watt meter, 10-watt resolution
- Exhaust air flow – Exhaust Fan Flow Meter manufactured by The Energy Conservatory
- Supply air flow – Flow Blaster power flow hood manufactured by The Energy Conservatory

Manometer – Digital pressure gauge, DG-700 manufactured by The Energy Conservatory

Appendix 3: TECHNICAL DETAILS & ILLUSTRATIONS

Integrated Design and Delivery

Many of the advanced features in this home (enumerated in Table A1-1) can be attributed to the perfect collaboration between the design team, engineering team, construction management and all the trades: foundation, framing, roofing, mechanical, electrical, plumbing, finish, painting, flooring, landscaping, etc. This collaboration concept, referred to as integrated design and delivery, has been in existence for decades but is seldom employed. The residential construction industry is notorious for compartmentalization and sequential handoffs.

On the SJC Habitat project, one person wore all the hats – making collaboration automatic. A simple example of how this collaboration worked on the exterior walls of this home: 1) the framer pre-drilled wiring holes at the bottom of each wall stud while the studs were still in stacks, 2) the electrician ran his wire through the pre-drilled holes and stapled the wire to the bottom plate and wall studs, and 3) this made wall insulation installation simple – lowering costs and increasing energy performance.

Figure A3.1 The Ideal Integrated Team (Chitwood Energy Management and Design AVEnues LLC)

Compact Plumbing Layout

The architectural design located all the plumbing fixtures grouped together in the center of the house (within red oval in Figure A3.1). The two bathrooms, kitchen, and utility room walls are all adjoining. The longest hot water supply pipe is only 12 feet long – from the water heater to the kitchen sink.

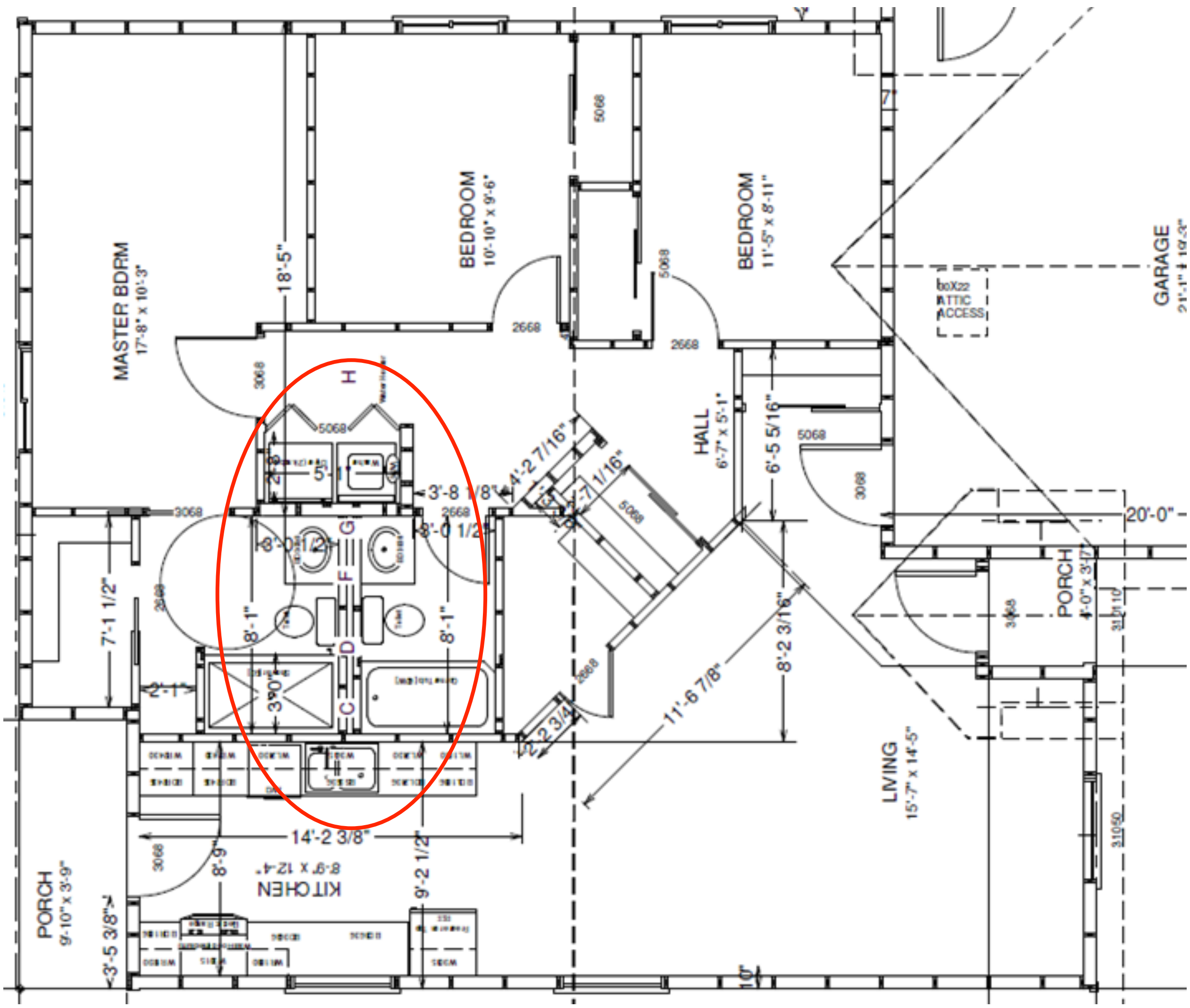

Figure A3.2 Compact Plumbing Layout (SJC Habitat)

Structural Design Using Building Code Defaults

The building code provides full structural engineering guidance in the form of tables and specifications for fasteners. Structural engineers are typically asked to focus their effort only on the home's structure. Using the Integrated Project Design and Delivery concept, the structural engineer should communicate with everyone involved in the design and construction of the home and achieve a proper balance between:

- Structural strength
- Cost

- Ease of construction
- Ease of insulating the wall cavities
- Resource conservation
- Thermal bridging, especially due to metal structural components
- Overall energy efficiency

The thermal conduction of steel is about 300 times that of wood, thus steel can have a large negative impact on the performance of an assembly. The structural design for this home was completed without the use of any metal hold-down brackets, metal strapping, or metal brackets in insulated walls.

Figure A3.3 Advanced Framing, 13% Framing Factor (Chitwood Energy Management)

Reduced Glazing Area

A good, affordable but energy-efficient window has a resistance to conductive heat flow (R-value) of about 4 and the walls on this home has an R-value of about 20 – one-fifth of the heat transfer of a window per square foot. So minimizing window area is a clear energy efficiency goal, but must be balanced with livability, especially allowing adequate light to enter the home. The final ratio of window area to floor area in this home is 10 percent; typical values for new homes are 15 to 16 percent.

Fixed Glass

Windows in this home are fixed except where required for egress. Historically, operable windows were needed for ventilation – to replace stale air in the home with fresh outdoor air – but the building code now requires that fresh air be supplied in homes by a mechanical ventilation system. Nevertheless, operable windows typically are still provided, although research indicates that they are seldom opened, due to:

- Concerns about security – having an intruder climb in an open window
- Noise from outside
- Dust and pollen entering the house

Fixed windows are less expensive, easier to install, leak less, provide more unobstructed views, and are never inadvertently left open.

Figure A3.4 Fixed Windows (Chitwood Energy Management)

Windows Sized and Placed to Fit Framing

All windows purchased today are custom, in that they are not manufactured until after the order is placed. As a result, there is no increase in price for custom sizing. Yet too often, window sizes are specified as even numbers, like 4 feet by 5 feet (48 by 60 inches), necessitating the use of more framing lumber and increasing thermal bridging. All windows in the Demonstration home have been sized to fit within the 24-inch-on-center framing, e.g., 46 inches by 60 inches.

This home's architectural design received special attention to assure that locating the windows did not interrupt the standard 24-inch-on-center framing layout. In addition, to assure that no extra framing lumber is used, every allowable stud is shown on the plans.

Figure A3.5 Window Fits Within the Framing (Chitwood Energy Management)

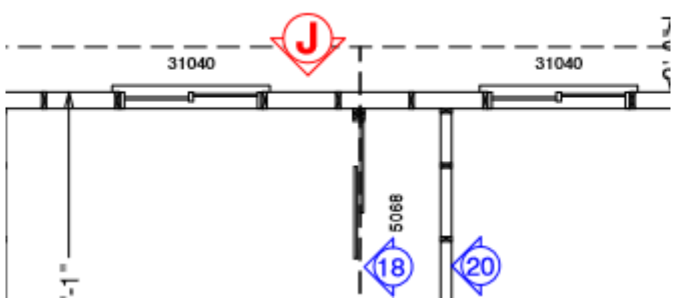

Figure A3.6 All Studs Shown on Plans (SJC Habitat)

Radiant Barrier Roof Sheathing

Radiant barrier roof sheathing was used on both the roof pitches and the vertical gable end walls to help control solar heat gain in the attic. This yields even more benefit if there are ducts and heating/cooling equipment in the attic – which this house does not have.

Figure A3.7 Radiant Barrier Roof Sheathing (Chitwood Energy Management)

Continuous Exterior Insulated Sheathing

R-5 extruded polystyrene exterior sheathing was installed under the stucco to eliminate thermal bridging due to the wall framing. This type of insulation is relatively resistant to installation defects.

Figure A3.8 Continuous Exterior Insulated Sheathing (Chitwood Energy Management)

Performance Testing and Commissioning

Performance testing was used to assure full energy feature performance both during construction and at the end of the project. The final commissioning report is in Appendix 2.

Figure A3.9 Performance Testing (Chitwood Energy Management)

Templates and Schematics

SJC Habitat's homes are constructed by volunteers and students. Templates and large-scale laminated schematics are provided for most tasks to provide consistency house-to-house, crew-to-crew, and to speed construction.

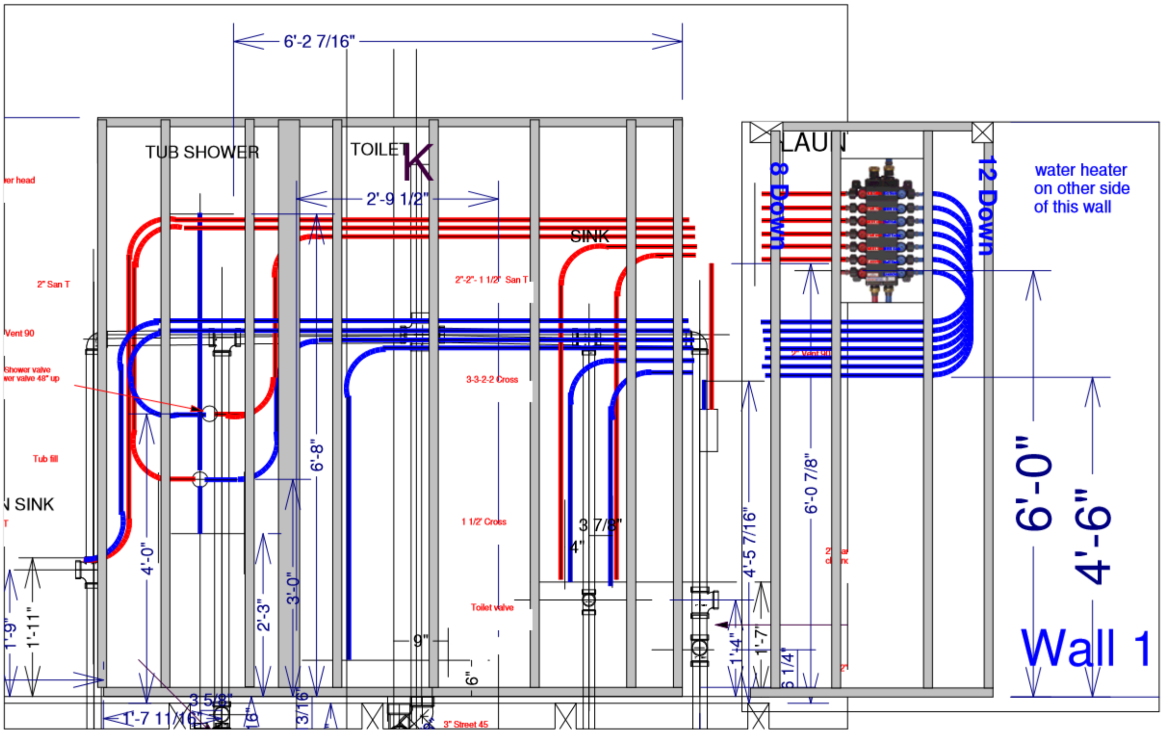

Figure A3.10 Plumbing Schematic (SJC Habitat)

Figure A3.11 Installed Plumbing (Chitwood Energy Management)

Advanced Framing Wall Intersections

Figure A3.12 Two-stud Corners (Chitwood Energy Management)

Figure A3.13 No Extra Framing at Wall Intersections (Chitwood Energy Management)

Engineered Single Top Plate

The engineered single top plate assures that the wall is straight. No joints are typically needed since this material can be purchased in lengths up to 60 feet.

Figure A3.14 Engineered Single Top Plate, From Above (Chitwood Energy Management)

Attic Access Does Not Penetrate the Ceiling Insulation

The access to the attic is first through the fire-rated attic access hatch in the garage, and then through an opening between the garage attic and the house attic.

Figure A3.15 Attic Access Does Not Penetrate the Ceiling Insulation (Chitwood Energy Management)

Drywall Clips

Affordable metal clips are used to eliminate all wood drywall backing. There are many advantages to using drywall clips rather than wood backing. Most importantly, the clips reduce callbacks – since both pieces of drywall are attached to the same stud, any stud warping during the lumber cure cycle won't pull a corner apart, also reducing nail popping. In addition, they are lower cost, require less labor, are more energy-efficient, since there is more room for insulation, and make for easier air-sealing of the ceiling without backing covering the top plate/ceiling drywall joint; and finally, they are more resource-efficient due to lumber savings.

Figure A3.16 Drywall Clips (Chitwood Energy Management)

Engineered Headers

Engineered window and door headers maximize the space for insulation and eliminate the thermal bridge that solid headers create. Headers are temporarily installed with screws so they can be removed to install insulation, defect-free, behind them.

Figure A3.17 Engineered Headers. (Chitwood Energy Management)

Drywall Splicing

The industry standard installation technique is to cut drywall so that a sheet ends on a framing member to which the end of the sheet is attached. Instead, using drywall splices (4-inch-wide scraps placed behind joints where two pieces come together) avoids the need to measure and cut a piece of drywall, until reaching the end of the wall. Benefits include:

- Reduced material cost because of less waste
- Reduced labor – less measuring and cutting
- Reduced waste disposal cost
- Easier to finish, since there are more factory sheet edges
- Stronger joints, since joints have 2 inches rather than ¾" of backing

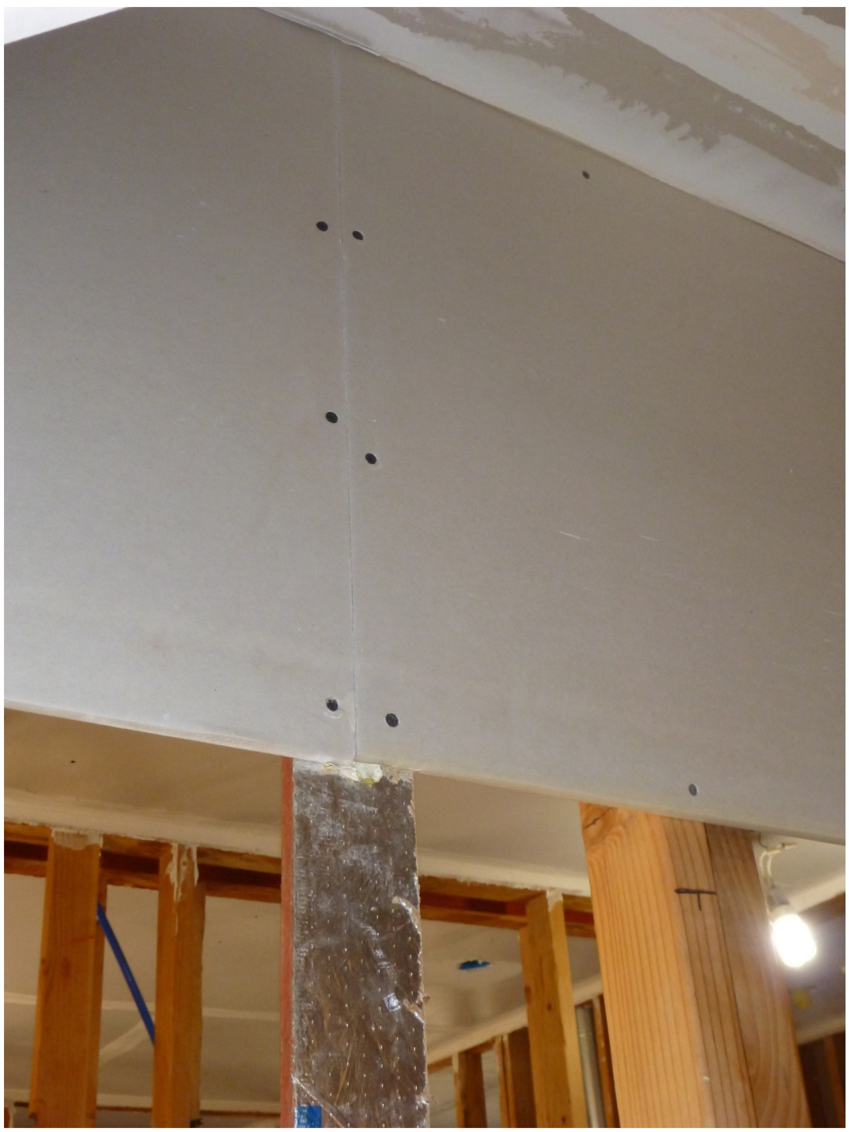

Figure A3.18 Drywall Splicing (Chitwood Energy Management)

Gable Ends Built on the Ground

With conventional building techniques, a lot of construction labor occurs on the first two trusses at the gable end – often with laborers 10 to 25 feet off the ground. On this project all that work – two trusses, look-outs, fascia, roof sheathing, venting, gable end sheathing, house wrap, etc. – was done on the ground, increasing both speed and safety. (OSHA identifies falls as the leading cause of death in the construction Industry.) The end units were then set, along with the rest of the trusses, with a truck-mounted crane. An additional benefit on this project, since it has a 4-in-12 roof pitch, is that the roof worker safety harnesses that would normally be required within 3 feet of the gables ends are not needed, due to the pre-sheathed work surface at the gable ends.

Figure A3.19 Gable End Trusses Built on the Ground (Chitwood Energy Management)

Figure A3.20 Gable End Trusses Being Craned into Place (Chitwood Energy Management)

Figure A3.21 Gable End Truss in Place (Chitwood Energy Management)

Horizontal Wall Sheathing

The home has continuous oriented strand board (OSB) wall sheathing. OSB sheathing is stronger (has less deflection) in the 8-foot direction than it does in the 4-foot direction – so if it is installed horizontally a thinner material can be used, as it was on the Demonstration home. Though not a structural engineering requirement for this house – just a good structural practice – a shear transfer connection was made between horizontal joints using a heavy gauge steel C-channel with screws every 6 inches. This C-channel has factory flattened flanges every 24" to assure near-perfect stud spacing. This structural connection also makes air sealing goals easier to meet and makes the air sealing more durable.

Figure A3.22 Horizontal Wall Sheathing with C-channel (Chitwood Energy Management)

Truss Hold-down Screws

The more common truss hold-down metal brackets (Simpson H-1) have been replaced with a truss hold-down screw (Simpson SDWC). There are multiple benefits to using an engineered screw rather than the standard H-1 bracket: energy efficiency, structural strength, and cost.

- Standard Simpson H-1 brackets are nailed to the face of the top plate. The bracket and the nail heads space the drywall away from the top plate, creating an air passage between the attic and the wall cavity. This air leakage path is one of the most difficult to seal because it occurs over a great many feet along the walls.
- The engineering specifications of the screw show higher strength all directions. The screw uplift rating is 76% greater. Lateral strength parallel to the supporting wall is 30% higher. And lateral strength perpendicular to the supporting wall is 96% higher.
- To install a Simpson H-1 bracket, eight nails must be manually driven through pre-punched holes in the bracket – four into the truss and four into the top plate. Driving one screw is much faster than pounding eight nails, significantly reducing installation costs.

Figure A3.23 Truss Hold-down Screws (Chitwood Energy Management)

Truss Tail Shear Transfer

This is one of the most elegant details developed by this builder. The continuous sheathing (two horizontal bands, each 4 feet wide) does not reach the single top plate – it falls about 4 inches short. The final sheathing strip, which bridges from this point (4 inches below the top plate) to the roof plane, has many purposes:

- Connects to the sheet below with another C-channel to fully transfer shear and provide air sealing;
- Strengthens the connection between the top of the wall studs and the single top plate;
- Connects the top plate to the raised-heel trusses, eliminating the need for dimensional lumber blocking, which would conventionally be used between the trusses;
- Eliminates any air intrusion into the attic insulation to assure full performance of the attic insulation;
- Provides shear transfer, with the installation of another C-channel, between the wall plane and the roof plane. The flanges on this C-channel are bent at 18^{o} to match the roof angle.

Figure A3.24 Truss Tail Shear Transfer (Chitwood Energy Management)

Weight-bearing Gable-end Trusses

Specifying weight-bearing gable-end trusses eliminates the need for window and door headers on two sides of the home. Eliminating these headers saves labor, materials, and leaves more room for wall insulation.

The result of all the innovative advanced framing features used on this project is a lumber savings of one-half to two-thirds, compared with a sample of 25 other new homes built in 2015, without any loss of structural integrity.

Figure A3.25 Weight-bearing Gable-end Trusses (Chitwood Energy Management)

Cantilevered Porches

The truss manufacturer was requested to design the trusses so that weight bearing posts and beams are not required at the porch, yielding a significant cost savings.

Figure A3.26 Cantilevered Porch (Chitwood Energy Management)

Studs Pre-drilled for Wiring

Holes were drilled in the studs to allow electrical wire to be run at the base of the wall rather than at outlet height, eliminating the need for insulation installers to split batts at the wiring.

On a typical residential construction project, it is not possible to transfer work between trades. Yet transferring tasks between trades can be very beneficial. In this case, it is less expensive for the framing crew to drill the wiring holes in the exterior wall studs while they are still banded in units, compared to the electrician drilling one hole at a time after the wall is constructed.

Figure A3.27 Studs Pre-drilled for Wiring (Chitwood Energy Management)

Air Sealing Tested at Rough Framing

To assure that the enclosure does not have excessive air leakage, the builder conducts an air leakage test before any insulation or drywall is installed in/on the walls. After the ceiling drywall is installed, the edges are taped to the single top plate. This eliminates all attic air sealing work.

The final air leakage test for this home was 250 CFM at 50 Pascals, or 1.53 ACH_{50}, less than one-third of the average new home leakage rate.

Figure A3.28 Air Sealing at Top Plate (Chitwood Energy Management)

Smoke Testing after Drywall

The enclosure is also smoke-tested after drywall to confirm that all air leaks are found and sealed.

Figure A3.29 Smoke Testing (Chitwood Energy Management)

Raised-heel Trusses

Raised-heel trusses provide space for full attic insulation thickness at the eaves.

Figure A3.30 Raised-heel Trusses (Chitwood Energy Management)

Low Attic Ventilation

Low (roof-edge) attic ventilation often reduces the performance of the attic insulation due to air intrusion. In this home, the use of raised-heel trusses allows the placement of low ventilation above the ceiling insulation and thus the insulation performance is not compromised.

Figure A3.31 Low Attic Ventilation (Chitwood Energy Management)

Wall Insulation Obstructions Eliminated

Clustering the plumbing in the center of the home and running electrical wiring across the bottom plate or on the studs – eliminating wall cavity obstructions – makes this a very easy home to insulate. In addition to the elimination of obstructions, the regular stud spacing, lack of drywall backing, and extra blocking at intersections make this home one of the easiest-ever homes to insulate.

Figure A3.32 Wall Insulation Obstructions Eliminated (Chitwood Energy Management)

Constant Balanced Ventilation with Energy Recovery

To provide good indoor air quality, two 40 CFM Panasonic ERVs were installed, one in the living area and one in the sleeping area. The two ventilation units provide almost twice the minimum ventilation required by the state energy code. (One ERV couldn't quite meet the ventilation requirements, calculated per ASHRAE 62.2, so two were installed.) This constant ventilation is in addition to the kitchen range hood and the two automatic bathroom exhaust fans provided for localized ventilation.

Figure A3.33 Energy Recovery Ventilator (Chitwood Energy Management)

Fresh Air Ventilation

To assure that the incoming ventilation air is free of dust and pollen, a large (15" x 20" x 2") MERV-8 filter (circled in red below) was installed in an accessible location – the ceiling of the north-facing back porch. This avoids bringing air super-heated from solar radiation into the house. Placing an intake on a roof or west-facing wall can elevate the temperature of the incoming air to more than 140°F.

Figure A3.34 Fresh Air Intake in Back Porch Ceiling (Chitwood Energy Management)

Exhaust Ventilation in Kitchen and Baths

An Energy Star kitchen range hood was installed to provide spot ventilation while cooking.
In addition to constant balanced ventilation and kitchen spot ventilation, a quiet, 110-CFM energy-efficient (0.20 Watts/CFM) exhaust fan is installed above the shower in each bathroom. The fans include sensors that control operation automatically based on occupancy and humidity: when someone enters the bathroom, the exhaust fan turns on automatically and stays on for 5 minutes after the occupant leaves. The fan also turns on automatically if it senses humidity greater than 70%, and stays on until the humidity drops below 60%.

Figure A3.35 Bath Exhaust Fan (Chitwood Energy Management)

High-performance Electric Mini-split Heat Pump

A small, high-performance ducted mini-split heat pump heats and cools the home. With all of the other advanced energy features in this home, it is difficult to find heating/cooling equipment that is small enough. The loads for this home are about 6,000 Btu/Hour, or ½-ton. A ¾-ton mini-split was installed. Conventional sizing usually has us installing 1 ton of capacity for every 500 to 800 square feet of floor area – this system is sized at 1,600 square feet per ton of capacity. Other specifications:

- MERV-8 air filtration
- Oversized air filter (20" x 30" x 2") to increase filter replacement intervals to every 2 years
- No electric resistance back-up (strip) heat, which is found with most heat pump installations
- SEER 24.5
- HSPF 12.5
- A clearly labeled "System Off" switch is installed indoors near the thermostat to eliminate standby energy consumption (a "vampire load") during the swing seasons.

Figure A3.36 Mini-split Heat Pump (Chitwood Energy Management)

Ducts in Conditioned Space

The ceiling of the hall is dry-walled to create a pressure boundary above the ducts, which are installed in a 12” soffit in the hallway. Zero duct leakage was measured to the outside – confirming that the ducts are truly in conditioned space. Additionally, there is no conductive loss to the attic.

After the ducts are installed, metal framing and drywall are used for the finish ceiling.

Oriented strand-board could be used for the pressure boundary as an alternative to drywall.

Figure A3.37 Ducts in Conditioned Space (Chitwood Energy Management)

Compact Duct Design

All duct lengths are minimized to reduce cost, simplify installation, and make it easy to install ducts in conditioned space. (The duct schematic below is for the 4-bedroom plan; the Demonstration house is a 3-bedroom plan.)

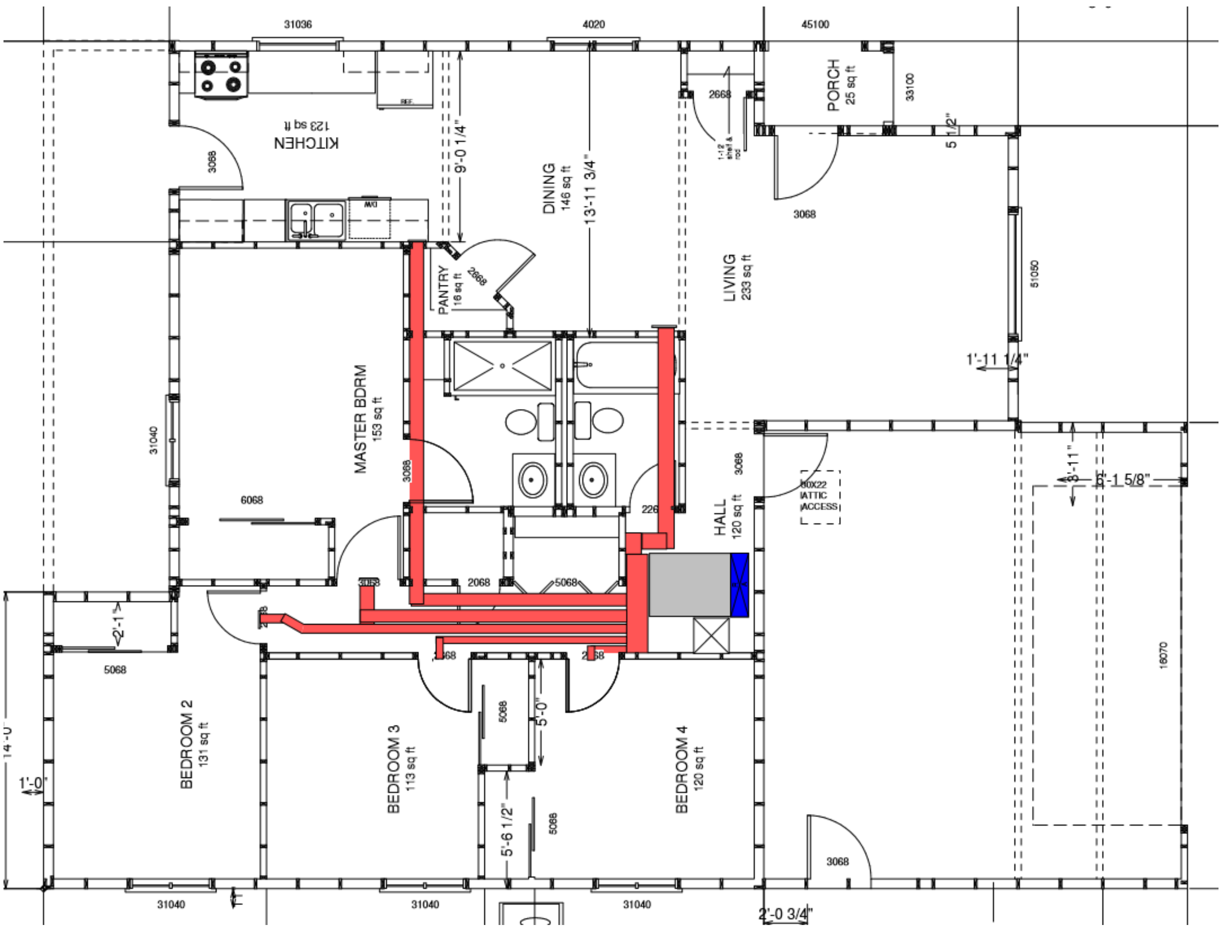

Figure A3.38 Compact Duct Design (SJC Habitat)

Low-pressure Duct Design

The mini-split ducted air handler has a very efficient fan and uses very little energy, *if and only if* the air flow resistance in the duct system remains low. The duct system design has many features that minimize static pressure so that fan watt draw is very low:

- Double-deflection supply grilles with air-foil blades
- Straight supply boots
- Short supply ducts
- Oversized supply ducts
- Oversized return air filter grille
- A filter grille that will accept a 2-inch-thick filter

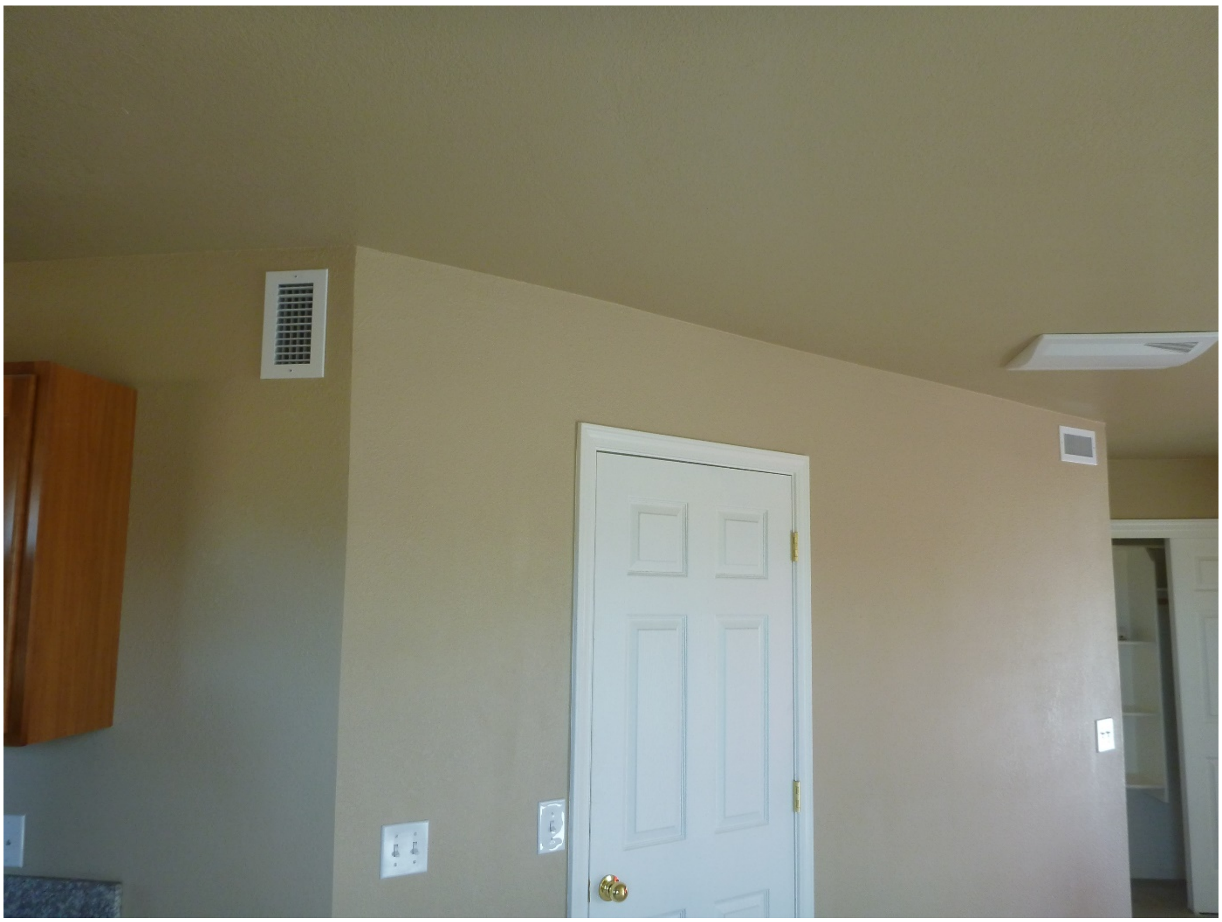

Figure A3.39 Double-deflection Supply Grilles (Chitwood Energy Management)

Tankless Water Heater

A tankless water heater is installed in the hall laundry closet. The water heater is 82% efficient and has no storage losses. Since it is located in the center of the home, all of the plumbing runs are very short – providing hot water at each fixture within a few seconds.

Figure A3.40 Tankless Water Heater (Chitwood Energy Management)

Manifold Water Distribution System

Using a manifold distribution system located in the same wall as the water heater has many advantages, principal among which is that it enables the use of small-diameter piping, so there is only a small amount of water in the pipe between the water heater and the faucet. This minimizes water and energy waste while waiting for hot water to reach the faucet or shower. Other advantages:

- Less piping is required
- Less labor is required
- Every fixture has its own hot water and cold water shut-off, making maintenance easy

Figure A3.41 Manifold Water Distribution System (Chitwood Energy Management)

Efficient LED Lighting

Light-emitting diode (LED) lighting is used everywhere in this house. Since the LED lights are small, they are mounted in standard electrical junction boxes like the one shown in the top photo, greatly reducing the air leakage potential (and facilitating sealing around them) as compared to large recessed light cans.

Figure A3.42 Electrical Box for LED Fixture (Chitwood Energy Management)

SLD Series
The LED Surface
Downlight Luminaire

LASTS 22* YEARS

SLD6
6" LED Surface Downlight Luminaire

SLD4
4" LED Surface Downlight Luminaire

Ø 7.75" [197mm]
Supply Wire Adapter (included)
0.7" [18mm]
1.5" [39mm]
Ø 7.75" [197mm]

SLD6 ENERGY DATA

	80 CRI	90 CRI
Lumens	675	675
Input Voltage	120V	120V
Frequency	50/60 Hz	50/60 Hz
Input Current	0.15 A	0.15 A
Input Power	12.5 W	12.9 W
Efficiency	54 lm/W	52 lm/W
THD	≤ 20%	
Power Factor	≥ 0.90	
T Ambient	-30 - +40°C	
Sound Rating	≤ 22 dba	

OVER $400** SAVINGS

* Based on average six hours use per day.

** SLD6
Savings are over the life of the Halo SLD6 luminaire.
Energy savings: $300
Replacement lamp savings: $100
Savings based on $0.115 per kilowatt hour, average six hours use per day, 50,000 hours of lamp usage, and 65W BR30 lumen equivalent.

6

Ø 6" [152mm]
Supply Wire Adapter (included)
0.7" [18mm]
2" [53mm]
Ø 6" [152mm]

SLD4 ENERGY DATA

	80 CRI	90 CRI
Lumens	650	625
Input Voltage	120V	120V
Frequency	50/60 Hz	50/60 Hz
Input Current	0.15 A	0.15 A
Input Power	12.5 W	12 W
Efficiency	52 lm/W	52 lm/W
THD	≤ 20%	
Power Factor	≥ 0.90	
T Ambient	-30 - +40°C	
Sound Rating	≤ 22 dba	

OVER $325^Δ SAVINGS

* Based on average six hours use per day.

^Δ SLD4
Savings are over the life of the Halo SLD4 luminaire.
Energy savings: $157
Replacement lamp savings: $170
Savings based on $0.115 per kilowatt hour, average six hours use per day, 50,000 hours of lamp usage, and 40W R20 halogen/IR lamp lumen equivalent.

7

Figure A3.43 LED Fixture Cut Sheet

Indicator Switches

Exterior lighting (indicated by arrow in photo below) and lights in the garage can inadvertently be left on for days – even weeks – especially lights like the one outside the garage side door. The indoor switches that control these lights glow red when the lights are on as a reminder to turn them off.

Figure A3.44 Exterior Lighting with Indoor Indicator Switch (Chitwood Energy Management)

Photovoltaics

After all of the opportunity with cost-effective energy efficiency measures has been captured, a small photovoltaic (PV) system (3.36 kW DC) is installed to offset most of the home's estimated annual energy consumption (based on TDV).