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EcoVillage: A Net Zero Energy Ready Community

L. Arena and O. Faakye
Consortium for Advanced Residential Buildings

February 2015

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EcoVillage: A Net Zero Energy Ready Community

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Office of Energy Efficiency and Renewable Energy

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The laboratory and/or field sites used for this work are not certified rating test facilities. The conditions and methods under which products were characterized for this work differ from standard rating conditions, as described.

Because the methods and conditions differ, the reported results are not comparable to rated product performance and should only be used to estimate performance under the measured conditions.

Contents

List of Figures

Unless otherwise noted, all figures were created by the CARB team.

List of Tables

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Definitions

ACH	Air changes per hour
AERC	Annualized energy related costs
ASHP	Air source heat pump
BEopt®	Building Energy Optimization simulation software
BB	Baseboard
Building UA	Characteristic whole-envelope heat transfer figure of merit. It represents a combined value for the entirety of the envelope, including attic and roof, walls, windows, doors, and foundation.
ccSPF	Closed-cell spray polyurethane foam
CPVC	Chlorinated polyvinyl chloride
DHW	Domestic hot water
ERV	Energy recovery ventilator
HPWH	Heat pump water heater
HRV	Heat recovery ventilator
PHHP	Passive House Planning Package
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
SIPs	Structurally insulated panels

Executive Summary

The U.S. Department of Energy's (DOE) Building America team, Consortium for Residential Buildings (CARB), is working with the EcoVillage cohousing community in Ithaca, New York, on the Third Residential EcoVillage Experience neighborhood. This community-scale project consists of 40 housing units—15 apartments and 25 single-family residences. Units range in size from 450 ft^2 to 1,664 ft^2 and cost from $80,000 for a studio apartment to $235,000 for a three- or four-bedroom single-family home.

The community is pursuing certifications for DOE Zero Energy Ready Home, U.S. Green Building Council® Leadership in Energy and Environmental Design Gold, and ENERGY STAR® for the entire project. Additionally, seven of the 25 homes, along with the four-story apartment building and community center, are being constructed to the Passive House (PH) design standard.

Because of its commitment to sustainability and energy efficiency, EcoVillage was chosen as a Building America research partner with two specific goals in mind. The first goal was to develop a commercial and economically viable 50% source energy-savings package. Two separate packages were developed: one for the homes attempting to achieve PH certification and one for those that were not. The packages developed resulted in predicted source energy savings of 47.5% and 47%, respectively.

In addition to energy savings, these homes were cost effective to construct. Construction methods used have been successfully implemented for years in previous projects and can easily be adopted by contractors that have not previously used them. The products used are commercially and readily available. In fact, construction costs were $100/$ft^2$ compared to an average of $138/$ft^2$ for that area of New York. This is a substantial accomplishment considering that these are not low-income homes where substantial donations and government subsidies often offset the costs of construction; neither are they custom homes for very wealthy customers. These homes represent standard homes for the average consumer. Therefore, the overall cost of construction was a significant design constraint.

Based on the builder's feedback, successful implementation of the energy-solutions package, and several successful certifications, it can be concluded that this solution package was economically and commercially viable. There were several lessons learned during the construction process, the most significant of which included:

- Proper air sealing of the energy recovery ventilator duct insulation and vapor tight jacket are crucial to prevent moisture damage and ensure proper performance.
- Based on the first 4 months of data collected, the homes are using less energy on average than predicted by the Building Energy Optimization (BEopt) simulation software.
- Occupants in super-insulated homes should be encouraged to maintain constant temperatures and not try to employ deep thermostat setbacks.

- A preheater is recommended for any energy recovery ventilator/heat recovery ventilator in a cold climate region to prevent the system from shutting down during extremely cold periods.
- In newly constructed, extremely air tight homes in cold climates, indoor relative humidity levels should be monitored, and ventilation adjusted or dehumidification used if levels exceed 40%.
- At the start of the planning process for super-insulated, high performance homes, a dedicated person to oversee the critical air sealing, insulation, and water management details should be factored into the budget at the start of the planning process.

CARB also analyzed current heating system sizing methods for super-insulated homes in cold climates to determine if changes in building load calculation methodology should be recommended. Actual heating energy use was monitored and compared to results from Manual J8 (MJ8) and the PH software, the Passive House Planning Package (PHPP). Results from that research indicate that MJ8 significantly oversizes heating systems for super-insulated homes and that thermal inertia and internal gains should be considered for more accurate load calculations.

For the two occupied homes, MJ8 calculations result in loads that are an average of 56% larger than actual measured design loads, while PHPP calculations resulted in loads that were 34% higher on average. Based on these results, it is recommended that a different method for sizing heating systems for super-insulated buildings is warranted, and thermal inertial and internal gains should be included in sizing calculations. Doing so results in a closer approximation of the building's design load while still providing a slight buffer zone.

It is anticipated that lessons learned and knowledge gained from this research will inform builders, designers, engineers, and consultants engaged in high performance production-ready residential projects.

1 Introduction

The ultimate goal of the Building America research program is to develop market-ready, cost-effective efficiency packages that result in energy reductions in new homes of 30% to 50% over the Building America Benchmark reference building, which is representative of 2010 construction practices. The final result should be innovations that can be implemented cost effectively in production-scale housing. Community-scale projects are the final step in demonstrating and documenting the viability of designs that meet these goals. Through these projects, critical information is obtained about the true costs to implement energy-efficient solutions packages on a production scale and the remaining gaps that require additional research.

The Consortium for Residential Buildings (CARB) team worked with the EcoVillage cohousing community in Ithaca, New York, on their third neighborhood—the Third Residential EcoVillage Experience (TREE). This community-scale project consists of 40 housing units—15 apartments and 25 single-family residences—designed to accommodate different size households. Units range in size from 450 ft^2 to 1,664 ft^2 and cost from $80,000 for a studio apartment to $235,000 for a three- or four-bedroom single-family home.

Through cohousing, EcoVillage fosters an intentional community where residents have chosen to live together with a common purpose, working cooperatively to create a lifestyle that reflects their shared core values. As part of this intentional community, residents have identified sustainable, green, and efficient building construction as a key value. To demonstrate this commitment, the occupants of this neighborhood are constructing seven of the 25 homes (Figure 1) along with the community living center to the Passive House (PH) design standard. They are also pursing U.S. Green Building Council® Leadership in Energy and Environmental Design (LEED) Gold and ENERGY STAR® certifications for the entire project. Steven Winter Associates, Inc. (CARB team lead) was brought into the project to support the implementation of the PH design and provide third-party verification for these programs. Soon after collaboration began, it became apparent that EcoVillage would be an excellent Building America community-scale project.

Figure 1. Finished homes in the TREE development

CARB led the research effort and worked with Jerry Weisburd, the architect, Mike Carpenter, the builder/construction manager, and a small group of future occupants to develop an efficient solutions package that achieves approximately 50% energy saving over the Building America Benchmark.

In cooperation with several homeowners, CARB also analyzed current mechanical system sizing methods for super-insulated homes in cold climates. Actual heating energy use was monitored and compared to results from Manual J8 (MJ8) and the PHPP. The results of this research are being used to create guidelines for sizing mechanical equipment in highly insulated homes.

2 Background

Building America teams have extensive experience working on community-scale new construction projects during the last 17 years (BSC 2007; CARB 2007, 2008; Aldrich 2012). For example, CARB recently finished working on the Wisdom Way Solar Village, a cold-climate community-scale project that consists of ten duplexes and a number of single-family homes. The project aimed for near-zero net energy homes that were affordable, healthy, and efficient. As part of this project, CARB determined that a successful community-scale project requires good planning for wall penetrations, especially for appliance venting, and mechanical system layout with the understanding that plans may need to be altered based on variations and utility locations (CARB 2010).

The TREE EcoVillage project built upon knowledge and experience from Wisdom Way and other previous work to provide a sound, vetted building science solution package. This research also extends recent work being performed to document the energy performance of a new construction test home, built to PH standards (Stecher and Allison 2012), to a community-scale level. Furthermore, CARB sought to investigate the viability and cost effectiveness of constructing a community-scale project that includes PH-certified units.

The PH Building Energy Standard is the most rigorous energy efficiency certification in the world and is gaining popularity in the United States. Although there is extensive performance data gathered from PH buildings constructed in Europe, very little data from buildings constructed in the United States exists to assess the detailed energy consumption and occupant comfort characteristics of completed super-insulated homes (Stecher and Allison 2012). This research was intended to address this need and to evaluate heating equipment sizing methods for super-insulated homes in cold climates.

This community is unique because the project tested the real affordability of going high performance on a production scale. These are not low-income homes where substantial donations and government subsidies often offset the costs of construction, but neither are they custom homes for very wealthy customers. These homes represent standard homes for the average consumer. Therefore, the overall cost of construction was a significant design constraint.

3 Research Questions

Two sets of research questions apply to this project. First, the viability of a 50% community is being evaluated and the entire process documented. Second, the applicability of current mechanical equipment sizing methods for super-insulated homes is also being investigated.

50% Community Scale Evaluation:

- Is the 50% solution package implemented in this project commercially viable?
- Where are opportunities to reduce costs?
- What are the specific gaps to achieving the specified solution package on a production scale; cost, risk adversity, and implementation complexity?
- Based on the experience of the project team during planning and construction, what alternative energy efficiency solution package(s) should be considered?

Equipment Sizing Analysis:

- How do the design loads calculated using MJ8 and PH methods compare to the measured peak building loads?
- If the modeled loads are significantly different from the actual loads, can the differences be explained?
- What recommendations can be made about heating equipment sizing for super-insulated buildings?

4 50% Community Scale Evaluation

4.1 Design Phase

4.1.1 Considerations and Limitations

The design phase for TREE involved extensive collaboration with the architect, builder, residents and subcontractors as well as rigorous modeling using several different design tools. The 2007 version of the PHPP was used to verify whether the buildings met PH requirements as well as predict annual heating loads, evaluate comfort parameters, and calculate heating equipment sizes. MJ8 was also used for equipment sizing. Building Energy Optimization (BEopt®) E+ Version1.2 was used to analyze different cost-effective building efficiency packages and predict annual energy savings compared to the Building America Benchmark with the ultimate goal of achieving 50% source energy savings. Using WUFI, several different high-R wall construction options were evaluated for potential moisture problems. And finally, THERM was employed to calculate overall heat transfer coefficients and detect any possible thermal bridging issues.

The design was primarily driven by the desire to determine if PH certification would be possible for all the homes. The PH threshold of 4.75 $kBtu/ft^2$ per year for space heating is based on insulation levels, window efficiencies, solar gain, and mechanical ventilation efficiencies, and must be met before heating and cooling system efficiencies are considered.

There were several constraints to address during the design process including wall depth, layout, and solar exposure. As can be seen from the site plan (Figure 2), several of the homes are significantly shaded by one another and the community center (SLC).

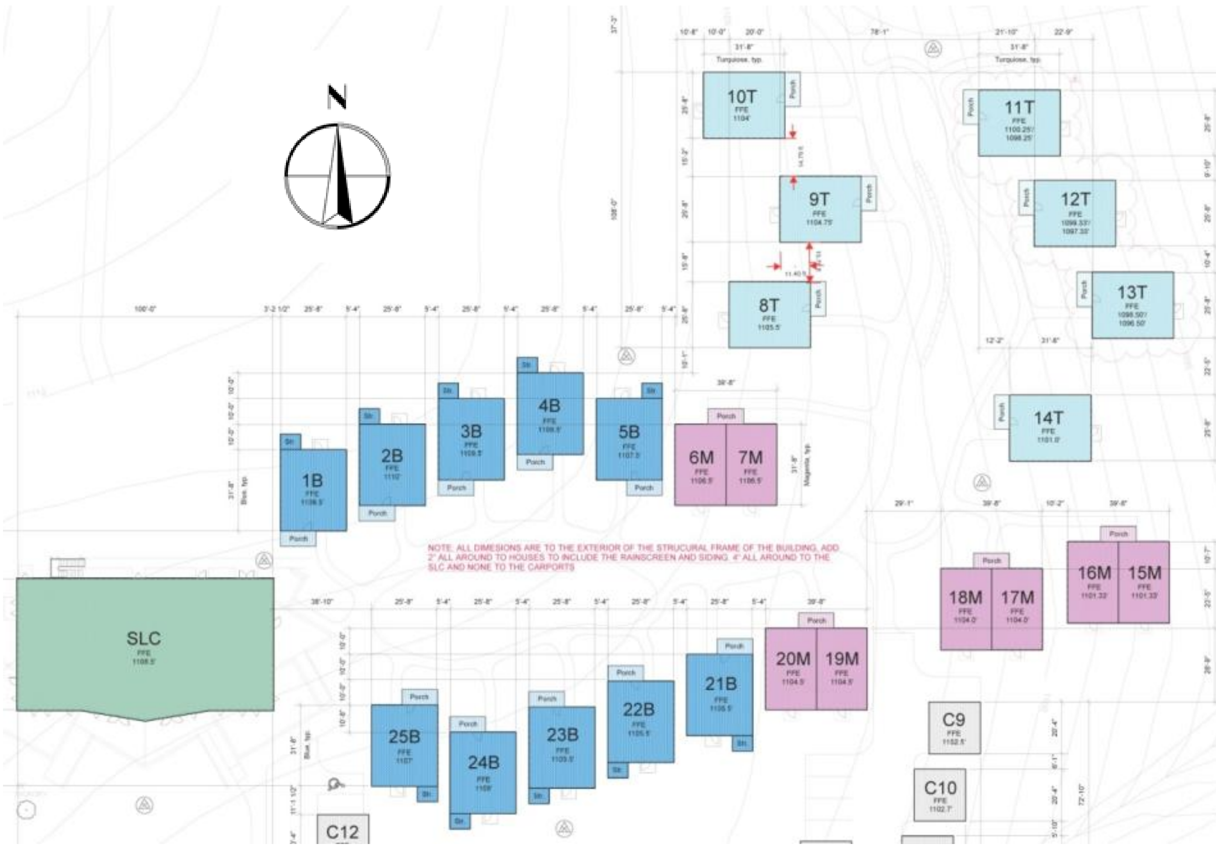

Figure 2. Site plan of the TREE neighborhood

Additionally, many have less than ideal orientation with the east/west axis of the home being elongated instead of the north/south. This reduced the potential for beneficial solar gains during the winter season and was further exasperated due to the fact that the Blue units were only 1-½-story homes, reducing the south façade even more. A summary of house types is presented in Table 1.

Table 1. Summary of House Types at TREE

Unit	Conditioned ft^2	# of Bedrooms	Stories
Turquoise – ft^2	1,664	3–4	2
Magenta – Duplex	1,280 (each side)	2–3	2
Blue – ft^2	1,248	2	1.5
Community Center (SLC)	20,000+	15 – 1 and bed apartments	4

Also inherent to cohousing projects is a strong focus on community and features that foster this, including porches, front doors with glazing, and windows facing the common space. While wonderful features to incorporate into any design, these can compromise the energy performance of the homes, and solutions needed to be considered at the beginning of the process.

Since the site plan was already formalized when CARB was brought into the process, the effects of the orientation and shading had to be compensated for with increases in efficiency of the building envelope. See Table 2 for the final efficiency levels decided upon to achieve PH certification for the single-family dwellings. Only five of the seven Turquoise homeowners and two of the Magenta owners opted to pursue PH certification. Due to budget constraints, or in the case of severe shading making compliance near impossible, some occupants opted out of certification.

Table 2. Building Envelope Efficiency Levels for PH Certification

Component	Efficiency Level
Roof	R-90
Walls	R-52
Slab	R20 Edge, 2 ft vertical, 2 ft horizontal/R36 under
Windows	Triple-pane, low-e, U_w=0.17, SHGC = 0.62
Air Leakages	0.6 ACH50
Ventilation	ERV, 83% Sensible

Selection of the final wall design was highly influenced by the fact that an entire community of homes needed to be built as opposed to just one. Issues concerning the framing process included speed, reproducibility from one home to the next, and cost. Initial designs incorporating Larson-style trusses hung on the exterior of a conventional structural 2×4 wall called for spray foam to be applied from the exterior, which would potentially require tenting of the homes to prevent overspray on neighboring buildings and equipment. Seasonal considerations included concerns about drying in the homes quickly and the ability to heat them so the trades could continue working in inclement weather. Decisions about the final design were highly dependent on the number of homes to be constructed, the speed at which that needed to happen, and the overall cost.

4.1.2 Final Specifications

Once all the limiting factors were considered, the final specifications were developed (see Table 3). The wall construction would consist of double 2×4 stud framing set 5 in. apart to provide a 12-in. cavity. For the homes striving to achieve PH certification, the outer stud bay would be filled with closed-cell spray polyurethane foam (ccSPF) and the remaining 8.5 in. would be dense-packed with cellulose to achieve the R-52 needed. For the remainder of the homes, the 12-in. cavity would be completely filled with cellulose for a final R-value of 43 (shown in red in Table 3).

Table 3. Final Design Specifications

Options Category	Simulated Options
Attic	Ceiling R-90 cellulose, vented
PH Walls	R-52, 8.5 in. Cellulose + 3.5 in. ccSPF, 2×4 staggered, 16 in. o.c.
Non-PH Walls	R-43, 12 in. Cellulose, 2×4 staggered, 16 in. o.c.
Foundation	R20 edge, 3 in. of polyiso to 2 ft depth and 4 ft horizontally/R36 under, 5.5 in. of polyiso
Windows	Triple-pane, low-E, CPVC*, U=0.17, SHGC = 0.62
PH Air Leakage	0.6 ACH50
Non-PH Air Leakage	1.5 ACH50
Ventilation	ERV, 83% efficient,
Refrigerator	392 kWh/yr
Cooking Range	Induction Range
Dishwasher	318 kWh/yr
Lighting	100% fluorescent
Space Conditioning	Electric resistance baseboard
Water Heater	Electric 80-gal storage w/65 ft^2 solar thermal
Photovoltaics (PV)	Systems ranged from 3.2 to 4.4 kW (not all homes elected to install PV)

*CPVC - Chlorinated polyvinyl chloride

The other main difference between the homes pursuing PH certification and those that were not was the air leakage threshold. For PH, the threshold is 0.6 air changes per hour @50 pascals (ACH50). The threshold for the remainder of the homes was set to approximately 1.5 ACH50.

To achieve a ceiling efficiency of R-90, it was decided that the most cost-effective method would be to construct a vented attic and spray approximately 24 in. of cellulose on the ceiling of the second floor. A vented cladding on the exterior walls was specified to aid in drying and reduce wetting through capillary action and rain splashback. The slab-on-grade foundations were insulated with 3 in. of polyisocyanurate (polyiso) installed 2 ft vertically down from the top edge of the slab and then horizontally away from the building about 4 ft (Figure 3). Three inches of polyiso was also installed under the footing as well as up the inside of the stem wall. Finally, 5-½ in. of polyiso was installed under the entire slab.

Figure 3. Slab edge (left) and under slab insulation (right) at TREE

For the mechanical systems, the group decided on electric resistance heat, no cooling, and solar thermal with electric backup for the domestic hot water (DHW). The community did not want to use any fossil fuels at this site; therefore, the remaining options were electricity and solar thermal. Air source heat pumps (ASHP) would have been a more efficient space heating option, but are much more costly, and even the smallest heat pumps can be oversized for a PH. And since they felt cooling is unnecessary for their location, the homeowners opted to go with electric resistance heat to save on cost. Heat pump water heaters (HPWH) were also considered instead of the solar thermal systems, but these homes do not have basements. This meant the HPWH would be close to the living space, and several occupants were concerned that they would be too noisy. More importantly, the occupants wanted to promote renewable technology.

4.1.3 Optimization

Although the design was highly influenced by the decision to pursue PH certification (preventing the envelope efficiency levels from being reduced), other efficiency packages were investigated to determine if similar source energy reductions could be achieved more cost effectively. An optimization was performed using BEoptE+ Version1.2 to assess the cost effectiveness of several different solutions packages. Table 4 shows the various specifications considered for the envelope insulation and mechanical equipment. Components selected for TREE are shown in bold.

Table 4. BEopt Simulation Options. PH Compliant Selected Design in Bold

Options Category	Simulated Options	Benchmark
Walls	R-13 fiberglass batts, 2×4, 16 in. o.c. R-19 fiberglass batts, 2×6, 16 in. o.c. R-29 SIP,.8 in. thick **R-43 vellulose, double-stud, staggered, 16 in. o.c.** R-47 ocSPF, 2×4, double-stud, staggered, 16 in. o.c. **R-52 8.5 in. vellulose + 3.5 in. ccSPF, 2×4 staggered, 16 in. o.c.**	R-13 Fiberglass Batts, 2×4, 16 in. o.c.
Wall Sheathing	**OSB** OSB, R-9 XPS	OSB, R-9 XPS
Attic	Roof R-48 SIP Ceiling R-49 fiberglass batt, vented Ceiling R-60 cellulose, vented **Ceiling R-90 cellulose, vented**	Ceiling R-38 cellulose, vented
Foundation	R10 edge, 2 ft depth **R-20 edge, 2 ft depth, 2 ft horizontal/r36 under**	2 ft depth, R-10 perimeter, r-5 gap XPS
Windows	Double-pane, low-e, insulated frame, U = 0.34, SHGC = 0.30 **Triple-pane, low-e, insulated frame, U = 0.17, SHGC = 0.62**	Double-pane, low-e, insulated frame, U = 0.35, SHGC = 0.44
Air Leakages	7.0 ACH_{50} **0.6 ACH_{50}**	7.0 ACH_{50}
Ventilation	**ERV, 96% Efficient, 110% ASHRAE 62.2**	Exhaust
Refrigerator	**18 ft^3, 392 kWh/yr**	Benchmark*
Cooking Range	**Electric range**	
Dishwasher	**318 kWh/yr**	
Lighting	**100% fluorescent**	
Space Conditioning	SEER 13, 7.7 HSPF SEER 19, 9.3 HSPF **Electric baseboard 100% efficiency**	SEER 13, 7.7 HSPF
Water Heater	HPWH, 50 gal **Electric w/solar thermal, 64 ft^2, 80-gal storage**	Standard gas water heater

* Details of the Benchmark specification can be found in Building America Housing Simulation Protocol, 2010

The results of the optimization are displayed in Figure 4. Each gray dot represents one iteration. The solid black curve is the minimum cost curve created by running six separate optimizations and plotting the lowest annualized energy related costs (AERC) against the associated source energy savings. Details of how the optimization was conducted are provided in the appendix.

The selected PH solutions package was analyzed with and without a 13 SEER air conditioner. Modeling the actual home with an air conditioner is required by the Building America House Simulation Protocols even though none of the homes in TREE used cooling systems. The package without an air conditioner results in a source energy savings of 47.6% over the Building America Benchmark and falls on the minimum cost curve, indicating the package is cost effective compared to the Benchmark.

For the occupants who were more cost conscious and did not wish to pursue PH certification, the walls were insulated to the full 12 in. depth with dense-packed cellulose only. The elimination of closed cell spray polyurethane foam (ccSPF) from the outer stud bay saved them approximately $4,000/home. Although not PH compliant, homes modeled with this efficiency level fall below the optimization curve at an annual source energy savings of about 47%, indicating that that package is cost effective as well.

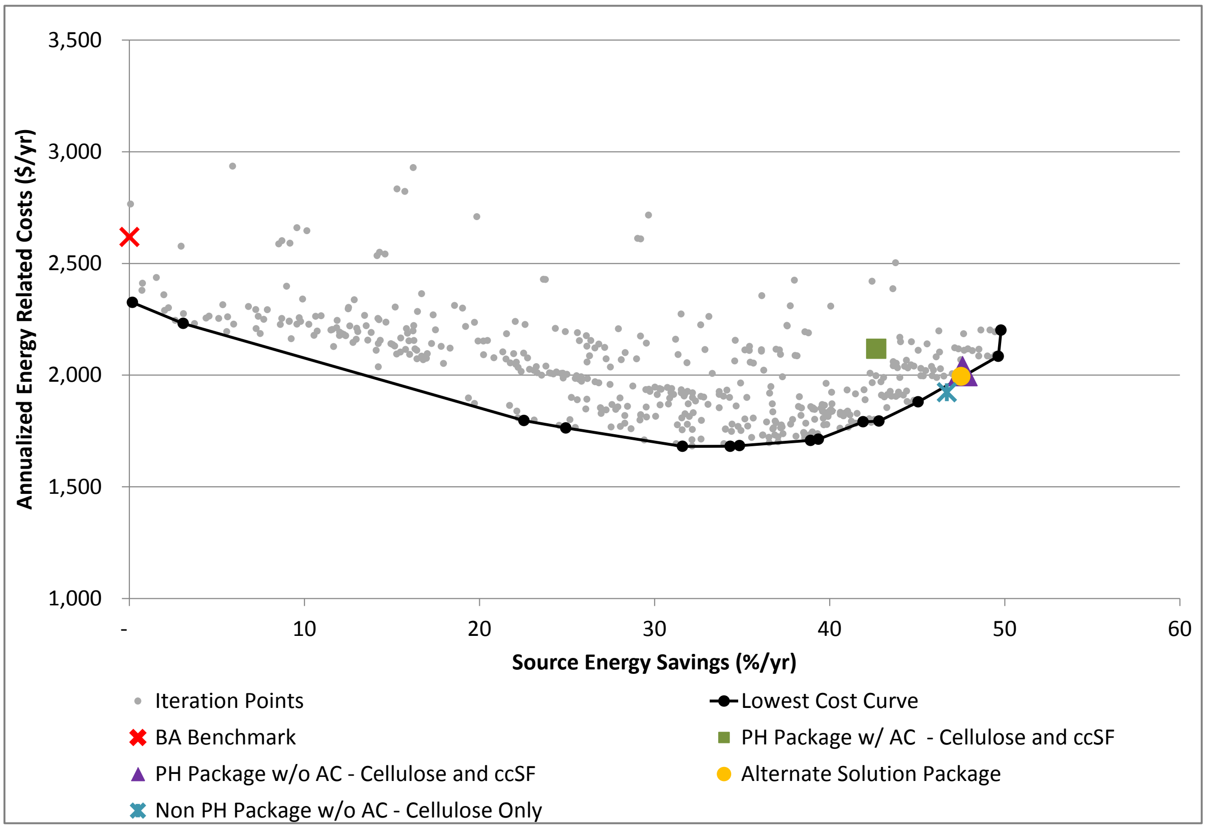

Figure 4. BEopt simulation cost/energy graph with proposed design with and without AC

The closest option package to the PH package is titled "Alternate Solution Package." It falls almost at the same point on the curve as the selected PH package. The differences between the alternate efficiency package and the packages implemented at TREE are outlined in Table 5. This alternative package results in a 47.5% source energy saving package and an AERC approximately $24 less than the selected PH solutions package.

Table 5. Selected Solutions Packages Compared to Alternate Solution Package

Package Option	PH Package	Non PH Package	Alternate Solution Package
Space Conditioning	Electric baseboard	Same as PH package	SEER 18, 9.3 HSPF
Ducts	None	None	15% leakage of total airflow, R-6 insulation
Water Heater	Electric standard + solar thermal	Same as PH package	HPWH, 50 gal, 140° F
Wall Insulation	R-52 cellulose+ ccSPF, 2×4 staggered, 16 in. o.c.	R-43 cellulose, 2×4 staggered, 16 in. o.c.	R-47 ocSPF, Gr-1, 2×4 staggered, 16 in. o.c.
Foundation	Whole slab R-37, R-20 gap	Same as PH package	2 ft R10 exterior
AERC ($/yr)	2,019	1,924	1,995
Source Energy Savings (%/yr)	47.6	46.7	47.5

Despite its lower AERC, this optimization alternative was not chosen because the building envelope insulation efficiencies were not high enough to meet the PH annual heating demand requirements. And, as noted earlier, even though heat pumps would have been a more efficient heat source, they are also much more costly, and even the smallest heat pumps can be oversized for a PH. Also, since cooling was deemed unnecessary, the homeowners opted to go with electric resistance heat to save on cost. HPWHs were also decided against because they would have had to be installed close to the living space, raising concerns about cold spots and noise.

4.2 Construction

Construction of TREE began in late 2012.The first homes built were the Turquoise units. Three different framing crews were hired at the start of the project, which resulted in three different levels of quality. The first three homes proved to have a steep learning curve for the entire project team.

4.2.1 Commercial Viability of Solution Package

Excluding land, water and sewer, the homes at TREE cost approximately $100/ft^2 to construct. According to the National Association of Home Builders (Taylor, 2013), the national average in 2013 was approximately $95/ft^2. However, if compared to typical single-family construction in upstate New York, the average is approximately $138/ft^2. From a cost perspective, the solution packages implemented proved to be economically viable.

To accommodate such high levels of wall insulation, the team decided on double-stud, 2×4 walls set 5 in. apart to provide a total cavity depth of 12 in. This method of construction has been used for more than a decade. Several builders in the northeast have successfully used “double wall” systems to more practically achieve higher R-values in thicker, framed walls. The builder favored this method over other options such as structurally insulated panels (SIPs) and Larson trusses due to the ability to dry the homes in quickly and the lack of contractor education that was needed.

Essentially, a double wall consists of a load-bearing external frame wall usually constructed with 2×4 framing at 16 in. on center. This wall is built and sheathed as a typical exterior frame wall, and windows and siding are installed using conventional methods. After the building is enclosed, an additional frame wall is constructed several inches inside the external load-bearing wall.

To builders of conventional stick-framed homes, often one of the most appealing features of double wall systems is that there are very few new exterior details. Exterior sheathing, structural bracing, house wrap or building paper, window and door flashing, and siding attachment are usually identical to good details in conventional, framed wall systems making achieving such high R-values a viable option for any builder.

The triple-pane, super-insulated windows are also common in PH construction. Most projects pursuing certification will need to install windows with these levels of efficiency. Prices for these windows have come down drastically in the last several years due to increased competition in the market. Windows as low as $30/ft^2 are available from several different manufacturers, and at least one well-known American manufacturer is currently developing a line that will comply with PH requirements.

The most difficult aspect of the solution package chosen was achieving the rigid air leakage requirement (0.6 ACH50) of the PH standard. This rate is approximately 10 times lower than typical new construction. To repeatedly achieve this level, the builder assigned a full-time staff person to ensure all the critical details were properly air sealed instead of relying on each of the trades to take care of their own areas. He felt that the person did not need to be highly qualified or expensive to the project, simply consistent in his actions and inspections. After the first couple of homes, the team felt confident that they knew how to achieve their goals.

All other aspects of the project are commercially available and implemented in standard practice on a regular basis. Based on the construction costs and repeatability of the practices, the solution packages chosen for TREE can be considered commercially viable options.

4.2.2 Opportunities To Reduce Cost

The biggest opportunity to reduce cost would have come from changes to the site plan. Solar access to several of the homes is significantly diminished by neighboring buildings. Less overlap, greater distance between homes, and setting the long axis to face north/south would have allowed for increased solar gain, which is heavily weighted in the PH software. These changes would have resulted in less south glazing, lower insulation levels and could have eliminated the need for the ccSPF in the walls.

From a non-energy standpoint, costs could have been reduced with respect to fire-rated construction. For example, locating the homes close to one another resulted in the need to increase the fire rating of the assemblies. Moving the homes slightly farther way from each other would have eliminated this need, further reducing costs. Limiting the community center to three stories instead of four would have resulted in similar reductions.

4.2.3 Gaps To Achieving the Solution Package on a Production Scale

One of the gaps experienced during the project was the lack of details available for installing the European-style windows. The window chosen is installed with clips that screw to the window frame and then to the rough framing of the opening. A typical flange was not available. Details showing proper incorporation into the drainage plane were not readily available and needed to be worked out with the help of the manufacturer and the subcontractors on site. The clips presented a challenge with respect to air sealing the windows properly and were found to be leaky during the first few tests until a consistent sealing method was developed. Finally, to reduce the thermal bridge around the window frame, it is typical in PH construction to insulate around the rough opening. Again, the clips posed an issue here and led to some of the insulation being carved away to provide a flat surface.

Another gap experienced was related to the continuous air barrier required to achieve the strict air tightness levels required by PH. While there are numerous details available to builders about how to air seal around windows and exterior penetrations, these alone are not sufficient to get below 0.6 ACH50. Attention to wall corners, wall/ceiling top plate connections and foundation/wall bottom plate connections are crucial. Minimizing any penetrations through the building shell is extremely important—simply caulking the plates and foaming around normal penetrations is not enough. Using the proper tapes in conjuction with continuous, properly sealed air barriers (whether sheathing or fabrics) is highly encouraged.

At EcoVillage, the team decided to install a continuous layer of sheathing on the underside of the roof trusses. Furring strips would be attached to the sheathing to create a chase for electrical wiring for lighting to eliminate any penetrations into the ceiling air barrier. Only crucial plumbing stacks would penetrate this plane. This ceiling barrier was to then be connected to the sheathing on the outer wall to seal any leaks at the top plate (see Figure 5).

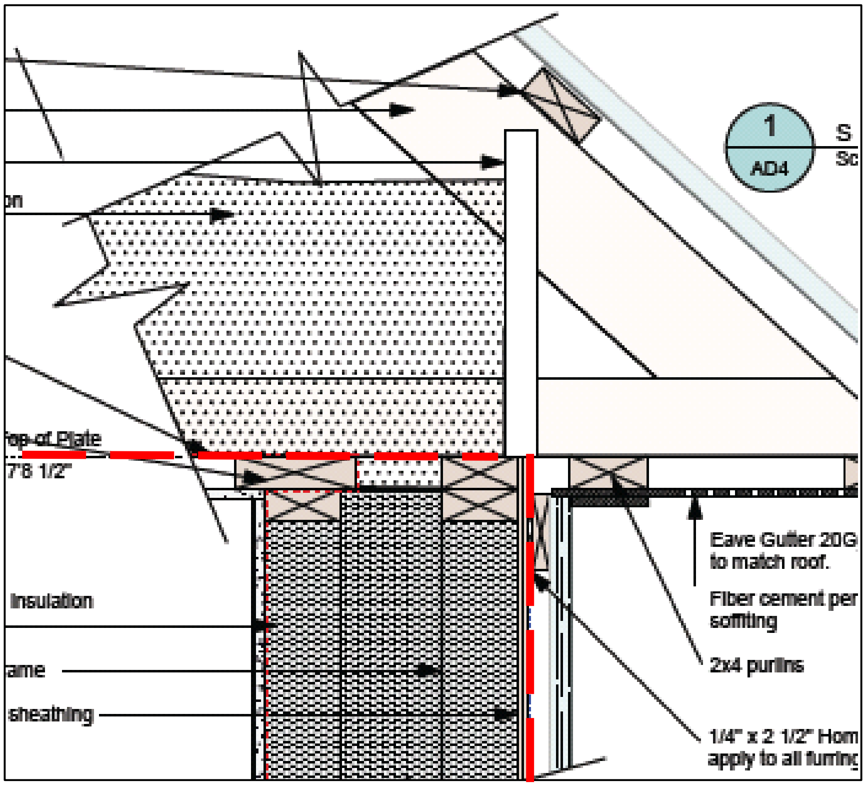

Figure 5. To effectively seal the top plate, a continuous air seal must be achieved from the interior ceiling air barrier over the top plates and connect with the exterior sheathing as shown by the dashed red line

However, transitioning from an interior air barrier plane to an exterior one can be very difficult to do correctly. The sheathing to framing connections and the roof ties shown in Figure 6 are two reasons why sealing this location was so difficult. As can be seen on the right, the sheathing doesn't line up with the top plate; it extends upward past it. This makes it impossible to tape or wrap building paper over this edge to create an air seal. The roof ties also prevent any continuous membrane or tape from being wrapped from the outside of the wall over the top plate. Properly connecting the exterior sheathing with the interior ceiling air barrier was not spelled out in detail in the plans. Contractors used a trial and error method in conjunction with the blower door to reduce the air leakage at this connection.

Figure 6. Exterior top plate connections are hard to properly seal due to interruption of roof ties

The team opted to use an aggressive air sealing strategy on the interior of the building using caulk along the exterior top plate as can be seen in Figure 7. Several passes were necessary at first for the crews to properly seal all the connections. Some areas couldn’t be totally sealed, such as where the plate meets the wall sheathing. Proper sealing along the entire length of this seam is prevented by the vertical wall stud.

Figure 7. The ceiling air barrier was created with sheathing (left) and then furred out to provide a chase for wiring to prevent penetrations into the attic. Crews aggressively sealed the top plate with caulk (right).

Incorporating the slab edge insulation into the design was another challenge facing the team . Because the slab was to be done in a monolithic pour, slab edge insulation had to be installed on the exterior of the building. This provided some complication because the double stud walls do not hang over the foundation, they are flush with the concrete edge. Therefore, incorporating the protruding slab edge insulation into the drainage plane proved tricky (Figure 8), because the drainage plane of the walls was built into the sheathing and could not be properly shingled over the slab edge flashing.

Figure 8. Flashing over slab edge insulation was taped to sheathing using the manufacturer's approved tape. The vented cladding was then attached with ¾ in. furring strips and overlapped the flashing.

The final gap encountered would actually apply to any home in a cold climate that has an ERV. Detailing of the exterior wall to duct connection is vital. Warm interior air getting past the vapor-tight insulation jacket will condense on the duct, wetting the insulation and pulling it further away from the wall, making the whole cycle worse. Critical details about how to do this properly are not readily available, but are vital to the performance of the ERV and the durability of the wall where the ducts penetrate. Also, inlet and exhaust hoods located on the windward side of the building may need to be shielded in such a way that windswept rain and snow cannot be blown directly into the ductwork. Longer vent hoods or other types of shields may be necessary.

4.2.4 Alternative Energy Efficiency Solution Package(s)

As noted earlier, the alternative package identified from the optimization was not chosen because the building envelope insulation efficiencies were not high enough to meet the PH annual heating load requirements. And, even though heat pumps would have been a more efficient heat source, the homeowners opted to go with electric resistance heat to save on cost. HPWHs were also decided against because they would have had to be installed close to the living space, raising concerns about cold spots and noise.

4.3 Final Testing

Because this was the team's first experience with PH construction, air leakage testing was conducted several times before drywall was installed on the first few homes. The builder even employed the insulating company to perform a few intermediate tests, and ultimately wound up renting equipment of their own so they could judge progress. Air tightness ranged from 0.38 to 0.59 ACH50 for the PH homes and from 1.0 to 1.9 ACH50 for the non-PH homes.

ERV testing and balancing is also a requirement for PH, and was performed on all the homes to ensure the proper levels of exhaust were being achieved. PH requires a minimum of 0.3 air changes per hour of continuous mechanical ventilation and the ability to boost these settings by the occupant when showering or using the kitchen. The minimum levels of exhaust are 24 for bathrooms and 35 for kitchens when the system is boosted. These settings were adjusted on a house-by-house basis depending on the interior RH levels. Several homes have four or more occupants and have higher than normal cooking and bathroom use. Boost and continuous settings were increased as needed to help manage moisture levels.

To meet the requirements of the DOE's Zero Energy Ready Home program, water efficiency testing was conducted to ensure no more than 0.6 gallons of water is wasted before hot water reaches the taps.

4.4 Discussion and Recommendations

According to the National Oceanic and Atmospheric Administration (NOAA), the 2013/2014 winter was the 34th coldest on record for the 48 contiguous states since 1895[1]. Needless to say, this put the homes and homeowners to the test. Issues that might not have arisen under normal circumstances came to light under these extreme conditions. The first of those was excessive condensation on some of the windows and doors. This was particularly problematic on the double-pane half and full light doors installed in the non-PH homes. With RH levels in the 40's, the dew point is only 43°F. Condensation readily formed on the glass on these doors except for the homes that had installed storm doors. It was particularly problematic in the homes with more than three people because the moisture levels in those homes tended to be higher than the others. This information is supported by data collected for nine homes in the community. Figure **9** and Figure 10 show that Houses 2, 7 and 9 experienced the highest humidity ratios of all the homes tested and consequently the highest dewpoint temperatures and exhibited the most serious problems with window condensation. In fact, these three homes did have more than three people in each home compared to the others, which had a maximum of two people.

[1] http://www.weather.com/news/winter-ncdc-state-climate-report-2013-2014-20140313

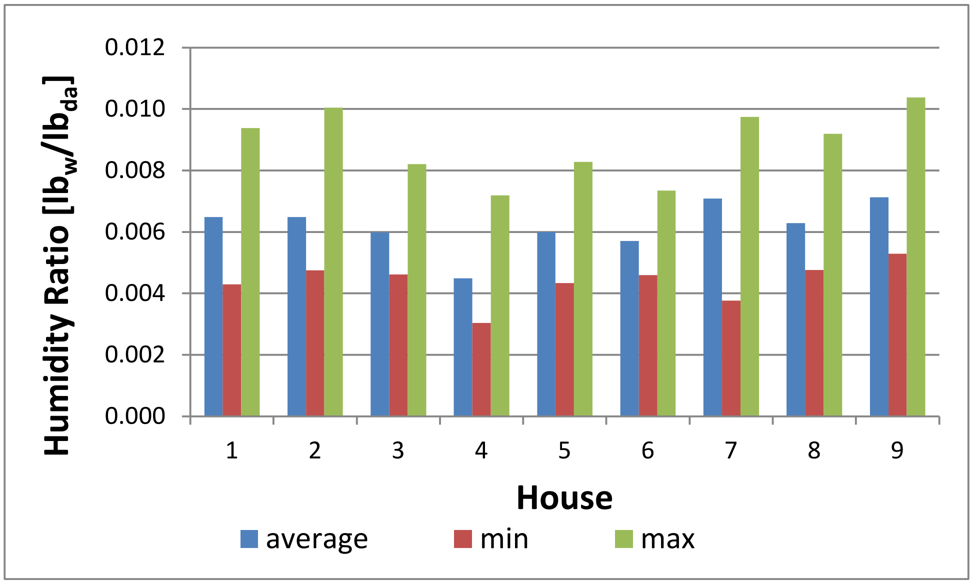

Figure 9. Comparison of average minimum and maximum humidity ratios for nine homes in TREE

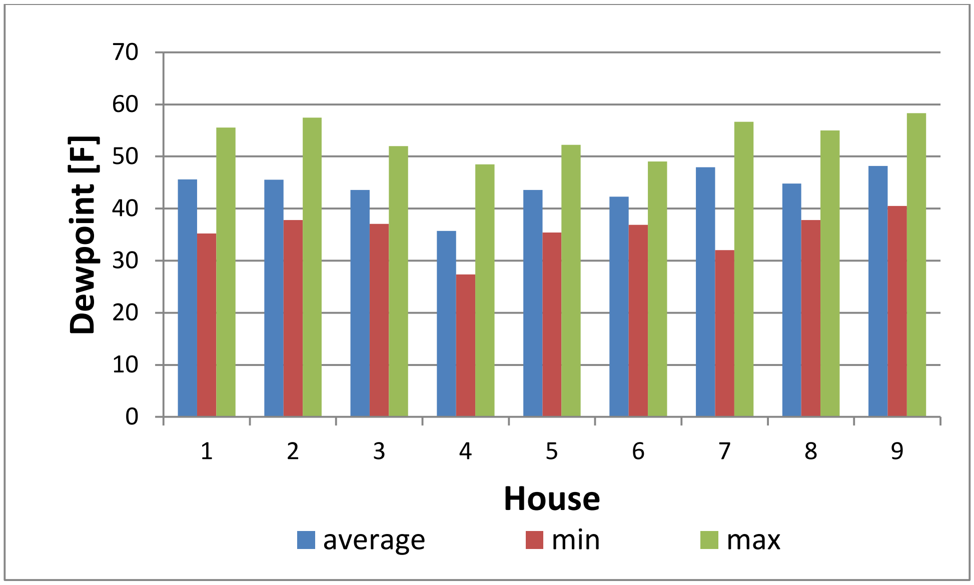

Figure 10. Comparison of average minimum and maximum dew point temperatures for nine homes in TREE

Even some of the smaller triple pane windows had condensation problems in the homes with higher moisture levels. With outside temperatures well below freezing and wind chill factors below that, condensation formed on the bottom of the windows and lower window frames. Storm doors are highly recommended for any double pane doors. Humidity levels should be closely monitored and ventilation increased or dehumidification used when levels exceed 40%.

The ERVs were also taxed by the cold weather. Supplemental preheat elements were not installed before the heat exchanger in any of the homes. The ERV has a freeze/thaw algorithm built in that is intended to shut it down if the temperature near the core falls below 8°F. Literature recommends preheating if the climate sees sustained periods under 10°F for several days. Based on historical climate data for Ithaca, a preheater is not necessary. Unfortunately, sustained periods below 10°F were experienced this year. The cores froze in many of the units due to either high interior humidity levels or temperature sensors that had fallen out of place. For the added cost of the preheat coil (approximately $500 installed) it is recommended that this is included in any cold weather package as a safeguard for the equipment, to prevent condensation due to moisture build up, and to ensure good indoor air quality.

One lesson that CARB is still trying to convey to the occupants is that thermostat setback is highly discouraged when living in a super-insulated home. Being so environmentally conscious, several occupants want to turn their thermostats back at night and when they are not around. Additionally, some people are just used to sleeping in cooler temperatures than they like to maintain in the rest of the home. Several occupants have commented that the heating system won't heat up the home. When asked if they are turning the thermostats down, they admit that they are and that they completely shut them off in some parts of the home. For better or worse, these homes will not respond quickly to any desired increase or decrease in temperature because of the mass of the structure. They will not lose heat fast enough for the occupants at night to reach the setback unless windows are open, and then the mechanical system will not be big enough to quickly recover from that temperature drop. A consistent temperature should be maintained and heat kept in in the winter and kept out in the summer. Ongoing occupant education is key to help them to find a comfortable operating mode throughout the year.

4.5 Predicted Versus Actual Utility Bills

The first occupants moved into their homes in the fall of 2013. Utility bill analysis for the middle of December through the middle of April (Figure 11 and Figure 12) shows that the homes are using 18% less energy on average compared to predictions from BEopt, but 61% more compared to predictions from PHPP before PV is factored in. When PV production is subtracted from the totals, the average net energy use of the homes is 9% less than predicted by BEopt and twice as much as predicted by the PHPP.

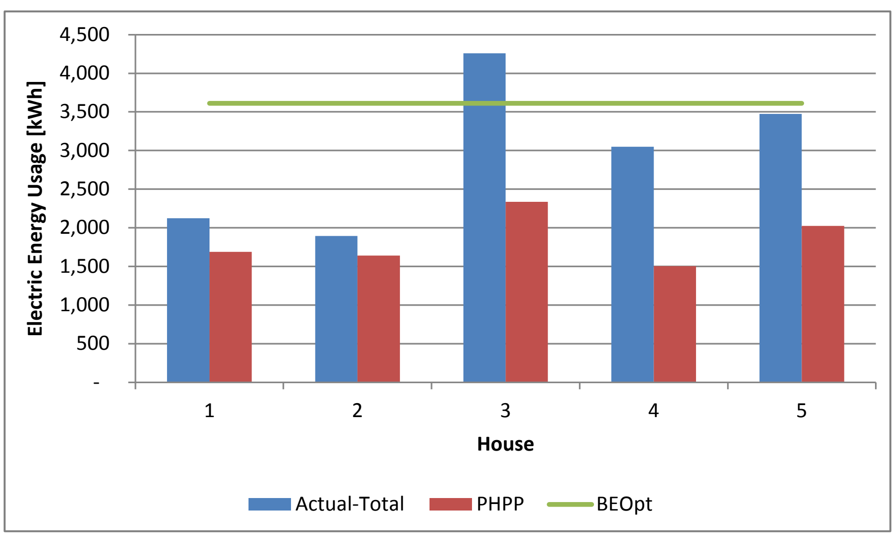

Figure 11. Predicted versus actual energy use (PV not considered)[2]

[2] Houses 3 and 5 did not have solar thermal or PV operational for three of the four months. The PHPP predictions have been adjusted to reflect that.

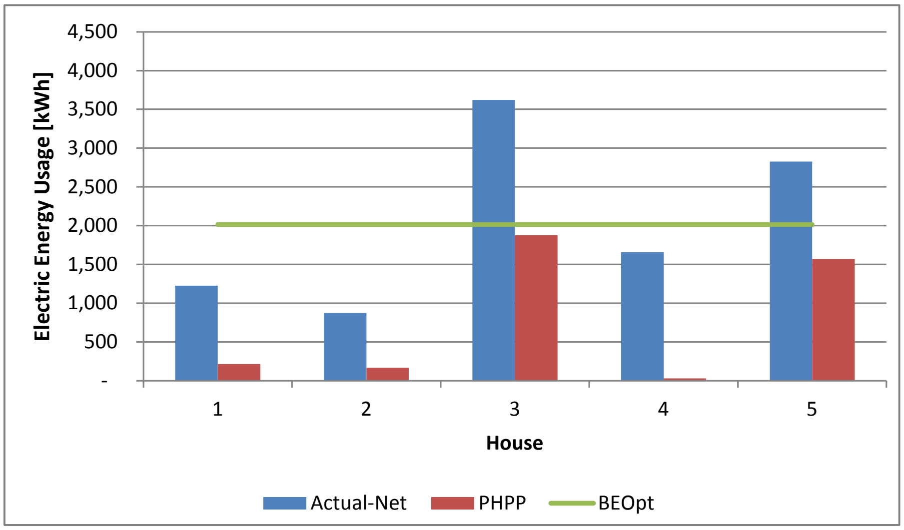

Figure 12. Predicted versus actual energy use (PV included)

A simple explanation for some of the difference between the predicted and actual energy use is the weather. It was a much colder winter than average and also snowier than normal possibly resulting in lower solar gain and lower energy generation from the PV than expected. Note that the PV for Houses 3 and 5 was not connected until April.

One of the main reasons for the differences in predictions between BEopt and the PHPP is the hot water consumption assumptions. The assumption for gallons of hot water used per person in the PHPP is less than half that assumed in BEopt. The PHPP predicts 8.5 MMBtu/yr energy use to produce hot water, while BEopt assumes 18.2 MMBtu. BEopt's values are typically closer to actual consumption in the United States than those assumed in the PHPP.

It is not surprising that Houses 4 and 5 use more energy since they have more than twice the number of occupants of Houses 1 and 2 and also keep their indoor temperatures more than 5 degrees warmer than Houses 1 and 2. In fact, they keep them warmer than the design temperature assumed by PH.

House 3 is an anomaly. It usually has only one occupant, but is using far more energy than any of the other homes. CARB has no interior temperature data for that particular house and is investigating why this home is using so much energy. It is possible that the solar DHW is not hooked up or may not be working properly. CARB will continue analyzing the utility bills for a full year and working with the occupants to determine possible behavior-related reasons that these homes may be using more energy than anticipated.

5 Calculating Design Loads for Super-Insulated Buildings

One of the goals of this research was to determine how two different methods for calculating design heating loads compared to measured peak loads. MJ8 is the primary method used in the United States to calculate residential design heating and cooling loads (ACCA 2009). The estimated heating load is calculated as an instantaneous load that is the sum of all building envelope and equipment loads.

Unlike Manual J, the PHPP software takes thermal inertia into account along with solar gains and other internal gains from occupants and equipment when calculating the design heating load. This results in a significantly lower design load than MJ8 predicts.

Both calculation methods were compared to measured design loads in two occupied PH homes and one unoccupied home in Climate Zone 6. The following sections outline the differences between both methods, discuss how predicted loads compare to measured design loads, and provide recommendations for calculating heating design loads for super-insulated homes.

5.1 Comparing MJ8 and Passive House Planning Package Predicted Design Loads

5.1.1 Manual J8

MJ8 is the primary standard used in the United States to calculate residential design heating and cooling loads (ACCA 2009). However, MJ8 states in Section 2 that this method should not be used for “Solar homes that have passive features.” While the term “passive features” is vague, many homes built to the PH standard incorporate sun tempering by increasing south-facing glazing and its corresponding SHGC to provide solar heating during the winter months. While these homes aren’t typically built with excessive mass in the form of concrete floors and walls, the amount of insulation in the structure can lead to a mass effect and store much more heat than a code-built home. Therefore, the question is whether or not MJ8 is appropriate for super-insulated buildings with sun tempering strategies.

MJ8 envelope loads include foundation, walls, ceiling/roof, and fenestration heat loss. HVAC equipment loads include duct losses and ventilation loads. Following recommended sizing protocols, the 1% winter design temperature (0°F in Ithaca, New York) was selected along with an indoor temperature of 70°F. For this project, WrightSoft Version 12.0 was used to implement the MJ8 calculations. Design loads were calculated for each room and the electric baseboards were sized accordingly.

5.1.2 Passive House Planning Package

Load calculations for sizing heating equipment using the PHPP software are performed in a similar fashion with a few key exceptions. Table 6 compares the design parameters from MJ8 and the PHPP. First, two different outdoor design temperatures are evaluated in the PHPP. These temperatures are daily averages and represent the maximum heating load days. They are determined from dynamic building simulations for the following conditions:

- A cold but sunny winter day with a cloudless sky (high pressure weather situation): weather condition 1, or

- A moderately cold but overcast day with minimal solar radiation: weather condition 2 (Feist 2007).

Heating loads are calculated for both conditions and the higher of the two is used to size the equipment. The resulting outdoor design temperatures for Ithaca in the PHPP were 14.6°F and 15.2°F, respectively.

Second, the PHPP also uses different interior design parameters. The interior design temperature used is 68°F for PHPP as opposed to 70°F for MJ8. This resulted in temperature differences between the interior and exterior of 53°F for PHPP load calculations as opposed to 70°F using MJ8.

Table 6. Design Parameters for Load Calculating Software

Parameters	Manual J8	Passive House	
		Weather Condition 1	Weather Condition 2
Outside Design Temperature	0ºF	14.6°F	15.2°F
Indoor Design Temperature	70ºF	68°F	68°F
Interior Relative Humidity	40 %	55 %	55 %
Mean Earth Temperature	50°F	42°F	42°F
Conditioned Area [ft^2]	1,664	1,267	1,267
Conditioned Volume [ft^3]	13,312	10,389	10,389

Another difference is in the calculation of the exterior surface areas. For PH, the wall height is measured from the top of the roof insulation at the wall's edge to the bottom of the slab foundation resulting in a higher wall area than would be calculated in MJ8. Thermal bridge calculations are then performed for the wall/roof and wall/foundation intersections and are added or subtracted as applicable.

The calculation of the conditioned volume is also significantly different in the PHPP. Conventional practice in the United States is to use the outside dimensions of the building envelope to calculate the conditioned square footage and then multiply that area by the ceiling height to get the volume. For PHPP inputs, only the interior floor area is used and any interior walls are eliminated.

Finally, note that internal and solar gains are deducted from the total design load in the PHPP, whereas MJ8 ignores both of these for design heating load calculations. Consequently, as can be seen in Table 7, these two methods of calculating heating load resulted in a 42% difference in the total predicted design loads; 9,059 Btuh for MJ8 and 5,352 Btuh for PHPP (higher of the two loads is used).

Table 7. Load Calculation Outputs

Building Heating Loads	Heating Load Values (Btuh)			
	Manual J8	Manual J8 w/ PH Parameters	Passive House	
			Weather Condition 1	Weather Condition 2
Walls	2,196	1,663	2,122	2,100
Glazing	2,750	2,082	2,139	2,117
Doors	412	312	299	296
Floors	1,259	953	723	723
Ceiling	641	485	474	469
Infiltration	1,641	991	977	976
Ventilation	188	188	183	181
Subtotal	**9,059**	**6,674**	**6,917**	**6,861**
Solar Heat Gain	0	0	–1,627	–867
Internal Gain	0	0	–643	–643
Total	**9,059**	**6,674**	**4,647**	**5,352**

For a more apples-to-apples comparison, the calculations were rerun in MJ8 using the PHPP interior and exterior design temperatures and volume. As can be seen in the table, the resulting heating load of 6,674 Btuh is very close to the PHPP heating load of 6,861 Btuh before subtracting solar and internal gains. The biggest differences between the two appear to be related to the predicted losses associated with the walls and slab floors. Considering the wall areas used in PHPP are almost 50% higher than that in MJ8, the difference in those component loads is understandable.

The PHPP predicted load for the slab, 723 Btuh, is 24% less than that predicted by Manual J, 953 Btuh. The fundamental difference between the method by which the two tools calculate the losses through the floor is that MJ8 multiplies a thermal resistance factor, F-value, by the perimeter of the slab as follows;

$$Q_{slab} = FP\Delta T \quad (1)$$

where,

F = F-value, Slab edge conductance (Btu/h-°F-ft)
P = Perimeter of slab-on-grade (ft)
ΔT = Difference between outdoor design temperature and indoor design temperature (°F)

F-values are taken from Table 4A in the MJ8 standard and are provided for insulation levels up to R-15. If different slab insulation levels are present as compared to Table 4A, the user must calculate a custom F-value for the slab as outlined on page 518 of the standard (see appendix). The F-value calculated for TREE was 0.155 Btu/ft·°F·h. Similar soil conductivities were used in both sizing calculations.

Slab losses in the PHPP are calculated by multiplying the overall heat transfer coefficient (U-value) through the body of the slab (as opposed to the perimeter) by the surface area of the slab as shown in Equation 2:

$$Q_{slab} = UA\Delta T \quad (2)$$

where,

U	=	Overall heat transfer coefficient of slab-on-grade (Btu/h-°F-ft^2)
A	=	Footprint area of slab-on-grade (ft^2)
ΔT	=	Difference between ground design temperature and indoor design temperature (°F)

The perimeter losses are accounted for by calculating the thermal bridge (psi value) between the slab and wall at the slab edge and multiplying that value by the perimeter length of the slab edge. This value is then added to the heat loss calculated through the floor of the slab.

5.2 Measured Design Loads

Predicted design heating loads were compared to measured data from three homes at TREE. Two of the three homes were occupied and monitored from November through July 2014. The third home is currently unoccupied and has only been monitored since the beginning of February.

Powerhouse Dynamics' eMonitor was used to collect long-term data. Current transformers were installed on the circuit breakers inside the electrical panel and connected to the eMonitor base. The eMonitor base communicates via wireless radio to the eMonitor Gateway, which in turn connects to the broadband service in the home. Data was collected by the eMonitor and stored on a cloud service where it was accessed and downloaded as needed.

One-minute data were collected for the following:

- Interior temperature [°F]
- Exterior temperature [°F]
- Total power at the main lines into the panel [W]
- Electric resistance baseboard heaters [W]
- Refrigerator [W]
- DHW [W]
- ERV [W].

Stove, dishwasher and washing machine energy use were also monitored separately, but were not used during the periods evaluated. Miscellaneous plug load energy use was calculated by subtracting the appliance and heating energy use from the total energy use recorded at the mains.

Actual peak heating loads were calculated using temperature data collected on site and the overall building UAs for each home. Only hourly blocks of data that met the following conditions were used in the calculations:

- Outdoor temperatures fell between –1°F and 1°F, (0°F was the outdoor design temperature used in MJ8).
- Hours fell between 12:00am and 6:00am to eliminate any effects of solar heat gains.

When these conditions were met, the following hourly values were calculated:

- Total electricity use
- Heating energy use
- Appliance energy use
- Miscellaneous plug loads.

Actual loads were calculated by multiplying the design UA values from MJ8 and PH by the measured temperature difference. Building UA values were calculated by dividing the design heating loads by the design temperature differences as shown in Equation 3:

$$UA = \frac{Q_{design}}{\Delta T_{design}} \quad (3)$$

where,

UA = overall heat loss coefficient [Btuh/°F]
Q_{design} = design load [Btuh]
ΔT_{design} = design temperature difference [°F]

Actual load, Q_{act}, for each design load calculation method was calculated as follows:

$$Q_{act} = UA \times \Delta T_{meas} \quad (4)$$

where,

Q_{act} = actual load [Btuh]
ΔT_{meas} = measured temperature difference [°F]

Internal gains from appliances and people, and the overall heat transfer coefficient of the building envelope assembly were calculated and/or measured where possible and verified against predicted values.

5.3 Results

Figure 13 and Figure 14 display the results of the monitoring compared to the predicted design values from MJ8 and the PHPP. Note that heating input energy never exceeds the PHPP design load predictions and total input energy exceeds the PHPP design loads in only six out of the 54 sample sets. Since all end uses measured during these periods were electric, it is assumed that all energy use resulted in heat input into the space and therefore, total input energy is being evaluated as the amount of mechanical heat provided, not just that from the baseboard heaters.

To determine the extent of the influence of actual interior temperatures on the design loads, MJ8 loads were recalculated using measured interior temperatures and displayed in the graph. While the difference between the adjusted loads and the design load was almost 1,500 Btuh at times, the adjusted MJ8 loads were still significantly higher than the total input into the spaces.

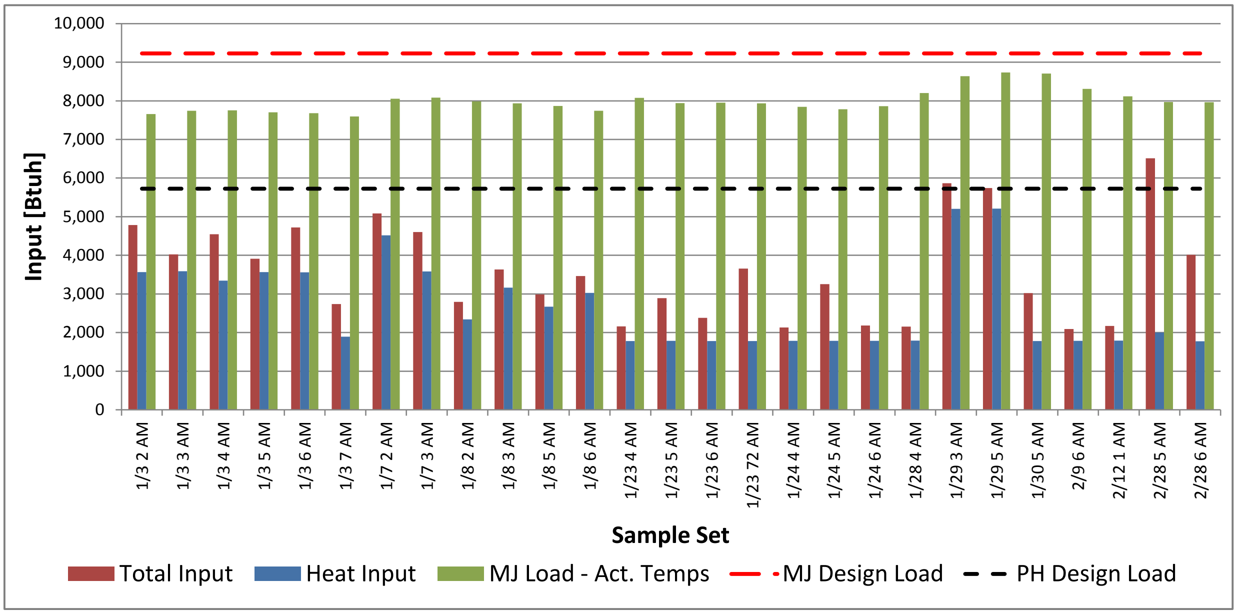

Figure 13. House 1, design heating loads compared to actual energy input at outdoor temperatures between -1°F and 1 °F

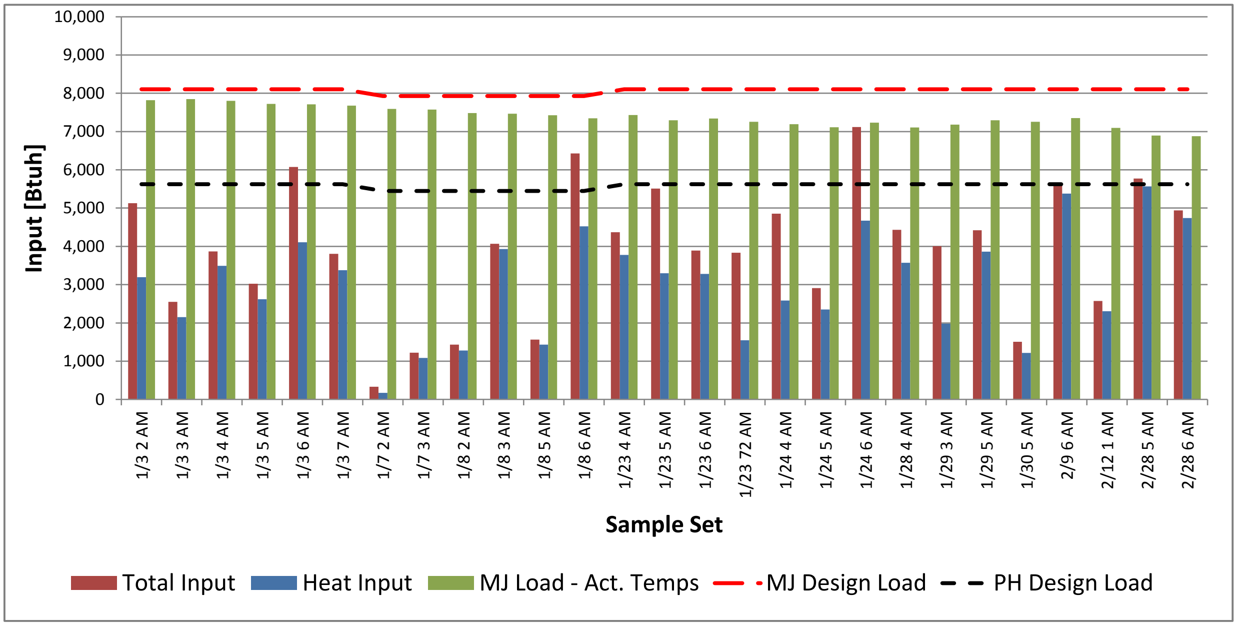

Figure 14. House 2, design heating loads compared to actual energy input at outdoor temperatures between –1°F and 1°F[3]

As stated earlier, the PHPP design loads include internal heat gains and solar gains. Figure 15 and Figure 16 display MJ8 predicted loads adjusted for these gains along with the PHPP loads

[3] The ERV in House 2 was inoperable for periods 7 through 11, therefore, the design loads were adjusted appropriately for both MJ8 and the PHPP.

adjusted for actual indoor temperatures. By making these adjustments, both load calculations now include internal and solar gains and have been adjusted for the actual interior temperatures, providing a side-by-side comparison of each calculation method.

Internal heat gains assumed in the PHPP for each home were 643 Btuh and predicted solar gains were 867 Btuh and 816 Btuh for Homes 1 and 2, respectively. The solar gains from the PHPP were also added to the total input for each home to evaluate whether those assumptions are valid.

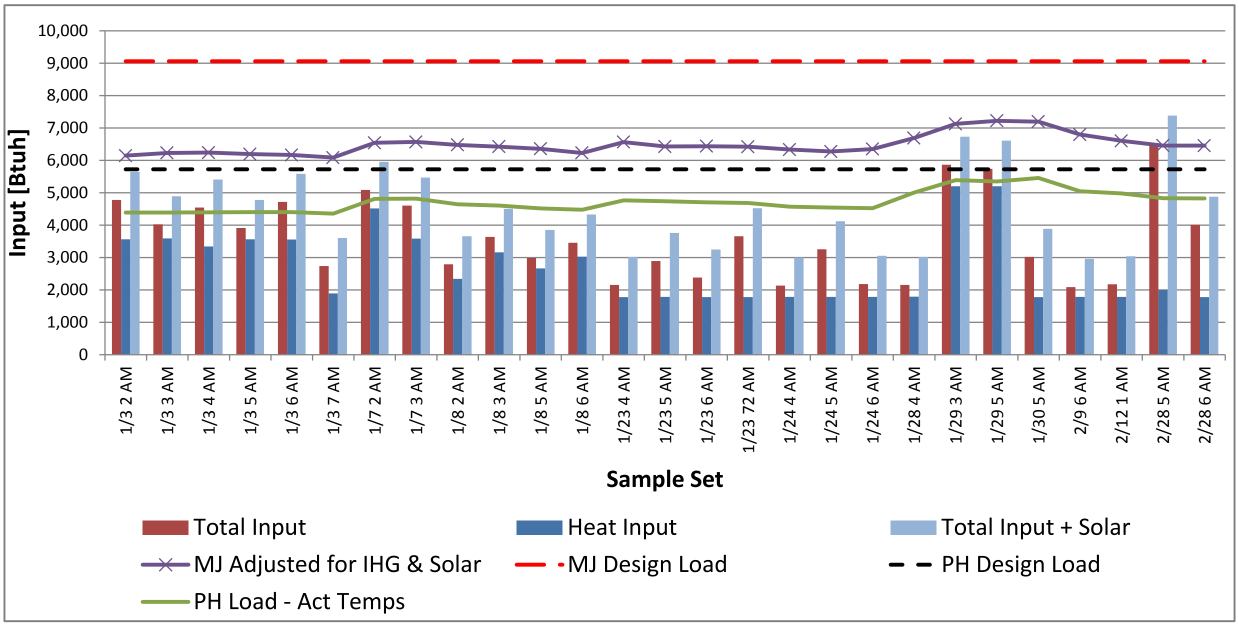

Figure 15. House 1 design loads adjusted for actual interior temperatures, interior heat gains and solar gains compared to measured input

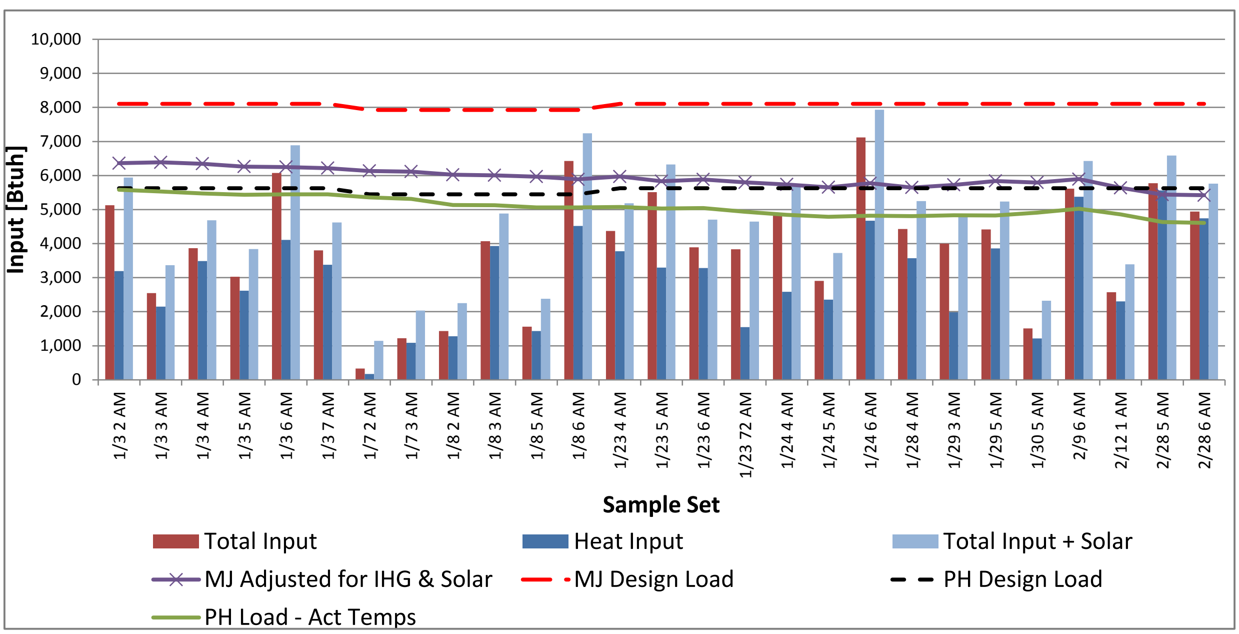

Figure 16. House 2 design loads adjusted for actual interior temperatures, interior heat gains and solar gains compared to measured input

Because so many factors could be affecting these 1-hour periods—recovery from a deep setback, a deep setback if someone has gone away, or unusual solar gain the day before—the data was averaged for each home and is summarized in Table 8. The percent difference between the total measured energy input and the predicted loads is provided in Table 9.

Results for unoccupied House 3 were only available for a couple of periods. The monitoring on that home started several months after the first two, and hour periods where the temperature was near 0°F during the night were far fewer. The results do indicate, however, that for those two periods, the PHPP provides a better estimate of design loads than MJ8. A comparison of the total and heat input show that there was not much else running in this home. None of the appliances were installed during the monitoring period. Without the normal internal gains from the DHW, lighting and the refrigerator to lend some heat, the predicted PHPP and actual loads are much closer.

Table 8. Comparing Average Modeled Design Loads With Average Measured Input

	Measured Indoor T	Total Input	Heat Input	MJ Design Load	PH Design Load	MJ Load - Actual Temps	MJ Adjusted for Internal Heat Gains and Solar	PH Load - Actual Temps
	°F	Btuh	Btuh	Btuh	Btuh	Btuh	Btuh	Btuh
House #1	61	3,613	2,690	9,059	5,726	7,994	6,484	4,729
House #2	64	3,898	3,017	8,067	5,587	7,385	5,926	5,076
House #3	67	5,186	5,120	7,795	4,874	7,331	6,291	4,743

Table 9. Percent Difference Compared to Total Input

	Total Input	Heat Input	MJ Design Load	PH Design Load	MJ Load - Actual Temps	MJ Adjusted for Internal Heat Gains and Solar	PH Load - Actual Temps
House #1	–	–34%	61%	37%	55%	44%	24%
House #2	–	–29%	52%	30%	47%	34%	23%
House #3	–	–1%	33%	–6%	29%	18%	–9%

PH sizing calculations are intended to result in designs that would provide adequate heat to the home even if it is unoccupied. Based on the limited data collected for House 3 (a currently unoccupied home) compared to the other two homes, it appears that the calculation method employed by PH would result in proper space conditioning. As can be seen in Table 9, the homes with occupants required 24% less energy to keep the space at temperature than the PH design load, even when using the actual interior temperatures and not the design condition. It would appear from these numbers that gains from occupants and plug loads are more significant than anticipated and can be used in design calculations.

5.4 Discussion

The difference between total energy and heating input in both House 1 and House 2 is due to the DHW. During periods when the DHW is replenishing standby losses, House 2's DHW energy averages about 500 W where House 1's tank averages about 200 W. However, the tank in House 1 replenishes loses every 2–3 hours while the tank in House 2 runs every 4–5 hours. Therefore, the spikes in input should not be assumed to happen every hour. Differences could be due to tank temperature sensors and settings. If the DHW loads are averaged based on the number of times they replenish during the night, the profiles look more like those in Figure 17 and Figure 18. Average energy use from the DHW is 81 W and 83 W per hour for House 1 and House 2, respectively.

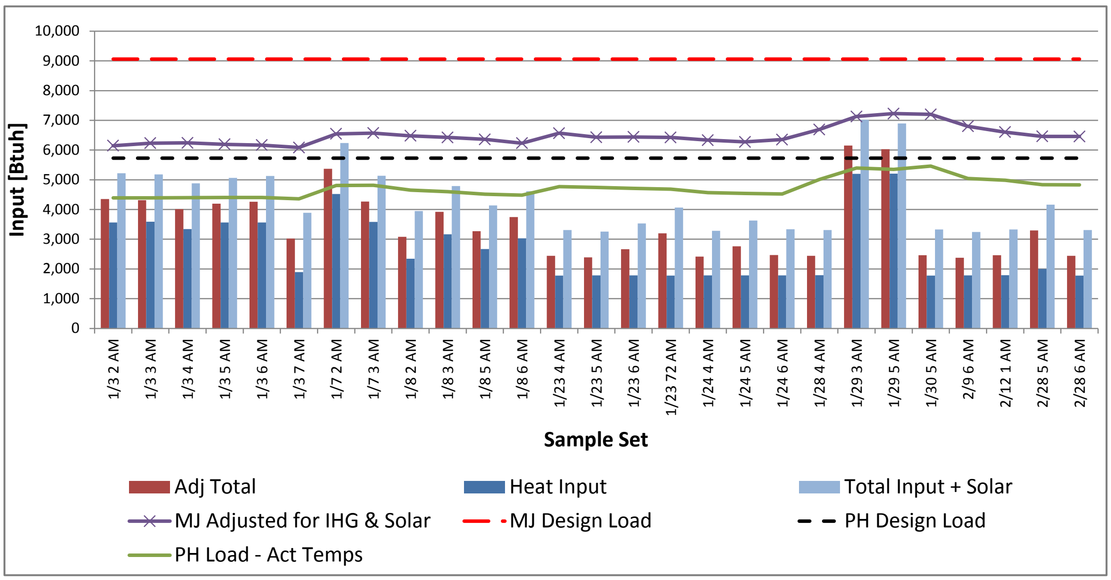

Figure 17. Predicted design loads for House 1 compared to total input adjusted to reflect average DHW energy use due to standby losses

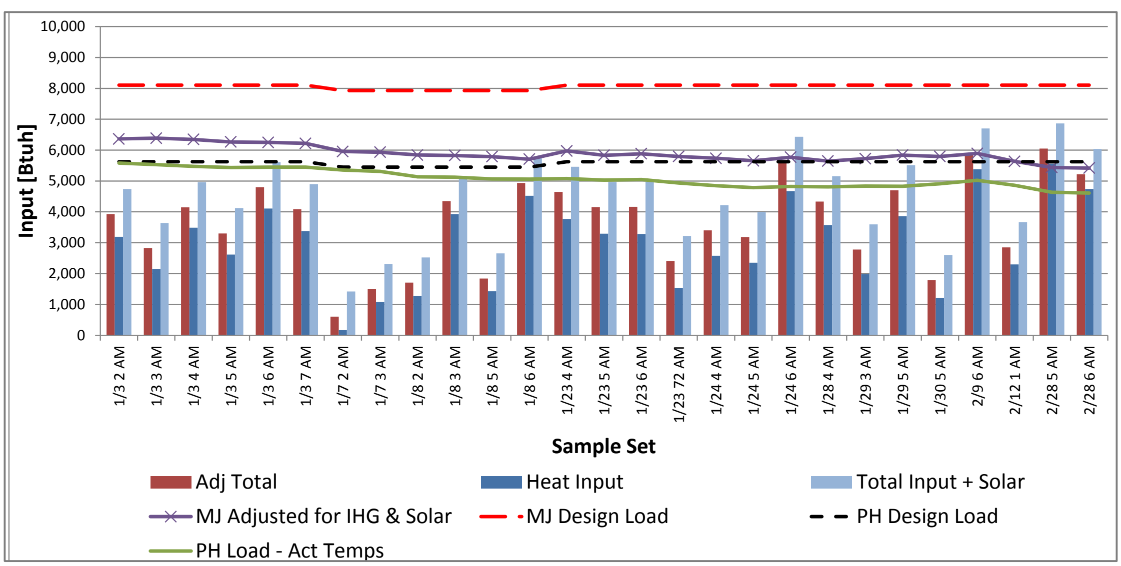

Figure 18. Predicted design loads for House 2 compared to total input adjusted to reflect average DHW energy use due to standby losses

The spikes in total and heating energy use in the two periods on January 29 for House 1 coincide with an increase in thermostat settings because the homeowner had company for two days (Figure 19). Due to the thermal inertia of the buildings, it would be expected to see a spike in heating energy use to recover from a period of setback. Excess energy is needed to bring the building structure up to temperature in addition to meeting the load.

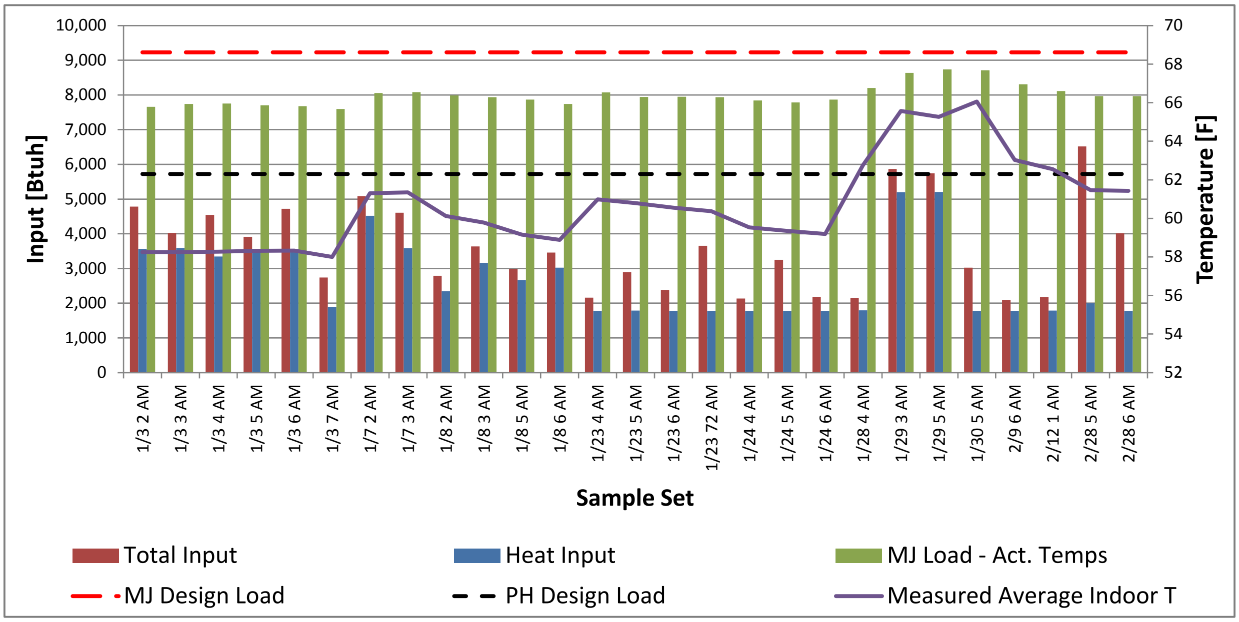

Figure 19. Design loads and measured input for House 1 compared to average indoor temperature

House 1 also saw an extreme spike in total energy use on February 28, which seems to be due to shower use as the bathroom heater was also running during that period just before the DHW energy use began. Typical tank replenishment for this home generally takes 4-5 minutes, but the water heater ran for 15 minutes during that period.

In Figure 20, the spike in indoor air temperature for House 2 on January 7 is a result of the thermostat being turned up a few hours before the data period shown. Several of the baseboard heaters were running and a closer look at the data for several hours before shows the temperature in the house being brought up a few degrees. The thermostats were then turned back down, resulting in the very low level of energy use in the following hours.

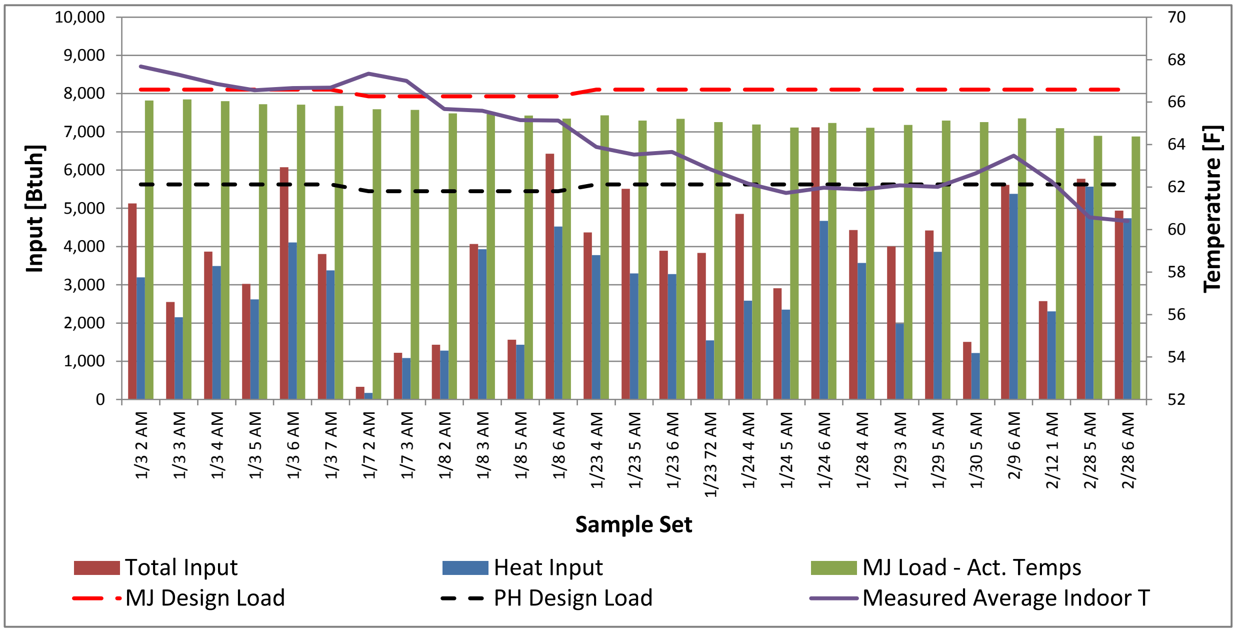

Figure 20. Design loads and measured input for House 2 compared to average indoor temperature

5.5 Recommendations for Sizing Heating Equipment for Super-Insulated Buildings

The data from this study suggest that sizing equipment for super-insulated homes should be based on loads that include some level of internal gains and the effects of thermal inertia. Results show that the total energy input into the space was far less under design conditions than predicted using recommended ACCA MJ8 design assumptions. Even the PHPP design load predictions exceeded the total input by more than 24% in the occupied homes.

6 Conclusions

50% Community Scale Evaluation:

Q. Is the 50% solution package implemented in this project commercially viable?

A. This research project evaluated two distinct concepts in partnership with the TREE neighborhood in the cohousing community of EcoVillage located in Ithaca, New York. First, the economic and commercial viability of this 50% community-scale project in climate zone 6 was investigated. Based on the builder's feedback, the successful implementation of the energy solutions package and several successful certifications, it can be concluded that this solution package was economically and commercially viable. The construction methods used have been successfully implemented for years in previous projects and can easily be adopted by contractors with no experience with these methods. The double-stud wall framing required little training and all insulation products used are commercially and readily available. The triple pane windows used are competitively priced and continue to be more so as competition increases. Installation guidelines for these products are being developed by the manufacturers to assist in effective incorporation into the building design.

Q. Where are opportunities to reduce costs?

A. Construction costs for this project came in at approximately $100/ft^{2,} not including site work or sewer and water lines. This is in line with national averages and is actually less than the New York state average. Opportunities to reduce cost in future projects lie mainly at the planning stage, particularly at the site planning stage. Insulation levels and expensive fire-rated assemblies could have been reduced if the homes had been more carefully oriented and further spaced apart. Air barrier details for PH-level construction are lacking in some areas, and would reduce delays and labor if these were more complete and readily available.

Q. What are the specific gaps to achieving the specified solution package on a production scale; cost, risk adversity, and implementation complexity?

One of the gaps experienced during the project was the lack of details available for installing the European-style windows. The window chosen is installed with clips that screw to the window frame and then to the rough framing of the opening. A typical flange was not available. Details showing proper incorporation into the drainage plane were not readily available and needed to be worked out with the help of the manufacturer and the subcontractors on site. The clips presented a challenge with respect to air sealing and insulating around the rough opening.

Another gap experienced was related to the continuous air barrier required to achieve the strict air tightness levels required by PH. While there are numerous details available to builders about how to air seal around windows and exterior penetrations, these alone are not sufficient to get below 0.6 ACH50. Attention to building component connections are crucial as is using the appropriate air sealing methods and products for each application.

Incorporating the slab edge insulation into the design was another gap the team faced. Because the slab was to be done in a monolithic pour, slab edge insulation had to be installed on the exterior of the building. Incorporating the protruding slab edge insulation into the drainage plane proved tricky because the drainage plane of the walls was built into the sheathing and could not be properly shingled over the slab edge flashing.

The final gap encountered would actually apply to any home in a cold climate that has an ERV. Detailing of the exterior wall to duct connection is vital. Critical details about how to do this properly are not readily available, but are vital to the performance of the ERV and the durability of the wall where the ducts penetrate. Also, inlet and exhaust hoods located on the windward side of the building may need to be shielded in such a way that windswept rain and snow cannot be blown directly into the ductwork.

Q. Based on the experience of the project team during planning and construction, what alternative energy efficiency solution package(s) should be considered?

As noted earlier, the alternative package identified from the optimization was not chosen because the building envelope insulation efficiencies were not high enough to meet the PH annual heating load requirements. And, even though heat pumps would have been a more efficient heat source, the homeowners opted to go with electric resistance heat to save on cost. HPWHs were also decided against because they would have had to be installed close to the living space, raising concerns about cold spots and noise.

Equipment Sizing Analysis:

Q. How do the design loads calculated using MJ8 and PH methods compare to the measured peak building loads?

A. The applicability of current mechanical equipment sizing methods for super-insulated homes were investigated. Based on data collected for three different homes, it appears that the PHPP assumptions and methods for sizing equipment are far more suited to these types of homes than ACCA's MJ8. For the two occupied homes, MJ8 calculations result in loads that are an average of 56% larger than actual measured design loads, while PHPP calculations resulted in loads that were 34% higher on average.

Q. If the modeled loads are significantly different from the actual loads, can the differences be explained?

Unlike Manual J, the PHPP software takes thermal inertia into account along with solar gains and other internal gains from occupants and equipment when calculating the design heating load. This results in a significantly lower design load than MJ8 predicts.

Interior temperatures were also kept lower than design assumptions in both homes. If actual interior temperatures are considered, MJ8 differences are reduced to 51% larger than actual, and PHPP results are 24% larger on average.

Q. What recommendations can be made about heating equipment sizing for super-insulated buildings?

A. Based on these results, it is recommended that internal and solar gains be included and some credit for thermal inertia be used in sizing calculations for super-insulated homes. Doing so results in a much closer approximation of the building's design load while still providing a slight buffer zone.

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Appendix

Builder Interview

The builder of record at TREE is the neighborhood itself, unlike most production-scale projects. However, the experienced builder or general contractor on the job that the neighborhood is relying on to actually build the structures is a local builder who has worked with the EcoVillage community in the past. To learn from their experiences and pass on any advice they have for others looking to build near zero communities, CARB interviewed the builder and his son who has been instrumental in the daily operations and project management during construction. Following is a recount of that interview.

Q. What are the areas of construction that could have been improved in terms of pace and accuracy?

A. During the interview, the need for better communication between various team members and subcontractors was a recurring theme. Project team buy-in is crucial to achieving the level of efficiency desired by the clients. If everyone on the team isn't in support of the ultimate goal, items can be missed and quality may not be what it should be to meet performance criteria.

Project oversight was also seen as a crucial addition to this type of project. Because of the management structure of the project, the team often found itself unable to keep up with the oversight that was necessary at each phase. If areas were missed, this would result in lost time and increased costs to make fixes.

Another issue brought up by the builder is that budgeting by subcontractors for these types of projects is not done well. Not enough knowledge about what they are being asked to do leads to overages, unexpected changes, and change order requests. Better and more current scopes of work could be very useful to help minimize this issue.

Q. What were the biggest challenges you faced on this project?

A. Budgeting was one of the biggest challenges. This builder was brought on after the site layout and much of the design was complete. He felt that he could have steered the design to keep costs low had he been involved sooner. For example, the homes were sited very close to one another, requiring the need for very costly fire-rated designs between the detached homes. These could have been avoided all together if considered earlier. There were also many costly delays dealing with site work and various code issues that arose.

Another challenge stemmed from the lack of cohesion of the project team. Few team meetings or calls were held. The builder spent a lot of time separately consulting with engineers, architects, consultants and subcontractors on whose responsibility certain items were and who could help when questions arose. Several items fell outside of everyone's scope of work and left the builder searching for the right person to fill the job.

Managing homeowner expectations was also difficult. The general path the occupants took as a community was to choose the least-cost path for many systems (not the cheapest products necessarily) with the intention of making any necessary changes in the future if things went wrong. However, when things went wrong, the tolerance for error was low.

Q. What would you do differently? Process, materials, insulation methods?

A. The project manager had a lot of input in this area. He felt that for smoother operation, it would be necessary to redefine the relationship between the partnerships on site and better clarify the responsibility chain. It was discovered that many of the special air sealing and water management details needed constant supervision. In the future, construction oversight for these details should be factored into the budget up front.

Q. Are there areas where you would have liked additional support?

Due to the fact that this project is at the forefront of energy efficiency, there was a lack of relevant details for some of the more cutting-edge components. For example, the triple pane windows chosen were installed with a clip system versus a flange, creating the need for water management and air sealing details that are different from those currently available. While several of the partners provided input, there wasn't any one place that provided a clear cut diagram, scope or set of instructions on how to specifically deal with some of these issues. While the result of this research will be to produce some of these details, the builder expressed some frustration at not having them readily available.

Q. What advice would you give to other builders interested in building to such high efficiency standards?

A. The builder strongly feels that efficiency doesn't have to be costly; it is common sense to build houses this way. He states that there was no additional cost compared to building to current code levels. The cost of construction, a mere $100/ft^2$, including electricity to the home (not water and sewer), strongly supports his argument.

Another strong conviction of this builder is that there needs to be a relationship-based process in this and any business, not simply a money-based process. The focus should not be to make as much money as possible, but to provide the best service for a reasonable fee. Trust in builders is always an issue. Building solid relationships based on a sense of cooperation and understanding would help alleviate some of this distrust.

Software Limitations

Manual J8

When calculating the heat loss of slab-on-grade foundations using MJ8, an F-value is selected from a table based on vertical, horizontal or complete slab insulation with R values ranging from R-0 to R-15. If the R-value of a slab-on-grade is greater than R-15, or the insulation configuration is different than those given, the user must calculate a custom F-value.

The following steps are taken to calculate the F-value for the heat loss to a typical slap on grade (ACCA 2009). Figure 21 illustrates the inputs needed.

1. Maximum radius considered (ft) = R_{max} = Slab width ÷ 2
2. Radii considered (ft) = R = 1ft, 2 ft , 3 ft…R_{max}
3. Soil path length (ft) = SPL = 3.14 × R – 1
4. Soil path R-value (ft^2-F-h/Btu) = R_{soil} = R per foot soil × SPL
5. Effective path R-value (ft^2-F-h/Btu)= R_{Eff} = $R_{(\text{air-to-air})}$material + R_{soil}
6. Effective path U-value (Btu/ft^2-F-h)= U_{Eff} = 1 ÷ R_{Eff}
7. F-value (Btu/ft-F-h) = F_{value} = sum of the effective path U-value for each foot up to the maximum radius

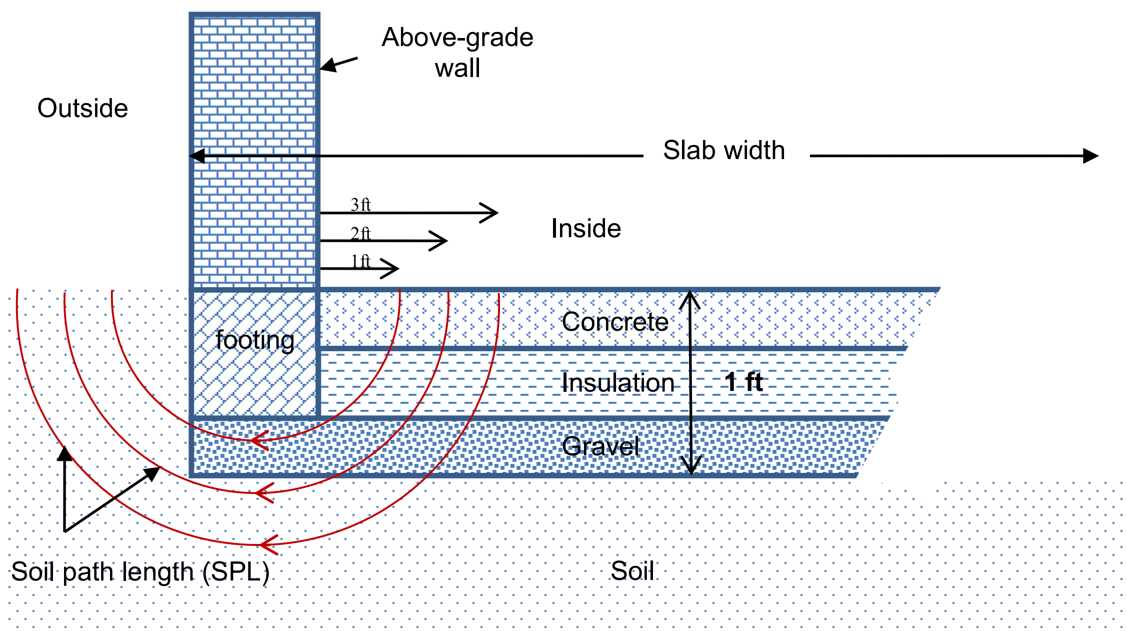


Figure 21. Sketch of construction detail of slab-on-grade

BEopt

To evaluate different wall insulation and heating systems, six separate optimizations were run in order to produce the graph in Figure 4.

Figure 22 shows the minimum cost curve for each optimization. The different shades of red represent three different optimizations with ASHP and three different walls types and insulation; single wall (sw), double wall (dw) and SIPs. The different shades of blue represent three different optimizations with electric baseboard (BB) and the three different walls types and insulation. Just as in Figure 4, the green square shows the selected solutions package with a 13 SEER air condition and the purple triangle show the same package without an air conditioner. The minimum cost curve shown in Figure 4 was obtained by plotting the lowest AERC for each Source Energy Savings point.

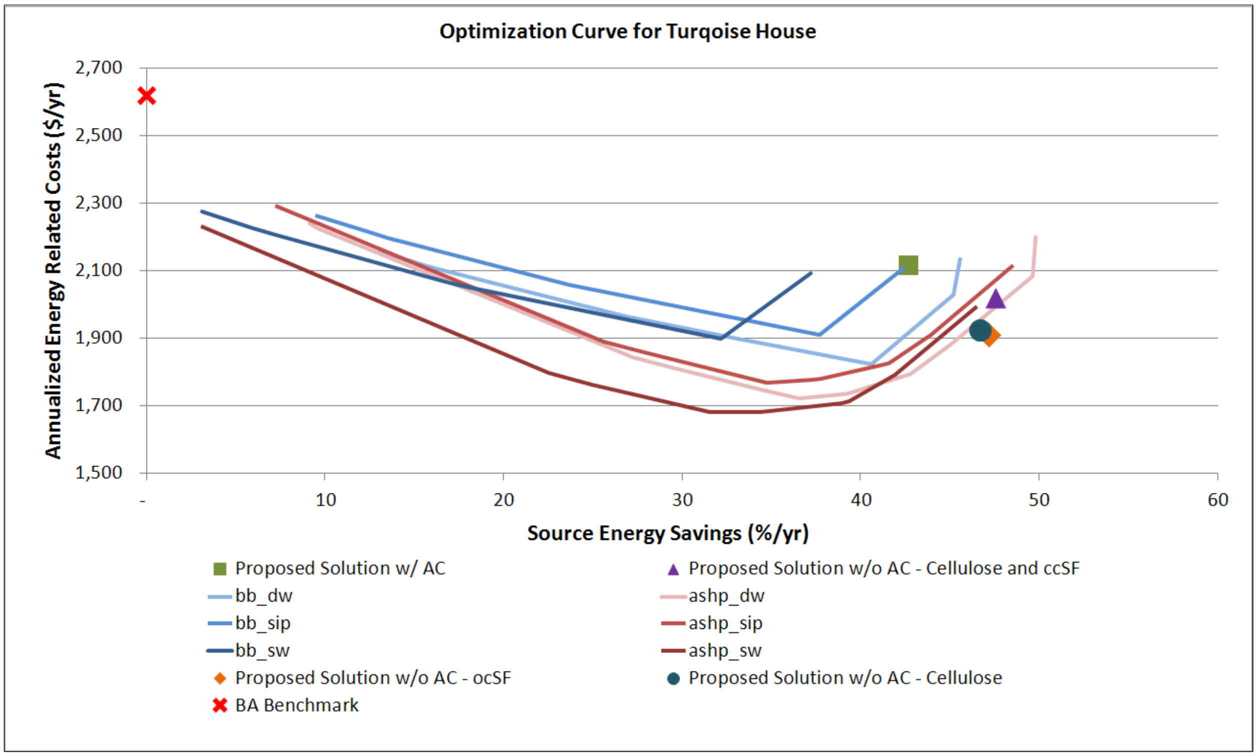


Figure 22. Minimum cost curve for each optimization

Zero Energy Ready Home Checklist

All the homes in EcoVillage are attempting to achieve the DOE's Zero Energy Ready Home certification. The checklists listed in Table 10 were completed for all homes. The applicable sections of each checklist and corresponding photo documentation are provided below.

Table 10. DOE Zero Energy Ready Home Program Requirements [Source: Challenge 2013]

Area of Improvement	Mandatory Requirements
ENERGY STAR for Homes Baseline	☑ Certified under ENERGY STAR Qualified Homes Version 3
Envelope	☑ Fenestrations shall meet or exceed latest ENERGY STAR requirements
	☑ Ceiling, wall, floor, and slab insulation shall meet or exceed 2012 IECC levels
Water Efficiency	☑ Hot water delivery systems shall meet efficient design requirements [no more than 0.5 gals in distribution system]
Lighting & Appliances	☑ All installed refrigerators, dishwashers, and clothes washers are ENERGY STAR qualified
	☑ 80% of lighting fixtures are ENERGY STAR qualified or ENERGY STAR lamps (bulbs) in minimum of 80% of sockets
	☑ All installed bathroom ventilation and ceiling fans are ENERGY STAR qualified
Indoor Air Quality	☑ EPA Indoor airPLUS Verification Checklist and Construction Specifications
Renewable Ready	☑ EPA Renewable Energy Ready Home Solar Electric Checklist and Specifications
	☑ EPA Renewable Energy Ready Home Solar Thermal Checklist and Specifications

Thermal Enclosure Checklist

1. High-Performance Fenestration
1.2 Performance Path: Fenestration shall meet or exceed 2009 IECC requirements

Windows (U-0.16, SHGC-0.62) meet required values for climate zone 6.

Intus Windows

PHPP INPUTS

Glazing inputs

#	Type	SHGC*	U_g-Value
#	Glazing options	SHGC*	U_g-Value
	High SHGC		BTU/hr.ft^2.F
	Triple Glazing		
1	SuperH4x18x4x20x4 Low E	0.62	0.106
2	4Low E x16x4x16x4 Low E	0.532	0.123
3	4Low E x16x4x16x4 Low E	0.578	0.158
4	4LowE x16x4x16x4Low E	0.494	0.106

*- SHGC for glazing only
**- more glazing options available upon request.

2. Quality-Installed Insulation

2.1 Ceiling, wall, floor, and slab insulation levels shall:

2.1.1 Meet or exceed 2009 IECC levels

2.2 All ceiling, wall, floor, and slab insulation shall achieve RESNET-defined Grade I installation or, alternatively, Grade II for surfaces that contain a layer of continuous, air impermeable insulation ≥ R-5 in Climate Zones 5 to 8

All insulation was installed to Grade I levels. Insulation levels are greater than the IECC requirements.

A polystyrene baffle was place in each rafter bay where the roof rafters intersect with the ceiling joist. The raised truss heel is spray foamed and the roof is filled with 24 in. blown-in cellulose.

There were two wall insulation strategies:
i. 12 in. double stud wall assembly dense packed with cellulose – R-43
ii. 12 in. double stud wall assembly with 3.5 in. of ccSPF in the outer stud and the remainder dense packed with cellulose – R-52

3. Fully Aligned Air Barriers
3.1 Walls
3.1.3 Attic knee walls

An air barrier (green) was place on the exterior of the building (walls and roof) and tape (black) at the joints to ensure a complete seal.

3. Fully Aligned Air Barriers
3.1 Walls
3.1.1 Walls behind showers and tubs

Closed-cell spray foam insulation was installed at the wall behind bathtub before the tub is installed to resist any moisture damage.

2. Quality-Installed Insulation
2.1 Ceiling, wall, floor and slab insulation levels
2.1.1 Slab insulation levels exceeds 2009 IECC levels
4. Reduced Thermal Bridging
4.2 For slab on grade in CZ 4 or higher, 100% of slab insulation to R-5 at the depth specified by 2009 IECC and align with thermal boundary of the walls

Slab was insulated to R20 edge and R-36 under and aligns with thermal boundary of walls

4. Reducing Thermal Bridging
4.4 Reduced Thermal Bridging at above-grade walls
4.4.5 Advanced framing
4.4.5a All corners insulated ≥ R-6 to edge

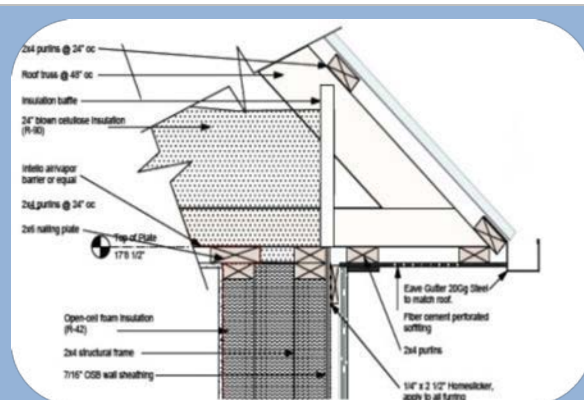
Corners were ensured to have only two studs to make room for adequate insulation

4. Reducing Thermal Bridging
4.4 Reduced Thermal Bridging at above-grade walls
4.4.5 Advanced framing
4.4.5c Framing limited at all windows and doors to one pair of king studs, plus one pair of jack studs per window opening to support the header and sill

4. Reducing Thermal Bridging
4.4.4 Double wall framing

4. Reducing Thermal Bridging
4.1 For insulated ceiling with attic space above (i.e., non-cathedralized), Grade 1 insulation extends to the inside face of the exterior wall below at these levels: CZ 1-5: ≥ R-21; CZ 1-5: ≥ R-21

This architectural drawing shows how the open cell foam wall insulation and 24 in. cellulose attic insulation was aligned with the inside face of the exterior wall. An insulation baffle allows the insulation to stay in place.



4. Reducing Thermal Bridging
4.4 Reduced Thermal Bridging at above-grade walls
4.4.5 Advanced framing
4.4.5b All headers above windows & doors insulated >= R-3 for 2×4 framing or equivalent cavity width.

All headers above windows and doors were fully filled spray foamed to R-42.

4. Reducing Thermal Bridging
4.4 Reduced Thermal Bridging at above-grade walls
4.4.5 Advanced framing
4.4.5d All interior/exterior wall intersections insulated to the same R-value as the rest of the exterior wall

Ladder blocking was installed to allow for closed cell spray foam to be applied in the wall cavity at the intersection between interior and exteriors walls.

5. Air Sealing
5.1 Fully seal penetrations to unconditioned
5.1.1 Duct/flue shaft

5. Air Sealing
5.1 Fully seal penetrations to unconditioned
5.1.2 Plumbing/piping

5. Air Sealing
5.1 Fully seal penetrations to unconditioned
5.1.3 Electrical wiring

5. Air Sealing
5.2 Cracks n building fully sealed
5.2.1 All sill plates adjacent to conditioned space sealed to foundation or subfloor with caulk, foam, or equivalent material. Foam gasket also placed beneath sill plate if resting atop concrete or masonry and adjacent to conditioned space

5. Air Sealing
5.2 Cracks in building fully sealed
5.2.3 Drywall sealed to top plate at all unconditioned attic/wall interface using caulk, foam, drywall adhesive (but not other construction adhesive), or equivalent material. Either apply sealant directly between dry wall and top plate or to the seam between the two from the attic above

Exterior top plates were sealed at the wall and ceiling plan. A layer of sheathing was run continuously over both interior and exterior top plate creating a solid air barrier.

5. Air Sealing
5.2 Cracks in building fully sealed
5.2.4 Rough opening around windows & exterior doors sealed with caulk or foam

Spray foam, caulk and tapes were used to seal the gaps between the rough opening and the door or window frame.

5. Air Sealing
5.2 Cracks in the building envelope fully sealed

A blower door test confirmed that the building has a tight envelope. For the PH homes, both pressurization and depressurization tests were performanced.

Lights and Appliances

5. Lights and Appliances
Feature energy efficient appliances and fixtures that are ENERGY STAR qualified.

All equipments are ENERGY STAR qualified and all fixtures meet WaterSense low flow limits.

5. Lights and Appliances
80% of lighting fixtures are ENERGY STAR qualified or ENERGY STAR lamps (bulbs) in minimum 80% of sockets

All light fixtures are either CFLs or LEDs and are ENERGY STAR qualified.

1. Moisture Control
1.1 Site and foundation drainage

Drains were designed to carry water away from the foundation.

1. Moisture Control
1.2 Capillary break below concrete slabs

Ground was layered gravel with more than 5 in. of polyiso and covered with 6 mil polyethylene sheeting serving as a capillary break.

1. Moisture Control
1.5 Continuous drainage plane behind exterior cladding, properly flashed to foundation (WMS 2.2)

All seams of the drainage plain (green) were fully sealed with an adhesive tape (black). Furring strips were installed under the siding to provide a vented cladding.

1. Moisture Control
1.6 Window and door openings fully flashed (WMS 2.3)

Flashing tape was installed on exterior wall sheathing seams and window rough opening before window installation. Window trim has header flashing for additional water management.

1. Moisture Control
1.11 Moisture-resistant materials/protective systems installed (i.e., flooring, tub/shower backing, and piping) (WMS 4.2)

Moisture-resistant sheet rock/backer board was placed behind the tub.

1. Moisture Control
1.13 Materials with signs of water damage or mold (WMS 4.5)

Initial moisture content measured from a sample of wood stud show values ranging from 7.9% to 9.0%

2. Radon
2.1 Approved radon-resistant features installed

Radon pipe was installed from below slab and extended through the building and to the roof.

3. Pest Barriers
3.1 Minimize pathways for pest entry

All penetrations and joints between foundation and exterior wall assemblies were sealed

3. Pest Barriers

3.2 Corrosion-proof rodent/birds barriers installed at all openings that cannot be fully sealed (e.g., attic vents)

4. HVAC Systems

4.5 Whole-house ventilation system installed to meet ASHRAE 62.2 requirements

HVAC-C:

1. **Whole-Building Mechanical Ventilation Design**

An ERV with its own dedicated distribution system meets ventilation requirements for healthy indoor air quality.

6. Low Emission Materials

6.2 Certified low-VOC or no-VOC interior paints and finishes used

Paint used have low-VOC or no-VOC for better indoor air quality.

6. Low Emission Materials

6.1 Certified low-formaldehyde pressed wood materials used (i.e., plywood, OSB, MDF, cabinetry)

All wood materials have little formaldehyde.

7. Home Commissioning

7.2 Ventilation after Material Installation

7.3 Buyer Information Kit

The home earned an Indoor airPlus label and an ENERGY STAR v3.0 label. Homeowner manual was provided.

Water Sense

3. Water Efficiency:
EPA Water Sense
3.0 Indoor Water efficiency Criteria

3.3 Hot Water Delivery System: To minimize water wasted while waiting for hot water, the hot water delivery system shall store no more than 0.5 gallons (1.9 liters) of water in any piping/manifold between the hot water source and any hot water fixture. To account for the additional water that must be removed from the system before hot water can be delivered, no more than 0.6 gallons (2.3 liters) of water shall be collected from the hot water fixture before hot water is delivered.

5. Lights and Appliances
Feature energy efficient appliances and fixtures that are ENERGY STAR qualified.

All equipments are ENERGY STAR qualified and all fixtures meet Water Sense low flow limits

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