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Integrated and Optimized Energy-Efficient Construction Package for a Community of Production Homes in the Mixed-Humid Climate

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Partnership for Home Innovation

October 2014

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Integrated and Optimized Energy-Efficient Construction Package for a Community of Production Homes in the Mixed-Humid Climate

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The National Renewable Energy Laboratory

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Office of Energy Efficiency and Renewable Energy

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Definitions

2 × 4	2 in. × 4 in. nominal framing lumber dimensions
2 × 6	2 in. × 6 in. nominal framing lumber dimensions
ACH50	Air changes per hour at 50 Pascals
BAB	Building America Benchmark
CFM	Cubic feet per minute
DOE	U.S. Department of Energy
ERV	Energy recovery ventilator
ft^2	Square feet
GSHP	Ground source heat pump
HEPA	High efficiency particulate air (filter)
HPH	High performance home
HPWH	Heat pump water heater
HVAC	Heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
IEQ	Indoor environmental quality
kWh	Kilowatt-hours
MBtu	Thousand British thermal units
MMBtu	Million British thermal units
MERV	Minimum efficiency reporting value (for media air filters)
NCTH	New Construction Test House
NGBS	ICC 700-2008 National Green Building Standard
ocSPF	Open cell spray polyurethane foam
OSB	Oriented strand board
PV	Photovoltaic
REC	Renewable energy credit
ROI	Return on investment
R-value	Measure of resistance to conductive heat flow
SHGC	Solar heat gain coefficient
SIP	Structural insulated panel
Tray Truss	Truss design that incorporates a space or offset below the truss bottom cord
U-factor	Measure of conductive heat flow (reciprocal of R-value)

Executive Summary

Selection and integration of high performance home features are two sides of the same coin in energy-efficient sustainable construction. Many advanced technologies are available for selection, but only by integrating these technologies into an affordable set of features can builders use these on a production basis. This practice will also ensure that whole-house performance meets expectations. This research test house project analyzes how a set of advanced technologies can be integrated into a healthy, green, durable, and energy-efficient house in the mixed-humid climate while remaining affordable to homeowners. The technical solutions documented in this report are the cornerstone of the builder's entire business model based on delivering high performance homes on a production basis as standard product offerings to all price segments of the residential market.

The builder started with a rectangular footprint to simplify construction, and worked with vendors and trade partners to increase construction efficiency, achieve resource optimization, and enable integration of all components and systems. The major components of the energy solution package were evaluated using energy simulation software. The package of production features include:

- Structural insulated panel (SIP) walls
- Spray foam insulation at the roof deck and rim joist areas
- Ground source heat pump system
- Heating and cooling ducts in conditioned space and within open-web truss floors
- Energy recovery ventilator (ERV) whole-house ventilation
- Energy management system
- Solar photovoltaic (PV) power generation.

With the support of the DOE Building America program, Home Innovation Research Labs partnered with production builder Nexus EnergyHomes to build a new construction test house in Frederick, Maryland. This urban infill project was a result of years of development with the community and the Housing Authority of the City of Frederick. The builder plans to adopt the successful components of the energy solution package for all 55 homes in the community. The research objective was to optimize the builder's energy solution package to improve energy performance and reduce construction costs where feasible. All of the major construction features, including envelope upgrades, space conditioning system, hot water system, and solar electric system were analyzed relative to the performance and cost effectiveness based on energy savings. Key findings from this research project include:

- The test house was estimated to save 36% whole-house energy use over the Building America Benchmark. This design could achieve 40% savings with modest design changes.
- The test house earned ENERGY STAR® (version 2.5) and Indoor airPLUS certifications, National Green Building Standard emerald-level green certification, and a 2012 Gold EnergyValue Housing Award; the builder was honored as 2012 EnergyValue Housing Award Builder of the Year. This design met all DOE Challenge Home requirements except the Water Efficiency (hot water delivery system) requirement.

- The factory-assembled structural components (SIP walls, open-web floor trusses, and roof trusses) reduced construction time (by at least 2 days) and installed costs. These systems also enabled integration of thermal enclosure functions (insulation and air sealing) and heating, ventilation, and air conditioning system (conditioned space for equipment and ducts).
- The building's thermal enclosure was practical to build on a production basis and cost effective based on return on investment, payback, and net annual cash flow.
- The use of SIP walls and spray foam insulation at the roof deck and rims resulted in a low house leakage rate of 1.1 ACH50. Developing an air sealing strategy during the design phase is important to achieve house leakage goals and control installed costs.
- This house construction allowed for conclusive air leakage testing before interior finishes were installed—when mitigation was relatively simple and inexpensive.
- The conditioned living area within the sealed attic cost less per square foot, based on the entire conditioned attic, than the first- and second-floor areas.
- The insulation levels can be further increased, if higher performance levels are desired, without major structural redesign or added installation labor.
- The ground source heat pump provided a predicted 13% energy savings over a high efficiency gas furnace and air conditioner; with incentives, the installed cost was competitive with installed costs for traditional high efficiency systems.
- The redesigned compact return duct layout, central duct chase, and supply ducts within the open-web truss joist floors contributed to an efficient heating, ventilation, and air conditioning air distribution system.
- A higher performing hot water system could be achieved by selecting a more efficient water heater than the 0.67 energy factor unit and a more efficient piping distribution layout.
- The installed solar electric (PV) system was estimated to provide sufficient energy to offset the estimated heating, cooling, and hot water energy on an annual basis. With a 5% reduction in cost (including incentives) this system would have a favorable annual cash flow when financed at 3.5% over 25 years.
- The energy consumption monitor would have a favorable net annual cash flow if the occupants can reduce whole-house energy use, based on the information provided, by less than 10%.
- The houses in this development will have a long-lasting environmental benefit as a result of lower utility costs.

The information in this report can be used by builders and designers to evaluate options, and the integration of options, for increasing the efficiency of home designs in climate zone 4. The data also provide a point of reference for evaluating estimates of energy savings and costs for specific features.

1 Introduction and Background

1.1 Problem Statement

Designing and building an affordable house that achieves 30%–40% whole-house energy savings is still a significant problem for many production builders. The purpose of this research effort was to analyze one builder's initial energy efficiency solution package by component in order to optimize the design for the mixed-humid climate: achieve at least 40% whole-house energy savings compared to the 2009 energy codes and reduce construction costs for energy features where feasible. The builder plans to adopt successful alternatives as standard practice for future houses in this and other communities. The results of this analysis should benefit other builders as they refine their energy solution packages. Finding market-ready solutions to this problem is a worthwhile effort to help achieve long-term Building America goals.

1.2 Project Overview

With the support of the U.S. Department of Energy (DOE) Building America Program, Home Innovation Research Labs (Home Innovation) partnered with Nexus EnergyHomes (Nexus) to evaluate and optimize a new construction high performance house design (Figure 1) in the mixed-humid region (International Energy Conservation Code [IECC] climate zone 4) of Frederick, Maryland. Completed in June 2011, the three-story infill duplex serves as a model home for the North Pointe community (Figure 2) in the heart of Frederick's downtown historic district. The home is one of about 55 new affordable homes being built as part of the Housing Authority of the City of Frederick's HOPE VI revitalization project, which aims to create affordable living options for eligible residents. The house design received an Emerald rating under the National Green Building Standard (NGBS 2009), the highest level of performance awarded by the program, while, for the location, being offered at an affordable market price ($320,000).

Figure 1. Nexus EnergyHomes model (left unit)

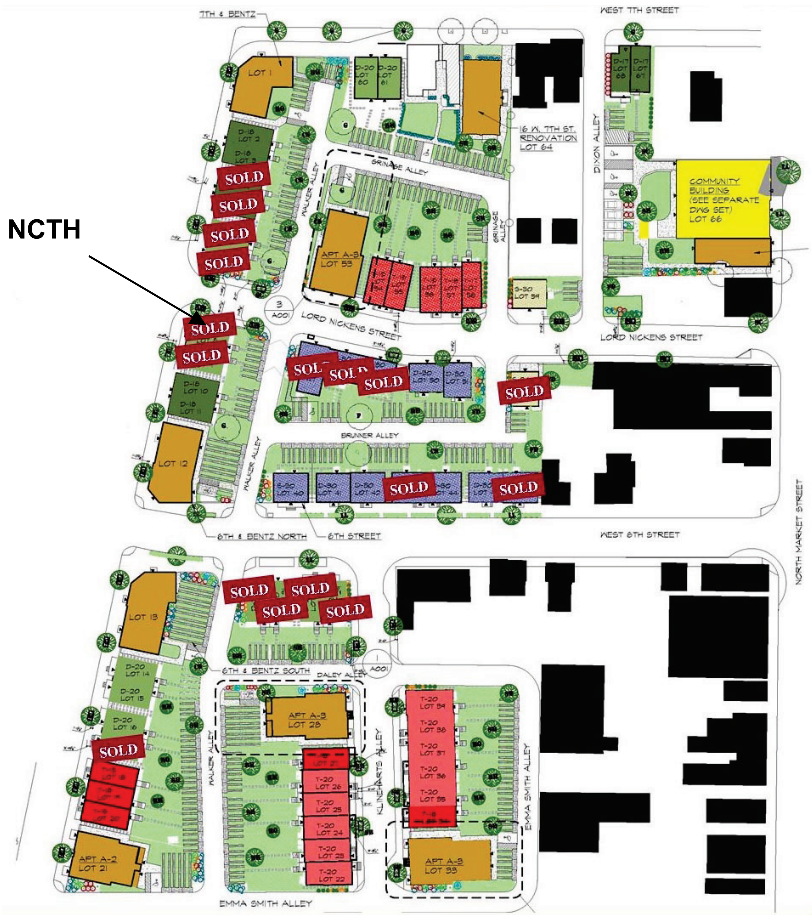

Figure 2. Nexus EnergyHomes North Pointe Community

Nexus is committed to building energy-efficient, healthy, affordable, and green program certified homes. Standard key features include:

- Structural insulated panel (SIP) walls
- Open cell spray polyurethane foam (ocSPF) insulation at the roof deck and rim areas
- Ground source heat pump (GSHP) systems
- Heating and cooling ducts entirely in conditioned space
- Energy recovery ventilator (ERV) whole-house ventilation
- Energy management system
- Solar photovoltaic (PV) power generation.

The Nexus philosophy is to continually improve the construction, performance, and whole-house cost of its high performance designs. For this project, Home Innovation involvement began immediately prior to construction, when the builder wanted to further hone the final product's performance estimates and the construction quality process. The goals for this project were:

- Improve the design to achieve 40% whole-house energy savings over the Building America B10 Benchmark (BAB) (the B10 Benchmark is equivalent to the 2009 IECC).
- U.S. Environmental Protection Agency ENERGY STAR® (v. 2.5) (EPA 2012) and Indoor airPLUS (EPA 2009) certifications.
- NGBS gold level green certification (NGBS 2009).
- Document and evaluate costs for efficiency measures.
- Achieve a house leakage rate of below 1.5 ACH50 and optimize the air sealing strategy.
- Optimize the heating and cooling duct distribution and air quality systems to improve performance without increasing installed costs.

1.3 Relevance to Building America

The goals for this project align well with Building America goals to develop market-ready solutions that improve energy efficiency (reduce whole-house energy use by 30%–50% compared to 2009 energy codes), durability, affordability, and comfort (DOE 2012).

This report documents the construction features of the New Construction Test House (NCTH), analyzes costs and expected energy performance, summarizes short-term performance testing results, and presents recommendations for improvement in future houses.

2 Experiment

2.1 Research Questions

Based on the project goals, the research questions for this project are:

- Are the individual design features practical to implement and cost effective?
- What features could be modified to cost-effectively achieve higher energy savings?
- What barriers need to be overcome to meet DOE Challenge Home requirements?
- Are there opportunities to improve the performance, testing, or integration of the mechanical systems?

2.2 Technical Approach

Computer modeling was used to evaluate the builder's energy solution package (36% whole-house energy savings) and look for opportunities to improve energy savings and installed costs; this analysis is presented in Section 3. Construction and implementation details are discussed in Section 4. Characterization testing was performed to establish the comparative performance features of the house; test results are presented in Section 5.

2.3 High Performance Home Design Features

A summary of the design considerations and solutions is presented in Table 1 and described below.

The three-story duplex design offers 1,830 ft^2 of finished floor area above grade, including a third-floor 390-ft^2 loft accessed from the second-floor master bedroom. The model also has 600 ft^2 of finished area and 120 ft^2 of unfinished area below grade. All elements of the home were designed for efficiency and simplicity of construction—including its simple shape, small footprint (20 ft × 36 ft), and architectural features outside of the thermal envelope.

The high performance home (HPH) was constructed using SIP technology to provide a wall R-value (R-22 for this 6.5-in.-thick panel) greater than that required by the current building code (IECC 2009). SIP construction speeds the building's assembly and provides sound attenuation in this urban neighborhood along a busy boulevard. SIP construction is tight when the panels are installed using industry best practices. The panels' large size (wall panels are 8–12 ft wide with smaller infill sections as needed) and continuous expanded polystyrene core minimize thermal bridging that is common in light-framed homes without continuous exterior insulating sheathing.

The structural systems—SIP walls, open-web floor trusses, and roof trusses—are integral to the building's high performance efficiency package. The builder investigated technologies and selected SIPS as an optimal wall system to achieve its energy and cost goals.

Table 1. Advanced High Performance Design Features

Design Consideration	Solution
Affordable Design[a]	• Simple rectangular design with exterior porches providing architectural detail • SIP wall construction • Open-web floor trusses • Conditioned attic under tray trusses
High R-Value[b] Building	• R-15 fiberglass batt basement insulation • R-22 SIP walls (6.5-in. thick) • R-44 ocSPF in floor rims • R-38 ocSPF in rafters of attic trusses • ENERGY STAR windows ($U^c = 0.31$, $SHGC^d = 0.27$)
Air Seal to 1.5 ACH50	• Minimized structural intersections • Very little architectural complexity in structure • SIP wall panels • Install closed cell spray polyurethane foam at roof deck and rim areas
Mechanical Systems, Lighting, and Appliances	• GSHP : 2-ton, 2-stage compressor, 18.6 energy efficiency ratio/4.2 coefficient of performance (high stage) and 26.8 energy efficiency ratio/4.7 coefficient of performance (low stage) • ENERGY STAR power-vented natural gas water heater (energy factor 0.67) with desuperheater loop from GSHP • Appliances: ENERGY STAR • Lighting: 100% compact fluorescent lamps or light-emitting diodes • 4.4-kW PV system
Improved IEQ[f]	• ERV integrated with heating and cooling ducts • Supplemental filtration using a bypass HEPA[g] filter also integrated with heating and cooling ducts • MERV[h] 13 air filter at the air handler • Ducts sealed and in conditioned space • Central vacuum system vented to the exterior • Low volatile organic compound paints, adhesives, caulks • No products containing formaldehyde
Quality Assurance and Control	• Factory production of major components provides quality assurance for floors, walls, roof trusses
Repeatable Design	• 20 ft × 36 ft footprint is a common townhouse or duplex size • Expansion space available in basement and attic • Components simplify and speed constructability • Walls and roof can be easily scaled to provide additional insulation value without major redesign effort • Architectural features are outside of the building envelope (i.e., porches and pergolas)

[a]Affordability regarding these solutions is addressed in the analysis and conclusions sections of this report; [b]Level of insulation in walls, roofs, and floors; [c]Insulation value in windows; [d]Solar heat gain coefficient; [f]Indoor environmental quality [g]High efficiency particulate air (filter); [h]Minimum efficiency reporting value (for media air filters)

The basement is conditioned, and its 8-in. poured concrete foundation is insulated on the interior with R-15 fiberglass batt insulation in a finished frame wall. Open-web floor trusses span the unit's 20-ft width to provide an accessible location for ductwork and other mechanicals. Floor truss connections at the rim joist are air sealed and well insulated with spray foam products.

An elastomeric sealant was spray-applied at key junctures to reduce air infiltration. It was used in the building's interior in lieu of butyl tape at SIP joints and was applied at framing lumber intersections, around windows, at H channel edges in the area separation wall, and at other locations identified as possible air leakage pathways.

The finished attic roof is framed with "tray truss" roof trusses and insulated at the roofline with R-38 ocSPF (Figure 3).[1] Approximately 10 in. (R-44) of ocSPF insulation in the rim joist area between the trusses creates an insulating air barrier that is first sealed with an elastomeric spray sealant. In addition to providing extra living space, the conditioned attic and basement contribute to the home's efficiency by allowing all components of the heating, ventilation, and air conditioning (HVAC) system to be entirely within conditioned space.

Figure 3. Conditioned attic bonus room at rough framing stage showing elastomeric sealant at framing junctures

[1] ocSPF was positively evaluated for this application due to the extensive air sealing that limits moist interior air into the roof cavity, the use of a dedicated automatic ventilation system, and the installation of painted gypsum over the bulk of the roof insulation.

3 Analysis

3.1 Benchmark Software Analysis

Home Innovation analyzed costs to help refine the package of solutions in the HPH design by conducting simulations using BEoptE+ v1.3.

Multiple simulations were performed to develop the benchmark energy use (Table 2). This was necessary to combine both the gas and electric end-use appliances into one simulation result.

Table 2. Simulated Source Energy Savings

End Use Parameter	BAB MMBtu	HPH MMBtu	Savings	End Use % of Total	
				BAB	HPH
Miscellaneous (E)	40.35	40.35	0%	22%	34%
Vent Fan (E)	3.32	6.04	–82%	2%	5%
Large Appliances (E)	9.79	7.99	18%	5%	7%
Lights (E)	25.59	16.54	35%	14%	14%
HVAC Fan/Pump (E)	8.45	4.90	42%	5%	4%
Cooling (E)	9.79	4.48	54%	5%	4%
Heating (G)	59.50	13.31	78%	32%	11%
Hot Water (G)	21.22	18.07	15%	11%	15%
Large Appliance (G)	7.37	6.19	16%	4%	5%
Miscellaneous (G)	0.9	0.9	0%	0%	1%
Total	186.28	118.77	36%	100%	100%

(E) electric source energy consumption
(G) gas source energy consumption

Simulation results show a 36% savings over the BAB house design. Additonal simulation results has shown that with the addition of a gas tankless demand water heater, energy savings would reach the 40% level.

3.2 Combination Ground Source Heat Pump and Photovoltaic System (GeoSolar) Costs and Energy Use

Renewable energy is desirable to reduce a community's carbon footprint and to mitigate the economic impact of escalating fuel costs. Thus, Nexus established its GeoSolar concept, in which a GSHP and PV system is planned for each home. Part of the GeoSolar concept includes homeowners' active monitoring and participation in controlling energy use in the home. To this end, NexusVision, a proprietary integrated energy management system, is also installed.

3.2.1 Analysis of Ground Source Heat Pump Costs and Energy Use

The reported costs of the GSHP features are summarized in Table 3. Total costs are net from a standard heat pump system adjusted by deducting federal and state incentives. The net cost for the GSHP system after incentives shows a negative net cost over installing a standard system. The negative net cost implies an immediate payback if the GSHP system uses no more energy than the standard system.

Table 3. Estimated Cost of GSHP System

Feature	Cost ($)
Standard Air Source Heat Pump, Installed	$10,000
GSHP, 2 Ton, Installed	$16,900
30% Federal Tax Credit, Geothermal	($5,070)
Maryland Energy Administration Rebate	($3,000)
Net Total Cost for GSHP, Incentives	–$1,170
Net Total Cost for GSHP, Without Incentives	$6,900

GSHP costs in Table 3 reflect the costs of well drilling (single vertical closed loop), equipment, installation, and ductwork. Before incentives, in the same efficient home design, the GSHP system reduces the utility costs by approximately $200 annually. The cost of financing the $6,900 premium cost for the GSHP system is about $445 annually (5% over 30 years) and compared with the annual savings does not result in a favorable benefit to cost ratio or a reasonable payback. However, when subtracting the estimated cost of the loop ($4,700) the premium of $2,200 for the GSHP equipment[2] and based on the estimated savings, a net annual benefit of more than $50 for the GSHP system and simple payback of about 11 years at current utility rates are calculated.

Often the comparison of source energy is made to compare the overall environmental performance of different technologies. Given that electricity, which results in a generation loss of more than three times the site energy use, is used rather than natural gas that can be used directly on site, an analysis of the source energy consumption is relevant. When comparing the GSHP system source energy consumption with that of a high efficiency furnace and electric air-conditioning system, the GSHP shows a source energy savings as outlined in Table 4.

Table 4. Source Energy Comparison of a High Efficiency Furnace and Air Conditioner With a GSHP

HVAC Component	Annual Source Energy Usage (MMBtu)	
	High Efficiency Furnace + Air Conditioner	GSHP (As-Built)
HVAC Fan/Pump (Electric)	4.03	4.90
Cooling (Electric)	6.34	4.48
Heating (Gas or Electric)	15.75	13.31
Total	26.12	22.89
Source Energy Savings	–	13.13%

Hence, when compared to a conventional high efficiency furnace and air conditioner, the GSHP system with incentives is the better option. In the absence of incentives, however, other options may be favorable.

[2] Both cost items that might be offset by incentives.

3.2.2 Photovoltaic System Costs and Electricity Production

The PVWatts simulation software (NREL 2012) was used to estimate the output of the PV system. On an annualized basis, the PV is expected to produce 5,061 kWh site (58.1 MMBtu source), offsetting 51% of the HPH's source energy use, or the equivalent of the expected combined energy use for HVAC and water heating (see Figure 4).

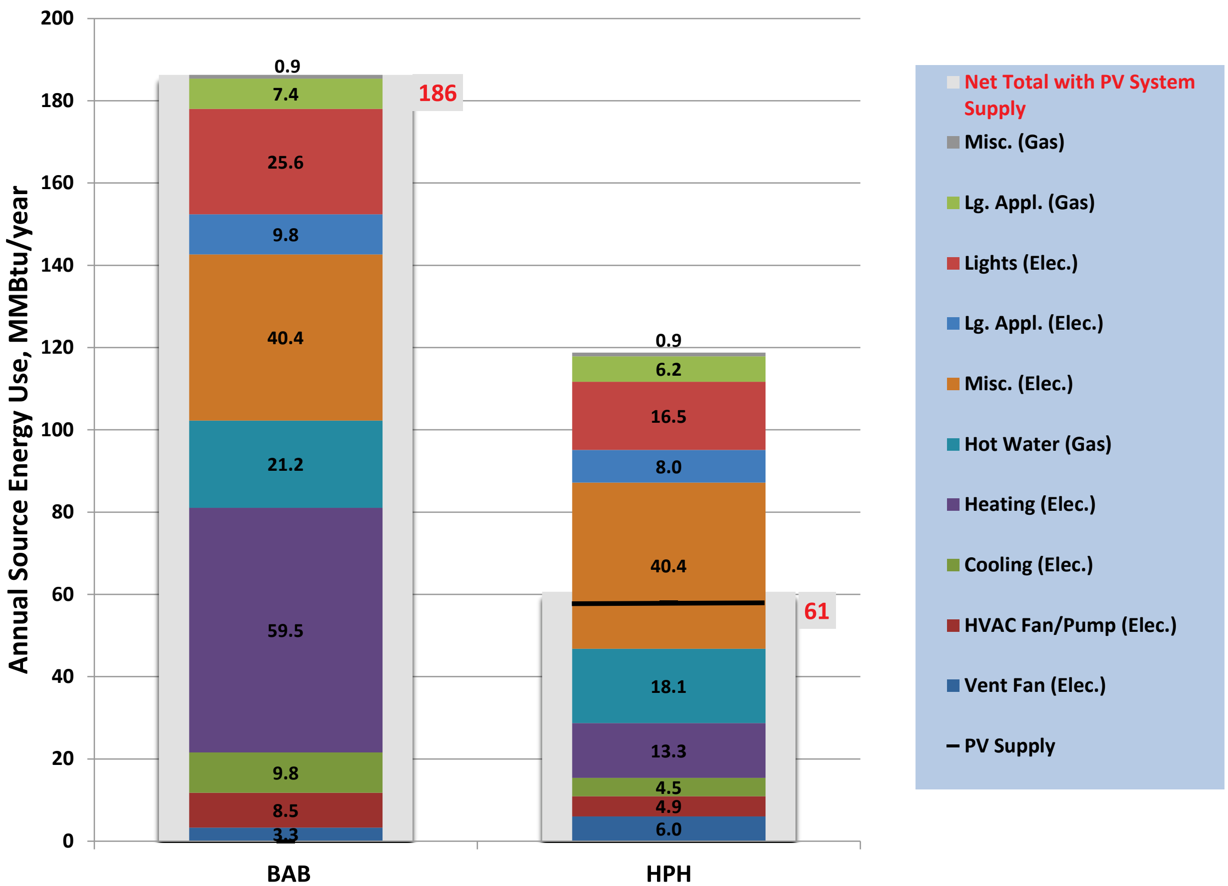

Figure 4. Annual source energy use comparison—benchmark and NCTH

Table 5 summarizes the estimated annual energy cost savings for the PV panels and provides simple economic estimates for the electricity produced over the expected 25-year life (based on warranty) of the PV system. Calculations assume net metering credit at retail electricity cost and with no utility monthly fee and no builder gross margin.[3]

[3] Builder gross margin, if included, would add the builder's markup to the system costs.

Table 5. Estimated Cost of Solar Package

Component	Unit	Cost ($)
235-W PV Panels (19) (Nominal System Size)	4.4 kW	$12,279
PV Installation	System	$2,221
Inverter (Including Installation)	Each	$3,000
American Recovery and Reinvestment Act 30% Federal Tax Credit, PV	Each	($5,250)
Total Net Cost for PV System		**$12,250**
NexusVision Energy Management Dashboard	Each	$2,200

Table 6. Estimated Simple Payback of PV System

Component	Quantity	Total
Estimated Annual Electricity Production	5,061 kWh/yr	$700/yr
System Installed Cost, Net First Cost		$12,250
ROI[a]		5.7%
Simple Payback		20.6 yrs
Value of PV Electricity Over 25-Year Useful Life[b]		$17,500
Mortgage Payment on PV System (25 Years at 3.5% Interest)	per year	$736/yr
Net Annual Cash Flow From PV		($36)/yr

[a] Return on investment.
[b] Over useful life of PV system with constant PV system output and utility rates. Similar results will be demonstrated if the PV system output degraded by 1%/yr and electricity costs increased by 1.25%/yr on average.

The results from Table 6 indicate that the PV system investment, even with a 30% federal incentive on installed cost, produces a modest 6% simple period annual ROI and a simple payback of approximately 20 years. Further, the system, when financed at a low interest rate (3.5%) over the expected 25-year life of the system, has a slightly negative annual cash flow at current utility rates. Given the simple payback falls within the expected life of the system, the investment viewed from various perspectives may or may not be sufficiently enticing to spur investment. Utility rate increases have been modest (Edison 2006); however, large variations between geographical locatons indicate the need to make an evaluation on a case-by-case basis. A brief analytical comparison of utility rates and including a 1%/year degradation of the system output indicates that utility rates increasing at 2%/year would cause a net positive cash flow over the life of the system.

Renewable energy credits (RECs) paid to the homeowner could make the PV system's economics much more promising. Although the price paid for RECs varies with market conditions, Maryland solar RECs traded at approximately $0.19–$0.28/kWh during the first half of 2012 (DSIRE 2012). Even at the lowest trading rate, the electricity produced would generate close to $1,000/year more, resulting in a much faster simple payback period and easily a net annual positive cash flow, even when including loan interest payments.

Other available incentives could improve the system economics. For example, Maryland's *Property Tax Exemption for Solar and Wind Energy Systems* (DSIRE 2012) excludes the cost of PV systems from a property's assessed value for real estate taxation purposes. The measure extends an approximate $117/year (0.081%) real estate tax exemption to the property owner. When factoring the property tax exemption and utility rates rising at 1.1%/year, this system produces a net positive cash flow in year 8 (albeit modest, netting an average of less than $50/year over the system life, assuming the tax exemption remains for the full 25 years).

The incentives for use of solar PV systems can be significant enough to encourage investment in the technology, and especially in new home construction where the installed costs may be somewhat lower than for existing homes. Furthermore, as with Nexus, the potential to optimize the location of the solar system at the house design stage, including the roof layout, and when the site plan is being prepared, significantly enhances the application of the solar system and can help to reduce installed costs.

3.3 Energy Management System Costs

The NexusVision energy management dashboard is meant to provide real-time information to the homeowner that will be useful in controlling the remaining electricity loads for lights, appliances, and miscellaneous uses. The system costs $2,200 (reflected in the GeoSolar costs in Table 5). No current information is available regarding the impact of this energy management system on actual energy usage. However, for example, if this cost were financed at 3.5% annual rate over 30 years, the use of the device would need to contribute to additional electricity savings of less than 10% or about $10/month.

3.4 Insulation and Air Sealing Costs and Savings

The estimated installed costs[4] for several wall assemblies that will meet the 2012 IECC wall thermal resistance requirements are shown in Table 7. The SIP wall assembly used in this HPH is competitively priced with comparable assemblies (costing slightly less than a 2 × 6 wall with exterior insulation having similar R-value).

Table 7. Estimated Costs of Wall Assemblies

Component	Assembly R-Value*	Quantity (ft^2)	Cost/ft^2 ($)	Total ($)
2 × 4 @ 16 in. On Center With R-13 Fiberglass Batt and R-6 Exterior Sheathing	R-17.0	1,402	$6.95	$9,744
2 × 6 @ 24 in. On Center With R-21 Fiberglass Batt	R-18.6	1,402	$6.58	$9,225
6.5-in. SIP	R-22.0	1,402	$7.77	$10,900
2 × 6 @ 24 in. On Center With R-19 Fiberglass Batt and R-5 Exterior Sheathing	R-22.1	1,402	$7.89	$11,062

* R-value covers named assembly, only. Values for air film, siding, gypsum board not included in calculation.
2 × 4 and 2 × 6 wall R-values include oriented strand board (OSB) structural sheathing.

[4] Costs were developed from a combination of builder information and estimates using contractor information or standard estimating references such as RSMeans construction cost estimates.

The finished basement was insulated with R-15 kraft-faced fiberglass batts in 2 × 4 walls spaced 24 in. on center. By going to R-13 batts instead of R-15, the builder can save about $100 in materials with negligible impact (approximately $2 annually) on energy consumption (see Table 8). Since the basement heat loss is to the more temperate earth rather than the outdoor ambient air, levels of insulation above R-13 are generally not cost beneficial in this case.

Table 8. Basement Insulation Cost and Energy Savings

Component	Cost/ft^2 ($)*	Material Cost Basement ($)	Source Energy Use (MBtu/yr)
R-13 Fiberglass Batt	$0.45	$277	118.9
R-15 Fiberglass Batt	$0.61	$375	118.8
Cost Difference		$98	0.1
Annual Energy Cost Savings		$2	

* Average Home Depot, Frederick, Maryland, September 21, 2012, and online prices.

Thermal and air sealing package total incremental costs for the HPH are outlined in Table 9. The builder reported that costs for the thermal and air barriers were typical of what they would pay for a comparable package of goods and services.

Table 9. Estimated Incremental Costs for Combined Thermal and Air Sealing Upgrades

Component	Nominal R-Value	Net Cost ($)
Basement Fiberglass Batt, Kraft Faced[a]	R-15	$98
Wall SIPs[b]	R-23	$1,675
Floor Rim Insulation	R-44	Incl.[c]
Window Upgrade	0.31/0.28	$124
Air Infiltration Barrier (Elastomeric)	None reported	$380
Attic, ocSPF	R-39	$3,426
Total of Envelope Upgrades[d]		**$5,703**

[a] Cost includes insulation and installation only.
[b] See Table 7.
[c] Cost included in attic insulation cost.
[d] Incremental upgrade cost over standard (2009 IECC).

The energy savings for the envelope features alone (with minimum equipment efficiencies) is approximately $677 annually. With a premium installed cost for the upgraded envelope features of $5,703 financed over 30 years at 5% interest, there is an annual savings of $310 and a simple payback of about 18 years.

3.5 Indoor Environmental Quality and Green Rating Costs

The HPH includes a comprehensive IEQ package consisting of elements that are highly valued (or mandatory) in the NGBS, ENERGY STAR, and U.S. Environmental Protection Agency Indoor airPLUS programs. The package includes:

- MERV 13 filter in the space conditioning air handler
- ERV integrated with heating and cooling ducts
- HEPA bypass filter (inlet ducted from supply plenum, and outlet ducted to return plenum)
- Ducts 100% in conditioned space and sealed
- Communicating thermostat (for remote adjustment with smart phone or computer)
- Central vacuum system vented outdoors
- Low or no volatile organic compound interior products
- No formaldehyde interior products
- No attached garage.

Table 10 presents the estimated additional cost of the IEQ features.

Table 10. Estimated Additional Cost of IEQ Features

Component	Cost[a]
MERV 13 HVAC Filter	$0, standard[b]
AprilAire Communicating Thermostat	$0, standard[b]
Whole-House Cleaning System	$1,500
ERV[c]	$1,150
HEPA Air Filtration	700
No Garage	$0
Total Added Cost of IEQ Features	$3,550

[a] All costs reported by the builder.
[b] Part of HVAC cost.
[c] $1,150 net of $1600 ERV – $450 standard return air duct and controller (for comparison as a common ventilation system option).

In many instances, the savings of garage or fireplace construction costs will more than make up for additional IEQ costs should the customer recognize the IEQ benefits in this way. However, it may be more feasible to include IEQ system costs of this magnitude if there were local incentives that could offset some of these costs. For example, the State of Maryland allows local governments to offer tax credits for high performance buildings. Although Frederick County has not yet adopted the tax credit, a home that achieved emerald NGBS status (which will include multiple IEQ requirements) in nearby Anne Arundel County would qualify for an 80% property tax credit (up to $3,000) for 5 years.

3.6 Optimized 40% solution

As constructed, this HPH was simulated at 36% savings over the BAB without factoring electricity generated by the 4.4-kW PV system which, when included, should offset all of the house's HVAC and water heating loads, resulting in a 67% savings over the BAB.

The simulations performed to optimize a 40% savings level are based on this HPH as a two-story with loft and unfinished basement, as it was offered in the community. Selection of the house features, and in particular those that add finished floor area, affect the savings estimates based on the size penalty associated with the additional finished area and additional lighting and miscellaneous energy use associated with a finished basement.

The results of the simulation analysis determined that, for future designs, achieving 40% source energy savings requires only minor adjustments to the current design. The optimized 40% package, summarized in Table 11, includes more detailed attention to the window ratings that allow more solar heat gain while lowering the U-factor,[5] a redesigned water heating system that employs solar thermal or is a high efficiency (96% annual fuel utilization efficiency) condensing tankless gas unit, and R-13 basement insulation in lieu of the costlier R-15 (since this change results in very little energy change and lowers overall costs).

Table 11. HPH As-Built Versus Optimized

Feature	HPH—As Constructed (36% Solution Without PV)	Example Design (40% Solution Without PV)
Foundation (Basement)	• Finished • R-15 batt insulation	• Unfinished • R-13 batt insulation
Structural Frame	• 8-in. formed concrete foundation • 6.5-in. SIP • 14-in. open-web floor trusses • Attic tray trusses • Unvented conditioned attic	• Same as HPH
Air Sealing	• SIPs set in ocSPF • Air infiltration barrier spray foam at all material intersections and openings at doors and windows • ocSPF for roof (R-38) and rim board (R-44) insulation	• Same as HPH
Windows	• Low-e, U-0.31, SHGC-0.27	• Low-e, U-0.30, SHGC-0.40
Systems	• GSHP • 64% gas power vented water heater • Ducts in conditioned space • Energy recovery ventilator • High MERV filtration • Whole house vacuum system • Communicating thermostat • NexusVision (energy usage dashboard)	• Same as HPH except closed loop solar hot water preheat system or a 96% efficient condensing tankless gas water heater

This combination of features was determined to be a straightforward path to achieving the energy saving goal target of more than 40%. However, these results were for a more simplified building

[5] In heating climates, the use of windows that allow more solar heat gain results in larger savings in winter than any penalties for cooling.

where the basement is unfinished (thereby reducing miscellaneous loads), tuning the windows to allow more winter solar gains for heating, and improving the performance of the water heater.

3.7 Alternative Water Heating Approaches to Achieve 40%+ Energy Savings

Additional simulation analysis was used to determine an alternative method to exceeding 40% source energy savings. The approach centered on hot water energy only and incorporated both hot water use reductions and alternative water heating systems other than solar thermal.

An alternative approach to water heating savings was explored. In this water heating approach, low-flow shower and sink faucets are modeled in the software to reduce hot water demand. For a gas water heating source, a condensing demand water heater at 96% energy factor was used. For an electric water heating source, a heat pump water heater (HPWH) was simulated. The water heaters are located in conditioned space. The HPWH uses heat in the air from conditioned space for water heating. This design causes the space heating energy to increase and the space cooling energy to decrease. In the climate simulated, operation of the HPWH results in a net increase in space conditioning energy but also a large reduction in water heating energy. Combining the space conditioning with the water heating energy, the GSHP with a standard electric water heater was simulated at 57.81 MBtu source energy. For the same GSHP system but with a HPWH, the total source energy was simulated at 40.19 MBtu source energy, a reduction of 30%. Figure 5 shows the end use breakout for each load.

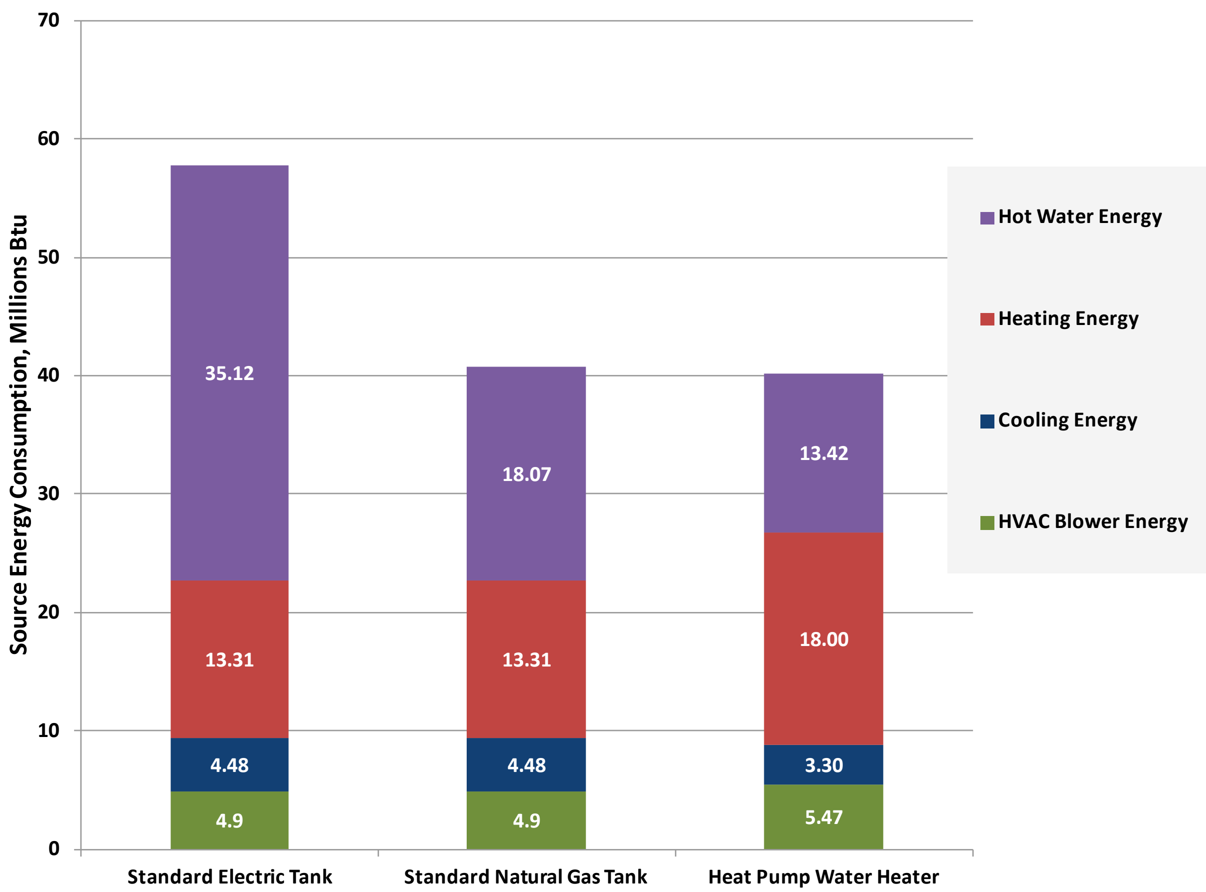

Figure 5. Comparison of heating, cooling, water heating energy use

Based on the simulation results, the use of an HPWH in the HPH and all electric end uses (if no gas used in the home), there is a 41% source energy savings (before PV use is considered). A similar savings is seen with a gas tankless heater in conjunction with low-flow water outlet devices.

One question that results is whether the GSHP could also serve the hot water load either directly to heat water or by use of a desuperheater. This analysis was not performed and the desuperheater use would need to consider the increase demand on the ground loop, particularly in the winter heating months.

4 Discussion

4.1 Structural Insulated Panel Wall Construction

SIP walls help reduce construction time and improve labor efficiency by combining the structural and thermal assemblies into one system. With instructions and installation support from the manufacturer, the builder paid special attention to connection details for air sealing at panel seams.

The wall panels for this project were specified to minimize thermal bridging and air leakage. The structural rims between floors eliminated the need for headers within the wall panels over windows and doors. The wall panels were set on 2 × 6 cleats secured first to the floor deck (see Figure 6). The wall panels were built at the factory with the rigid foam recessed at the edges to accommodate this cleat and window and door rough framing (see Figure 7). At the vertical panel-to-panel edge, the wall panels were built with two channels for OSB splines and one channel in the middle for spray foam (see Figure 8). Splines were used to connect the panels, instead of the typical 2 × 6 spline, to minimize thermal bridging (see Figure 9). Single-part foam from a can was used at the cleats and splines to seal this connection as the wall panels were assembled (Figure 10).

The panels also came with horizontal chases for electrical wiring (see Figure 11). These openings were sealed at the corners of the house where exposed. House wrap was installed and all seams were taped (see Figure 12).[6] Wall panels were additionally sealed from the interior at panel joints, bottom plates, top plates, and around windows and doors using a spray-applied elastomeric air barrier product (shown red in Figure 13).

Figure 6. Wall panel is set on a cleat attached to the deck

Figure 7. Installed wall panels before window and door bucks

[6] DRYline HP; Perm 60 ASTM E 96 Method A; Air resistance < 0.01 l/s/m^2 @ 75 Pa ASTM E 2178. www.drylinewrap.com/resourcelibrary/dryline_hplp_spec.pdf

Figure 8. Vertical channels in wall panels for splines (next to OSB and foam (in the middle)

Figure 9. The splines are installed between wall panels

Figure 10. Spray foam is applied at the bottom cleat and vertical channel as the wall panels are installed

Figure 11. Horizontal chases for electrical wiring

Figure 12. House wrap

Figure 13. Spray applied elastomeric air sealing product (red)

4.2 Duplex Common Wall Construction

The common walls of the duplex were framed and insulated, using R-13 open faced batts, on either side of the gypsum fire wall (Figure 14). The fire wall was sealed using the elastomeric spray at the H-clips before insulation (Figure 15). Without this application, an alternative air sealing method would be required to control air leakage between units and where the fire wall meets the exterior wall.

Figure 14. Framed and insulated common wall

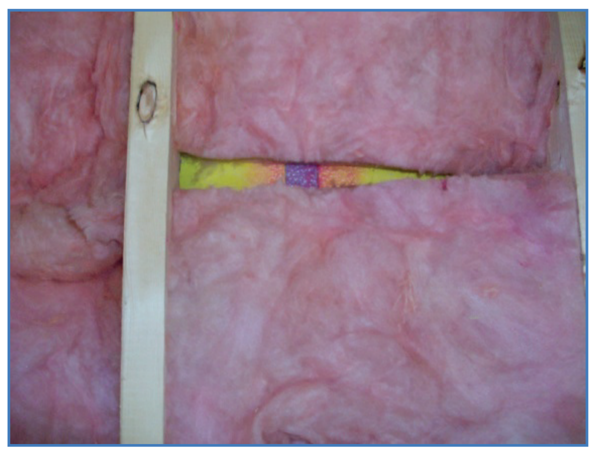

Figure 15. View of sealed fire wall behind insulation of the common wall

4.3 Floor Framing and Roof Trusses

Fourteen-inch deep floor trusses (4-in. × 2-in. open-web) were installed to clear span the design's 20-ft width at 24-in. spacing for all three floors. Because the wall panels do not have integral headers, the floor trusses were attached to the engineered structural rim joists using hangers above window and door openings (Figure 16). The engineered rim joists were installed for the second and third floors (Figure 17).

The open-web trusses allowed sufficient space for efficient installation of heating and cooling ducts, plumbing, sprinkler piping, and electical wiring within the floors.

Figure 16. Open-web truss and engineered rim floor framing

Figure 17. Engineered structural rim joists

The attic was framed with tray trusses (Figure 18). Tray trusses combined with spray foam insulation at the roof deck allowed for finished space on the third floor without increasing the house's footprint. Additionally, all ducts were in conditioned space, and air sealing the attic was simplified.

The builder reports that the truss systems cost no more than comparable structural systems. In addition, the factory-built SIP walls and trusses saved two days of construction time between rough framing and close-in for the duplex (both units). Minimizing construction cycle time saves money, but it can be even more desirable—particularly in an infill neighborhood—for securing the building as quickly as possible for materials storage and liability mitigation.

Figure 18. Tray trusses

4.4 Air Sealing and Insulating With Spray Foam

To air seal and insulate the rim areas and attic, the builder selected ocSPF (ICC-ES 2011). The selected open-cell product is air impermeable at a thickness of 3.5 in., and was applied to full depth in one application. The builder chose a product considered a more sustainable alternative to other foam types because it uses water as its blowing agent and is composed of 10% biobased material. The use of spray foam simplified air sealing and insulating the complicated framing at the reverse gabled duplex roofs and connecting cricket (Figure 19).

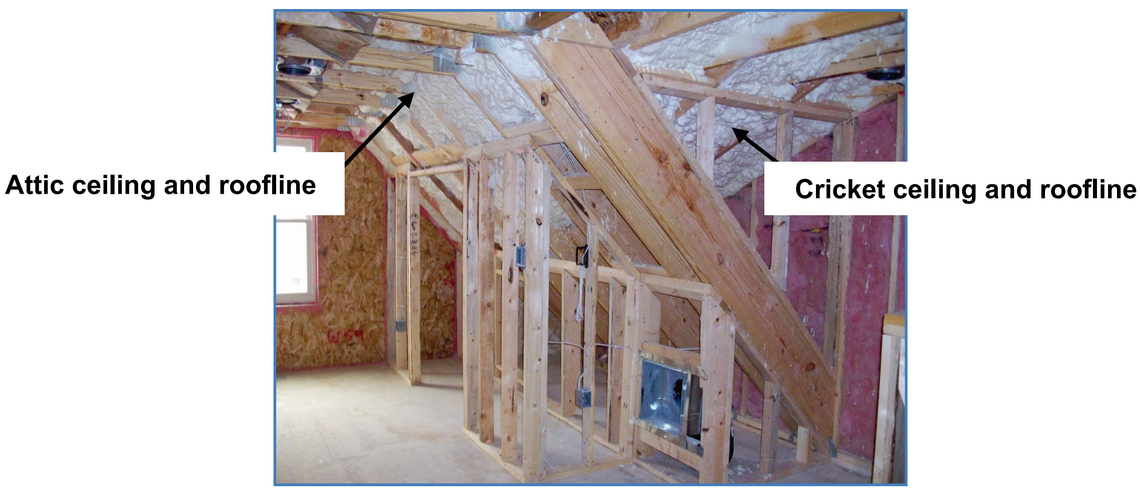

Figure 19. Attic roof at cricket fully sealed and insulated with spray foam

The use of spray foam insulation and a spray-applied elastomeric sealant required two separate contractors, each installing proprietary products. This likely increased construction time and costs. This approach was initially deemed appropriate due to the house tightness goal and the need to seal different types of joints and connections. The elastomeric sealant was applied to the critical rim areas (Figure 20) before the ocSPF; this redundant appication was likely not necessary considering the air sealing effectiveness of 10 in. of ocSPF.

Figure 20. Edges of open-web trusses in rim area create potential air leakage sites

4.5 Mechanical Systems

The heating and cooling equipment and duct system were installed entirely in conditioned space. The GSHP was installed in the basement. A central duct chase was installed directly above the GSHP (Figure 21). The return trunk, serving one central return grille per floor, is within this chase. Transfer grilles provide a return air path for the bedrooms (Figure 22). This simplified return duct layout improves duct distribution efficiency by decreasing static pressure losses and fan motor power. This duct layout also reduced installed costs. Additionally, the central duct chase provides a convenient location to install plumbing and sprinkler piping and electrical wiring.

Figure 21. Central duct chase

Figure 22. Bedroom transfer grilles at rough-in stage

The vertical section of the supply trunk serving the second and third floors was also installed within the chase (Figure 23). The horizontal supply trunks were installed within the floor framing; the trunk serving the first floor and basement was installed within the first floor, and the trunk serving the second and third floors was installed within the third floor (Figure 24). Dampers were installed in the supply trunks near the GSHP to allow air balancing between the upper floors and lower floors. Additional dampers would be ideal but would not be accessible after drywall.

Figure 23. Supply and return trunks within the central duct chase

Figure 24. Supply ducts within floor framing

The builder specified natural gas for the kitchen range, clothes dryer, fireplace, and water heater. The kitchen range hood exhaust fan (100–200 CFM ducted outdoors in accordance with ASHRAE Standard 62.2) is integrated with the microwave (Figure 25). To ensure air quality and minimize back-drafting potential, the fireplace is direct-vent (outside air for combustion); the concentric vent termination hood is shown in Figure 26. The power-vented water heater uses 2-in. polyvinyl chloride pipe instead of a conventional metal "B-vent" flue used for a natural draft heater. Not installing a B-vent flue partially offset the additional cost of the power-vent heater. Although power-vent appliances still use indoor air for combustion (unless they are also direct vent), these are less likely to back-draft than natural draft appliances (power-vent appliances have a higher depressurization limit (BPI 2012) and generally include a pressure switch that turns off the appliance during back-drafting conditions).

Figure 25. Gas range with integrated exhaust fan/microwave

Figure 26. Concentric vent termination hood for the direct-vent gas fireplace

4.6 Photovoltaic System

The HPH did not have as much south-facing roof as the connected duplex (Figure 27). In order to meet design goals, PV panels were also installed on top of the the rear trellis of the HPH.

Figure 27. Solar PV panels installed on south-facing roofs (NCTH on right) and trellis

5 Test Results

Final test results are summarized in Table 12.

Table 12. Characterization Testing: House and Duct Leakage

Performance Metric	NCTH
Finished Floor Area (ft^2)	1,830
Conditioned Floor Area (ft^2)	2,550
House Volume (ft^3)	24,480
Total House Leakage (CFM50)	620
Net House Leakage, Adjacent Depressurized Unit (CFM50)	450
Net House Leakage (ACH50)	1.1
Duct Leakage, Total (CFM25)	208
Duct Leakage, Total (CFM25/100 ft^2 Conditioned Floor Area)	8.1
Duct Leakage to the Outside (CFM25)	0

The construction of this house allowed for intermediate testing after spray foam and before drywall (sees Figure 28). The intermediate house leakage test measured 794 CFM50 and 1.9 ACH50. During the test, leakage areas were identified for resealing. These areas included a few rough openings at windows and doors, and a few electrical outlets (despite sealing the horizontal wire chases at the house corners). An intermediate duct leakage test was also conducted at this time, and theatrical smoke was used to identify leaks (see Figure 29).

Figure 28. Intermediate blower door test before drywall

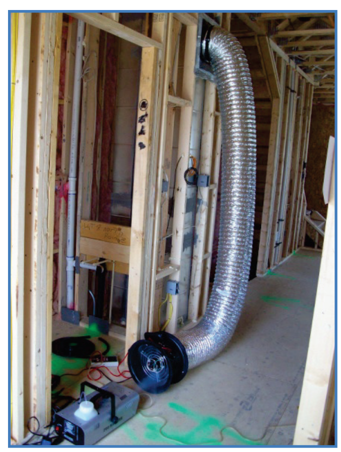

Figure 29. Intermediate duct blaster test using theatrical smoke

The final net house leakage to the outdoors was measured by concurrently depressurizing the adjacent unit. The leakage between units was simply the difference between total house leakage and the net leakage. The final total duct leakage was somewhat higher than during the intermediate test. This was attributed to duct leakage between the metal duct and drywall at some registers and grilles (these do not have to be sealed for ducts in conditioned space but contribute to total leakage). The duct leakage at the air handler appeared to be relatively significant (based on noticeable air leakage during the theatrical smoke demonstration). Air balance testing indicated that the majority of leakage was at the air handler and return ducts. The bedroom transfer grilles provided pressure balance for these rooms within the 3 Pa ENERGY STAR limit. Duct leakage to outdoors was zero for both tests.

6 Conclusions

6.1 Research Questions

Are the individual design features practical to implement and cost effective?

The HPH demonstrated numerous practical design details: the simple rectangular house layout, with exterior porches providing architectural appeal, simplified the framing, air sealing, and insulation. The factory-assembled structural components—SIP walls, open-web floor trusses, tray-type roof trusses—combined with the ocSPF insulation at the attic and rim areas and efficient HVAC resulted in a high performance house that reduces energy costs yet remains affordable.

The SIP walls combined the structural and thermal components into one wall assembly that contributed to the tight building enclosure.The installed cost for the SIP walls was slightly less than a 2 × 6 wall with exterior rigid foam insulation with similar R-value.The use of SIP walls compared to conventional stick-framed wall construction shortened the construction schedule by two days. For Nexus EnergyHomes, even when compared to other less expensive, somewhat less efficient walls, the advantages of the SIP walls justified the relatively minimal incremental cost.

The open-web truss floor joists allowed the heating and cooling ducts to be installed in conditioned space within the floors, and without the need for below-ceiling bulkeads to conceal the ducts. These floor joists also allowed for convenient (faster) installation of plumbing, electrical wiring, and fire sprinkler piping. The builder considers these energy- and labor-saving benefits, and the flexibility to make changes during construction, a valuable and cost-effective tradeoff to offset the additional cost of the trusses.

The attic truss system, combined with ocSPF insulation at the roof deck, provided conditioned living space for this house design. Even after the additional incremental costs for these trusses (compard to standard trusses) and ocSPF (compared to blown insulation and additional air sealing at the second-floor ceiling plane), this additional area was less expensive (in terms of dollars per square foot) than first- and second-floor areas. This design also allowed the heating and cooling ducts to be installed in conditioned space. Some house designs in this development have slab foundations instead of basements; for those, the conditioned third floor also houses the GSHP and water heater.

Overall, the building enclosure was energy efficient and practical to build. The envelope improvements as a stand-alone upgrade are cost effective based on ROI, simple payback, and net annual cash flow. The construction time savings attributed to the SIP walls and open-web floor trusses was particularly valuable for an urban infill project. The SIP walls and ocSPF in conjunction with careful air sealing resulted in a house leakage rate of 1.1 ACH50 (below the 1.5 ACH50 target). The use of SIP walls and ocSPF also allowed for intermediate house leakage testing before interior finishes; this was an important advantage because mitigation was simple and relatively inexpensive at this rough stage.

The GSHP with forced-air distribution was a good match for this tight and well-insulated house. With federal and state incentives, the GSHP cost less to install and operate than conventional natural gas furnace or air source heat pump systems while providing energy savings over even a high efficiency natural gas furnace and air conditioner. Without incentives, the GSHP did provided a less advantageous ROI or payback. The compact return duct layout, central duct chase, and supply duct layout within the open-web floor trusses contributed to an efficient air distribution system. The compact return also reduced installed cost. The four-level house was comfortable during both cooling and heating seasons.

The IEQ features appear to be worthwhile—anecdotal evidence from occupants with allergies suggests that they feel better in their new homes than anywhere else, including work, outdoors, and in previous homes. The builder considers the balanced ventilation provided by the ERV, with a known source of fresh air, a critical IEQ component. The additional higher level of filtration provided by the HEPA bypass filter primarily benefits those with above-average allergy sensitivity or other health issues.

When including the renewable energy PV system, the energy savings increased to 62% whole-house source energy savings over the BAB. The builder's personal metric of supplying the annual HVAC and water heating use estimates with PV was met based on simulation estimates. The actual PV system size on the available roof and trellis space (4.2 kW) was estimated to supply sufficient electricity (48.3 MBtu source energy) to offset the HVAC and water heating consumption (46.8 MBtu source energy) on an annual basis. In terms of cost savings, the PV system supply to the house was valued higher ($583) than the energy costs to operate the HVAC and water heating equipment ($546). At current prices for electricity and installed equipment, the investment in the PV system, with incentives, resulted in a 5.7% ROI, 20.6-year simple payback (25-year expected life of the system), and a negative $36 annual cash flow if financed over 25 years. In the future, higher utility costs, lower installed costs, or other incentives such as RECs could make PV a more favorable investment option.

What features could be modified to cost-effectively achieve higher energy savings?

Using an optimization analysis, these HPH features were modified to include an unfinished basement, R-13 basement wall insulation (versus R-15), tuned windows to increase winter solar gains, and a solar or high efficiency natural gas demand water heater. These modifications resulted in 40% energy savings without PV. A separate analysis modified the HPH by substituting various options such as a high efficiency natural gas demand heater, or an HPWH with low-flow plumbing fixtures, and resulted in 41% energy savings without PV. Installing an HPWH could eliminate the need for the natural gas supply infrastructure in the house.

The insulation value of the above-grade walls could be increased, as needed, by specifying thicker SIPs or SIPs with higher-R foam (e.g., polyisocyanurate versus expanded polystyrene). Thicker SIPs would affect the floor plan of the house. Analysis showed that reducing the basement foundation wall insulation from R-15 to R-13 would reduce installed cost at an insignificant energy penalty.

For this project, the use of spray foam was cost effective primarily because the third-floor attic is conditioned living space. This approach is even more important for other houses in the community that have slab-on-grade foundations and mechanical rooms in the third floor. For house designs that do not have conditioned floor area within an attic, a conventional vented attic could result in cost savings, but builders would need to carefully air seal the ceiling plane and install ducts in conditioned space for comparable energy savings.

The air sealing methods were successful. The use of elastomeric spray sealant was redundant or unnecessary in some locations: at rim areas that were later insulated with ocSPF, at interior faces of attic framing below the ocSPF, and at wall panel-to-panel and bottom plate (cleat) interior seams that were already sealed during installation (although additional sealing at these seams may be prudent). The air sealing value of applying sealant at the common fire wall was not quantified, and this application may not be considered part of the rated assembly. Eliminating this specific proprietary sealant should result in cost savings, but the effect on house leakage should be measured during an intermediate test of a similar house design; conventional air sealing alternatives would still be required at penetrations and window and door rough openings.

Generally, the more efficient the building enclosure, the more difficult it may be to justify an expensive and complicated high efficiency space conditioning system. Without incentives, a high efficiency natural gas furnace or conventional air source heat pump would be a cost-effective alternative to the GSHP.

What barriers need to be overcome to meet DOE Challenge Home requirements?

The HPH was certified to the U.S. Environmental Protection agency ENERGY STAR New Homes Version 2.5 and Indoor airPLUS Version 1 programs. Based on a review of the ENERGY STAR Version 3.0 checklists, the HPH would also have been in accordance with those requirements. This project was completed before the DOE Challenge Home program started; the HPH is in accordance with the mandatory requirements for the duct system, lighting and appliances, and renewable ready. For the envelope, the attic insulation would have to be increased from R-38 to R-49 to meet prescriptive requirements, but would have been acceptable by applying the alternative equivalent UA calculation. The installed plumbing distribution system would not have met the Challenge Home water efficiency requirements. All of the hot water pipes in the chlorinated polyvinyl chloride trunk and branch layout were insulated, but the volume of hot water from the water heater in the basement to the fixtures exceeded the 0.5-gallon limit for the second-floor bathrooms by a factor of three.

Are there opportunities to improve the performance, testing, or integration of the mechanical systems?

The actual airflows of kitchen range hood exhaust fans and balanced ventilation (ERV) systems can be difficult to measure using conventional test tools such as anemometers and hood-type balometers; an improved test method would be helpful to ensure that measured ventilation rates meet design expectations. Installing the ERV with a dedicated duct system (independent of the heating and cooling distribution system) or partially dedicated duct system (independent “stale” air exhaust ducting), would provide fresh air distribution without requiring the heating and cooling air handler to operate, and the airflows would be simpler to measure. Combustion testing should be performed to determine if house depressurization due to exhaust fans creates potential problems for the operation of the water heater for this project. A more efficient direct-vent water heater and plumbing distribution alternative, such as a cross-linked polyethylene manifold layout, could be installed to achieve a higher performing hot water system.

6.2 Key Findings and Lessons Learned

This project demonstrated that a home certified to U.S. Environmental Protection Agency's Indoor AirPlus and the *National Green Building Standard* and is estimated to save more than 35% in energy costs in the mixed-humid climate can be affordable to build.

The major components of the energy solution package were evaluated using energy simulation software. Nexus was able to further trim costs by working with vendors and trade partners to increase construction efficiency and reduce waste.

As constructed, this HPH was estimated to save 36% whole-house energy use over the BAB. This design could achieve 40% savings with modest changes to the design.

The HPH earned ENERGY STAR and Indoor airPLUS certifications and NGBS emerald-level green certification. With minor modifications, this design could meet DOE Challenge Home requirements.

The factory-assembled structural components (SIP walls, floor trusses, and roof trusses) reduced construction time and installed costs.

The building thermal enclosure was practical to build on a production basis and cost effective based on ROI, payback, and net annual cash flow.

The use of SIP walls and spray foam insulation at the roof deck and rims resulted in a low house net leakage rate of 1.1 ACH50. Developing an air sealing strategy during the design phase is important to achieve house leakage goals and control installed costs.

This house construction allowed for conclusive air leakage testing before interior finishes were installed—when mitigation was relatively simple and inexpensive.

The conditioned living area within the sealed attic cost less per square foot than the first- and second-floor areas.

The insulation levels could be increased, as required, without major structural redesign or added installation labor.

The GHSP provided 13% energy savings over a high efficiency gas furnace and air conditioner; with incentives, the installed cost was competitive with traditional high efficiency systems.

The compact return duct layout, central duct chase, and supply ducts within the open-web truss joist floors contributed to an efficient HVAC air distribution system.

A higher performing hot water system could be achieved by selecting a more efficient water heater and piping distribution layout.

The solar electric (PV) system was estimated to provide sufficient energy to offset the estimated heating, cooling, and hot water energy on an annual basis. With a 5% reduction in cost (including incentives), this system would have a favorable annual cost benefit when financed at 3.5% over 25 years.

The energy consumption monitor would have a favorable net annual cash flow if the occupants can reduce lighting and applicance loads, based on the information provided by the monitor, by less than 10%.

The houses in this development will have a long-lasting environmental benefit as they provide the homeowners with lower utility costs (see Figure 30).

Figure 30. Houses in the new development

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