New York State Energy Research and Development Authority

High Performance Residential Design Challenge:

Case Studies 1-4

Final Report

March 2014

Report Number 14-45

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High Performance Residential Design Challenge: Case Studies 1-4

Final Report

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Acronyms and Abbreviations List

ACH	Air Changes per Hour
BTU	British Thermal Units
CFM	Cubic Feet per Minute
EF	Energy Factor
EPS	Expanded polystyrene
ERV	Energy Recovery Ventilator
ft	Feet
HERS	Home Energy Rating System
HfH	Habitat for Humanity
HRV	Heat Recovery Ventilator
HSPF	Heating Seasonal Performance Factor
IBTS	Institute for Building Technology and Safety
ICF	Insulating Concrete Form
INHS	Ithaca Neighborhood Housing Services
kWh	Kilowatt-hour
LEED	Leadership in Energy and Environmental Design
MMBtu	Million Btu
MOU	Memorandum of Understanding
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
SEER	Seasonal Energy Efficiency Rating
SF/HDD	Square foot per heating degree day
SIP	Structural Insulating Panel
STEM	Short-Term Energy Monitoring
XPS	Extruded polystyrene

1 Background

1.1 NYSERDA Residential Challenge

The New York State Energy Research and Development Authority (NYSERDA) High Performance Residential Design Challenge (the Challenge) was created to assist New York State builders in the design, construction, and energy performance monitoring of new, high-performance homes.

In addition to Team IBTS, led by the Institute for Building Technology & Safety (IBTS), NYSERDA selected several other teams across New York State (NYS) to provide builders with the technical support that they needed to take their current high-quality construction to the next level.

This research and demonstration effort was intended to focus on cost-effective methods to achieve energy efficiency, comfort, and durability in new home construction. NYSERDA was especially interested in builders that were already "on the path" toward energy efficiency as shown through their past and current participation in ENERGY STAR® or voluntary green building programs. Likewise, builders familiar with innovative high-performance building systems such as insulated concrete forms (ICFs) and structural insulated panels (SIPs) were well-suited to the project.

1.2 Building Envelope Focus

A unique aspect of the Challenge was a focus on the building envelope as the primary means to achieve energy efficiency improvements. This approach was intended to increase the likelihood that the innovative construction techniques that were demonstrated would be cost-effective, replicable, and applicable to other "mainstream" builders.

The Challenge was explicitly intended to target building envelope technologies and techniques rather than to demonstrate net-zero energy home or renewable energy approaches. Likewise, though optimization of mechanical systems was achieved in the redesign process, the first priority was always to focus on the building envelope. Typically by reducing the home's energy loads through building envelope improvements, construction tradeoffs were achieved that, in turn, enabled reductions in mechanical equipment size and related cost savings.

1.3 Team IBTS

Team IBTS included of a broad consortium of both supply- and demand-side industry experts including:

- BuildingInsight LLC.
- Chaleff & Rogers Architects.
- Insulating Concrete Form Association (ICFA).
- Oak Ridge National Laboratory (ORNL).
- Performance Systems Development (PSD).
- Structural Insulated Panel Association (SIPA).
- Taitem Engineering.

In addition, each of the Team IBTS Challenge homes included the contributions of local HERS raters, LEED Accredited Professionals, architects, and engineers, among others.

2 Approach/Scope

Team IBTS invited builders from across NYS to participate in the Challenge. Team IBTS was originally tasked with constructing one Challenge home with each of four builders. Due to unfavorable home building business conditions in NYS during the early phases of the Challenge project, three of the builders that Team IBTS established agreements with were forced to withdraw from the project.

Given this situation, Team IBTS modified the approach with NYSERDA's approval to include two homes in the form of a duplex unit. This resulted in a total of five completed homes rather than the originally intended four homes. Overall, Team IBTS established memorandums of understanding (MOUs) and completed the current practices evaluation and redesign process for seven homes as opposed to the four homes that were originally part of the Challenge project's scope.

Before agreeing to work with a builder, Team IBTS used a screening process to identify the prospective participants' suitability for the Challenge. An initial meeting was held to identify topics of interest or problems encountered with the builder's current construction practices. An MOU was established between Team IBTS and each builder outlining benefits, expectations, and responsibilities as described in Table 1.

Table 1. Builder Benefits and Responsibilities

Builder Benefits	Builder Responsibilities
Engineering & architectural assistance to improve existing home designs	Work with NYSERDA team to identify potential areas of improvement
Improved HERS rating including field testing for Energy Star compliance	Adopt improvements for one or more homes
Recognition as a market leader committed to quality & the environment	Provide cost data for original & high- performance home
Financial assistance to offset incremental construction costs	Allow for post-construction energy monitoring & analysis

It is important to note that Team IBTS' focus was on the builder's needs and interests rather than to make recommendations for specific predetermined products or technologies. Team IBTS approached each Challenge project through a five step process tailored to suit each builder:

- **Step 1 - Home Builder Participant Identification.** Establish agreements with homebuilders in New York State that are interested in building one or more High Performance Residential Challenge Homes.
- **Step 2 - Quantifying Performance Improvements.** Evaluate builders existing home designs for adaptation and optimization. Use integrated design approaches to identify construction tradeoffs. Provide alternative designs via interactive design charrette. Conduct energy modeling to quantify potential performance improvements.

- **Step 3 - Cost Variation Analysis.** Compare labor and materials costs of Challenge Home designs to builders' current construction practices. Provide assistance with requesting and evaluating vendor and trade contractor bids and work scopes.
- **Step 4 - Construction Support.** Conduct on-site training and provide technical support during construction to ensure successful integration of strategies. Provide architectural and engineering design assistance to support builder's existing design team. Provide public relations and marketing communications support as requested and appropriate.
- **Step 5 - Post-Construction Monitoring.** Evaluate energy performance via co-heat test short-term energy monitoring and utility bill analysis. Complete ENERGY STAR certification and Home Energy Rating System (HERS) rating.

2.1 Builder Characteristics

Team IBTS selected builders in locations across New York State ranging from rural to inner urban areas and from Adirondack State Park in the north to Yonkers in the south. Challenge Homes were completed with Kraft Construction, Habitat for Humanity-Westchester, and Ithaca Neighborhood Housing Services (INHS).

Challenge Homes were begun with Bishop Builders, Portrait Homes, and Xcel Fine Homes. Work was completed through the redesign process described in Step 2 and Step 3 before these three builders withdrew from the program due to poor residential construction business conditions (Figure 1 and Table 2).

Figure 1. Map of Builder Locations

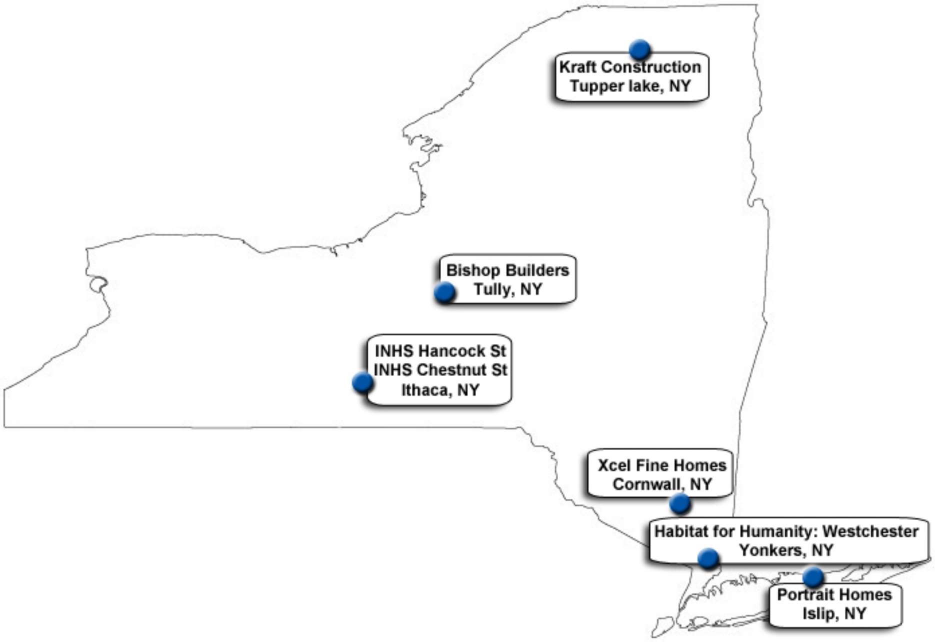

Table 2. Participating Builders

	Builder	Location	Description
1	Kraft Construction	Tupper Lake, NY	Rural, wooded location, single-family home, one level, full basement, SIPs roof, ICF foundation/above-grade walls
2	Bishop Builders	Tully, NY	Development with 26 duplex patio homes, one level, slab-on-grade, ICF foundations, SPF (spray foam) 2x6 walls
3	Habitat for Humanity - Westchester	Yonkers, NY	Urban infill, single-family home, two story, full basement, SIPs walls/roof, poured concrete/foam board foundation, based on ORNL ZEH5 design
4	INHS – Ithaca A	Ithaca, NY	Urban infill, single-family home, two story, full basement, scattered lot, SIPs walls/roof, ICF foundation
5	Portrait Homes	Islip, NY	Suburban, single-family home, two story, SIPs walls/roof, high wind area
6	Xcel Fine Homes	Cornwall, NY	Suburban, single-family homes, two story, full basement, 32 lots in community, SIPs, pre-cast foundation walls
7	INHS –Ithaca B	Ithaca, NY	Two duplex units, two homes stick built walls/roof, two homes SIPs walls/roof, both homes ICFs foundations

2.2 Review Current Practices

Job site visits, telephone interviews, and in-person meetings were held with builder participants, their trade contractors, and their design teams to establish the builder's current construction practices. Construction drawings, bills-of-materials and HERS ratings of the builder's past homes were evaluated to establish a baseline for energy efficiency and construction cost improvements.

2.3 Integrated Design

Team IBTS stressed the importance of the integrated design process that included input from the builder's in-house personnel, design architects and engineers, energy raters, trade contractors, and even building officials. Early in each Challenge Home project, an interactive design charrette was facilitated by Team IBTS to identify potential paths forward and discuss advantages, disadvantages, and trade-offs of various construction alternatives. When possible, the design charrette was held in-person at the builder's office or in a model home in one of their communities.

2.4 Construction Support

Team IBTS provided construction support tailored to suit the needs and interests of each builder. This support ranged from architectural, engineering, and building science guidance to hands-on and classroom training and jobsite installation supervision. For example:

- Kraft Construction needed assistance with the radiant heating equipment manufacturer to design a properly sized and optimized hydronic piping layout. Team IBTS facilitated the engagement of engineering and technical staff from Uponor, the radiant piping supplier, to refine their current design practices to suit the highly insulated ICFs/SIPs building shell.
- INHS was interested in having all of their trade contractors receive formal SIPs installation training to ensure integrated trade contractor work scopes. Team IBTS arranged for and funded Al Cobb of the SIPs School in West Virginia, one of the leading SIPs experts in the country, to lead an all-day workshop in Ithaca. The workshop was open to all local trade contractors and builders in addition to INHS' contractors.
- Habitat for Humanity needed extensive building codes and regulatory support to address zoning and technical questions from the Yonkers building department. On several occasions, Team IBTS met with Yonkers city officials to review and address these issues. Ultimately, Team IBTS provided formal architect of record services through New York-based team member Chaleff & Rogers Architects.

In addition, Team IBTS worked with each builder's HERS raters and energy auditors to ensure that their evaluations correctly considered the high-performance aspects of the construction. Team IBTS assisted builders in reviewing trade contractor and material supplier bills of material, bids, specifications, and work scopes to ensure that their estimates for goods and services were responsive to the high-performance construction techniques.

2.5 Evaluation

Post-construction evaluation of the high-performance construction approaches implemented by each builder was completed in one of the five ways described in this section.

HERS Score/Index. The builder's typical construction methods were used to identify the HERS Index[1] that would have been achieved without high-performance construction approaches. This HERS Index was then compared to the new HERS Index of the as-designed Challenge Homes. In both cases, local, independent, RESNET-certified energy raters completed the energy modeling using the most current version of REMRate software. Team IBTS' certified HERS raters used their own REMRate software and libraries of building assemblies and construction details to share best practices that were often new to the builders' local HERS rater.

Blower Door Test. The air tightness of each home was determined using a blower door test conducted by an independent energy auditor. The blower door test identifies how many times in one hour (air changes per hour or ACH) the entire volume of air inside the home leaks to the outside. The blower door creates a pressure difference of 50 Pascals between the inside and outside of the home to simulate an approximately 20 mile per hour wind blowing against the home. The leakier the home, the higher the ACH50 score. The blower door test is an effective method of evaluating as-built construction and identifying construction defects that can be corrected before the home is completed.

Short-Term Energy Monitoring (STEM). A co-heat test is a specialized STEM approach that is used to determine overall heating system efficiency. This is defined as the ratio of the power required to heat the home by electric space heaters to the power used by the central heating system during normal cycling to provide the same average room temperatures. Co-heat tests must be conducted over night when temperatures are stable, less than 65 degrees, and wind is limited. The accuracy of co-heat tests can be impacted by unpredictable weather, hidden construction defects, mechanical system performance variations, and thermal mass effects.

Utility Bill Analysis. Builders shared the monthly electric and gas utility bills for 12 months after each home[2] was sold and occupied. The utility bills were compared to the energy consumption and energy savings predicted by the REMRate energy modeling software used to establish the home's HERS Index.

Incremental Construction Cost. Construction costs were established for each home built according to the builders' typical construction techniques and for the high-performance Challenge Home construction techniques. In several

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[1] A HERS Index is a relative energy efficiency performance score that considers the energy consumption for heating, cooling, water heating, lights, and some appliances. The lower the number, the more energy efficient the home. A one- point reduction in the index corresponds to a one percent reduction in energy consumption. Typical existing homes score 130 on the HERS Index. Code-compliant new homes receive a HERS Index of 100. Note that HERS results are also reported using the pre-2009 scale which provides a HERS Score. The higher the score, the more energy efficient the home.

[2] Utility bills were not analyzed for the Habitat for Humanity home built in Yonkers. Instead, the utility bills in both units of the INHS duplex Chestnut Street duplex homes were analyzed.

instances, the value of material and service donations was identified to avoid evaluation of below-market pricing for several products. Conversely, incremental construction costs were not evaluated for the Habitat for Humanity (HfH) home because the vast majority of products and services are donated to HfH as part of their charitable mission.

3 Kraft Construction

3.1 Builder Profile

> ***"We will never do a plain, poured concrete wall again. ICFs work great. We recently took the installer training course for Arxx." - Rich Kraft, Kraft***

Kraft Construction typically builds one to three custom homes per year. Kraft has more than 20 years of new home building, remodeling, and custom cabinetry experience in the Tupper and Saranac Lake areas of New York. The extremely cold climate (more than 8,000 Heating Degree Days per year with a winter design temperature of -15 degrees F) in the area has created increased awareness of the importance of energy efficiency and durability.

Kraft's previous experience with high-performance construction includes building a log home and a timber frame home with SIPs. Current construction practices include ICFs for foundations.

3.2 Project Description

The Kraft home site was 14 wooded acres on high ground near Upper Saranac Lake. The 1,827-square-foot, one-level home with a full basement was positioned for optimized solar orientation. The home incorporated certain fundamental Universal Design concepts including locating the master bedroom on main level and primary egress at grade as well as wheelchair accessible doors and bathrooms.

The foundation and above-grade walls of the Challenge Home were built using ICFs (Figure 2). The roof system was built using SIPs (Figure 3 and Figure 4). The primary heating system was a propane-fired boiler using PEX hydronic piping in the basement slab and a lightweight concrete first-floor slab over an engineered wood floor system (Figures 5 through 7. Secondary heating was provided by a wood-burning stove. Table 3 summarizes the redesign.

Figure 2. Kraft Neopor ICF Foundation

Figure 3. Kraft SIPs Roof Installation

Figure 4. Kraft Home SIPs Installation Complete

Figure 5. Kraft Home Hydronic Piping Layout

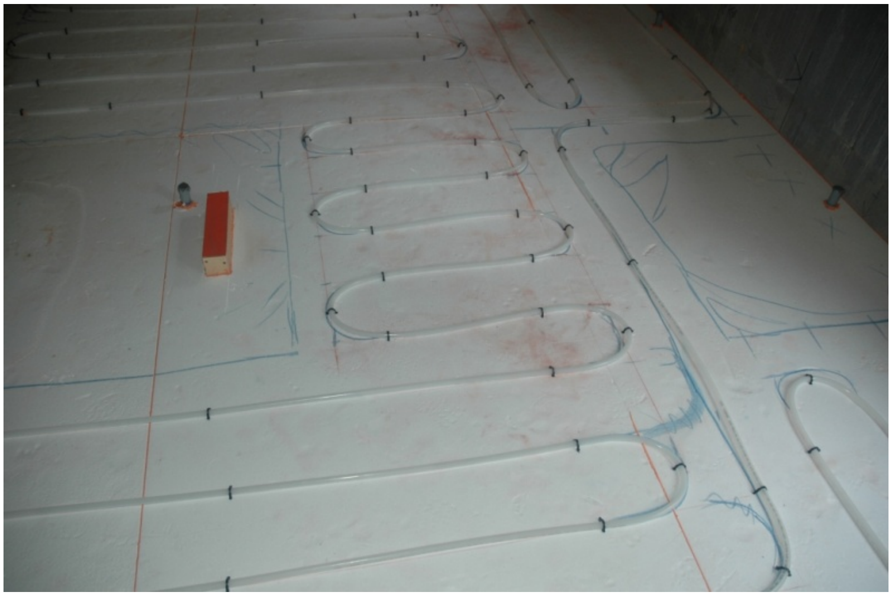

Figure 6. Kraft Home Rear Elevation

Figure 7. Kraft Home Interior

Table 3. Kraft Construction Redesign

	Typical Construction	High-Performance Construction	Change in Cost + or (-)
Slab	Poured Concrete, 100% 2” XPS, R9	Poured Concrete, 100% 3” EPS, R12	($400)
Foundation Walls	CMU, 2” XPS, R9	ICF, 11.75” Neopor EPS, R27	$3,748 + $1,000 donation
Above-Grade Walls	2x6, Fiberglass, R19	ICF, 11.75” Neopor EPS, R27	
Roof	2x4 Trusses, R49	SIPs, 11” Neopor EPS, R53.6	$10,424 + $500 donation
Windows	Marvin, U 0.35, SHGC 0.55	In-Line, Fiberglass, U 0.31, SHGC 0.54	$0
Entry Door	Metal/Urethane, R7	Fiberglass, 2” Urethane, R15	$400
Basement/Service Door	Metal/Urethane, R7	Metal, 2” Urethane, R14	$200
Patio Doors	Marvin, U 0.35, SHGC 0.55	In-Line, Fiberglass, U 0.32, SHGC 0.54	($1234)
Heating	85% Boiler	95% to 98% Boiler, Viessman Vitocell V-100	$500 +$500 donation
Cooling	None	None	$0
Controls	2 Zone	Multi-zone	$200
Distribution System	12” o.c. PEX	Optimized PEX piping design	($500) Uponor design labor donation
Water Heating	40 Gallon, 0.53 EF Gas	Integrated Sidearm/Boiler, Solar ready	$500
Mechanical Ventilation	Exhaust only	ERV, 75 CFM, 40 Watts	$1,400
Lighting	50% FL / 50% CFL	20% FL / 80% CFL	$100
Refrigerator	700 kWh/yr	526 kWh/yr	$300
Dishwasher	0.46 EF	0.60 EF/Energy Star	$300
HERS Score/Index	88/60	92/41	Total = $17,938

3.3 Construction Support

Team IBTS supported construction of the Kraft Home by completing a detailed comparative analysis of windows from several manufacturers, optimizing the home's hydronic piping design, adapting the home's existing architectural designs to SIPs, and providing on-site SIPs installation expertise.

See Appendix A for a detailed analysis of the window glazing options that were evaluated for the Kraft home.

3.4 Results

The Kraft house is clearly very energy efficient. Tupper Lake has a winter design temperature of -15 ºF, and so a design temperature difference of 70 – (-15) = 85 ºF. The Kraft home had a design heat load of only 17,900 Btu/hr, which is extremely low for a home of this size. Another indicator of overall energy efficiency is the normalized annual consumption of 1.4 Btu/SF/HDD in an 8,255 heating-degree-day climate. This is extremely energy efficient and very close to the Passive House requirements.

The blower door test results of 0.92 ACH50 indicate the Kraft Home is remarkably tight. Though the home uses sealed combustion appliances and an Energy Recovery Ventilator (ERV), initially this air tightness resulted in whistling of the entry door during high winds and difficulty regulating the temperature within the home.

The Kraft Home STEM test was the first indication of certain limitations in the co-heat test methodology. That is to say, the co-heat test is better suited to light-frame construction than the relatively massive construction of the Kraft Home with concrete basement and first floor slabs in addition to poured concrete within the ICF walls. The home's thermal lag did not allow the home to equilibriate fully between co-heat test cycles. This issue coupled with potentially ground-coupling related radiant losses through the basement slab resulted in a surprisingly low over heating system efficiency of 53% (Table 4).

Lower than predicted energy usage in the Kraft Home is likely related to the use of the unknown amount of wood burned in the wood burning stove.

See Appendix B for Kraft monthly energy usage data.

Table 4. Kraft Construction Results

	Results	Comments
Blower Door Test (50Pa)	296 CFM	Conducted by Northern Lights Energy
Blower Door Test (ACH50)	0.92	
STEM Test	52.7%	Relatively low efficiency shown by co-heat test results is likely because the concrete slab with radiant floor heating had not achieved steady-state temperature by the time of the electric heat test. There also may have been radiant heat losses into the ground below the slab in spite of the 100% sub-slab insulation.
Predicted Energy Usage	155.5 MMBtu	REMRate
Utility Bill Energy Usage	99.0 MMBtu	National Grid. Electricity and propane usage is lower than predicted due to use of wood burning stove.
$/HERS Point	$2,990	HERS Point Change=92(Challenge)–86 (Conventional)=6
$/Square Foot	$9.82	Home size = 1,827 sq ft

4 INHS – Ithaca A

4.1 Builder Profile

Ithaca Neighborhood Housing Services (INHS) is a nonprofit community development corporation that was established in 1977. INHS has extensive experience with energy-efficient construction but had never built with structural insulated panels prior to the Challenge. INHS regularly builds homes to both ENERGY STAR and LEED for Homes requirements.

INHS Mission: Expanding opportunities for quality, energy-efficient, affordable housing for renters and owners in Tompkins County.

4.2 Project Description

INHS built the Challenge Home on an urban infill site located at 711 Hancock Road in Ithaca. The 1,352-square-foot, two-level home had three bedrooms on the second floor and a full basement.

The foundation was built using ICFs (Figure 8). The above-grade walls and roof system were built using SIPs (Figure 9). The primary heating system was a natural gas-fired boiler utilizing baseboard radiators. See Figure 10, Figure 11, and Table 5 for additional construction details.

Figure 8. INHS Ithaca A ICF Foundation

Figure 9. INHS Ithaca A SIPs Installation

Figure 10. INHS Ithaca Front (View 1)

Figure 11. INHS Ithaca A Front (View 2)

Table 5. INHS-Ithaca A Redesign

	Typical Construction	High-Performance Construction	Change in Cost + or (-)
Slab	Poured Concrete, Edge 1.5"XPS, R7	Poured Concrete, Edge, 3" EPS, R12	$611
Foundation Walls	CMU, 2"XPS, R8.6	ICF, 11.75" EPS, R24	$3000
Above-Grade Walls	2x6, Fiberglass, R19	SIPS, 4.5" EPS, R18	$2,250
Roof	2x4 Trusses, R49	SIPS, 8.25" EPS, R34	Both included above
Windows	Low E vinyl, U.36, SHGC.45	Paradigm, ~U.32, SHGC.40	$3,000
Entry Door	Wood, Solid, Storm, ~R2.8	Fiberglass/2" Urethane, R15	$300
Basement/Service Door	Wood, Solid, Storm ~R2.8	Metal/2" Urethane, ~R14	NA
Patio Doors	NA	NA	NA
Heating	~83% Boiler	Baxi Luna HT380, ~95% Boiler	$4,000
Cooling	NA	NA	NA
Controls	Thermostat	?	W/ price of boiler
Distribution System	Ducts in Conditioned Space	Boiler in Conditioned Space	$300
Water Heating	Integrated with Boiler	Integrated with Boiler	Included with Boiler
Mechanical Ventilation	Exhaust only	ERV	$1,500
Lighting	20% FL/ 80% CFL	20% FL/ 80% CFL	No change from INHS standards
Refrigerator	~ 775 kWh/yr	~550 kWh/yr	$100
Dishwasher	.46 EF	.50 EF/ Energy Star	$135
HERS Score/Index	83/85	91/45	$15,196

4.3 Construction Support

In addition to typical Challenge building science and engineering project support, Team IBTS supported construction of the INHS Ithaca A Home by organizing a whole-day SIPs installer training program conducted by Al Cobb of the SIPs School based in Shenandoah Junction, West Virginia (Figure 12 and Figure 13). Team IBTS architect, Bill Chaleff of Chaleff & Rogers, worked closely with the INHS architect to adapt the home's existing architectural designs to SIPs.

Figure 12. INHS Ithaca A SIPs School Classroom

Figure 13. INHS Ithaca A SIPs School Hands On

4.4 Results

The INHS Ithaca A home provided a useful platform to educate a wide range of Ithaca trade contractors, both those that work with INHS and those that do not, about the use of high-performance building envelope systems, ICFs and SIPs. The construction of the home proceeded largely as planned. The end result was very tight home with blower door test results of 1.29 ACH50.

Interestingly, the high-performance building envelope helped point out installation flaws in other phases of construction. Specifically, once the home's energy loads were significantly decreased through the use of SIPs and ICFs, the co-heat test identified the significant impact the non-insulated heating distribution pipes in the basement had on overall building energy efficiency. To account for this the co-heat test was repeated after the distribution pipes were insulated (Table 6).

See Appendix C for monthly energy usage data.

Table 6. INHS Ithaca A Hancock Construction Results

	Results	Comments
Blower Door Test (50Pa))	337 CFM	Tested by Snug Planet Attic access blocked off with temporary foam/plywood hatch was potential leakage location.
Blower Door Test (ACH50)	1.29	
STEM Test	56.21%	After insulating the pipes, overall heating system efficiency of the house increased to 83.5%. Other heating system energy losses included baseboard radiators losing heat directly through outside walls and boiler operational losses (primarily combustion losses).
Predicted Energy Usage	77.1 MMBtu	REMRate
Utility Bill Energy Usage	113.8 MMBtu	NYSEG
$/HERS Point	$2032	HERS Point Change=91(Challenge)–83(Conventional)=8
$/Square Foot	$11.42	Home size = 1,352 sq ft

5 Habitat for Humanity - Westchester

5.1 Builder Profile

Habitat for Humanity-Westchester (HfH-W) is a nonprofit community development corporation that was established in 1977. Though HfH-W had previous experience with certain high-performance construction approaches gained through projects built several years ago, there was limited in-house familiarity with these concepts, products, or processes for the Challenge.

HfH Vision:

A world where everyone has a decent place to live.

5.2 Project Description

HfH-W built the Challenge Home on an urban infill site located at in Yonkers. The vacant site was donated to HfH-W by the city of Yonkers as part of an overall neighborhood revitalization effort. The Challenge Home was initially modeled on the net zero energy homes homes built by Habitat for Humanity in collaboration with the Oak Ridge National Laboratory (ORNL) in Oak Ridge, Tennessee. The Challenge Home footprint and most building envelope characteristics are consistent with and leverage the ORNL on-going net zero energy homes research efforts.

The foundation was built using poured concrete with two inches of extruded polystyrene (XPS) foam board insulation on the outside. The above-grade walls and roof system were built using SIPs. The primary heating system was a natural gas-fired boiler utilizing baseboard radiators. See Figures 14 through 17 and Table 7 for additional construction details.

Figure 14. HfH–W Homesite

Figure 15. HfH–W Front Elevation

Figure 16. HfH–W Foundation Insulation Crew

Figure 17. HfH–W Front Yard

Table 7. HfH-W Redesign

	Typical Construction	High-Performance Construction
Slab	Poured Concrete, R10 perimeter	Poured Concrete, R10 Perimeter
Foundation Walls	CMU, Fiberglass, Full Draped, R13	2" XPS Exterior, R10
Above-Grade Walls	2x6 Fiberglass, R19	SIPS, 4" EPS, R18
Roof	Trusses, R38 Blown FG	SIPS, 10.25" EPS, R42
Windows	U.35, SHGC.58	Andersen, U= .27, SHGC=.21
Entry Door	Wood Core, U.58	Wood Core, U.58
Basement/Service Door	NA	Metal/Urethane, R14
Patio Doors	NA	NA
Heating	Heat Pump 44.0kBtuh, 6.8 HSPF,	Elite EL80-N Natural Gas Boiler (95%)
Cooling	Heat Pump 27 kBtuh, 14 SEER	Natural
Controls	Thermostat	Programmable Thermostat, Mechanical ventilation
Distribution System	Ducts in conditioned space, R5	NA
Water Heating	50 gal, Electric, 0.84 EF	Integrated/Boiler, 0.86 EF
Mechanical Ventilation	None	AirCycler-to-Air handler/duct system
Lighting	20% FL	100% FL
Refrigerator	~ 650 kWh/yr ENERGY STAR	~550 kWh/yr Energy Star
Dishwasher	.46 EF	>.50 EF/ Energy Star
HERS Score/Index	84 / 80	90 / 50

5.3 Construction Support

Team IBTS supported construction of the HfH-W Orchard Street Home by providing a significant amount of architectural, engineering, and design support. Team IBTS architect, Bill Chaleff of Chaleff & Rogers, adapted the home's existing architectural designs to SIPs and became the project's architect of record.

The HfH-W home experienced major delays due to zoning and building code issues raised by the Yonker's building department. These issues were surprising given the fact that the HfH-W team shared the preliminary Challenge Home designs with the Yonkers building department prior to committing to the project. Team IBTS met in-person with Yonkers building officials on multiple occasions to address their questions and concerns. Team IBTS members participated in several on-air radio broadcasts along with the HfH-W's executive director to publicize the home.

5.4 Results

The HfH-W Challenge Home faced significant hurdles on several fronts. For example, after the start of construction the very tight home site was found to have significant ledge of bedrock that conflicted with the home's placement, excavation, and foundation construction. In addition, numerous zoning, regulatory, and building code delays were encountered such that the project ended up nearly two years behind the original construction schedule. The variable nature of building product donations led to certain conflicts with the home's original design intent. Lastly, the lack of locally available *pro bono* architectural support services resulted in Chaleff & Rogers architects developing the construction drawings and providing architect of record services.

Ironically, one of the reasons that HFH-W was selected for the Challenge was their previous experience building with structural insulated panels. The use of the SIPs proceeded comparatively smoothly. The SIP construction offered the ability to close the home in rapidly and reduce or eliminate the need to stage material on site for extended periods of time. It is interesting to note that while the building envelope is very tight compared to typical hollow-wall construction, the HfH-W home is significantly less tight (2.08 ACH50) than the other Challenge Homes.

Following completion of the home, HfH-W was not able to supply energy usage data provided by the home buyer. With NYSERDA's consent, energy use data for the second INHS Chestnut Street duplex unit was collected as an alternative. Construction results are summarized in Table 8.

Table 8. HfH-W Construction Results

	Results	Comments
Blower Door Test (50Pa))	950 CFM	Tested by Robison Energy LLC
Blower Door Test (ACH50)	2.08	
STEM Test	NA	Second INHS duplex unit evaluated instead
Predicted Energy Usage	94.2 MMBtu	
Utility Bill Energy Usage	NA	Utility bills not available
$/HERS Point	NA	HERS Point Change=90(Challenge)–84(Conventional)=6 Goods and services donated.
$/Square Foot	NA	

6 INHS – Ithaca B

6.1 Builder Profile

As described previously, INHS has extensive experience with energy efficient construction but had never built with structural insulated panels prior to the Challenge. INHS is a leader in the nonprofit housing industry and is well known for building energy-efficient, high-quality homes to serve Tompkins County

6.2 Project Description

INHS built the Challenge Home duplexes on an urban infill site located in Ithaca. Two Challenge Homes were built to create an opportunity to compare traditional stick-built construction to SIPs. The two were built with 2×6 above-grade walls and roof trusses. The two units were built with SIPs above grade walls and roofs.

The duplex units were in many respects mirror images of each other. The two larger units in each duplex had three bedrooms on the second floor while the two smaller units had two bedrooms on the second floor. The main level of each home included a living room, dining room, and kitchen.

The foundation of all four units was built using ICFs. The primary heating system in each home was a natural gas-fired boiler utilizing baseboard radiators. See Figures 18 through 26 and Table 9 for additional construction details.

Figure 18. INHS-Ithaca B Home Site

Figure 19. INHS-Ithaca B SIPs

Figure 20. INHS-Ithaca B Trusses

Figure 21. INHS-Ithaca B Front Elevation

Figure 22. INHS-Ithaca B SIPs Framing

Figure 23. INHS-Ithaca B View

Figure 24. INHS-Ithaca B Interior

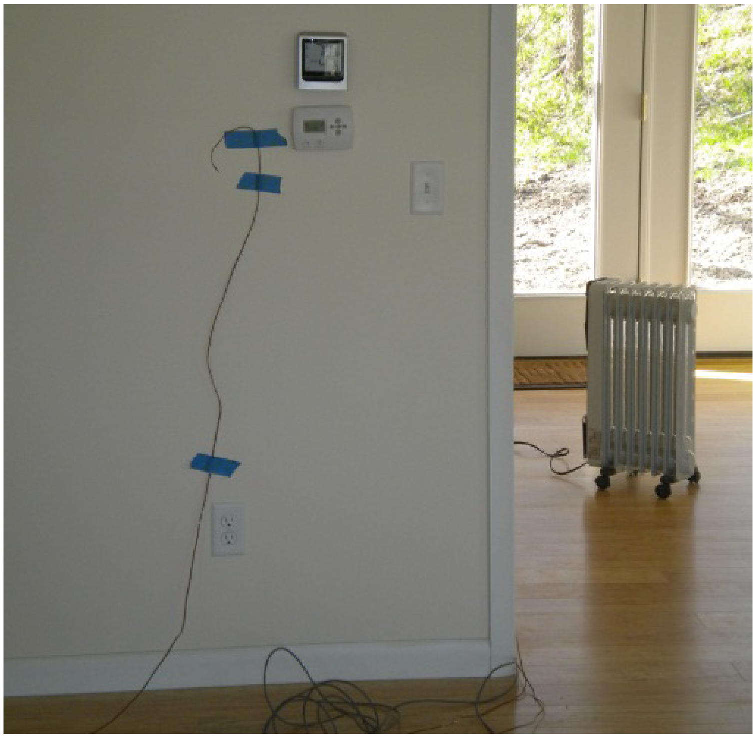

Figure 25. INHS-Ithaca B Vented Siding

Figure 26. INHS-Ithaca B Front Elevation

Table 9. INHS-Ithaca B

	Typical Construction	High-Performance Construction	Change in Cost + or (-)
Slab	Poured Concrete, Edge 1.5"XPS, R7	Poured Concrete, Edge, 3" EPS, R12	$1291
Foundation Walls	CMU, 2"XPS, R8.6	ICF, 11.75" EPS, R22	$6500
Above-Grade Walls	2x6, Fiberglass, R19	SIPS, 4.5" EPS, R26	
Roof	2x4 Trusses, R49	SIPS, 10.25" EPS, R45	
Windows	Low-E vinyl, U.36, SHGC.45	Paradigm, ~U.32, SHGC.40	$2500
Entry Door	Wood, Solid, Storm, ~R2.8	Fiberglass/2" Urethane, R15	$300
Basement/Service Door	Wood, Solid, Storm ~R2.8	Metal/2" Urethane, ~R14	NA
Patio Doors	NA	NA	NA
Heating	~83% Boiler	Baxi Luna HT380, ~95% Boiler	$3000
Cooling	NA	NA	NA
Controls	Thermostat	?	--
Distribution System	Ducts in conditioned space	Boiler in conditioned space	$300
Water Heating	Integrated w/Boiler	Integrated w/Boiler	--
Mechanical Ventilation	Exhaust only	ERV	$1500
Lighting	20% FL/ 80% CFL	20% FL/ 80% CFL	NA
Refrigerator	~ 775 kWh/yr	~550 kWh/yr	~$100
Dishwasher	.46 EF	.50 EF/ Energy Star	~$120
HERS Score/Index	83/85	91/45	$15,511

6.3 Construction Support

In addition to typical Challenge project engineering and building science assistance, Team IBTS supported construction of the INHS-Ithaca B Duplex by adapting the home designs to SIPs. The initial design concepts were under development but had not been finalized or submitted for permits at the time that INHS entered the Challenge with these homes. Team IBTS architect, Bill Chaleff of Chaleff & Rogers, worked with INHS' local architect to modify the original designs in detailed ways to optimize the designs for SIPs.

Following their initial experience with SIPs on the Ithaca A Challenge Home, INHS was interested in evaluating extruded polystyrene rather than expanded polystyrene SIPs cores. In addition, INHS decided to field fabricate door and window openings in the SIPs rather than have the openings created at the SIPs plant. To explore potential impacts of heating system location on the overall energy efficiency of the two SIPs homes, the heating system in the first unit in Ithaca B was placed largely within conditioned space while the heating system in the second unit in Ithaca B was placed in unconditioned space.

6.4 Results

SIPs are generally thought to enable more airtight construction on a repeatable basis than stick-built construction. INHS builds a highly energy efficient home that already incorporates air sealing measures beyond code minimums. Improving upon this well-built stick home results in less dramatic improvements than would likely be the case compared to typical stick-built construction by other builders.

That said, blower door test results indicate that the SIPs home at the first unit in Ithaca B (1.06 ACH50) was slightly more than 20% tighter than the mirror image stick-built home at the first unit in the other duplex of Ithaca B (1.29 ACH50). It is important to remember that these are both very well built, tight homes. It is not uncommon for typical stick-built construction to be in the 4.5 to 5.0 ACH50 range.

Evaluation of the overall heating system efficiency of the two SIPs homes yielded surprising results given the placement of one heating system within condition space and the other heating system within unconditioned space. Counterintuitively, the heating system in unconditioned space (83%) had a higher overall efficiency rating than the system in unconditioned space (68%). These results are likely related to differences in overnight temperatures, differences in the percentage of unfinished space in the two homes, as well as potential variations in combustion efficiency and distribution flow rates.

The SIPs units were built with field fabricated openings. The framer reported that though labor cost savings were anticipated, the amount of framing labor required on the jobsite ended up being almost equal to the stick-built homes. This need was attributable to both the labor to create the openings in the SIPs panels as well as the difficult site conditions that increased the time needed for material handling.

Table 10. INHS-Ithaca B Construction Results

	Results – SIPS 530-1	Results – SIPs 530-2	Results – Stick Built 528-1	Comments
Blower Door Test (50 Pa)	420 CFM	411 CFM	511 CFM	Tested by Alpha Energy
Blower Door Test (ACH50)	1.06	1.44	1.29	
STEM Test	67.85%	83.37%	81.27%	%=Overall heating system efficiency
Predicted Energy Usage	66.9 MMBtu	57.8 MMBtu	NA	REMRate
Utility Bill Energy Usage	56.94 MMBtu	42.37 MMBtu	NA	NYSEG
$/HERS Point	$2,216	$1,551	NA	530-1= 1,980 ft2 530-2= 1,584 ft2
$/Square Foot	$7.83	$7.83	NA	HERS Point Change=91(Challenge)–83 (Conventional)=8

7 Conclusions

Cost Effectiveness. The use of SIPs in the wall and roof structures and ICFs in the foundations of most Team IBTS Challenge Homes proved to be a cost-effective alternative to conventional residential construction. This result was readily shown by the consistently low air infiltration test results (0.87 to 1.29 ACH50), cost per HERS point ($1,500 to $3,000 per point), and cost per square foot ($8 to $11.50 per sq ft). Underutilized construction tradeoffs enabled through the use of these technologies include reduced heating distribution line length achieved by placing radiators on interior walls and reduced hydronic piping used achieved through optimized piping layouts due to more thermally stable indoor environments.

Energy Efficiency Potential. SIPs and ICFs were highly effective in reducing building loads on the Challenge homes. Reduced air infiltration was the largest driver of the home's increased energy efficiency. Both systems met or exceeded builder and trade contractor expectations for in-place performance. Interestingly, the increasingly energy efficient building envelope of the Challenge Homes magnified the relative impact of nonbuilding envelope energy losses and building loads. For example, as the Challenge Homes became more energy efficient, distribution losses were shown to be a more significant part of overall energy usage. The potential for the Challenge Homes to realize their energy efficiency fully was hampered by the inefficiency of other systems within the home.

STEM Tests. Most prior co-heat tests have been done on houses with forced-air systems and hollow-wall construction. Based on the results with the Challenge Homes, the co-heat test does not work well in houses with radiant heating and masonry or SIPs construction. A central concept of the co-heat test is that the energy consumption of the home is measured when the home reaches steady-state as indicated by constant zone temperatures and energy input. The standard co-heat test cycles the fossil-fuel heating system on and off at two-hour intervals. This frequency is too short for homes with hydronic heating and high-performance construction. The co-heat methodology was modified to run the Challenge Home's heating system for an entire night and the electric heaters for another entire night.

Product vs. Process Changes. Builder personnel, trade contractors, design professionals, supply chain stakeholders, and building officials all were challenged by the high-performance design and construction approaches used in the Challenge Homes. It was clear that it was significantly more difficult to change the construction processes they use compared to changing specific products. It was especially true for trade contractors since they play such a pivotal role in the adoption of new technologies and are accountable for the warranted performance of their work. In addition, during the procurement process it was often very difficult for builders to make informed decisions, evaluate construction tradeoffs, and compare innovative products on an apples-to-apples basis. Quotes and estimates from ICF and SIPs suppliers were particularly difficult for builders to evaluate because of inconsistencies in format and level of detail provided.

Appendix A: Kraft Construction Window Analysis

Team IBTS

Kraft Window Options
Modeling of Predicted Energy Use

Taitem Engineering
February 17, 2009

Background

Windows are available from manufacturers with a variety of glazing options. Options which affect energy performance include changing the u-value and SHGC (solar heat gain coefficient) of the window. A lower u-value means that less heat is conducted through the window. A lower SHGC means that less heat from sunlight is allowed to pass through the window. The cost of the windows typically increases relative to a window with air-filled double glazing if an alternate glazing is selected. The question was studied of whether decreased building energy use, resulting from varying window glazing options, justified the increased cost of the windows.

TREAT 3.0.27 software was used to model expected energy use. TREAT models the effect of solar heat gain in a structure, taking into account sun angles, intensity of sunlight, window glazing and frame properties, and the mass of the structure.

The model parameters represent the preliminary design of the Kraft residence. The purpose of the energy modeling was to choose whether double glazed air-filled, double glazed argon-filled, triple glazed argon-filled, or triple glazed argon-filled with higher or lower solar heat gain should be installed in the home. The criterion for choosing was the energy cost savings relative to the extra cost of the more energy-efficient windows.

Energy Model Parameters

The weather data used in the model is 30 year average weather for Massena, NY.

Heating fuel:	Natural gas, cost $1.20 per therm
Electricity cost:	$0.15 per kWh
Building area:	Two floors, 1,757 ft2 each, total 3,514 ft2 of conditioned space.
Foundation slab:	Insulated slab, R-10
Foundation wall:	Insulated concrete form system, R-24
Exterior walls:	Structural insulated panel system, R-24
Roof:	Structural insulated panel system, R-46
Infiltration:	0.20 Air changes per hour
Heating boiler:	Natural gas, 90% AFUE
Indoor Temp:	First Floor: 68 F for 16 hours per day, 63 F for 8 hours per day Basement: 63 F for 24 hours per day
Hot Water:	Indirect tank supplied by heating boiler
Lighting:	First floor: (15) 13 W lamps, 5 hours per day Basement: (5) 13 W lamps, 5 hours per day
Appliances:	First floor: refrigerator, electric range, computer, washer, gas dryer
Glass doors:	Area: 107 sq ft Double glazed: U = .33, SHGC = .29 The large glass doors in the living room were not included in the evaluation of alternate glazing, because of limited availability and large incremental cost.
Predicted yearly energy use:	Electricity for lights and appliances: 1,534 kWh, $230
Gas for heating:	640 therms, $768
Gas for appliances and domestic hot water:	239 therms, $287

Windows

The windows were modeled with specific sizes and exposures as shown on the construction drawings. The windows on the east side of the first floor were modeled as being shaded by the porch.

- Quantity: 17 windows
- Area of windows (glass and frame): 239 sq ft

The basis of design specification refers to a specific window model, referenced by the Certified Products Directory number (CPD #) from the NFRC (National Fenestration Rating Council).

Base windows: Argon-filled double-glazing: U = .31, SHGC = .5

Basis of design: CPD# IFL-A-5-00042, manufacturer: Inline Fiberglass, series name: 325 Casement, manufacturer product code: "Cl-arg-LOF, f-te"

Option 1, Argon-filled double glazing with lower u-value: U = .25, SHGC = .3
Basis of design: CPD# IFL-A-5-00043, manufacturer: Inline Fiberglass, series name: 325 Casement, manufacturer product code: "272-arg-Cl, f-te"

Option 2, Argon-filled triple glazing: U = .22, SHGC = .39
Basis of design: CPD# IFL-A-5-00048, manufacturer: Inline Fiberglass, series name: 325 Casement, manufacturer product code: "LOF-arg-Cl-arg-LOF, f-t-te"

Option 3, Argon-filled triple glazing with lower SHGC: U = .2, SHGC = .25
Basis of design: CPD# IFL-A-5-00050, manufacturer: Inline Fiberglass, series name: 325 Casement, manufacturer product code: "272-arg-Cl-arg-272, f-t-te"

For the base windows and each glazing option, different window operating types (patio door, horizontal slider, fixed, casement, and in-swing casement) were specified for different locations in the building. Within each option, the u-value and SHGC for each operating type varied slightly. The energy modeling was simplified by assigning the u-value and SHGC for the typical operating type, casement, to all windows.

Results

Predicted heating fuel savings per year:

Option 1, Argon-filled double glazing with lower u-value and lower SHGC: savings of 26 therms, $31.

Option 2, Argon-filled triple glazing relatively high SHGC: savings of 25 therms, $30.

Option 3, Argon-filled triple glazing with lower SHGC: negative savings of -2 therms, $-3.

The payback period based on the cost of the glazing options was not calculated.

For context, other changes that affect building energy use were modeled:

Air-filled double-glazed windows: U = .33, SHGC = .29 Basis of design: CPD# IFL-A-5-00029, manufacturer: Inline Fiberglass, manufacturer product code: “272-air-CI, te”: negative savings of -71 therms, $-85.

100 cfm exhaust fan running for 1 hour per day, negative savings of -14 therms, $-17.

Lower indoor temperature by 1 degree, savings of 24 therms, $28.

Raise indoor temperature to a constant 70 degrees, negative savings of -94 therms, $-113.

Conclusion

The energy modeling results are specific to this structure, in this location.

The differences in predicted energy use among the different window glazings are small relative to the incremental cost of the optional glazings. Additionally, the differences in predicted energy use that would result from optional glazings are also similar to the effects that variations in occupant behavior would have on predicted energy use.

In this case, the predicted energy cost savings which would result from optional glazings are too small to justify the increased costs which are typically associated with the optional glazings. The base window, In-Line Fiberglass U=0.31 should be used.

Predicted Yearly Heating Fuel Use based on Preliminary Design of the Kraft Residence		
	Heating Fuel	
	Therms	$
Base case: argon-filled double glazing	640	768
Changes to Base Case		
Option 1: argon-filled double glazing with lower u-value and lower SHGC	-26	-31
Option 2: argon-filled triple glazing with relatively high SHGC	-25	-30
Option 3: argon-filled triple glazing with lower SHGC	2	3
Air-filled double glazing	71	85
100 cfm exhaust fan running 1 hour per day	14	17
Lower indoor temperature by 1 degree	-24	-28
Raise indoor temperature to constant 70 degrees	94	113

Appendix B: Kraft Construction Annual Energy Usage

	Electricity
Month	**kWh**
August 2010	514
September 2010	508
October 2010	602
November 2010	723
December 2010	629
January 2011	725
February 211	712
March 2011	619
April 2011	535
May 2011	477
June 2011	633
July 2011	567
Total	**7244**
Convert to MMBtu	**24.7**
12 Month Propane Usage	
875 gallons @ 84,950 Btu/gallon = 74.3MMBtu	
Total Electricity + Propane = 99.0 MMBtu	

Appendix C: INHS Ithaca A Annual Energy Usage

	Electricity	**Gas**
Month	**kWh**	**Therms**
March 2010	826	80.9
April 2010	777	71.8
May 2010	521	36.7
June 2010	679	25.6
July 2010	660	16.4
August 2010	792	18.5
September 2010	799	28.7
October 2010	695	44.2
November 2010	676	57.6
December 2010	821	72
January 2011	1330	88.5
February 2011	1200	72
Total	**10,643.0**	**774.9**
Convert to MMBtu	36.3	77.5
Total MMBtu	**113.8**	

Appendix D: INHS Ithaca A SIPs School Announcement

NYSERDA

High-Performance Residential Challenge

Residential Structural Insulated Panel Construction Workshop

SPONSORED BY

Institute for Building Technology & Safety

AND

Ithaca Neighborhood Housing Services

When: March 25, 2009

Schedule:

8:00 Registration /Continental Breakfast

8:30 Classroom Session

11:30 Lunch

12:30 Jobsite Session

4:00 Wrap-Up

Where: Half-Day Classroom Session:

Holiday Inn Downtown, 222 South Cayuga Street, Ithaca, NY, 14850

Half-Day Hands-On Field Session:

INHS Jobsite, Location in Ithaca TBD

Who Should Attend: Builders, Trade Contractors, Building Officials, Architects, Engineers

Instructor: Al Cobb, Director of the SIPschool in Shenandoah Junction, WV, is a nationally recognized trainer and expert in SIPs construction. He has provided hands-on and classroom-based SIPs training across the country and his firm, PanelWrights LLC, has constructed more than 450 SIP projects. He has been on the Board of Directors of the Structural Insulated Panel Association (SIPA) for 15 years.

Registration: Ruben Legaspi (rlegaspi@ibts.org) 703.481.2000

Space is limited **Pre-registration required**

Appendix E: INHS Ithaca B Annual Energy Usage

Chestnut Street Duplex	Stick-Built				SIPs			
Address	**528-1**		**528-2**		**530-1**		**530-2**	
Fuel	**Electricity**	**Gas**	**Electricity**	**Gas**	**Electricity**	**Gas**	**Electricity**	**Gas**
Month	**kWh**	**Therms**	**kWh**	**Therms**	**kWh**	**Therms**	**kWh**	**Therms**
October 2012					113.0	21.6	239.0	5.1
November 2012			222.0	45.3	150.0	57.6	267.0	4.1
December 2012			292.0	65.2	194.0	66.2	288.0	8.2
January 2013			267.0	68.1	218.0	78.4	257.0	9.3
February 2013	51.0	23.7	289.0	77.2	155.0	83.3	296.0	25.7
March 2013	76.0	27.8	245.0	62.7	154.0	68.9	283.0	44.2
April 2013	126.0	28.8	220.0	40.1	156.0	45.2	331.0	59.7
May 2013	133.0	13.4	167.0	15.4	126.0	21.6	314.0	52.6
June 2013	134.0	8.2	194.0	17.4	163.0	19.5	276.0	46.6
July 2013	118.0	4.1	260.0	8.2	166.0	12.3	261.0	36.0
August 2013	130.0	5.1	391.0	14.3	204.0	15.4	150.0	14.4
September 2013	126.0	6.1	350.0	14.3	177.0	12.3	78.0	14.4
Total	**894.0**	**117.2**	**2867.0**	**428.2**	**1976.0**	**502.3**	**3040.0**	**320.3**
Convert to MMBtu	3.05*	11.7*	9.88^	42.3^	6.74	50.2	10.37	32.0
Total MMBtu	**14.75***		**52.18^**		**56.94**		**42.37**	

* = eight months

^ = eleven months

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High Performance Residential Design Challenge: Case Studies 1-4

Final Report
March 2014

Report Number 14-45

State of New York
Andrew M. Cuomo, Governor

New York State Energy Research and Development Authority
Richard L. Kauffman, Chair | John B. Rhodes, President and CEO