New York State Energy Research and Development Authority

High Performance Residential Design Challenge:

Case Studies 5-11

Final Report

October 2014

Report Number 14-47

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High Performance Residential Design Challenge: Case Studies 5-11

Final Report

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Notice

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Acronyms and Abbreviations

ACH50	measured air change rate at 50 Pascals
AHU	air handler unit
BIBS	blown in bagged system
CCSF	closed cell spray foam
cfm	cubic feet per minute
DHW	domestic hot water
EPS	expanded polystyrene (open cell foam)
EF	energy factor (rating for water heaters)
HHQ	Home Headquarters, Inc.
HRV	heat recovery ventilator
HVAC	heating ventilation and air conditioning
ICF	Insulated concrete forms
kWh	kilowatt hours
OCSF	open cell spray foam
NYS	New York State
NYSERDA	New York State Energy Research and Development Authority
W	watts
SEER	seasonal energy efficiency ratio (rating for air conditioners)
SHGC	solar heat gain coefficient (rating for window assemblies)
SIP	structurally insulated panel
SIS	structural insulated sheathing
sq ft	square feet
XPS	extruded polystyrene (closed cell foam)
UA-value	product of conduction factor (U) and surface area (A) represents total heat loss rate (in Btu per hour) from home per degree Fahrenheit

1 Introduction

The purpose of the High Performance Residential Design Challenge was to work with builders to develop cost-effective, high-performance designs that exceed the typical requirements of the New York ENERGY STAR® Certified Homes The intent was to identify practical, easily implemented improvements to a builder’s home design and then fully document the added costs as well as measure and analyze the impact of the energy performance improvements. The measure impacts were compared to the expected impacts predicted by the REM/Rate software tool – the standard package widely used by the Home Energy Rating community in New York State to determine a Home Energy Rating Score (HERS).

This project involved two teams working on a total of six homes. One team worked with the builders to redesign or make recommendations for the houses. The Central NY team included:

- CDH Energy Corp. (Hugh Henderson, Jeremy Wade).
- Camroden Associates, Inc. (Terry Brennan).
- Northeast Green Building Consulting (Kevin Stack).
- Building Performance Contractors Association of New York (Jim Hammel, Ed Voytovich).

The Levy Partnership (Jordan Dentz) took the lead on the project for the Hudson Passive House in Claverack, NY.

2 Redesign Process

The approach was to work with the builders to improve or redesign a given house to meet the business model needs of the builder and improve their technical skills. This process started by identifying a builder with specific project and a basic plan set. The team met with the builder and proposed concepts and design improvements that might be appropriate for the project. Based on that meeting, the team developed detailed drawings and specifications and then worked with the builder's architect to integrate these details into the plan set. For at least two of the projects the redesigned plan sets were used to build additional versions of the home beyond the specific houses described in this report. The team also worked with the builders to document the incremental costs of these improvements relative to the original or base design. For most projects, the redesign project budget was used to pay for some or all of these incremental costs in return for the builder's time and effort to breakdown costs and provide access for post-construction measurements and monitoring. The construction process and details were documented and monitoring results can be found at www.cdhenergy.com/HomePIC

3 Description of Homes and Improvements

The section describes the homes and improvements in each home. Table 1 summarizes basic information about each home and briefly describes the key features or improvements that were implemented in each case. The focus was primarily on building envelope improvements.

Table 1. Summary of Houses, Features, and Improvements

Home (finish date)	Size & Type	Envelope Features	Mechanical Features
1 - Syracuse (2010)	1,586 sq ft new, single family	2” exterior foam, ICF foundation, OCSF and CCSF in shed roofs and garage, Window U = 0.29, 2.12 ACH50 (w/ basement)	Two-stage 95% furnace, power-vented DHW (EF=0.65), AHU fresh air intake (or skuttle)
2 – Syracuse (2011)	2,265 sq ft new, townhouse	1” SIS panels with 6” BIBS, 2” XPS on basement wall, Window U = 0.28, 3.8 ACH50 (w/o basement)	Two-stage 92.5% furnace, power-vented DHW (EF=0.65), AHU fresh air intake (or skuttle), 13 SEER AC
3 – Troy (2010)	1,840 sq ft “gut rehab”, 2 apartments	2” CCSF on masonry walls, with blown cellulose, 2x4 staggered walls for stairways, 4” CCSF on basement walls with membrane over dirt floor, 3.3 ACH 50 (w/ basement)	Wall-hung 95% modulating boiler in each apartment, indirect WH tank, exhaust fans for ventilation
4 – Liverpool (2011)	1,984 sq ft new, duplex	2” exterior foam with 6” BIBS, Superior Wall basement w/ 2.5“ foam, 2” slab insulation, closed cell spray foam with 2” board foam(on top of rafters) with BIBS in cathedral ceilings, Window U = 0.22, 1.8 ACH (w/ basement)	Combi system with 95% tankless WH and solar system, AHU with HW coil, AHU fresh air intake with Honeywell damper controller, 13 SEER AC
5 – Claverack (occupied 2011)	1,660 sq ft new, single family	SIP with 12.25” EPS, 12” foam under slab insulation, 0.16 ACH50	Two Mitsubushi Hyper-heat heat pumps, Zender HRV, Tankless electric DHW
6 – Chittenango (2014 est)	2,097 sq ft new, townhome	2” exterior foam with OCSF in 2x6 wall cavity, CCSF in other walls, dormers, ICF footers with 4” underslab foam, Window U = 0.22	High performance heat pump with ducted indoor unit (minimal ducting), exhaust fan for ventilation

3.1 House 1 – Syracuse

This new house was completed in spring 2010 by Home Headquarters (HHQ: www.homehq.org). This 1,586-square-foot, two-story house includes an insulated concrete forms (ICF) foundation and 2 inches of exterior foam. Closed cell foam is used in the shed roofs. House area is 2,326-square-foot with the partially finished basement. The details of the baseline and proposed and actual design are given in Table 2.

The design for this energy-efficient house – known as the Energy Efficient Sherwood – was originally developed for another location in Syracuse in 2008. The design has since been built by HHQ at other locations in the City of Syracuse.

Figure 1. Completed House 1 in Syracuse

Source: CDH Energy

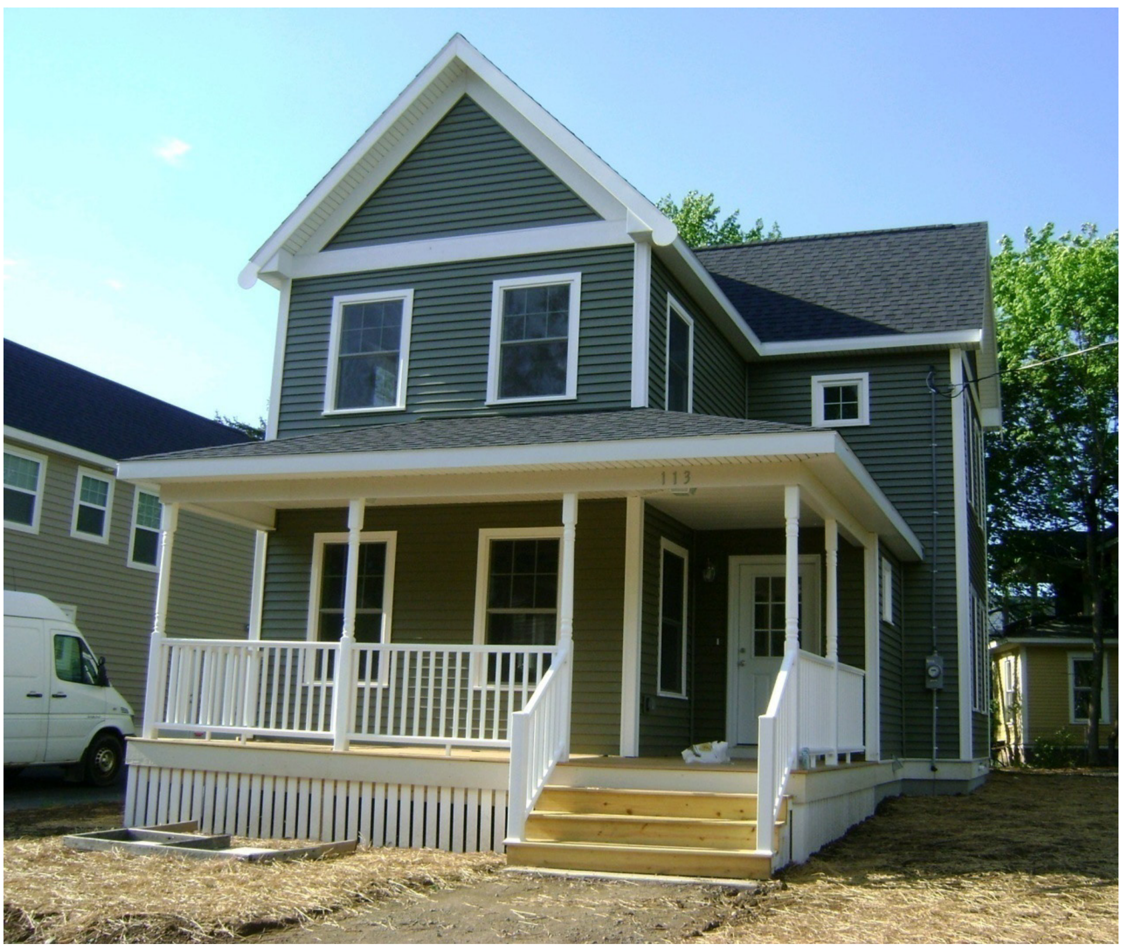


Table 2. Summary of Improvements at House 1 in Syracuse

Colored entries are changes compared to proposed design. Blue text indicates envelope design and green indicates mechanical design.

	Base Design	Proposed Design (2008)	Actual Design (2010)
Walls	2x6 walls w/ Fiberglass Batts 16 in oc R19	2x4 wall cellulose, w/ 2 in exterior XPS foam board (DOW Wallmate)	2x6 wall 24 in OC Spacing w/ BIBS, w/ 2 in exterior XPS foam board (DOW Wallmate) R32
Attic	Fiberglass batts R38	R41 blown cellulose (11.5 in) Foam top plates, spray to proper vent	**Blown Fiberglass (18 in) R45**
Basement Walls	Masonry wall with 5½ inch Fiberglass Blanket (6 ft down wall)	2 in exterior XPS foam board (DOW Perimate)	**Nudura Insulated Concrete Form (ICF) R22**
Windows	U=0.35, SHGC=0.52 (double hung) U=0.33, SHGC=0.50 (inoperable)	U=0.35, SHGC=0.52 (double hung) U=0.33, SHGC=0.50 (inoperable)	**U=0.29, SHGC=0.26 (double hung)**
Rim/Band Joists	5½ inches of Fiberglass R21	6 in Closed Cell Spray Foam	**4 in XPS foam board/froth pack sealed w/ 2 in exterior XPS Foam Board R30**
Garage Ceiling	Fiberglass batts R30	Fiberglass batts R30	**Open cell foam w/ 1 in Polystyrene R35**
Shed Area Roofs	Fiberglass batts R38	3 in Closed Cell Spray Foam R21	3 in Closed Cell Spray Foam R21
Garage Walls	None	2 in exterior XPS foam board (DOW Wallmate) R10	2 in exterior XPS foam board (DOW Wallmate) R10
Garage-to-house Wall	2x6 walls w/ Fiberglass Batts 16 in oc R19	2x4 wall cellulose, w/ 1 in DOW Thermax taped	**2x6 wall w/ Blown Fiberglass w/ 2 in exterior XPS foam board (DOW Wallmate) R29**
Air Tightness	5 ACH50 (with basement)	1-2 ACH50 (with basement)	2.12 ACH50 (with basement)
Ventilation	Bathroom & kitchen exhaust fans 100 cfm, 15 hours/day, 20 Watts	Air Cycler 65 cfm continuous distributed to each bedroom	**Fresh air scuttle 65 cfm continuous**
Heating	92% efficiency Gas Furnace	94% efficiency boiler	95% efficiency 2-stage Gas Furnace
Water Heating	0.65 EF, 40 gallon, Gas Water Heater	Indirect Tank on Boiler	**0.65 EF, 40 gallon, Gas Water Heater**

3.2 House 2 – Syracuse

HHQ purchased this partially completed four-unit townhome and then completed construction as part of this project. The HomePIC team helped to develop an energy-efficient redesign for all four units. The four redesigned units were started in 2009 and completed in stages throughout 2010 and 2011. The HomePIC project paid for the improvements to the end unit (Figure 2), whereas the other three units were supported with additional funding from the Syracuse Center of Excellence.

Structural insulated sheathing (SIS) panels were used for exterior sheathing instead of traditional Oriented Strand Board (OSB) or Zip Panels. The SIS panels from Dow nominally have 1 inch of foam, which provides an R-5 rating (compared to R-0.8 for OSB) while still providing adequate structural support and racking strength. The SIS foam panels are taped to provide a water seal as well as an air barrier. SIS panels were applied to insulated wall areas as well on the attic gable ends and the exterior garage walls. The details of the base, proposed, and actual design are given in Table 3.

Figure 2. End Unit at House 2 in Syracuse

Source: CDH Energy

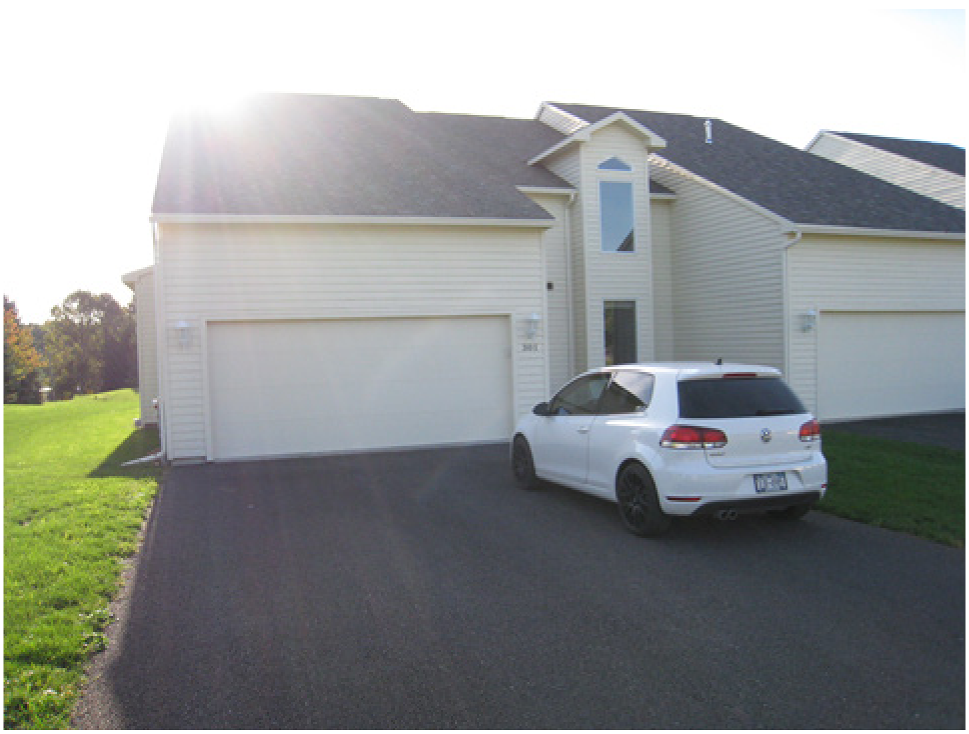


Table 3. Summary of Improvements at House 2 in Syracuse

Blue text indicates envelope design changes compared to proposed design.

	Base Design	Proposed Design	Actual Construction
Walls	Wafer Board Siding w/ OSB Sheathing; 2x6 Frame wall with Fiberglass Batt (R19)	Wafer Board Siding SIS Panel (1 inch foam, R5) ; 2x6 frame wall w/ BIBS (R23 cavity+ R5 Continuous)	Wafer Board Siding SIS Panel (1 inch foam, R5) ; 2x6 frame wall w/ BIBS (R23 cavity+ R5 Continuous)
Open Attic	Scissor Truss with 2x4 Bottom Cord 11.5 inch Fiberglass Batt (R38)	Scissor Truss with 2x4 Bottom Cord 16 inch Cellulose (R60)	Scissor Truss with 2x4 Bottom Cord 11 inch Cellulose (R42)
Cathedral/ Vaulted Ceiling	2x6 Parallel Cord Truss with Fiberglass Batt (R38)	2x6 Parallel Cord Truss with 11 inch Cellulose (R42)	2x6 Parallel Cord Truss with 11 inch Cellulose (R42)
Basement Walls	CMU Block with Fiberglass Batt 5 ft down from ceiling (R11)	CMU Block with 2 inch rigid foam (Thermax) on inside (R10)	CMU Block with 2 inch rigid foam (Thermax & XPS) on inside (R10)
Garage-to-Exterior Wall	Wafer Board Siding w/ OSB Paneling Sheathing on 2x4 frame wall	Wafer Board Siding SIS Panel (1 inch foam, R5) on 2x4 frame wall	Wafer Board Siding SIS Panel (1 inch foam, R5) on 2x4 frame wall
Garage-to-Interior Wall	Fiberglass Batt, OSB Panel, 2x6 Framing (R19)	BIBS System, SIS Panel, 2x6 framing (R23+ R5 Continuous)	BIBS System, ZIP Panel, 2x6 framing (R23) + 2 inches XPS foam board (R10)
2nd Floor-to-Attic Wall	Fiberglass Batt, OSB Panel, 2x6 Framing (R19)	BIBS System, SIS Panel, 2x6 framing (R23+ R5 Continuous)	BIBS System, SIS Panel, 2x6 framing (R23+ R5 Continuous)
Windows	U=0.31, SHGC=0.35 (double hung)	U=0.31, SHGC=0.35 (double hung)	U=0.28, SHGC=0.32 (casement)
Rim/Band Joists	5.5 inches of Fiberglass (R21)	4 inches Rigid Foam w/ 1 inch exterior SIS foam (R25)	4 inches Rigid Foam w/ 1 inch exterior SIS foam (R25)
Air Tightness & Thermal Bypass	5 ACH50 (with basement)	2 ACH50 (with basement) Various air sealing and thermal bypass improvements	3.8 ACH50 (w/o basement) Various air sealing and thermal bypass improvements
Heating	90% Efficient Gas Furnace	95% Efficient Gas Furnace	92.5% Efficient Gas Furnace
Ventilation	Exhaust Only Ventilation	HRV	Inside Unit: HRV Outside Unit: Exhaust Only Ventilation (58cfm)

3.3 House 3 – Troy

The right side of this existing duplex building Unit A was gutted to the studs and rebuilt in the spring 2010 by The Madison Project Partnership. The left side of the building Unit B was gutted and renovated, insulated, and rebuilt to meet ENERGY STAR® standards in 2008. The goal for Unit B was to improve on that 2008 design.

The two sides of the buildings are separately deeded (Figure 3). Each has property been made into upstairs and downstairs apartments, each with their own gas and electrical utility meters. The Madison Project currently plans to rent the apartments, but may consider selling the property in the future.

The project used closed-cell spray foam the inside of the masonry surfaces as well as on the basement walls. Offset 2×4 walls were used in the unheated stairways. The details of the base and actual designs are given in Table 4.

Figure 3. Two Apartment Units in Troy (after all renovations were complete)

Source: CDH Energy

Table 4. Summary of Improvements in Troy

	Base Design (Unit A)	**Improved Design (Unit B)**
Walls (Front and Back Exterior)	Masonry w/ air gap and 2” Poly Iso Foam Board, 2x4 Frame w/ 6.5” netted cellulose (R-38)	Masonry w/ 2” closed cell spray foam, 2x4 w/ 6.5” to 8” netted cellulose (R-36)
Wall (Exterior Stairwell, Front)	Masonry and furring strips w/ Pieced in 1” Foam Board (R-7)	Masonry and furring strips w/ 1-1/2” closed cell spray foam (R-9)
Wall (Interior Stairwell, Front)	2x4 Frame, 4.5” Dense Deck Cellulose (R-25.5)	2x4 Frame, 1st Floor: 4.5” Dense Deck Cellulose with 1” Rigid Foam (R-25.5) 2nd Floor: 3.5” Fiberglass Batts with 1”Rigid Foam (R20)
Wall (Interior, Rear Stairwell)	2x8 Frame w/ Fiberglass batts and 1” Rigid Foam (R-24)	1st Floor, 8” wall with staggered 2x4 stud frame w/ 8” cellulose (R-30) 2nd Floor, 10” (R-37) cellulose upstairs
Wall (Kitchen and Bath)	Masonry and 2x4 Frame w/ 4.5” Cellulose and 2” Rigid Foam (R-24)	Masonry w/ 2” closed cell spray foam, 2x4 w/ 4.5” netted cellulose (R-24)
Wall (Exterior, Rear Stairwell)	Masonry and Stucco	Masonry and furring strips w/ 1-1/2” Closed cell spray foam (R-9) with sheet rock on top
2nd Floor Bonus Room Walls	2x4 Frame w/ Fiberglass Batts R13	2x4 frame w/ 3.5” Fiberglass w/ 1” rigid foam (R-20)
Bonus Room Floor	10” Fiberglass (R-35)	10” Fiberglass (R-35)
Attic	2x10 frame with 16” cellulose (R-60)	2x10 frame with 16” loose cellulose (R-60)
Basement Walls	Masonry w/ 4” closed cell spray foam (R-24)	Masonry w/ 4” closed cell spray foam (R-24)
Basement Floor	4” Stone with Poly	EPDM on dirt
Windows	U=0.32 (double hung)	U=0.32 (double hung)
Rim/Band Joists	3” Closed cell spray foam (R-18)	3” Closed cell spray foam (R-18)
Attic Hatch	4” Rigid Insulation	4” Rigid Insulation
Heating/DHW	(2) 95% Efficiency Goodman Gas Furnace with (2) Takagi T-K3 instantaneous water heaters	(2) 95% efficiency Prestige triangle tube fully condensing water boiler w/ Smart 30 indirect fired DHW heater
Air Tightness & Thermal Bypass	3.75 ACH50 (with basement)	3.29 ACH50 (with basement) Various air sealing
Ventilation	Exhaust Only Ventilation, manual control	Exhaust Only Ventilation, manual control

3.4 House 4 – Liverpool

This 2-unit model townhome was built by Miller Homes in September 2011 (Figure 4). The house was part of the 2011 Syracuse Parade of Homes. This model has 2-story units with a loft option. The left side of the duplex was the finished model while the right side was left unfinished to highlight the construction and insulation details. The unfinished side was also open during Parade of Homes to educate the public about the energy efficiency improvements available in these units. As part of the redesign process, the team worked with the builder's architect to revise the plans for the two-story unit with loft (1,984 square feet [sq ft]) that was built at this site. In addition, the architect implemented the efficiency improvements into the plans for the one-story unit (1,582 sq ft) and the two-story without loft (1,841 sq ft).

The major energy efficiency improvements incorporated into these homes included the Superior Wall precast foundation system with 2.5 inches of insulation in the basement as well as the exterior walls with 2 inches of exterior foam and 2×6-inch with 24 inches of On Center (OC) framing. The wall cavities were filled with BIBS blown fiberglass. The cathedral ceiling used blown fiberglass, closed cell spray foam, and 2-inch exterior rigid foam on the rafters but under the roof deck. Blown cellulose was used in the attic. The details of the base, proposed, and actual design are given in Table 5.

Figure 4. Two-Unit Model in Liverpool

Source: CDH Energy

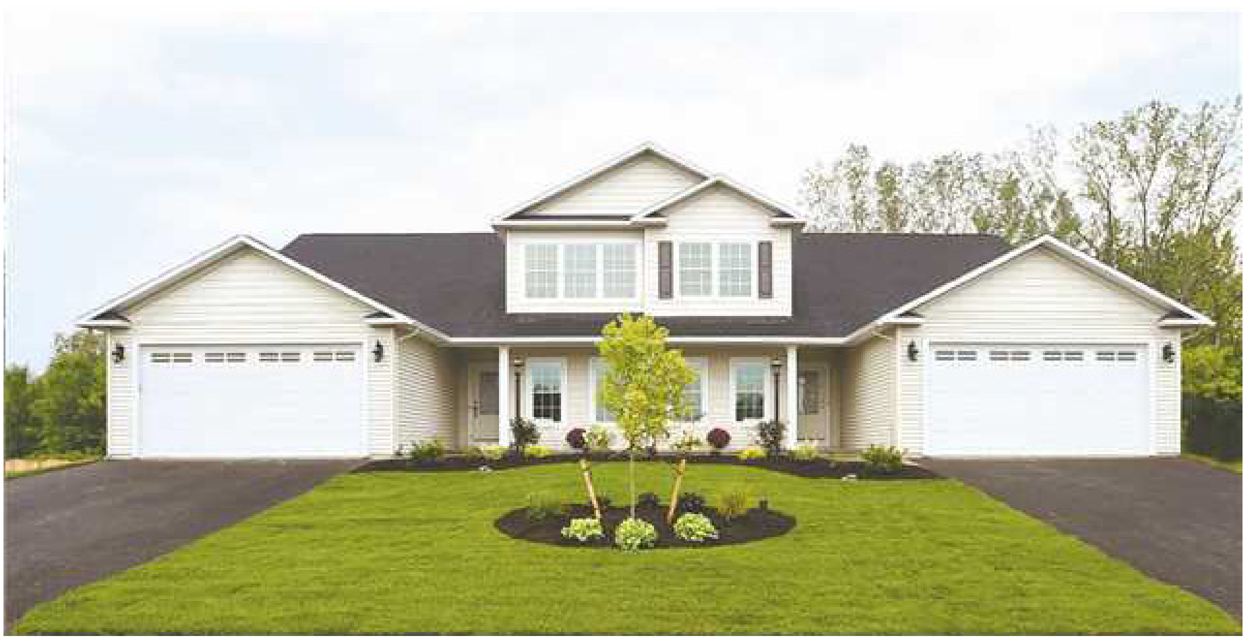


Table 5. Summary of Improvements in Liverpool

	Base Design	Proposed Design	As Built Details
Walls	Vinyl Siding, 1-1/2" exterior foam, 2x6" framing w/ Fiberglass batts R29	Vinyl Siding, 2"Exterior Foam, 2x6" framing w/ dense packed cellulose R30	Vinyl Siding, 2" Exterior Foam, 2x6" framing, BIBS blown in fiberglass R33
2nd Floor Knee Walls	2x4" framing w/ fiberglass batts R13	2" Exterior Foam, 2x6" framing w/ dense packed cellulose R30	2" Exterior Foam and Closed Cell foam 2nd floor to attic walls
Garage (Exterior)	Vinyl Siding, 2x6" framing	Vinyl Siding, 2x6" framing	Vinyl Siding, 2x6" framing
Attic	2x12 rafters frame with Fiberglass batts R38	2x12 rafters frame with 16" cellulose R49	2x12 rafters frame with blown cellulose R60
Cathedral Ceiling	R38 Fiberglass Batts	Blown Fiberglass with 2" Exterior Foam above roof deck R58	BIBS, Closed Cell foam, and Exterior Foam beneath roof deck R67
Basement Walls	10" CMU w/ 5' Hanging Blown in Fiberglass R10	10" CMU, 2.5" white Thermax R15	Superior Walls Xi Foundation System with 2.5" Dow® Extruded Polystyrene Insulation R15
Basement Floor	Uninsulated poured concrete floor	2" Rigid Foam under poured concrete floor R10	2" Rigid Foam under poured concrete floor R10
Windows	U=0.33 Low E Argon double hung	Super Seal Windows U = 0.20	DH: Triple glazed, Low E, U = 0.22, SHGC = 0.23 Slider: Double glazed, Low E Argon filled, U = 0.30, SHGC = 0.20 Basement: Double glazed, Low E Argon/air filled, U=0.28, SHGC=0.35
Rim/Band Joists	6" Fiberglass batts w/ 1-1/2" Ext Foam R 29	3" Closed Cell foam in Band joists w/ 2" ext Foam R32	3" Closed Cell foam in Band joists w/ 2" ext Foam R32
Garage-to-house Wall	2x6 framing w/ Fiberglass batts R19	2"Exterior Foam, 2x6" framing w/ dense packed cellulose R33	2" Exterior Foam, 2x6" framing, BIBS system blown in fiberglass.
Air Tightness & Thermal Bypass	5 ACH50 (with basement)	2 ACH50 (with basement) Various air sealing and thermal bypass improvements	1.79 ACH50 with basement (actual)
Heating/ Cooling	90% Natural Gas Furnace 13 SEER AC Unit	94% Natural Gas Furnace 13 SEER AC Unit	95% Rheem tankless water heater and heating coil Combi System 13 SEER 2.5 ton AC unit
Ventilation	Exhaust Only Ventilation	HRV Fantech SH704 run 24 hours, 36 watts, 55 cfm	Fresh Air Ventilation with damper. Honeywell Whole House Ventilation Control. Exhaust fan in garage

3.5 House 5 – Claverack

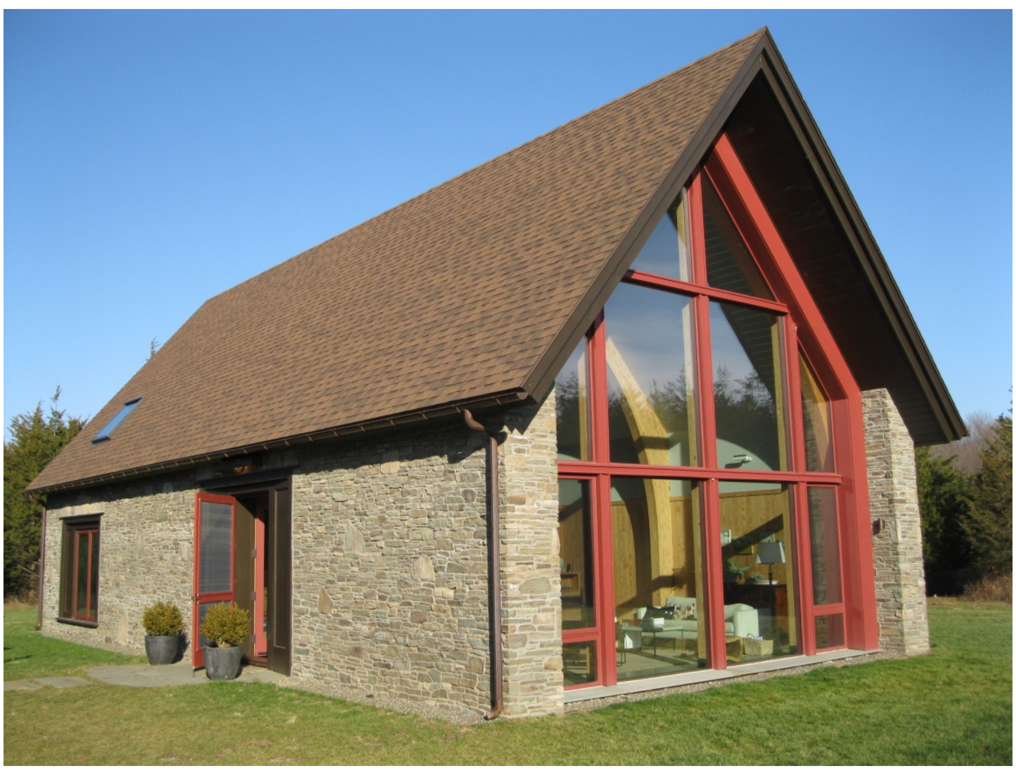
This single-family detached home was completed and occupied in October 2011 (Figure 5). The house was built to the German Passive House Standard with the goal of minimizing heating and cooling loads and thereby reducing the scale of the required mechanical equipment. The exterior walls and roof are 12-¼ inch thick structural insulated panels (SIP) with a Neopor expanded polystyrene (EPS) core. The foundation slab is insulated with 12 inches of a combination of EPS and extruded polystyrene (XPS). The infiltration level was tested at 0.16 ACH50.

The house has the following mechanical equipment:

- Mitsubishi MUZ-FE09A, ¾-ton heat pump serving the bedroom.
- Mitsubishi MUZ-FE12A, 1-ton heat pump serving the main living area.
- Zehnder heat recovery ventilator (HRV).
- Steibel Eltron tankless electric water heater.

Figure 5. Passive Project in Claverack, NY

Source: The Levy Partnership



3.6 House 6 – Chittenango

New-Paradigm Developers is building nine townhomes on the southern shore of Oneida Lake in the town of Chittenango, NY. The team helped to develop an energy efficient design for these nine units. The first four units are scheduled for completion in 2014. The HomePIC project is supporting the improvements to one of these four units.

These two-story units have a slab on grade foundation with 4-inch rigid foam under the poured concrete slab. The foundation footings use an Insulating Concrete Form wall system (ICF) that uses 2 inches of expanded polystyrene (EPS) on each side as forms for the footings and remain in place. The exterior walls were designed with 2 inches of exterior rigid foam where it was practical. In other locations, the exterior wall cavities are filled with 5½ inches of closed cell spray foam.

The planned HVAC system is a minimally ducted heat pump such as the Mitsubishi MUZ-FE series Hyper-heat units. The indoor unit will be mounted near the ceiling in the first floor laundry room with short ducts to common areas, the upstairs loft, and the front bedroom. Electric baseboard is used in the other remote bedrooms. Each townhouse will also have a solar thermal system with electric resistance to provide water heating. The solar domestic hot water tank will also be able to provide heat to the in-floor piping. The details of the base and improved design are given in Table 6.

Figure 6. Townhomes Under Construction in Chittenango

Source: CDH Energy

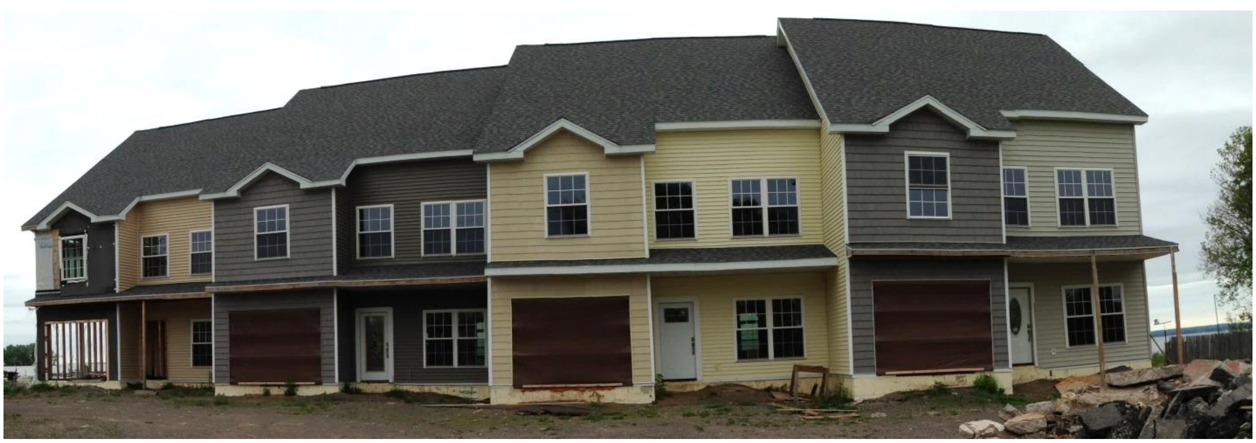


Table 6. Summary of Baseline and Proposed Design in Chittenango

	Base Design	Improved Design
Walls	2x6 Frame and Fiberglass Batt. **R19**	2” Rigid Foam Insulation on exterior of OSB 2x6 frame, Open Cell Spray Foam in Wall Cavity. ~**R33**
Lake-Side Walls and Dormers	2x6 Frame and Fiberglass Batt. **R19**	Closed Cell Spray Foam in Wall Sections w/o Exterior Foam. ~**R30**
Attic	Scissor Truss with 2x4 Bottom Cord 11.5” Fiberglass Batt. **R38**	Scissor Truss with 2x4 Bottom Cord 16” Cellulose. ~**R50**
Cathedral/Vaulted Ceiling	2x4 Parallel Cord Truss with Fiberglass Batt. **R38**	2x4 Parallel Cord Truss with 7-8” Closed Cell Spray Foam. ~**R42**
Foundation Walls and Slab	Poured concrete. 2” foam board on footer	ICF Forms with 2.5” Foam on Each Side of Poured Concrete. 4” Rigid Foam Under Poured Concrete Slab
Garage Walls and Ceiling	Fiberglass Batt	Closed Cell Spray Foam in ceiling Open Cell Spray Foam on exterior walls
Windows	U=0.31, SHGC=0.35 (double hung)	U=0.22, SHGC=0.20 (double hung)
Rim/Band Joists	5.5 inches of Fiberglass. **R21**	Caulked and Spray Foamed.
Garage-to-Interior Wall	Fiberglass Batt, 2x6 Framing. **R19**	Blown Bagged Cellulose, 2x6 Framing. **R19**
Air Tightness	5 ACH50	2 ACH50 Various air sealing and thermal bypass improvements
DHW	Electric water heater	Solar Hot Water System
Heating and Cooling	92.5% Efficient Gas Furnace	Solar HW tank connected to Radiant In-floor Heating 2 or 2-½ ton Hyper heat pump with some electric baseboard heaters.
Ventilation	Exhaust Only Ventilation	Exhaust Only Ventilation

4 Cost of Improvements and Expected Savings

Table 7 summarizes the incremental costs of the improvements in each house along with the baseline and actual HERS scores. The energy savings predicted by REM/Rate are also given. More details are given in the detailed construction reports for each house at the project web site (www.cdhenergy.com/HomePIC).

Generally the implemented improvements increased the HERS score by about 3 points at a cost of $2,300 to $4,400 per point (excluding Liverpool). Incremental costs per square foot were $3 to $7 except at Claverack. Simple paybacks based on actual energy savings ranged from 14 to 46 years.

Table 7. Summary of Costs, HERS scores, and Predicted Savings in Each House

Gas costs at $1.50 per therm. Electric costs at $0.12/kWh.

House Project	House Size (sq. ft.)	Incremental Cost of Improvements	ACH 50	Base HERS Score	Actual HERS Score	Cost per HERS Pt point	Inc Cost ($/sq ft)	Energy Savings (MMBtu)	Cost Savings	Simple Payback	Notes
Syracuse 1	1,586	$ 11,440	2.12	85.8	88.8	$ 3,813	$ 7.21	24.4	$ 366	31	
Syracuse 2	2,265	$ 6,916	3.7	85	88	$ 2,305	$ 3.05	32.1	$ 482	14	
Troy	1,840	$ 10,250	3.29	86.8	90.2	$ 3,015	$ 5.57	14.8	$ 222	46	
Liverpool	1,984	$ 10,322	1.8	84.6	89.6	$ 2,064	$ 5.20	28.5	$ 428	24	Score includes solar, but costs do not
Claverack	1,660	$ 22,563	0.16	84.4	89.6	$ 4,339	$ 13.59	38.6	$ 1,359	17	all electric house
Chittenango	2,097	$ 9,400		86	89	$ 3,133	$ 4.48				

5 House Performance Measurements

Table 8 summarizes the energy use for each house broken down by major end use. Total electric ranged from 2,081 kilowatt-hours (kWh) in the apartments at Troy to 7,680 kWh per year in the all-electric Claverack house. The other electric uses in the homes, which include lights, appliances, and plug loads – but excludes HVAC power – ranged from 2,081 to 6,530 kWh per year, or 1.8 to 4.1 kWh per sq ft per year. Furnace or air handling unit (AHU) fan power was measured to be as high as 1,097 kWh per year. The AHU supply fan used as much as 600 watts at high speed for cooling; less power was usually used when operating at lower speed for ventilation and mixing. Cooling energy use for the condensing unit was typically smaller than AHU fan energy use, ranging from 140 kWh to 476 kWh per year.

Most homes used natural gas for space and water heating. Total gas use in the houses was determined from the utility bills. The gas use associated with space and water heating was typically determined from monitored data such as equipment runtimes. Space heating gas use was only 223 therms per year at the Syracuse 1 house in part because of the high internal gains (i.e., from “other” electric use). Surprisingly at this house natural gas use for domestic hot water (DHW) was much larger than furnace gas use. Conversely, Syracuse 2 had smaller internal gains from electric (and DHW) so it used slightly more gas for space heating. On a per square foot basis, space heating loads ranged from 0.14 to 0.34 therms per sq ft per year. The apartments at Troy had mismatched heating loads: the downstairs apartment accounting for most of the heating energy use while the upstairs apartment set its thermostat so that it used almost no gas for space heating.

Table 8. Summary of Energy Use in Each House

		Annual Electric Use						Annual Gas Use			
			Estimated or Measured						Estimated or Measured		
House	Floor Area (sq ft)	Total Electric Use (kWh)	DHW (kWH)	Space Htg or AHU Fan (kWh)	AC/Cooling Electric Use (kWh)	"Other" Electric Use (kWh)	"Other" Electric (kWh/sq ft)	Total Gas Use (therms)	DHW Gas Use (therms)	Space Heating Gas Use (therms)	Space Heating (therms/ sq ft)
Syracuse 1	1,586	7,479		949	-	6,530	4.1	631	408	223	0.14
Syracuse 2	2,265	5,719		1,097	476	4,146	1.8	823	111	712	0.31
Troy (downstairs)	920	2,484				2,484	2.7	392	84	312	0.34
Troy (upstairs)	920	2,081				2,081	2.3	112	102	14	0.02
Liverpool	1,984	5,543		382	140	5,021	2.5	611	120	491	0.25
Claverack	1,660	7,680	3,302	106	289	3,983	2.4				

Table 9 lists various space heating statistics determined from the monitored data collected at each house or from co-heat tests conducted at some houses. Syracuse 2 was one of the houses with higher space heating gas use at 0.31 therms per sq ft per year; in this case, higher use was primarily driven by the higher space temperature set points used by these older homeowners. The normalized space heating gas use in the downstairs apartment in Troy also was high, though the total space heating use for two apartments combined was only 0.18 therms per sq ft per year.

The house UA-values, which were determined by various means as indicated in the table, were similar for the Syracuse 1 and Liverpool houses. The UA-value is slightly higher for Syracuse 2 house. The Claverack house had a much lower UA-value.

Table 9. Space Heating Statistics Determined From Measurement and Analysis

House	Space Heating (therms/ sq ft)	Overall UA-value (Btu/h-F)	Heating Balance Point (F)	Peak Heating Load (therms/h @ -20F)	Notes
Syracuse 1	0.14	255	53.2	0.20	UA from load line
Syracuse2	0.31	396	70.5	0.38	UA from load line
Troy (downstairs)	0.34		73	0.18	
Troy (upstairs)	0.02				
Liverpool	0.25	315		0.26	UA from co-heat test
Claverack	-	177			UA from calculations

Table 10 compares the measured energy use to the values predicted (or assumed) by REM/Rate. Some of these numbers, such as total electric and DHW energy, are assumptions that depend on occupant behavior. The calculated heating and cooling loads are strongly affected by these assumptions. In some cases, the assumed load was significantly different from the REMRate prediction/assumption.

Table 10. Comparing REM/Rate Predictions to Actual Energy Use

DHW gas use predicted by REM/Rate is low because of the solar hot water system at this site.

	Total Electric (kWh)		Total Gas (therms)		DHW Gas (therms)		Space Htg Gas (therms)	
House	Actual	REM/Rate	Actual	REM/Rate	Actual	REM/Rate	Actual	REM/Rate
Woodland Ave, Syracuse	7,479	4,478	631	692	408	212	223	480
Bunker Hill, Syracuse	5,719	5,983	823	717	111	197	712	431
Madison St, Troy (downstairs)	2,484	6,710	400	411	84	109	312	302
Madison St, Troy (upstairs)	2,081		115		102		14	
Astible Path, Liverpool	5,543	6,606	611	470	120	40	491	466
Hudson Passive House	7,680	12,184						

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