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Performance Evaluations of Prototype Houses: Minimum 40% Residential Building Energy Savings Level Habitat for Humanity of Greater Newburgh Liberty Street Project

April 2003 to September 2004

Ric Guilbert and Amanda Magee
Consortium for Advanced Residential Buildings (CARB)
Norwalk, Connecticut

U.S. Department of Energy
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Building Technologies Program

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List of Definitions

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
CARB	Consortium of Advanced Residential Buildings
cfm	cubic feet per minute
EFI	Energy Federation, Inc.
ELA	effective leakage area
EPA	Environmental Protection Agency
ERBP	Existing Residential Buildings Program
HERS	Home Energy Rating Score
HfHGN	Habitat for Humanity of Greater Newburgh
HfHI	Habitat for Humanity International
MEC	Model Energy Code
NYSERDA	New York State Energy Research and Development Authority
NYES	New York ENERGY STAR-Labeled Homes Program
SEER	Seasonal Energy Efficiency Ratio
SHGC	Solar Heat Gain Coefficient
SWA	Steven Winter Associates, Inc.

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Introduction

The National Renewable Energy Laboratory (NREL) is the technical field manager for the U.S. Department of Energy's (DOE) Building America Program (BAP). The goal of the BAP is to develop innovative system engineering approaches to advanced housing that will enable the United States housing industry to deliver affordable and environmentally sensitive housing while maintaining profitability and competitiveness of homebuilders and product suppliers in domestic and overseas markets.

For innovative building energy technologies to be viable candidates over conventional approaches, it must be demonstrated that they can cost-effectively increase overall product value and quality while significantly reducing energy use and use of raw materials when used in community-scale developments. To accomplish this goal, each of the Building America Teams partners with material suppliers, equipment manufacturers, developers, builders, designers, and state and local stakeholders.

The Consortium for Advanced Residential Buildings (CARB), led by Steven Winter Associates, is one of five Building America teams working throughout the country to develop, test, and design advanced building energy systems for all major climate regions in the United States. This report summarizes the successful research initiative with the Habitat for Humanity of Greater Newburgh (HfHGN) in Newburgh, New York. CARB partnered with HfHGN to design and build six prototype homes on Liberty Street in Newburgh.

Background

Habitat for Humanity International (HfHI) is a nonprofit organization that engages volunteers and would-be homebuyers in programs that emphasize sweat-equity and self-help. Having built about 30,000 houses across the nation, Habitat is among the top-ten housing producers in the United States. Habitat not only undertakes new housing construction, often in inner-city neighborhoods on infill sites, but it also engages in housing rehab—rescuing older, derelict homes and improving them to extend their service life.

In collaboration with the HfHI Department of Construction & Environmental Resources, Steven Winter Associates, Inc., (SWA) began working with the Habitat for Humanity of Greater Newburgh (HfHGN) affiliate in Newburgh, New York, in April 2003. Initially, CARB partnered with HfHGN to develop innovative cold-climate high-performance retrofit strategies, as part of the Existing Residential Buildings Program (ERBP). The goal of the ERBP was to develop approaches that would enable the housing retrofit industry to deliver energy-efficient housing improvements, while maintaining profitability and the competitiveness of home retrofitters and product suppliers.

Since October 1999, HfHGN has acquired and renovated abandoned houses for an average cost of $45,000 per home. The affiliate serves area families living in overcrowded, substandard housing and spending 50% to 80% of their income on housing. In August 2003, HfHGN began their first new construction project, six row houses located on Liberty Street in Newburgh.

As a result of their enthusiasm and willingness to implement new retrofit strategies under the ERBP, SWA invited HfHGN to participate in the Building America Program. Through this partnership, CARB provided recommendations for the Liberty Street Row Houses to achieve increased energy savings. The first two row houses (Figure 1) were completed and tested in mid-December 2004. The third and fourth units were completed shortly thereafter and tested in late January 2005. A dedication event for the last two units has been planned for the end of July 2005, with Unit #6 ready for occupancy by the end of August.

Project Time Line

A summary of the project milestones is shown in Table 1. From planning through construction, all six homes are expected to be completed in less than 2 years. Unlike production builders, HfHGN relies heavily on volunteer labor. Although this reduces construction costs, it often results in a longer construction cycle.

Table 1. Project Time Line

August 6, 2003	Initial CARB presentation to HfHGN architecture team
August 21, 2003	Presentation to HfHGN Board of Directors to discuss energy goals
October 5, 2003	Liberty Street ground-breaking event
November 18, 2003	First Five Foundations Formed and Poured
December 17, 2003	Setting the open-web trusses, CARB onsite
January 6, 2004	Framing training for volunteers and project managers, CARB onsite
March 26, 2004	Assembly of Unit #1 and #2 roofs, CARB Staff Volunteer Day
April 1, 2004	Setting of the roofs, CARB onsite
June 29, 2004	NYES insulation inspection, CARB onsite
October 16, 2004	Unit #1 Dedication Ceremony
December 14, 2004	Gas meters set in Units #1 and #2
December 16, 2004	Final performance testing of Units #1 and #2 by CARB
January 28, 2005	Final performance testing of Units #3 and #4 by CARB
January 28, 2005	Re-testing of combustion equipment in Units #1 and #2 by CARB
February 8, 2005	ENERGY STAR certificates issued for Units #1 through #4
May 28, 2005	Roof installed on Unit #6 by volunteers
June 2, 2005	Tentative ENERGY STAR insulation inspection for Unit #5 by CARB
Late July 2005	Expected completion date for Unit #5
Late August 2005	Expected completion date for Unit #6
July 30, 2005	Dedication event for Unit #5 and possibly Unit #6

Figure 1. Liberty Street row houses

Standard Practice Home

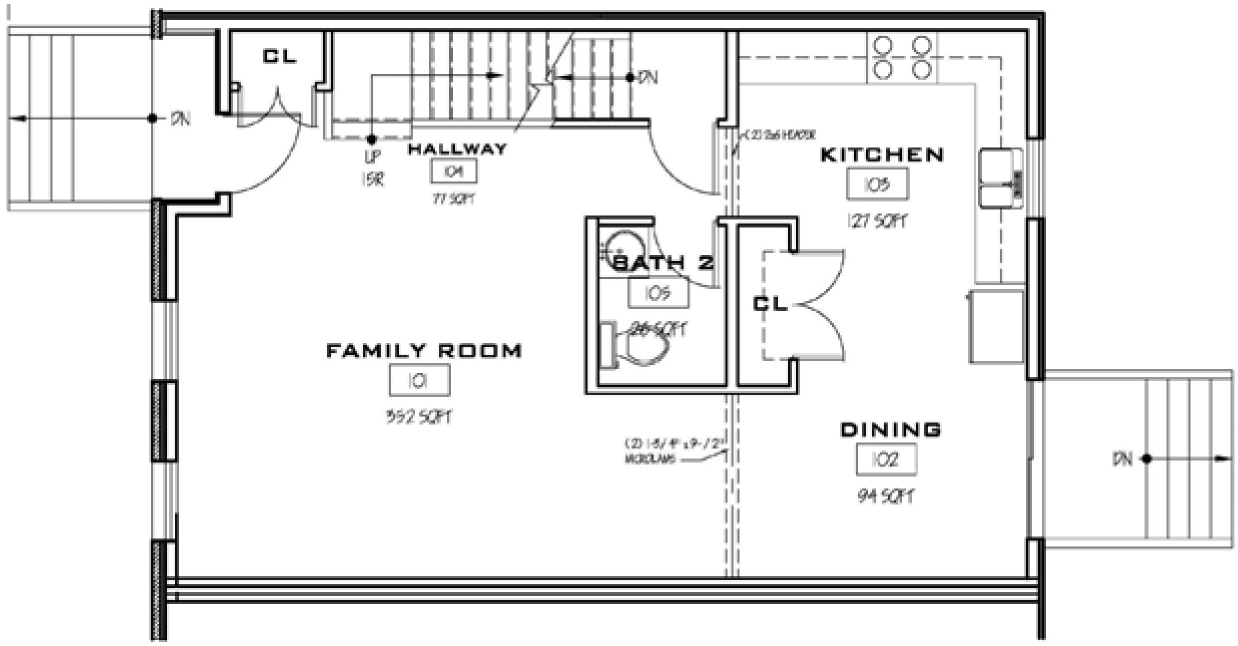
The first step was a review of HfHGN's proposed building specifications, as summarized below.

Wall Construction:	Exterior walls - 2x6 studs at 16 in. on-center with R-19 cavity insulation
	Interior walls - 2x4 studs at 16 in. on-center
Roof Construction:	Wood trusses with R-30 attic insulation
Foundation Walls:	R-5 insulation required by code
Windows:	Double-pane, clear, wood frame in front and vinyl frame in back
Mechanical Equipment:	80% AFUE boiler serving baseboard heating
	Atmospheric hot-water storage tank
	Window air-conditioning units (A/C not provided by HfH)
	Conventional, manually switched bath fans

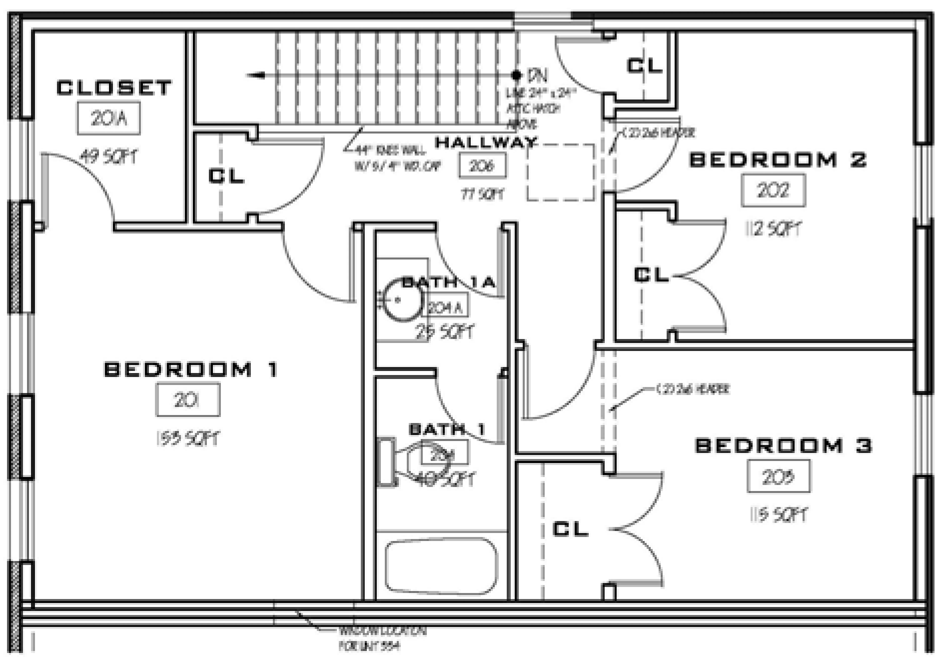
Prototype Home

As part of their commitment to the program, HfHGN agreed to work with CARB to target a 40% total energy reduction for their first new construction project. This target included space conditioning, hot-water heating, lighting, and electrical use. When complete, the Liberty Street site will contain six new single-family row homes. Through HfHGN's fund-raising efforts, the homes were constructed in sets of two. The construction of four of the six units has already been completed, and the homes are occupied. Units #5 and #6 are nearing completion and expected to be ready for occupancy by late August 2005. CARB will perform the final ENERGY STAR testing.

Each of the row houses is two stories tall and has three bedrooms. Including the full-conditioned basement, each unit provides approximately 2,000 ft^2 of living space. The floor plans in Figure 2 differ slightly from the original design. A powder room was added to the first floor, and the master bath was removed.



1st Floor Plan



2nd Floor Plan

Figure 2. Final floor plans for the Habitat for Humanity row houses on Liberty Street

CARB Recommendations

After reviewing HfHGN's standard building specifications, CARB recommended a list of improvements for a "whole building systems" approach to design. During a design meeting held on August 6, 2003, each of these recommendations was presented to the architectural design team for HfHGN. Based on the discussions that arose during that meeting, CARB gave a full presentation to the HfHGN Board of Directors on August 21, 2003. At that time, each of the following recommendations was presented for the board to evaluate. Because HfH is a democratic organization, the building committee had to vote on these recommendations before the final specifications could be determined. CARB's recommendations included the following:

- Panelized Construction
- Architectural Redesign
    - Structural and Fire Concerns
    - Integration of the Mechanical System
- Optimal Value Engineered Framing
- New York ENERGY STAR Labeled Homes Program Certification
- Low-e Windows
- Insulation Details
    - Basement Walls
    - Above-Grade Walls
- Mechanical Equipment Upgrades
- Mechanical Ventilation
- Lighting and Appliance Package.

Panelized Construction

To simplify and accelerate the construction process, CARB offered to help HfHGN panelize the Liberty Street Row Houses (Figure 3). With minimal design changes, the framing plan was divided into sections that could be pre-assembled into panels. Each panel would be approximately 12 feet long and was designed to be lightweight. To reduce the weight of the panels, CARB proposed 2x4 framing and advanced framing techniques.

For this particular project, panelization offered many advantages. The panels could be pre-assembled, delivered to the site, and quickly erected using a crane. This approach is volunteer-friendly and expedites construction. Given the site location, panelizing the row houses would reduce the risk of theft and vandalism. The photo in Figure 3 shows the assembly of panelized townhouses that CARB developed with Ryan Homes in Maryland.

Despite the many advantages of panelization, HfHGN opted to stick frame the houses. Primarily, the organization was concerned about erecting the homes "too quickly." After raising community awareness and construction funding, HfHGN wanted a project that the public could see in development and be able to track the ongoing progress. CARB was concerned about

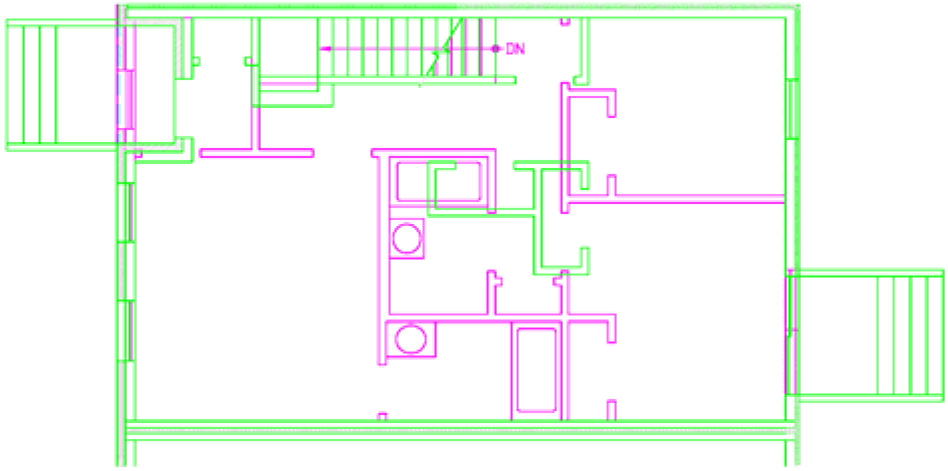
Figure 3. CARB panelized townhouses Ryan Homes, Frederick, Maryland

volunteer safety and believed the project would still take time, even with panelization. HfHGN could not be convinced to reconsider panelization as a safer option for unskilled labor. Unfortunately, one volunteer was injured during the framing of the first unit, when he fell from the second floor. There is a learning curve for construction teams more familiar with rehab construction, in which the structural shell is already complete.

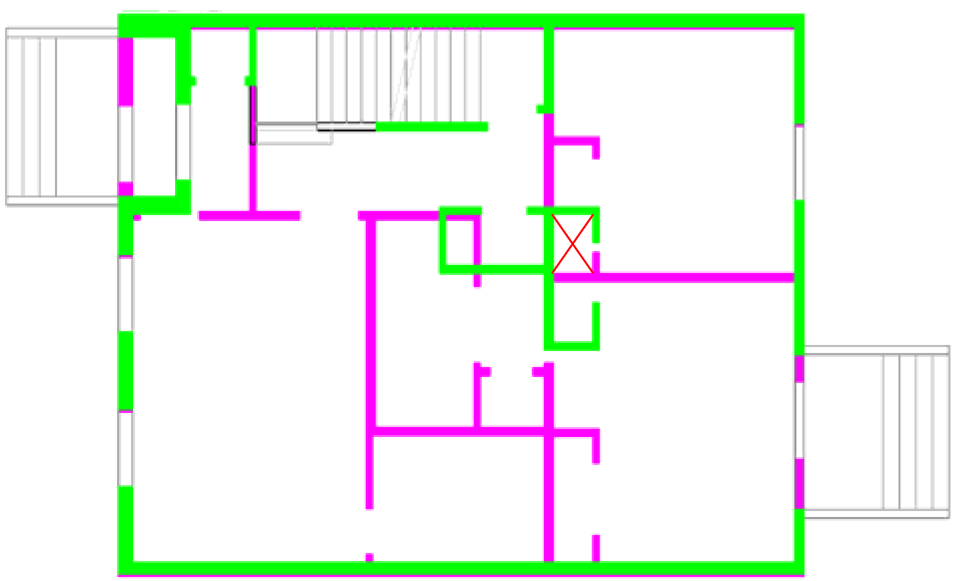
Architectural Redesign

An architectural review of the row houses was performed to rationalize the floor plan for advanced framing and to maximize the use of the space. Initially, HfHGN agreed to panelize the homes, and CARB re-designed the plan around this concept. In addition to panelizing the framing, the key components of the architectural review included structural/fire concerns and the integration of mechanical ductwork (Figure 4).

In the revised plans (Figure 4), the walls were shifted to provide a load-bearing wall between the kitchen and the living space. The bedroom walls above were aligned with this wall to create a continuous load path. Unlike the original design (top, Figure 4), which utilized all four exterior walls to carry the load, only the two end walls became load bearing. This provided separation for the structural and fire concerns, creating a safer home. In the event of fire, the structural integrity of the home is not threatened. By aligning this wall and shifting some doorways and closets, accommodations could be made for a central chase to run ductwork for the mechanical system (shown with a red X). During the preliminary design phase, HfHGN was considering heating the home with a forced-air system.



Overlay – First and second floor of original HfH design



Overlay – First and Second Floor, as proposed by SWA

Figure 4. Comparison of floor plans by HfH (top) and SWA (bottom)

Optimal Value Engineered Framing

Habitat's proposed construction for the exterior walls included 2x6 studs at 16-in. on-center with R-19 cavity insulation. To keep the panels lightweight, CARB recommended 2x4 studs at 24-in. on-center with R-15 cavity insulation, using 2x6 walls in structural locations. However, when HfHGN reversed their decision to panelize the homes, CARB revised the drawings for 2x6 wall construction.

CARB also provided framing drawings to help HfHGN implement optimal value engineered (OVE) framing techniques. These include inlined 2x6 studs at 24-in. on-center, OSB sheathing on the exterior, insulated headers, and two stud corners with drywall clips (Figures 5 and 6).

These advanced framing techniques have been in use for more than 20 years and have a proven track record of cost savings. CARB worked with the HfHGN construction managers to help them understand the concepts and benefits of this type of framing.

HfHGN chose to build the units two at a time, as funding allowed. Although the homes were not truly panelized, CARB did recommend that HfHGN implement some panelization concepts into the construction process (Figures 7, 8, 9, and 10). HfHGN accepted the proposed panelized approach for building and setting the roofs for all six homes.

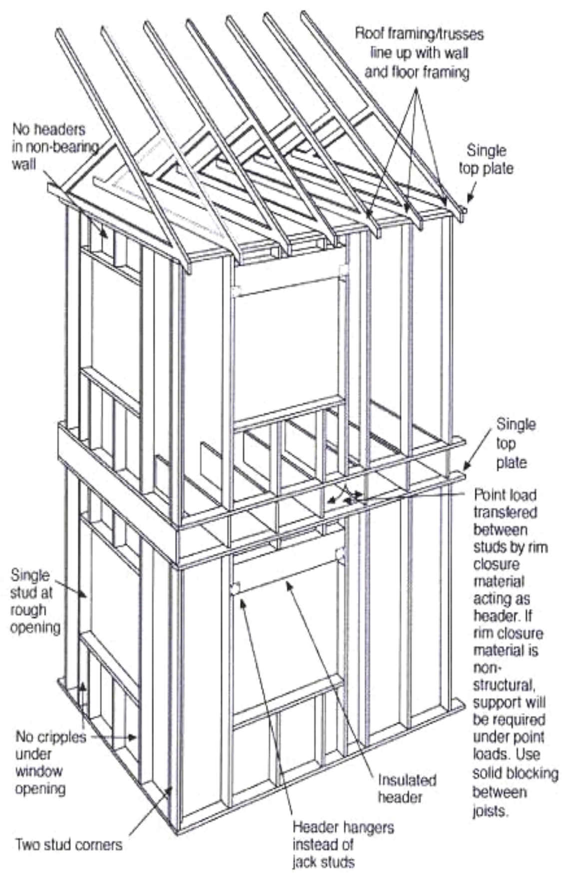
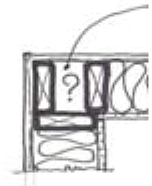


Figure 5. OVE framing techniques

Improved three-stud corner allows insulation to be installed later



Conventional three-stud corner leaves uninsulated hole

Two-stud corner with drywall clips

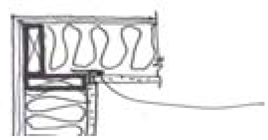


Figure 6. Corner framing options

Because safety was a major concern, CARB recommended that the roofs be built on the deck level and lifted into place with a crane. As shown in the following photos, decking for the first five units was completed first. Next, the exterior walls for Units #1 and #2 were erected. Then, using the decks for Units #3 and #4, the roof trusses were laid out and covered with OSB sheathing and tarpaper. Additional bracing was added to keep each roof square while it was transported. Each of the roof systems was then lifted into place with a crane and attached to the wall systems. Finally, the shingles were added and the roofs were watertight.

Building the roofs at the deck level had a number of advantages. Like panelized walls, the process was simple and quick to erect. It was also safer, eliminating the need for unskilled volunteers to work on scaffolding or a sloped roof. HfHGN was concerned about the cost of renting a crane for this task. Luckily, a local company donated the crane time for this project.

Figure 7. Building each roof on the deck of the next unit

Figure 8. Two roofs with sheathing and tarpaper — ready for the crane

Figure 9. Lifting the roofs into position

Figure 10. First two roofs in place

New York ENERGY STAR® Labeled Home Program Certification

Because HfHGN is a nonprofit organization, keeping the first-cost low was a key part of this project. However, HfHGN recognizes that increasing the efficiency of their homes results in a reduction in the operating costs, making it more affordable for the low-income families that will take ownership of the homes. To offset some of the initial cost increases associated with upgrading the windows and mechanical equipment, SWA recommended that HfHGN pursue certification from the New York ENERGY STAR Labeled Homes Program (NYES). In 2004, the program offered an $850 incentive to the builder.

The NYES Program is based on the national ENERGY STAR Homes Program, sponsored by the Environmental Protection Agency (EPA) and the Department of Energy (DOE). The program is administered by the New York State Energy Research and Development Authority (NYSERDA) and is paid for by a System Benefits Charge on the electricity transmitted and distributed by the state's utilities.

ENERGY STAR homes are nationally recognized for saving 30% or more on home energy costs for space conditioning and hot water. These homes feature the best building practices and technologies for higher energy efficiency. Certified homes must meet the guidelines set forth by the EPA, which require a Home Energy Rating Score (HERS) of 86.0 or greater. In addition, the 2004 NYES program required 450 kWh of electric savings from lights/appliances; a ventilation system and control; and no atmospheric combustion equipment, unless a worst-case depressurization test was performed. At the completion of the project, testing was done to verify compliance with the program requirements.

Low-e Windows

To improve energy performance and meet the NYES program requirements, low-e windows were specified (Figure 11). As discussed in the standard specifications, double-pane windows are typically installed. Because the project is in a historic district, the windows on the front façade facing the street must have wood frames and be approved by the historical preservation committee. Vinyl frames are permitted for the remaining three sides of the building, which are less visible. In the front, HfHGN installed double-pane, wood frame, low-e, argon-filled windows with a U-value = 0.36 and a Solar Heat Gain Coefficient (SHGC) = 0.28. The remaining walls had vinyl windows with a U = 0.33 and SHGC = 0.46.

Figure 11. Window installed and flashed

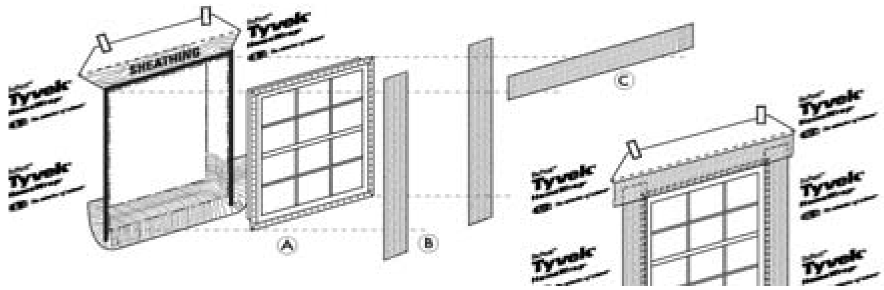


Figure 12. Detail of housewrap around windows

CARB also made recommendations for flashing the windows. HfHGN covered the homes with housewrap to provide a drainage plane. As a best practice, CARB recommended the flashing approach specified by one housewrap manufacturer, which prevents moisture intrusion by shingling. As shown in the manufacturer's detail in Figure 12, butyl tape is applied to the bottom of the window opening, the window is installed, the sides are sealed with butyl tape, the house wrap is folded over the top of the window and secured in place. This creates a weather-resistive barrier.

Insulation Details

Through national partnerships with manufacturers, HfHGN is eligible to receive some materials for free or at discounted rates. A partner since 1987, the Dow Chemical Company supplies Habitat affiliates throughout the country with free Dow Styrofoam Brand insulation products. To take advantage of these free materials, CARB developed wall and ceiling insulation details for both retrofit and new construction applications that use rigid extruded polystyrene board.

Foundation Insulation

For the Liberty Street row houses, CARB recommended the basement walls be insulated with 2 in. of rigid insulation, to provide a total insulating value of R-10. Furring strips (1-in. x 4-in.) were used to hold the insulation in place and provide a nailing surface for the sheetrock installation (Figure 13). Rigid insulation was also cut to fit in the band joist at the top of the foundation and sealed with foam (Figure 14). Drywall was then applied over the rigid insulation to meet fire code requirements. Habitat also receives drywall for free.

Figure 13. Foundation insulation with furring strips

Figure 14. Band joist insulation cut to fit and sealed with foam

Above-Grade Wall Insulation

A similar approach was used to insulate the above-grade walls. CARB recommended 4 in. of rigid insulation, for a total insulating value of R-20. In 2x6 construction, the stud cavity is 5-½ in. deep. With 4 in. of insulation, this leaves a 1-½ in. space for electrical wiring and boxes. As shown in Figures 15 and 16, volunteers cut two layers of 2-in. insulation to fit in each stud cavity.

In conjunction with each of these insulation strategies, CARB continued to emphasize the importance of tightly air sealing the homes. HfHGN was introduced to air-sealing practices in the rehab projects. After cutting each piece of rigid insulation to fit, the volunteers then sealed the perimeter of the piece with foam to reduce air infiltration.

The same method used in the rim joist was used to insulate the band joist. Although this method is cost-effective for HfHGN because both labor and materials are free, R-19 fiberglass batts were used in the next two houses to accelerate the project schedule. As seen in Figures 15 and 16, the HfHGN project managers added bracing to the walls. Although advanced framing methods have been proven time and again, old habits are hard to change.

Attic Insulation

For the attic, CARB recommended either R-38 batt insulation, blown-in insulation (Figure 17), or a similar detail using layers of rigid insulation to obtain an equivalent R-value. HfHGN has installed rigid insulation in the attics of their rehab homes, as part of the Building America retrofit program. However, to simplify the new construction project, they chose to use blown-in cellulose insulation in the attics of these homes.

Figure 15. Volunteers cut insulation to fit in above-grade walls

Figure 16. Finished wall with foam around each piece

Figure 17. Blown-in cellulose insulation

Figure 18. Programmable thermostat

Figure 19. Installed combination boiler

Mechanical Equipment Upgrades

CARB provided HfHGN with recommendations for a number of alternative heating and cooling systems. Each recommendation was based on achieving a minimum HERS rating of 89. It is not Habitat for Humanity's policy to include air conditioning in their low-income projects. However, with a desire to increase the future resale value of the row houses, HfHGN asked CARB to consider central air conditioning as part of the recommendations. To meet that request, CARB integrated a central duct chase into the floor plans and provided three recommendations for space conditioning and water-heating equipment.

The first option utilized a power-vented combination hot-water heater and boiler with a hydro-air system. Similarly, Option 2 combined a direct-vent combination water heater and boiler with a hydro-air system. Either of the first two options required the installation of ductwork and would have enabled the homeowner to add central air conditioning at a later date. The third option that was presented utilized the same direct-vent combination boiler and hot-water heater recommended in Option 2 in conjunction with hydronic baseboard, which is standard practice for HfHGN. Because a hydro-air system is less efficient than hydronic baseboard heating and HfHGN did not plan to install the air conditioning equipment, CARB recommended Option 3.

HfHGN selected Option 3 and planned to install the modulating gas-fired combination boiler/hotwater heater that CARB had specified. HfHGN was already familiar with this equipment because it had been successfully installed in previous CARB rehab prototype homes. The specified unit has an efficiency rating of 85% AFUE, is a direct-vent appliance, and contains an automatic burner that can modulate from 57% to full fire.

In addition, the recommended model includes a 20-gallon domestic hot-water storage tank. After the tank is depleted, instantaneous domestic hot water is provided by a heat exchanger with a Recovery Rate of 4 gpm. The installation of a direct-vent boiler ensured that the criteria for combustion equipment under the NYES Program were met. CARB also specified programmable thermostats for the homes. Each floor included a 7-day programmable thermostat (Figure 18).

After further discussing equipment alternatives with their plumber, HfHGN asked CARB if they could substitute a different combination boiler for that which CARB had recommended (Figure 19). After reviewing the equipment specifications, CARB agreed.

The alternative unit is a wall-hung, dual-purpose, hydronic heating system, providing both heat and hot water. The model HfHGN proposed has an efficiency rating of 90% AFUE, is sealed combustion, and has a modulating blower assembly. The intake fan assembly modulates to provide the correct airflow for combustion. Domestic hot water is provided on demand using a heat exchanger. Unlike the unit initially proposed, the alternative equipment does not include a storage tank for the domestic hot water. Controls internal to the unit give domestic hot water priority over heating.

HfHGN debated about which type of unit to install in these homes. Although they were pleased with the performance of the combination units that had been installed in a number of rehab projects, the local distributor was offering HfHGN a significantly discounted price on the alternative unit. However, the plumber had some concerns about the availability of parts and installation requirements. HfHGN opted to install the newer unit in all six homes (Figure 19).

Although supportive of the decision to install equipment with a greater efficiency rating, CARB was disappointed in the behavior of the installed units during final testing. In the first four homes, the boilers were not performing properly. There were both combustion and comfort issues with the units.

Outside of Unit #1, the smell of gas was strong, and the blower fan was not modulating correctly. CARB tested the products of combustion being exhausted from each of the homes. In Unit #1, 44 parts per million (ppm) of CO were measured. When compared to Unit #2, which measured 1430 ppm, it was evident that gas was being exhausted from the unit before it could be combusted. CARB immediately recommended that the plumber return to rectify the situation.

Although the boiler in Unit #2 did not display combustion problems, it did not react properly to a call for heat. Even when the thermostat setpoint was not met, the unit would stop firing. Similar comfort problems arose in all four units, and CARB encouraged HfHGN to work with the plumber, the distributor, and the manufacturer to resolve the problems.

CARB returned to Liberty Street a second time to re-test the combustion of the boilers in Units #1 and #2, as well as perform the final testing for Units #3 and #4. During that visit, all the boilers passed the combustion tests, and CARB was able to issue the ENERGY STAR certification. However, HfHGN continued to investigate the comfort complaints.

Ultimately, the boiler issues at Liberty Street were resolved enough to satisfy the new occupants. CARB believes the problems were largely a result of inexperience and lack of oversight. After numerous calls, the boiler manufacturer sent a technical representative to the sight to investigate the problem. Unfortunately, each of the boilers in the four units was installed in a slightly different manner and by a number of different plumbers. As is often the case with new products, there was only one local plumber familiar with the installation of this unit. He, unfortunately, did not install the first two units. Along with the manufacturer's representative, this plumber did eventually help to identify and rectify the installation problems.

The primary problem was associated with the internal low water cut-off switch. Concerned about meeting the building code requirements, some of the plumbers who installed these units added an external low-water cut-off switch. The code requires the low-water cut-off, and the plumbers were adamant that the code inspectors would not pass the homes without one. Because the unit already included the switch internally, the two controls competed with one another and problems arose. Other minor issues, related to parts failure, also occurred and the distributor provided replacement components for the systems.

Unfortunately, the project managers at HfHGN have decided to discontinue the use of this boiler for future projects. Although CARB can understand their frustration, it seems that proper training and coordination could have eliminated many of these problems. CARB would not discourage the use of this equipment. However, CARB would highly recommend a properly trained plumber and technical assistance from the manufacturer.

Mechanical Ventilation

CARB recommended improvements to HfHGN's standard practice for bathroom ventilation. The inexpensive bath fans that are typically installed tend to be noisy and are seldom operated for sufficient periods of time. Instead, CARB specified an upgraded bath fan rated for continuous operation, quiet performance, and improved energy-efficiency. This fan was installed with controls to ensure extended run time.

As part of the NYES program, a mechanical ventilation system must be provided for the home that is capable of delivering a continuous airflow equal to 15 cubic feet per minute (cfm) per house, plus an additional 15 cfm for each bedroom. CARB recommended a ventilation system capable of complying with the guidelines set forth by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in *Standard 62.2, Ventilation and Acceptable Indoor Air Quality in Low-rise Residential Buildings*.

Through a partnership with Energy Federation, Inc., (EFI) HfHGN receives special pricing on upgraded bath fans. CARB recommended a fan/light combination for the bathroom (Figure 20). This model provides 75 cfm at a pressure drop of 0.25 in. wg, with a sound rating of less than 0.7 Sones. CARB also recommended that this fan be controlled by a wall timer switch (Figure 20). This timer switch was mounted to a standard single-gang electrical box in the bathroom to provide automatic control of the bath fan. It was set to run the fan for 20-minute intervals throughout the day. This is a simple, low-cost way to ensure that the bathroom fan operates for long enough periods to adequately remove moisture and provide fresh air for the home. HfHGN installed the timer in the bathroom in Unit #1. CARB recommended that for future units the timer be installed in a closet, to reduce homeowner interference.

Lighting and Appliance Package

As part of the NYES program, HfHGN was required to demonstrate a 450-kWh reduction in the electricity use of lighting and appliances. Through a national partnership with Habitat for Humanity International, the Whirlpool Corporation donates a free ENERGY STAR® refrigerator to all new and rehabbed Habitat houses in the United States and Canada. To reach the Building America goals, CARB also specified that fluorescent lamps or fixtures be installed to provide 100% of the lighting in the home.

Figure 20. Recommended bath fan (left) and timer control (right)

CARB performed a thorough lighting audit and confirmed that all the lighting in the home had been fitted with appropriate bulbs.   As shown in Figures 21-23, HfHGN went to great efforts to find compact fluorescent bulbs that would work in the fixtures that they typically install. The first photo shows a chandelier that was donated for the home, retrofitted with two 15-Watt screw-in fluorescent bulbs (Figure 21). In the center is an example of a typical bedroom fixture, which uses two 13-Watt pin-type compact fluorescent bulbs (Figure 22). HfHGN wanted to install a strip-lighting fixture in each bathroom (Figure 23). CARB encouraged them to find more efficient bulbs that would screw into a standard fixture. This option, which uses four 14-Watt bulbs, was less expensive than purchasing a pin-type fixture. This same fixture with four 60-Watt bulbs would use 240 Watts, the fluorescent bulbs reduce the electrical use by 184 Watts.

Figure 21. Chandelier with two 15-Watt CFLs

Figure 22. Pin-type dome light

Figure 23. Strip light with CFLs

Energy Modeling

These homes were one of the first CARB projects designed to achieve the Building America Program goal of 40% total energy savings, as compared to the "Building America Research Benchmark Definition." However, during the Liberty Street design development phase in early 2003, the Building America Benchmark was still being refined. CARB based the project recommendations on modeling with REM/Rate software and a draft of the Benchmark issued on April 11, 2003 (Version 1).

With a loosely defined Benchmark and a need to get a commitment from potential builder partners for the upcoming year, CARB asked HfHGN to target a goal of 40% better than the Model Energy Code (MEC) or an equivalent HERS score of 89. In addition, CARB outlined requirements for reducing the electrical loads in the house, which included 100% compact fluorescent lighting and ENERGY STAR-rated appliances. Because no cooling was provided for the home, higher SEER air conditioning was not recommended.

As development of the Benchmark progressed, CARB developed an energy model for the prototype using EnergyGauge USA 2.3 software. The energy performance of the home was modeled and compared to the "Building America Research Benchmark Definition version 3.1." An updated summary of the EnergyGauge results is included in Appendix A: Energy Modeling.

The energy modeling results shown are for a Liberty Street row house end unit, specifically Unit #1. Based on the proposed specifications, the prototype will have an estimated 24% total energy reduction compared to the Benchmark and use 27% less energy than HfHGN Standard Practice. The combination boiler system will reduce the hot water energy use by a projected 39% and the heating energy use by 21%, when compared to the Benchmark. Installing compact fluorescent light bulbs in 100% of the fixtures will decrease the lighting electrical use by 64%.

For the hourly energy analysis, the EnergyGauge version 2.3 simulation tool was used. There are several limitations to this software when dealing with attached homes. The primary issue arises when trying to deal with party walls in the Building America Benchmark home. Because solar neutrality is desired, the window glazing needs to be evenly distributed to all sides of the house, including the party wall(s). If solar neutrality is not considered, the party wall can simply be omitted from the EnergyGauge model because DOE 2.1e does not require that the geometry of the building being modeled to be closed. But to have solar neutrality, a window needs to be inputted on the party wall, and DOE 2.1e will not permit a window to float in space without a wall assignment.

For this reason, the party wall in all three models (Benchmark, Builder, and Prototype) is modeled as a low mass, high R-value wall. This is done to simulate an adiabatic wall to which window area can be assigned for the Benchmark house. The U-value and solar heat gain of the window is inputted as specified by the Benchmark definition.

The inclusion of the party wall as an adiabatic surface in the Prototype homes resulted in less than 0.3% increase in the overall source energy total. For the Benchmark, if we compare the adiabatic party wall to the case when the party wall is omitted and the window glazing is divided only between the three exterior wall surfaces, the result is less than a 1.1% increase in the overall source energy total.

Therefore, it is not a large issue but a method should be agreed upon to ensure that all analysts are using the same methodology to model this case. Also, as the party wall is a north-facing wall, the Benchmark specifies that the 40 ft^2 of opaque door area should be placed on this surface. Some of these issues, including the appropriate method for modeling solar neutrality, have been dealt with in the most recent Benchmark definition (12/29/2004).

The HERS ratings provided by EnergyGauge are not accurate when dealing with attached homes. The score is inaccurate because EnergyGauge uses the detached HERS reference home to generate a HERS score. This is not an issue in dealing with the Benchmark analysis, but when discussing with clients and builders the HERS score is the primary market tool used to determine energy efficiency.

CARB provided ENERGY STAR ratings for the first two prototype homes. When modeled separately with REM/Rate software version 11.41, Unit #1 received a HERS of 92.3. Unit #2, which is an interior unit with the same floor plan, received a HERS score of 91.3. These scores far exceed the HERS 86.0 requirement of the NYES program. In terms of HERS scores, each of these homes demonstrates at least 50% energy savings for space heating and hot water over the 1993 Model Energy Code and exceeds the originally proposed target of HERS 89.

Performance Testing

At the completion of the project, CARB returned to Newburgh to evaluate the homes through performance testing. CARB also provided rating for the first two homes under the NYES Program. Because these homes have hydronic heat and no air conditioning, there were no air-handling units or duct systems to test. The testing included the following:

1. Air infiltration measurement using a blower door
2. Bathroom exhaust fan airflow measurements using the balometer
3. Combustion safety testing of all gas appliances
4. Confirmation that all equipment and materials were installed according to the specifications

Air Infiltration

Using a Blower Door, the houses were depressurized to measure the air-infiltration rate. The leakage rate for Unit #1 at 50 Pascals (Pa) was 1017 cfm. The effective leakage area (ELA) for the home was 44.6 $in.^2$ measured at 4 Pa. The natural air-change rate, based on the Sherman-Grimsrud infiltration model, is equivalent to 0.25 ACH_n. Given the skill level and air-sealing experience of the volunteers, this is a relatively good infiltration rate. Although many of CARB's new construction projects have lower leakage, this is a significant accomplishment for a builder primarily involved in rehab construction. A comparison of the blower door tests for both Units #1 and #2 is shown in Table 1.

Bathroom Exhaust Fans

Using a Balometer, each bath fan was tested and the results are summarized in Table 2. One upgraded bath fan was installed in the main bath of each home. This fan is controlled by a pin timer. The powder rooms have "contractor-grade" fans rated for 50 cfm. Each of the upgraded

Table 2. Blower Door Summary

House	CFM_{50}	ELA	ACH_n
Unit #1	1017	44.6	0.25
Unit #2	1450	70.3	0.36

Table 3. Bath Fan Performance

Location	Manufacturer	Model	Rated* CFM	Measured CFM
Unit #1, Main Bath	Panasonic	FV-08VQL3	76	67
Unit #1, Powder Room	Marley	A664IC	50	26
Unit #2, Main Bath	Panasonic	FV-08VQL3	76	71
Unit #2, Powder Room	Marley	A664IC	50	28

* Rating based on a static pressure of 0.25 inches.

fans performed well. To achieve proper airflow, CARB suggested that HfHGN transition from the 4-in. fan outlet to a 6-in. flex duct.

Combustion Safety Testing

As discussed previously, CARB tested the combustion safety of each gas appliance in the home. The NYES Program requires that each appliance be tested according to the test procedure established by the Building Performance Institute. The tests revealed no problems with combustion gases impacting the interior of the home. However, CARB observed that neither of the combination appliances providing heating and hot water for the first two homes was working properly. Combustion testing equipment was used to verify this concern, and CARB requested that the plumber be contacted immediately. While testing the gas oven in Unit #2, CARB also found that control knob was faulty, and the unit would not shut off. After CARB managed to turn the oven off, HfHGN was informed of the problem, and a new stove was installed the next day.

Design versus Installed Specifications

During the final performance testing, CARB performed a walk-through of the home to verify that all equipment and materials had been installed according to the design specifications. In some cases, such as wall insulation and framing, inspections are performed during construction. The key goals of the final inspection were verification of low-e windows, confirmation of all wall and ceiling insulation levels, documentation of the make and model numbers of all mechanical equipment, activation of the mechanical ventilation system, and performance of a detailed lighting and appliance audit.

CARB was pleased to find that all the windows in the prototypes were low e. The wall insulation and framing had been inspected prior to sheetrock. However, CARB was able to verify that the rigid insulation in the basement rim band had been cut-to-fit and sealed properly. Cellulose insulation was blown into each attic. CARB verified that the depth and quality of this installation were adequate to meet the design specifications. CARB also documented the change in boiler specifications and encouraged HfHGN to contact the installer and manufacturer to rectify the problems, as discussed earlier in this report.

After measuring the bath fan performance, CARB calculated the fan run-time necessary to meet the ventilation guidelines set forth in ASHRAE Standard 62.2. Based on these calculations, CARB set the pin timer to automatically turn the fan on for 20 minutes per hour. In the first two units, the timer control had been installed in the bathroom next to the light switch. CARB requested that the timer be remote-wired to a nearby closet for the remaining four units. This minimizes concerns that the timer will be reset or disabled by the occupants accidentally.

Last, CARB performed a detailed lighting and appliance audit. HfHGN had gone to great lengths to find appropriate lamps and fixtures that were energy-efficient. In most cases, HfHGN incorporated compact fluorescent bulbs into their standard fixtures. However, a number of pin-type fixtures were also installed to meet the NYES Program requirements. Each home included an ENERGY STAR-rated refrigerator and a gas range. CARB verified that the range had been properly vented to the outside.

Cost Estimates

During the initial project planning stage, HfHGN had their architectural intern investigate the costs of incorporating CARB's recommendations. Table 3 shows the original breakdown of the cost impacts for an individual row house unit. These estimates were based on CARB's initial recommendations, which included the following: panelizing the walls, utilizing open-web trusses to simplify duct coordination, and installing a high efficiency boiler. Although many of the items specified in Table 4 were ultimately not incorporated, this cost information helped HfHGN understand the cost trade-offs and weigh the benefits of upgrading the energy performance of their homes. Unfortunately, as a result of staffing changes, HfHGN was not able to provide CARB with final cost information based on the final building specifications.

Table 4. Cost Estimates for CARB Recommendations for an Individual Row House Unit Control

Recommendation	Unit	Standard Unit Price	Upgrade Unit Price	Incremental Unit Price	Incremental Cost
Panelized Construction					
-Exterior Walls	1,332 ft2	$6.00	$4.50	-$1.50	-$1,998.00
-Party Walls	528 ft2	$6.00	$4.50	-$1.50	-$792.00
Architectural Redesign					
-Structural/Fire Redesign	528 ft2	$6.00	$5.25	-$0.75	-$396.00
-Integration of Mechanicals (TJI instead of Floor trusses)	936 lf	$1.65	$2.29	$0.64	$599.04
Optimal Value Engineered Framing					
-Materials	1 House	$10,990.00	$8,455.00	-$2,535.00	-$2,535.00
Low e Windows					
-Upgrade from clear glass to Low e	153 ft2			$1.25	$191.25
Basement Insulation					
-Rigid Insulation (R-10) interior and drywall(1)	666 ft2	$0.00	$1.68	$1.68	$1,118.88
Increase Ceiling Insulation					
-Increase from R-30 to R-38	677 ft2	$0.28	$0.32	$0.04	$27.06
Mechanical Equipment Upgrade					
-Install a High Efficiency Boiler (85.5% AFUE)	1 Vent	$300.00	$500.00	$200.00	$200.00
Mechanical Ventilation					
-Panasonic Low Sone Bath Fan	1 Fan	$38.00	$90.00	$52.00	$52.00
-Grasslin KM-2 In Wall Timer Switch	1 Control	$0.00	$38.00	$38.00	$38.00
Lighting and Appliance Package					
-Replace Incandescent Fixtures with CFL Fixtures	4 Fixtures	$28.00	$40.00	$12.00	$48.00
-Energy Star Refrigerator(2)	1 Fridge	$0.00	$0.00	$0.00	$0.00
				Total Incremental Cost per Row House =	**-$3,446.77**

Notes:

1.) This estimate is based on the cost of rigid insulation and drywall. However, HfHGN recieves these materials for free.

2.) Through a national partnership, Habitat for Humanity recieves a free Energy Star Refrigerator from Whirlpool Corporation for each of their homes.

Appendix A: Energy Modeling

Table 5. Building America Benchmark / Builder / Prototype Specifications

Building America Benchmark/Builder/Prototype Specifications

Project name: HfH of Greater Newburgh
Model name: Liberty Street Row Houses - Unit #1
Location: Newburgh, NY

General Description	
Area of living space = 1,353 ft^2	Floors above grade = 2
Glazing Area = 178 ft^2	Attached Garage = N/A
Conditioned Basement Area = 677 ft^2	TMY site: Albany, NY

Side-by-Side Study of Homes
Specifications of Standard and Energy Construction

Characteristic	Benchmark Home	Builder Home	Prototype Home
Foundation Construction	full basement - concrete	full basement - concrete	full basement - concrete
Foundation Insulation	U-0.099	R-11 batts	2" Dow Blue Board on walls (R-10)
Framed Floor Construction	9 1/2" I-joist @ 16" o.c.	9 1/2" I-joist @ 16" o.c.	9 1/2" I-joist @ 16" o.c.
Framed Floor Assembly	--	--	--
Wall Construction: 1st Floor	2x4 wood framing - 16" o.c.	2x6 wood framing - 24" o.c.	2x6 wood framing - 24" o.c.
Wall Assembly: 1st Floor	U-0.085	R-19 batt insulation	R-20 rigid (4") insulation
Wall Construction: 2nd Floor	2x4 wood framing - 16" o.c.	2x6 wood framing - 24" o.c.	2x6 wood framing - 24" o.c.
Wall Assembly: 2nd Floor	U-0.085	R-19 batt insulation	R-20 rigid (4") insulation
Garage Interior Wall Const.	2x4 wood framing - 16" o.c.	2x6 wood framing - 24" o.c.	2x6 wood framing - 24" o.c.
Garage Interior Wall Assembly	U-0.085	R-19 batt insulation	R-20 rigid (4") insulation
Ceiling/Roof Construction	pre-engineered wood trusses @ 24" o.c.	pre-engineered wood trusses @ 24" o.c.	"raised heel" energy wood trusses @ 24" o.c.
Ceiling Assembly	U-0.031	R-30 insulation	R-38 insulation
Window Type	benchmark	vinyl double	vinyl double low-e
Window U-Value	0.45	0.49	0.36
Window SHGC	0.58	0.58	0.28
Interior Shading	interior shading multiplier = 0.7 in cooling season and 0.85 in heating season	--	--
Doors	U-0.20	U-0.40	U-0.40
Infiltration	ELA 104.8 in^2 (0.528 natural ACH)	0.4 natural ACH	1,017 cfm_{50} (0.202 natural ACH)
Heating System	NG Boiler 80 AFUE	NG Boiler 80 AFUE	QuietSide Boiler 90.0 AFUE
Cooling System	Air Conditioner SEER 10	Air Conditioner * SEER 10 *	Air Conditioner * SEER 10 *
Water Heater	NG Water Heater EF 0.54	NG Water Heater EF 0.56	QuietSide Boiler EF 0.90
HW Tank Size	40 gals	40 gals	20 gal/instant. RR = 4 gpm
Water Heater Location	basement	basement	basement
Duct R-value	R-3.3	R-3.3 *	R-3.3 *
Supply Duct Area	406 ft^2	406 ft^{2} *	406 ft^{2} *
Return Duct Area	162.4 ft^2	162.4 ft^{2} *	162.4 ft^{2} *
Supply Duct Location	65% basement or unconditioned	100% interior *	100% interior *
Return Duct Location	100% basement or unconditioned	100% interior *	100% interior *
AHU Location	basement	basement *	basement *
Duct Leakage to Outside	10%	10% *	10% *
Leakage Fraction	return:30%/AHU:5%	return:30%/AHU:5% *	return:30%/AHU:5% *
mechanical ventilation	(ventilation fan energy only)	exhaust only	exhaust only
	--	67 cfm / 19.4 Watts / 33% run-time	67 cfm / 19.4 Watts / 33% run-time
Temperature	cooling: 78°F	cooling: 78°F	cooling: 78°F
	heating: 68°F	heating: 68°F	heating: 68°F
Lighting	10% fluorescents (100 W / 30 W)	10% fluorescents (100 W / 30 W)	100% fluorescents (60 W / 15 W)
Energy Star Appliances	--	--	refrigerator

Benchmark version: Building America Benchmark Definition version 3.1
Software version: Energy Gauge USA - USResRatePro - version 2.3

** no cooling system, inputted solely for comparison to the BA Benchmark*

Builder: **HfH of Greater Newburgh**
Model: **Liberty Street Row Houses - Unit #1**
Location: **Newburgh, NY**

Table 6. Summary of Energy Consumption by End-Use

	Annual Site Energy						Annual Site Cost		
	Benchmark		Builder		Prototype		Benchmark	Builder	Prototype
End-Use	kWh	Therms	kWh	Therms	kWh	Therms	$	$	$
Space Heating	114	414	138	502	101	328	$ 408	$ 495	$ 325
Space Cooling	971	0	1052	0	741	0	$ 97	$ 105	$ 74
DHW	0	249	0	245	0	154	$ 239	$ 235	$ 148
Lighting	2329		2329		833		$ 232	$ 232	$ 83
Appliances	2419	0	2419	0	2300	0	$ 240	$ 240	$ 229
Plug Load	3390		3390		3390		$ 337	$ 337	$ 337
OA Ventilation	198		37		36		$ 20	$ 4	$ 4
Total Usage	9421	663	9365	747	7401	482	$ 1,572	$ 1,647	$ 1,198
Site Generation					0				
Net Energy Use	9421	663	9365	747	7401	482	$ 1,572	$ 1,647	$ 1,198

Table 7. Summary of End-Use Source-Energy and Savings

	Annual Source Energy			Source Energy Savings				Component %	
				Percent of End-Use		Percent of Total			
	Benchmark	Builder	Proto	Builder	Prototype	Builder	Prototype	Builder	Prototype
End-Use	MBtu/yr	MBtu/yr	MBtu/yr						
Space Heating	43.5	52.7	34.5	**-21%**	**21%**	**-5%**	**5%**	**116%**	**22%**
Space Cooling	10.5	11.3	8.0	**-8%**	**24%**	**-1%**	**1%**	**11%**	**6%**
DHW	25.4	25.0	15.7	**2%**	**38%**	**0%**	**6%**	**-5%**	**24%**
Lighting	25.1	25.1	9.0	**0%**	**64%**	**0%**	**10%**	**0%**	**40%**
Appliances	26.1	26.1	24.8	**0%**	**5%**	**0%**	**1%**	**0%**	**3%**
Plug Load	36.6	36.6	36.6	**0%**	**0%**	**0%**	**0%**	**0%**	**0%**
OA Ventilation	2.1	0.4	0.4	**81%**	**82%**	**1%**	**1%**	**-22%**	**4%**
Total	169.2	177.2	129.0	**-5%**	**24%**	**-5%**	**24%**	**100%**	**100%**
Site Generation			0.0						
Net Energy Usage	169.2	177.2	129.0	**-5%**	**24%**	**-5%**	**24%**		

Notes: The "Percent of End-Use" columns show how effective each building is in reducing energy use over the Benchmark in each end-use category.
The "Percent of Total" columns show how the energy reductions in each end-use category contribute to the overall savings.

energy costs	$0.0994	/kWh for electricity	Central Hudson Gas & Electric Corp
	$0.96	/therm for natural gas	New York Average

	equipment sizing		
Benchmark	35.0 kBtu/hr for heating		
	17.8 kBtu/hr for sensible cooling	-->	2.5 nominal tons
Builder	38.5 kBtu/hr for heating		
	26.8 kBtu/hr for sensible cooling	-->	3.5 nominal tons
Prototype	29.6 kBtu/hr for heating		
	19.8 kBtu/hr for sensible cooling	-->	2.5 nominal tons

*Sizing of cooling nominal tons is based on a SHR of 0.7, 0.7, 0.7, respectively

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Habitat for Humanity International (HfHI) is a nonprofit organization that engages volunteers and would-be homebuyers in programs that emphasize sweat-equity and self-help. Habitat is among the top-ten housing producers in the United States. In collaboration with the HfHI Department of Construction & Environmental Resources, Steven Winter Associates, Inc., (SWA) began working with the Habitat for Humanity of Greater Newburgh (HfHGN) affiliate in Newburgh, New York, in April 2003. Since October 1999, HfHGN has acquired and renovated abandoned houses for an average cost of $45,000 per home. The affiliate serves area families living in overcrowded, substandard housing and spending 50% to 80% of their income on housing. In August 2003, HfHGN began their first new construction project, six row houses located on Liberty Street in Newburgh.

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