FINAL REPORT FOR PATH FIELD EVALUATION OF RESOURCE & ENERGY EFFICIENT CONSTRUCTION

ARUNDEL HABITAT FOR HUMANITY
ANNAPOLIS, MD

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field evaluation

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The project is part of "The Houses The Senate Built," phase two of the Congressional Builds program, involving members of the U.S. Senate and Habitat for Humanity International. U. S. Senator Barbara Mikulski (D-MD) acted as honorary chairperson for the project, and raised the first wall.

NAHB Research Center staff members Marie Del Bianco and Craig Drumheller facilitated the material integration, energy efficiency analysis, and subsequent performance testing. Pam Eggleston provided report design, layout and formatting.

DISCLAIMER

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Final Report for Field Evaluation of Resource and Energy Efficient Construction

Arundel Habitat for Humanity
Annapolis, MD

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1.0 INTRODUCTION

This project reflected Habitat for Humanity International's (HFHI) Environmental Initiative to promote energy-efficient, environmentally sensitive construction that encourages good stewardship of natural resources, and minimizes the environmental impact of home building. The NAHB Research Center teamed with local affiliate, Arundel Habitat, Partnership for Advancing Technology in Housing (PATH) of the U.S. Department of Housing and Urban Development (HUD), and numerous industry leaders and benefactors, like the Hanley Foundation and Freddie Mac, in the planning and construction of a duplex building in Annapolis, MD.

The builder, Arundel Habitat for Humanity, has worked diligently to save and transform some desirable sites in the heart of Annapolis, Maryland's State Capital, for the working families of the area. This infill construction approach often requires home designs to be customized for each site. Due to this project's strategic location on Clay Street, at the heart of a thriving mixed use downtown area, city requirements for the area separation wall between units and setbacks from adjacent buildings drove this design to a large extent. The parcel's dimensions allowed the siting of a duplex, sized 25' by 42' overall, with 3' side yard setbacks on a narrow, well traveled city street. The overall size of the duplex building then dictated that its bisection into two units with street frontage would result in two long, narrow (less than 13' wide) units.

Project planners were tasked to define materials and practices that were environmentally sensitive, durable, energy efficient, and reproducible, to potentially form the cornerstone for the Habitat affiliate's future ventures. Technologies that were selected for the design were insulating concrete forms (ICFs), engineered wood products matched with optimum value engineering (OVE) practices, and pre-painted fiber-cement shingle and lap sidings. Along with the technologies, planners wanted to employ methods that would make the home ENERGY STAR® qualified, a benchmark that was chosen as a level of energy efficiency that would promote affordability over the long term and benefit the homeowner. Planners and trades people were asked to pay strict attention to sealing the building envelope, designing the ductwork into the conditioned space of the home, and properly sizing and selecting the performance level of the HVAC equipment. To further minimize the utility costs, fluorescent lighting and ENERGY STAR® rated appliances were specified.

2.0 MATERIALS AND INSTALLATION

2.1 Insulating Concrete Form Basement Walls

An in-ground basement foundation was designated as the location for the mechanical systems and washer/dryer. However, to meet strict overall square footage constraints imposed by HFHI, and minimize the first cost of these homes, only one half of the building's footprint was excavated to a 6'6" room height, with the rear portion of the building transitioning to a 2'8" high crawl space foundation.

This foundation plan fostered the use of a material that would be air tight, insulated, lightweight, and structurally compliant for the two-story structure on marine clay soil. Insulating concrete forms, each weighing about 7 ½ pounds, would possess these characteristics after the placement of reinforcement and concrete.

ICF Installation

Insulating concrete forms are lightweight foam (extruded polystyrene) forms with integral webs that are placed like building blocks. Typically measuring 48" x 16", the forms are placed, secured, fitted with steel reinforcement, and filled with concrete to complete a reinforced concrete wall with insulation on both the interior and exterior face. After completion, forms are left in place to provide thermal resistance. The basement required five courses, while the crawl space used only two courses.

Using the forms presented challenges for a volunteer labor force. The form manufacturer requires that all installers attend one eight-hour training session. The logistics involved with scheduling the training course and the added burden it posed on the volunteers' schedules was problematic. In addition, the forms required specialized accessories, like bracing and scaffolding, for the installation. The bracing could be fashioned from 2" x 4" wood studs, once the installers were familiar with how to place and secure them, but scaffolding had to be rented.

The tight layout of the excavation on the site, and the labor force's lack of training in form placement, setting reinforcement, and safe bracing techniques, Habitat decided to use a professional ICF installer for the foundation work. But this metropolitan area was in the throes of a residential construction boom and local certified installers were fully employed. To meet the timetable for a prescheduled wall-raising event, an out of state ICF installer was contracted, so the cost of the foundation included housing for a two person team. Rough estimate indicates that the ICF foundation cost $2.50 per square foot more than the builder's standard CMU block foundation. Calculations included the batt insulation for the CMU block walls to have a comparable thermal resistance.

The concrete pump that was brought in to place the concrete in the foundation forms was a challenge for the infill site. The narrow street fronting the excavation was the only location for setting up the equipment and overhead electric wires inhibited pump maneuverability. Concrete placement in the forms was ultimately accomplished with a large labor force and trailer hose. The effort might have been better served by a suppliers' site visit prior to delivery, which had been suggested by those attending a pre-construction startup meeting.

Once completed, the ICF foundation did provide the desired envelope characteristics. To complete the energy efficiency initiative, the crawl space was designed to be unvented to outside air. Passive air exchange in the crawl space was provided via a lattice access panel open to the full basement area.

Unvented crawl space moisture mitigation details included maintaining a 2% slope at exterior grade and covering the interior of the crawl space excavation with 8-mil poly held in place with 2” of smooth gravel. Joist pockets or rimboards atop the foundation were insulated with R-11 batt insulation.

2.2 Engineered Wood, Sustainable Lumber Species, and Optimum Value Engineering

A combination of solid sawn lumber and engineered wood products were chosen for the above grade structural components of the project, based on availability, affordability, workability, and dimension. Engineered wood products can be manufactured from fast growing, underutilized, and less-costly wood species. So, these products promote efficient use of wood resources while minimizing some of the variable characteristics of solid wood, like cupping, bowing, and edge wane, which detract from the appearance of the finished planar surfaces. The floor joists and roof rafters used on the project were I-joists with oriented strand board (OSB) webs and laminated veneer lumber (LVL) chords.

Wall studs were originally specified to be finger-jointed structural studs, but inadequate order lead-time required a last minute change to 2” x 4” SPF studs. Floors were sheathed with exterior grade fir plywood for its low VOC content and weatherability. The wall sheathing was 7/16” OSB, chosen for its price and structural capacity. A proprietary oriented strand board product, called Solid Start® that was precision cut in the factory to match the depth of the floor joists was used as the I-joist rim board. The 1 1/8” thick product was applied at the floor deck perimeter to laterally brace the joists, provide a header over the basement windows (doubled), and present a solid fastening surface for exterior cladding, and deck and porch band boards. A weather resistant barrier wrap was applied to the exterior wall surface prior to installation of windows, trim, and fiber-cement siding.

<u>Installation</u>

Structural members and sheathings selected were easily handled and assembled by the volunteers. Arundel Habitat’s regular labor force was familiar with all these materials, so tools and techniques were at hand.

To conserve material, the floor structural members and walls were installed in-line at 16” on center spacing. This allowed for single top plates to be installed on the bearing walls.

This technique saved over sixteen 2” x 4” x 14’ pieces per unit, valued at roughly $75. Other resource efficient framing techniques included right-sizing headers at bearing walls and installing ladders, rather than solid blocking, at intersections of exterior and interior walls. Both techniques not only saved on the amount of studs used to frame the house, but allowed insulation to be placed in a larger section of exterior wall, which promoted energy conservation, without compromising structural performance.


Note single top plate

Figure 1 - The first wall is raised

2.3 Pre-painted Fiber-cement Siding

The exterior wall cladding was fiber-cement siding. Fiber-cement is more dimensionally stable than wood, so its paint finish holds up longer than that of wood sidings. Manufactured from cellulose fibers, Portland cement, and sand, the siding is also rot and pest resistant. Factory primed and painted fiber-cement lap siding was installed on three building sides where that style was specified. The building front received a fiber-cement shingle product, in keeping with the period appearance of the architecture. The fiber-cement shingle product, as well as, trim material were painted after installation.

Installation

Volunteers used a carbide-tipped saw blade for cutting, and manually driven nails for fastening the material. The pre-painted product worked well on the tight side elevations, where only six feet of space separated this building from its neighbor. Caulking at trim abutment was installed in tandem with the siding. The shingle product used on the home’s front elevation proved to be a labor-intensive undertaking, as each shingle was applied individually. Leveling the shingle’s bottom edge was tedious because volunteers had not been instructed to place a butt guide first.

3.0 ENERGY STAR® QUALIFICATION

As the first step in energy efficient design, MECcheck's[1] prescriptive methods for the geographical area were reviewed. These methods test compliance with the 1995 Model Energy Code (MEC). While MEC compliance is not as stringent as the more ambitious target of qualifying for ENERGY STAR®, the program quickly highlights basic building envelope details that may require improvement for energy code compliance.

For the Clay Street design, walls and roofs were of known dimensions, so maximum insulation R-values were also known. Given that the walls were to be R-13, and the ceiling between R-30 and R-37, and employing the prescriptive methods of MECcheck, the original design's eighteen windows per unit was reduced by five windows, and all rear transoms were eliminated, dropping the ratio of glazing to exterior wall surface area below 10%.

Again, MECcheck provided some guidance as to the next step in energy efficient design. Glazing percentage and R-values indicated a minimum U-value of .45 for the windows, and recommended normal efficiency for HVAC equipment. A single hung vinyl window with LowE, argon-filled, double-paned glass, and a U-value of .31 was selected.

4.0 ENVELOPE DETAILING

Because of the importance of the thermal envelope to the overall performance of the home, the insulation was meticulously installed. Fiberglass batts with an R-13 value were installed in the exterior walls, and an air seal package developed for the climate was employed. The sealing process incorporated caulking and chinking with fiberglass insulation at all wood to wood connections of the exterior walls and openings. Insulation was secured behind plastic electrical boxes, and gaskets were attached between the box and the cover at exterior wall receptacles. Two coats of latex wall paint served as an interior vapor barrier.

Insulation with an R-value of 30 was installed in the I-joist roof rafters, because it provided the most thermal resistance available for the 9 ½" space. The assembly was further protected against heat loss/gain with ½" rigid polyisocyanurate sheets (4'x 8') that provided the built-up slope of the roof.

Initially, batts of fiberglass insulation were installed between the first floor joists above the basement and crawlspace foundation. However, the building envelope was specified to include the unvented crawlspace and the basement, where both supply and return ducts and the air handler for the HVAC system were housed. Batts of insulation were removed from between the joists and refitted at the perimeter rim boards to complete the thermal seal.

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[1] Department of Energy, now called REScheck, at http://www.energycodes.gov/rescheck.
The reader will note that ENERGY STAR® qualification is not dependent on Model Energy Code compliance. REScheck is merely a user-friendly, first assessment tool for executing an energy efficient home building effort.

5.0 DESIGNING DUCTS WITHIN CONDITIONED SPACE

It stands to reason that a forced air delivery system should be designed for thermal resistance like exterior walls and roof. Yet, many HVAC ducts are installed in attics above the blown-in insulation, or crawl spaces below the floor insulation. Running ductwork through unconditioned space negatively impacts the operational and energy efficiency of HVAC units and can compromise the quality of the air being delivered.

In addition, condensation can occur inside the duct during heating season and outside the duct during cooling season. The resultant liquid moisture can sustain mold and bacteria, as well as, degrade insulation and cause rot and discoloration to the underlying structural and finish components. Mold and bacteria delivered with the conditioned air can also affect occupant health.

To maximize HVAC design efficiency, the duct runs – both supply and return – were installed within the building's thermal envelope. The tight construction and compact size of the unit also allowed the duct size and lengths to be minimized. One trunk line, installed in a first floor ceiling bulkhead on the exterior wall that spans the length of the home, serves registers on both floors. One large central air return is located on the landing wall of the open stairway that bisects the home.

Ducts within conditioned space were sealed to minimize air leakage, and assure occupant comfort and optimum system performance.

6.0 BENCHMARKING ENVELOPE TIGHTNESS

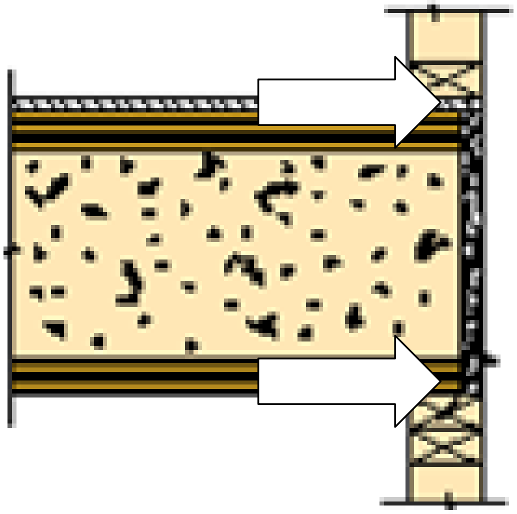
A generally practiced method of testing the air tightness of a house is to use a blower mounted in an exterior door opening to pressurize the indoor air. The rate at which the house loses pressure determines the amount of "leakage" that occurs. The "leakage" is expressed as air changes per hour (ACH), and converted to the natural air pressure for the geographic region where the house is located. Initial results of a Blower Door test indicated that the house was not as tight as the design and practices employed would have predicted.

Investigation revealed that the area at the first floor rim board was a weak point. Because the rim board had been precision cut to the floor joist depth, there was a significant air gap at the rim board edges that abutted the subflooring and sill plate. A continuous bead of latex caulk was applied to these junctions to seal the gaps throughout the basement and crawl space. It is probable that a similar condition existed at the second floor rim board, but the area was inaccessible due to the unit's finished condition. Figure 2 details the junctions that were isolated as sources of air leakage.

In fact, Blower Door tests provide limited application as a diagnostic instrument, because the building must be in a finished condition to conduct the test. Once a house is finished, the opportunity for remedial action to stem leakage to the outside is compromised by lack of accessibility, and impacts on the cost of a repair.

However, major air leakage points through the building envelope should be sealed. Therefore, the execution of this practice should begin with specific design details on the architectural plans, so that potential air pathways can be blocked as the house is being built. Platform framing, with common configurations of wood materials, suggests that there are quite a few junctions or intersections that one could predict to be "leaky". Universal details should be specified and addressed during the construction process. As an example, the air leak area detailed at the upper arrow in Figure 2, could have been sealed with a continuous bead of glue applied to the top edge of the band board at the time the subfloor was laid. The leak depicted by the lower arrow is easily handled with caulking from an unfinished basement at any step in the construction process. But, a more systemic approach would be to specify a product, such as that shown in Figure 3, to seal critical assembly junctions against air and water penetration.

Figure 2 - Air Leakage at Rim Board



Detail courtesy of Louisiana-Pacific Corp.

Figure 3 - Protecto Wrap® sill plate seal with integral adhesive for an air and water seal

7.0 VENTILATION FOR INDOOR AIR QUALITY

The final result of the Blower Door test, 0.28 air changes per hour at 20 pascals of pressure (ACH20), indicates the rate at which stale indoor air is being exchanged for fresh, outdoor air through leakage in the building envelope during typical weather conditions. A minimum air exchange threshold of 0.35 has been established, so buildings that are tight enough to qualify for ENERGY STAR®, may require supplemental air exchange. There are several ways to induce fresh air, or remove stale air from an indoor environment. Project planners chose to rely on an unbalanced method, whereby the bathroom exhaust fan serves as the ventilator, principally by removing air, only. This method relies on ventilation via infiltration and occupant intervention to turn on the fan, or open a window. Generally only recommended in moderate climates, exhaust fan ventilation is a low cost acceptable solution. The practice of unbalanced ventilation could be better served by installing a timer on the fan to assure measured usage, and by specifying a quiet (below 1.5 sones) fan. Wiring the fan control to the light switch might also ensure regular operation.

8.0 COST OF SELECTED TECHNOLOGIES AND TECHNIQUES

The Clay Street project concluded as one of the more costly endeavors, on a square foot basis, for the Arundel Habitat for Humanity chapter. The Construction Manager reported costs of $41 per square foot, or $7 per square foot more than their average costs. Some of the costs are associated with the difficult access posed by this infill building site, such as excavation, and concrete placement with a trailer hose and pump. Table 1 details some of the cost increases associated with the technologies and techniques covered in this report.

Table 1 - Added Cost of Technologies and Techniques

Technology / Technique	Added cost	Cost per Sq. Ft.
ICF Foundation	2,463.35	2.44
OVE & Wood Composites	(75.00)	(0.07)
Fiber-Cement Siding (a)	2,412.00	2.39
EnergyStar Qualifying Details:		
Deleting 5 Windows (REScheck) (b)	(975.00)	(0.97)
Air Sealing	250.00	0.25
Normal Efficiency HVAC Equipment	0.00	0.00
Ducts in Conditioned Space (c)	200.00	0.20
Exhaust Ventilation	0.00	0.00
Total	**4,275.35**	**4.24**

a) This product was donated by James Hardie, Inc. Cost does not include paint application. Baseline product is vinyl siding.
b) See footnote 1, page 4. MECcheck was replaced by REScheck.
c) Cost covers bulkhead installation and finish.

Other areas that are being considered for future projects include additional envelope air and water sealing, enhancing indoor air quality with mechanical ventilation, and a better match between occupants and water heating and storage capacity. Table 2 details some of the areas under consideration by Arundel Habitat.

Table 2 - Additional features under consideration

Feature	Incremental Cost		Annual Energy Savings
	Unit Cost	$/SF	
Rim Board sill seal/air barrier	296.00	0.29	(c)
Normal Efficiency HVAC Equipment (a)	0.00	0.00	Baseline
Higher Efficiency HVAC (b)	400.00	0.40	(34.00)
Exhaust Ventilation	0.00	0.00	Baseline
Upgrade Bath Fan	66.00	0.07	(d)
Add Kitchen Exhaust Fan	190.00	0.19	(d)
HWH 52 gal. EF .87	0.00	0.00	Baseline
HWH 40 gal. EF .90	(20.00)	(0.02)	(72.00)

a) SEER 10.5, HSPF 7.15
b) SEER 12.0, HSPF 8.6
c) Contribution indeterminate
d) Indoor air quality enhancement feature; minor increase in energy use was not calculated.

9.0 SUMMARY

The Arundel Habitat for Humanity's Clay Street project provided a challenging venue for the implementation of energy and resource sensitive building practices and technologies. Yet, with the initial trial of the integration process behind them, Arundel Habitat for Humanity staff are eager to take the best of the employed practices forward to incorporate into the specifications for future builds.

Technologies and techniques that added energy or resource efficiency, without adding significant first cost are receiving the highest consideration. These are, from Table 1:

- Performing an energy code compliance analysis of the design prior to permit application (REScheck)
- Engineered or composite wood products installed to optimize structural performance and energy efficiency
- Air sealing
- Installing HVAC ductwork within conditioned space with service by normal efficiency, right-sized equipment.

REM/Rate™[2] analysis performed on 60 Clay Street indicates the projected annual energy use shown in Table 3.

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[2] REM/Rate™ is a proprietary software product of Architectural Energy Corp. that is available for use by certified raters to aid in the analysis of ENERGY STAR® qualification.

Table 3 - Estimated Annual Energy Costs

Load	Annual Energy Cost ($)	Percentage of Annual Usage
Heating	145	
Cooling	89	
Subtotal/Conditioning	234	25.5
Water Heating	283	30.8
Lights & Appliances	341	37.1
Service Charges (a)	60	6.5
Subtotal/Non-Conditioning	684	74.5
Total Projected Usage	**917**	**100.0**

a) BGE schedule rate R.

With space conditioning projected to account for only 25.5%, or one quarter of the annual energy cost of this home, obvious targets for further trimming consumption hinge on a smaller or more efficient water heater, and fluorescent light fixtures or compact fluorescent bulbs, paired with conservation measures, like turning the lights out when not in use.

10.0 CONTACTS

Arundel Habitat for Humanity
http://www.arundelhabitat.org

EnergyStar Program
http://www.energystar.gov

Habitat for Humanity International's Environmental Initiative
http://www.habitat.org/env/

Insulating Concrete Forms Association
http://www.forms.org

James Hardie Building Products (Fiber-cement siding)
http://www.jameshardie.com

REM/rate software link.
http://www.eere.energy.gov/buildings/tools_directory/software.cfm/ID=50/pagename_submenu=/pagename_menu=materials_components/pagename=subjects

U. S. Department of Energy, REScheck software (formerly MECcheck)
http://www.energycodes.gov/rescheck