U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Hybrid Wall Evaluation for Ten New Construction Homes in Wyandotte, Michigan

A. Lukachko, A. Grin, and D. Bergey
Building Science Corporation

January 2013

Building America
U.S. Department of Energy

Available electronically at www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

Hybrid Wall Evaluation for Ten New Construction Homes in Wyandotte, Michigan

Prepared for:
The National Renewable Energy Laboratory
On behalf of the U.S. Department of Energy's Building America Program
Office of Energy Efficiency and Renewable Energy
15013 Denver West Parkway
Golden, CO 80401
NREL Contract No. DE-AC36-08GO28308

Prepared by:

A. Lukachko, A. Grin, and D. Bergey

Building Science Corporation

30 Forest Street

Somerville, MA 02143

NREL Technical Monitor: Cheryn Metzger

Prepared under Subcontract No. KNDJ-0-40337-00

January 2013

[This page left blank]

Contents

List of Figures

Unless otherwise noted, all figures were created by BSC.

List of Tables

Unless otherwise noted, all tables were created by BSC.

Definitions

ACH50	Air changes per hour at 50 Pascals
ASHP	Air source heat pump
BA	Building America Program
BEopt	Building Energy Optimization
BSC	Building Science Corporation
ccSPF	Closed-cell spray polyurethane foam
CFIS	Central fan integrated supply
CFL	Compact fluorescent lighting
cfm	Cubic foot per minute
CMU	Concrete masonry unit
COP	Coefficient of performance
DHW	Domestic hot water
EECBG	Energy Efficiency and Conservation Block Grant
EF	Energy factor
EPS	Expanded polystyrene
ft^2	Square foot
GSHP	Ground source heat pump
HERS	Home Energy Rating System
HSPF	Heating seasonal performance factor
HUD	U.S. Department of Housing and Urban Development
in.	Inch
MBtu	Million British thermal units
MSHDA	Michigan State Housing Development Authority
NSP2	Neighborhood Stabilization Program 2
OSB	Oriented strand board
Pa	Pascal
pcf	Pounds per cubic foot
PIC	Polyisocyanurate
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
SPF	Spray polyurethane foam
XPS	Extruded polystyrene
yr	Year

Executive Summary

Under the Wyandotte Neighborhood Stabilization Program 2 (NSP2), 20 new houses are being built and 20 existing houses are being retrofitted in Wyandotte, Michigan. This report details the design and construction of 10 new houses in the program. Wyandotte is part of a program led by the Michigan State Housing Development Authority consortium, which is funded by the U.S. Department of Housing and Urban Development under the NSP2. The City of Wyandotte has also been awarded Energy Efficiency and Conservation Block Grant funds from the U.S. Department of Energy that are being used to develop a district ground source heat pump (GSHP) system to service the project.

This report examines the energy efficiency recommendations for new construction at these homes. The report will be of interest to builders of high performance homes in a cold-climate zone, particularly where affordability is a priority. Building code officials, designers, and homeowners might also find value in the results of this project.

All of the homes were constructed and fully commissioned by spring 2012. Building Science Corporation explored the following research goals and questions with the 10 test houses:

1. Does the proposed hybrid wall assembly meet expectations for whole-building air tightness and construction efficiency?
2. Can water management details for insulating sheathing be cost-effectively executed by the construction team?
3. Does the total project cost fall within the project requirements and deliver higher than expected energy performance?
4. Is the sizing method for the GSHP accurate for small houses with high thermal resistance enclosures?
5. Can the GSHP unit be reduced in size to accommodate additional homes on the same well?

Results from this research work suggest that the technology package employed (which includes a hybrid insulating sheathing and a spray foam insulation, above-grade wall with Advanced Framing) does meet the whole-house water, air, and thermal control performance specification established for this project, along with the project's affordability goals. The technology specification for the NSP2 houses has achieved a 37% reduction in whole-house energy use relative to the Building America Benchmark. This consistent result has been achieved in a construction setting that involves several general contractors building the same floor plan with different trades and work processes.

1 Introduction

This report describes work conducted by the Building Science Corporation (BSC) Building America [BA] Research Team's Energy Efficient Housing Research Partnerships project.[1] This technical report covers 10 single-family new homes in Wyandotte, Michigan.

Through the pilot community evaluation in Wyandotte, BSC has acquired important information about the performance of energy efficient technology packages designed for U.S. Department of Housing and Urban Development (HUD) NSP2 projects in a cold climate. This research addresses the following important gaps and barriers:

- Affordable high performance enclosure assemblies
- Complete high performance technology packages for affordable homes.

Through this work, BSC also collected information about cost and implementation issues with hybrid high R-value assemblies.

1.1 Project Background

Wyandotte NSP2 project partners are building 20 new houses and retrofitting 20 existing houses in Wyandotte. This project is part of a consortium led by the Michigan State Housing Development Authority (MSHDA), which is funded by HUD under the NSP2.[2] The City of Wyandotte has also been awarded Energy Efficiency and Conservation Block Grant (EECBG) funds from the U.S. Department of Energy that are being used to develop a district ground source heat pump (GSHP) system to service the project (Table 1).[3]

The first 10 new houses constructed in this NSP2 project were selected as part of the BA research project.

Research work undertaken by BSC on this project is connected to previous research work on high R-value enclosures, the effectiveness of ventilation systems, and other whole-house energy efficiency packages for affordable housing, described later. In 2010, BSC undertook a project to establish a cold-climate energy efficiency package working with the first three houses in Wyandotte's NSP2 program (Lukachko and Bergey 2010).

Hybrid wall assemblies have been studied and reported on by BSC in 2010 as part of a high R-value wall assembly study (Straube and Smegal 2009), and research work on this technology continues. The 2009 study compares many traditional and nontraditional assemblies in terms of thermal control, moisture control, cost, and constructability. Findings indicate that a wood frame wall with insulating sheathing and a secondary layer of high density spray foam is a cost-effective approach to attaining the thermal resistance and airtightness expected of a high R-value enclosure. In addition, this approach reduces the risk of wintertime interstitial condensation. In the configuration examined, the balance of the cavity can be filled with lower cost insulation.

[1] See www.buildingamerica.gov for more information.
[2] See www.michigan.gov/mshda/0,1607,7-141--217713--,00.html for more information about the Michigan State Housing Development Authority program. See www.hud.gov/offices/cpd/communitydevelopment/programs/neighborhoodspg/arrafactsheet.cfm for more information about the NSP2.
[3] See www1.eere.energy.gov/wip/eecbg.html for more information about the DOE EECBG grant.

Table 1. Summary of Wyandotte NSP2 Energy Efficiency Package Components

Wyandotte NSP2 Specifications		
	NSP2 Program Specifications	2010 BA Benchmark
Building Enclosure		
Roof	R-45 unvented cathedralized attic 5-in. ccSPF to underside of roof sheathing with R-13 fiberglass batt in cavity	R-38
Walls	R-32 hybrid insulation walls with 2-in. EPS insulating sheathing (R-7); 2-in. ccSPF to inside of wall sheathing (R12); R-13 fiberglass batt insulation in stud cavity (R-13)	R-13 batt + R-5 insulating sheathing
Basement Floors	R-10 full-width subslab insulation with 2-in. XPS insulation (R-10)	Uninsulated
Basement Walls	R-13 full-height interior insulation with 2-in. PIC insulation (R-13)	Uninsulated
Windows	Above grade: Vinyl double-glazed (U = 0.32, SHGC = 0.32) Basement: glass block windows (U = 0.6, SHGC = 0.6)	Above grade: U = 0.35, SHGC = 0.35 Basement: glass block windows (U = 0.6, SHGC = 0.6)
Infiltration Mechanical Systems	2.2 ACH50	8.8 ACH50
Heating	GSHP, 3.7 COP	7.2-HSPF air source heat pump
Cooling	GSHP, 3.7 COP	10-SEER air source heat pump
DHW	0.94-EF electric tank water heater	0.86-EF electric tank water heater
Ducts	All ducts in conditioned space	R-6 ductwork in attic, 15% total leakage
Ventilation	CFIS supply-only as per ASHRAE 62.2 (ASHRAE 2010)	45-cfm continuous ventilation with ASHRAE 62.2-rated exhaust fan
Appliances and Lighting		
Lighting	100% fluorescent	33% fluorescent
Appliances	ENERGY STAR appliances	Standard appliances

Notes: EPS, expanded polystyrene; XPS, extruded polystyrene; PIC, polyisocyanurate; SHGC, solar heat gain coefficient; ACH50, air changes per hour at 50 Pa; COP, coefficient of performance; HSPF, heating seasonal performance factor; SEER, seasonal energy efficiency ratio; DHW, domestic hot water; EF, energy factor; CFIS, central fan integrated supply (a mechanical ventilation design; www.fancycler.com/ for more information)

The enclosure included in the Wyandotte NSP2 energy efficiency package is a hybrid insulation assembly using Advanced Framing (Lstiburek and Grin 2010; BSC 2009), insulating sheathing as the primary thermal control layer and the drainage plane (BSC 2007; Baker 2006), and 2.0-pcf closed-cell spray polyurethane foam (ccSPF) insulation for thermal control and airtightness. In addition to providing air sealing and condensation protection, ccSFF increases the R-value within the cavity, which allows the thickness of insulating sheathing to be reduced. This eliminates the relatively tricky installation of the second layer of rigid foam and the associated window and trim details. Spray foam is installed by a dedicated skilled contractor. It is easy to fit into the production schedule and is especially economical when many houses can be insulated in close succession.

The NSP2 package draws on whole-house energy efficiency research work that has been published by BSC in the builder's field guides series (Lstiburek 2006) and in research reports on community-scale evaluations in cold and other climate zones (BSC 2011; BSC 2010). The Wyandotte houses offer a community-scale demonstration of an energy efficient technology package in construction conditions compatible with the constraints of large-scale production home builders. In particular, the affordability aspects of the NSP2 package draw on past cold-climate research work with Habitat for Humanity (BSC 2010; BSC 2002) and other community builders (BSC 2008; BSC 1999).

Contact information for the project team members can be found in Appendix D.

1.2 Relevance to Building America Goals

Overall, the goal of the U.S. Department of Energy's BA program is to "reduce home energy use by 30%–50% (compared to 2009 energy codes for new homes and pre-retrofit energy use for existing homes)." To this end, BSC conducts research to "develop market-ready energy solutions that improve efficiency of new and existing homes in each U.S. climate zone, while increasing comfort, safety, and durability."[4]

The technology package proposed for this pilot community project is most appropriate for affordable single-family or attached 1½-story houses with basements. From a building science perspective, the Wyandotte NSP2 package is suitable for other cold-climate NSP2 projects. The information gained through this research about implementing the technology package at a community scale, along with the longer term performance data from the community of houses, will support widespread deployment of this package in new housing across the cold-climate zone.

The most immediate effect of the research project will be to inform the work of the 12 Michigan municipalities that are part of the Michigan NSP2 consortium. These municipalities are Detroit, Highland Park, Hamtramck, Wyandotte, Flint, Saginaw, Pontiac, Lansing, Battle Creek, Kalamazoo, Grand Rapids, and Benton Harbor. The consortium has received approximately $224 million in funding from HUD for redevelopment of blighted and vacant land within the participating communities (see Table 2). Looking at "Use E"—the funding for the redevelopment of vacant properties—BSC estimates that the research work with Wyandotte will affect the construction of more than 100 new Michigan homes within the first round of NSP2

[4] See http://www1.eere.energy.gov/buildings/residential/ba_index.html for more information.

development and 50–100 additional homes that could be constructed in subsequent rounds of development as the sales revenue from the project is redeployed.

Table 2. Proposed NSP2 Allocations by Eligible Use (MSHDA undated)

Target Market	NSP2 Funds	Percent of Requested NSP2 Funds
Administration	$26,350,000	10%
Use A—Financing Mechanisms	$13,175,000	5%
Use B—Purchase and Rehabilitation of Abandoned or Foreclosed Homes and Residential Properties to Sell, Rent, or Redevelop	$105,400,000	40%
Use C—Land Bank Acquisitions and Management of Foreclosed Residential Properties	$26,350,000	10%
Use D—Demolition Blighted Structures	$65,875,000	25%
Use E—Redevelop Demolished or Vacant Properties	$26,350,000	10%
Total	$263,500,000	100%

The project also has the potential to affect BA measure guidelines on high R-value enclosure assemblies (walls, roofs, foundations) for cold climates and GSHPs. The Wyandotte NSP2 community might also offer an opportunity for long-term research on GSHP system performance in individual homes, in shared-well installations, and at a community-scale installation.

1.3 Project Location

All the construction for this project will be done in the NSP2 neighborhood in Wyandotte (see Figure 1 and Appendix A). As the project progresses, specific property addresses will be drawn from a preselected inventory of vacant or foreclosed properties. Table 3 lists the houses by unit type (property addresses are not reported) and shows how the construction of the houses will be tendered in sequence for construction.

Table 3. Wyandotte NSP2 Properties by Bid Package

Item	New Address		Type	Style
NSP2 Bid Pack 1				
Item	**New Address**		**Type**	**Style**
1	Cedar 1[a]		Existing	1½ story
2	Walnut 1 [b]		New Design	1½ story
3	Walnut 2 [b]		New Design	1½ story
NSP2 Bid Pack 2				
Item	**New Address**		**Type**	**Style**
1	Vinewood 1 [b] *		New Modified	1½ story
2	Poplar 1 [b]		New Modified	1½ story
3	Cora 3 [b]		New Design	1½ story
4	Cora 4 [b]		New Design	Ranch
5	Cora 1 [b]		New Design	Ranch
6	Cora 2		New Modified	1½ story
7	Cedar 1 [a]		Existing	1½ story
NSP2 Bid Pack 4				
Item	**New Address**		**Type**	**Style**
1	Poplar 2 [b]		TBD	TBD
2	Vinewood 2 [b]		TBD	TBD
3	Poplar 3		TBD	TBD
4	Cora 5 [b]		TBD	TBD
5	Cora 6		TBD	TBD
6	Poplar 4		TBD	TBD
7	Poplar 5		TBD	TBD

[a] These houses have been included in BSC's TO2 8.5 project.
[b] These houses have been included in BSC's TO2 4.3 project.

2 Mathematical and Modeling Methods

2.1 Energy Modeling Methods

BSC analyzed the initial drawings the design team supplied to establish the level of energy efficiency that the as-designed, code-level homes were likely to achieve. This was followed by BSC analysis to determine measures needed to achieve energy target levels; the development of recommendations for moisture control, durability, and indoor air quality improvements; and the discussion of relevant construction details with the design and construction team.

BSC used a systems engineering approach, which looks at the performance of the house as a whole instead of focusing only on the building elements related to specific disciplines. Recommended improvements were considered because of their benefit for multiple subsystems in the home and their benefit to the overall house performance. Although energy is the most important driver for improvement in BA research, other vital attributes were considered, including sustainability, durability, comfort, and indoor air quality.

The energy analysis is presented as a parametric study. The overall energy reduction is broken down into incremental changes to show what impact a specific improvement has on overall performance (i.e., "How much energy does this house save from upgrading the windows?"). This portion of the research work involved continuous back and forth correspondence with the design team, including discussions on the feasibility of incorporating various measures into the builder's practices and on the cost implications.

Whole-house hourly energy simulations were completed to calculate the source energy consumption savings for the target house compared to the 2010 BA benchmark definition created by the U.S. Department of Energy. An explanation of site and source energy can be found in Ueno and Straube (2010).

The following tools were used:

- Energy modeling through computer simulations (including the Building Energy Optimization [BEopt] tool, a house energy simulation program and primary analysis tool for BA homes) to predict the energy savings of the home; this analysis is performed on all BA homes so that a percent energy savings is calculated
- HVAC design - Manual J8 heating and cooling load calculation, equipment sizing, and duct layouts (ACCA 2011).

3 Experimental Methods

3.1 Testing Methods

All 10 test homes were performance tested by a local Home Energy Rating System (HERS) rater employed by the City of Wyandotte. BSC conducted a broader program of testing on a limited number of houses. The performance testing is intended to confirm that the house meets the energy efficiency specification of the technology package.

The BSC performance testing included the following measurements:

- Blower door test to measure the house infiltration rate
- Duct blaster test to measure duct leakage (both total duct leakage and duct leakage to outside)
- Outside air ventilation rate measurement
- Register flow measurement (to ensure proper airflow from each supply register)
- HVAC equipment static pressures (measures steady state operation of air handler equipment)
- Bedroom to hallway pressure difference while door is closed (to ensure that the transfer grille or the jump ducts were sized properly to prevent room pressurization when the door is closed).

Indoor temperature and relative humidity measurements were also taken during site visits. Pending agreements with the homeowners, these conditions might be logged over the long term. If implemented, these measurements will continue into 2013.

The analysis of the building performance testing will include conversion of the CFM50 blower door result to additional units of infiltration rates. Below is the equation for converting a CFM50 result to ACH50:

$$ACH_{50} = [\text{cfm } 50 / \text{conditioned volume (cf)}] * 60$$

Duct blaster results, both total and duct leak to outside, were compared between the 10 project homes. Outside air measurements were taken to confirm proper ventilation rates in the project homes. Register cfm and air handler static pressures were measured as part of the HVAC commissioning process. The individual register cfm flows were compared to the Manual J8 design flows.

In addition to the information BSC gathered, the public utility that is owned by the City of Wyandotte will collect basic long-term data. The data will not be analyzed by the researchers in this project but would be available for use by future investigators.

3.2 Collection of Utility Bill Data

Community-scale projects deliver the best performance feedback to the BA program. For this project, the City of Wyandotte will hold responsibility for collecting monthly utility bill data for each constructed home and, if possible, for similar new or existing houses in the NSP2 project area. Monthly utility bills include the monthly dollar amount, units of energy used (e.g., therms of gas, kilowatt-hours of electricity, and gallons of propane), and floor plan type. The study period is typically 2 or 3 years following construction. BSC will analyze the data semiannually and distribute a report to all research partners.

For each NSP2 house, a release form signed by the new homeowner will be collected at the time of sale. The City of Wyandotte has proposed that this be included in the purchase agreement for each house. Homeowners will be given an explanation of the BA program, the goals and objectives for the Wyandotte project, and a statement of how the data will be used. The data will be connected to the type of house built (e.g., Plan type A) but does not need to be connected to a particular homeowner (i.e., the data can be anonymous).

A complete analysis of the data also requires data collection from a matching group of houses that are built to "normal" standards. For Wyandotte, this could involve recruiting participants from existing houses in the neighborhood given that the city-owned utility is the service provider of electricity for all houses in Wyandotte. Some houses in Wyandotte have gas service, and a separate arrangement will need to be made to secure the full participation of occupants of existing houses in the area. Although firm plans have not yet been made, a study of the whole-house energy use on this scale would also fit well with the city's plan to build a GSHP-based district system. An expanded study would yield solid information about how existing houses in the area use energy compared to the new houses built or renovated to a higher performance standard. The city might, in fact, have already collected this information, and city representatives are investigating this possibility.

4 Results

This section of the report details the results of the following:

- The work to refine the energy efficiency technology package for the project (including the enclosure and mechanical specifications)
- The energy analysis of the package (including the cost effectiveness of the selected measures)
- The performance testing of the completed houses.

4.1 Final Energy Efficient Technology Package

This section describes the final package of energy efficient technology that was developed for the Wyandotte NSP2. The package was developed through discussions between BSC, the City of Wyandotte staff (including building department officials), and the project architect. As part of these discussions, BSC analyzed this specification, and Appendix B contains an initial energy analysis for comparison.

This project included constraints that affected the selection of energy efficient technology. The most significant one was the choice to use GSHP systems for heating and cooling for all NSP2 houses. Wyandotte city planners made this choice early in the project as part of a strategy to introduce green technology into the city-owned utility's portfolio. The long-term vision for Wyandotte is to create a district system that will start with the NSP2 neighborhood and then expand to service the remaining city center areas. The city contracted for supply and installation of the GSHP systems and wells before the housing program was started. As a result, the individual houses examined for BA started with the GSHP as a fixed element of the technology package, constraining both system choice and total cost.

The proposed construction technology was also intended to be compatible with the technology traditionally employed by trades in the Wyandotte area. This limited the selection of enclosure systems but was compatible with the proposed high thermal resistance hybrid wall recommended by BSC.

4.1.1 Enclosure Specifications

Table 4 summarizes the enclosure design.

Table 4. Wyandotte NSP2 Enclosure Specifications

Enclosure	Specifications
Roof	
Description	Dark color asphalt shingles on rafter roof, unvented cathedralized attic
Insulation	3-in. (R-18) ccSPF on underside of roof, R-28 fiberglass batt below
Walls	
Description	Hybrid wall with insulating sheathing and spray foam
Insulation	2-in. (R-10) XPS sheathing, 2-in. (R-12) ccSPF in cavity, 3.5-in. (R-12) fiberglass
Foundation	
Description	Conditioned basement/crawlspace
Insulation	2-in. XPS (R-10) or 2-in. (R-12) ccSPF on walls
Windows	
Description	Double-pane vinyl framed with low emissivity spectrally selective glazing
Manufacturer	Anderson
U-Value	0.28
SHGC	0.29
Infiltration	
Specification	2.5-in.^{2} leakage area per 100-ft^2 enclosure @ 50 Pa
Performance Test	Initial test result = 2.0-in.^{2} leakage area per 100-ft^2 enclosure @ 50 Pa

4.1.1.1 Roof

The architectural designs for the NSP2 houses employ several roof assembly types in each house. The most common assembly is a cathedralized unvented attic that employs 4 in. of 2.0-pcf ccSPF sprayed to the underside (interior) of the roof sheathing with fiberglass batt to fill the rafter cavity. This allows the kneewall spaces to be used for ductwork distribution and gives the homeowner generous storage areas. Some house designs allow for a partial vented roof assembly. In this part of the roof area, cellulose insulation is installed on the ceiling plane.

4.1.1.2 Walls

The above-grade structure of the houses is 2 × 6 construction with Advanced Framing. The house designs vary significantly to fit in with neighboring houses: one of the plans is a full two-story house, two are one-and-a-half story houses, and two are single-story houses. Engineered wood floor joists, rim joists, and beams are commonly used. Dormers and gable bedrooms on the second floors are common, so most of the roofs are framed with dimensional lumber with oriented strand board (OSB) roof sheathing. Shear panels are provided in exterior walls where needed. The houses typically use OSB panels, but several houses were constructed with structural insulated sheathing panels to slightly increase the R-value of the walls where these shear panels are located. These panels, however, added to the construction time, so after this experiment, the design team decided to return to OSB panels for the remainder of the construction.

Exterior walls employ a hybrid insulation approach: the advanced frame structure is clad with 1.5 in. or 2 in. of XPS insulating sheathing, the interior surface of the sheathing is sprayed with 2.0-pcf ccSPF insulation (in the framing cavity) to a depth of 2 in., and the remainder of the framing cavity is insulated with fiberglass batt insulation. The exterior surface of the insulating sheathing is taped with sheathing tape and integrated with windows, doors, and other penetrations to form a drainage plane. A variety of claddings are used in the architectural plans, but vinyl siding applied directly over the face of the insulating sheathing and fastened to the framing is the most common. This treatment covers the majority of the surface area on each house. The insulating sheathing and ccSPF form the primary air barrier system. Penetrations through top and bottom plates for services are sealed to compartmentalize the framing cavities. In this configuration, the ccSPF effectively controls vapor diffusion and surface temperature of the (interior) condensing surface to limit the risk of wintertime interstitial condensation. This assembly is considered to be a vapor-open assembly, in that each enclosure layer from the ccSPF can dry to either the interior or exterior.

4.1.1.3 Foundation

All of the NSP2 houses are constructed on a full basement foundation. Builders were awarded bid packs (groups of several houses to be constructed) that allowed them to choose the foundation structure. Approximately half the houses were constructed with a site cast concrete foundation and the remaining houses with a concrete masonry unit (CMU) foundation. This difference is not considered to be significant from an energy perspective. The basement walls are insulated with full-height foil-faced PIC insulation. Basement floor slabs are insulated under the entire surface with 2 in. of XPS insulation. The subslab insulation is turned up at the slab edges as a thermal break and to maintain continuity with the foundation wall insulation.

4.1.1.4 Windows

The manufacturer of the windows installed varies slightly with the builder. All windows, though, have vinyl frames with low emissivity spectrally selective glazing and meet the same performance specification: a U-value of 0.28 and an SHGC of 0.29. This glazing technology has some secondary benefits as well, such as reducing ultraviolet damage on interior floors or fading on furniture. The flanged window units are integrated with the exterior face of the insulating sheathing with flashing tape. All window openings were first lined with pan flashing. After insulation, low expansion foam was used as an air seal between the window unit and the framing of the rough opening.

4.1.1.5 Infiltration

The air infiltration rate target is the BSC BA infiltration goal of 2.5 in^2 of free area per 100 ft^2 of enclosure. The layer of spray foam applied to the interior side of the wall and roof sheathing is the primary air barrier system. The low expanding spray foam that is installed between the window frame and the rough opening is the transition from the wall to the window unit. In the basement, rim joist areas are sealed from the inside with ccSPF to connect the basement wall insulation to the underside of the first-floor deck. The basement floor and concrete structure completes the whole-house air barrier system.

4.1.2 Mechanical Specifications

Table 5 summarizes the mechanical systems used in the NSP2 project.

Table 5. Wyandotte NSP2 Mechanical System Specifications

Mechanical Systems	Specifications
Heating	
Description	9.2-HSPF GSHP
Manufacturer and Model	WaterFurnace
Cooling (Outdoor Unit)	
Description	18-SEER GSHP
Manufacturer and Model	WaterFurnace
Cooling (Indoor Unit)	
Description	Electronically Commutated Motor air handler with heat pump coil
Manufacturer and Model	WaterFurnace
DHW	
Description	Tank electric hot water heater (EF = 0.98), desuperheater
Manufacturer and Model	Rheem
Distribution	
Description	R-6 flex ducts in conditioned unvented cathedralized attic
Leakage	Maximum 5% duct leakage to outside
Ventilation	
Description	Supply-only system with Aprilaire 8126 ventilation control system, 33% Duty Cycle: 10 min on; 20 min off, 50-cfm average flow
Manufacturer and Model	Aprilaire 8126 ventilation control system fan cycler
Return Pathways	
Description	Central return on first floor, jump ducts in bedrooms

GSHPs shift energy consumption from direct combustion to electricity, and have higher COPs than air source heat pumps, especially during periods of extreme temperatures when building loads are highest. Their application in single-family homes is limited because of the high cost of drilling. The horizontal heat exchangers common in residential construction also reduce performance.

As part of the project, the City of Wyandotte will drill vertical boreholes (see Figure 2) at each NSP2 property in the city-owned portion of the front yard. These wells are estimated to support GSHP units totaling 6 to 8 tons. The expectation is that although each well will initially connect to only one NSP2 house, in the long term, Wyandotte Municipal Services will connect two or three houses to each well and possibly join the wells together to create a district GSHP system. The utility will lease the heat exchanger back to the house occupants. In this way, the per-house cost of the system is reduced, and the cost is amortized over a longer period than most homebuyers or builders can accommodate. A more complete discussion of costs is provided in Section 4.2.1. The energy efficiency of each NSP2 project is important because the load on the well will determine whether one or two additional houses can be added to the well. The City of Wyandotte has agreed to handle the long-term collection of energy use data for these homes and is interested in the possibility of the National Renewable Energy Laboratory monitoring the district GSHP system.

Figure 1. Photograph of a well borehole operation for a GSHP system in the NSP2 neighborhood

Room by room Manual J8 system sizing and duct layout calculations were performed by BSC on several of the plans to confirm duct design and system sizing. The very efficient enclosure and HVAC system resulted in smaller GSHPs than had been anticipated.

The package specifies a CFIS that has been extensively researched and tested by BSC (Hendron et al. 2008; Rudd 2008). This system draws outside air via a 5-in. flex duct to the return plenum of the HVAC system (see Figure 3). This allows the introduction of outside air to the living space whenever space conditioning is already operating. Fan cycling will turn on the fan at a 33% duty cycle (10 min on, 20 min off), drawing outside air during periods of no space conditioning. A 6-in. mechanical damper is also installed on the 6-in. outside air duct. The damper is controlled by the fan cycler and will close off the outside air duct during periods of consistent space conditioning to prevent overventilation of the living space.

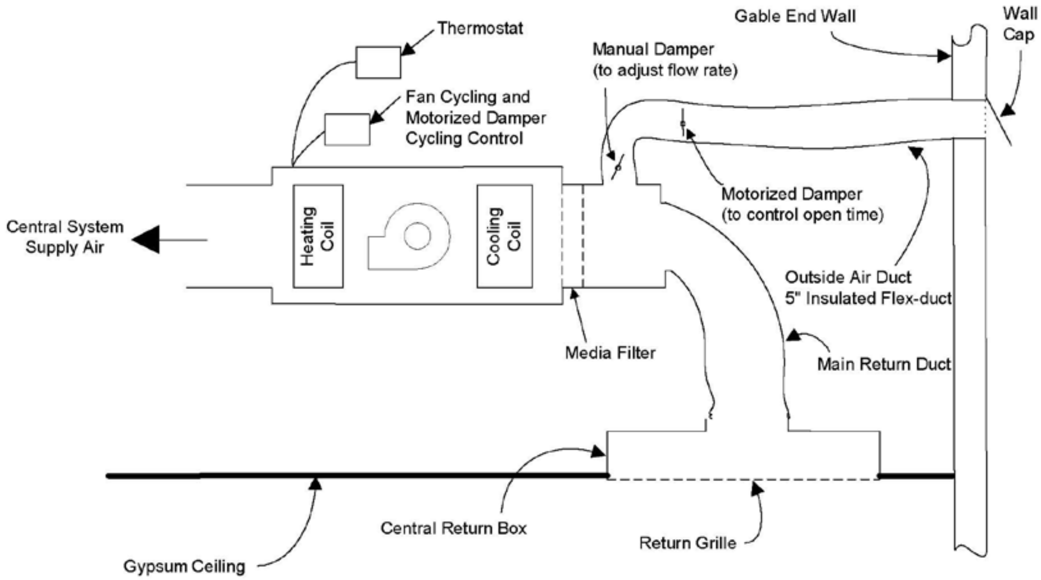


Figure 2. CFIS ventilation schematic

In addition to the building enclosure and mechanical system specifications described, ENERGY STAR appliances and compact fluorescent lighting (CFL) fixtures are to be installed in all homes with the goal of further reducing internal loads and electricity use.

Figure 3. Wyandotte NSP2 houses (Walnut 1 and 2) under construction

4.2 Energy Analysis Results: Cost Effectiveness of the Energy Efficiency Measures

4.2.1 Background and Cost Information

The project team designed the Wyandotte NSP2 energy efficient solution package to meet the cost and performance requirements of houses eligible for the HUD NSP2in the cold-climate zone. Specifically, the Wyandotte NSP2 project, administered under MSHDA's NSP2 Consortium, aims to build a significant number of houses that can be sold or rented to households earning less than 50% of the area median income. This is a different working definition of cost effectiveness than is typically used for BA projects. The result will be that robust solutions developed for the NSP2 in Wyandotte will be appropriate for both affordable and market-rate housing.

BSC participated in the project architect's work to value engineer the plans and specifications to meet the affordability requirement. BSC has analyzed energy efficiency measures and other elements of the technology package to optimize the cost. This effort to reduce the construction cost while maintaining or increasing the energy performance of the houses will continue throughout each phase of the program. The objective of the work was to develop a package that can be built for approximately $\$120/ft^2$ and use approximately 30% less whole-house energy than required by 2009 energy codes (ICC 2010). The City of Wyandotte established the $\$120/ft^2$ cost as the program target by based on the NSP2 funding and the expected sale price of the finished homes.

Initial cost studies of the Wyandotte NSP2 package indicated that the new houses could be built for between \$135 and $\$145/ft^2$.

Table 6 records reported incremental costs for energy efficiency measures in the final technology package.

Table 6. Cost Information Summary

Category	Description	Cost	Source
Wall	Hybrid R-32	default	
Windows	Double GlazedVinyl (U = 0.28, SHGC = 0.29)	$6,500	Builder pricing (average)
	Window flashing	$400	Builder pricing
Roof	Unfinished attic	default	
	Finished 5-in. ccSPF + R-13	default	
Foundation	Full-height R-10 rigid insulation	$2,400	Builder pricing
	Capillary break at footing	$150	Builder pricing
Infiltration	2.5 ACH50	default	
Ventilation	CFIS	$365	Builder pricing
	Jump ducts, transfer grilles	$150	Builder pricing
Duct System	Ducted supply and panned return	$1,750	Builder pricing
Duct Sealing	Fully ducted return	$900	Builder pricing
	Conventional (tape)	$175	Builder pricing
	Recommended (mastic)	$275	Builder pricing
Heating and Cooling	18 SEER GSHP, 3.7 COP	$11,800	BSC cost data sheet (for 3 ton; less $800 for DHW)
Hot Water	Well for GSHP	$10,000	Builder pricing
	Electric tank with desuperheater connection to GSHP	$800	Builder pricing
Lighting	100% CFL	0.98	BSC cost data sheet (per square foot)
Appliances	ENERGY STAR washer, refrigerator	$800	BSC cost data sheet (imputed, 2/5 of $2,000 for 5 appliances)

4.2.2 BEopt Modeling Results

The cost effectiveness of the energy efficiency measures considered for these projects was analyzed with BEopt, the BA performance analysis tool. This tool includes an optimization capability that uses user-supplied cost data and energy use information. The output is a specified set of energy saving measures to determine combinations of measures that are optimal or near optimal in terms of cost effectiveness. BEopt plots the average source energy savings per year against the annualized energy related costs. In this output, the optimal packages are those that form the lower bound of the plotted data points. Because BEopt uses a sequential searching technique, not every possible combination of options is simulated.

BEopt modeling confirms that each proposed building upgrade reduces the annual source energy requirement. Using price data from BEopt, the total annual energy-related dollar cost is roughly constant as the upgrades proceed. In many cases this reflects lumping what could be construed as multiple upgrades into a single building component. For instance, going from R-19 walls to R-24 saves more energy than upgrading from R-27 to the final nominal R-value of 32. If plotted separately, these two measures would appear as one that saved money and one that saved energy at some additional cost.

Figure 5 presents the parametric study results. This study was used to help assess cost saving measures early in the design process.

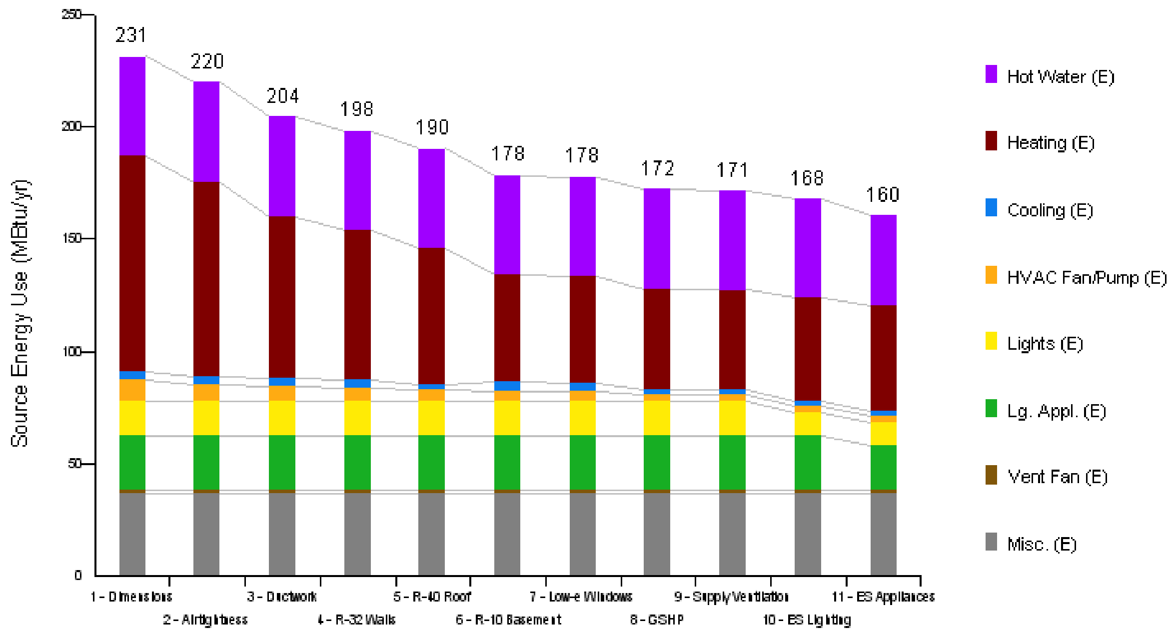


Figure 4. BEopt parametric study for Wyandotte NSP2 pilot

The analysis was repeated toward the end of the design process for the final technology specification after several refinements had been made (Figure 6). The results indicated an estimated 32% reduction in annual whole house energy use compared to the BA benchmark.

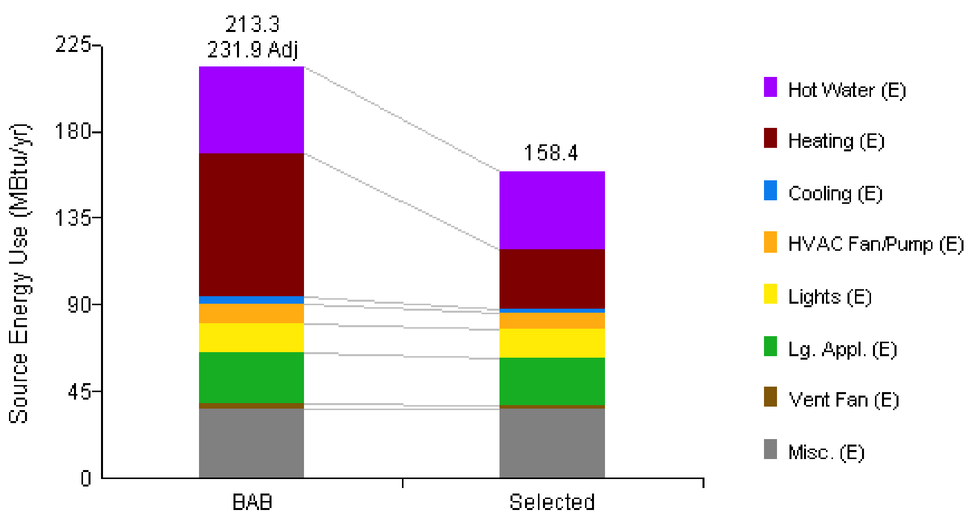


Figure 5. Final BEopt energy analysis results by end use

The analysis was updated after performance testing of the houses to include measured whole-house airtightness values (Figure 7). Values of 2.2 ACH50, 1.9 ACH50, and 1.5 ACH50 were chosen to represent the typical, excellent, and best measurements, respectively, from a range of houses tested.

Using what BSC considers to be the typical airtightness of a house in the program, the results indicated an estimated 37% reduction in annual whole house energy use compared to the BA benchmark.

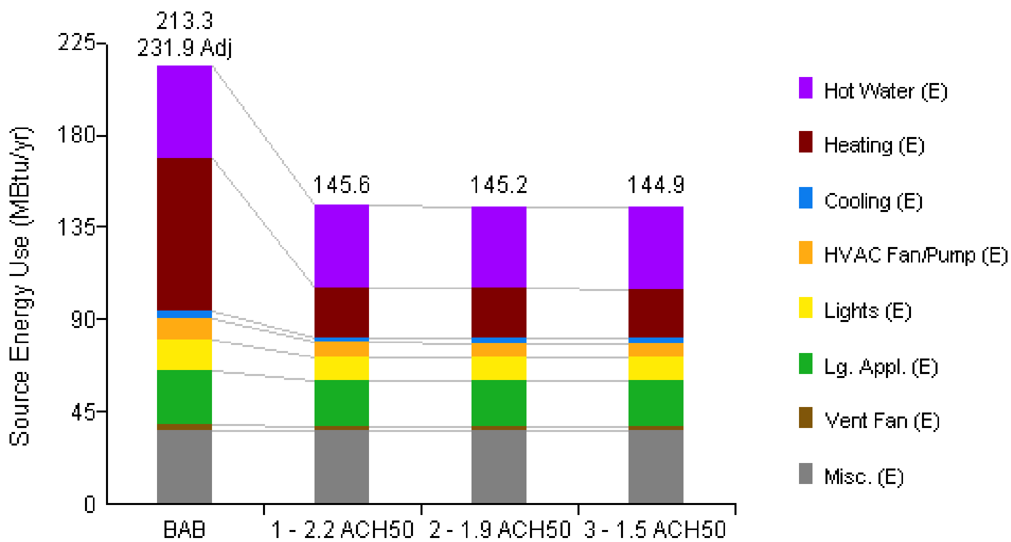


Figure 6. BEopt energy analysis by end use for measured whole-house airtightness

Figure 8 displays the results of the BEopt cost study for the final package. The annualized cost curve for the full optimization has an unusual shape, showing many measures with very large cost savings. The cost savings come from downsizing the GSHP from 5 tons to a minimum of 1.5 tons. Not all of these options are possible for this project.

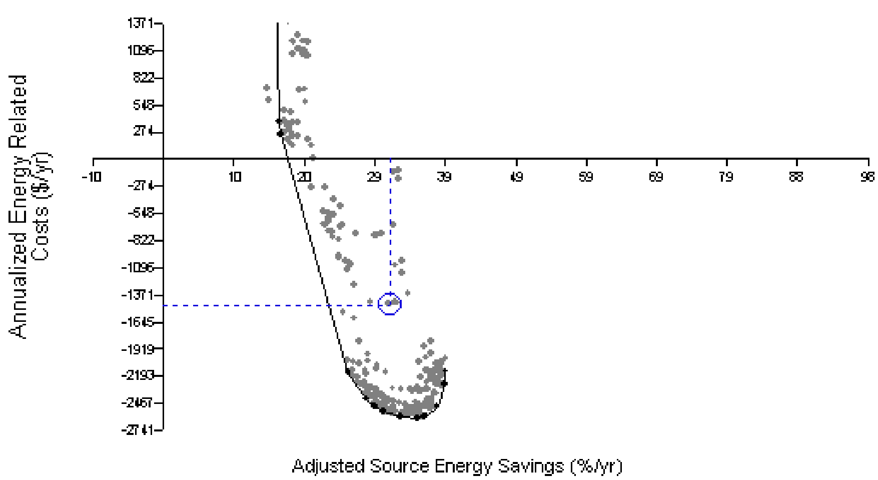


Figure 7. Final BEopt cost study

Recall that the choice of GSHP equipment for the houses included in this project was made as a separate decision by the City of Wyandotte. Some additional analysis was completed to further understand the potential effect of a different heating and cooling selection. In its benchmark mode, BEOpt does not allow a comparison of GSHP directly to an air source heat pump (ASHP) or other heating system. The following graphs compare GSHP to several different ASHP equipment selections in terms of energy (Figure 9) and cost (Figure 10).

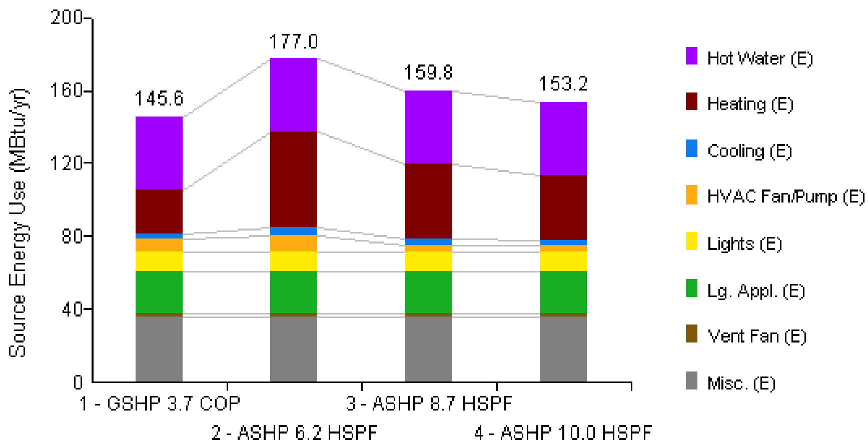


Figure 8. BEopt energy analysis for GSHP and ASHP options by end use

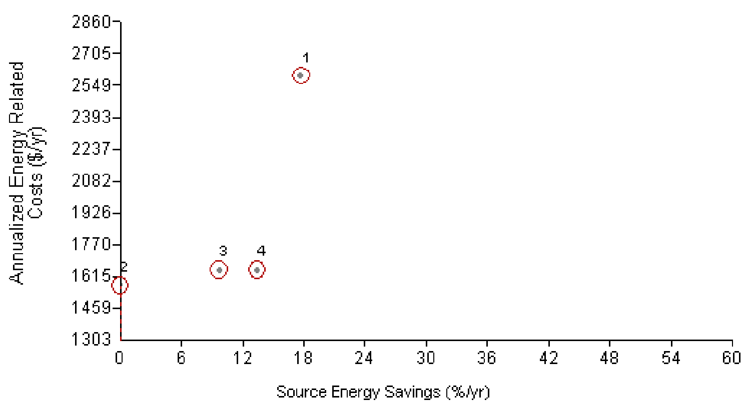


Figure 9. BEopt cost study for GSHP and ASHP options

The GSHP option for heating and cooling is (according to BEopt) the most efficient of the compared options, but it is considerably more expensive than the ASHP options.

4.3 Airtightness Testing Results

Table 7 summarizes the performance testing results for the houses completed under the research program.

Table 7. Airtightness Test Results Summary

House Number	Airtightness Test Results		
	CFM50	ACH50	CFM50/ft^2
Walnut 1	1030	2.7	0.20
Walnut 2	1007	2.6	0.19
Cora 5	678	3.6	0.49
Vinewood 2	539	2.7	0.36
Poplar 4	447	2.3	0.31
Cora 1	407	2.1	0.28
Poplar 3	202	0.92	0.14
Cora 2	197	1.0	0.14
Cora 6	148	0.8	0.11
Vinewood 1	n/a	n/a	n/a

Appendix C contains additional performance testing and site visit reports.

5 Discussion

5.1 General

The NSP2 project in Wyandotte is producing housing that generally meets or exceeds the specifications. Some challenges need to be overcome to reach targets on energy efficiency and cost, but given the commitment of the City of Wyandotte and the responsiveness of the builders, these targets seem within reach.

5.2 Documentation

The project has a special bid process and other MSHDA requirements that would not be found in typical projects, and these contribute to the level of detail in the drawings. Although atypical, this documentation set is an excellent example of the level of detail that is needed for the construction of a high performance home using new construction techniques.

One area where communication with the builders could be improved through additional drawing work is in the framing details, particularly for locations where blocking is needed to attach trim and exterior services. This could be addressed by preparing “knockdown” framing drawings (see Figure 12) for each plan set. An additional benefit of this approach would be greater consistency between framing crews working for different builders on the same plan types. This drawing work does, however, add costs to each set of drawings, and the drawings for most of the planned unit types have already been completed and bid. This communication is likely to take place on site instead.

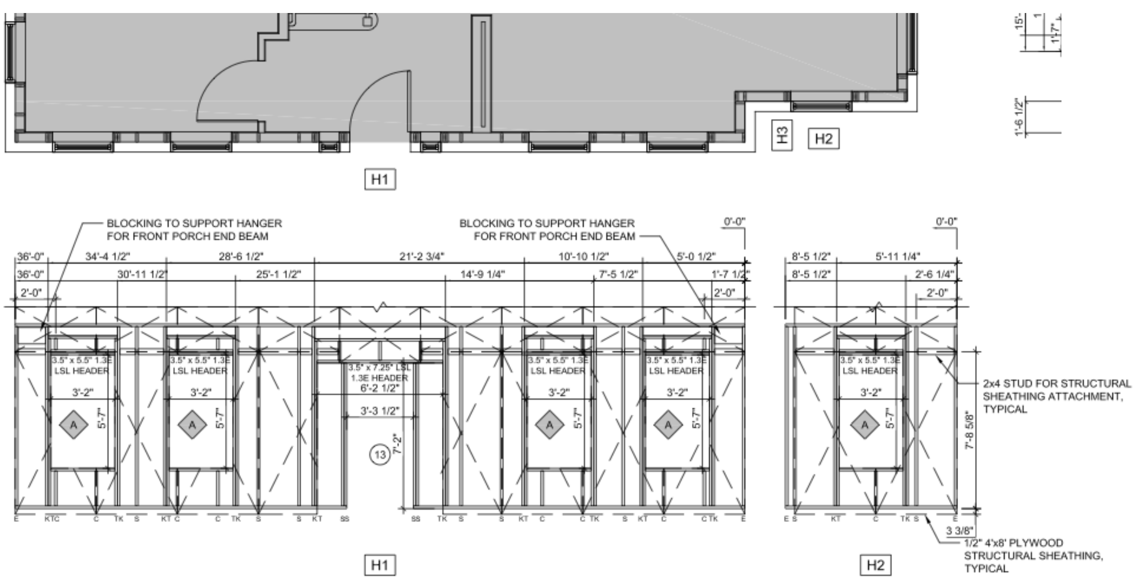


Figure 10. Example of knockdown framing drawings with partial floor plan

Another drawing-related issue is the separation of architectural and mechanical information. This stems from a unique situation on the Wyandotte project: the mechanical design and installation was bid as a separate package. With the separation also extending to the construction site (the builder of the house does not hold the contract for the mechanical system installation), the layout of the mechanical system has been negotiated on the construction site. In a more conventional situation, BSC would recommend an integration drawing like the example in Figure 12.

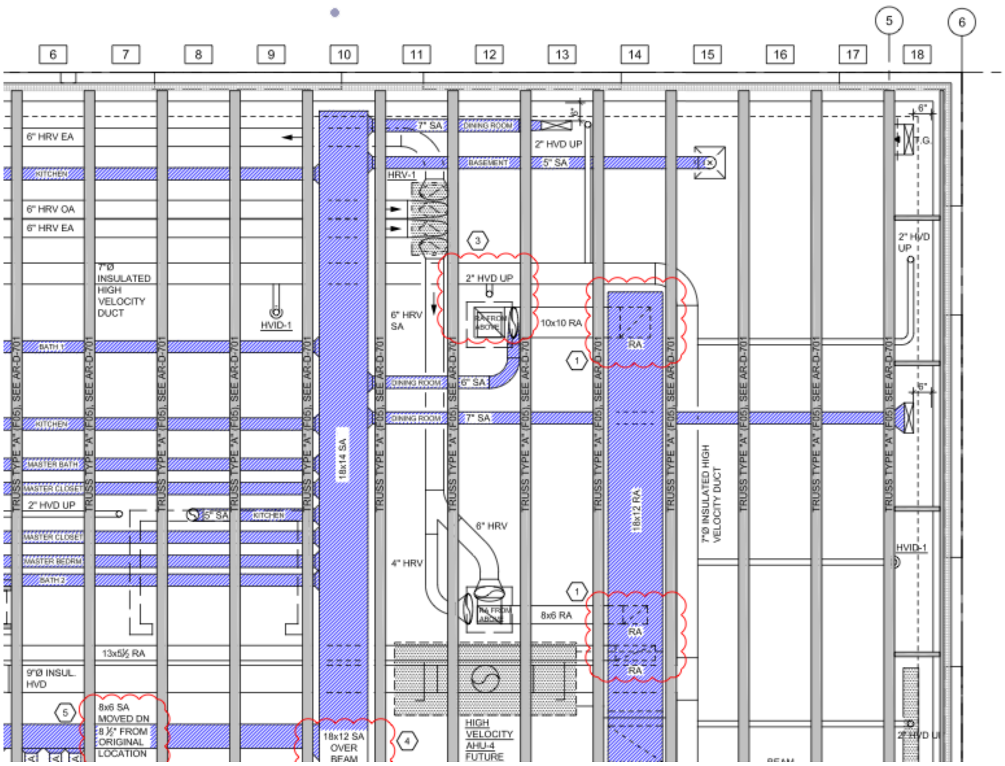


Figure 11. Example of floor framing plan with mechanical layout

If future phases of the Wyandotte project were expected to involve further drawing work, additional refinement of the drawing sets would likely be possible. One consideration that should be taken into account is the possibility for additional material and labor savings if future unit types are developed using a 24-in. module and the framing package is optimized using the framing plans rather than by the builder during construction.

5.3 Builder Selection and Training

Advanced Framing techniques were identified early on in the project as an area where special training would be needed. The project team decided that all bidders on the project would be required to attend an Advanced Framing workshop. This approach ensured that the successful bidder had detailed information about what would be expected before submitting a price. This strategy also meant that bidders that were not chosen to be participate in the project would also gain some exposure to Advanced Framing and other energy efficient technologies included in the technology specification, which is consistent with BA's industry transformation objective.

BSC staff conducted workshops on June 18 and October 6, 2011. The presentation material and attendance list for these workshops are included in Appendix C. A typical workshop included three parts: an introduction to BA and high performance housing, a presentation on Advanced Framing, and an on-site discussion of framing details. BSC was able to demonstrate and explain blower door testing in one of the workshops.

5.4 Foundations

As mentioned previously, builders chose either cast-in-place concrete or CMU foundations. From a structural perspective, these systems provide equivalent performance but CMU foundations present additional challenges for the control of air flow and bulk water intrusion. The installation of a "dimple sheet" membrane on the exterior of the CMU foundations would allow bulk water control to be significantly improved.

A roller-applied capillary break on the footing was specified, and installation was verified on several houses, but it was not clear that installation occurred in all cases.

The subslab XPS insulation was turned up at the slab edges but some interior partitions were installed before the foundation wall insulation, complicating the air sealing and thermal insulation (as pictured in Figure 13).

Figure 12. Photograph of slab edge insulation

5.5 Insulation and Air Sealing

The hybrid insulation strategy chosen for this project allowed the construction teams to consistently achieve a high level of airtightness and insulation installation quality. The process could, however, be improved in several areas.

BSC staff observed that a significant amount of air leakage was occurring in several areas in the house that was tested. From previous experience with ccSPF installations, these are common problems that can generally be addressed with additional training and minor adjustments to the scope of work for the framing crew and insulation installers. Figure 14 describes several areas that have been identified on several houses under construction.

	**#1 Rim joists** There are two issues with this detail. The first (A) is a common issue. If the first floor joist inside of the rim joist is too close, the closed cell spray polyurethane foam (ccSPF) installer may have difficulty angling the applicator to spray foam from the sill plate, up the rim joist, to the underside of the floor deck. The foam might or might not expand to seal this area. Inspection after foaming is difficult. The second issue (B) is uncommon. The first floor overhangs the sill plate to align with a brick veneer. This detail must have blocking for spray foam and creates a surface that is difficult to reach from the interior.
	**#2 Beam pockets** A beam has not been grouted into place. The underside of an exterior deck is visible through the opening (A). This area cannot be easily sealed or inspected from the outside. The geometry of structural elements in this location makes air sealing with spray foam difficult. It is likely that cavities behind and around the beam and wood blocking will not be fully sealed.
	**#3 Framing at dormers** Blocking is missing between the rafters in the dormer. The dormer side wall framing creates an air leakage path that is not sealed by the SPF installation.
	**#4 Air seal from rafter to floor deck** The rafter bays pictured have blocking and are ready for SPF installation. Preliminary blower door testing indicated that significant leakage occurred in this area.

Figure 13. Common points of air leakage

5.6 Exterior Finishing

As houses were moved through the construction process, several details related to the insulating sheathing were identified as needing special attention. These are discussed in Figure 15.

	**#1 Roof to wall flashing** A roofing membrane has been run up the wall from the roof sheathing and step flashing properly installed with the shingles. It is not clear, however, that the roof membrane bridges to the roof deck. The top of the membrane strip might not be not properly integrated with the surface of the insulating sheathing. BSC recommends that sheathing tape be used to terminate the top of the membrane, or, even better, the membrane be regletted into the insulating sheathing.
	**#2 Similar roof to wall detail** No transition membrane or step flashing has been installed.
	**#3 Similar roof to wall detail** Here there is no membrane but step flashing has been installed. Note that in this case, the drainage plane is not carried over onto the roof surface but instead will allow water to drain behind the step flashing.
	**#4 Bottom flange of window** The bottom flange of this window has been sealed with flashing tape. This will not allow the window unit and window opening to be drained to the exterior as intended. This issue is typically resolved easily by removing the tape and discussing with the installer.

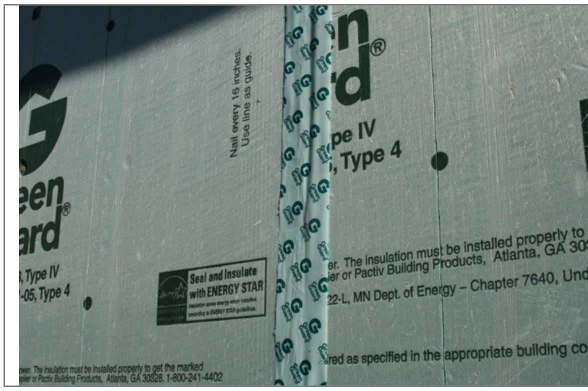
	**#5 Sheathing tape** The sheathing tape has not been rolled after application and the tape has bubbled. Even on a vertical joint, this increases the risk of water penetration and must be corrected.

Figure 14. Common water management issues with insulating sheathing

Figure 16 describes other areas of concern.

	**#1 Deck ledgers** The ledgers for attached desks should be "stood off" the structural frame to allow for continuous insulation and a continuous drainage plane down to the foundation wall level. This detail is at lower risk of water-related damage because the attached decks in the Wyandotte house designs are well sheltered by a porch roof.
	**#2 Corner and banding trim boards** Trim boards are typically installed in direct contact with the sheathing. It is not clear that proper flashing details have been put in place to direct water over and away from the back side of the trim. Adding furring behind these trim boards would greatly decrease the risk of water damage. Another trim-related issue is the provision of adequate blocking behind the insulating sheathing for trim attachment. This is being addressed by the framing crews.

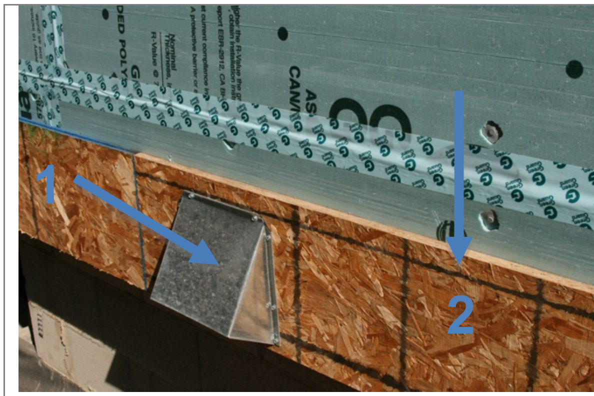
	**#3 Water table** Two issues are pictured here. The first (1) is that mechanical penetrations through this trim board are not properly flashed. The second (2) is that a regletted flashing must be installed over the trim board to direct water over and away from the small gap behind the trim board.

Figure 15. Common exterior finishing issues

5.7 Heating, Ventilation, and Air-Conditioning Installation

Installation of the ductwork on the first and second floors has been completed and finished. As specified, all ductwork joints and seals have been sealed with mastic (see Figure 15).

Figure 16. Typical duct sealing at boot and through interior partition top plate

5.8 Lighting and Appliances

A 100% CFL package and ENERGY STAR appliances have been specified for the NSP2 houses and these will be included in the final sale.

5.9 Sales and Marketing

The NSP2 houses were not marketed the way that typical production houses might be, although there were some common elements. The first houses completed for the program were used as open houses for public viewing, and the City of Wyandotte hired a real estate agency that posted the homes online (see Figure 18).

To attract attention to the program, the City of Wyandotte used local media and announcements through city correspondence with residents. As a result, a significant number of potential buyers joined a waiting list before construction.

Homeowners wishing to buy one of the NSP2 homes needed to qualify for the MSHDA low-income requirements and then join a lottery with other interested buyers. The low-income screening was a requirement of the program. Qualified buyers would receive the house at a subsidized price as part of a long-term lease/ownership model that was designed to ensure affordability. Note that the lower operating costs expected for the NSP2 houses in the program was a fundamental part of the affordability strategy.

Bed:3 Bath:2.0
List Price: $118,000

Wyandotte Nsp2 Home! Income & Credit Guidelines Apply. Buyers To Complete Counseling Class, Ctc Lighthouse Of Oakland County. See Attached Application & Requirements. Downpayment Assistance Available. New Construction. Energy Efficient. Geo Thermal Heating And Cooling. All Appliances Included. Open Houses April 1st And 15th 11 A.m. - 4 P.m.STV, REF, DISHW, WASH, DRY, MICRO, DISPSL Wyandotte

More abou[redacted]
MLS ID#: [redacted]

Listing Office: DOWNRIVER REAL ESTATE GROUP -- Listing Broker Address: 1644 FORD AVE

Figure 17. Example real estate website listing for Wyandotte NSP2 house

5.10 Purchase Price

As of April 2012, several houses in the Wyandotte NSP2 program were complete and ready for sale to qualifying homeowners. The NSP2 focus area in Wyandotte has an average list price of $74,248[5]. Table 10 shows that the total project costs for each house were significantly above the average sale price for other homes in the community. The average sale price, though, includes many smaller houses that would need significant renovation work.

As part of the program, the list price for the NSP2 houses was reduced using a financing arrangement with MSHDA. Table 8 gives the list price for the houses ready for construction.

[5] Information from real estate listing site on April 3, 2012: www.trulia.com/property/3074663891-247-Walnut-St-Wyandotte-MI-48192

Table 8. Construction Cost and List Price for Wyandotte NSP2 Homes

House Number	Construction Cost	List Price	Description
Walnut 1	$190,000	$120,000	1,460 ft^2, 3 bedroom, 2 bath
Walnut 2	$199,000	$115,000	1,491 ft^2, 3 bedroom, 2 bath
Cora 5	$168,000	$128,000	1,443 ft^2, 3 bedroom, 2 bath
Cora 1	$172,000	$128,000	1,143 ft^2, 3 bedroom, 2 bath
Cora 2	$169,000	$118,000	1,463 ft^2, 3 bedroom, 2 bath
Vinewood 1	$192,000	$118,000	1,504 ft^2, 3 bedroom, 2 bath
Poplar 1	$210,000	$118,000	1,504 ft^2, 3 bedroom, 2 bath
Poplar 2	$192,000	$113,000	1504 ft^2, 3 bedroom, 2 bath

5.11 Homebuyer Education

A homeowner manual based on previous work by BSC was developed for this project and will be given to purchasers.

BSC typically recommends making an introductory presentation on the operation of a high performance house. In this case a public presentation for home buyers and prospective home buyers would seem to be a good fit with the program goals. This session has not been scheduled and this topic will be discussed after houses have been prepared for sale.

6 Conclusions

6.1 Responses to Research Questions

The new construction projects discussed in this report will serve as examples of successful affordable, high performance homes that could be built in a cold-climate area similar to Detroit. The specifications that are recommended as part of this technology package show a clear improvement in energy efficiency, durability, and indoor air quality when compared to typical construction in the area. BSC's energy modeling and field testing work shows an estimated 37% whole-house energy savings, and the Wyandotte NSP2 project has demonstrated that this level of performance is achievable in an affordable construction package.

The following answers can be given to the project research questions:

1. **Does the proposed hybrid wall assembly meet expectations for whole building airtightness and construction efficiency?** Yes, but there is room for improvement. The construction process and detailing of the assembly can both be adjusted as construction progresses. The preliminary blower door testing conducted on the first substantially complete house indicated that even as a first attempt by the builder, the BA airtightness target of 2.5-$in.^2$ leakage area per 100-ft^2 enclosure @ 50 Pa was achievable with the hybrid wall system.

As construction progressed, trades and other project stakeholders (general contractors, building code officials, the project architect's staff, and the city project manager) became more familiar with the common points of air leakage and changes were made to the drawings, scopes of work, and construction inspection. Well into the construction process, a whole-house airtightness of 0.5-$in.^2$ leakage area per 100-ft^2 enclosure @ 50 Pa was consistently achievable.

Based on this experience, BSC recommends that the predrywall enclosure airtightness test be conducted following four construction steps: (1) the installation of the windows, (2) the installation of the window flashing; (3) the spraying of foam on the interior of walls and roofs; and (4) the integration with the foundation air barrier system. An advantage of the hybrid enclosure assembly is that the air barrier system is complete at this early stage of construction and testing and remedial work can be very effective at this time. BSC plans to develop a scope of work for this testing.

2. **Can water management details for insulating sheathing be cost-effectively executed by the construction team?** Yes. The water management details were part of the drawings and specifications included in the bid package and builders were not asked to price this work separately. Work on site to date has indicated that the details can be executed with reasonable speed and effectiveness given some initial training for the installers. Although areas for improvement were identified on several houses, the project team was able to correct these issues.
3. **Does the total project cost fall within the project requirements and deliver higher than expected energy performance?** Measured energy performance of the Wyandotte houses is not available for confirmation. BSC's modeled results, however, show an estimated 37% whole-house energy savings over the BA benchmark. This is higher than expected.

The project cost requirements are more difficult to assess. Table 10 in the previous section shows that the construction cost of the houses is much higher than the sale price. The final construction costs work out at between \$115/ft^2 and \$125/ft^2. This is close, however, to the \$120/ft^2 cost that was planned from the beginning of the NSP2 project. Consequently, it should be considered an expected result.

Further cost savings should be possible as construction of the remaining houses in the project continues. Certainly the GSHP system is an expensive line item (including wells, it represents about 10%–15% of the total construction cost). Less expensive options for heating and cooling could be employed on other projects.

4. **Is the sizing method for the GSHP accurate for small houses with high thermal resistance enclosures?** Data from completed and occupied houses are not currently available. Equipment sizing calculations have shown, however, that the enclosure improvements should result in a decrease in the capacity that was expected. More information is needed to make a final determination. This question will need to be answered by future research work.
5. **Can the GSHP unit be reduced in size to accommodate additional homes on the same well?** Based on load calculations using the relatively high levels of insulation, above-average windows, and the BA airtightness specification, it would seem possible to accommodate two small houses on a typical 6- to 8-ton well. The final as-built airtightness of the enclosure and the performance of the wells that have been installed, though, are major variables in this estimation. With some work, efforts to reduce the building heating and cooling loads can be increased. The progress that has been made on the houses constructed to date demonstrates that this is a real possibility. Wyandotte Municipal Services should measure the performance of the wells. In the future, Wyandotte Municipal Services intends to examine the possibility of linking wells together to form a district system. Low-load houses will be an asset if a district system is developed.

6.2 Future Development for Higher Performance Levels

Specific challenges must be overcome to reach the estimated energy savings, including the following:

- Achieving a coordinated approach between the architectural plans and the mechanical system design and installation
- Supporting multiple builders as they adjust to new construction techniques and new materials
- Implementing a quality control process based on performance testing and feedback for the builder, specifically in the areas of air sealing and cladding attachment
- Adjusting plans and specifications to incorporate solutions for issues observed on site, specifically involving framing and water management details
- Developing a plan for marketing to buyers and educating homeowners.

Many issues could change the specifications in these homes going forward. They include cost and budget concerns, requirements of other rating and certification programs, material availability, and labor experience. BSC will continue to work with the City of Wyandotte to make necessary changes to the improvements while maintaining the high standard of construction required by the BA program.

6.3 Gaps in Existing Measure Guidelines

The following gaps were identified in existing measure guidelines:

- **Quality management strategies.** Wyandotte NSP2 is not a typical project in the way that the funding and project management is structured. As codes and standards change, however, it could become more common for local building departments, state housing authorities, or utility programs to specify a high performance housing product. For many of the strategies that are incorporated into construction similar to what has been built in Wyandotte, a quality management process is essential to achieving the estimated energy performance. Experience with the Wyandotte project suggests that this measure guideline should include local building departments, state housing authorities, and utility providers as part of the target audience.

- **Wall air sealing and insulation methods.** Insulating sheathing has been examined by many different BA research projects and has been found to be an effective way of achieving higher levels of enclosure insulation. Lack of information from manufacturers on the attachment of different cladding types over more than 1.5 in. of insulating sheathing, though, has created a limitation for the architect in the important task of developing designs that would fit well with neighboring houses. The information gap has also caused problems for trades installing cladding and trim. This is a clear example of the nonenergy-related practical challenges faced when deploying new energy efficient technology. Changing energy codes and consumer expectations for energy performance make it likely that the use of greater thicknesses of insulating sheathing in cold-climate homes will become more widespread. Guidance on this topic should be developed.

6.4 Recommendations for Future Measure Guidelines

Based on the work completed in Wyandotte, the following measure guidelines would address key problems with performance or general knowledge:

- **GSHPs for Cold-Climate Homes.** This technology is a popular choice for many builders in cold-climate locations. Information about the proper sizing and operation of these units is not available from BA in the form of a measure guideline. Additional research that includes longer term monitoring of installed systems in a number of situations would seem to be an important part of such a publication.

- **Heat Recovery Ventilation and Energy Recovery Ventilation Systems for Cold Climates.** These systems are not being used in the Wyandotte NSP2 houses, but this technology was considered during the energy analysis phase and several builders in the program have asked about using these systems. Clear guidance from BA—particularly about the effectiveness of both heat recovery ventilation and energy recovery ventilation systems in cold climates—is needed.

- **Water Management Details for Insulating Sheathing.** BSC is conducting research on this topic. Guidance on a number of specific details (including roof to wall, foundation to wall, and window installation, among others) was given to the Wyandotte team but this information should be gathered together as a measure guideline.

7 References

ACCA (2011). *Manual J Residential Load Calculation (8th Edition).* Arlington, VA: Air Conditioning Contractors of America.

ASHRAE (2010). 2010 ASHRAE Standard 62.2 – Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings. Atlanta, GA: ASHRAE.

Baker, P. (October 2006). RR-0604: Incorporating Insulating Sheathing into the Design of the Thermal and Moisture Management System of the Building Enclosure. BSC. Accessed January 3, 2011: www.buildingscience.com/documents/reports/rr-0604-incorporating-insulating-sheathing-into-design-of-thermal-and-moisture-management-system-of-building-enclosure/.

BSC (November 2010). *RR-1004: 2010 Community Scale Evaluations.* Accessed January 3, 2011: https://www.buildingscience.com/documents/reports/rr-1004-ba-special-research-advanced-framing-deployment/view?searchterm=rr-1004.

BSC (February 2010). *Designs that Work - Cold Climate: Habitat for Humanity High R-Value Prototype.* BSC. Accessed January 3, 2011: www.buildingscience.com/documents/case-studies/cs-ma-westford-hfh/.

BSC (May 2009). *Info-201: Common Advanced Framing Details.* BSC. Accessed January 3, 2011: http://www.buildingscience.com/documents/information-sheets/information-sheet-common-advanced-framing-details

Lstiburek, J.; Lukachko, A. (December 2008). *Plans for Energy Efficient Homes in Greensburg, KS.* BSC. Accessed April 26, 2011: www.buildingscience.com/documents/reports/rr-0804-energy-efficient-plans-greensburg-ks/

BSC (June 2008). *Research Reports # 305: Why it's So Important (and Troubling) to Keep Ducts and Equipment in Conditioned Space.* Accessed May 15, 2011: www.buildingscience.com/documents/reports/rr-0305-why-it-s-so-important-and-troubling-to-keep-ducts-and-equipment-in-conditioned-space/view?searchterm=ducts.

BSC (October 2007). *Guide to Insulating Sheathing.* Accessed January 3, 2011: www.buildingscience.com/documents/guides-and-manuals/gm-guide-insulating-sheathing/.

BSC (August 1999). "Designs that Work—Cold Climate: Cleveland Infill Prototype House." Accessed January 3, 2011: www.buildingscience.com/documents/case-studies/cs-cleveland-infill/.

Hendron, R., R. Anderson, D. Barley, A. Rudd, A. Townsend, and E. Hancock. (October 2008). "Field Test of Room-to-Room Distribution of Outside Air with Two Residential Ventilation Systems." Prepared for ASHRAE IAQ 2007, Baltimore, Maryland, October 15–17, 2007. NREL/CP-550-41210. Golden, CO: National Renewable Energy Laboratory.

ICC (2010). *2009 International Energy Conservation Code*. Washington, DC: International Code Council, 2010.

Lstiburek, J. (2006). *Builder's Guide to Cold Climates.* Westford, MA: Building Science Press.

Lstiburek, J.; Grin, A. (December 2010). *RR-1004: Building America Special Research Project—Advanced Framing Deployment.* BSC. Accessed January 3, 2011: www.buildingscience.com/documents/reports/rr-1004-ba-special-research-advanced-framing-deployment/.

Lukachko, A.; Bergey, D. (2010). Wyandotte NSP2 Cold Climate Commercially Viable Energy Efficiency Solution Package. BSC unpublished report.

MSHDA (undated). "Michigan NSP Consortium Application Program Design." Accessed May 10, 2011: www.michigan.gov/documents/mshda/mshda_NSP2_Program__Design_posting_for_public_comment_284962_7.pdf.

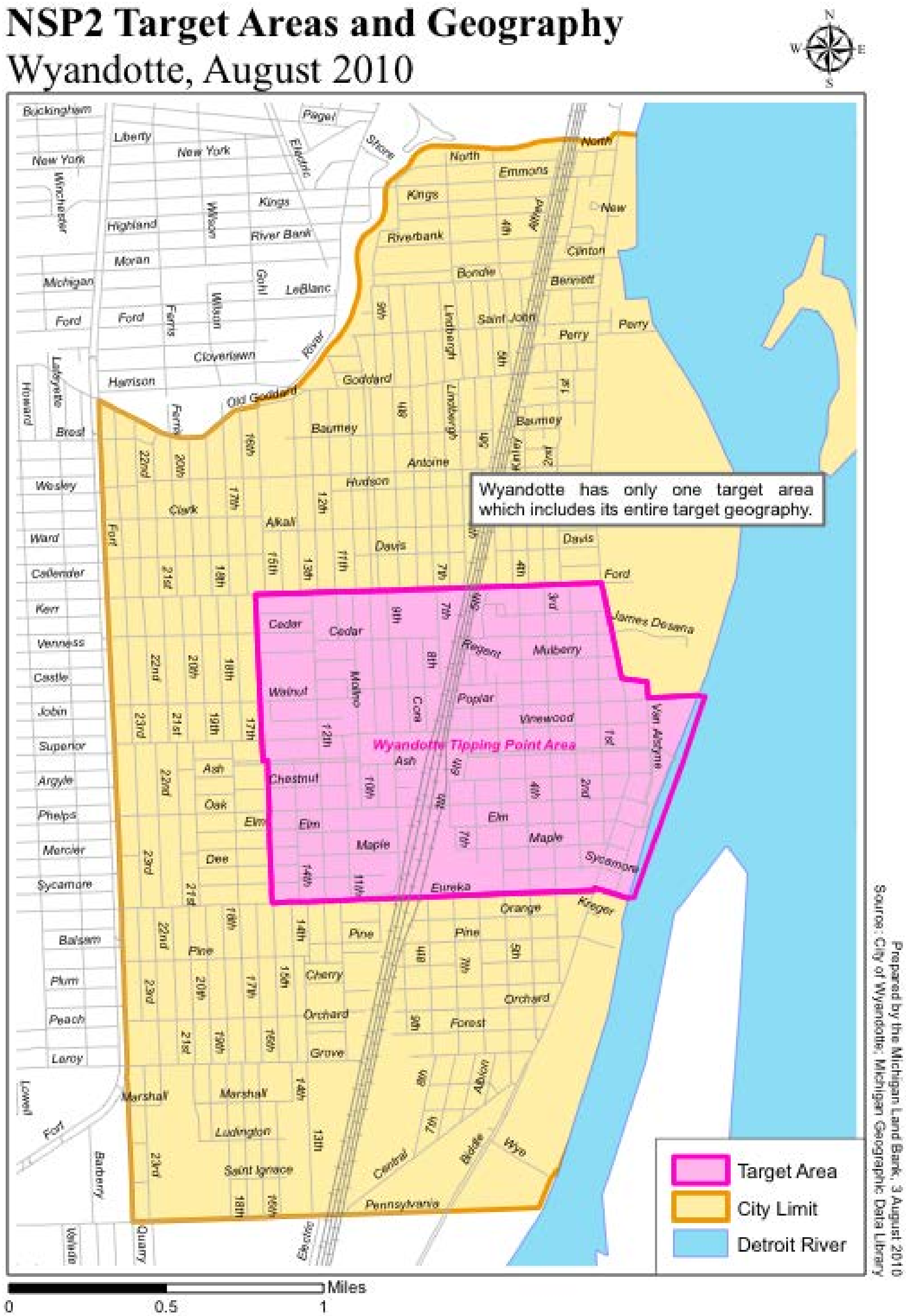
Rudd, A. (June 2008). *RR-0304: Central Fan Integrated Supply Ventilation—The Basics.* BSC. Accessed January 3, 2011: www.buildingscience.com/documents/reports/rr-0304-central-fan-integrated-supply-ventilation-the-basics/.

Straube, J.; Smegal, J. (March 2009). *RR-0903: Building America Special Research Project—High-R Walls Case Study Analysis.* BSC. Accessed January 3, 2011: https://www.buildingscience.com/documents/reports/rr-0903-building-america-special-research-project-high-r-walls/.

Ueno, K. (October 2001). *Research Reports # 110: HVAC Equipment Sizing Strategies: Taking Advantage of High Performance Buildings.* BSC. Accessed May 15, 2011: www.buildingscience.com/documents/reports/rr-0110-hvac-equipment-sizing-strategies-taking-advantage-of-high-performance-buildings/view?searchterm=right%20sizing.

Ueno, K.; Straube, J. (2010). Building Science Digests: BSD-151: Understanding Primary/Source and Site Energy. BSC. Accessed October 14, 2012: www.buildingscience.com/documents/digests/bsd151-understanding-primary-source-site-energy.

Appendix A: MSHDA Wyandotte, MI NSP2 Target Areas



Appendix B: Wyandotte NSP2 Initial Energy Analysis (November 9, 2010)

TECHNICAL SUPPORT FOR ENERGY EFFICIENT, AFFORDABLE NSP2 HOUSING IN WYANDOTTE, MI – PRELIMINARY REPORT

Alex Lukachko and Philip Kerrigan, Building Science Corporation
November 9, 2010

Introduction

In 2010, Building Science Corporation, through the Building America research program, assisted the City of Wyandotte with the first phase of a mixed new and retrofit affordable housing Neighborhood Stabilization Project 2 (NSP2) project in Michigan. Initial work included refinement of plans and specifications that were included in the preliminary bid package. The project, which is expected to extend into 2012, will include approximately 25 new houses and 19 retrofits of existing homes in the downtown area.

Project Information Summary Sheet

PROJECT SUMMARY	
Company	City of Wyandotte
Company Profile	Incorporated in 1867, the City of Wyandotte is often described as the 'Heart of Downriver.' The site where Wyandotte sits today was, in the 1700s, a village for the Native American tribe known as the Wyandot, a part of the Huron Nation. A waterfront community, Wyandotte is rich in history and is known for its distinctive architecture, charming downtown district and variety of cultural offerings. The City has been awarded the designation of a Preserve America Community by the Federal Government. Wyandotte Municipal Service Commission provides electricity, water, and telecommunication utilities for Wyandotte. This City owned utility was created in 1889. More information about the City of Wyandotte can be found at www.wyandotte.net
Contact Information	Mark A. Kowalewski, P.E., City Engineer City of Wyandotte 3131 Biddle Ave. Wyandotte, MI 48192 Tel: (734) 324-4500
Division Name	n/a
Company Type	City - NSP2 recipient
Community Name	Wyandotte NSP2
City, State	Wyandotte, MI
Climate Region	Cold, Climate Zone 5

SPECIFICATIONS	
Number of Houses	25 new, 19 retrofit
Municipal Address(es)	varies
House Style(s)	Various single family homes
Number of Stories	1.5 stories typical
Number of Bedrooms	3 typical

Plan Number(s)	247 Walnut
Floor Area	1475 sq ft
Basement Area	~600 sq ft
Estimated Energy Reduction	Greater than 40% under BA Benchmark
Estimated Energy Savings	More than $780 per year
Estimated Cost	Target construction cost is $100 per sq ft
Construction Start	Expected late 2010
Expected Buildout	End of 2012

Preliminary Technical Support

In August, BSC worked with industry partner BASF and the City of Wyandotte to develop a technical specification for the new and existing houses in the planned project. The project architect working for the City prepared plans for the first 3 houses to be tendered. BSC provided initial advice on enclosure and mechanical systems, and planned to complete an energy analysis when the house plans were moved to a more developed stage. A major issue for the design team was the planned budget for each house. The architects worked with an estimator to establish baseline costing for proposed enclosure and mechanical system specifications. BASF worked with the City on material supply and pricing in an effort to provide more certainty on the material pricing.

On September 22 and 23, BSC staff met with the City of Wyandotte and BASF. With the City, BSC discussed the systems engineering approach that will be employed on the new and retrofit plans being developed by the architect. BSC also presented the results of a preliminary energy analysis (see section below) based on as-is plans and specifications. BSC discussed deployment strategies for the planned high performance houses, which will include some element of information/education for trades bidding on the work for this project. This will be designed to broaden the understanding of high performance housing techniques in the local workforce. Plans for collecting utility bills from the completed houses were discussed and will be implemented by the City.

Following the meeting with the City, BSC and BASF met with the project architect and HERS provider. A brief review of the tender packages for the first three houses was conducted. Testing and inspection requirements were discussed with the HERS rater.

On September 23rd, BSC and BASF met with the architect to review the plans in more detail. Technical specifications and details for air tightness, water management and thermal control were discussed. BSC and the architect then met with the engineering firm that will provide the district GSHP system for the city. Basic details of the system were discussed. BSC noted that significant technical support and monitoring may be required for this system - possibly a research interest for NREL researchers. More information on equipment sizing, DHW, ventilation, and ducting will be collected from the HVAC installer hired for this project at a future meeting.
A visit to several of the proposed project sites was made at the end of the day. BSC observed that the sites are well distributed in a lively neighborhood and will be excellent examples of neighborhood development.

Preliminary Whole-House Performance and Systems Engineering

The following is a preliminary energy analysis of one of the new house plans developed for the project. The reader should note that at the time of this analysis, not all energy efficient upgrades to the original specifications were agreed upon and implemented. While the preliminary analysis shows a significant energy savings, the project team expects that additional savings will be realized as the project develops.

The 247 Walnut floor plan is a two story detached house with a full conditioned basement. Table 9 below lists some of the basic dimensions and areas that were calculated through a plan takeoff. Some dimensions (such as floor area) may be different than what is listed in the drawing set due to our takeoff procedures.

Table 9. Basic Dimensions and Areas for 247 Walnut

Floor area (sf)	Surface Area (sf)	Volume (cf)	Beds (ct)	Baths (ct)	Glazing Ratio
1475	4077	24969	3	2.0	24.8%

Whole house hourly energy consumption simulations were completed calculating the source energy consumption savings for 247 Walnut compared to the 2010 Building America Benchmark Definition created by the Department of Energy. The Building America Benchmark is a protocol for creating a reference house to which the target floor plan (247 Walnut, in this case) is compared to in order to calculate a % savings. The BA Benchmark specifies a home with similar dimensions vs. the target floor plan but with standard code specifications that are based on the 2003 IECC.[6] Other assumptions are built into the definition (lighting, appliances etc) so a complete model of the entire house can be created. This provides an energy “baseline” that allows a percent savings to be calculated for Building America homes using our computerized models (Energy Gauge USA).

Whole house hourly energy consumption simulations were also completed vs. the 2009. Table 10 summarizes the characteristics for each of the three categories. In some cases BSC had to make some assumptions, those are noted in the table.

[6] See www.energycodes.gov/ for more information.

Table 10. Building Energy Specifications

	Current Builder Specifications	2010 BA Benchmark	2009 IECC
Building Enclosure			
Roof	Unvented cathedralized attic R-49 total: 2" SPRAYTITE® (R-10.48) + 10" R-38	Assembly U-value 0.026 (~R-38 equivalent)	R-38 unvented cathedralized attic
Walls	R-33 total: 2x6 @ 24" o.c. framing with 2" SPRAYTITE® (R-10.48) and R-13 batts 2" NEOPOR® R-9.2 as insulating sheathing	Assembly U-value 0.058 (~R-17 equivalent)	R-13 cavity insulation with R-5 insulating sheathing
Basement Walls	2" foil faced polyisocyanurate full length	Assembly U-value 0.096 (~R-10.5 equivalent)	R-10 continuous rigid insulation
Windows	vinyl double glazed assumed (U=0.32, SHGC=0.32) glass block windows (U=0.6, SHGC=0.6)	U=0.39, SHGC=0.32 glass block windows (U=0.6, SHGC=0.6)	U=0.32, SHGC=0.40 glass block windows (U=0.6, SHGC=0.6)
Infiltration	1944 CFM 50 (3.55 Ach 50) assumed	2786 CFM 50 (5.08 ACH 50)	3239 CFM 50 (ACH 50)
Mechanical Systems			
Heat	3.3 COP (assumed) ground source heat pump	6.8 HSPF air source heat pump	7.7 HSPF air source heat pump
Cooling	14.1 EER (assumed) ground source heat pump	10 SEER air source heat pump	13 SEER air source heat pump
DHW	0.90 EF electric tank water heater assumed	0.86 EF electric tank water heater	0.86 EF electric tank water heater
Ducts	R-8 flex runouts in conditioned space 15% total duct leakage assumed	R-3.3 ductwork in conditioned space 15% total duct leakage	R-6 ductwork in conditioned space 15% total duct leakage
Ventilation	45 CFM continuous ventilation with ASHRAE 62.2 rated exhaust fan)	45 CFM continuous ventilation with ASHRAE 62.2 rated exhaust fan)	45 CFM continuous ventilation with ASHRAE 62.2 rated exhaust fan)
Appliances and Lighting			
Lighting	86% Incandescent / 14% Compact Fluorescent	86% Incandescent / 14% Compact Fluorescent	86% Incandescent / 14% Compact Fluorescent
Appliances	Standard Appliances assumed	Standard Appliances	Standard Appliances

Table 11 below outlines the calculated energy savings for 247 Walnut for both comparisons. The house saves 39.1% vs. the Benchmark. The predicted HERS Index is also listed for each configuration. The floor plan with the current specifications receives a HERS Index of 75, compared to the 70 or lower that is needed to be Builder's Challenge certified.

Table 11. Simulation Results for 247 Walnut

Description of change	% savings	Annual energy cost	Savings	HERS Index
2010 BA Benchmark	n/a	$2,342	n/a	111.0
Current Builder Specifications	39.1%	$1,560	$782	75.0
2009 IECC	n/a	$2,251	n/a	102.0
Current Builder Specifications	30.7%	$1,560	$692	75.0

The total annual energy costs were predicted using local utility rates:
Wyandotte Municipal Services *~$0.09/kWh Residential Rate*

Figure 19 is a bar graph that shows the whole house source energy use broken down into components. Energy consumption for heating was reduced the most. This is due to the enclosure upgrades along with the ground source heat pump.

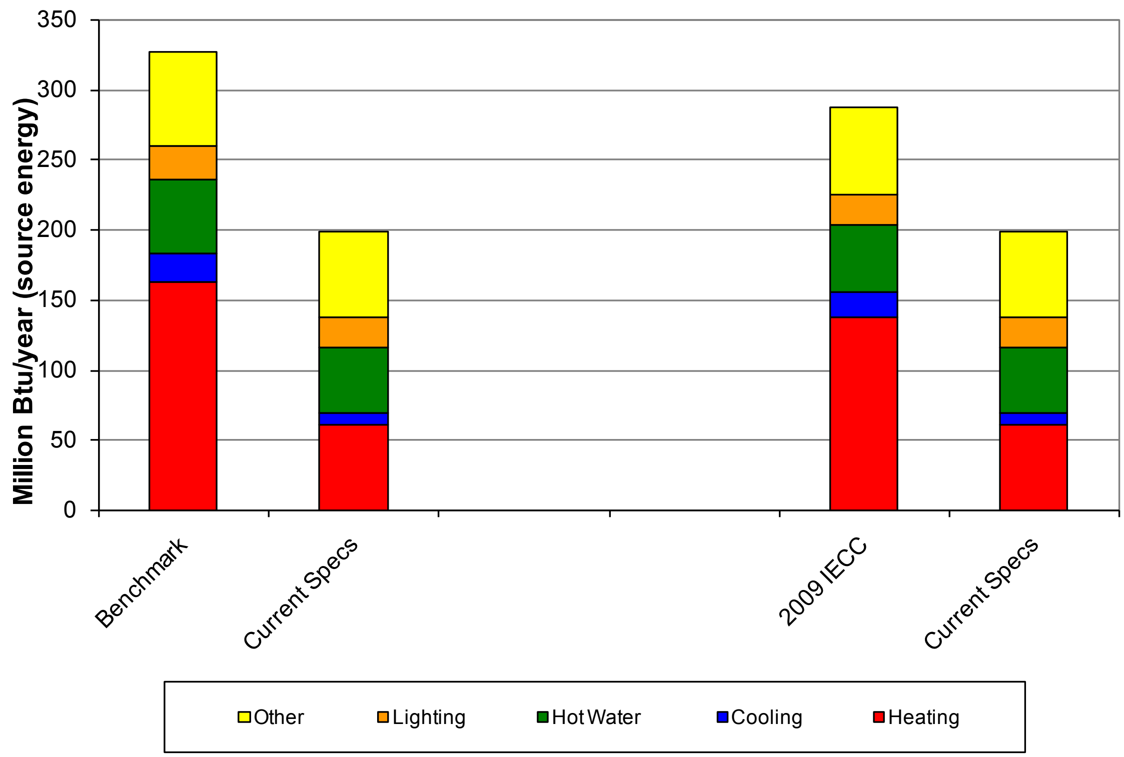


Figure 18. 247 Walnut Parametric Results Graph

Preliminary Conclusions

The NSP2 project of the City of Wyandotte has good potential to achieve affordable high energy savings for new and existing homes. The preliminary plans developed by the project architect show excellent attention to building science detail and a significant amount of work has been done to integrate energy efficiency and durability measure into the buildings while maintaining the aggressive construction cost target set by the City. BSC anticipates that additional energy savings will be secured as subsequent plan sets are developed.

The City of Wyandotte has proposed a long-term plan to create a district ground source heat pump (DGSHP) service run by the City-owned utility company. The initial stage of this plan will be for each of the NSP2 houses to be equipped with a single well drilled in the boulevard in front of the house. Initially, the wells will provide heating, cooling and domestic hot water for the homes. In the long term, these wells will be linked to form the source/sink for the district system. The efficiency of each of the new and existing houses in the project will in part determine the additional capacity of the DGSHP system that can be sold to residents that were not part of the initial NSP2 program. The energy efficiency goals of the housing project therefore are fundamentally connected to the long-term viability of the DGSHP project, creating a further reason to anticipate additional energy savings.

Appendix C: Site Visit Reports

2011-06-08 Wyandotte Site Visit Report

2011-06-28 Wyandotte Site Visit Report (included presentation attendance list and slides)

2011-08-22 Wyandotte Site Visit Report

2011-10-06 Wyandotte Site Visit Report (included presentation attendance list and slides)

2011-11-28 SNAPSHOT form for Walnut 1

2011-11-28 SNAPSHOT form for Walnut 2

Appendix D: Project Team Contact Information

Table 12. Industry Team Member Contact Information

Company Name	Team Member	Email	Phone
City of Wyandotte	Ralph Hope, project manager	rhope@wyan.org	734-324-4525
City of Wyandotte	Mark Kowalewski, chief city engineer	mkowalewski@wyan.org	734-324-4554
Sarnacki & Associates Architects	John "Jay" Sarnacki, AIA	jsarnacki@sarnackiaia.com	734-282-3900
Sarnacki & Associates Architects	Dan Boggs	dboggs@sarnackiaia.com	734-282-3900
Hardin Geothermal	Dave Congdon	dcongdon@hardingeo.com	734-890-1889
Cappy Heating and Air Conditioning	Jeff Caplan	jeff@cappyheating.com	313-218-2846
Building Science Corporation	Alex Lukachko	alex@buildingscience.com	978-589-5100
Building Science Corporation	Daniel Bergey	daniel@buildingscience.com	978-589-5100
Building Science Corporation	Aaron Grin	agrin@buildingscience.com	978-589-5100
Warm Training Center	Stephen Christensen	schristensen@warmtraining.com	313-418-5419
BASF	Paul Campbell	paul.w.campbell@basf.com	704-587-8283
BASF	Aaron Davenport	aaron.davenport@basf.com	980-207-8192

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102013-3634 · January 2013

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.