# 5. SANDSTONE, ELLENDALE, DE

## 5.1 Executive Summary

### Gate 3 – Community: Sandstone, Colter Construction, Ellendale, DE

### Overview

Colter Construction is developer and builder for the Sandstone community. Sandstone will include 48 houses and a community park, on a total 49 acres. The first homes were built in 2009, and construction is ongoing. Energy efficiency has been a part of Colter Constructions company strategy, and Building Science Corporation is working with the builder to bring company practice up to Building America standards for energy and durability.

### Key Results

One home has been completed to Building America specifications, and one more is in progress. The builder has successfully implemented BSC's recommendations for enclosure and mechanical design. A few deficiencies have been identified and will be remedied in future houses.

### Gate Status

**Table 5.1.1: Stage Gate Status Summary**

| "Must Meet" Gate Criteria | Status | Summary |
|---|---|---|
| Source Energy Savings | Pass | The Sandstone houses are saving 44% relative to mid-90's Benchmark construction. |
| Quality Control Requirements | Pass | The Builder's Challenge checklist was used to verify quality of construction. |
| Market Coverage | Pass | Sandstone is expected to complete 10 homes in 2010. |
| Neutral Cost Target | Pass | Net cash flow to the homeowner is expected to exceed $800 if the upgrade costs are financed as part of a 30 year mortgage at 7%. |

| "Should Meet" Gate Criteria | Status | Summary |
|---|---|---|
| Marketability | Pass | Homes are being sold in an active market at locally competitive prices. |
| Market Coverage | Pass | Sandstone is located in a Mixed Humid climate (DOE Climate Zone 4). |
| Builder Commitment | Pass | Colter Construction intends to build out the rest of the community to Building America standards. |
| Gaps Analysis | Pass | Colter Construction is continuing to work with BSC to evaluate the efficiency, reliability, and practicality of dual-fuel heating systems. |
| Quality Assurance | Pass | Colter Construction owner Terrance Babbie is frequently on site, and communicates design changes to the contractors. He employs experienced construction teams who demonstrate excellent workmanship for familiar and new methods. |

## Conclusions

Over the next few years, Colter Construction will be building 45 more high-performance homes featuring exceptional airtightness, very high levels of insulation for the region, and state of the art mechanical systems.  All of these homes are expected to meet current or future Building America source energy targets.

Future homes will correct deficiencies in water management, foundation connection details, and mechanical controls which were evident in the first houses built.  BSC and the builder will continue to investigate the best available mechanical options in this climate and market.  A good dual-fuel system should maintain comfortable temperature and humidity throughout the year, minimize energy consumption, and be relatively simple to install and especially to operate.  Such a system would be broadly applicable to homes in mixed and cold climates, save homeowners money, and provide an excellent platform for time dependant electricity pricing or other peak-shifting strategies.

## 5.2 Introduction

### 5.2.1. Project Overview

Sandstone is a 49-home subdivision located in Ellendale, DE. The project is Colter Construction's first entry into community-scale development. The homes are intended to be attractive to the first-time homeowner, and to empty nesters, two strong markets in the region. The company has considerable experience building energy efficient custom homes in Sussex County.

Founder and owner Terrance Babbie contacted BSC in May of 2009 for help in bringing his construction practices up to the state of the art. Terrance was already familiar with much of BSC's published materials, and works with subcontractors who are also accustomed to standard energy measures in the custom market. This experience was invaluable in rapidly implementing BSC's recommendations for airtightness, insulating sheathing, duct layout, and other efficiency measures.

The homes are single-family detached residences of 1200 to 2000 sf with unvented crawlspaces. The community is located in DOE Climate Zone 4, a mixed humid climate. Humidity control and mechanical efficiency, for both heating and cooling, were of special concern.

The Building America energy consumption reduction goals (minimum 40% source energy consumption reduction compared to the 1990's Benchmark construction) were exceeded for the community. The homes were modeled at around 44% savings, an exceptional performance in this market.

**Figure 5.2.1: Front entrance (South) of Allen home before testing**

Figure 5.2.2: Front entrance of Smith house plan

Figure 5.2.3: Alexander house plan during construction

## 5.2.2. Project Information Summary Sheet

| PROJECT SUMMARY | |
|---|---|
| **Company** | Colter Construction |
| Company Profile | For the last 20 years, Colter Construction has specialized in new custom homes in Sussex County and the Delaware Beach area. The company is committed to delivering highly efficient homes at an affordable price. Fine craftsmanship and personal attention to the buyer have earned Colter a reputation as “The Builder Most Referred”. |
| Contact Information | Terrance Babbie<br>[company]<br>[address]<br>[phone number] |
| **Division Name** | […] |
| **Company Type** | […] |
| **Community Name** | Sandstone |
| **City, State** | Ellendale, DE |
| **Climate Region** | Climate Zone 4 |

| SPECIFICATIONS | |
|---|---|
| **Number of Houses** | 48 |
| **Municipal Address(es)** | 11385 Smith Rd |
| **House Style(s)** | single family |
| **Number of Stories** | 1 |
| **Number of Bedrooms** | 3 |
| **Plan Number(s)** | Alexander, Allen, Andrew, Clifton, Jefferson, Smith |
| **Floor Area** | 1265—1956 $ft^2$ |
| **Basement Area** | No basement |

| | |
|---|---|
| **Estimated Energy Reduction** | 44% over BA Benchmark |
| **Estimated Energy Savings** | $1600 per year based on local utility rates |
| **Estimated Cost** | [estimated construction cost – total or per sq ft] |
| **Construction Start** | May 2009 |
| **Expected Buildout** | March 2012 |

### 5.2.3. Targets and Goals

Building America Community houses must reach a minimum of 40% vs. the 2008 Building America Benchmark in cold climates. This is an energy efficiency target established by Building America to promote quality design and construction. A HERS score of 50 or less was also important to the builder for marketing purposes.

Given the mixed-humid climate zone, special emphasis was placed on substantially exceeding the Building America minimum airtightness standards. Airtightness is valuable both in reducing winter heating load and summertime latent load. The need for efficient cooling also suggested that these houses would be good targets for BSC's research on dual-fuel heat pump systems.

## 5.3 Whole-House Performance and Systems Engineering

### 5.3.1. Energy Analysis Summary

**Table 5.3.1: Estimated Whole House Energy Use for Allen Plan, Sandstone, Ellendale, DE**

| ESTIMATED WHOLE HOUSE ENERGY USAGE | | |
|---|---|---|
| Source ($10^6$ BTU/yr) | Site ($10^6$ BTU/yr) | Area + Bsmt (sq ft) |
| 112 | 46 | 1280 + 0 |
| | % Electric | No. of Bedrooms |
| | 59% | 3 |

With the enclosure and mechanical characteristics presented in Table 5.3.3 and Table 5.3.4, this plan achieves a performance level of 44% reduction relative to the Building America Benchmark.

#### *5.3.1.1. Parametric Energy Simulations*

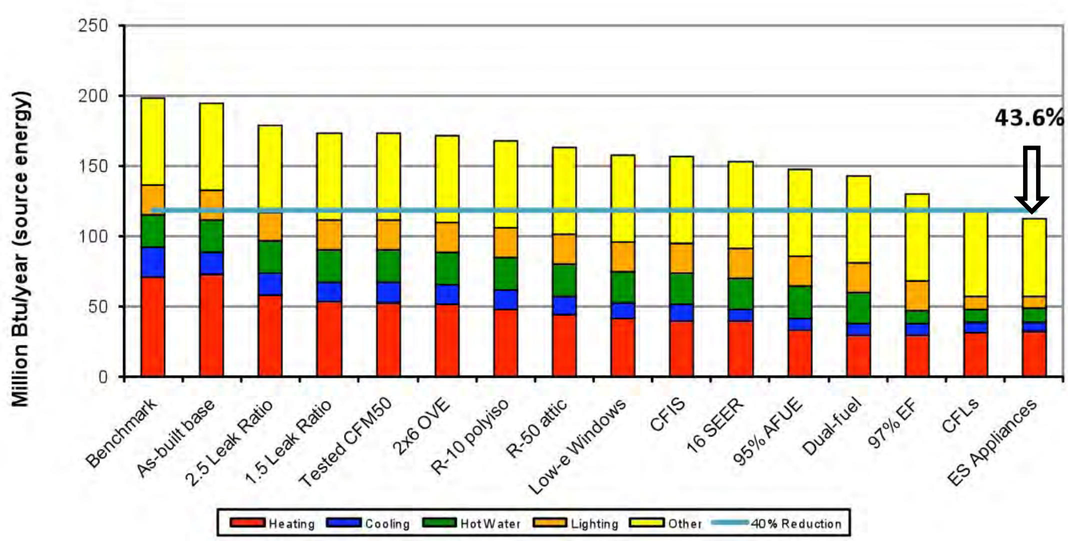


**Figure 5.3.1: Parametric energy simulations for "Allen" Plan**

### *5.3.1.2. End-Use Site and Source Energy Summaries*

**Table 5.3.2: Summary of End-Use Site-Energy**

| | Annual Site Energy | | | |
|---|---|---|---|---|
| | BA Benchmark | | Prototype 1 | |
| End-Use | kWh | therms | kWh | therms |
| Space Heating | 412 | 595 | 1538 | 101 |
| Space Cooling | 1871 | 0 | 499 | 0 |
| DHW | 0 | 212 | 0 | 86 |
| Lighting* | 1837 | | 786 | |
| Appliances + Plug | 5396 | 0 | 4800 | 0 |
| OA Ventilation** | 53 | | 324 | |
| Total Usage | 9570 | 807 | 7947 | 187 |
| *Site Generation* | 0 | 0 | 0 | 0 |
| *Net Energy Use* | 9570 | 807 | 7947 | 187 |

*Lighting end-use includes both interior and exterior lighting

**This OA Ventilation energy consumption is for fan energy only, space conditioning is included in Space Heating and Cooling

**Table 5.3.3: Summary of End-Use Source-Energy and Savings**

| | | | Source Energy Savings | |
|---|---|---|---|---|
| | Estimated Annual Source Energy | | Percent of End-Use | Percent of Total |
| | BA Benchmark | Prototype 1 | Prototype 1 savings | Prototype 1 savings |
| End-Use | 106 BTU/yr | 106 BTU/yr | | |
| Space Heating | 70 | 29 | **59%** | **21%** |
| Space Cooling | 21 | 6 | **73%** | **8%** |
| DHW | 23 | 9 | **59%** | **7%** |
| Lighting* | 21 | 9 | **57%** | **6%** |
| Appliances + Plug | 62 | 55 | **11%** | **3%** |
| OA Ventilation** | 1 | 4 | **-508%** | **-2%** |
| Total Usage | 198 | 112 | **44%** | **44%** |
| *Site Generation* | 0 | 0 | | **0%** |
| *Net Energy Use* | 198 | 112 | **44%** | **44%** |

The "Percent of End-Use" columns show how effective the prototype building is at reducing energy use in each end-use category.

The "Percent of Total" columns show how the energy reduction in each end-use category contributes to the overall savings.

The Allen house meets the 40% target.

## 5.3.2. Discussion

### *5.3.2.1. Enclosure Design*

Table 5.3.4 (below) summarizes the building enclosure assemblies used for this project.

**Table 5.3.4: Enclosure Specifications**

| ENCLOSURE | SPECIFICATIONS |
|---|---|
| **Ceiling** | |
| Description - | Vented truss-framed attic |
| Insulation - | R-50 blown fiberglass at ceiling level |
| **Walls** | |
| Description - | 2x6 Advanced Framing |
| Insulation - | R-10 1.5" polyisocyanurate sheathing with R-23 Fiberglass |
| **Foundation** | |
| Description - | Concrete block foundation walls over unvented crawlspace |
| Insulation - | R-10 2" XPS on interior walls |
| **Windows** | |
| Description - | Double Pane Vinyl LoE² |
| Manufacturer - | BF Rich |
| U-value - | 0.27 |
| SHGC - | 0.24 |
| **Infiltration** | |
| Specification - | 1.5 $in^2$ leakage area per 100 $ft^2$ envelope |
| Performance test - | 500 CFM 50 (2.2 ACH 50; 1.0 sq in / 100 sf) |

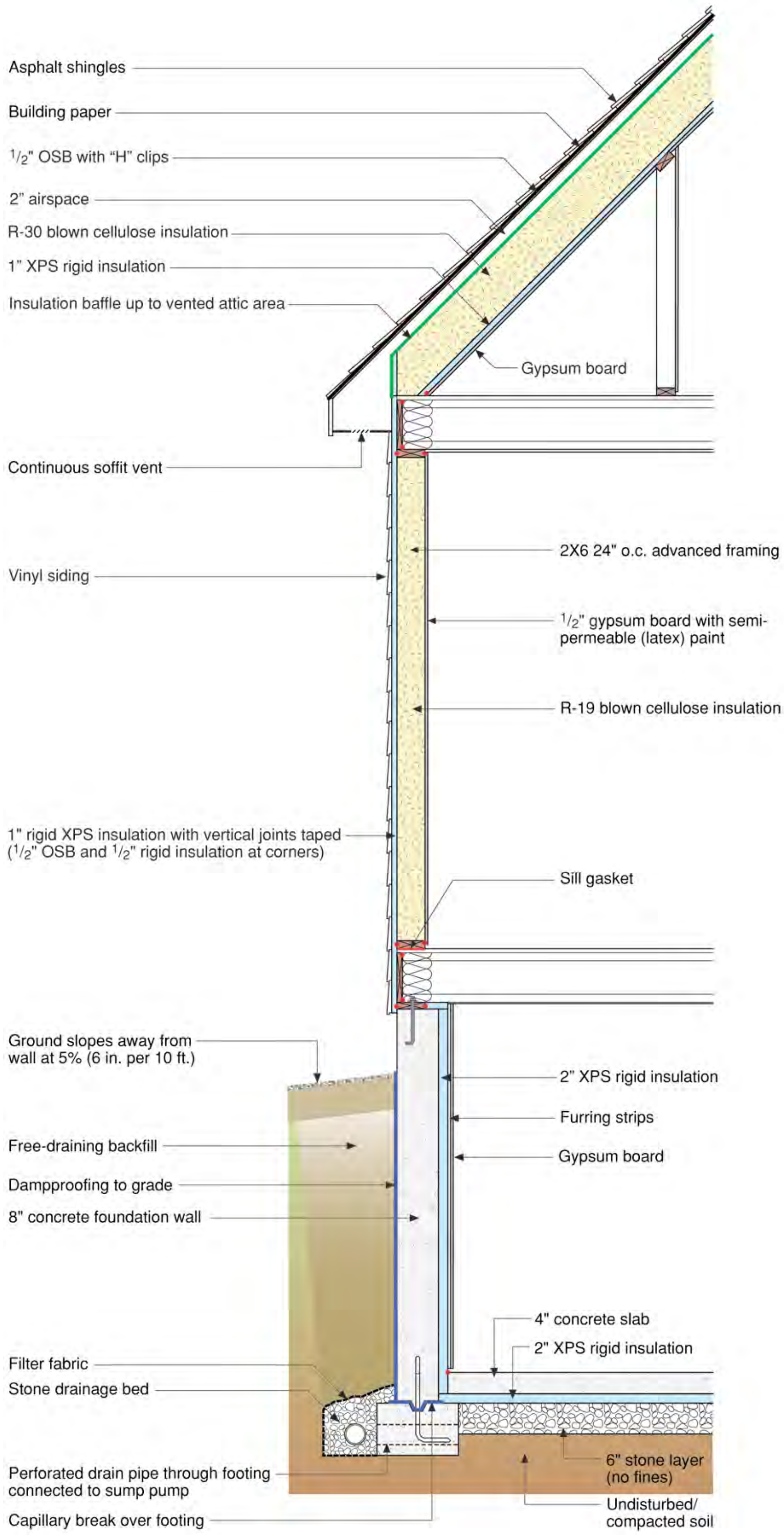


**Figure 5.3.2: Enclosure Building Section**

**Roof:** The roof assembly is designed as a vented attic framed with trusses. R-50 fiberglass was blown above the ceiling. This is a standard construction in the region except for the high level of insulation used.

**Walls:** The walls are framed with 2x6's on 24" centers. 1.5" of polyisocyanurate board insulation was installed on the exterior of the frame, reduced to 1" where OSB is required to provide racking resistance.

Exterior foam insulation was new to the builder, but proved to be an easy addition. The foam was installed according to published BSC drawings, with joints taped and windows flashed to the exterior face of the foam. In this configuration, the foam also acts as the drainage plane behind vinyl siding.

**Windows:** The windows are BF Rich vinyl double paned low-e with argon. These windows have a U-Value of 0.27 and SHGC of 0.24. The coated glazing has superior insulating properties compared to clear glass. The glass coating allows transmission of most of the visible light (unlike tinted windows), while cutting ultraviolet light transmittance by approximately 90%. Therefore, they reduce cooling load from solar gain, increase comfort, and reduce UV damage to furnishings. The windows were installed over a flexible membrane pan flashing to drain water that penetrates the windows.

**Figure 5.3.3: Taped connections at jambs, head, and joints in foam**

**Figure 5.3.4: Membrane flashing at window sill**

**Air Sealing:** Dropped soffits in the kitchen present a challenge to air barrier continuity. OSB blocking above the soffits allows the air barrier to continue in the same plane. (Figure 5.3.5) This is much easier to execute than would be bringing the air barrier down around the soffit. While airsealing was a standard part of past Colter houses, the ambitious airtightness target for the Sandstone houses required additional measures. A secondary airseal was accomplished between the exterior sheathing and the building frame. (Figure 5.3.6) All framing members at the rim joist were connected with caulk to provide continuity between the foundation wall below and the wall assembly above.

**Crawlspace:** The crawlspace floor is covered with 6-mil polyethylene to prevent infiltration of air, moisture, and soil gasses. Joints in the groundsheet are sealed with mastic. The foundation wall is concrete block, with 2" of XPS on the interior.

**Figure 5.3.5: Blocking in ceiling assures airtightness**

**Figure 5.3.6: Spray foam connects sheathing to framing**

#### *5.3.2.2. Mechanical System Design*

Table 5.3.5 (below) summarizes the mechanical systems used by this project.

**Table 5.3.5: Mechanical system specifications**

| MECHANICAL SYSTEMS | SPECIFICATIONS |
|---|---|
| **Heating** | |
| Description - | 8.5 HSPF Air Source Heat Pump / 95% AFUE Hybrid |
| Manufacturer & Model - | Carrier Infinity 25HCB524 |
| **Cooling (outdoor unit)** | |
| Description - | 15 SEER Air Source Heat Pump |
| Manufacturer & Model - | Carrier Infinity 25HCB524 |
| **Cooling (indoor unit)** | |
| Description - | 2 Ton DX Coil and Furnace |
| Manufacturer & Model - | Carrier Infinity |
| **Domestic Hot Water** | |
| Description - | 97% EF Instantaneous Water Heater |
| Manufacturer & Model - | Navien CR-180 |
| **Distribution** | |
| Description - | R-4 sheet metal ducts in conditioned crawlspace |
| Leakage - | None to outside (5% or less) |
| **Ventilation** | |
| Description - | Supply-only system integrated with AHU,43 CFM 33% Duty Cycle: 10 minutes on; 20 minutes off |
| Manufacturer & Model - | Aprillaire fan cycler |
| **Return Pathways** | |
| Description - | e.g., Transfer grilles/jump ducts at bedrooms, central return |
| **Dehumidification** | |

| MECHANICAL SYSTEMS | SPECIFICATIONS |
|---|---|
| Description - | Whole House Dehumidifier ducted to main supply system |
| Manufacturer & Model - | ThermaStor Ultra-Aire |
| **PV System** | |
| Description - | None |
| **Solar Hot Water** | |
| Description - | None |

**Cooling:** A 16 SEER split system central air conditioner connected to a compact duct system provides cooling. The AC unit and ductwork were sized according to Manual J. A separate central dehumidifier, with its own return and ducted to the main AC supply, provides additional latent capacity during shoulder seasons when the sensible load is small. (Figure 5.3.7)

**Heating:** Building Science Corporation recommended a dual fuel air source heat pump as a relatively low-cost upgrade to the planned furnace and split-system AC. Heat pumps perform very well except in the coldest weather. Historically, resistance heating has been used as backup on the coldest days and after setbacks. The propane backup prevents this very inefficient use of energy. Simulations and manufacturer data show that this system can save 10% to 20% of annual heating energy in the relatively mild Delaware winter.

**Ventilation:** Outdoor air is provided by a central fan integrated supply (CFIS) system. An insulated duct from the outside to the air handler return brings in fresh air. A fan cycler control located adjacent the thermostat ensures minimum fan runtime of 10 minutes of every half hour, to bring in and distribute outside air. The fan cycler also operates a mechanical damper in the outside air duct to limit ventilation air during longer heating or cooling calls.

**Domestic Hot Water:** The Navien condensing instantaneous hot water unit is the highest efficiency water heater on the market. Colter Construction and BSC look forward to feedback on its performance and reliability. (Figure 5.3.8)


**Figure 5.3.7: Dehumidifier installed in crawlspace**


**Figure 5.3.8: Terrance Babbie and BSC's Armin Rudd with Navien water heater**

#### *5.3.2.3. Lighting and Miscellaneous Electrical Loads*

Colter construction has been installing compact fluorescent bulbs in their homes.  Energy Star appliances were installed by the builder.

#### *5.3.2.4. Site-generated Renewable Energy*

The target sales price for the Sandstone homes places onsite renewable energy out of reach.  The homes have excellent solar exposure and a large expanse of south-facing roof, as shown in Figure 5.2..

## 5.4 Construction Support

### 5.4.1. Construction Overview

Construction of the Sandstone community began before Colter Construction invited BSC to become involved. Two houses were built without BSC's energy upgrades, and the third was in progress when BSC began contributing details and modeling services. This first collaborative home presented a steep learning curve for Colter Construction, and a challenge to BSC to provide advice in advance of the ongoing construction.

BSC provided initial advice on airsealing the home, with particular attention to blocking behind bathroom fixtures, the unvented crawlspace, and its junctions with the framing above. BSC also provided tables for sizing single headers over windows, and provided details for header insulation compatible with builder practice. As construction progressed, attention turned to the mechanical systems.

As discussed above, the combined space conditioning equipment is quite complicated. Supply ventilation is new to the builder, as is dehumidification. BSC worked to educate the builder, the HVAC contractor, and other involved parties about the need for supplemental dehumidification in tight, high-performance housing, in a region where winter-time humidification is more often specified.

### 5.4.2. Educational Events and Training

BSC hosted several conference calls between our engineers, Terrance Babbie, and the local HVAC professionals---both those doing the installation and representatives of the equipment manufacturers. These helped to educate all involved about the equipment involved, why each piece was needed, and how they ought to interact. Further informal meetings took place at the Westford Building Science Symposium in August, and the construction site during BSC's testing. The major topics at both meetings were selection of an appropriate heat pump, duct design for adequate distribution, and equipment and controls to provide sufficient dehumidification.

### 5.4.3. Systems Testing

As each home nears completion the home BSC is scheduled to perform the standard battery of performance testing, including overall air infiltration (blower door), duct leakage (total and to exterior), HVAC system static pressure and overall flow, HVAC register flows, room pressurization, and ventilation system flows.

As one home has been completed, BSC has tested only one home so far. The home met all criteria. See Appendix D.5.7.2 for notes taken during testing. BSC is also working with the local HERS rater to establish whether their measurements are reliably close to ours, and can be used to reduce site visits.

### 5.4.4. Monitoring

BSC is exploring the possibility of monitoring dual fuel heat pumps in situ in order to provide better direction as to optimal operation and inform modeling of annual energy usage. No monitoring equipment has been installed yet.

## 5.5 Project Evaluation

The following sections evaluate the performance of the final production building designs using energy simulations and targeted field tests, if needed. References are made to the results from field tests and energy simulations, which are included as an appendix to this report.

### 5.5.1. Source Energy Savings

| | |
|---|---|
| Requirement: | *Final production home designs must provide targeted whole house source energy efficiency savings based on BA performance analysis procedures and prior stage energy performance measurements.* |
| Conclusion: | ***Pass*** |

The homes at Sandstone are exceeding the minimum whole house source energy savings based on BA performance analysis and energy performance measurements. The Building America goal for communities is 40% savings and the houses are reaching about 44% savings (based on tested airtightness).

Notable contributions to this performance include the airtightness (10.8% whole-house energy reduction), the Navien instantaneous water heater (6.9%), and the dual-fuel heating system (2.1%).

| Measure |
|---|
| Tested Airtightness < 500 CFM at 50 Pa |
| Blown Fiberglass in 2x6 Advanced Frame Wall |
| 1.5" Polyisocyanurate Sheathing (R-10) |
| 14" Blown fiberglass at ceiling plane (R-50) |
| Low-e Double-glazed Windows (U=0.27, SHGC=0.24) |
| Central Fan Integrated Supply Ventilation |
| 15 SEER Split-System AC |
| Dual Fuel Heating: 8.5 HSPF, 95% AFUE |
| 97% EF Instantaneous Water Heater |
| Compact Fluorescent Lightbulbs |
| Energy Star Appliances |

### 5.5.2. Market Coverage

| | |
|---|---|
| Requirement: | *Must have a minimum of 10 homes per project (including projects from all teams). At least five homes must be completed by March/April to be used as a case study in the annual Joule* report.* |
| Conclusion: | ***Pass*** |

While actual rate of construction depends on the pace of sales, 5 homes should be complete by April, and 10 by September of 2010. Final build-out is likely to be some time in 2014.

## 5.5.3. Neutral Cost Target

| | |
|---|---|
| Requirement: | *The incremental annual cost† of energy improvements, when financed as part of a 30 year mortgage, must be less than or equal to the annual reduction in utility bill costs relative to the BA benchmark house.* |
| Conclusion: | ***Pass*** |

Local utility prices are 13.3 cents per kWh, and $2.07 per gallon of propane ($2.26 per therm). At these prices, net cash flow to the homeowner is $842 per year. See Appendix D.5.7.1 for incremental upgrade costs.

| | Annual Electric Energy (Site) | | Annual Gas Energy (Site) | | |
|---|---|---|---|---|---|
| | Benchmark | Prototype House | Benchmark | Builder Standard Practice (Optional) | Annual Utility Bill Reduction vs Benchmark |
| **End Use** | **(kWh/yr)** | **(kWh/yr)** | **(therms/yr)** | **(therms/yr)** | **($/yr)** |
| Space Heating | 412 | 1538 | 595 | | $969 |
| Space Cooling | 1871 | 499 | 0 | | $178 |
| DHW | 0 | 0 | 212 | | $285 |
| Lighting | 1837 | 786 | | | $137 |
| Appliances and MELs | 5396 | 4800 | 0 | | $77 |
| Ventilation | 53 | 324 | | | ($35) |
| **Total Usage** | **9569.5** | **7947** | **806.75** | **0** | **$1,611** |
| Site Generation | 0 | 0 | 0 | 0 | $0 |
| **Net Energy Use** | **9569.5** | **7947** | **806.75** | **0** | **$1,611** |
| **Added Annual Mortgage Cost w/o Site Gen.** | | | | | **$670** |
| **Net Cash Flow to Consumer w/o Site Gen.** | | | | | **$942** |
| **Added Annual Mortgage Cost with Site Gen.** | | | | | **$670** |
| **Net Cash Flow to Consumer with Site Gen.** | | | | | **$942** |

## 5.5.4. Marketability

| | |
|---|---|
| Requirement: | *Based on initial response from model homes, should be marketable relative to the value-added benefit seen by consumers at increased or neutral cost.* |
| Conclusion: | ***Pass*** |

At this time there is very limited information available as to the local market demand for energy efficiency. Colter Construction expects to price the homes competitively with similarly sized code-built homes. The local market is brisk for homes which are similar but lacking the energy upgrades.

## 5.5.5. Market Coverage

| | |
|---|---|
| Requirement: | *Project case studies should cover a representative range of weather conditions and construction practices in major metropolitan areas in the targeted climate region.* |
| Conclusion: | ***Pass*** |

Colter Construction is a production builder with extensive experience in the custom home market. The expectation for this community is to build out at about 10 houses per year, and to sell them at prices which are competitive in the local market. Energy improvements are expected to increase the attractiveness of the homes, but not to materially increase their sale price. The single story homes on concrete block foundations are typical of local practice.

Based on the nearest long-term weather station, at Milton AFB (25 miles north of Ellendale), the site has 4800 Heating Degree Days (base 65F) and 1050 Cooling Degree Days (base 65F). Nearby Milton, DE received 52 inches of rainfall in the last year.

### 5.5.6. Builder Commitment

| | |
|---|---|
| Requirement: | *Should demonstrate strong builder commitment to continued construction at current or future BA performance targets.* |
| Conclusion: | ***Pass*** |

The owner and founder of Colter Construction approached BSC this year for our expertise. His personal attention to construction details and building physics is the best demonstration of the company's plans to continue building high-performance homes. This attention is amply demonstrated in the success of the first Sandstone home. The marketing for Sandstone heavily emphasizes the energy performance of the home, and we expect the full build-out to meet BA targets.

### 5.5.7. Gaps Analysis

| | |
|---|---|
| Requirement: | *Should include a summary of builder technical support requirements, gaps analysis, lessons learned, optimal builder business practices, what not to do, documentation of failures, recommendations for policy improvements, and remaining technical and market barriers to achieving current and future performance levels.* |
| Conclusion: | ***Pass*** |

The complexity of mechanical systems, particularly in mixed-humid climates, presents the greatest challenges for Colter Construction. During testing, BSC found that the outdoor air damper was wired to be always closed, and the dehumidifier was running continuously. This cannot be laid entirely at the feet of the contractors; calling the manufacturer of one piece of equipment confirmed that the official wiring diagram shows hot and common wires the reverse of how the device is actually sold.

These are relatively simple gaffes, which can be corrected easily by the responsible parties. A more interesting problem is the tension between optimizing each piece of equipment alone and compatibility with an entire house system. This dual fuel heating system is operated by a so-called "communicating" proprietary controller. These integrated systems can provide higher efficiency, increased comfort, and additional dehumidification capacity, but they come at a cost.

The balance of the HVAC system included a dehumidifier and an outside air duct with a mechanical damper. Prior Building America research has established the importance of preventing operation of the dehumidifier during cooling runtime Three separate controllers were required to control the various pieces of equipment, with additional field-installed relays to coordinate the dehumidifier and fan cycler with the main AHU fan.

**Figure 5.5.1: Thermostat, dehumidistat, and fan cycler during system debugging**

This complexity makes it very hard to specify the system components, and is likely to slow adoption, or encourage installation of heat pumps without sufficient provision for ventilation and dehumidification. Further research is required to establish how other manufacturers address these problems, and how to handle Quality Assurance for such systems.

The first house built features an inadequate airseal between the crawlspace and the ground beneath. (Figure 5.5.3) This leakage pathway could admit soil gasses into the interior. BSC has provided direction to the builder as to how the connection between the polyethylene groundsheet and the foundation wall can be managed with mastic or tape. This should be corrected on future houses.

**Figure 5.5.2: Groundsheet lines interior of crawlspace**

**Figure 5.5.3: Air gap behind foam and groundsheet**

BSC has also provided details of window flashing details which improve on the builder's current practice. The windows on the first houses were installed with flexible membrane flashing, but without a backdam or drainage space. In order to effectively remove water that leaks through the window, the membrane should be installed on a surface which tilts to the outside, and the window should be elevated slightly above the membrane drainage plane.

**Figure 5.5.4: Installed window with flexible membrane**

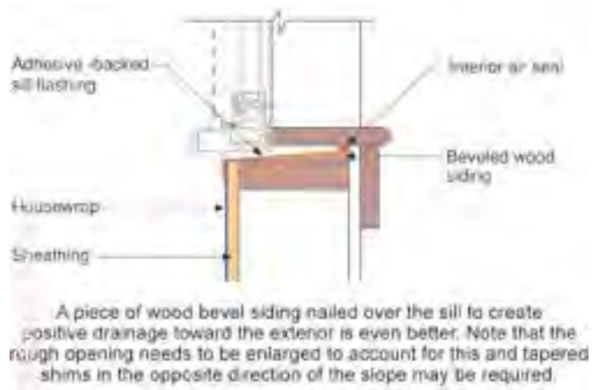


**Figure 5.5.5: Window detail with sloped drainage pan**

## 5.5.8. Quality Assurance

| | |
|---|---|
| Requirement: | Should provide documentation of builder's energy related QA and QC processes. |
| Conclusion: | ***Pass*** |

BSC discussed all Required provisions of the Builders' Challenge QA Checklist with the builder in phone conversations and written correspondence. The measures fulfilling these requirements have been discussed elsewhere in the report. These conversations identified those areas where further details were needed to support best practices in construction. Where BSC recommendations conflicted with advice from subcontractors and manufacturer representatives, additional meetings between BSC and these parties resolved the matter. This was particularly necessary prior to the installation of supplementary dehumidification.

Manufacturers are recommending that central cooling equipment, together with specialized controls, can provide all necessary dehumidification. Builders in many regions are not accustomed to installing dehumidification of any sort. Both need to be educated about the particular needs of high performance housing. On this project, the builder and mechanical contractor were receptive to BSC's recommendations once they understood the causes of seasonal humidity variations, and the limits of cooling equipment under high latent load fraction.

## 5.6 Conclusions/Remarks

Over the next few years, Colter Construction will be building 45 more high-performance homes featuring exceptional airtightness, very high levels of insulation for the region, and state of the art mechanical systems. All of these homes are expected to meet current or future Building America source energy targets.

Future homes will correct deficiencies in water management, foundation connection details, and mechanical controls which were evident in the first houses built. BSC and the builder will continue to investigate the best available mechanical options in this climate and market. A good dual-fuel system should maintain comfortable temperature and humidity throughout the year, minimize energy consumption, and be relatively simple to install and especially to operate. Such a system would be broadly applicable to homes in mixed and cold climates, save homeowners money, and provide an excellent platform for time dependant electricity pricing or other peak-shifting strategies.

## 5.7 Appendices

### 5.7.1. Energy Modeling

### 5.7.2. Site Visit Report

# Appendix D.5.7.1
# Energy Modeling

| Parametric Run ID | Description of change | Estimated Individual Cost | Incremental Over Benchmark | Extended Cost Effectiveness Analysis | | | |
|---|---|---|---|---|---|---|---|
| | | | | Savings [$10^6$ BTU / yr] | $ per 10^6 BTU Saved (1 year) | Estimated Lifetime [yr] | $ per 10^6 BTU Saved (Lifetime) |
| 0 | Benchmark | n/a | n/a | n/a | | | |
| 1 | Windows as designed | n/a | 2.1% | 4.1 | | | |
| 2 | Airseal 2.5 | $1,000 | 7.7% | 15.2 | $66 | 73 | $0.90 |
| 3 | Airseal 1.5 | $1,000 | 3.0% | 5.8 | $171 | 74 | $2.31 |
| 4 | Tested Airtightness | $10 | 0.1% | 0.2 | $41 | 75 | $0.55 |
| 5 | R-19 in 2x6 OVE | $0 | 0.8% | 1.5 | $0 | 75 | $0.00 |
| 6 | 1.5" polyisocyanurate | $693 | 1.9% | 3.7 | $189 | 75 | $2.52 |
| 7 | R-50 attic | $307 | 2.4% | 4.8 | $64 | 75 | $0.85 |
| 8 | Windows (U=0.27, SHGC=0.24) | $273 | 2.7% | 5.3 | $52 | 40 | $1.29 |
| 9 | CFIS Ventilation | $250 | 0.5% | 0.9 | $276 | 30 | $9.21 |
| 10 | 16 SEER AC | $500 | 1.9% | 3.7 | $134 | 30 | $4.47 |
| 11 | 95% AFUE Furnace | $700 | 3.0% | 5.9 | $119 | 30 | $3.97 |
| 12 | Dual fuel heating 16 SEER, 95% | $1,500 | 2.1% | 4.2 | $355 | 20 | $17.76 |
| 13 | 97% EF DHW | $510 | 6.9% | 13.6 | $37 | 20 | $1.87 |
| 14 | CFLs | $128 | 5.5% | 10.9 | $12 | 3 | $3.93 |
| 15 | Energy Star Appliances | $750 | 3.2% | 6.4 | $117 | 15 | $7.83 |

# Appendix D.5.7.2
# Site Visit Reports

9/22/09

Colter Const. testing, Lot 4
1279 ft²
HERS 48

Tin = 78 RHin = 57% 1130am
Blower door tst
499 cfm50, C = 29.6 n = 0.722 R² .998
ELA = 22.8

DB
Total 202cfm@25 w/DG700 202 cfm@25 w/DG300 (manual unit)
Outside 29 cfm@25

Room pressures

Front door clockwise
Bed 1 +1.0
Bed 2 +1.1
Mbed +2.8

Room air flow

| | |
|---|---|
| Bed 1 | 75 cfm |
| Bed 2 | 75 |
| Bath | 51 |
| K. Nook | 73 |
| Ma Bed | 91 |
| Ma Bath | 44 |
| Ma Closet | 51 |
| Laundry | 42 |
| By door | 91 |
| Kitchen | ? |

-148 Pa OA duct wrt crawl
-158 return wrt crawl

OA damper was spring open, power closed, unwired one leg of damper, damper opened
- 72 OA duct after damper + 2 90°'s
- 118 before 2 90°'s + damper
- 118 in return plenum
+ 69 in supply after coil

- Checked low-e on all windows, + patio door, all had low-e on far side from inside
- had problems w/ 65H + D43000 wiring, and D4 damper 8" was NO not NC as was supposed to be, need to field convert per Honeywell instructions