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Serenbe Nest Cottages

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Contents

List of Figures vi
List of Tables vi
Definitions vii
Executive Summary viii
1 Introduction 1
1.1 Background 1
1.2 Overview 1
1.3 Goals 2
2 Energy Efficient Solutions Package 3
2.1 Overview 3
2.2 Thermal Boundary 5
2.2.1 Foundation and Framing 5
2.2.2 Air Sealing and Insulation 6
2.2.3 Fenestration 7
2.3 Systems 7
2.3.1 HVAC 8
2.3.2 Plumbing 9
2.3.3 Lighting and Appliances 9
2.4 Estimated Cost of Energy Efficiency Solution 10
2.5 Measure Interactions 10
3 Technical Pathway 11
3.1 Inputs to Building Energy Optimization Software 11
3.2 Energy Simulation Results 11
4 Experiment 14
4.1 Test Plan 14
4.2 Research Questions 14
5 Short-Term Testing 17
5.1 Short-Term Characterization Testing 17
6 Summary 18

List of Figures

Figure 1. Nest, lot nine 1
Figure 2. Nest Cottage nine building envelope 5
Figure 3. Foundation wall and framing, Nest Cottage nine 5
Figure 4. Air sealing detail at exterior basement wall corner, Nest Cottage nine 6
Figure 5. Insulation at second floor and roof, Nest Cottage nine 7
Figure 6. Window specification, Nest Cottage nine 7
Figure 7. CFIS system schematic © 2009 by Building Science Corporation; reprinted with permission 9
Figure 8. Source energy savings for Nest Cottage, lot nine over the B10 benchmark and the builder's typical package 12
Figure 9. Annualized utility bill comparison for Nest Cottage, lot nine against B10 benchmark and the builder's typical package 13

Unless otherwise noted, all figures were created by Southface.

List of Tables

Table 1. Nest Cottage Building Specifications 4
Table 2. Research Measurements and Equipment 15
Table 3. Short-Term Equipment and Test Measurements 17

Unless otherwise noted, all tables were created by Southface.

Definitions

ACH_{50}	Air changes per hour at 50 Pa, infiltration measurement
BA	Building America
BEopt	Building Energy Optimization software
CFIS	Central fan integrated supply, ventilation method
CFL	Compact fluorescent lamp
CFM	Cubic feet per minute, air flow volume measurement
CFM_{25}	Air flow at 25 Pa, duct leakage measurement
CFM_{50}	Air flow at 50 Pa, infiltration measurement
COP	Coefficient of performance, heating efficiency
EER	Energy efficiency ratio, cooling efficiency
EF	Energy factor
GSHP	Ground source heat pump
HSPF	Heating seasonal performance factor, heating efficiency
HVAC	Heating, ventilation, and air conditioning
IECC	International Energy Conservation Code
LFL	Linear fluorescent lamps
NCTH	New construction test house
SEER	Seasonal energy efficiency ratio, cooling efficiency
SLA	Specific leakage area, infiltration measurement

Executive Summary

As part of the NAHB Research Center Industry Partnership, Southface partnered with Martin Dodson Builders and the Serenbe community on the construction of a new test home in the suburbs of Atlanta, Georgia, in the mixed humid climate zone. The most recent subdivision within the Serenbe community, the Nest, will contain 15 small footprint cottage style homes, and Southface selected lot nine as the test home for this study. This Nest subdivision serves as a project showcase for both the builder partner and the Serenbe community as a whole. The planning and design incorporated into the Nest cottages will be implemented in each home within the subdivision. These homes meet Building America (BA) savings targets and serve as a basis of design for other homes Martin Dodson plans to build within the Serenbe community. Significant changes to the builder's typical specifications include increased levels of wall and roof insulation using open cell spray foam insulation and the use of a ground source heat pump (GSHP) rather than a split system air conditioner and gas furnace.

As a BA test home, this home will be evaluated to detail whole-house energy use and HVAC efficiency. The main research priorities for this home include (1) determining the operational efficiency and energy consumption of the home's HVAC system, with a focus on the additional system fan run time and load associated with the home's central fan integrated ventilation supply, and (2) examining the cost effectiveness of certain high-profile energy upgrade measures, specifically a GSHP, and how these measures compare to projected energy savings and other potential energy upgrades.

1 Introduction

With the support of the DOE Building America (BA) Program, Southface partnered with Martin Dodson Builders to build a new construction test house (NCTH). The Serenbe community is located 32 miles southeast of Atlanta, Georgia, in mixed humid climate zone 3. A sustainable master planned community, Serenbe worked closely with the EarthCraft green building program to establish guidelines for development of the community and its structures. The most recent subdivision within the Serenbe community, the Nest, will contain 15 small-footprint cottage style homes, and Southface selected lot nine as the test home for this study. All of the homes within the Nest subdivision meet the BA savings goals of using 30% less energy than comparable homes that meet the 2009 International Energy Conservation Code (IECC) and feature a ground source heat pump (GSHP) tied to a shared closed loop that exchanges heat with an adjacent lake.



Figure 1. Nest, lot nine

1.1 Background

With technical support from Southface, the design team selected design elements, technologies, and construction methods that minimize cost increases while achieving substantial energy savings and maintaining whole-building performance metrics of durability, comfort, and suitable indoor air quality. The design is a test home in the mixed humid climate targeting BA and builder partner energy efficiency and cost goals that will ultimately develop into a commercially feasible energy efficiency solution package.

1.2 Overview

This single-family detached home, a two-story design over walkout basement, has 1,686 ft^2 of conditioned floor area, excluding the unfinished basement, and was completed in 2011. The first floor has the kitchen, dining, and living areas as well as a bedroom and full bath. The second floor has two bedrooms and full baths as well as storage and mechanical spaces. Ceilings are 10 feet at the first and second floors with portions of the second level including cathedral ceilings

sloped to follow the roofline. The full height basement has an 8-ft ceiling height and includes both foundation and framed walls with a walkout at the rear of the home.

1.3 Goals

Specific goals for the Nest community as a whole and this NCTH in particular were established during the planning phase:

- Develop and implement a durable design that improved energy efficiency by at least 30% over a comparable house that meets the 2009 IECC.
- Create a tight thermal boundary to reduce air leakage and improve thermal performance.
- Design the HVAC system 100% in conditioned space for significant energy savings.
- Design a high performance GSHP HVAC system that ensures occupant comfort and minimizes costs by using common infrastructure.
- Develop a cost-effective design that could provide a basis for future home designs for Martin Dodson Builders and other homes in the Serenbe community.
- Develop a test and monitoring plan to determine the operational efficiency and energy consumption of the home's HVAC system and examine the actual to projected energy savings and cost effectiveness of certain high-profile energy upgrade measures.
- Earn ENERGY STAR and EarthCraft house certification.

Southface plans to apply the lessons learned from this test home to future projects, and anticipates the findings will be particularly relevant to others in the mixed humid climate zone. These specific data will also provide additional documentation of in situ performance of GSHPs in homes to the BA Program. Given that 15 homes will be built within the Nest, Southface plans to apply the lessons learned from each home in subsequent homes. Utility data will be collected throughout the community to gain a better understanding of the effect of occupant behavior on overall energy consumption and the performance of the homes compared to modeled projections.

This report outlines the features of this individual test home, discusses construction and installation, and details short-term testing and monitoring.

2 Energy Efficient Solutions Package

2.1 Overview

The components included in these homes are used to improve the overall thermal performance of the building envelope, and bring mechanical components within conditioned space. These upgraded measures presented cost and energy tradeoffs to the project team, with the final measures chosen by the builder based on cost and constructability. The project team wished to improve on a base set of specifications that they have used on past residential projects. Table 1 lists the building specifications for the home, as well as the base set of specifications and the BA 2010 benchmark specifications for reference.

The first step of this project was to detail the building envelope. The builder and Southface wanted to explore advanced options for using high R-value exterior walls that are not typically built in this climate zone. Initial specifications called for single 2 × 6 top and bottom plates with 2 × 4 staggered studs at 16-in. o.c., but based on cost and implementation concerns, this plan was put aside in favor of a more conventional approach. Exterior insulated sheathing was also considered, but also not selected based on implementation concerns from the builder and feedback from the framing subcontractor. Final specifications called for a more conventional approach with a 2 × 6 wall assembly and full fill open cell spray foam insulation, resulting in a cavity insulation value of R-20.

Next, the design team considered options for the HVAC system. Because space conditioning often represents the largest portion of residential energy consumption and has been a primary target for achieving substantial use reductions, it was a goal of this project to implement the most efficient system possible. Based on initial energy simulation studies and the partnership of an HVAC manufacturer, GSHPs were chosen to provide space conditioning. Because the Nest subdivision will include 15 homes when complete, the development partner from the Serenbe community saw the opportunity to reduce the installed cost of the GSHPs by using shared infrastructure. Instead of individual wells associated with the GSHPs for each home, the community features two separate loops tied to heat exchangers in the adjacent lake. Each loop serves multiple homes, seven homes on one loop and eight on the other, and includes a supply and return line. Individual pump stations are installed in each home to move water through the loops.

With the reduced infrastructure and installation costs associated with the manufacturer partnership, GSHPs become a more cost-effective option. Southface has found however, that many projects choose to use GSHPs without evaluating other high efficiency alternatives, decisions that Southface believes are based on performance and cost perceptions not yet proven by real-world evaluation and monitoring. To further explore this issue, the primary system investigation in this home includes researching the HVAC system.

Table 1. Nest Cottage Building Specifications

Measure	B10 Benchmark	Base Specification	Nest Cottage
Foundation	Sealed Crawlspace	Basement	Basement
Foundation Insulation	R-5	R-10	R-10
Wall Construction	2 × 4	2 × 4	2 × 6
Wall Insulation	R-13	R-13	R-20
Ceiling Construction	Vented Attic	Vented Attic	Cathedral Attic
Ceiling Insulation	R-30	R-30	R-26
Window Ratings	U-0.40, SHGC-0.30	U-0.35, SHGC-0.31	U-0.35, SHGC-0.31
Infiltration	SLA = .00036	ELR $\leq$ 0.40	$ACH_{50} \leq 5$
Heating Efficiency	7.7 HSPF	92 AFUE	5.5 COP
Cooling Efficiency	13 SEER	13 SEER	16 EER
Supply Duct Location	65% crawlspace, 35% conditioned space	50% conditioned space, 50% basement	50% conditioned space, 50% basement
Return Duct Location	100% crawlspace	50% conditioned space, 50% basement	50% conditioned space, 50% basement
Duct Leakage	15% total	< 5% to outside	< 5% to outside
Ventilation	Exhaust 100% ASHRAE 62.2	Central fan integrated supply, 100% ASHRAE 62.2	Central fan integrated supply, 100% ASHRAE 62.2
Hot Water Efficiency	0.86 EF, electric	0.59 EF, gas storage	0.67 EF, gas storage
Lighting	66% incandescent, 21% CFL, 13% LFL	66% incandescent, 21% CFL, 13% LFL	20% incandescent, 80% CFL
Appliances	Benchmark	ENERGY STAR	ENERGY STAR

2.2 Thermal Boundary

The thermal boundary for this home includes the insulated basement walls, exterior walls, and full cathedral ceiling. This design achieves the goal of bringing all HVAC equipment and distribution within the conditioned envelope.

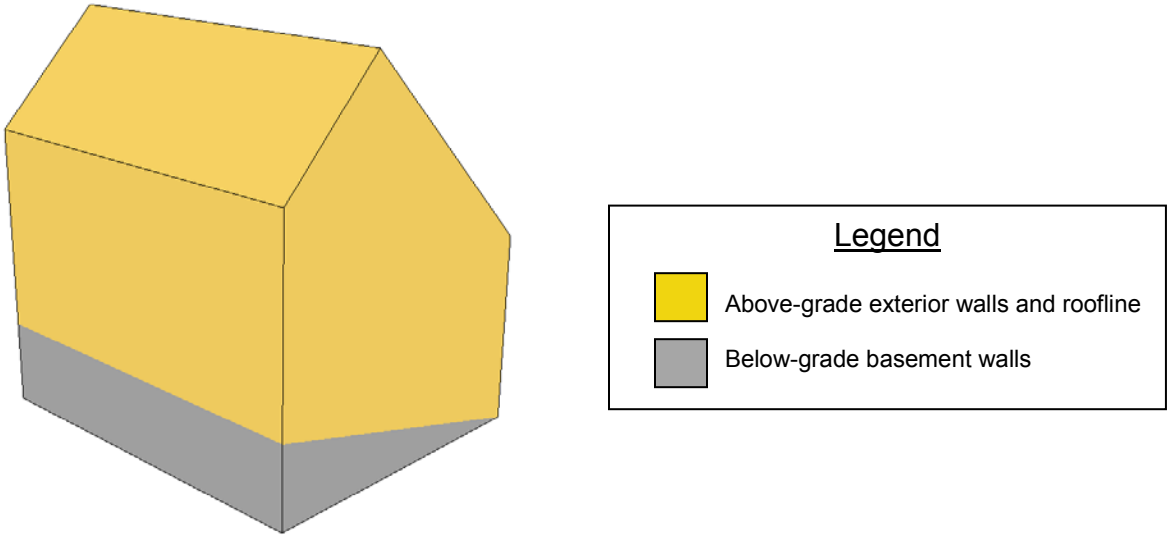


Figure 2. Nest Cottage nine building envelope

2.2.1 Foundation and Framing

The home is built on a poured concrete foundation wall at the front of the home that drops off to follow grade moving toward the rear of the home. The home has 2 × 6 exterior walls, a conventionally framed roof assembly, and engineered floor joists.



Figure 3. Foundation wall and framing, Nest Cottage nine

2.2.2 Air Sealing and Insulation

A single contractor completed air sealing measures and insulation installation as a package, following the standard air sealing and insulation requirements of the EarthCraft and ENERGY STAR programs. Caulk and expanding foam were used for air sealing in the following areas:

- Penetrations through top and bottom plates
- Bottom plate to subfloor
- Penetrations through band
- Penetrations through subfloor
- Window and door rough openings
- Gaps in exterior sheathing
- Exterior wall penetrations
- Penetrations through insulated ceilings
- Wall/ceiling penetrations through drywall in attached garage.

Figure 4 shows air sealing details at an exterior basement wall corner, including the caulk to seal the bottom plate to the basement slab and the expanding foam to seal seam and gaps in the exterior sheathing. Also note the two stud corner, which allows for more complete insulation fill.



Figure 4. Air sealing detail at exterior basement wall corner, Nest Cottage nine

Open cell spray foam was used for insulation in all areas, providing additional resistance to air infiltration. Insulation specifications included an R-10 exterior drainage mat at the foundation walls, full fill of the exterior 2× 6 wall cavities with open cell spray foam insulation resulting in R-19, and 7 inches of foam applied to the roof deck resulting in R-26. The exposed insulation in the attic space required a spray-applied ignition barrier. This full fill approach represents a major change from typical building practices in this climate zone, where open cell spray foam is typically applied to a depth of 3.5 inches, resulting in a cavity insulation value of R-13. The first home built in the subdivision received these typical levels of insulation installation because of communication problems between the builder and insulation subcontractor. This error was

corrected on subsequent homes, with additional installation guidance provided by the insulation manufacturer. Given the high humidity of the local climate, the moisture performance of this assembly remains unknown and a topic for future research efforts.



Figure 5. Insulation at second floor and roof, Nest Cottage nine

2.2.3 Fenestration

The home features high performance glazing with low solar heat gain coefficient, U-0.35, SHGC-0.31 throughout.



Figure 6. Window specification, Nest Cottage nine

2.3 Systems

The primary system investigation in this home includes researching the HVAC system. Regarded as one of the most efficient system choices, GSHPs incorporate complex components and

extensive infrastructures to reduce the effect of fluctuating ambient conditions for heat exchange, and rely on sophisticated controls strategies to extract efficiency out of part-load conditions. Research and testing have documented efficacies that are double a standard efficiency conventional air-to-air system, but this comes at more than twice the initial cost. When this cost premium is considered, along with the lowered space conditioning loads of high performance homes and the capabilities of the typical HVAC contractor to size, install, and commission a GSHP, the question of cost effectiveness becomes a major issue in the choice of this technology over high efficiency conventional systems or emerging technologies such as variable refrigerant flow split systems. Currently, the market has demonstrated that the high price, technological complexity, available tax incentives, and acoustic and aesthetic benefits of GSHPs from the elimination of exterior condensers have given the system cachet in the high-end residential market, similar to marquee kitchen appliances and luxury automobiles.

2.3.1 HVAC

The GSHPs included in this project present an opportunity to evaluate the cost effectiveness and in-field efficiency of this technology in a lake loop application. The GSHPs used in these homes are rated at 16 energy efficiency ratio (EER) and 5.5 coefficient of performance (COP) at full load and 18.6 EER and 6.3 COP at part load for water loop applications per AHRI/ISO 13256-1 (Air-Conditioning, Heating, and Refrigeration Institute, 1998). Southface has found that many projects, including the Nest development, choose to use GSHPs without evaluating other high efficiency alternatives and believe that these decisions are based on performance and cost perceptions that have not been proven by field evaluation. Collecting installation and operating costs in this project will allow for improved decision making on future projects. Southface plans to follow the Advanced Systems Research Draft GSHP monitoring guidelines.

Meeting ASHRAE 62.2 ventilation rates introduces another tradeoff choice to builders in the mixed humid climate zone. Builders want to meet the air flow requirements in the most cost-effective manner, while choosing a system that mitigates the added costs and latent loads that are introduced by ventilation air in this climate. The most popular ventilation strategy in the local market is the central fan integrated supply (CFIS). This strategy consists of a ducted outside air intake connected directly to the return plenum of the central HVAC system. The negative pressure of the return pulls ventilation air through the intake, and the air is distributed throughout the home using the blower and ductwork of the central system. The intake duct includes a mechanical damper equipped with a ventilation timer, allowing variable amounts of outside air to be introduced into the central system. This timer ensures adequate ventilation on mild days when the central system is not calling for heating or cooling by opening the damper and calling on the central fan to run.

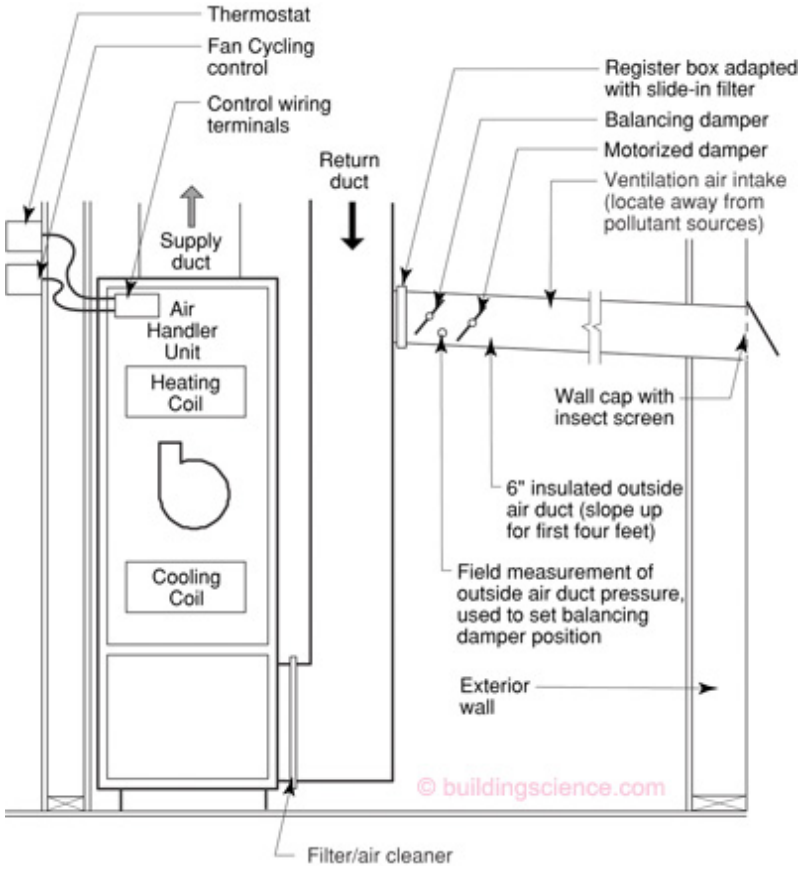


Figure 7. CFIS system schematic
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Monitoring the additional system runtime linked to the CFIS controller, as well as the temperature and relative humidity of the incoming air stream, will produce more data on the energy costs and effectiveness of this ventilation approach. Southface hopes to build on the past BA Program ventilation studies conducted by the Building Science Corporation and the Consortium for Advanced Residential Buildings teams focusing on the additional heating, cooling, and fan energy consumption associated with this ventilation strategy (Building Science Corporation, 2009) (Constortium for Advanced Residential Buildings, Steven Winter Associates, Inc., 2010)

2.3.2 Plumbing

A 0.67 energy factor (EF) gas storage water heater provides water heating for the home. All plumbing is located within the home's thermal boundary.

2.3.3 Lighting and Appliances

The home includes a lighting package with a mix of 80% CFL and 20% incandescent bulbs, as well as ENERGY STAR kitchen and laundry appliances.

2.4 Estimated Cost of Energy Efficiency Solution

Southface is still working with the project partners to collect detailed cost data regarding the upgraded envelope measures and HVAC systems, including the shared loop infrastructure, GSHPs, and ventilation controllers used by the project. These data will be incorporated into the long-term monitoring report in 2012 to answer research questions regarding the cost effectiveness of these upgraded measures and to address gaps in the current NREL cost database.

2.5 Measure Interactions

These upgraded measures present cost and energy tradeoffs to the project team, with the final measures chosen by the owners based on cost. Many of the energy efficiency features incorporated into the home design are new to the design team and trade contractors and require a learning curve that will subsequently be evaluated for success and opportunities for improvement as the testing results emerge. Based on the changes from the initial project specifications that took place during construction, knowledge gaps with trade subcontractors and product suppliers continue to present barriers to implementing high performance housing in this market. Given the learning curve, detailed construction documents, scopes of work, and builder oversight are necessary to implement measures that are unfamiliar for trade subcontractors.

3 Technical Pathway

3.1 Inputs to Building Energy Optimization Software

Because design and construction began in 2009, initial energy simulations were completed using Energy Gauge software and the 2008 BA benchmark. Southface has since completed energy simulations and cost tradeoff analysis using the Building Energy Optimization (BEopt) tool demonstrate that the home meets the current BA goals of 30% above the B10 BA benchmark. The finalized building specifications for the Serenbe Nest cottages residence were compared to a base set of specifications that the project team has used on past projects of similar scope (see Table 1).

Several assumptions were made for this comparison based on gaps in the available BEopt inputs. At this time BEopt does not have an option to include the GSHP used in this project. In lieu of this option, the most efficient air-source heat pump from the BEopt options library was chosen for the simulation, 18 SEER, 9.2 HSPF, and 0.95 EF, respectively. It is anticipated that the added efficiency of this option would increase the source energy and utility bill savings above the estimated levels listed in the results section.

Southface plans to update the simulation models on the release of updated versions of BEopt that include input options for GSHPs. The long-term monitoring data gathered will also allow for additional refinement of modeling results, and give a true picture of the home's total energy consumption.

3.2 Energy Simulation Results

The Nest Cottage, lot nine test home is projected to save 30.1% over the BA B10 benchmark. Optimization studies for the project were not completed given that construction specifications had been finalized before the introduction of the BEopt tool. Figure 8 graphically depicts the simulation results.

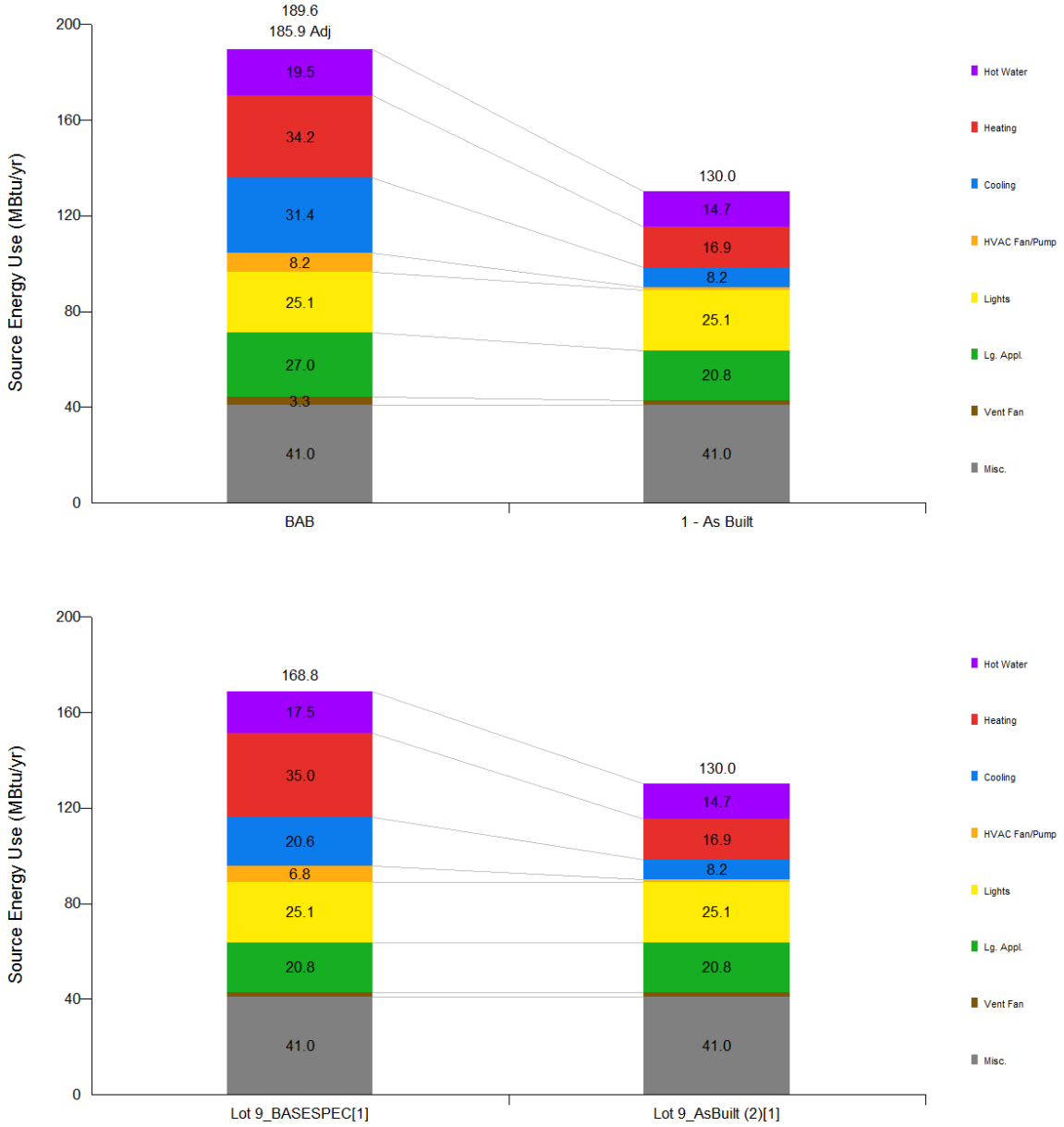


Figure 8. Source energy savings for Nest Cottage, lot nine over the B10 benchmark and the builder's typical package

The preliminary annual cost savings are estimated to be more than $417 per year compared to the B10 benchmark. Figure 9 depicts components of the savings.

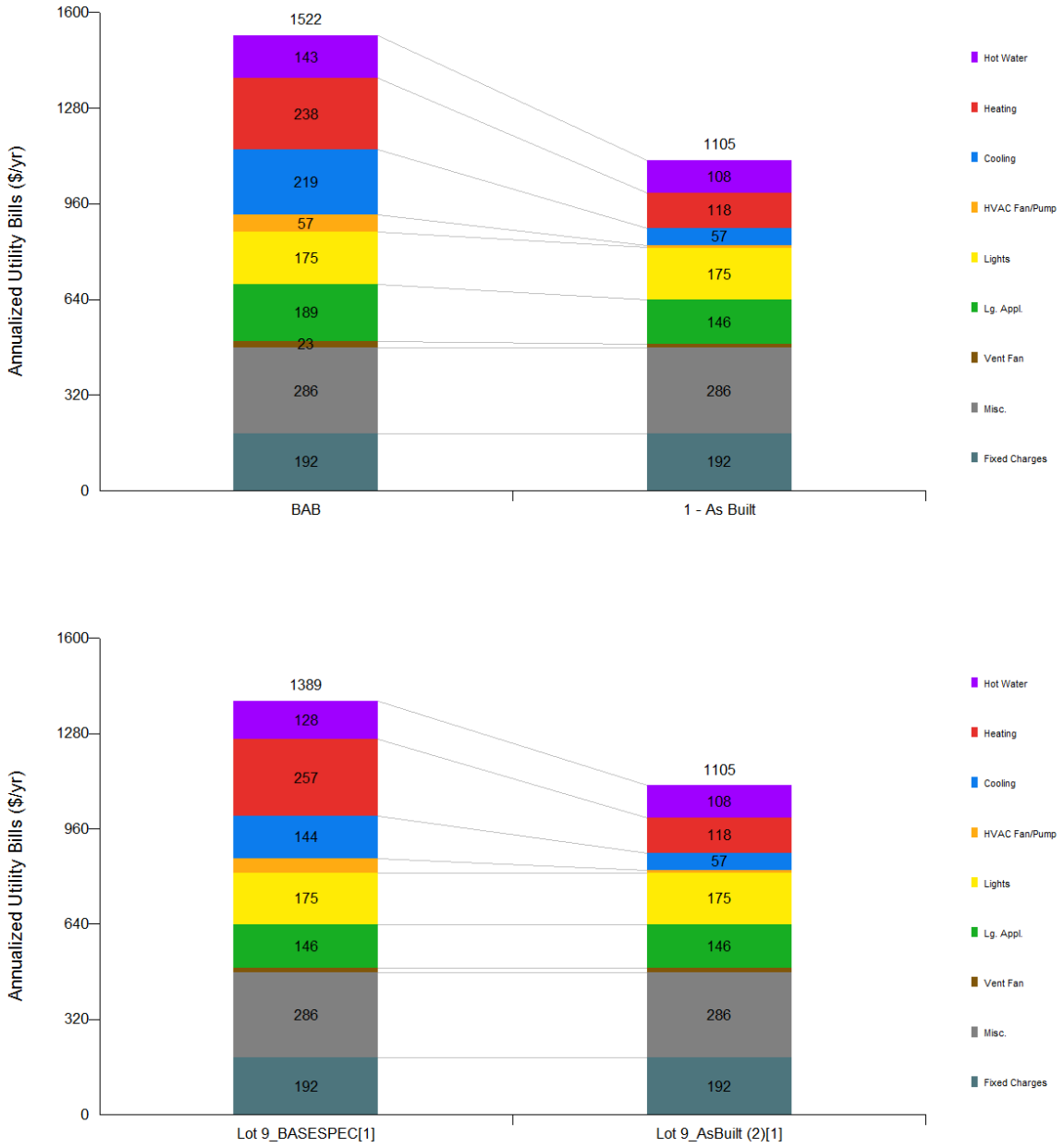


Figure 9. Annualized utility bill comparison for Nest Cottage, lot nine against B10 benchmark and the builder's typical package

4 Experiment

4.1 Test Plan

A detailed short-term testing and long-term monitoring plan was presented in Southface's test plan for the Nest Cottages, focusing on whole-house performance. The primary thrust of the investigation for this home will include whole-house performance, with a detailed evaluation of the GSHP (e.g., performance against rated efficiency values, previous studies, and the modeled consumption of high performance conventional systems). Test results will produce data to address the question of real versus perceived value.

4.2 Research Questions

Using this new construction test house for testing and evaluation is critical to answering the following research questions:

- Is the measured energy use for heating and cooling consistent with modeled estimates given similar ambient weather conditions?
- How do the efficiency, capacity, and operation costs of the GSHPs compare to AHRI ratings and manufacturer's published data?
- What is the additional fan energy, heating, and cooling consumption associated with the central fan integrated ventilation system?
- How does the cost effectiveness of certain high-profile energy upgrade measures, specifically a GSHP, compare to projected energy savings and other potential energy upgrades?

To answer these questions, the following research measurements were made or equipment installed:

Table 2. Research Measurements and Equipment

Parameter of Interest	Test Method	Purpose
House Infiltration Rate	Blower door test and diagnostic evaluation	• At construction completion, provide overall infiltration rate and locate remaining major leakage paths.
HVAC Duct Tightness and Overall Duct System Performance	Duct leakage test; air handler and diffuser flow rates; room pressure differentials (air handler running, doors closed); total external static pressure	• At construction completion, characterize overall air delivery system.
Ventilation System Performance	Balometer and hot wire anemometer measurements	• At construction completion, measure supply ventilation air flow rate and exhaust fan flow rates. Measure house depressurization during exhaust fan operation.
Whole-House Electric	Energy transducer and recording devices	• Record whole-house electricity use. • Identify a demand profile.
Space Conditioning Equipment	Energy transducers • Compressor • Air handler fan • Supp. heat • Loop pump Temperature/RH sensors • Supply plenum • Return plenum Temperature/flow sensors • Ground loop supply • Ground loop return	• Document the operation of the HVAC system relative to interior setpoints and exterior ambient drivers. • Document the real time efficiency of the HVAC system. • Document the added run time attributed to the CFIS ventilation system.
Indoor Environment	• Temperature/ RH sensors • 1 sensor in each HVAC zone (1 on each floor) • 1 sensor located in supply duct for each zone supply • 1 sensor in basement • 1 sensor outside	• Analyze the operation of the HVAC system relative to interior and exterior temperature and humidity drives.
Other	TBD	• Additional short-term tests or monitoring devices may be added based on ongoing measured data inspections, and/or field performance reported by builder staff or consumers.

Short-term tests are detailed in the following section. Long-term monitoring will be detailed in a future report after at least one year of monitored data has been collected.

5 Short-Term Testing

5.1 Short-Term Characterization Testing

Table 3 outlines the short-term measurement parameters and equipment used to obtain accurate and reliable measurements.

Table 3. Short-Term Equipment and Test Measurements

Measurement	Equipment	Test Measurements
Infiltration Rate	Blower door apparatus	950 CFM_{50}, 2.9 ACH_{50}
Duct Loss	Duct Blaster apparatus[1]	160 CFM_{25}, 11.9% of conditioned floor area total leakage; 0 CFM_{25}, 0% of conditioned floor area leakage to the outside
Air Handler Flow Rate	Trueflow grid[2]	1,040 CFM

1. Energy Conservatory Duct Blaster System
2. Energy Conservatory TrueFlow Air Handler Flow Meter

The short-term characterization testing results outlined in Table 4 include infiltration and duct leakage. The testing results show that the project met two of its primary goals—creating a tight thermal boundary to reduce air leakage and improving the thermal performance of the HVAC system by placing the air handler and ductwork 100% within conditioned space—with an infiltration rate of 2.9 ACH_{50} (950 CFM_{50}) and duct loss to the outside of 0% of floor area served (0 CFM_{25}). Air handler and duct flow rates continue to be gathered as part of the ongoing systems commissioning and startup of the long-term monitoring sensors.

Long-term monitoring will include sensors that record electric load and consumption, temperature, relative humidity, and fluid flow. The sensors in the home's mechanical room monitor electricity draw and the operation of the space conditioning and hot water equipment; they are hard wired for power and data logging. Temperature and relative humidity sensors located in the home's conditioned space, basement, and outdoors are equipped with a long-lived battery-fueled wireless transmitter that communicates with the main data logger in the mechanical room. A receiver/modem in the home receives and uploads data at preprogrammed intervals to a central server via an internet connection.

6 Summary

The design and implementation goals for this test house have been achieved. The home is projected to reach the 30% savings goal, a high performance thermal boundary that reduces air infiltration and brings mechanical equipment within conditioned space has been constructed, and the home will serve as a showcase and example for future development in the Serenbe community. With monitoring efforts planned to start in December 2012, Southface plans to focus on (1) determining the operational efficiency and energy consumption of the home's HVAC system, with a focus on the additional system fan run time associated with homes central fan integrated ventilation supply; and (2) examining the cost effectiveness of certain high profile energy upgrade measures, specifically a GSHP. Next steps include the following:

- Finalize collection of detailed cost data regarding the upgraded envelope measures and HVAC systems, including the shared loop infrastructure, GSHPs, and ventilation controllers used by the project, and prepare a detailed payback analysis.
- Prepare a long-term monitoring report based on at least one year's performance data.

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