

TaC Studios New Construction Test House

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NAHB Research Center

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TaC Studios New Construction Test House

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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	4
2.2.1 Framing.....	4
2.2.2 Air Sealing and Insulation	6
2.2.3 Fenestration.....	8
2.3 Systems	9
2.3.1 Heating, Ventilation, and Air Conditioning.....	9
2.3.2 Plumbing.....	11
2.3.3 Lighting and Appliances.....	11
2.4 Estimated Cost of Energy Efficiency Solution	12
2.5 Measure Interactions	15
3 Technical Pathway	16
3.1 Inputs to BEopt	16
3.2 Energy Simulation Results.....	16
4 Experiment	18
4.1 Test Plan.....	18
4.2 Research Questions	18
5 Short-Term Testing	21
5.1 Short-Term Characterization Testing	21
6 Summary	22
References	23

List of Figures

Figure 1. TaC Studios residence	1
Figure 2. TaC Studios residence building envelope	4
Figure 3. Over-designed framing at panel juncture.....	5
Figure 4. TaC Studios residence framing	5
Figure 5. Taped exterior sheathing panels.....	6
Figure 6. TaC Studios residence air sealing detail around exterior wall studs.....	7
Figure 7. TaC Studios residence air sealing detail at rim	7
Figure 8. TaC Studios residence insulation detail at exterior wall and roofline.....	8
Figure 9. Window installation	9
Figure 10. CFIS system schematic (<i>image from Building Science Corporation</i>).....	10
Figure 11. Insulated hot water piping at second floor shower.....	11
Figure 12. Source energy savings for TaC Studios residence compared to base specification and the B10 Benchmark	17
Figure 13. Annualized utility bill comparison for TaC Studios residence compared to base specification and the B10 benchmark.....	17
Figure 14. Monitoring layout diagram.....	19

Unless otherwise noted, all figures were created by Southface.

List of Tables

Table 1. TaC Studios Residence Building Specifications.....	3
Table 2. Costs of Included Energy Upgrades.....	13
Table 3. Research Measurements and Equipment	20
Table 4. Research Measurements and Testing Results.....	21

Unless otherwise noted, all tables were created by Southface.

Definitions

ACH ₅₀	Air changes per hour at 50 pascals
BEopt	Building Energy Optimization
CFA	Conditioned floor area
CFIS	Central fan integrated supply
CFL	Compact fluorescent lamp
cfm	Cubic feet per minute
cfm ₂₅	Air flow at 25 pascals
cfm ₅₀	Air flow at 50 pascals
COP	Coefficient of performance
DHW	Domestic hot water
EER	Energy efficiency ratio
EF	Energy factor
GSHP	Ground source heat pump
h	Hour
HSPF	Heating seasonal performance factor
in.	Inch
kBtu	Thousand British thermal units
kWh	Kilowatt-hour
LFL	Linear fluorescent lamp
NREL	National Renewable Energy Laboratory
o.c.	On center
PV	Photovoltaic
SDHW	Solar domestic hot water
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
SLA	Specific leakage area
WRB	weather-resistant barrier

Executive Summary

As part of the National Association of Home Builders (NAHB) Research Center Industry Partnership, Southface partnered with TaC Studios, an Atlanta-based architecture firm specializing in residential and light commercial design, on the construction of a new test home in Atlanta in the mixed-humid climate zone. This residence will serve as a model home for the builder partner. The planning and implementation of a design package that meets Building America Program energy savings targets in this home will serve as a design basis for the builder partner's future homes.

As a Building America test house, this home will be evaluated to detail whole-house energy use, end use loads, and HVAC and hot water efficiency. The main research priorities for this home are (1) determining the operational efficiency and energy consumption of the home's HVAC and hot water systems, focusing particularly on assessing part-load efficiency and system run times related to the operation of the home's zoning controls; and (2) examining the actual to projected energy savings and cost effectiveness of certain high-profile energy upgrade measures, specifically a ground source heat pump and an induction cooktop. This report outlines the features of this house, discusses the implementation of the energy efficient design, and presents the results of short-term characterization testing.

1 Introduction

With the support of the U.S. Department of Energy Building America Program, Southface partnered with TaC Studios to build a new construction test house. This single-family detached house is located in the mixed-humid climate zone 3 in Atlanta, Georgia. The three-story modern home was completed in 2011 and functions as a living/working space for the homeowners, in addition to a studio space and demonstration home for their clients (see Figure 1).



Figure 1. TaC Studios residence

1.1 Background

Under the Building America Program, TaC Studios, an Atlanta-based architecture firm specializing in residential and light commercial design, teamed with Southface through the National Association of Home Builders (NAHB) Research Center Industry Partnership. The team's goal was to design and construct a new single-family detached home that uses more than 30% less energy than a comparable house that meets the *2009 International Energy Conservation Code* (ICC 2009). 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 for the mixed-humid climate that addresses Building America and builder partner energy efficiency and cost goals of a commercially viable energy efficiency solution package.

1.2 Overview

The three-story design has 3,570 ft² of conditioned floor area over a sealed crawlspace foundation. The first floor includes the kitchen, dining, and living areas with a half bath and an attached garage (564 ft²). The second floor includes two bedrooms, a library, three full baths, and

a studio space that has the flexibility to function as two bedrooms in the future. The third floor includes a small entertaining space with access to a rooftop deck. Ceilings are 10 ft at the first floor and 9 ft at the second floor. The third-floor ceiling is sloped. The home's modern architecture includes many unique overhang and cantilevered details that required special attention to the air sealing and insulation design and installation.

1.3 Goals

Specific goals for the NCTH 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 International Energy Conservation Code* (ICC 2009).
- Create a tight thermal boundary to reduce air leakage and improve thermal performance.
- Design the HVAC system so that 100% is in conditioned space, leading to significant energy savings.
- Design the HVAC system to ensure occupant comfort in this home with four separate conditioned zones served by one system.
- Develop a cost-effective design that could function as a demonstration home for the homeowners and serve as a basis for their future home designs.
- Develop a test and monitoring plan to determine the operational efficiency and energy consumption of the home's HVAC and hot water systems, assess the impact of the home's lighting control system on lighting energy consumption, and examine the actual to projected energy savings and the cost effectiveness of certain high-profile energy upgrade measures.
- Earn LEED for Homes, ENERGY STAR, and EarthCraft House Certification.

The intent of this report is to outline the features of the house, discuss construction and installation, and detail short-term testing and monitoring.

2 Energy Efficient Solutions Package

2.1 Overview

The components included in this home are designed to improve the overall thermal performance of the building envelope, deliver high performance space conditioning and domestic hot water (DHW), and bring mechanical components within conditioned space. The design team members 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, the base set of specifications, and the Building America 2010 (B10) benchmark specifications (NREL 2010) for reference.

Table 1. TaC Studios Residence Building Specifications

Measure	B10 Benchmark	Base Specification	TaC Studios Residence
Foundation	Sealed Crawlspace	Sealed Crawlspace	Sealed Crawlspace
Foundation Insulation	R-5	R-5	R-7
Wall Construction	2 × 4	2 × 4	2 × 6
Wall Insulation	R-13	R-13	R-13
Ceiling Construction	Vented Attic	Vented Attic	Cathedral Attic
Ceiling Insulation	R-30	R-30	R-20
Window Ratings	U-0.40, SHGC-0.30	U-0.40, SHGC-0.30	Varies: U-0.34, SHGC-0.26 maximum U-0.28, SHGC-0.19 minimum
Infiltration	SLA = 0.00036	ACH ₅₀ ≤2.5	ACH ₅₀ ≤2.5
Heating Efficiency	7.7 HSPF	8.1 HSPF	3.9 COP
Cooling Efficiency	13 SEER	13 SEER	18 EER
Supply Duct Location	65% crawlspace, 35% conditioned space	50% crawlspace, 50% conditioned space	50% crawlspace, 50% conditioned space
Return Duct Location	100% crawlspace	50% conditioned space, 50% crawlspace	50% conditioned space, 50% crawlspace
Duct Leakage	15% total		<15% total
Ventilation	Exhaust 100% ASHRAE 62.2	CFIS, 100% ASHRAE 62.2	CFIS, 100% ASHRAE 62.2
Hot Water Efficiency	0.86 EF, electric	0.91 EF, electric	0.92 EF, electric (desuperheater)
Lighting	66% incandescent, 21% CFL, 13% LFL	66% incandescent, 21% CFL, 13% LFL	100% incandescent w/ automated dimming
Appliances	Benchmark	ENERGY STAR	Induction cooktop, ENERGY STAR

Notes: SHGC, solar heat gain coefficient; SLA, specific leakage area; ACH₅₀, air changes per hour at 50 pascals; HSPF, heating seasonal performance factor; COP, coefficient of performance; SEER, seasonal energy efficiency ratio; EER, energy efficiency ratio; CFIS, central fan integrated supply; EF, energy factor; CFL, compact fluorescent lamp; LFL, linear fluorescent lamp

2.2 Thermal Boundary

The thermal boundary of this home includes the insulated crawlspace walls, the exterior walls, the garage wall, the floors over ambient conditions and the attached garage, and a full cathedral ceiling. This design achieves the goal of bringing all HVAC equipment and distribution within the conditioned envelope (see Figure 2).

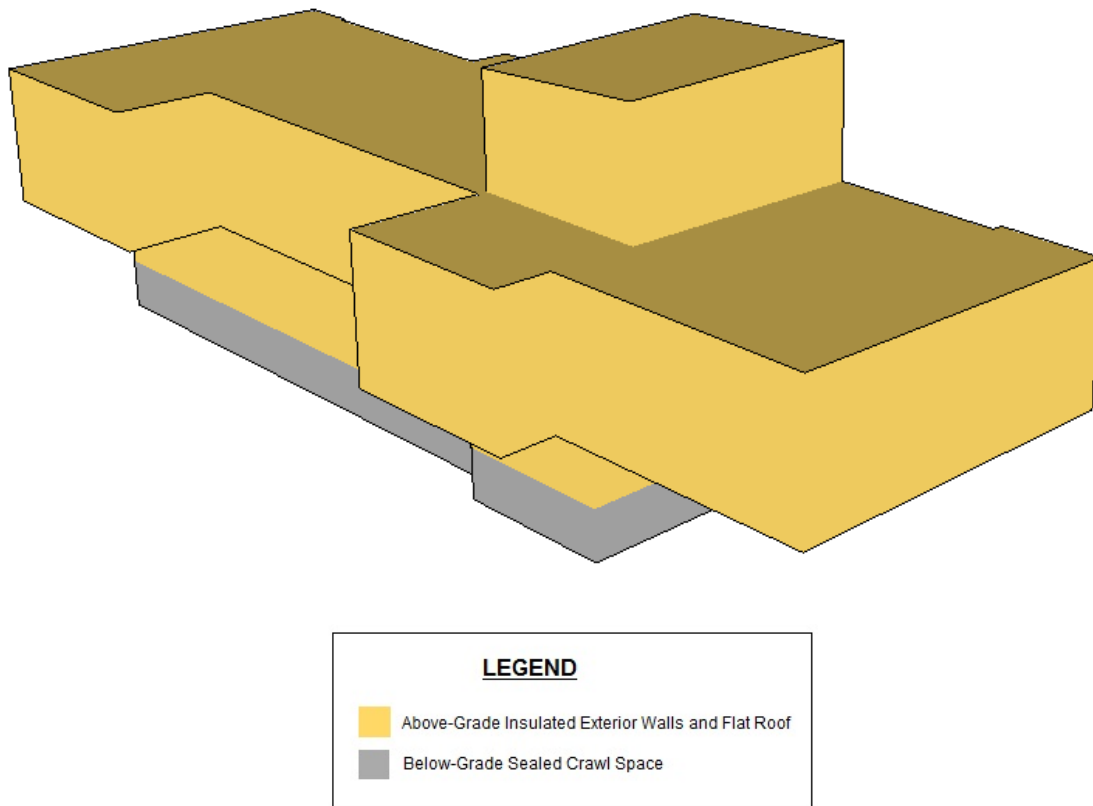


Figure 2. TaC Studios residence building envelope

2.2.1 Framing

The wall framing for the home was assembled off site as prefabricated panels, reducing construction time, but miscommunication between the factory and design team increased the framing factor in many areas. Initial plans called for 2×6 framing at 24 in. on center (o.c.) and advanced framing details including single top plates, two stud corners, and ladder t-walls, but the factory-built walls were built with 16 in. o.c. spacing and without the majority of the advanced framing details. Single top plates were still used. This change, along with changes to the insulation specification that will be discussed later, reduced the overall assembly U-value for the home from that of the initial design. This discrepancy highlights the ongoing knowledge gap in the industry about the execution of advanced framing details. Floor framing consists of 16-in. truss joists, and roof framing consists of 12-in. open-web trusses.



Figure 3. Over-designed framing at panel juncture

In addition, large window and door headers, comprising three 14-in. laminated veneer lumber members, were required at the first floor to accommodate the ceiling and window spans at the first floor and the load from the second floor and the roof. The sizing of these headers took into account the added load of a green roof, which the homeowners hope to install in the future.



Figure 4. TaC Studios residence framing

The walls came to the site including exterior sheathing formed of Zip Systems panels that include a preapplied weather-resistant barrier (WRB). Once framing and installation of exterior

sheathing had been completed, the Zip panel seams were taped (see Figure 5), resulting in a full WRB system and negating the need for house wrap or other applied WRB. This detail reduced construction time.



Figure 5. Taped exterior sheathing panels

The lessons learned from this process present an opportunity for a future measures guideline covering advanced framing measures.

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 to provide air sealing in the following areas:

- Penetrations through top and bottom plates
- Bottom plate to subfloor
- Penetrations through band
- Penetrations through insulated 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
- Blocking at cantilevered floors and garage ceiling.

Open-cell spray foam (OCSF) was used for insulation in all areas, adding resistance to air infiltration. Taping the seams in the home's exterior sheathing also contributed to the tight building envelope.



Figure 6. TaC Studios residence air sealing detail around exterior wall studs



Figure 7. TaC Studios residence air sealing detail at rim

OCSF insulation was selected based on its combination of insulation and air sealing attributes, and because of its high permeability levels and ability to diffuse water vapor, a particular concern in the mixed-humid climate zone. Initial design called for full fill of the exterior

2 × 6 wall cavities with OCSF insulation and 7 in. of foam applied to the roof deck (R-19 and R-26, respectively), but the homeowners elected to install 3.5 in. in the exterior walls and 5.5 in. at the roof deck (R-13 and R-19 respectively), based on cost concerns and the guidance of the insulation subcontractor. Insulation at the crawlspace walls was applied to a depth of 2 in. resulting in R-7.5, and insulation in the band areas was installed to 5.5 in. resulting in R-19. These levels of OCSF insulation represent standard practice in the Atlanta market, and many insulation installers are reluctant to install the insulation at higher levels based on the increased cost and past guidance from insulation manufacturers. Spray foam has many advantages over other insulation products, but its air sealing properties are no substitute for increased R-value. Additional contractor education and guidance is necessary to move the market forward in this area.



Figure 8. TaC Studios residence insulation detail at exterior wall and roofline

2.2.3 Fenestration

High glazing area is a prominent feature in many modern homes, and the performance of the upgraded glazing in this home is of particular interest given the high glazing area, 980 ft² (23% window to wall area ratio). The B10 Benchmark limits glazing to 15% of total wall area and even distributes the glazing on all sides of the modeled geometry. While rejection of solar gain was of particular interest to the homeowners, the home is well shaded to the south and west, a predominant amount of glazing faces east. The windows selected for the project all feature low SHGC values (see Figure 9).



Figure 9. Window installation

2.3 Systems

The primary systems investigation in this home was researching the HVAC system. Regarded as one of the most efficient system choices, ground source heat pumps (GSHPs) incorporate complex components and extensive infrastructures to reduce the impact of fluctuating ambient conditions for heat exchange. They also rely on sophisticated controls strategies to extract efficiency out of part-load conditions. Research and testing have documented efficacies that can double that of a standard efficiency conventional air-to-air system (Puttagunta, 2010), 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 choosing this technology over high efficiency traditional 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/aesthetic benefits of GSHPs (arising from the elimination of exterior condensers) have given these systems a cachet value in the high-end residential market, similar to marquee kitchen appliances and luxury automobiles.

2.3.1 Heating, Ventilation, and Air Conditioning

The GSHP included in this project presents an opportunity to evaluate the cost effectiveness and in-field efficiency of this technology in a ground loop application. Per standard testing procedure (ANSI/ASHRAE, 1998), this dual-stage GSHP is rated at 22.7 EER and 4.6 COP at full load with full load cooling and heating capacities of 70.7 kBtu/h and 56.8 kBtu/h, respectively. At

part load it is rated at 29.3 EER and 4.8 COP, with 51.5 kBtu/h and 39.6 kBtu/h of heating and cooling capacity, respectively. The unit includes a desuperheater option to preheat water. The home was designed with four separate HVAC zones, all served by this single unit. Characterizing the operation of the unit during part-load conditions, when, for example, a single zone calls for conditioned air, is a research priority for this study.

Meeting ASHRAE 62.2 ventilation rates introduces another trade-off 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 CFIS (see Figure 10). 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, which allows 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.

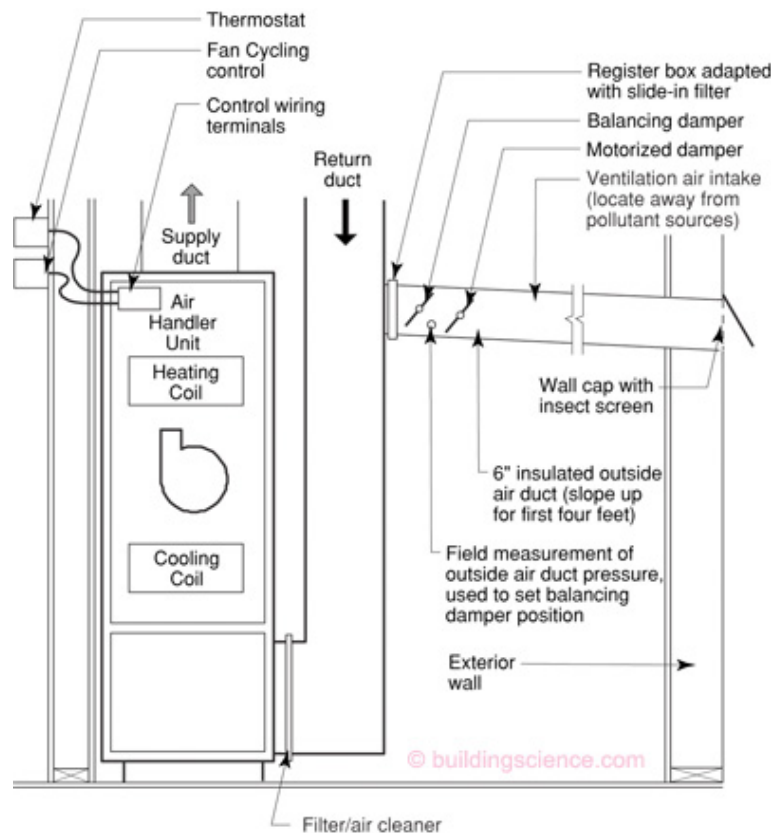


Figure 10. CFIS system schematic (image from Building Science Corporation)

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

Southface also plans to focus research efforts on determining the payback associated with the high-profile energy upgrades implemented in this home, including the GSHP. Southface has found that designers of many projects, including the TaC Studios residence, choose to use GSHPs without evaluating other high efficiency alternatives. Southface designers believe that these choices are based on performance and cost perceptions that have not been proven by real-world evaluation and monitoring. These perceptions might be reinforced by available utility or tax incentives. Collecting installation and operating costs on this project will allow for better decision making on future projects. Southface plans to follow the monitoring guidelines from Steven Winter Associates (2010).

2.3.2 Plumbing

Because of a significant incentive from the electric utility, an 85-gal electric storage water heater was chosen to provide DHW. This system is augmented by the desuperheater from the GSHP. All hot water plumbing within the home has been insulated to a level of R-4 (see Figure 11).



Figure 11. Insulated hot water piping at second floor shower

2.3.3 Lighting and Appliances

This home features a lighting control system from Lutron that automatically sets lighting power to pre-set dimming levels based on occupancy. The design team chose to use incandescent

lighting based on impressions about the low lighting quality of CFLs and light-emitting diode options; however, according to the controls manufacturer, dimming the incandescent lamps from full on levels has the potential to produce savings similar to those of CFLs. Southface plans to determine the accuracy of these claims by monitoring the operation of the controls.

Because this home is all electric, several high-end kitchen appliances were chosen, including an induction cooktop and a steam oven. The overall consumption of these end uses will be monitored to determine their contribution to whole-house energy consumption.

A portion of the second story of this home—846 ft² including a studio and library space—will function as a home office for the residents. This specialized end use consumption will also be monitored to determine its contribution to whole-house energy consumption. The homeowners hope to contrast the energy consumption of the home office to the energy consumption associated with commuting and working off site.

2.4 Estimated Cost of Energy Efficiency Solution

The project test plan included preliminary cost estimates for the energy efficiency solution package completed using Building Energy Optimization (BEopt) software. BEopt has since been updated based on actual cost data provided by the project team. These new cost data filled several gaps that had been identified in the previous BEopt cost library:

- Wood stud walls: OCSF insulation, R-13: \$3.90/ft²
- Interzonal walls: OCSF insulation, R-13: \$3.08/ft²
- Finished roof: OCSF insulation, R-19: \$2.81/ft²
- Crawlspace: OCSF wall insulation, R-7: \$1.46/ft²
- Exposed floor: OCSF insulation, R-9: \$1.46 /ft².

Actual insulation costs were added to uninsulated RSMeans wall assembly costs to arrive at these cost estimates. Where applicable, estimated costs from the BEopt cost library were updated using the following actual costs from the project team:

- Window type: \$36.95/ft²
- Refrigerator: \$5,836
- Cooktop: \$4,960
- Dishwasher: \$1,424
- Clothes washer: \$672
- Clothes dryer: \$723
- GSHP: \$39,000.

With these updated costs, the estimated incremental cost to the project team for the specified energy efficiency package, compared to its base specification, is \$24,999. The results from this test house and further analysis of the long-term monitoring data collected will confirm the cost effectiveness for these upgrades. Note that \$8,652 of this incremental capital cost can be

attributed to upgraded kitchen appliances chosen by the homeowners. Table 2 shows the BEopt results for the project's incremental capital costs.

Table 2. Costs of Included Energy Upgrades

Group Name	Category Name	Incremental Capital Cost (\$)	Current Option Name	Reference Option Name
Building				
	Orientation	0	South	Same as prototype
	Neighbors	0	at 20 ft	None
Operation				
	Heating set point	0	71°F	
	Cooling set point	0	76°F	
	Miscellaneous electric loads	0	1	4,203 kWh
	Miscellaneous gas loads	0	1	0 therms
	Miscellaneous hot water loads	0	Benchmark	60.0 gal/day
	Natural ventilation	0	Benchmark	
Walls				
	Wood stud	4,397	R-13, 2 × 6, 16 in. o.c.	R-13, batts, 2 × 4, 16 in. o.c.
	Exterior finish	0	Stucco	Absorption = 0.60 Emissivity = 0.90
	Interzonal walls	213	R-13, OCSF, 2 × 4, 16 in. o.c.	R-13, batts, 2 × 4, 16 in. o.c.
Ceilings/Roofs				
	Finished roof	1,766	R-19 OCSF	R-30.0
	Roofing material	0	Asphalt Shingles White or cool colors	Abs = 0.75 Emiss = 0.90
Foundation/Floors				
	Crawlspace	146	Wall R-7 OCSF	Wall R-5 Rigid
	Interzonal floor	335	R-19 OCSF	R-16.2
	Exposed floor	0	100% Exposed	None
Thermal Mass				
	Floor mass	0	Wood Surface	
	Exterior wall mass	0	½-in. Drywall	
	Partition wall mass	0	½-in. Drywall	
	Ceiling mass	0	½-in. Ceiling Drywall	
Windows and Shading				
	Window areas	0	TaC Studios	812 ft ²
	Window type	8,840	TaC Studios	U-0.40, SHGC 0.30

Group Name	Category Name	Incremental Capital Cost (\$)	Current Option Name	Reference Option Name
	Interior shading	0	Benchmark	Benchmark (0.70)
	Eaves	0	2 ft	
	Overhangs	0	None	
Airflow				
	Infiltration	(1,050)	TaC tested infiltration	SLA = 0.00036
	Mechanical ventilation	0	Supply 100% of A-62.2	Exhaust 100%, 67 WH cfm
Major Appliances				
	Refrigerator	4,536	TaC refrigerator	Standard (669 kWh)
	Cooking range	3,593	TaC induction	Electric (500 kWh)
	Dishwasher	521	TaC Dw	Standard (175 kWh)
	Clothes washer	2	ENERGY STAR (2)	Standard (78 kWh)
	Clothes dryer	(37)	Electric (2)	Electric (1,076 kWh)
Lighting				
	Lighting	0	B10 Benchmark	Living space, 2,366 kWh; garage, 52 kWh; exterior, 544 kWh
Space Conditioning				
	Ducts	(378)	In finished space	Unconditioned R-0.0 15% 0% outside air
	Ceiling fans	0	Benchmark	
Water Heating				
	Water heater	90	Electric premium	Gas, 50 gal, 0.90 EF
	Distribution	(434)	R-2 TrunkBranch PEX	R-0 TrunkBranch copper
	Solar DHW (SDHW)	0	None	
	SDHW azimuth	0	Back roof	None
	SDHW tilt	0	Roof pitch	None
Power Generation				
	Photovoltaic (PV) system	0	0 kW	
	PV azimuth	0	Back roof	None
	PV tilt	0	Roof pitch	None
HVAC Sizing				
	Cooling capacity	0	5.0 tons	
	Heating capacity	0	70 kBtu/h	120 kBtu/h
Total Incremental Capital Cost		23,080		

2.5 Measure Interactions

These upgraded measures present cost and energy trade-offs 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 the implementation of high performance housing in this market.

3 Technical Pathway

3.1 Inputs to BEopt

Because design and construction began in 2009, initial energy simulations were completed using EnergyGauge software and the then current version of the Building America Benchmark (Herndon, 2008). Southface has since completed energy simulations and cost trade-off analysis using the BEopt energy optimization tool, which shows that the home meets current Building America goals. The finalized building specifications for the TaC Studios residence were compared to a base set of specifications that the design team has used on past projects of similar scope (refer to Table 1). Savings estimates have been updated since the project test plan was completed to reflect spec changes made by the project team.

Several assumptions were made for this comparison based on gaps in the available BEopt inputs. Without an input option to accurately capture the functionality of the home's lighting system, the final design was simulated using the B10 benchmark lighting package. Similarly, at this time BEopt does not include the option to input the GSHP or the desuperheater. In lieu of these options, the most efficient air-source heat pump and electric storage tank options—18 SEER, 9.2 HSPF, and 0.95 EF, respectively—were chosen for the simulation. It is anticipated that the added efficiency of these options would increase the source energy and utility bill savings above the estimated levels listed in Section 3.2. On the other hand, BEopt lacks inputs for many luxury features included in the home including a pool and a pond. As a result, the energy consumption for these features is not reflected in the modeling results.

Southface plans to update the simulation models once updated versions of BEopt that include input options for GSHPs are released. 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 including the added luxury loads.

3.2 Energy Simulation Results

Based on the BEopt simulation and input assumptions previously discussed, the TaC Studios residence test home is projected to save greater than 30% over the Building America B10 benchmark (see Figure 12). This compares to roughly 11% savings for the project team's base specification.

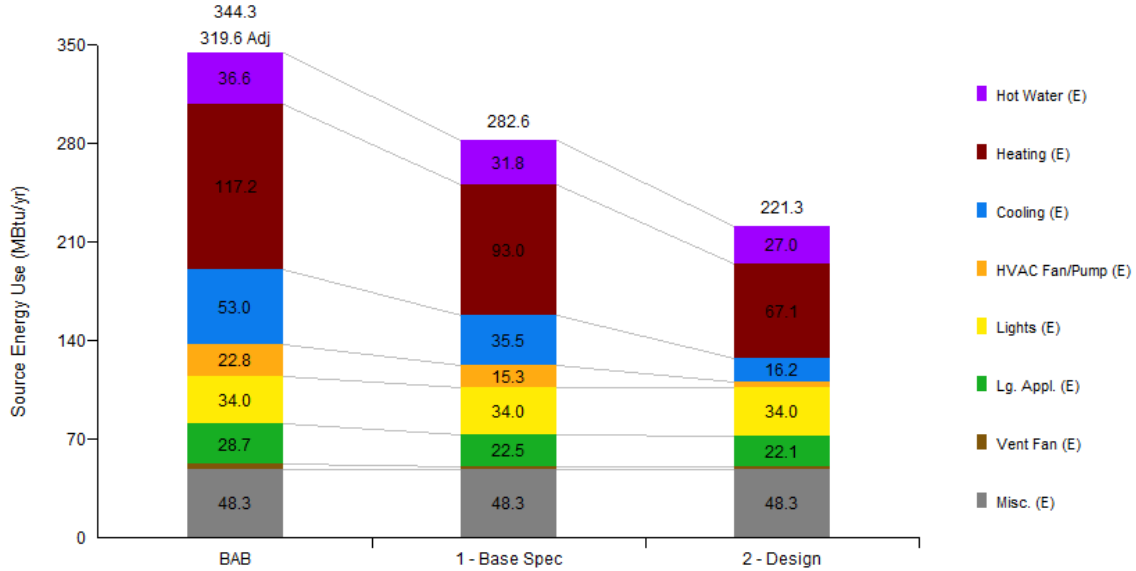


Figure 12. Source energy savings for TaC Studios residence compared to base specification and the B10 Benchmark

The preliminary annual cost savings are estimated to be greater than \$989 per year. Figure 13 depicts components of the savings.

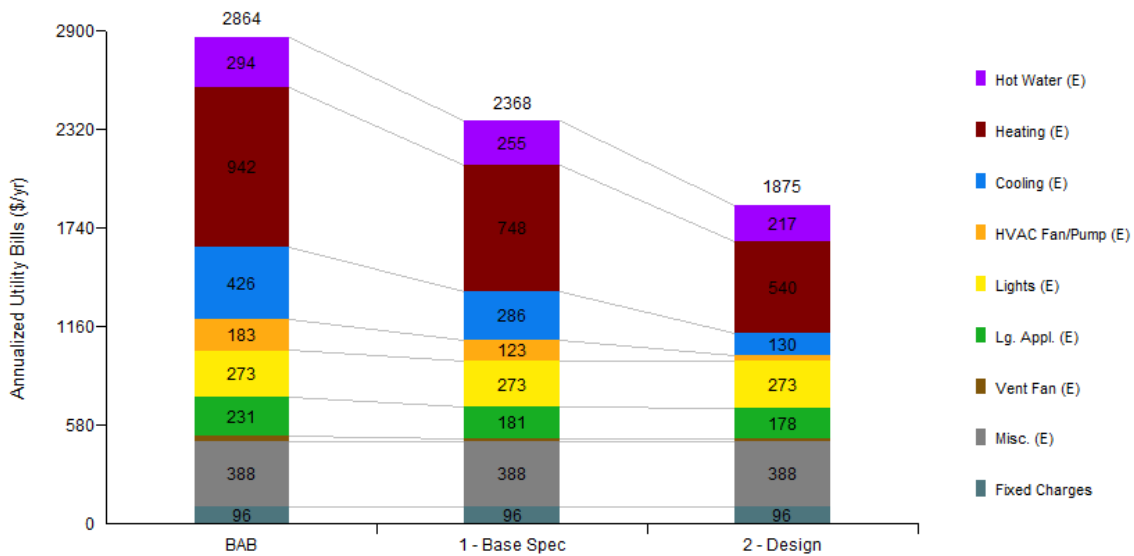


Figure 13. Annualized utility bill comparison for TaC Studios residence compared to base specification and the B10 benchmark

4 Experiment

4.1 Test Plan

A detailed short-term testing and long-term monitoring plan, focusing on whole-house performance, was presented in Southface’s Test Plan (Southface 2011). Figure 14 shows a diagram of the monitoring layout. The primary thrust of the investigation of the TaC Studios residence will be the evaluation of the GSHP performance against rated efficiency values, previous studies, and the modeled consumption of high performance conventional systems. Test results will yield data to address the question of real versus perceived value.

4.2 Research Questions

Use of this new home 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 with similar ambient weather conditions?
- What is the contribution of the desuperheater to satisfying the home’s hot water load given the chosen tank design and resident consumption patterns?
- How do the efficiency, capacity, and operation costs of the GSHPs compare to Air-Conditioning and Refrigeration Institute published data, manufacturer’s data, and modeled energy consumption?
- Is “rule of thumb” loop sizing adequate for this application?
- 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 and induction cooktop, compare to projected energy savings and other potential energy upgrades?
- Do dimmable lighting controls paired with incandescent bulbs produce similar energy savings to other high-efficacy lighting options at full power?
- How much does a home office contribute to the total energy consumption of the home?

Table 3 shows the research measurements made and the equipment installed to answer these questions:

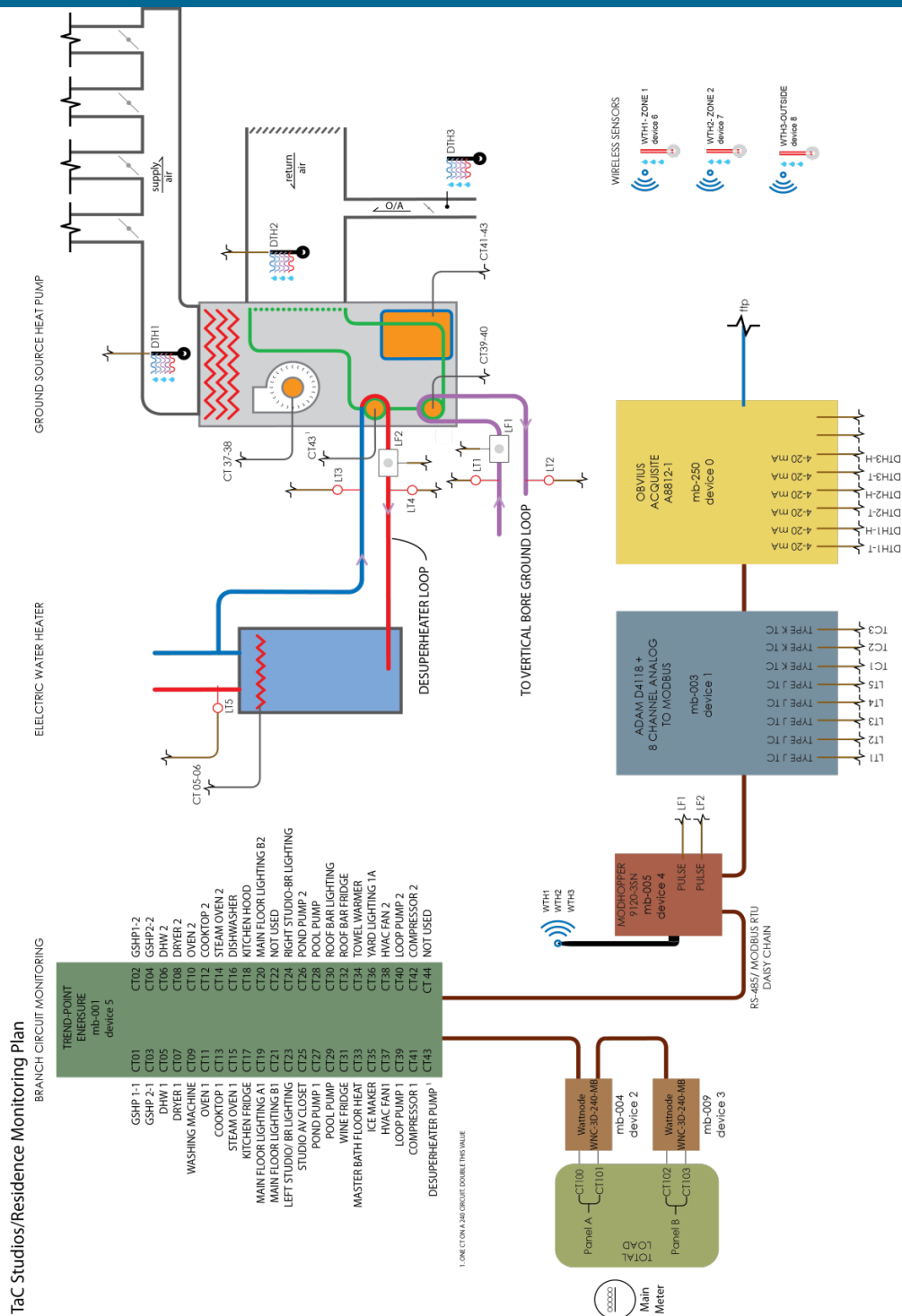


Figure 14. Monitoring layout diagram

Table 3. Research Measurements and Equipment

Label	Measurement	Equipment	Test Type
n/a	Infiltration Rate	Blower door apparatus	Short-term characterization test
n/a	Duct Loss	Duct Blaster apparatus	Short-term characterization test
n/a	Air Handler and duct flow rates	Trueflow grid, balometer, hot wire anemometer	Short-term characterization test
CT 01-43	Electric energy	Wattnode Trendpoint Enersure Branch Circuit Monitor	Long-term monitoring
DTH1-3	Duct air temperature, humidity	Vaisala HMD40Y	Long-term monitoring
LF1-2	Ground/desuperheater loop flow	Seametrics SPX-100/SPX-050	Long-term monitoring
LT1-4	Ground/desuperheater loop temperature	Omega TC-J-NPT-U-72	Long-term monitoring
LT-5	Water heater tank temperature	Omega M12JSS-1/4-U-12-B	Long-term monitoring
WTH1-3	Zone and Ambient Temperature, Humidity	Omega OMWT-TEMPRH wireless sensor	Long-term monitoring
as labeled	Sensor Signal Conversion/Data Recording	Obvious Acquisuite A8812-1, ADAM D-4018-BE, Omega OMWT-XREC-MOD,	Long-term monitoring

Short-term tests are detailed in Section 5. Long-term monitoring will be covered in a future report after at least 1 year of monitored data has been collected.

5 Short-Term Testing

5.1 Short-Term Characterization Testing

Table 4 outlines the short-term measurement parameters and equipment used to obtain accurate and reliable measurements.

Table 4. Research Measurements and Testing Results

Measurement	Equipment	Testing Results
Infiltration Rate	Blower door apparatus	1,696 cfm ₅₀ ; 2.15 ACH ₅₀
Duct Loss	Duct Blaster apparatus	Total: 407 cfm ₂₅ , 11.4% Outside: 128 cfm ₂₅ , 3.6%

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 2.15 ACH₅₀ (1,696 cfm₅₀) and duct loss to the outside of 3.6% of conditioned floor area served (128 cfm₂₅). 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 located in the home’s mechanical room to monitor electricity draw and the operation of the space conditioning and hot water equipment are hard wired for power and data logging. Temperature/relative humidity sensors located in the home’s conditioned space, crawlspace, and outdoors are equipped with a long-lived battery-fueled wireless transmitter that communicates with the main data logger located in the mechanical room. A receiver/modem located within 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 work space for the homeowners and a showcase for TaC Studio's future customers. With monitoring efforts under way, Southface plans to focus on (1) determining the operational efficiency and energy consumption of the home's HVAC and hot water systems with a special focus on assessing part-load efficiency and system run times related to the operation of the home's zoning controls and (2) examining the actual to projected energy savings and cost effectiveness of certain high-profile energy upgrade measures, specifically a GSHP and an induction cooktop.

Next steps include the following:

- Prepare a detailed payback analysis.
- Complete open items identified in Section 5.
- Prepare a long-term monitoring report based on at least 1 year's performance data.
- Complete LEED for Homes, ENERGY STAR, and EarthCraft House Certification.

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