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Fort Benning Indianhead Townhome Renovations

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Contents

List of Figures

Unless otherwise noted, all figures were created by Southface.

List of Tables

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Definitions

ACH_{nat}	Air changes per hour at natural conditions
AFUE	Annual fuel utilization efficiency
BEopt	Building Energy Optimization
Btu	British thermal unit
CFA	Conditioned floor area
cfm_{25}	Air flow (cubic foot per minute) at 25 pascals
DHW	Domestic hot water
E	Electric
EF	Energy factor
ft^2	Square foot
G	Gas
h	Hour
HPwES	Home Performance with ENERGY STAR
HSPF	Heating seasonal performance factor
in.	Inch
kBtu	Thousand Btu
kWh	Kilowatt-hour
MBtu	Million Btu
NREL	National Renewable Energy Laboratory
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
yr	Year

Executive Summary

As part of the National Association of Home Builders Research Center Partnership for High Performance Homes, Southface Energy Institute completed a post-renovation analysis of the Fort Benning, Georgia, Indianhead townhomes renovation project. Completed by Clark Realty Partners in 2010, the project included the rehabilitation of 207 townhome units for base housing to Army personnel at Fort Benning. The Building America Program goals for this project included determining the projected energy savings over the pre-renovation condition, evaluating the quality assurance approach implemented by the project team, and identifying gaps and barriers in current Building America simulation tools associated with attached housing. The intent of this report is to outline the energy upgrade package implemented in this project and the findings of the Southface Energy Institute's post-renovation analysis.

1 Introduction

1.1 Background

Southface Energy Institute (Southface) conducted a post-renovation evaluation of the Fort Benning, Georgia, Indianhead Townhomes project as part of the National Association of Home Builders Research Center Industry Partnership through the Building America Program. Completed in 2010, the project included the renovation of 207 townhome and duplex units by Clark Realty for Army personnel housing at Fort Benning. Table 1 shows the four unit types that were renovated.

Table 1. Fort Benning Unit Types

Unit Type	Number of Units	Conditioned Area (ft^2)
Townhome W4	6	1,440
Townhome W5	28	1,456
Townhome W6	42	1,350
Townhome W7	220	1,536

These existing homes were unoccupied and in a state of disrepair when the renovations began (see Figure 1). Previous occupants had complained of high energy bills, interior moisture issues, and poor indoor air quality. Appendix A contains plans for each type of unit.

Figure 2 shows one of the units after renovation.

Figure 1. Fort Benning Indianhead townhomes, pre-renovation

Figure 2. Fort Benning Indianhead townhomes, post-renovation

1.2 Overview

When completed at scale like the Fort Benning Indianhead renovation project, upgrades of existing housing offer opportunities to save a significant amount of energy. This project was the first Home Performance with ENERGY STAR (HPwES) project in the nation to use sampling for quality assurance. In this case, the 207 townhome and duplex units included in the project had essentially identical existing conditions given their common history of construction and maintenance. They received a standardized upgrade package including improved building envelope components and new HVAC and domestic hot water (DHW) systems. Given the uniform nature of the project, applying methods from production-scale, new construction, quality assurance approaches—specifically sampling methods for pre and post-renovation inspections—presented an opportunity to meet the project's energy savings and improvement goals in a cost-effective manner.

Southface initially provided quality assurance and administrative support for this project through Clark Realty's involvement with the HPwES program. The energy upgrade package for the project was chosen based on the current Southface HPwES renovation priority list and the energy improvement measures incentivized through the Georgia Power energy efficiency rebate program. As a result, no simulation modeling was completed during the design phase of the project. Southface has completed a post-renovation analysis of the project. This analysis compared the selected measures to those recommended by energy modeling tools and was designed to determine the energy savings achieved by the project, identify any missed energy upgrade opportunities, and evaluate the current structure of the HPwES priority list. Given that incentive programs continue to influence homeowner and developer decisions on which energy upgrade measures to include in a major renovation project, this post-renovation analysis also allows the impact of the rebate program on the chosen measures to be assessed.

The post-renovation simulation analysis also offered an opportunity to evaluate Building America simulation tools and their applicability to attached housing. Current Building America simulation tools, namely Building Energy Optimization (BEopt, E+ version 1.1), do not include options for evaluating attached housing with adiabatic walls or homes with multiple wall types. Alternative approaches include using parallel path analysis to determine a total U-value wall input for BEopt or the use of alternative software packages following the Building America House Simulation Protocols (Hendron & Engebrecht, Building America House Simulation Protocols, 2010). The comparison of the results from these different approaches highlights current gaps for modeling attached housing.

1.3 Goals

Specific goals for the post-renovation analysis for this project included the following:

- Document and estimate the cost of each energy upgrade measure included in the renovation.
- Determine the projected savings over the pre-renovation condition.
- Complete statistical analysis of pre- and post-renovation diagnostic testing results to determine if sampling serves as a valid quality assurance model for large-scale renovation projects of this type.
- Identify gaps and barriers in current Building America modeling tools.
- Compare the structure of Southface's HPwES priority list and the Georgia Power incentive program with energy upgrade packages derived from modeling tools.

The intent of this report is to outline the energy upgrade package implemented in this project and the findings of Southface's post-renovation analysis.

2 Energy Efficient Solutions Package

2.1 Overview

The energy improvement measures implemented as part of this renovation were in large part chosen to bring the project up to current energy code standards, International Energy Conservation Code 2006.[1] Table 2 lists the existing building specifications and chosen energy upgrades for the project.

Table 2. Fort Benning Indianhead Townhomes Building Specifications

Measure	Pre-Renovation	Post-Renovation
Foundation	Slab	n/a
Foundation Insulation	R-0	n/a
Wall Insulation	R-9	R-13
Ceiling Construction	Vented attic	Vented attic
Ceiling Insulation	R-8	R-30
Window Ratings	U-1.27, SHGC-0.75	U-0.33, SHGC-0.24
Average Infiltration	1.31 ACH_{nat}	0.41 ACH_{nat}
Heating Efficiency	80 AFUE	8 HSPF
Cooling Efficiency	10 SEER	13 SEER
Average Duct Leakage	0.69 cfm_{25}/CFA	0.056 cfm_{25}/CFA
Thermostat	Analog	Programmable
Hot Water Efficiency	0.57 EF, natural gas	0.94 EF, electric

Notes: SHGC, solar heat gain coefficient; ACH_{nat}, air changes per hour at natural conditions; AFUE, annual fuel utilization efficiency; HSPF, heating seasonal performance factor; SEER, seasonal energy efficiency ratio; cfm_{25}, cfm at 25 Pa; CFA, conditioned floor area, EF, energy factor

The project's participation in the Southface HPwES program and the availability of energy rebates from the local electric power utility, Georgia Power, also drove the decision process around specific energy improvement measures. Until 2011, Southface administered Georgia Power's residential demand side management and incentives program, which used the structure of the Southface HPwES to award energy upgrade rebates. The program includes training and quality assurance requirements for participating contractors (Clark Realty in this case). Projects participating in the program undergo a comprehensive whole-house audit to assess existing conditions within the homes and establish priorities for energy upgrade measures to be included in renovation work. The priority list shown in Table 3 grades existing conditions based on the audit results, with an "A" priority representing a high opportunity for improvement, a "B" priority representing slightly less of an opportunity, and so on. Southface developed this priority list in 2003 based on experience with existing home renovation projects and the feedback of industry experts. The existing conditions found for the Fort Benning Indianhead Townhomes are highlighted in bold in Table 3 (Southface Energy Institute, 2008).

[1] Available for purchase from the International Code Council at http://shop.iccsafe.org/2006-international-energy-conservation-code-soft-cover.html.

Table 3. HPwES Prioritization Table

Improvement	Existing Condition	Priority
Air Sealing	**≥0.75 ACH_{nat}**	**A**
Air Sealing	0.50–0.74 ACH_{nat}	B
Air Sealing	0.4–0.49 ACH_{nat}	C
Improve Ducts	**≥25% duct leakage**	**A**
Improve Ducts	16.0%–24.9% duct leakage	B
Improve Ducts	10.0%–15.9% duct leakage	C
Improve Ducts	5.0%– 9.9% duct leakage	D
Insulate Attic (Attic Floor Air Sealing Must Precede Insulation Work)	**R-0– R-9**	**A**
Insulate Attic (Attic Floor Air Sealing Must Precede Insulation Work)	R-10–R-19	B
Insulate Attic (Attic Floor Air Sealing Must Precede Insulation Work)	R-20–R-29	C
Insulate Attic Kneewalls	None	A
Insulate Attic Kneewalls	Insulated, unsheathed, or incomplete sheathing	B
Insulate Attic Kneewalls	Insulated: sheathed, but only effective R-13	D
Insulate Walls	None	C
Insulate Floor	None	B
Insulate Floor	Any	C
Insulate Basement/Crawlspace Walls	None	B
Insulate Basement/Crawlspace Walls	**Any**	**C**
Radiant Barrier	**No radiant barrier**	**D**
Replace Heating System	60–69 AFUE/5 HSPF	A
Replace Heating System	70–79 AFUE/6 HSPF	C
Replace Heating System	**80–89 AFUE/7 HSPF**	**D**
Replace Cooling System	6.0–7.9 SEER	A
Replace Cooling System	8.0–9.9 SEER	B
Replace Cooling System	**10 SEER**	**D**

Improvement	Existing Condition	Priority
Replace Water Heater	<0.5 gas, <0.85 electric	C
Replace Water Heater	<0.56 gas, <0.89 electric	D
Insulate Water Heater and Pipe	electric	B
Insulate Water Heater and Pipe	**gas**	**C**
Install/Upgrade Passive Attic Ventilation (Confirm Presence of Effective Air Barrier Between Attic and Living Space)	Passive ventilation net free area does not meet code standard	B
Remove Powered Roof Ventilation And Install/Upgrade Passive Attic Ventilation (Confirm Presence of Effective Air Barrier Between Attic and Living Space)	Powered roof ventilators on roof	A
Improve Windows	Jalousie windows	A
Improve Windows	**Metal single pane**	**B**
Improve Windows	Wood single pane	C
Improve Windows	Metal single pane with storm	C
Improve Windows	Wood single pane with storm	D
Improve Windows	Metal double pane	D

The audit and priority list identified infiltration, duct leakage, attic insulation, and window replacement as high priorities for energy improvements. Additionally, the HVAC and DHW systems were in a poor state of repair and required replacement. Georgia Power also provided the following incentives to the project for specific upgrade measures, totaling $1,200.

Table 4. Georgia Power Incentives

Incentive ($)	Requirement
250	Air sealing when priority A or B
100	Duct sealing when priority A or B
200	Attic insulation when priority A or B and when air sealing and sealing of ducts located in attic performed
550	Wall insulation to R-13
100	Install programmable thermostat (allowable models) only when duct sealing and duct insulation performed or not an A or B priority

The incentives offered through the Georgia Power HPwES program and the low cost of electricity available to the project through its association with the Army ($0.06/kWh) drove the decisions on the chosen energy upgrades and the switch from gas to electric for heating and cooking.

2.2 Building Enclosure

The thermal boundary for these homes includes a slab-on-grade foundation, exterior walls, and the attic-floor/second-floor ceiling, as well as adiabatic demising walls that separate units (see Figure 3). These homes underwent a gut rehabilitation renovation where the existing structure was left in place and all insulation was replaced.

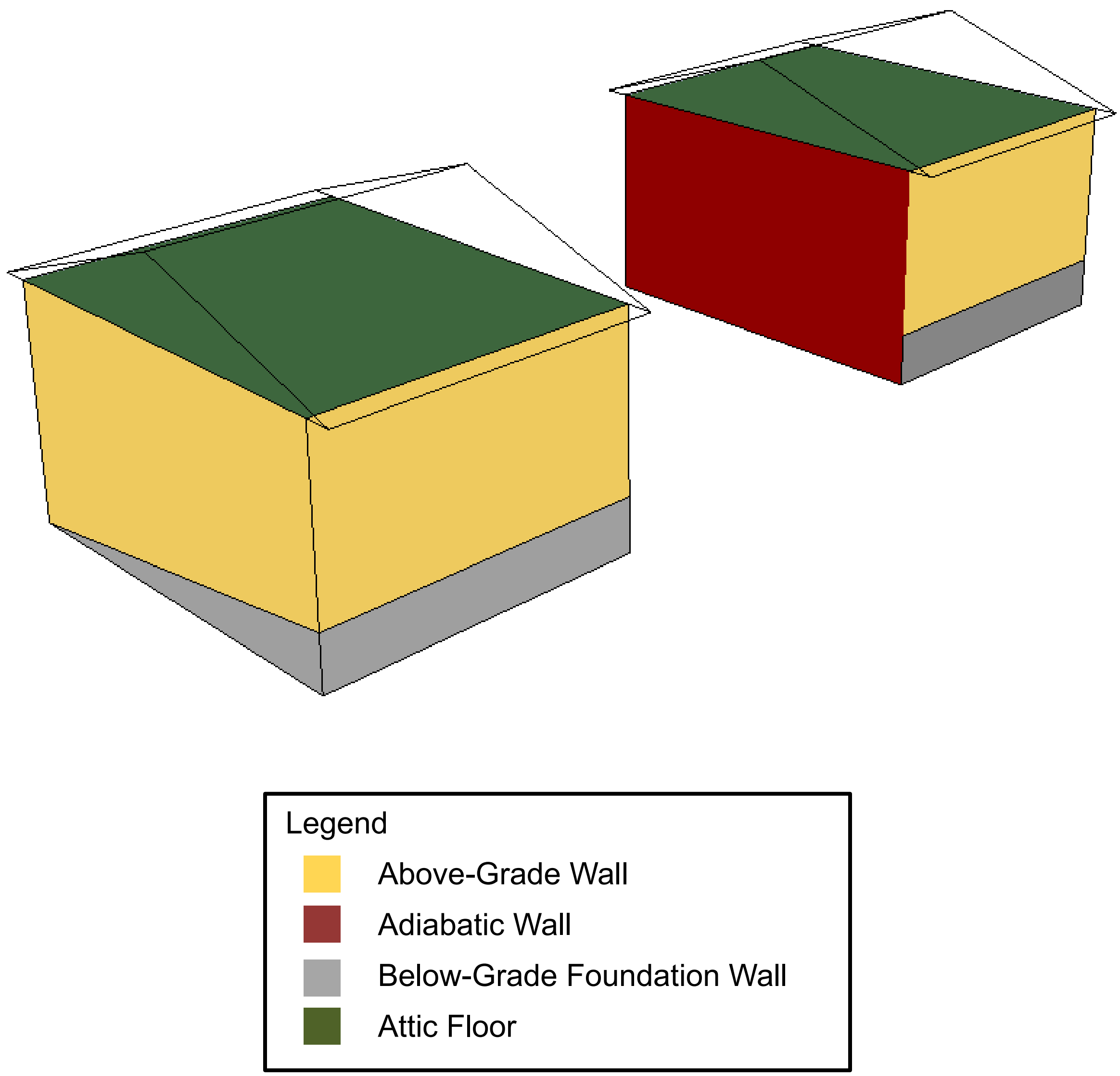


Figure 3. Townhome building envelope

2.2.1 Foundation and Framing

All homes in the project had slab-on-grade foundations, with some homes having small foundation retaining walls to account for changes in grade. The first-floor exterior walls of these homes were built with 8-in. concrete masonry unit block, with 2 × 4 furred out interior wood framing (see Figure 4), and the second floor was built with 2 × 4 wood studs. Traditional framing was used for the roof structure to create a vented attic assembly.

Figure 4. Interior framing at first floor

2.2.2 Air Sealing

The pre-renovation inspections identified the following areas as air leakage pathways and prioritized air sealing measures in these areas:

- Attic access doors
- Electrical and plumbing penetrations
- Baths at exterior walls
- Window and door rough openings
- Floor and ceiling HVAC penetrations
- Sill plate to slab and subfloor at second floor.

Small penetrations were sealed with caulk and expanding foam, and for larger holes, sheet goods (plywood, oriented strand board, sheet metal, or rigid foam board) were used.

2.2.3 Insulation

Existing insulation (fiberglass batts in exterior walls and at the attic ceiling) was removed and replaced with new fiberglass batts that met current energy code insulation requirements of R-13 fiberglass batts in exterior walls and R-30 blown fiberglass insulation in attic ceilings.

2.2.4 Fenestration

The single pane metal framed existing windows (see Figure 5)were removed and replaced with new vinyl clad low-E glazing units with a low SHGC of –0.24 and a U-value of 0.33 (see Figure 6). Rough openings were sealed with expanding foam.

Figure 5. Existing single pane, metal framed windows

Figure 6. New double pane, vinyl framed windows with low-E glazing

2.3 Systems

2.3.1 HVAC

The existing HVAC systems, 10-SEER air-conditioning units and 80-AFUE furnaces, were in extreme states of disrepair. In some cases building cavities had been used for air distribution, and furnace flues were not correctly functioning. Completely replacing the HVAC systems and duct distribution systems in each unit alleviated these problems. Air source heat pumps (13 SEER and 8 HSPF) replaced the existing furnaces (see Figure 7). The units were placed in sealed closets and ductwork was sealed following HPwES protocols. No building cavities were used for air distribution with all runs fully ducted.

Figure 7. New air handler installation

Existing kitchen range hoods and bath exhaust fans were replaced with new models that vented to the outside.

2.3.2 Domestic Hot Water

New electric storage water heaters (0.94 EF; see Figure 8) replaced existing gas-fired units. Plumbing was replaced or repaired where necessary.

Figure 8. New electric storage water heater

2.3.3 Lighting and Appliances

Kitchens were outfitted with ENERGY STAR refrigerators and dishwashers. Lighting fixtures were replaced with standard fixtures with incandescent bulbs.

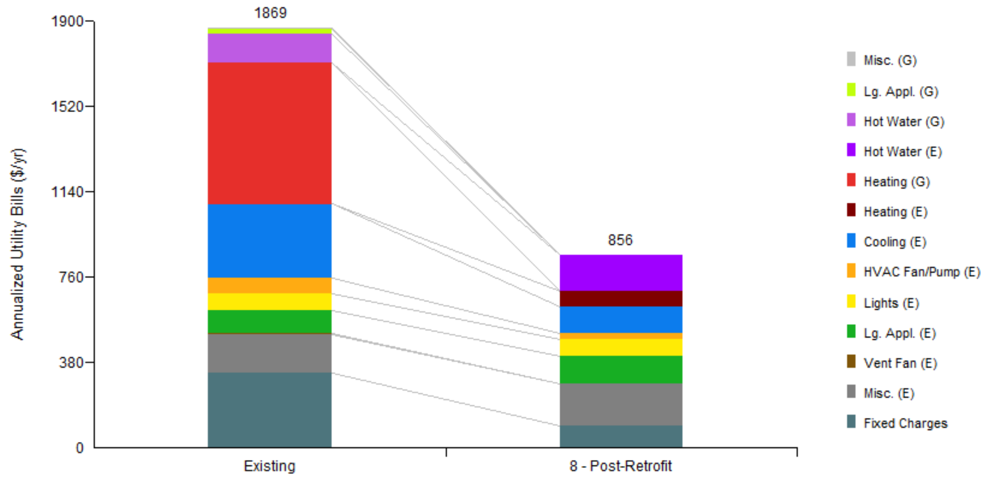
2.4 Estimated Cost of Energy Efficiency Solution

Actual cost data were not available for this project, but BEopt's cost library showed an incremental capital cost for the project of $11,230 for the modeled unit. When reduced by the $1,200 local utility rebates earned by the project, the incremental capital cost was approximately $10,030 (Table 5). The $1,000 annual savings in utility bills shown by the BEopt simulation model (Figure 9) gives a simple payback projection for the project of approximately 10 years. Given that these are rental homes, however, the utility bill savings will immediately benefit the residents. Because the developer is not directly experiencing any benefit from these utility bill savings, monetary, marketing, or other drivers are needed to motivate developers to include energy efficiency measures in rental housing projects. The Fort Benning Indianhead Townhomes renovation project demonstrates the impact of energy efficiency incentives on the developer decision-making process, because Clark Realty would not have engaged with the HPwES program without the incentives from the Georgia Power rebate program.

Table 5. Estimated Costs of Energy Efficiency Options

Group Name	Category Name	Incremental Capital Cost ($)	Post-Retrofit	Existing
Building	Orientation	0	East	
	Neighbors	0	None	
Operation	Heating set point	0	71F	
	Cooling set point	0	76°F	
	Misc. electric loads	0	1	
	Misc. gas loads	0	1	
	Misc. hot water loads	0	Benchmark	
	Natural ventilation	0	Benchmark	
Walls	Wood stud	4,483	Fort Benning retrofit walls R-13	Fort Benning existing walls R-9
	Exterior finish	0		
Ceilings/ Roofs	Unfinished attic	414	Ceiling R-30 cellulose blown-in vented	Fort Benning existing attic R-8
	Roofing material	0	Asphalt shingles dark	
	Radiant barrier	0	None	
Foundation/ Floors	Slab	0	Uninsulated	
	Exposed floor	0	20% exposed	
Thermal Mass	Floor mass	0	Wood surface	
	Exterior wall mass	46	½ in. drywall	
	Partition wall mass	0	½ in. drywall	
	Ceiling mass	0	½ in. ceiling drywall	
Windows/ Shading	Window areas	0	Front 70, back 101, left 0, right 0	Front 110, back 102, left 0, right 0
	Window type	0	U 0.33, SHGC 0.24	U 1.2, SHGC 0.75
	Interior shading	0	Benchmark	
	Eaves	0	2 ft	
	Overhangs	0	None	
Airflow	Infiltration	386	0.49 ACH_{nat}	2.14 ACH_{nat}
	Mechanical ventilation	0	Spot vent only	
Major	Refrigerator	780	ENERGY STAR top	Standard top

Group Name	Category Name	Incremental Capital Cost ($)	Post-Retrofit	Existing
Appliances			mount freezer	mount freezer
	Cooking range	0	Electric conventional	Gas conventional
	Dishwasher	50	ENERGY STAR	Standard
	Clothes washer	0	Standard	
	Clothes dryer	0	Electric	
Lighting	Lighting	0	B10 benchmark	
Space Conditioning	Air conditioner	0	None	SEER 10
	Furnace	(1,251)	None	Gas 80% AFUE
	Heat pump	4,511	SEER 13, HSPF 8.1	None
	Ducts	1,891	3% leakage, R-8	68% leakage, R-4
	Ceiling fans	0	Benchmark	
Water Heating	Water heater	(80)	Electric EF 0.94	Natural gas EF 0.60
	Distribution	0	R-0 Trunk branch copper	
	Solar DHW	0	None	
	Solar DHW azimuth	0	Back roof	
	Solar DHW tilt	0	Roof pitch	
Power Generation	Photovoltaic system	0	0 kW	
	Photovoltaic azimuth	0	Back roof	
	Photovoltaic tilt	0	Roof pitch	
HVAC Sizing	Cooling capacity	0	3 tones	
	Heating capacity	0	80 kBtu/h	
First Year Total Incremental Capital Cost		11,230		
Energy Rebates		1,200		
Total Incremental Capital Cost Less Energy Rebates		10,030		



Notes: G, gas; E, electric

Figure 9. Annualized utility bill comparison for pre- and post-renovation cases

2.5 Measure Interactions

Many of the energy efficiency measures incorporated into the renovation package had additional benefits for occupant health and comfort and mitigated existing moisture, mold, and combustion safety risks. Previous occupants had complained of high energy bills, interior moisture issues (see Figure 10), and poor indoor air quality. The existing ductwork in these homes was in a high state of disrepair and in some cases building cavities had been used as open plenums (see Figure 11), introducing moisture and contaminants into the air stream and causing pressure imbalances in the homes. Complete replacement of the ductwork alleviated these issues. Moisture damage was also repaired and the resulting mold growth was removed. Replacing gas furnaces, water heaters, and ranges with electric units also removed potential combustion safety risks from the homes.

Figure 10. Existing ductwork, mold and moisture damage

Figure 11. Existing ductwork, building cavity used as return plenum

3 Technical Pathway

3.1 Inputs to Building Energy Optimization Software

Through simulation, BEopt produces a comparison of the pre- to post-renovation conditions. The comparison includes source energy use and equivalent annual energy cost based on energy costs and the costs of the improvement measures, within the limits of the software and cost data. A W-4 end unit was chosen as a worst-case unit for simulation modeling because it had the highest percentage of exposed wall area and the highest window to floor area ratio. A worst-case orientation was also chosen for the simulation modeling with the front of the home facing east and the exterior end wall facing south. Optimization studies for the project were not completed because this simulation analysis occurred after the renovation.

3.2 Simulation Results

Energy simulations for the worst case W4 end unit showed a post-renovation source energy savings of 43% over existing conditions. The post-renovation energy simulations included source energy savings analyses and cost-effectiveness comparison. Figure 11 graphically depicts the simulation results.

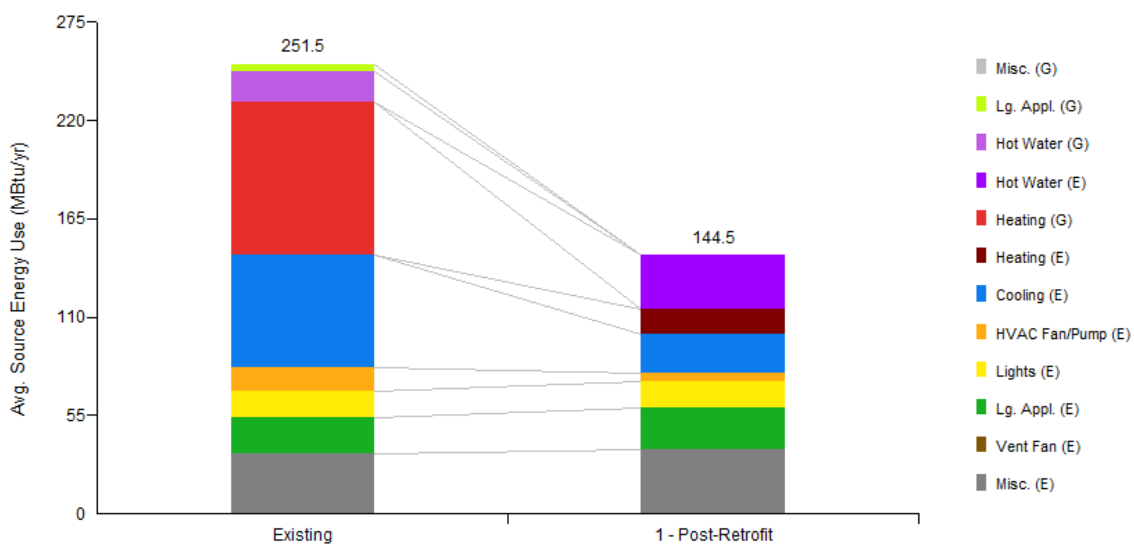


Figure 12. Source energy comparison of the pre and post-renovation cases

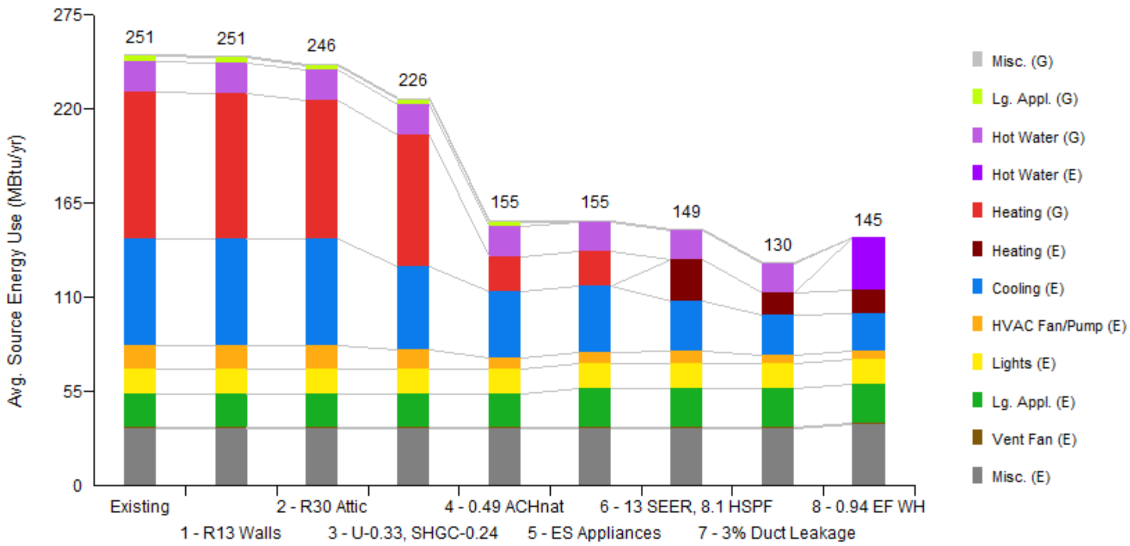


Figure 13. Source energy savings contribution for individual renovation measures

Additional simulations were run to determine the contribution of the individual measures included in the renovation package (refer to Table 2). The largest savings came from improved duct and envelope leakage rates, as well as high performance window upgrades. Although the switch to an electric water heater saved money because of the low electric rate ($0.06/kWh) available through the project's connection with Fort Benning, a source energy penalty was incurred with the switch from natural gas.

To input these attached housing units into the BEopt software, a parallel path workaround was used to calculate an average U-value input for the exterior walls based on the different exterior wall types and the adiabatic party walls. Tables 6 and 7 show these calculations for the existing and post-renovation conditions.

Table 6. Parallel Path Analysis, Existing Conditions

W4 Wall U-Value Brick, End Unit			W4 Wall U-Value Siding, End Unit		
Framing Width (in.)		3.5	Framing width (in.)		3.5
Block Width (in.)		8	Block width (in.)		8
Block Face Thickness (in.)		1.25	Block face thickness (in.)		1.25
Brick Width (in.)		4			
	Cavity	Framing/Rib		Cavity	Framing
Interior Film	0.68	0.68	Interior film	0.68	0.68
Interior Covering	0.45	0.45	Interior covering	0.45	0.45
Frame/Cavity	9	3.85	Frame/cavity	9	3.85
Sheathing	0.5	0.5	Sheathing	0.5	0.5
Block Face (1.25 in.)	0.125	0.125			
Cavity (Air)/Rib	1	0.55			
Block Face (1.25 in.)	0.125	0.125			
Exterior Insulation	0	0	Exterior insulation	0	0
Exterior Air Space	0.97	0.97	Exterior air space	0	0
Exterior Covering, Brick	0.44	0.44	Exterior covering, siding	0.61	0.61
Exterior Film, Winter			Exterior film, winter		
Path Thermal Resistance	13.29	7.69	Path thermal resistance	11.24	6.09
% of Clear (Framing)	75%	25%	Percentage of clear	75%	25%
% of Clear (Block)	84%	16%			
Isothermal Plane	11.9	R-value	Isothermal plane	9.0	R-value
	0.084	U-value		0.111	U-value
Parallel Path	11.2	R-value	Parallel path	9.3	R-value
	0.089	U-value		0.108	U-value
Conductivity	1.134	Btu-in./h·ft^2·°F	Conductivity	0.377	Btu-in./h·ft^2·°F
	Brick	Siding	Adiabatic		
Wall Proportion R-Value	11.24	9.28	100		
Wall Proportion U-Value	0.089	0.108	0.010		
% of Wall	34.4%	38.6%	27.0%		
Average Assembly Thickness	8.46	inches			
Parallel Path	13.4	R-value			
	0.075	**U-value**			
Overall Conductivity	**0.634**	**Btu-in./h·ft^2·°F**			

Table 7. Parallel Path Analysis, Post-Renovation Conditions

W4 Wall U-value brick, end unit			W4 Wall U-value siding, end unit		
Framing Width (in.)		3.5	Framing width (in.)		3.5
Block Width (in.)		8	Block width (in.)		8
Block Face Thickness (in.)		1.25	Block face thickness (in.)		1.25
Brick Width (in.)		4			
	Cavity	**Framing/Rib**		**Cavity**	**Framing**
Interior Film	0.68	0.68	Interior film	0.68	0.68
Interior Covering	0.45	0.45	Interior covering	0.45	0.45
Frame/Cavity	13	3.85	Frame/cavity	13	3.85
Sheathing	0.5	0.5	Sheathing	0.5	0.5
Block Face (1.25 in.)	0.125	0.125			
Cavity (Air)/Rib	1	0.55			
Block Face (1.25 in.)	0.125	0.125			
Exterior Insulation	0	0	Exterior insulation	0	0
Exterior Air Space	0.97	0.97	Exterior air space	0	0
Exterior Covering, Brick	0.44	0.44	Exterior covering, siding	0.61	0.61
Exterior Film, Winter			Exterior film, winter		
Path Thermal Resistance	17.29	7.69	Path thermal resistance	15.24	6.09
% of Clear (Framing)	75%	25%	Percentage of clear	75%	25%
% Of Clear (Block)	84%	16%			
Isothermal Plane	14.9	R-value	Isothermal plane	10.4	R-value
	0.067	U-value		0.096	U-value
Parallel Path	13.2	R-value	Parallel path	11.1	R-value
	0.076	U-value		0.090	U-value
Conductivity	0.968	Btu-in./h·ft^2·°F	Conductivity	0.316	Btu-in./h·ft^2·°F
	Brick	**Siding**	**Adiabatic**		
Wall Proportion R-Value	13.18	11.08	100		
Wall Proportion U-Value	0.076	0.090	0.010		
% of Wall	34.4%	38.6%	27.0%		
Average Assembly Thickness	8.46	in.			
Parallel Path	15.7	R-value			
	0.064	**U-value**			
Overall Conductivity	**0.538**	**Btu-in./h·ft^2·°F**			

To validate this workaround approach, a comparison was conducted between the BEoptE+ v1.1 simulation results and the results from an alternative hourly energy simulation software, EnergyGauge USA v2.8.05. Identical inputs were used for both software packages based on the specifications outlined in Table 2. The 2008 Building America House Research Benchmark Definition was used for the EnergyGauge USA simulation runs, though, because the software package has not been updated with 2010 Building America House Simulation Protocols. Table 8 shows the average annual source energy consumption results for both the pre- and post-renovation cases from both software packages.

Table 8. Average Annual Source Energy Use Results

	Average Source Energy Use (MBtu/yr)			
	BEopt Pre-Renovation	EnergyGauge Pre-Renovation	BEopt Post-Renovation	EnergyGauge Post-Renovation
Miscellaneous (E)	33.615	29.677	35.919	33.283
Vent Fan (E)	0.252	0.287	0.252	0.276
Large Appliance (E)	19.685	18.422	23.075	24.497
Lights (E)	14.717	14.712	14.717	14.712
HVAC Fan/Pump (E)	13.574	19.352	4.713	6.914
Cooling (E)	62.677	80.933	21.838	24.497
Heating (E)	0.000	0.000	14.053	12.323
Heating (G)	87.444	85.176	0.000	0.000
Hot Water (E)	0.000	0.000	30.019	29.447
Hot Water (G)	17.802	16.271	0.000	0.000
Large Appliance (G)	3.178	4.914	0.000	0.000
Miscellaneous (G)	0.767	1.201	0.000	0.000
Total (E)	144.520	163.382	144.586	145.948
Total (G)	109.190	107.562	0.000	0.000
Total MBtu	253.711	270.944	144.586	145.948

The results agree fairly well, with EnergyGauge USA showing a 46% source energy savings compared to the 43% source energy savings found using the workaround method in BEopt (see Figure 14). The largest discrepancies arise with the miscellaneous electric, HVAC fan/pump, cooling, large appliance, and miscellaneous natural gas loads. The discrepancy in cooling load is of most concern for this workaround approach. The differences in miscellaneous electric, cooling, large appliance, and miscellaneous natural gas loads can be traced to the changes between the 2008 and 2010 Building America Benchmark and the differences in the modeling software packages used. Based on the outcome of this comparison, the parallel path workaround used appears to present a valid simulation approach that can be used until BEopt is updated to include attached housing units.

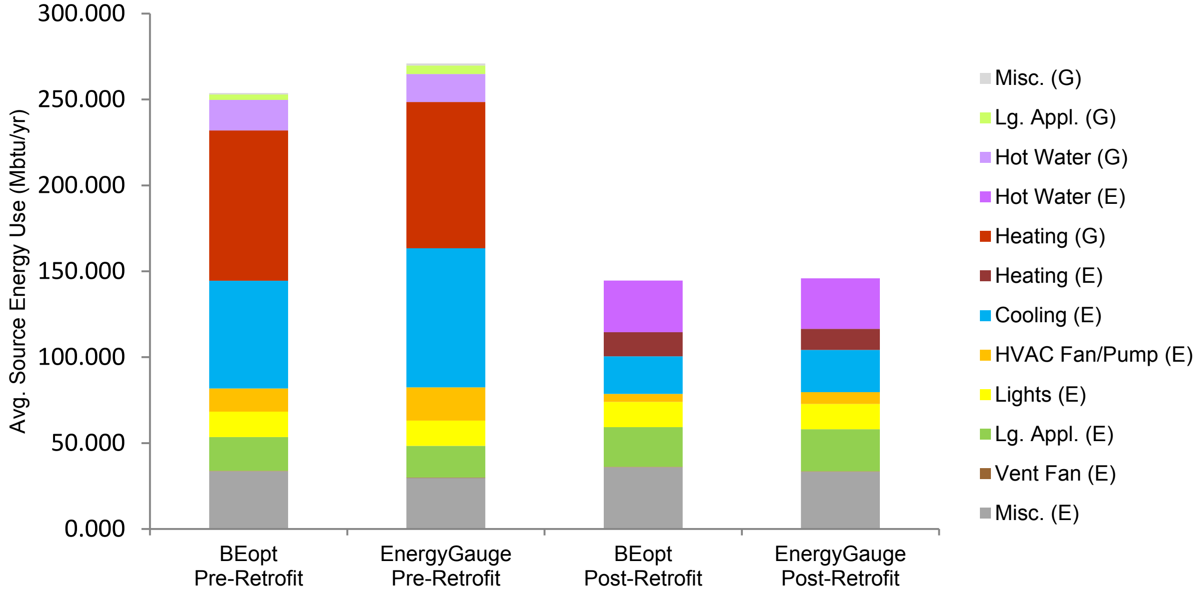


Figure 14. Average annual source energy use results

4 Experiment

4.1 Test Plan

A detailed testing plan was presented in Southface's Test Plan outlining simulation comparisons and short-term characterization testing completed to answer the research questions outlined in the next section (Southface Energy Institute, 2011). The focus of this test plan was on short-term testing and analysis. Long-term monitoring is not planned for this project.

4.2 Research Questions

This project answered the following research questions:

- What gaps and barriers currently exist in BEopt software for attached housing applications and do planned software updates adequately address these issues?
- Does sampling serve as a valid quality assurance model for large-scale renovation projects of this type? If so, what is the appropriate sampling size?
- How does the cost effectiveness of the energy upgrade measures chosen for this project compare with that of other potential energy upgrades?
- How does the structure of Southface's HPwES priority list and Georgia Power incentive program compare with energy upgrade packages derived from modeling tools?

4.3 Technical Approach

The technical approach for this project called for short-term characterization testing to establish pre-renovation conditions and verify the post-renovation whole-house infiltration and duct leakage rates. With guidance from the HPwES program, a sampling approach for this testing was developed. Requirements included the following:

- Pre-renovation testing of each unit type (interior and exterior) until the average of testing results ±1 standard deviation (SD) was completely within one priority range
- Post-renovation testing for all units in pre-renovation test sets, as well as 1/7 of remaining units.

Table 9 briefly describes the test methods employed and their purposes.

Table 9. Test and Monitoring Parameter Description

Parameter of Interest	Test Method	Purpose
House Infiltration Rate	Blower door test and diagnostic evaluation	• Test-in: Find overall infiltration rate and assess primary leakage paths • Test-out: Find overall infiltration rate and locate remaining major leakage paths
HVAC Duct tightness	Duct leakage test	• Test-in: Assess leakage and opportunities for improvement • Test-out: Discover duct leakage rate to the outside

Short-term test results are detailed in Section 5.

5 Testing

5.1 Short-Term Characterization Testing

Testing results showed a drastic improvement in both duct leakage and house infiltration rate from the pre- to post-renovation condition. The project achieved the HPwES goal of reducing air infiltration by a minimum of 0.40 ACH_{nat} and reducing duct leakage to less than 10% of total floor area served in all unit types. In all, 48 units underwent pre-renovation testing and 61 units underwent post-renovation testing, which represents 23% and 29% of the total units, respectively. Four W5 units types burned following test-in and were not rebuilt. Average test results are shown in Table 10, and Appendix B contains test results for each unit type. Average duct tightness was measured at 5% of floor area served at test-out and average house infiltration was measured at 0.43 ACH_{nat}, with very low SDs for the results of both tests.

Figures 15 and 16 depict aggregate results from pre- and post-renovation testing for HVAC duct tightness and house infiltration rate. The low variation in post-renovation testing demonstrates that sampling represents a valid approach for quality assurance for large-scale renovation projects of this type.

Table 10. Average Test Results

	HVAC Duct Tightness (cfm_{25}/unit area)			House Infiltration Rate (ACH_{nat})		
Test-In	Mean	Median	SD	Mean	Median	SD
48 Units (23% of Total)	68%	70%	0.085	1.54	1.46	0.567
Test-Out	Mean	Median	SD	Mean	Median	SD
61 Units (29% of Total)	5%	5%	0.016	0.43	0.42	0.049

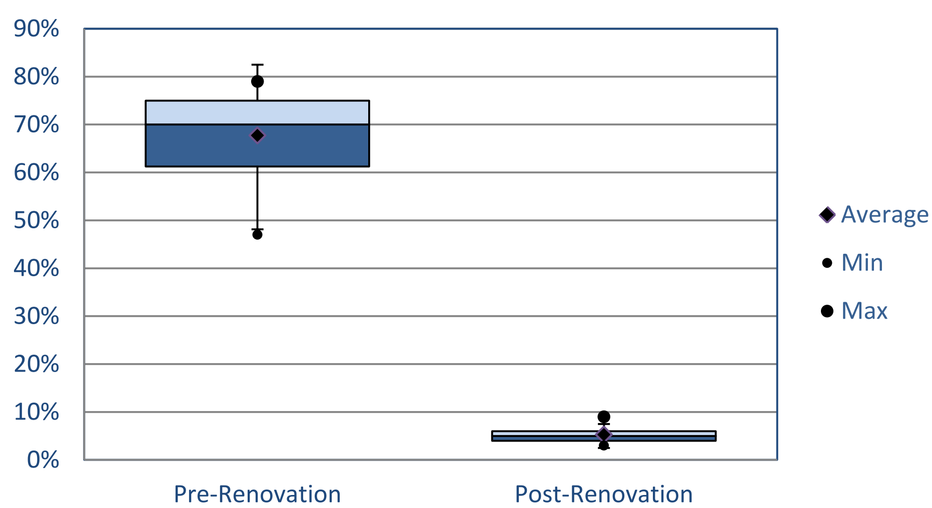


Figure 15. HVAC duct tightness (cfm_{25}/unit area)

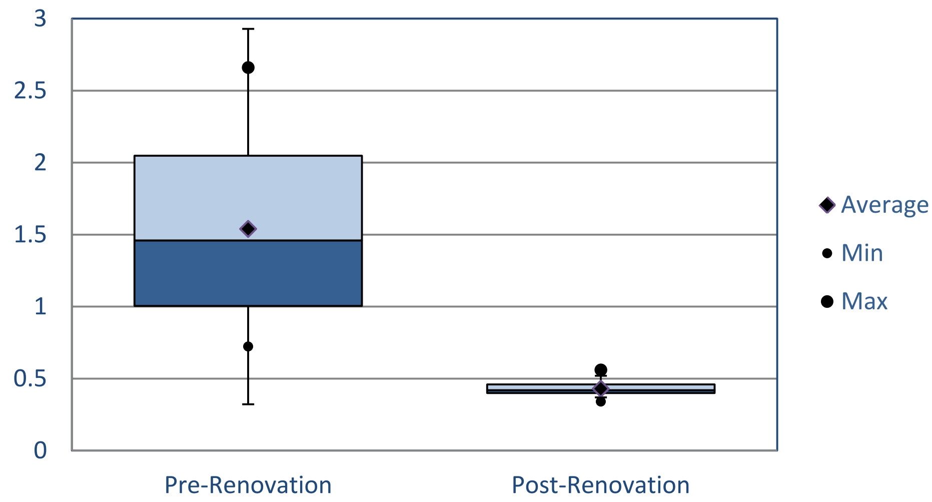


Figure 16. House infiltration rate (ACH_{nat})

6 Summary

The renovation approach used in this project proved to be a cost-effective approach for implementing energy improvement measures at scale. Implementing a large-scale renovation project for homes of similar vintage and condition using a standard upgrade package has the potential to achieve significant energy savings, projected at greater than 40% in this case. Simulation models showed that the current structure of the Southface HPwES priority list led the project to a fairly optimized package of energy upgrade measures. The Fort Benning Indianhead townhomes renovation project demonstrated the impact of energy efficiency incentives on the developer decision-making process. Clark Realty would not have engaged with the HPwES program without the incentives from the Georgia Power rebate program.

Applying quality assurance methods from production-scale new construction, specifically sampling methods for pre- and post-renovation inspections, presents an opportunity to meet the project's energy savings and improvement goals in a cost-effective manner. For this project 23% of all units underwent a test-in inspection and 29% underwent test-out. The project met its performance goals on all units, reducing infiltration by 0.40 ACH_{nat} and duct leakage to less than 10% of total floor area served in all unit types. Future research efforts could focus on the minimum sampling rate necessary to consistently meet project goals.

The current version of BEopt, BEoptE+ v1.1, does not include options for simulating attached housing types. The parallel path workaround implemented in this project, however, appears to be valid based on modeling results from alternative hourly energy simulation packages that include options for simulating attached housing. Southface plans to further validate the results found using the parallel path workaround once an updated version of BEopt that includes options for simulating attached housing types is released.

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Appendix A: Unit Plans

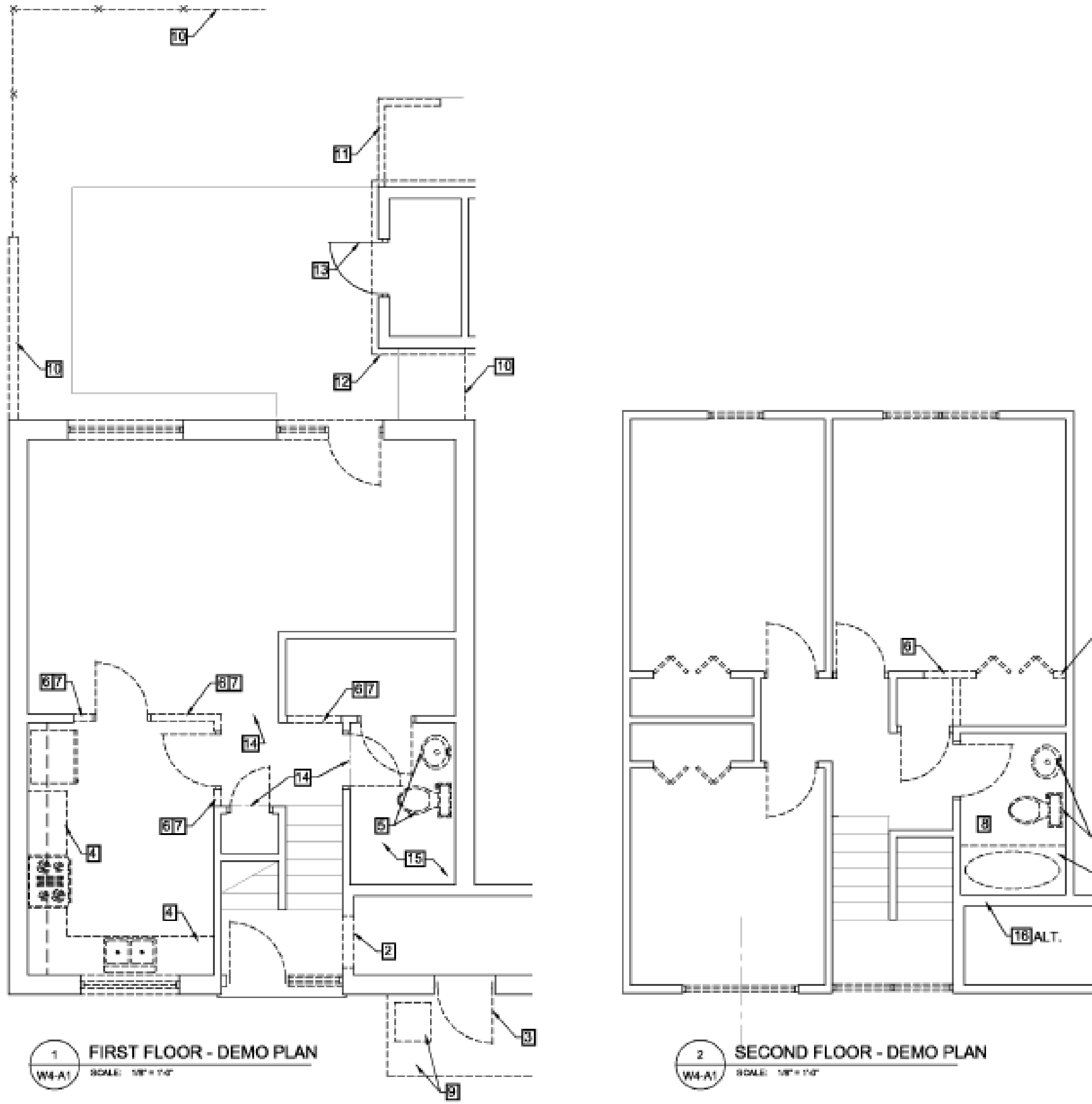

Figure 17. W4 unit plan (not to scale)

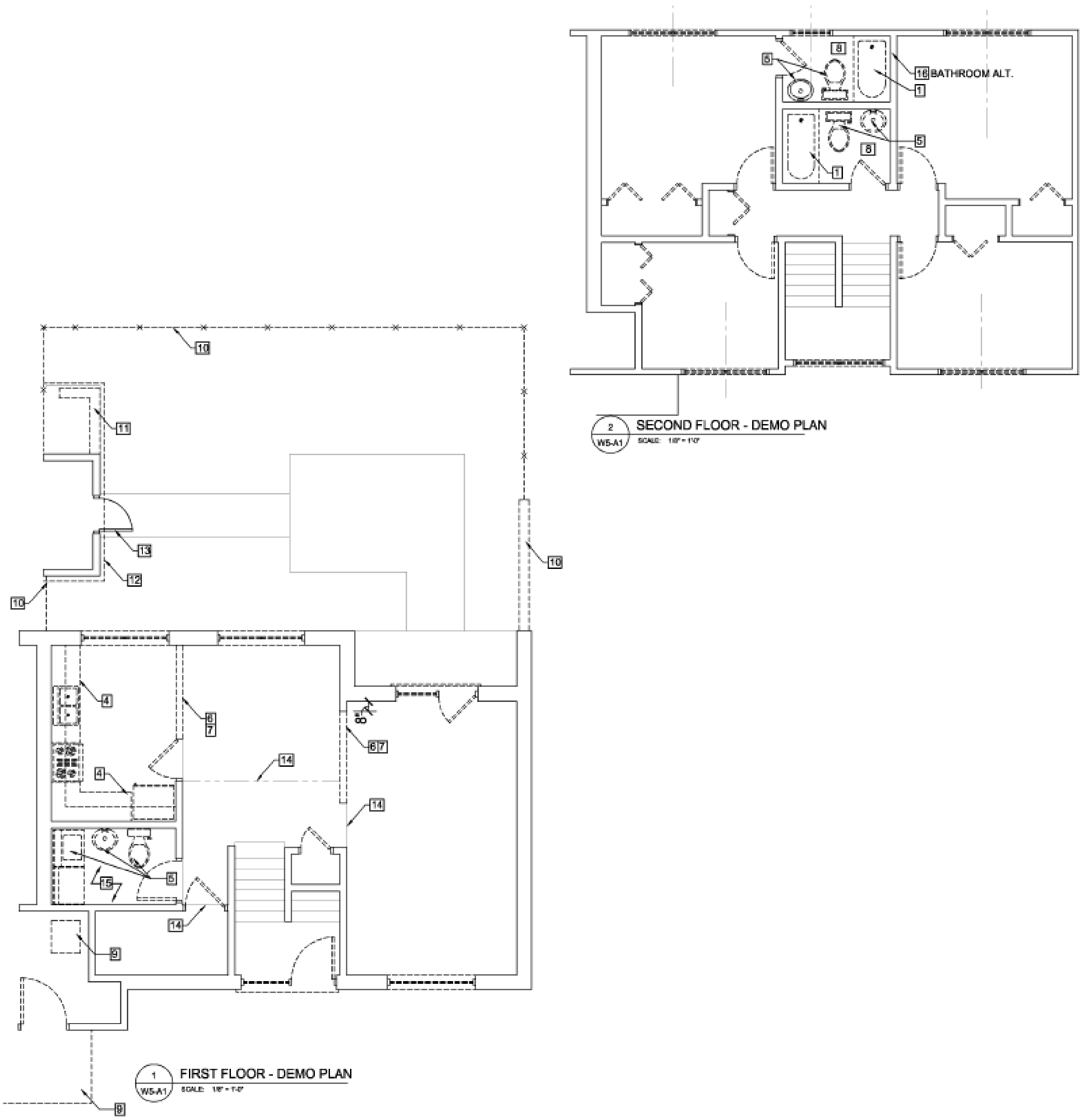

Figure 18. W5 unit plan (not to scale)

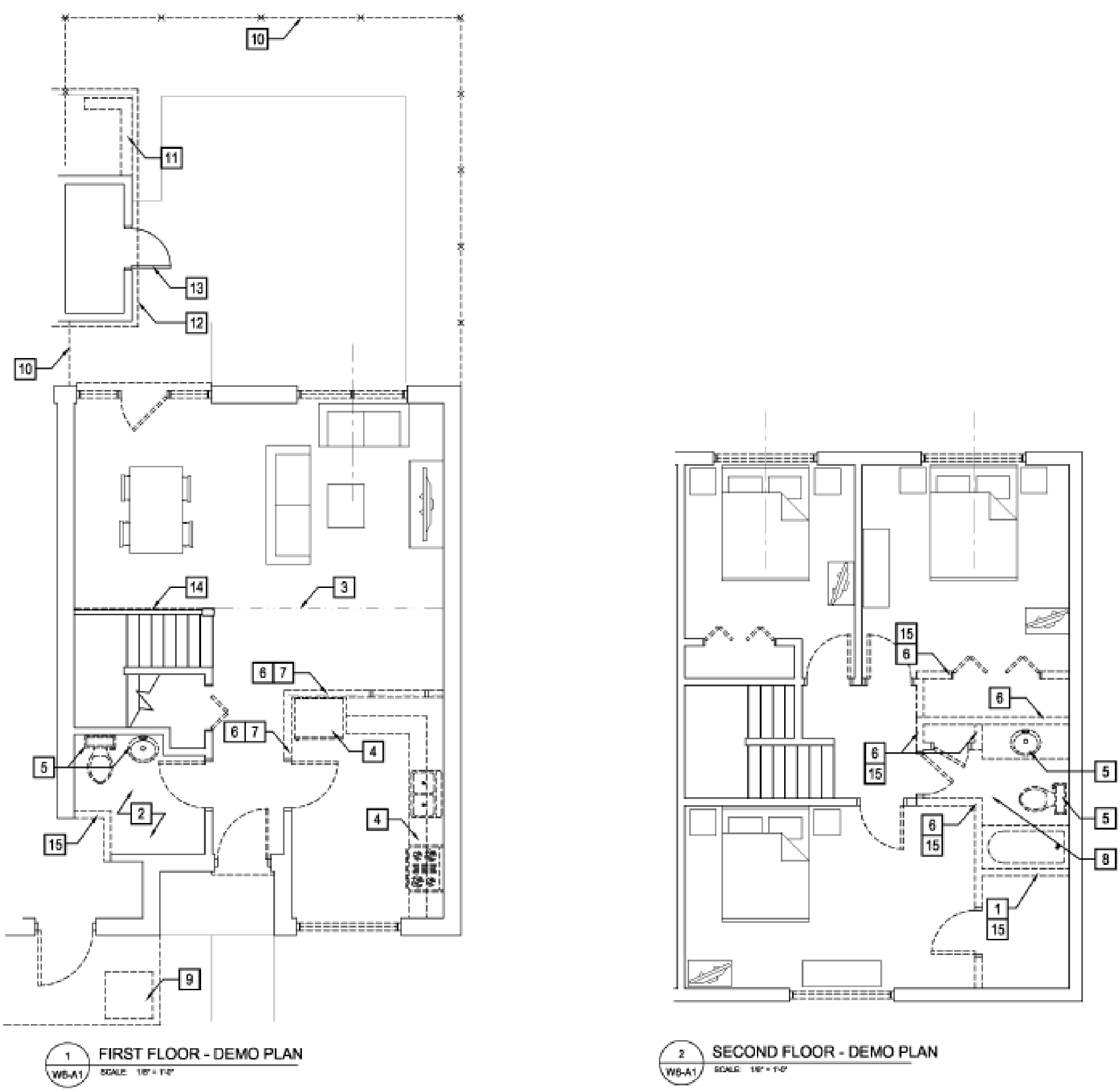

Figure 19. W6 unit plan (not to scale)

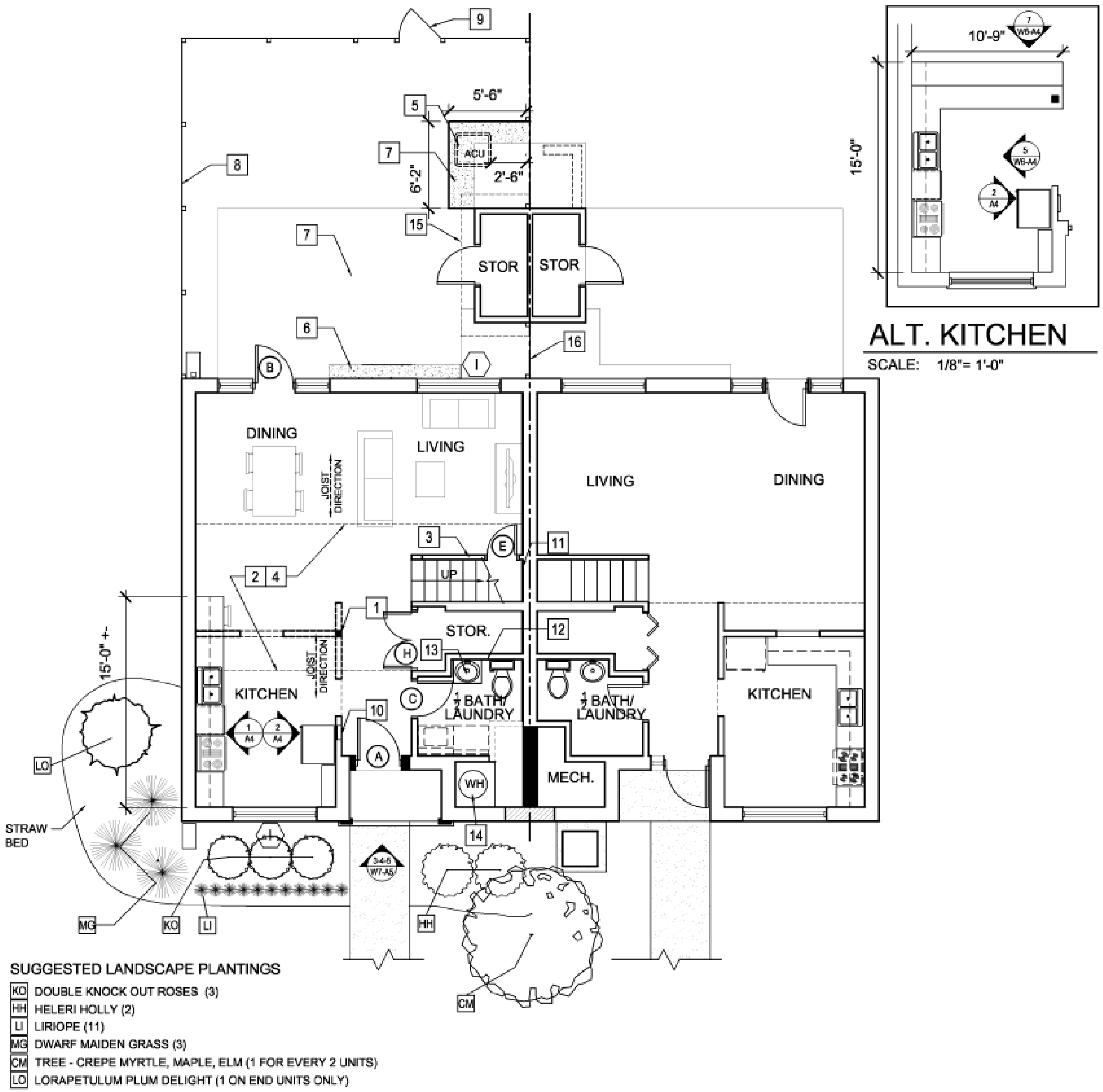

Figure 20. W7 unit plan, first floor (not to scale)

Appendix B: Test Results by Unit Type

W4

Total Units	6

		% Leakage			ACH_{nat}		
Test-In	Total	Average	Median	SD	Average	Median	SD
Interior	2	66%	66%	0.072	2.03	2.06	0.417
End	4	69%	69%	0.148	2.35	2.35	0.071
All	6	67%	66%	0.087	2.14	2.21	0.365
%	100%	34%					

		% Leakage			ACH_{nat}		
Test-Out	Total	Average	Median	SD	Average	Median	SD
Interior	2	3%	3%	0.000	0.49	0.50	0.022
End	4	4%	4%	0.007	0.48	0.48	0.064
All	6	3%	3%	0.004	0.49	0.48	0.064
%	100%						

W5

Total Units	22	(28 total, 6 burned)

		% Leakage			ACH_{nat}		
Test-In	Total	Average	Median	SD	Average	Median	SD
Interior	2	58%	58%	0.085	2.13	2.13	0.141
End	6	61%	59%	0.088	2.03	2.12	0.281
All	8	60%	59%	0.081	2.06	2.12	0.247
%	36%						

		% Leakage			ACH_{nat}		
Test-Out	Total	Average	Median	SD	Average	Median	SD
Interior	0						
End	2	6%	6%	0.009	0.45	0.45	0.014
All	2	6%	6%	0.009	0.45	0.45	0.014
%	9%						

W6

Total Units	42

		% Leakage			ACH_{nat}		
Test-In	Total	Average	Median	SD	Average	Median	SD
Interior	7	71%	69%	0.040	1.28	1.23	0.161
End	5	73%	74%	0.043	1.26	1.26	0.197
All	12	72%	74%	0.040	1.27	1.24	0.168
%	29%						

		% Leakage			ACH_{nat}		
Test-Out	Total	Average	Median	SD	Average	Median	SD
Interior	9	5%	5%	0.011	0.49	0.48	0.037
End	7	5%	5%	0.013	0.41	0.42	0.037
All	16	5%	5%	0.012	0.45	0.45	0.054
%	38%						

W7

Total Units	137

		% Leakage			ACH_{nat}		
Test-In	Total	Average	Median	SD	Average	Median	SD
Interior	12	69%	75%	0.078	1.32	0.94	0.587
End	10	75%	0.75	0.149	1.35	1.01	0.656
All	22	69%	0.75	0.089	1.33	0.95	0.604
%	16%						

		% Leakage			ACH_{nat}		
Test-Out	Total	Average	Median	SD	Average	Median	SD
Interior	19	5%	5%	0.015	0.41	0.40	0.032
End	18	6%	5%	0.019	0.41	0.40	0.039
All	37	6%	5%	0.016	0.41	0.40	0.037
%	27%						

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