Chamberlain Heights Redevelopment: A Large Scale, Cold Climate Study of Affordable Housing Retrofits

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Consortium for Advanced Residential Buildings (CARB)

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Definitions

ACH	Air Changes per Hour
AFUE	Annual Fuel Utilization Efficiency
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BA	Building America Program
CARB	Consortium for Advanced Residential Buildings
cfm	Cubic Feet per Minute
ft^2	Square Foot, Square Feet
HERS	Home Energy Rating System
HVAC	Heating, Ventilation, and Air Conditioning
JRC	Jonathon Rose Companies
MEL	Miscellaneous Electric Load
MHA	City of Meriden Housing Authority
NG	Natural Gas
o.c.	On Center
ocSPF	Open-Cell Spray Polyurethane Foam
Pa	Pascal
PEX	Cross-Linked Polyethylene
SEER	Seasonal Energy Efficiency Ratio
SWA	Steven Winters Associates
XPS	Extruded Polystyrene

Executive Summary

The City of Meriden Housing Authority (MHA) collaborated with affordable housing developer Jonathon Rose Companies (JRC) to complete a gut renovation of 126 residential units in the Chamberlain Heights retrofit project. The affordable housing community comprises 36 buildings in duplex and quad configurations located on 22 acres within two miles of downtown Meriden, Connecticut. JRC and MHA established that the primary goal for the project was long-term affordability, including superior energy performance and durability. In pursuit of this objective, the team joined the Building America program in partnership with the Consortium for Advanced Residential Buildings (CARB). In addition to pursuing high levels of energy efficiency and performance improvements, JRC and MHA identified three certification programs to pursue with Steven Winter Associates, Inc.: LEED for Homes, ENERGY STAR, and the Green Communities Criteria. These programs prioritize occupant health and comfort in addition to energy/resource efficiency and durability.

The existing units were built in the early 1950s with 2 × 4 wood framing over poured concrete basements. Most of the dwellings are two stories, with a few accessible one-story units. The redevelopment consists of three phases, allowing occupants to move out of the untouched Phase III units into newly finished Phase I or II units. Demolition and construction started July 2010. Phases I and II, which account for 76 of the total 126 units, were completed by September 2011. Phase III is anticipated to be completed by May 2012. The buildings were gutted down to framing, board-sheathing, and foundations. Except for the first floor brick veneer, all exterior finishes were removed. All existing mechanical, electrical, and plumbing systems were replaced.

CARB evaluated whether Building America 50% savings targets might be applicable to a cold-climate affordable housing retrofit project with aggressive energy efficiency goals. CARB conducted energy modeling using EnergyGauge USA software to establish baseline performance. For the evaluation, CARB selected a representative worst case dwelling unit as well as a best case unit and developed a package of specifications to address air sealing and energy upgrades. The project was evaluated against the 2009 Building America Benchmark for new construction, and preliminary analysis predicted 44%–45% source energy savings relative to that criterion. The final post-retrofit analysis simulations showed 40%–45% source energy savings over the existing pre-retrofit conditions. The final Home Energy Rating System indices on completed homes have ranged from 58 to 63.

Three insulation techniques (extruded polystyrene, closed-cell spray polyurethane foam, and blown fiberglass) were used to deal with a variety of building conditions. Retrofit projects require the team to respond to new discoveries during the first stages of construction, and several modifications were made before a workable methodology for envelope retrofit was established. CARB introduced the team to the foamed over buried duct approach in attic spaces, with positive results. Unanticipated challenges included leakage from block basement partitions between adjacent units, and moisture problems in basements.

Final test results show energy savings slightly below the early predictions. However, the overall project has been deemed a success because: (1) the project is on track to earn Green Communities, LEED for Homes Gold certification, and ENERGY STAR Homes label; (2) the

developer will qualify for approximately $3,970 per unit in local incentives for achieving a Home Energy Rating System Index below 65; (3) expected annual utility bills should decrease $600–$900; and (4) the return on investment for the energy efficiency improvements for these retrofit units over a 10-year period is 40% and would pay back in about 7 years.

1 Introduction and Background

The City of Meriden Housing Authority (MHA) is seeking to improve its portfolio of homes serving low-income inhabitants of the city. As part of that effort, it selected Jonathan Rose Companies (JRC) to assist in the formation of a design and construction team, and to act as the overall project development manager. The project goals included long-term affordability, ENERGY STAR® Home labels and associated incentives from local utilities, and green building certification. Following a formal request for proposals process organized by JRC, Steven Winter Associates, Inc. (SWA) was selected to support the project's sustainability goals. SWA's initial analysis of the project indicated that the project goals for performance enhancements were in alignment with Building America Program (BA) goals. With the project team's cooperation, the Consortium for Advanced Residential Buildings (CARB) provided architectural design recommendations; building specification optimization; energy use analysis; heating, ventilation, and air conditioning (HVAC) system sizing and integration support; contractor training; on-site observation and quality control; midterm testing and analysis; and final testing and analysis.

The 126 attached housing units of Chamberlain Heights date from the 1950s and are located in a residential neighborhood near downtown Meriden, Connecticut, on a hilly and wooded property (see Figure 1). The project team wanted to improve building aesthetics, reduce runoff, and manage long-term operating costs by improving energy efficiency and reducing maintenance. The budget was limited, and MHA required the project to follow strict requirements for durability, sustainability, and occupant safety and comfort. The developer leveraged local utility incentives for energy efficiency to finance significant energy upgrades.

Figure 1. Chamberlain Heights quad and duplexes prior to retrofit, September 2009

Project designer Paul Bailey Architects (New Haven, Connecticut) worked with the project team to investigate options for improving envelope and mechanical systems specifications and performance characteristics, within the limitations of the existing buildings' structure and form. First floor brick was preserved for cost reasons; the remainder of the envelope was gutted from both the interior and the exterior, down to 2 × 4 balloon framing and board sheathing. The builder and designer provided feedback on constructability issues, and several different envelope strategies were evaluated to address air sealing, thermal barrier, and drainage plane.

Funding for the affordable housing project depended on improving occupant comfort, including mandatory addition of central cooling to the buildings. High-efficiency equipment helped the project earn incentives from the Connecticut Clean Energy Fund.

Covered entries and porches were added to the homes, enhancing both durability and aesthetics. Community sidewalks and connection points to the surrounding neighborhood were improved. A substantial rain garden installation was designed to manage runoff from the increased roof area of the porches and to improve pre-existing storm water runoff conditions (see Figure 2 and Figure 3). The project anticipates successfully earning Green Communities certification and LEED for Homes Gold.

Figure 2. Chamberlain Heights quads and duplexes after retrofits, May 2011

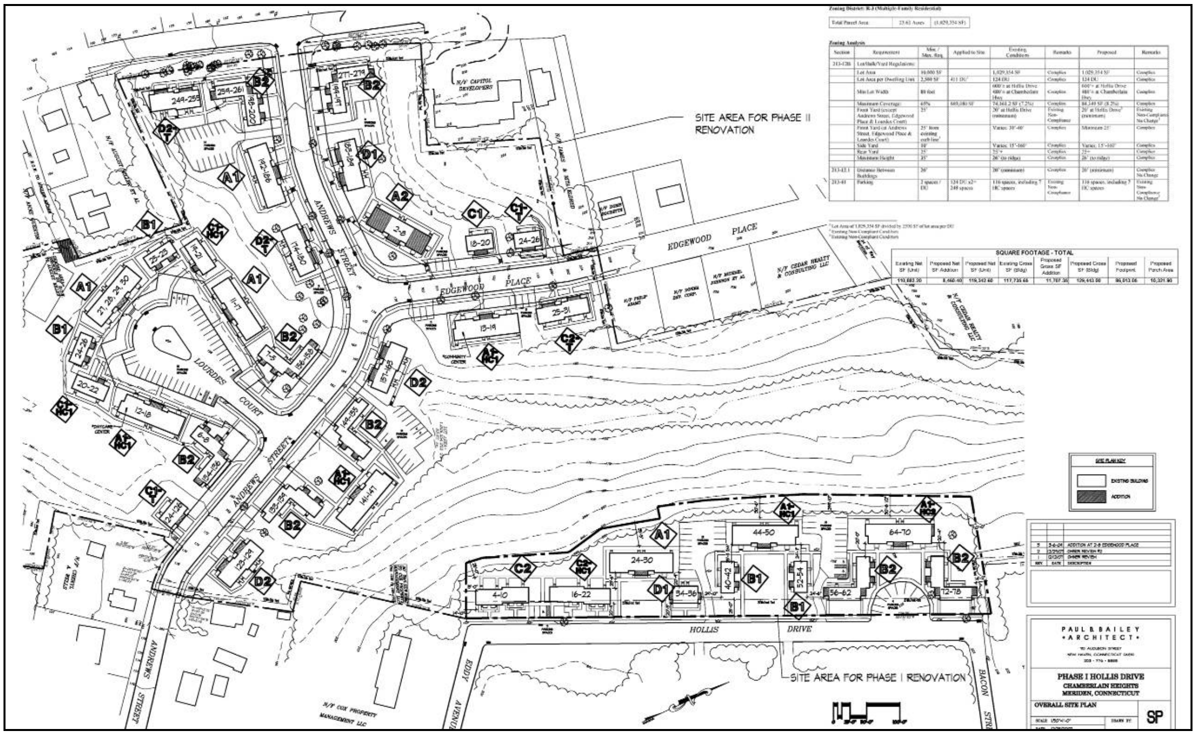

Figure 3. Chamberlain Heights site plan

2 Research Methods

When the project design began, BA lacked a target performance threshold for rehab and retrofit projects. Therefore, CARB set out to determine whether 50% energy savings relative to the new construction BA Benchmark (updated December 2009) might be feasible for an affordable housing gut rehab project. The research team sought to identify the primary barriers to that performance target, and to evaluate market interest and consumer reactions; developer and builder reaction and feedback loops; and stakeholder enthusiasm for the pursuit of similar follow-up projects. Specific technical issues for evaluation included the application of high-R wall systems within spatially limited existing wall framing; the effectiveness of low-cost exhaust-only ventilation systems within the context of attached dwelling units, and the effectiveness of foamed and buried HVAC ducts in a community-scale retrofit context.

2.1 Energy Use Modeling

To model the energy use of the proposed buildings, CARB used EnergyGauge USA version 2.8.03. The alternative option for analysis, BEopt, was not used because of its inability to adequately model the common wall configuration found in the Chamberlain Heights homes. CARB analyzed projected energy savings relative to the BA Benchmark, targeting as close to 50% energy savings as practical. CARB determined that the likely worst-case dwelling was Unit A in Building Type B2: end-unit, 1,100 ft^2, two stories, three bedrooms (see Figure 4 through Figure 6).

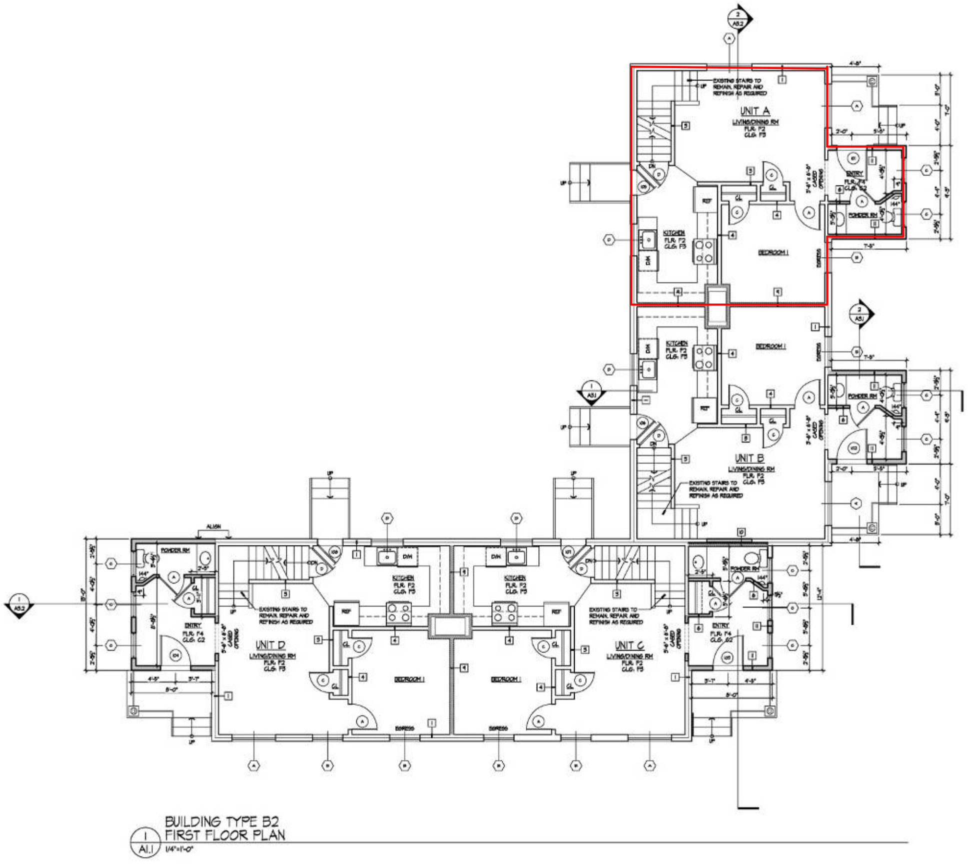

Figure 4. First floor plan, building type B2

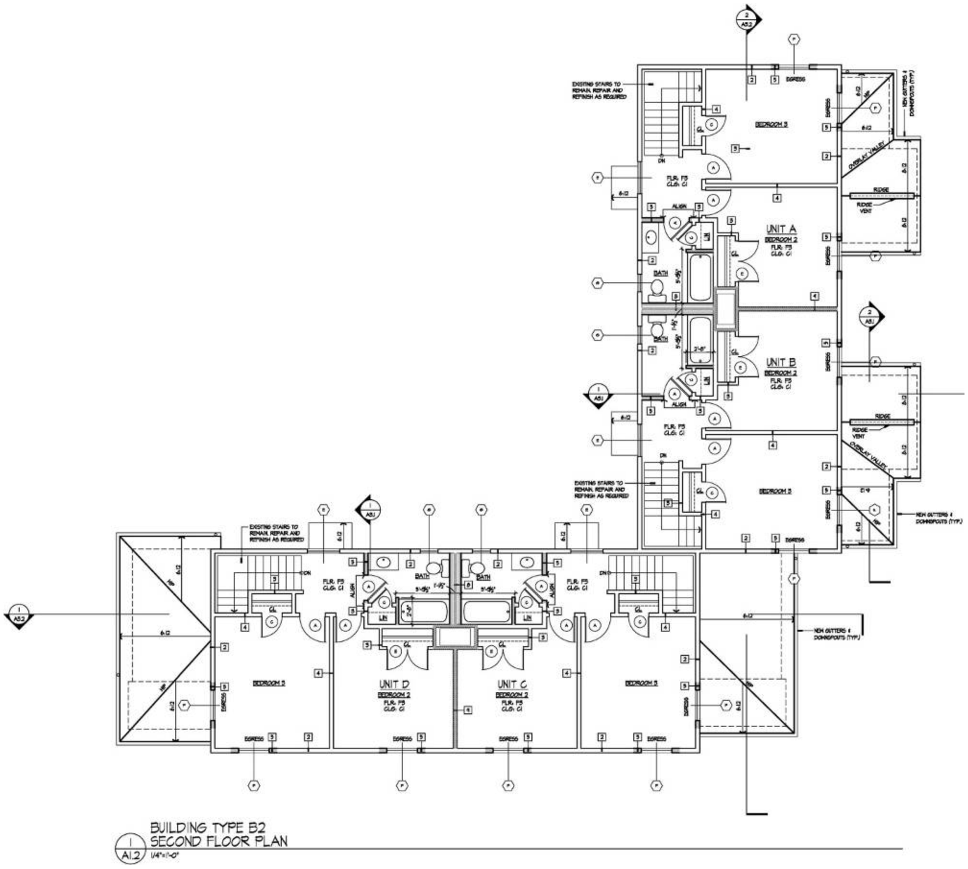

Figure 5. Second floor plan, building type B2

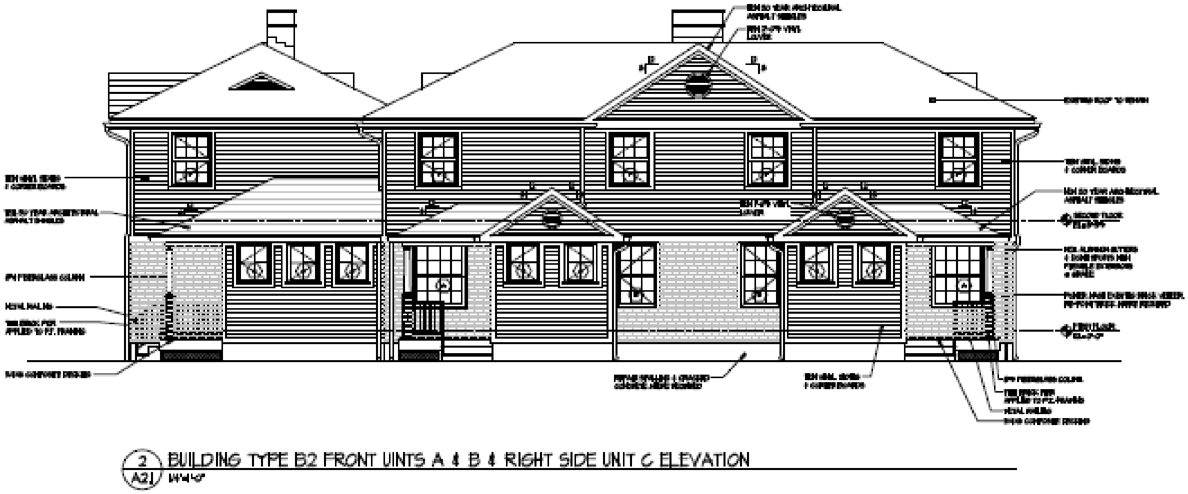

Figure 6. Typical elevation, building type B2

The current version of the BA House Similation Protocols (revised October 2010) includes specific analysis methods for retrofit projects, so CARB has since updated the energy modeling to be consistent with current reporting procedures.

2.2 Building America Recommended Specifications

CARB prepared a package of recommended specifications based on best-practice approaches to retrofits, bearing in mind the project objectives and limitations. The dimensionally limited exterior walls, desire to preserve existing brick façade, requirement for central cooling, and available incentives for specific energy measures figured prominently in the recommendations. The existing and proposed specifications are shown in Table 1.

Table 1. Existing and Proposed Specifications

	Existing Condition	BA Recommendation
Below-Grade Walls	8-in. poured concrete foundation, 7 in. tall uninsulated	R10 foil faced polyisocyanurate adhered to interior side of wall
Above-Grade Walls	2 × 4 wood framing @ 16 in. with R-11 mineral wool batts	1-in. ccSPF* at interior of spaced boards sheathing, 2x interior horizontal strapping with 4.5-in. dense pack cellulose
Ceiling Assembly	R-19 mineral wool	R-50 cellulose
Rim and Band Joists	Uninsulated rim/band joist	Spray with ccSPF
Insulation Measures	Uninsulated balloon frame	Frame with blocking, drill holes, fill with dense pack cellulose
	1st floor corner detail: 2 × 4 studs create open corners behind brick	Drill holes in 2 × 4s and fill with 4.5 in. dense pack cellulose
Windows	Aluminum-insulated double-pane, clear U 0.60, SHGC 0.65	Vinyl-insulated double-pane, low E U 0.30, SHGC 0.32
Cooling	No central air cooling	1.5 ton, SEER** 16, modulating, single zone ducted a/c
Heating	NG*** boiler with convectors, 76 AFUE[†]	Natural Gas Condensing Furnace 94 AFUE
Ductwork	Radiators for heat distribution	Ductwork, sealed with mastic at seams and joints, 70% inside thermal envelope, 30% in attic sprayed with ccSPF buried in fiberglass
Ventilation	Whole-house ventilation and local exhaust nonexistent	Exhaust only, run continuously with boost up for occupancy in bathrooms
Hot Water	Indirect from NG boiler 67 EF[††]	NG Tankless, 87 EF
Lighting	100% incandescent light bulbs	100% pin-based fluorescent
Appliances	None ENERGY STAR	ENERGY STAR refrigerator, dishwasher, clothes washer with single throw shut off at clothes washer

* Closed-cell spray polyurethane foam
** Seasonal energy efficiency ratio
*** Natural gas
[†] Annual fuel utilization efficiency
[††] Energy factor

2.3 Energy Analysis Relative to Building America Benchmark (2009)

Initially, a preliminary analysis was conducted to demonstrate the project's feasibility of achieving BA Benchmark goals of meeting the 50% source energy savings target. For this study, CARB chose two units that represented the best- and the worst-case scenarios. A two-bedroom middle unit (with units on either side) was chosen as the best-case scenario because of the lower exposed thermal envelope area. This unit is described as Unit B in Building type C2. The worst-case scenario is a three-bedroom end unit, described here as Unit A in Building B2.

Both the best- and the worst-case scenarios were modeled relative to 2009 BA Benchmark. The worst-case unit shows slightly better percent savings relative to the Benchmark; however, the total predicted energy consumption in the best-case home is lower. Both homes are consistent in their predicted Home Energy Rating System (HERS) Index of 61. Load distribution in the modeled units and the Benchmark are shown in Table 2 and Table 3 for the worst-case unit and the best-case unit, respectively. As typical of cold-climate homes, heating is the highest end use for both units, and the area with the greatest room for improvement.

Table 2. Modeling Type B2 Unit A (3-Bedroom End Unit): Predicted Energy Distribution

Loads	Benchmark			BA Recommended Prototype		
	Source MMBtu	Site kWh	Site Therms	Source MMBtu	Site kWh	Site Therms
Cooling	11.1	972	–	4.9	435	–
Heating	48.4	304	412	20.5	124	181
Lighting	16.3	1,428	-	4.5	398	–
Hot Water	22.9	–	210	11.9	–	109
Appliances	22.9	1,056	108	20.7	874	108
MELs	28.7	2,410	–	28.7	2,410	–
Outside Air Ventilation	1.7	154	–	1.6	141	–
TOTAL ENERGY	**152**	**6,324**	**730**	**94**	**4,380**	**398**
House Size Multiplier	**170**					
Savings Source %				**44.7%**		
HERS Index				**61**		

Table 3. Modeling Type C2 Unit B (2-Bedroom Middle Unit): Predicted Energy Distribution

Loads	Benchmark			BA Recommended Prototype		
	Source MMBtu	Site kWh	Site Therms	Source MMBtu	Site kWh	Site Therms
Cooling	8.2	715	–	3.3	291	–
Heating	33.8	210	288	14.5	85	125
Lighting	15.3	1,341	–	4.2	373	–
Hot Water	20.1	–	185	10	–	92
Appliances	20.3	991	91	18.4	822	91
MELs	25.6	2146	–	25.6	2146	–
Outside Air Ventilation	1.7	152	–	1.6	143	–
TOTAL ENERGY	**125**	**5,555**	**564**	**78**	**3,860**	**308**
House Size Multiplier	**138**					
Savings Source %				**43.6%**		
HERS Index				**61**		

2.4 Energy Analysis Relative to Prior Conditions

In addition to the above exercise, CARB compared the existing (pre-retrofit) conditions with the final anticipated specifications using EnergyGauge USA version 2.8.03. The existing units did not have a cooling system, but for modeling purposes, a SEER 8.7 cooling system, typical of those installed in the 1980s, was assumed. These houses were originally built in the 1950s and mechanical systems would likely have been replaced around then. Further modeling assumptions include ductwork with R-4 insulation, 15% duct leakage to outside and 8.0 ACH_{50} for infiltration (the units had already been gutted prior to CARB's involvement and pre-retrofit infiltration data were not available).

Table 4 shows an estimated 47.2% improvement in energy performance for the worst case unit; Table 5 shows a 43.7% improvement in the best case unit. The lower exposed exterior wall area in the best case unit is consistent with the lower energy savings predicted in the analysis. Both units reduce heating energy consumption by almost 70%.

Table 4. Modeling Type B2 Unit A (3-Bedroom End Unit): Predicted Energy Distribution

Loads	Existing			Prototype		
	Source MMBtu	Site kWh	Site Therms	Source MMBtu	Site kWh	Site Therms
Cooling	19.9	1,734	–	4.9	435	–
Heating	68	126	610	20.5	124	181
Lighting	18.3	1,597	–	4.5	398	–
Hot Water	19.7	–	181	11.9	–	109
Appliances	22.9	1,056	108	20.7	874	108
MELs	28.7	2,410	–	28.7	2,410	–
Outside Air Ventilation	0.2	20	–	1.6	141	–
TOTAL ENERGY	**178**	**6,943**	**899**	**94**	**4,380**	**398**
Savings Source %				**47.2%**		
HERS Index	**134**			**61**		

Table 5. Modeling Type C2 Unit B (2-Bedroom Middle Unit): Predicted Energy Distribution

Loads	Existing			Prototype		
	Source MMBtu	Site kWh	Site Therms	Source MMBtu	Site kWh	Site Therms
Cooling	12.4	1,088	–	3.3	291	–
Heating	45.8	84	411	14.5	85	125
Lighting	17.2	1,499	–	4.2	373	–
Hot Water	16.9	–	155	10	–	92
Appliances	20.3	991	100	18.4	822	91
MELs	25.6	2,146	–	25.6	2,146	–
Outside Air Ventilation	0.2	20	–	1.6	143	–
TOTAL ENERGY	**138**	**5,828**	**666**	**78**	**3,860**	**308**
Savings Source %				**43.7%**		
HERS Index	**122**			**61**		

2.5 Post-Retrofit Energy Analysis (Benchmark 2010)

Post-retrofitting, a final round of simulations were conducted to compare the energy savings between the pre-retrofit (existing), the BA recommended case, and the post-retrofit (installed) conditions. The BA Benchmark protocols were updated over the course of the construction build-out, so this final analysis is performed using the BA House Simulation Protocols with respect to existing construction. Table 6 shows the post-retrofit worst-case unit performed 44.8% better than the existing case. Table 7 shows that the best-case unit performed 40.2% better post-retrofit compared to the existing case. These two units achieved a HERS index of 60 and 62 for the best-case and the worst-case units, respectively. HERS values in this range were achieved consistently across all units modeled and tested to date.

Table 6. Energy Analysis, Final Predicted Post-Retrofit Condition; Type B2 Unit A (3-Bedroom End Unit)

Loads	Existing	BA Recommended	Installed Condition
	MBtu	MBtu	MBtu
Cooling	19.9	4.9	5
Heating	68	20.5	27
Lighting	18.3	4.5	4.5
Hot Water	19.7	11.9	11
Appliances	22.9	20.7	20.7
MELs	28.7	28.7	28.7
Outdoor Air Ventilation	0.2	1.6	1.2
TOTAL LOADS	**178**	**93**	**98**
Savings Source %	**–**	**47.8%**	**44.8%**
HERS Index	**134**	**61**	**62**

Table 7: Energy Analysis, Final Post-Retrofit Construction; Type C2 Unit B (2-Bedroom Middle Unit)

Loads	Existing	BA Recommended	Installed Condition
	MBtu	MBtu	MBtu
Cooling	12.4	3.3	3.6
Heating	45.8	14.5	20.5
Lighting	17.2	4.2	4.2
Hot Water	16.9	10.0	9.3
Appliances	20.3	18.4	18.4
MELs	25.6	25.6	25.6
Outdoor Air Ventilation	0.2	1.6	1.2
TOTAL LOADS	**138**	**78**	**83**
Savings Source %	**–**	**43.9%**	**40.2%**
HERS Index	**122**	**61**	**60**

In pursuit of 45%–50% energy savings over existing conditions, CARB began with high-impact envelope energy efficiency measures such as insulating attics, below-grade walls, and above-grade walls, and air sealing all potential leaky components in the envelope.

Heat loss from uninsulated attics, crawlspaces, and basements was one of the major components that led to high energy consumption in the existing units. The existing homes did not have any basement insulation. To rectify this, 1½-in. foil-faced polyisocyanurate boards (R-10) were recommended on the interior side of all below grade walls. Site specific challenges and actions taken to achieve the R-values on below grade walls are discussed in Section 3.1.

The existing above-grade walls were 2 × 4 wood frame studs at 16 in. on center (o.c.) with spaced board sheathing and mineral wool batt cavity insulation. Although the insulation strategy recommended by CARB was not implemented, the insulation in these wall cavities was removed and replaced with 3½-in. thick ccSPF insulation, increasing the wall cavity R-value to R-20 (@ ccSPF R-5.7 per inch) and achieving similar performance as the initial BA recommendation of 1-in. ccSPF and 4.5-in. dense pack cellulose. In addition to 3½ in. of spray foam in the wall cavities, on the exterior of the second floor walls, continuous ¾-in. extruded polystyrene (XPS) insulation (R-4) was installed. Above-grade walls are discussed in detail in Section 3.2.

Leaky homes increase energy costs because the conditioned air escapes outside or unconditioned air enters through the leaks, holes, and openings in the thermal envelope. This increases the demand on the heating and cooling systems. Following BA recommendations to reduce infiltration through diligent air sealing, all the below-grade walls, ceiling penetrations, attic access panels, and above-grade wall leaks were air sealed thoroughly to create a tighter envelope. Old leaky windows were also replaced with tight new energy-efficient windows.

All the envelope upgrades were coupled with mechanical system upgrades to reach the energy efficiency goals set for this project. The existing units did not have cooling systems installed and after much discussion, SEER 14.5 central air-conditioning systems (rather than SEER 16 as recommended) were chosen as a cost-effective solution. The 80 AFUE gas boilers were replaced with 94 AFUE condensing gas furnaces. Only one third of the new ducts were laid in attics, which were sealed with mastic at seams and joints, sprayed with closed cell spray foam and then buried in blown fiberglass, effectively eliminating duct leakage to the unconditioned attic. Section 3.5 discusses these systems in depth.

The final step was to reduce energy consumption by swapping out all the incandescent lighting with compact fluorescent lamps and replacing refrigerators, dishwashers, and clothes washers with ENERGY STAR qualified versions. These were installed as recommended.

From the predicted energy modeling results, the ventilation loads are higher for the BA recommended package than the installed condition. This can be attributed to the continuously run exhaust-only ventilation fans recommended in the BA package. In the post-retrofit case, ENERGY STAR qualified exhaust fans were installed with intermittent operation (8 hours/day). These achieved the same overall air exchange, but reduced electricity consumption. Post-retrofit, cooling slightly increased as expected, because of the lower installed SEER, and heating increased because of the higher infiltration than assumed in the BA recommended cases. The reduction in predicted hot water energy use is explained by the higher EF for the installed tankless water heater.

2.6 Cost Benefit Analysis

The developer provided the following cost information (see Table 8) for the cost premium of the efficiency measures over code for the installed specifications. Utilizing the predicted annual energy savings over the 2009 BA Benchmark (as this is based on code rather than pre-existing conditions), the return on investment over a 10-year period is 40% and the simple payback is just over 7 years on average per unit.

Table 8: Average Cost Premium of Efficiency Measures Above Code per Unit

Item	Code Requirement	Installed	Premium/Unit
Wall Insulation	R-18 (batt) [1]	R-22 (spray/rigid)	$1,817
Basement Insulation	N/A	R-13 (rigid) [2]	$714
Attic Insulation	R-38 (batt)	R-44 (loose fill)	$227
Duct Insulation	N/A	R-13 (spray)	$442
Drywall Sealing	N/A	Seal top of drywall	$185
Windows	U-0.4	U-0.3 [3]	$156
Gas Furnace	0.80 AFUE	0.94 AFUE	$0 [4]
Air Conditioner	13 SEER	15 SEER	$417
Water Heater	0.60 EF (storage)	0.92 EF (on-demand)	$800
Appliances	N/A	ENERGY STAR [5]	$790
		Totals:	**$5,548**
		Percent of Total Hard Cost:	**3.99%**
		Cost Per Square Foot:	**$5.43**

[1] This is based on an R-15 for the code cost, as unable to achieve an R-18 with fiberglass batt in a 2 × 4 wall.

[2] The cost of the deleted insulation in the floor framing is included as an offset.

[3] There is an approximate upcharge of 5.5% for argon, which gives the window a better U-value.

[4] Costs offset due to no b-vent through the roof and the associated plan coordination costs.

[5] This is for the stainless steel ENERGY STAR appliances.

3 Retrofit Solutions

Although the two dwellings modeled fail to achieve the original 50% source energy savings target either compared to the 2009 BA Benchmark home or the existing baseline, the consensus of the designer, developer, and construction manager was that the cost effectiveness of the energy upgrades had been optimized and savings of 44%–47% were still an achievement. The team set out to implement the recommended retrofit specifications described in detail in the next sections.

3.1 Below-Grade Basements

The existing foundations were uninsulated poured concrete walls measuring 7 ft in height and 8 in. in thickness. Concrete block walls divided the basements of adjoining units. Mechanical equipment was housed in the basements and some tenants used the area as additional living space. Windows in foundation walls were uninsulated, leaky, and often broken, as shown in Figure 7.

Figure 7. Basement prior to retrofit

The basement was brought into the thermal boundary with the addition of 1½-in. polyisocyanurate boards (R-10) directly adhered to the interior surface of the poured concrete foundations. The contractor installed ledger boards at the top and bottom of the concrete walls, installed the rigid insulation in between, and covered with ½-in. painted oriented strand board to provide a durable surface for tenants. For units with mudroom additions, crawlspaces were constructed of poured concrete and also insulated with 12½-in. polyisocyanurate. The crawlspaces communicate directly with the full basements without access doors. Basement windows were reframed, air sealed, and replaced (see Figure 8).

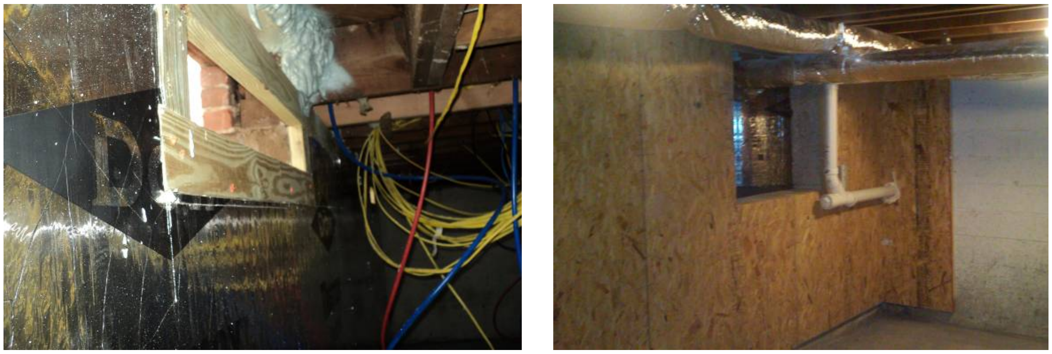

Figure 8. Basement after retrofit

Additionally, a dehumidifier with humidistat was recommended for all basements.

3.2 Above-Grade Walls

The existing 2 × 4 wood frame studs are 16 in. o.c. with spaced board sheathing, and most first floor units were balloon framed (see Figure 9). First floor brick veneer was preserved but second story siding was replaced. Concerns about the vapor barrier and drainage plane behind brick veneer led the team to consider a combined thermal and vapor barrier application (closed cell foam).

Figure 9. Above-grade wall prior to retrofit and balloon framing

Based on the limits of 2 × 4 studs and brick veneer, the design team identified potential solutions for high-performance insulation. An early solution that satisfied both the R-value requirement and the cost/constructability requirement was 3½-in. ccSPF for the first floor, and 3½-in. ccSPF for the second floor above grade walls with an additional ½-in. XPS insulation (R-3) on the exterior of the second story. In order to fill the cavity, the ccSPF would need to be over-applied and then trimmed back flush with interior face of studs. CARB expressed concerns about the constructability of this approach.

Because of the number of crews operating onsite coupled with concerns about fiber-cement board siding attachments, the development team requested an alternative wall assembly without exterior foam sheathing on the second story. Following confirmation by the architect that it would be possible and practical to fur the exterior walls 1½ in., the following alternative was proposed by CARB: 1-in. ccSPF sprayed against the interior side of the spaced board sheathing on all exterior walls, with dense-pack cellulose applied to the remaining 4½-in. stud and furred out walls. This application would produce some positive results: same specifications throughout both stories would simplify construction; ccSPF use would be reduced, decreasing cost and labor for trimming; R-22.3 would be achieved for all walls; the spaced board sheathing would still be air sealed; and moisture would be controlled in the inaccessible space behind the brick veneer.

Late concerns about spatial limitations associated with proposed furring led the team to proceed with the first option. Therefore 3½-in. ccSPF was applied in existing studs (R-5.7/in.) and 5½-in. ccSPF in the new mudroom additions. The ccSPF was trimmed flush. Where there was no brick veneer, an additional ¾-in. (R-4) XPS was adhered to exterior. Code officials insisted on replacing XPS with DensGlass (R-1) in conditions where common walls intersected exterior walls on the upper floors as a fire-rated barrier. The second floor framing is cantilevered out over the brick so the siding drains to the exterior surface of the brick in a flush detail (no ledge) (see Figure 10 and Table 9).

Figure 10. Above-grade walls after retrofit

Table 9. Wall Assembly Insulation Values

Assembly	Component R-Value	U-Value
1st Floor 2 × 4 @ 16 o.c. 3½-in. ccSPF Brick Veneer	20 in stud bays	0.069
2nd Floor 2 × 4 @ 16 o.c. 3½-in. ccSPF + ¾-in. XPS	20 in stud bays + 4 continuous	0.054

First floor rim joists were sprayed with closed cell foam and, where balloon framing existed, the bays were blocked and drilled, then sprayed full with foam (see Figure 11).

Figure 11. Balloon framing after retrofit

3.3 Attics

Pre-retrofit, vented attics were accessible to tenants and insulated with mineral wool batts (R-19 approximate). Ceiling penetrations were not air sealed and baffles at soffit vents were not secured into place. Based on the pre-retrofit conditions, it was assumed that a significant amount of air infiltration traveled from the attic through wall cavities and out floor, ceiling, or wall penetrations.

Consideration was given to spraying the rafters with ccSPF to create unvented attics and R-50 blown cellulose at the attic floor. The more cost-effective alternative was to blow 18 in. of fiberglass insulation at the ceiling joists (R-44) and spray foam baffles into place to maintain a vented attic. Prior to fiberglass, effective air sealing was to be accomplished at the ceiling plane at all through-ceiling penetrations (smoke/carbon monoxide detectors, surface-mounted fixtures) and gypsum-board-to-top-plate intersections using ccSPF. Similar air sealing and blown-in fiberglass (R-44) was achieved in mudroom addition attics. CARB recommended against using hat channels on the top floor to attach gypsum board, but a late change saw the channels re-introduced and blower door testing revealed infiltration on the top floor. Attic access panels were insulated and gasketed with key access to discourage tenant use (see Figure 12).

Figure 12. Baffles foamed in place and blown fiberglass in attics

3.4 Windows

Existing windows were clear uninsulated aluminum with U-value 0.60 and SHGC 0.65. The cost-effective solution that met the aesthetic and durability requirements was to replace windows with aluminum clad low-E argon-filled units. The new ENERGY STAR qualified windows are U-value 0.32, SHGC 0.25 (see Figure 13).

Figure 13. Windows during and after retrofit

3.5 Heating, Cooling, and Distribution Systems

Each unit previously had an 80 AFUE gas boiler with wall-mounted convectors. It was a goal of the project team to eliminate tenant installation of window-mounted air conditioners, so space cooling options were investigated. Central air conditioning proved the most cost effective, which led the team to select a forced air system throughout: minimum 94 AFUE condensing gas furnaces, 39 kBtu/h (smallest available unit) with modulating capacity; a humidistat control integrated into the air handler to detect high levels of humidity and adjust the airflow to target the latent load without overcooling the space; and 1½-ton (smallest available) SEER 16 outdoor condensing units (see Figure 14). Cost benefit analysis for Climate Zone 5 showed that lower SEER units would be more cost effective, so SEER 14.5 units were ultimately installed. The outdoor units were charged with HCF-410A refrigerant using a thermal expansion valve during favorable outdoor temperatures (approximately 70°F).

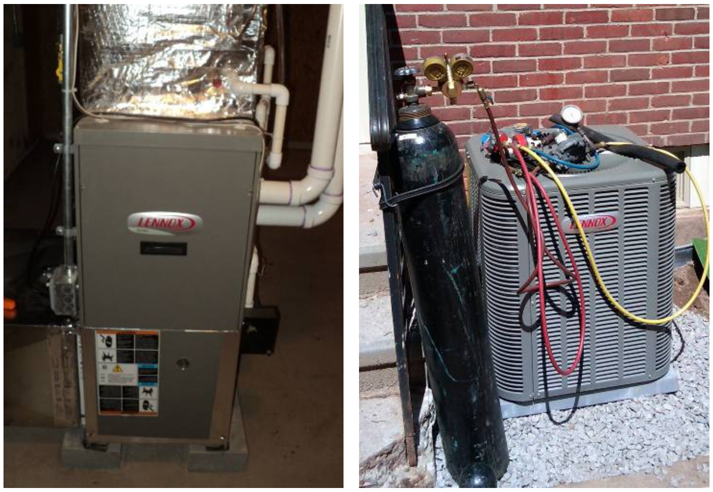

Figure 14. 94 AFUE NG condensing furnace and technician equipment for line purging

Most of the newly installed ductwork was run from the basement air handler throughout the first floor, keeping them in conditioned space. However, the first floor ceiling height restrictions (7 ft, 6 in.) limited space for second floor runs so the horizontal supplies were located in the attic. The return riser is within the second floor conditioned space. The attic ducts were sealed with mastic at joints and seams, sprayed with 2 in. ccSPF, and buried in the blown-in fiberglass (see Figure 15). CARB has successfully implemented this foam-encapsulated, buried duct technique on other projects to mimic inside-conditioned-space distribution performance. This approach achieves a thermal equivalent of R-25 and duct blaster tests typically result in negligible leakage to the unconditioned attic.

Because there were no ducts installed previously, the team had the opportunity to implement a compact duct layout approach in this retrofit. The relatively high-performance envelope compared to the pre-retrofit case, combined with the small room sizes, allows the conditioned air to be delivered to the closest point in a room rather than extending supply trunks all the way to the home's exterior. This approach saved material and installation costs, and helped contribute to overall comfort by reducing opportunities for leakage and balancing problems.

Figure 15. Attic ducts sprayed with ccSPF and buried in blown fiberglass

3.6 Domestic Hot Water

The installed hot water system eliminates standby losses by replacing the indirect tank off the existing boiler with a tankless water heater (0.94 EF). Additionally, all pipes were insulated with a R-5 minimum, and PEX branch runs were no longer 22 in. from source to fixture. Additional water savings features installed are: (1) 1.75-gpm low-flow showerheads, (2) 1.5-gpm low-flow lavatory faucets, and (3) efficient dishwashers that use less than 6 gallons per cycle (see Figure 16).

Figure 16. Insulated copper at tankless unit and insulated PEX at branch runs

3.7 Ventilation

The team's objective is to maintain indoor air quality without over ventilating. Ventilation needs required by American Society of Heating, Refrigerating and Air-Conditioning Engineers

(ASHRAE) 62.2-2010, Green Communities, and LEED for Homes ask for local exhaust and whole-house ventilation. In these units, both are provided through an exhaust-only strategy by installing ENERGY STAR qualified exhaust fans in bathrooms. The fans operate at timed intervals to meet whole-house ventilation requirements, with an override switch that meets local exhaust requirements and allows occupants to use when necessary or desired.

The ENERGY STAR bathroom exhaust fans are rated for up to 80 cfm, and the first phase of 19 units tested showed actual flow rates of 55–73 cfm. The contractor and SWA raters adjusted each unit's fan timers to meet the ASHRAE 62.2 standard whole-house ventilation rates, based on actual measured flow rates. ASHRAE also requires a minimum of 50 cfm for intermittent bath exhaust operation, which has been met in all tested units to date.

Affordable housing criteria required kitchen ventilation range hoods to remove point source pollutants, but allows hoods to be recirculating. ASHRAE requires kitchen exhaust to be vented to the outside, but accepts either room exhaust or vented range hoods. The target flow rate for intermittent kitchen exhaust is 100 cfm. The project installed 110 cfm rated ENERGY STAR ceiling exhaust fans in the kitchen ceilings to remove moisture and pollutants as well as recirculating range hoods to filter grease and particulates (see Figure 17). Testing by SWA raters on early units showed actual flow rates of 83–97 cfm. CARB is working with the contractor to identify solutions that would allow the fans to perform as rated, which may include streamlining flex duct runs in the attic. Although points are awarded for meeting the target flow rates, certification is not jeopardized by failure to do so. The team is seeking to improve performance as a means to control cooking moisture and pollutants.

Figure 17. Kitchen room fans and testing bath fan performance

4 Project Results

As of July 2011, SWA had completed final inspections and testing on 23 units and submitted (via sampling) 58 of the total 126 project units for the ENERGY STAR Homes label. The learning curve on the first few homes was significant, but after an education effort with the subcontractors and installers, subsequent work quality has been consistent. Test results gathered to date are displayed in Table 10.

Table 10. Performance Testing Results

Unit Description	Air Infiltration ACH50	ACH50/ft^2 of Enclosure Area	Duct Leakage to Outside (cfm25)	Bath Fan 1 Flow (cfm)	Bath Fan 2 Flow (cfm)	Kitchen Fan Flow (cfm)	HERS Index (REM/Rate)
End 2story	5.69	0.75	18	73	62	91	60
Interior 2story	6.22	0.82	18	70	61	86	60
Interior 2story	6.61	0.82	27	73	68	88	57
End 2story	6.53	0.84	29	70	68	93	60
End 2story	6.02	0.77	45	70	60	91	59
End 1story	3.76	0.94	30	n/a	65	30	59
End 1story	4.05	1.01	42	n/a	57	97	61
End 2story	7.31	0.96	34	68	69	95	62
Interior 2story	8.26	1.08	40	77	67	90	63
End 2story	6.43	0.83	24	72	67	86	62
End 1story	4.75	1.19	0	n/a	n/a	90	60
End 2story	7.50	0.98	58	n/a	n/a	85	62
Duplex 2story	4.84	0.62	50	61	63	92	58
Interior 2story	7.54	0.97	37	55	50	83	62
End 2story	7.27	0.95	19	58	58	89	62
2story	7.51	0.97	0	n/a	56	n/a	62
Duplex 2story	7.95	1.04	35	57	63	86	63
Duplex 2story	7.99	1.04	37	n/a	69	64	63
Interior 2story	7.72	0.99	55	n/a	68	64	60
End 1story	4.10	1.03	50	n/a	71	86	61
Interior 2story	7.86	1.03	50	64	60	95	63
Interior 2story	7.65	0.95	30	52	57	89	59
End 1story	5.95	0.74	21	n/a	62	75	60
AVERAGE	**6.50**	**0.93**	**33**	**66**	**63**	**84**	**61**

During construction and at final testing, CARB recommended corrections to duct sealing, insulation installation, and exhaust fan installation. Duct sealing in basements proved challenging but was ultimately accomplished (discussed in section 5.2.1) and results have been consistent through the construction phases. Air sealing and insulation improvements were made as requested, with the exception of the hat channels on top floors discussed in Section 5.1.3. Although overall unit tightness did not quite meet CARB expectations of 2 ACH at 50 Pa, likely points of failure have been identified. Corrections to installed exhaust fans are ongoing. All units met their target to reduce HERS Index below 65, and associated incentives are in process. Table 11 summarizes the as-built specifications.

Table 11. Existing, Recommended, and Installed Specifications

	Existing Condition	BA Recommendation	Installed Condition
Below-Grade Walls	8 in. Poured concrete foundation, 7 in. tall uninsulated	R-10 foil faced polyisocyanurate adhered to interior side of wall	R-10 foil faced polyisocyanurate adhered to interior side of wall with OSB for physical protection
Above-Grade Walls: 1st Floor	2 × 4 wood framing @ 16 in. w/ R-11 mineral wool batts	1 in. ccSPF at interior of spaced boards sheathing, 2x interior horizontal strapping with 4.5 in. dense pack cellulose	3.5 in. ccSPF in existing 2 × 4 @ 16 in. o.c.
Above-Grade Walls: 2nd Floor	2 × 4 wood framing @ 16 in. w/ R-11 mineral wool batts	Same as first floor	3.5 in. ccSPF in existing 2x4 @ 16 in. o.c. plus 3/4 in. (R-4) XPS except where prohibited by code officials
Ceiling Assembly	R-19 mineral wool	R-50 cellulose	18 in. R-44 blown in Fiberglass
Rim and Band Joists	Uninsulated rim/band joist	Spray with ccSPF	sprayed with ccSPF
Insulation Measures	Un-insulated balloon frame	Frame with blocking, drill holes, fill with dense pack cellulose	blocked with wood framing, holes drilled, filled with ccSPF
	1st floor corner detail 2 × 4 studs create open corners behind brick	Drill holes in 2 × 4s and fill with 4.5-in. dense pack cellulose	Drill holes in 2 × 4s and fill with 3 in. ccSPF
Windows	Aluminum-insulated double-pane, clear U 0.60, SHGC 0.65	Vinyl-insulated double-pane, low E U 0.30, SHGC 0.32	Aluminum-clad wood U 0.32, SHGC 0.25
Cooling	No central air cooling	1.5-ton, SEER 16, modulating, single zone ducted A/C	1.5-ton, SEER 14.5, modulating, single-zone ducted A/C
Heating	NG boiler with convectors, 76 AFUE	NG condensing furnace 94 AFUE	NG furnace 94.1 AFUE
Ductwork	Radiators for heat distribution	Ductwork, sealed with mastic at seams and joints, 70% inside thermal envelope, 30% in attic sprayed with ccSPF buried in fiberglass	Ductwork, sealed with mastic at seams and joints, 70% inside thermal envelope, 30% in attic sprayed with ccSPF buried in blown fiberglass
Duct Leakage	No ducts	Assumed 5% leakage to outside	~1% leakage to outside
Ventilation	Whole-house ventilation and local exhaust nonexistent	Exhaust only, run continuously with boost up for occupancy in baths	Bath and kitchen exhaust fans intermittently
Air Leakage	8 ACH50	Assumed 2 ACH50	Tested: ~6.5 ACH50

Hot Water	Domestic water heating indirect from boiler 67 EF	NG Tankless 87 EF	NG tankless 94 EF
Lighting	100% Incandescent	100% pin-based fluorescent	100% pin-based fluorescent
Appliances	Appliances, none ENERGY STAR	ENERGY STAR refrigerator, dishwasher, clothes washer with single throw shut off at clothes washer	ENERGY STAR refrigerator, dishwasher, clothes washer with single throw shut off at clothes washer

Energy analysis of the as-built package shows that a 50% energy improvement over the 2009 BA Benchmark was not practical for the Chamberlain Heights retrofit because of cost and constructability limitations. However, the project's predicted energy savings exceeded 40% compared to the pre-retrofit conditions. Higher energy savings could have been achieved without the higher-than-anticipated air infiltration from attics and adjacent basements. Aside from this shortcoming, the retrofit achieved its original energy efficiency goals in a cost-effective manner.

5 Discussion of Lessons Learned

A number of lessons were learned during the retrofit of the Chamberlain Heights affordable housing project. This section will discuss the challenges of creating a high-performance building envelope within the spatially limited existing framing conditions, and the change to a forced air HVAC system in a cold climate residential retrofit.

5.1 Building Envelope Lessons Learned

The project was built in the 1950s with 2 × 4 wood framing on poured concrete foundations. Walls were generally balloon framed. Board sheathing covered the studs on both first and second floors. The exterior finishes consisted of brick veneer on the ground floor and vinyl siding on the second floor.

5.1.1 Uninsulated Corners

First floor corners were framed to accommodate the brick returns; the two stud ends meet at the interior corner, leaving an open space to the outside (see Figure 18). CARB recommended drilling the corner studs to spray ccSPF in the open cavity. The project team rejected this technique due to time and cost constraints, so corner studs were air sealed with foam or caulk at the interior joint. During intermediate inspections and air infiltration testing, infrared images show temperature differences at the corners and air infiltration with the blower door operating (see Figure 19). Based on the infrared analysis, CARB confirmed that the uninsulated corners represent still a significant source of energy loss/gain and potentially lead to occupant discomfort.

Figure 18. Corner framing, uninsulated space, air-sealed joint

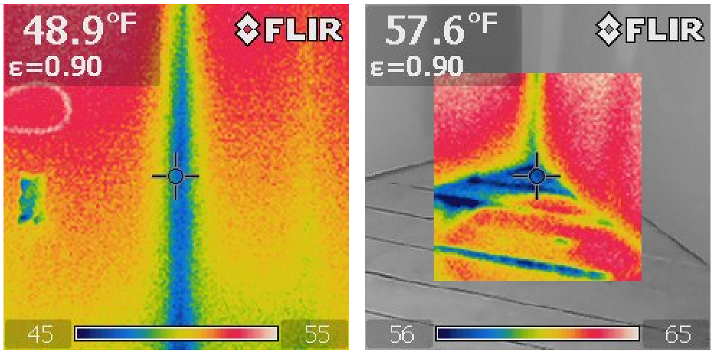

Figure 19. Infrared of cold corner and blower door pulling across the floor

5.1.2 Closed Cell Spray Foam Insulation

The ccSPF worked effectively, although it proved to be less constructible than the project team had hoped. Spray foam cannot be installed with a perfectly flat finished surface. To completely fill the cavity means some overfilling is required, and the excess must be removed for gypsum board to be installed flush with studs. Shaving excess is common with open cell applications, but more challenging with closed cell. The subcontractors found the process more labor intensive than they originally estimated. Furthermore, it was discovered that the foam pushed through the larger joints in the board sheathing, and created obstacles in installing XPS and cladding on the exterior of the second floor. To deal with the situation, the contractor spread low-cost caulking along the seams in the sheathing from the interior prior to application of ccSPF. Regardless of the extra time involved with insulating the envelope, the end result is a good thermal envelope.

5.1.3 Air Sealing in Attics and Basements

During planning stages, CARB reviewed air sealing details with the project team during site visits and project meetings. The architect favored the use of hat channels on the top floor to level the ceiling drywall. SWA recommended against the strategy as it is creates a pathway for air movement and makes air sealing particularly challenging in a retrofit. A late-stage change order after CARB's review of construction documents called for the re-introduction of the hat channels to the design without the addition of extra air sealing specifications. As a result, during blower door testing the site personnel observed significant leakage from interior partitions on the upper floor, including at doorways, outlets, and light fixtures. SWA's observations indicate that this is the most significant identifiable leakage source contributing to the average 6.52 ACH50 infiltration rate (unguarded testing).

One unanticipated source of leakage contributing to the overal unit infiltration rate was through the basements of adjacent units. While the exterior is poured concrete, the demising walls are 1950s concrete block. The walls were painted but very little other work was done during the retrofit. Site personnel observed noticable leakage across the entire block wall surface. In future retrofits, CARB may encourage project teams to apply a sealant product to mitigate this point of air transfer.

5.2 Heating, Cooling, and Ventilation Lessons Learned

The HVAC contractors diligently implemented the duct sealing specifications for distribution. As a reference, CARB has written a report on the subject: *Measure Guideline: Sealing and Insulating of Ducts in Existing Homes*, which has been published on the BA website.

5.2.1 Compact Duct Layout

The decision to switch from hydronic heating to a forced air system for heating and cooling stemmed from a project goal to eliminate tenant-installed window air-conditioning units. The developer's pricing analysis showed that installing a condensing gas furnace with high-efficiency air handler and split condensing unit was the most cost-effective space conditioning solution. CARB used the opportunity of a fresh install to use a compact duct design. Confidence in the building's improved thermal envelope allowed the team to deliver conditioned air to the interior edges of rooms rather than using longer duct runs to deliver air at exterior windows. As a result, the longest duct laterals in the project are 8 feet. Compact duct layout is one of the techniques developed in high-performance new construction projects that proved extremely applicable to the Chamberlain Heights retrofit (see Figure 20).

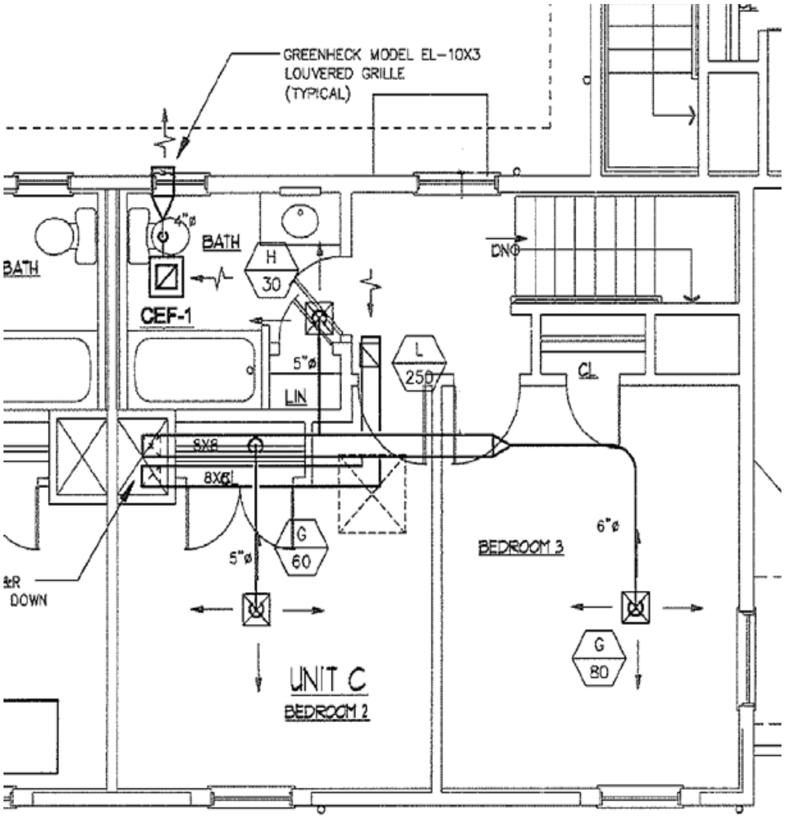

Figure 20. Building type B2 2nd floor compact duct layout

5.2.2 Ducts in Conditioned Space

Another strategy utilized by CARB on previous new construction projects that lent itself well to the retrofit was foam-encapsulated, buried ducts. Space constraints and existing framing conditions required that conditioned air be delivered to the second floor via the attics. In order to get the ducts into conditioned space, the team explored creating a sealed conditioned attic via application of ccSPF at the rafters. Budget concerns led CARB to suggest applying spray foam only to the compact ducts, sealing them to the attic floor, and blowing fiberglass insulation over the ducts and floor in a standard application. The technique was new to the engineer, architect, and installers but yielded very good thermal and air sealing results.

The HVAC contractors diligently implemented the duct sealing specifications for distribution runs in the attic and above-grade conditioned spaces, but were remiss with ducts in the basement. SWA raters visually inspected installed ducts during intermediate site inspections but basement ducts were not installed until final stages of construction, therefore, they were not assessed until final testing. Final duct blaster results showed significant duct leakage. Although the air infiltration numbers were somewhat high (3.7–8.2 ACH50), the duct leakage seemed very high given the sealing strategies specified. After investigative testing, SWA identified conditions contributing to the duct leakage: (1) air handler cabinets and filter housings; (2) unsealed basement duct work; and (3) unsealed registers (see Figure 21). Generally speaking, the air handler cabinets were very leaky so HVAC foil tape was used to seal the joints. Apparently time constraints caused the HVAC installer to neglect to seal basement ducts before covering them with insulation. The problems were identified after the first five units were completed. Corrections were made to these sample homes, and the practices were successfully carried through to future units. One CARB recommendation that was not implemented was use of rigid filter racks. The team used sheet metal chambers to save cost, which remain a point of leakage because sealing would inhibit changing of filters in the future. Table 12 shows the improvement in duct leakage numbers after the issues described above were addressed.

Figure 21. Basement ducts were unsealed in initial units

Table 12. Duct Leakage Testing Before and After Corrections

Tested Unit 30 Hollis Drive	Tested Leakage to Outside cfm at 25 Pa	Leakage to Outside per 100 ft^2 (cfm at 25 Pa)
Before Corrections	178	21.2
After Corrections	30	3.57

6 Conclusions

CARB used the retrofit of 126 attached housing units at Chamberlain Heights in Meriden, Connecticut, to evaluate whether a 50% energy saving relative to the 2009 BA Benchmark was a feasible target for a cold climate affordable housing retrofit. JRC and MHA's goals for long-term operational affordability allowed them to prioritize energy upgrades and implement most of CARB's recommendations. These included maximizing envelope thermal resistance within spatial limitations via ccSPF, and installing a new energy-efficient forced air system with compact duct layout and foamed over buried ducts. The project achieved its energy efficiency goals, reducing energy consumption by 40%–45%, and was able to qualify for substantial incentives from the local utility program and other certifications, but still fell short of the BA goal for new construction energy savings. Based on observation and analysis, CARB concluded that the 50% saving target would be economically difficult for similar retrofit projects.

Several important lessons were learned during the course of the project. First, SWA observed that retrofits are susceptible to a steeper learning curve than new construction projects. Through site inspections and performance testing during Phase I of the project, CARB was able to identify several performance problems that were later corrected. These corrections were successfully carried through to later phases of the project. One of the most notable corrections made was to the forced air system in the basement, including duct sealing, air handler sealing, and sealing at first floor registers. Performance testing demonstrated to the subcontractors where additional attention was needed, and subsequent tests showed improved results. CARB attributes the steeper learning curve during Phase I of the retrofit to discovery of unexpected existing conditions and an aggressive schedule dependent upon existing tenant move-out and move-in dates.

The Chamberlain Heights retrofits experienced some problems with constructability related to the spray foam in exterior walls. In future projects, SWA would recommend furring out walls on the inside, taping seams in board sheathing (if applicable), spraying a 2-in. layer of ccSPF, and filling the remaining space with blown cellulose or fiberglass. This would eliminate the labor-intensive process of scraping ccSPF flush with the studs on the interior and sheathing on the exterior. Furthermore, SWA would eliminate the hat channels used on the top floors to remove the pathway for air movement, reducing infiltration between the unconditioned attic and the top floor.

Because the HVAC upgrades involved a switch from hydronic heating and window air conditioners to a forced air system for heating and cooling, CARB was able to apply two technologies from new construction projects to this retrofit. The compact duct layout succeeded in reducing the amount of ductwork required, and the foamed over buried duct approach provided duct tightness and brought ducts into conditioned space. Both techniques were new to the designers and subcontractors, and both were well received.

Chamberlain Heights is on track to obtain three certifications recognizing accomplishments in energy efficiency and sustainability: LEED for Homes Gold, Green Communities, and ENERGY STAR. As of the writing of this report, 19 homes had undergone final testing using sampling protocols, and 58 units had been submitted for ENERGY STAR labels. The average HERS Index for the completed homes is 61, and the local utility pays $3,970 per unit in combined incentives for overall performance and specific equipment installation. Occupants returning to their homes post-retrofit should see their utility bills reduced by more than $600 per year. CARB believes that this project represents an aggressive but attainable model for future retrofits of similar cold climate wood frame affordable housing projects.

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