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56th and Walnut—A Philly Gut Rehab Development

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Consortium for Advanced Residential Buildings

July 2013

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56^{th} and Walnut—A Philly Gut Rehab Development

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Definitions

A/C	Air conditioner
ACH50	Air changes per hour at a pressure differential of 50 Pascal
AFUE	Annual fuel utilization efficiency
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BA	Building America
BEopt	Building Energy Optimization software
CARB	Consortium for Advanced Residential Buildings
ccSPF	Closed-cell spray polyurethane foam
CFL	Compact fluorescent lamp
CFM50	Cubic feet per minute of airflow needed to create a change in building pressure of 50 Pascal
CO	Carbon monoxide
EF	Energy factor
HERS	Home Energy Rating System
HVAC	Heating, ventilation, and air-conditioning
IECC	International Energy Conservation Code
kBtu/h	Thousands of British thermal units per hour
LAMEL	Lighting, appliances, and miscellaneous electric load
LED	Light-emitting diode
LFL	Linear fluorescent lighting
MBtu	Millions of British thermal units
MERV	Minimum efficiency reporting value
o.c.	On center
NREL	National Renewable Energy Laboratory
QA	Quality assurance
RESNET	Residential Energy Services Network
ROI	Return on investment
RH	Relative humidity
SEER	Seasonal energy efficiency ratio
SHGC	Solar heat gain coefficient
SPB	Simple payback period
TPO	Thermoplastic polyolefin
XPS	Extruded polystyrene

Executive Summary

Load-bearing brick-masonry multifamily buildings are prevalent in urban areas across much of the Northeast and mid-Atlantic. In most instances, these buildings are uninsulated unless they have been renovated within the past two decades. Affordable housing capital budgets typically limit what can be spent and energy improvements often take a back seat to basic capital improvements. The Consortium for Advanced Residential Buildings (CARB) is researching cost-effective solution packages for significant energy efficiency and indoor air quality improvements in these urban building types. Past projects have focused on up to 30% energy savings targets on this housing type; CARB sought to approach 50% energy savings for this case study. In terms of specific research effort, this report takes an in-depth look at retrofitting wet foundations in a manner that is affordable and suitable for this type of housing type.

To explore how these low-cost retrofits can effectively integrate energy efficiency upgrades, CARB partnered with Columbus Property Management on a gut rehabilitation project located at 56th Street and Walnut Street in Philadelphia, consisting of 32 units in 11 three-story buildings. These buildings were built in the early 1900s using stone foundations and solid brick-masonry walls. They were renovated in the 1990s to have interior light gauge metal framing with R-13 batt in the above-grade walls, induced-draft furnaces, and central air conditioning.

During the design phase of this project, a comprehensive field survey and energy audit were performed. The documented physical conditions and predicted energy use established the baseline. Using BEopt™ energy modeling/economic analysis software, CARB explored various optimization scenarios for energy performance and cost; and through this analysis arrived at a recommended implementation package, including improvements to the thermal enclosure, moisture management, heating, ventilation, and air conditioning, hot water, and lighting. Moisture management proved to be a major driver, mostly due to chronically damp basements. Even though enclosure moisture improvements skew the cost-effectiveness equation, these improvements are essential to durability and indoor air quality in a tighter building enclosure.

CARB made several visits to the project site to verify that the construction execution corresponded with the drawings and specifications. There were no major incongruities between design and as-built conditions; however, there were a few correctable defects that were observed and ultimately corrected. These defects primarily related to inconsistency in the spray foam application resulting in bypasses in the thermal, air, and vapor barriers.

During the final test out of this project, the apartments outperformed the initial Building America specification targets for building and duct tightness. The average apartment infiltration rate of 4.0 ACH50 was lower than the goal of 5.0 ACH50. The average duct leakage to outside rate of 2.6 cfm25/100 ft^2 was also lower than the goal of 4.0 cfm25/100 ft^2.

Post-implementation and test-out, BEopt analysis for multiple sample dwellings yielded estimated performance improvements ranging from 45% to 47%. For one typical dwelling, that equates to a predicted utility cost savings of $707/yr. The cost of the improvements, amortized in a 30-year mortgage, is $520/yr, for a net cash flow improvement of $187 annually. Not included in these cost-benefit figures are the qualitative improvements to moisture management, indoor air quality, comfort, and durability.

1 Introduction

Load-bearing brick-masonry buildings are prevalent in urban areas across much of the Northeast and mid-Atlantic portion of the country, including Philadelphia, New York, Boston, Baltimore, and Washington, D.C. In most instances, these buildings are uninsulated unless they have been renovated within the past two decades. The Consortium for Advanced Residential Buildings (CARB) is researching cost-effective solution packages for significant energy efficiency improvements in urban gut rehabilitation projects. Common obstacles include moisture control and insulation challenges, while often including exterior façade restrictions (limiting what can be done). Furthermore, affordable housing capital budgets typically limit what can be spent, so efficiency measures typically take a back seat to basic capital improvements that may be required, as well as interior finish updates (e.g., new kitchens, baths, and paint). Therefore prioritizing those efficiency measures that are performed is critical.

Some interesting findings have come out of past research on this housing type. A 1986 study of retrofits to more than 100 multifamily buildings in a variety of climate zones showed that mechanical system retrofits were more cost effective than envelope improvements when seeking energy savings in the 10%–25% range of pre-retrofit energy use (Goldman and Greely 1986). A more recent 2012 study looked at a 500-unit renovation project including low-rise and mid-rise structures in Boston and found that energy consumption could be reduced by 30% by implementing air sealing, window replacements, and mechanical system upgrades (Neuhauser et al. 2012). In both of the studies, increasing or adding exterior wall insulation is not a prioritized energy efficiency measure unless seeking higher than 30% energy savings.

To evaluate low-cost multifamily retrofits seeking energy savings of roughly 50% over existing conditions, CARB partnered with Columbus Property Management and Development, Inc. (Columbus) on a gut rehab project located at 56th Street and Walnut Street in Philadelphia, Pennsylvania. This substantial rehab project consists of 32 units in 11 three-story buildings. These buildings were built in the early 1900s using stone foundations and solid brick-masonry walls. They were renovated in the 1990s and have light gauge metal framing with R-13 batt in the walls.

Figure 1. Street view of the 56th and Walnut Street rehabilitation project

CARB is familiar with Columbus's construction methods based upon previous Steven Winter Associates, Inc. work with Columbus on its Temple II North Gratz Street project.[1] That rehabilitation project consisted of 40 dwellings in 29 buildings, also located in Philadelphia. Though of similar brick construction, Temple II was a townhouse building type versus the low-rise multifamily apartment buildings of 56th and Walnut.

Figure 2. Street view of the Temple II North Gratz rehabilitation project

The 56th and Walnut project focused on gut rehabs of multifamily brick masonry buildings in climate zone 4A. Older brick buildings are common throughout this region and up through New England. The challenge of these buildings is incorporating energy efficiency measures cost effectively while maintaining the exterior brick façades. This requires that efficiency measures be completed on the interior of the building shell, rather than the exterior.

[1] http://americanbuildersquarterly.com/2012/rebuilding-through-red-tape/

2 Research Goals

The overarching question is:

- What solution package(s) can be readily implemented in the mixed, humid climate to existing brick multifamily buildings by a developer or builder on a community-wide basis to achieve a 50% energy savings home compared to the existing conditions?

Questions specific to this study:

- Is the selected solution package for these apartment buildings commercially viable? Where are opportunities to reduce costs in the solution package?
- What specific issues are there regarding quality assurance and quality control to maintain consistency throughout the project build-out?
- What additional risk concerns need to be addressed as a result of this being retrofit construction?
- How effective is each individual energy efficiency measure at meeting its specific cost and performance targets? How effective is it when integrated into a whole-house package?

3 Research Method

CARB, in conjunction with Columbus, set a performance goal of 50% source energy savings over the pre-existing conditions with a cost-effective solution package. The project comprised three major stages: initial audit of existing conditions and design recommendations based on BEopt analysis, oversight of construction implementation, and final performance testing of units.

3.1 Energy Auditing

The apartments of 56th and Walnut range in size from 461 ft^2 to 999 ft^2 and from one to three bedrooms. The overall condition of the units was poor and required, at a minimum, a thorough cleaning of the interiors and replacement of mechanical equipment. In addition, performance testing could not be performed during the initial audit of the buildings due to lack of power to run test equipment, and some demolition had already taken place. The existing building infiltration and duct leakage estimates were based on visual inspections and results from other similar projects that Steven Winter Associates, Inc. has worked on in Philadelphia region. A summary of the existing conditions is provided in Table 1.

Table 1. Existing Apartment Specifications

Building Component	Existing Condition
Foundation	Uninsulated rubble stone foundation
Above-Grade Walls	Brick wall, R13 cavity insulation derated for steel studs and G-III installation
Attic	R-30 at ceiling plane. Asphalt roof
Windows	Dual pane, clear windows with metal frame (U-0.76, SHGC[a]-0.68)
Building Infiltration	9 ACH@50[b] (estimated)
Ventilation	Local bathroom exhaust fan only
Cooling	10 SEER[c], 2 ton (degraded to 8 SEER due to poor maintenance)
Heating	90% AFUE[d]
Duct Leakage	12 CFM[e]/100 ft^2 (estimated)
Hot Water	Gas, 40 gal storage tank EF[f] 0.57
Lighting	CFL[g]–LED[h]–LFL[i] = 50%–0–0
Appliances	Non-ENERGY STAR® refrigerator

[a] Solar heat gain coefficient
[b] Air changes per hour at 50 Pascals
[c] Seasonal energy efficiency ratio
[d] Annual fuel utilization efficiency
[e] Cubic feet per minute
[f] Energy factor
[g] Compact fluorescent lamp
[h] Light-emitting diode
[i] Linear fluorescent lamp

3.1.1 Building Envelope

The exterior wall assembly of these apartments comprises multiwythe solid brick-masonry with vertical wood furring between 2 × 4 steel studs at 16 in. on center (o.c.) and the masonry wall (see Figure 3). The steel-stud wall cavities are filled with R-13 Kraft-faced fiberglass insulation. The poor installation (Grade III), conductive nature of the steel studs, and signs of air movement in the wall cavity, as evidenced by the dirt on the backside of the fiberglass insulation, result in a derating of the fiberglass insulation to the equivalent of R-4 cavity insulation.

Figure 3. (L) View of wall assembly construction; (R) spot checks of the batt insulation showed poor installation and air movement within the wall cavity

It was also found that the rim/band joist areas were poorly insulated. In some cases, where ductwork ran near the exterior wall, no insulation was found due the duct obstruction (Figure 4).

Figure 4. (L) Poor installation of batt insulation at the rim/band joists; (R) missing rim/band insulation due to ductwork obstruction

Once the interior walls were gutted, it was observed in a couple small areas that the brick mortar was deteriorating (Figure 5). Cracks in the brick wall were found above these areas. This deterioration was likely a result of a bulk moisture migration breaking down the high lime content mortar of the masonry wall. There were additional signs of moisture issues on several of the window sills, as evidenced in Figure 6, with paint bubbling and the wood sill being soft to the touch.

Figure 5. Brick mortar crumbling just from the touch of a finger

Figure 6. Bubbling of paint on window sill

The apartment buildings have uninsulated rubble stone foundations. During the initial inspection, water was observed on the rubble stone as well as the concrete slab. Rarely do these buildings have proper water- and damp-proofing on the exterior of the foundation walls or a capillary break and vapor retarder under the foundation slab. In this portion of Philadelphia, the water table is roughly 12–18 in. below the slab, so moisture continually wicks up into the basement.

Resolving this moisture issue is complicated in existing structures without ripping up the existing slab. CARB offered various alternatives to address this common and significant barrier. These foundation solutions are not cost effective, as they go beyond just energy consumption and address durability, indoor air quality, and comfort issues. The benefits cannot be objectively quantified solely in terms of monetary savings, especially in these apartments, as the basement is common space and not part of any specific apartment.

Figure 7. (L) The existing foundation has moisture issues with water intruding through the foundation walls and slab. (R) When additional footing supports were being dug, it was clear that the water table is quite high in this area.

The flat roofs of these buildings were in need of repair to control bulk water, as the asphalt hot-mop roof was deteriorating (Figure 8). Insulation of the roof assembly was R-30 batt insulation installed at the ceiling plane in the unvented cockloft attic space.

Figure 8. Deterioration of roof as evidenced by "alligatored" asphalt coating and degraded coating on parapet

Dual-pane steel-frame windows were installed during the 1990s renovations, but there was no focus on air sealing or insulating the rough window openings. In many instances, the inner brick course under the window sill was knocked out (Figure 9). In addition, in several locations the steel angle headers over windows deflected, allowing additional pathways for air, moisture, and water to enter the wall assemblies.

Figure 9. The inner course of brick was removed when installing the windows back in the 1990s renovation

Figure 10. Deflection of steel angle window header

3.1.2 Mechanical Equipment

The majority of the existing mechanical equipment for these apartments were systems that included an induced-draft furnace, split-system air conditioner (A/C) with condensing unit located on roof top (Figure 11), and an atmospheric gas storage water heater. These heating, ventilation, and air-conditioning (HVAC) systems were installed during the 1990s renovations. Based on manufacturer dates on the A/C condensing units, it appears the renovations occurred in 1990 or 1991, so these systems are more than 20 years old. The effective life expectancy of HVAC equipment is typically between 15–18 years, thus placing the equipment past its typical useful life. In a couple instances, the furnace had been replaced with a sealed-combustion furnace, but the condition of these units resulted in their being replaced as well.

Figure 11. A/C condensing units on rooftop

The furnace units had a heating capacity of 45 kBtu/h with a burner efficiency of 90% AFUE. On the cooling side, 2-ton A/Cs with a SEER 10 rating were supplying each apartment. The cooling equipment was in poor condition. The condenser fins on many of these units were dented or damaged, debris was observed on the indoor evaporator coils resulting in restrictions to heat transfer and airflow, and the A/C units hadn't been serviced in years, so the refrigerant charge was likely low. Actual performance was estimated to be SEER 8 or less. Ductwork runs in the basement for the first-floor apartments (Figure 12), between floors for the second-floor apartments, and in the unvented attic space for the third-floor apartments. The existing sheet metal ductwork was uninsulated, in poor condition, and showed no signs of duct sealing.

Figure 12. Uninsulated and leaky HVAC system for a first-floor apartment located in an unconditioned basement

Hot water for each apartment was provided by an atmospheric gas storage tank water heater with an EF of 0.57. In two apartments, the water heater had been replaced more recently with a power/direct venting system (0.63 EF). To provide make-up air for the atmospheric water heaters, the installing contractor made a concentric flue, as shown in Figure 13. This is not a recommended practice.

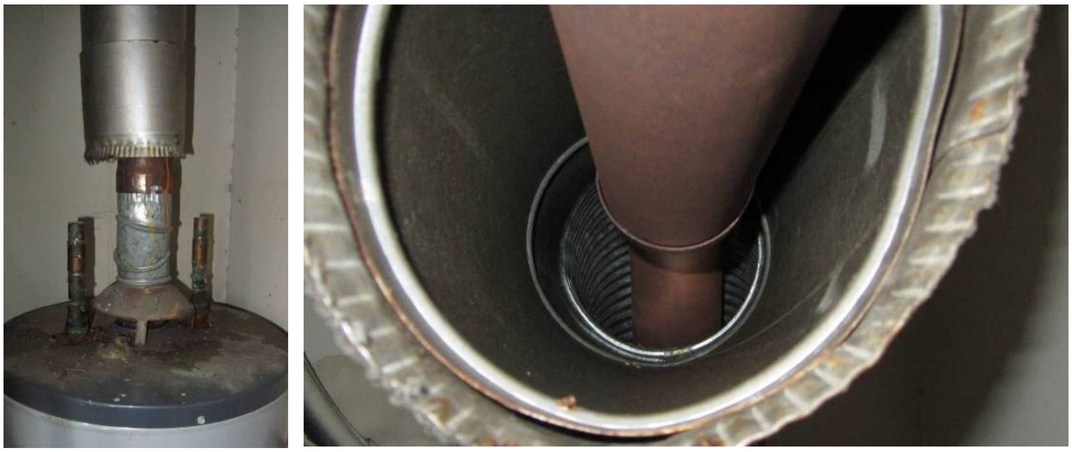

Figure 13. Make-up combustion air being provided for the water heater

Of greater concern is the location of the atmospheric water heater, as it is located in a bedroom mechanical closet with the furnace. The issue is that the furnace utilized a central return. This central return was a platform box under the furnace with a grille facing the closet door. The closet door also had a transfer grille cut into it to draw air from the main living space. With the high amount of air leakage around the return plenum platform, there is the potential for the return to cause the mechanical closet to be depressurized and lead to back-drafting of the water heater (spilling flue gases, including carbon monoxide (CO) back into the living space).

Figure 14. Atmospheric water heater located in furnace air handler closet with poorly sealed central return

An additional health concern was the improper filtration of the existing furnaces. In several instances, improper filters were installed in the furnaces as the filter size was not a standard option. The filters shown in Figure 15 are both the wrong size for this furnace cabinet and improper media filter material to provide appropriate particulate removal capacity. Filters are classified by a minimum efficiency reporting value (MERV). Fiberglass panel filters tend to have MERV ratings of 4 or less and will tend to have a dust spot efficiency of less than 20%. At a minimum, a 1-in. pleated air filter is recommended to remove more particulates (3–10 pm particle size) from the air stream, but this type of filter needs to be accounted for in the HVAC design to not adversely affect system airflow. A 1-in. pleated air filter will typically have a MERV between 5–8 and have a dust spot efficiency between 20%–75%.[2]

Figure 15. Improper air filters installed into existing furnaces

These apartments did not have any whole-house ventilation installed. Still, the local exhaust ventilation in the kitchens and bathrooms was poor or nonexistent. Bathroom fans were quite old and haven't been maintained at all, as shown in Figure 16. Kitchen range hoods were not ducted to the exterior.

Figure 16. Condition of existing bathroom exhaust fan

[2] www.mechreps.com/PDF/Merv_Rating_Chart.pdf

3.2 Energy Use Modeling

Considering the primary barriers to reaching the performance target, which includes historic building preservation, maintaining adequate indoor air quality, and high moisture levels in the basement, a cost-benefit analysis of various improvement measures was performed. A typical apartment unit (Type F) was modeled in an hourly energy simulation tool to investigate the effects of various energy saving measures to be recommended. CARB analyzed the building performance in BEopt™ (Building Energy Optimization version 1.3), a software produced by the National Renewable Energy Laboratory that provides capabilities to evaluate residential building designs and identify cost-optimal efficiency packages at various levels of whole-house energy savings along the path to net-zero energy capable homes. For the economic analysis, the economic values in Table 2 were used. Initial modeling was primarily performed on a first-floor Type F end unit (Figure 17); it has a floor area of 975 ft^2 with two bedrooms and one full bath.

Table 2. Inputs of Economic Analysis

Economic Variables	Modeling Inputs
Project Analysis Period	30 years
Inflation Rate	1.6%
Discount Rate (Real)	3.0%
Loan Period	30 years
Loan Interest Rate	4.0%
Electricity Rate	$0.1075/kWh + $5.18 monthly charge
Natural Gas Rate	$1.1479/therm + $8.00 monthly charge
Fuel Escalation Rate	0.0%

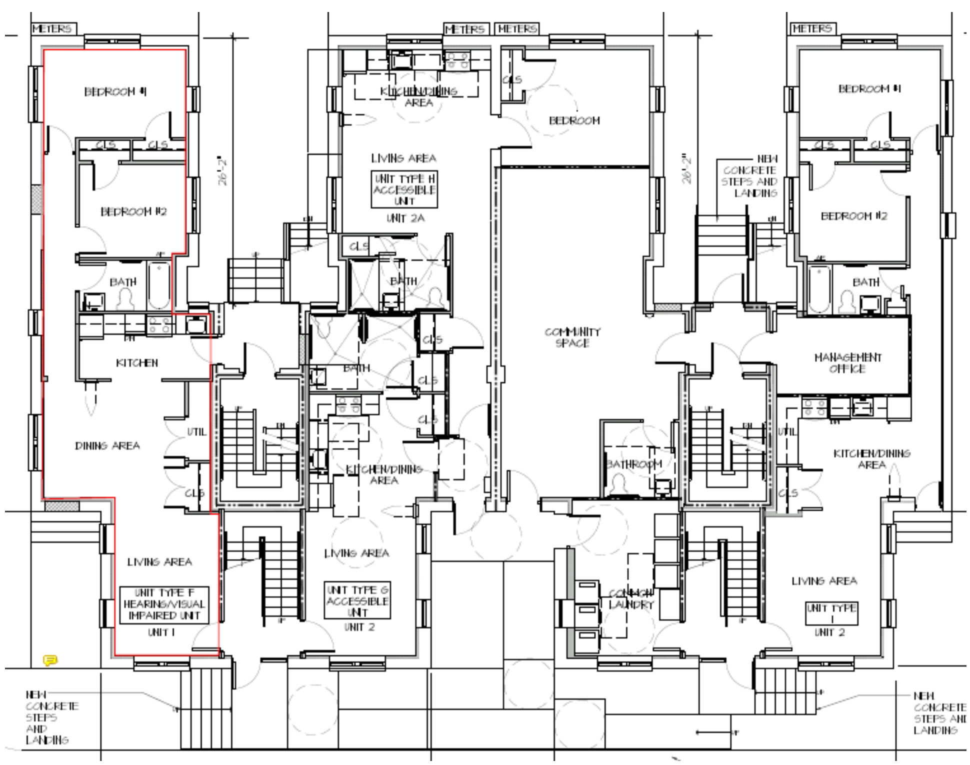

Figure 17. First floor plan (Type F apartment outlined in red)

3.3 Building America Recommended Specification

Bearing in mind the challenges of renovating an exterior brick façade building with affordable housing cost restraints, CARB evaluated several solution packages to meet the constraints and goals of this project. Minimizing building leakage and improving the indoor air quality were key focuses in this gut rehabilitation project. Table 3 shows the pre-retrofit and final proposed Building America (BA)-recommended building specifications.

Table 3. Recommended Building Specifications Summary

Component	Pre-Retrofit	BA Recommended
Foundation Assembly (Applies to First-Floor Units)	Uninsulated stone without damp-proofing or below slab vapor retarder	R-13 of ccSPF against stone foundation. Capillary break at slab
Above-Grade Wall Assembly	Solid brick-masonry wall, R-13 cavity insulation de-rated for steel studs and G-III insulation	Reframe interior 2 × 4 steel stud wall at 16 in. o.c. spaced 1 in. from brick and filled with 3.5 in. of ccSPF
Ceiling/Attic Assembly (Applies to Third-Floor Units)	R-30 on ceiling plane; asphalt roof	3 in. of polyisocyanurate (R-19) above roof deck covered with white TPO* membrane. 3 in. of ccSPF on underside of roof deck.
Window Glazing	Dual-pane, clear windows with metal frame (U-0.76/SHGC-0.68)	Dual pane, low-e windows with vinyl frame (U-0.29/SHGC-0.22)
Building Infiltration	9 ACH50 (estimated)	5 ACH50 (target)
Whole-House Ventilation	none	Exhaust-only set at 100% of ASHRAE 62.2-2010 continuously
Cooling System	2-ton A/C (10 SEER, derated to 8 SEER due to poor maintenance)	1.5-ton A/C (SEER 16)
Heating System	Natural gas furnace (90% AFUE)	Natural gas condensing furnace (95% AFUE)
Ductwork	12 cfm/100 ft^2 leakage (estimated)	Ducts located in conditioned space; 4 cfm/100 ft^2 leakage
Water Heating	Natural gas tank water heater (EF 0.57)	Natural gas tank water heater (EF 0.67)
Lighting	CFL–LED–LFL = 50%–0–0	CFL–LED–LFL = 62%–0%–13%
Appliances	Non-ENERGY STAR appliances	ENERGY STAR appliances
Plumbing Fixtures	Standard flow shower and sinks	Low flow shower and sinks

* Thermoplastic polyolefin

3.4 Energy Analysis Relative to Existing Conditions

As mentioned in Section 2.1.1, there were thermal and air bypass issues throughout the envelope of the building. With the interiors of these units being gutted, it was possible to offset the steel studs 1 in. from the brick wall (no longer having the wood furring strip between the steel stud and brick wall. Closed-cell spray polyurethane foam (ccSPF) can then be applied to the brick wall to fill the 1-in. gap and extend into the stud cavity space for a total thickness of roughly 3.5

in. This provides a continuous thermal, air, and vapor barrier on the interior of the brick surface. For this to be effective, the exterior brick needs to have appropriate water drainage to prevent water and moisture from penetrating through the brick and deteriorating the structure. Additional improvements to the above-grade building envelope are discussed in Section 4.2.

The improvements to the building envelope allow for the HVAC equipment and distribution systems to be reduced in size. The HVAC systems were already likely nearing the end of their serviceable lives, so this was an opportune time to increase the efficiency of these units. The HVAC system replacements include condensing furnaces (replaced poorly maintained 90% AFUE furnaces with a 95% AFUE), more efficient A/Cs (replace an old R-22 refrigerant, SEER 10 A/C with a SEER 16 unit), and a direct current-motor exhaust fan with variable-speed (adjustable continuous low speed that can be boosted to full capacity when desired) and a delay timer (to allow the unit to continue to run for a set period of time at full capacity after the occupant has turned the fan switch off). A single-stage SEER 16 A/C was recommended over a two-stage SEER 18 A/C for purposes of installation simplicity. CARB has found that improper installation of two-stage units to be a fairly common occurrence unless installed and commissioned by an experienced HVAC contractor. Figure 18 shows the BEopt optimization iterations (and least-cost optimization curve), a minimum 2009 International Energy Conservation Code-compliant building, the selected solutions package for the BA-recommended design, and the least-cost optimization point (depicted as a red dot) achieving similar source energy savings as the BA design.

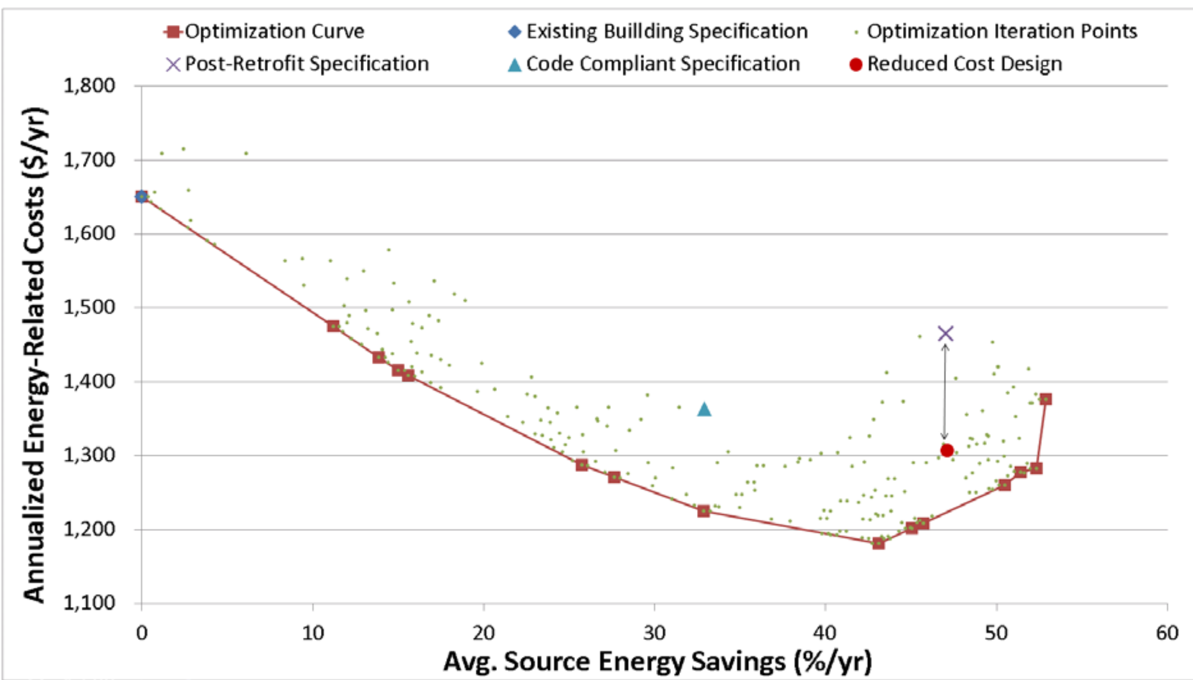

Figure 18. Optimization curve from BEopt

Though not a least-cost solution based on BEopt, the BA-recommended design will result in a lower annualize energy-related cost total than the pre-retrofit conditions. One of the key reasons that the BA-recommended design is well above the least-cost optimization curve is due to the treatment of the basement. The basement is a common space separated from the apartments, but the HVAC system (including ductwork) and water heater for the first-floor apartments are located in the basement. To minimize the impact of having this equipment in unconditioned space, it was determined that the foundation should be brought within the thermal envelope of the building. The only option for insulating the foundation walls was to use more costly ccSPF to control water and moisture migration through the rubble stone. This also provides health and durability benefits not accounted for within BEopt. The ccSPF was an added cost that was applied to each first-floor apartment. The foundation details are discussed in greater detail in Section 4.1.

Table 4 provides an estimated breakdown of the source energy consumption for various building loads. The total estimated source energy savings was 47%. The target goal was 50% source energy savings, but with the addition of whole-house ventilation, the overall savings are just shy of the target. The 2012 International Residential Code specifies whole-house ventilation for any home tighter than 5 ACH50, so with our target being at 5 ACH50, whole-house ventilation was included. Switching to a tankless water heater would increase energy savings to 49%. With a higher EF rating and no standby losses, it would seem that there is no reason not to install a tankless gas water heater. It is true that they can be beneficial, but here were some of the concerns of the project team:

- Tankless water heaters eliminate the standby loss of tank water heaters, but they do not provide hot water any quicker to the faucet. In fact, they may take 5–15 s longer as the unit senses the call for hot water and turns on the burner.
- Tankless water heaters require a minimum flow rate of typical 0.5 gpm before they will fire. This is to prevent continual operation in the case of a leak or a faucet not fully shut off. With low-flow fixtures and aerators being implemented as a water-saving feature, this flow rate may not be regularly met.
- If the water has a high mineral content, scaling of the low-mass heat exchanger is likely. The heating coils should be flushed with a descaling solution per the manufacturer's specifications, but this is maintenance that homeowners would likely not keep up with.
- Venting can be expensive (Category 3 stainless steel).

Table 4. Predicted Source Energy Use Distribution

Loads	Pre-Retrofit (MBtu/yr)	BA Recommended MBtu/yr)	Percentage Savings
Vent Fan	0	1	0%
Major Appliances	11	10	13%
Lights	10	9	9%
HVAC Fan/Pump	11	3	73%
Cooling	16	4	75%
Heating	56	13	77%
Hot Water	16	10	38%
Total	149	79	47%

Comparing the BA-recommended solutions package to the least-cost optimization curve, there is no point on the curve that falls directly under the BA-proposed package. There is a lower cost option (roughly $200 lower in annualized energy-related costs) with nearly the same percentage energy savings, 47%. The difference between the BA-recommended specifications and this point (noted by the red dot in Figure 18) is provided in Table 5. By ignoring the health, safety, durability, and comfort issues of the uninsulated rubble stone foundation, higher infiltration rate, and leaky ductwork a lower cost option is achieved. Though energy simulation is beneficial, in cases like this, engineering judgment and a more holistic approach must be used.

Table 5. BA Solution Package Comparison to Least-Cost Package with Similar Energy Savings

Component	BA Solution Package	Least-Cost Package With 47% Energy Savings
Above-Grade Wall Assembly	Stud wall spaced 1 in. from brick and filled with 3.5 in. of ccSPF	Stud wall filled with 3.5 in. of fiberglass insulation
Building Infiltration	5 ACH50	9 ACH50
Whole-House Ventilation	Exhaust 100% of A-62.2	None
Ductwork	4 cfm/100 ft^2 leakage	9 cfm/100 ft^2 leakage
Water Heating	Gas tank EF 67%	Gas tankless EF 82%

The least-cost solutions package that achieves 50% energy savings in Figure 18 is similar to the 47% least-cost package discussed in Table 5, but it includes the above-grade wall assembly of the BA solutions package and a SEER 18 A/C. Still the ignored health, safety, durability, and comfort issues that would result from this package cannot be justified to simply meet the target savings goal. Therefore, the recommended BA solutions package was determined to be a successful outcome for this project.

Figure 19 shows the modeled cumulative percentage energy savings (line graph) resulting from adding each improvement measure and the impact on the whole-house source energy use (bar graph). The above-grade walls insulated with ccSPF realized the highest energy savings followed by a more efficient condensing furnace with tighter ductwork. Adding double-pane low-e windows brings the building to the 36% energy savings mark. This could be an ideal solution package point on its own; however, CARB went further to increase the percentage energy savings and improved comfort in the building. The introduction of ASHRAE 62.2-2010 recommended levels of whole-house ventilation air (equivalent of 32 CFM continuous) incurred an energy penalty, bringing the energy savings down from 50% to 47%.

Figure 20 shows the cumulative annualized energy cost savings (bar graph) contributed by the addition of each measure of the solution package and its respective corresponding percentage energy savings (line graph). The largest annualized cost savings were obtained at the 36% and 50% energy savings marks. The total solutions package results in the source energy usage savings of 79 MBtu/yr and an annualized energy cost saving of $117/yr.

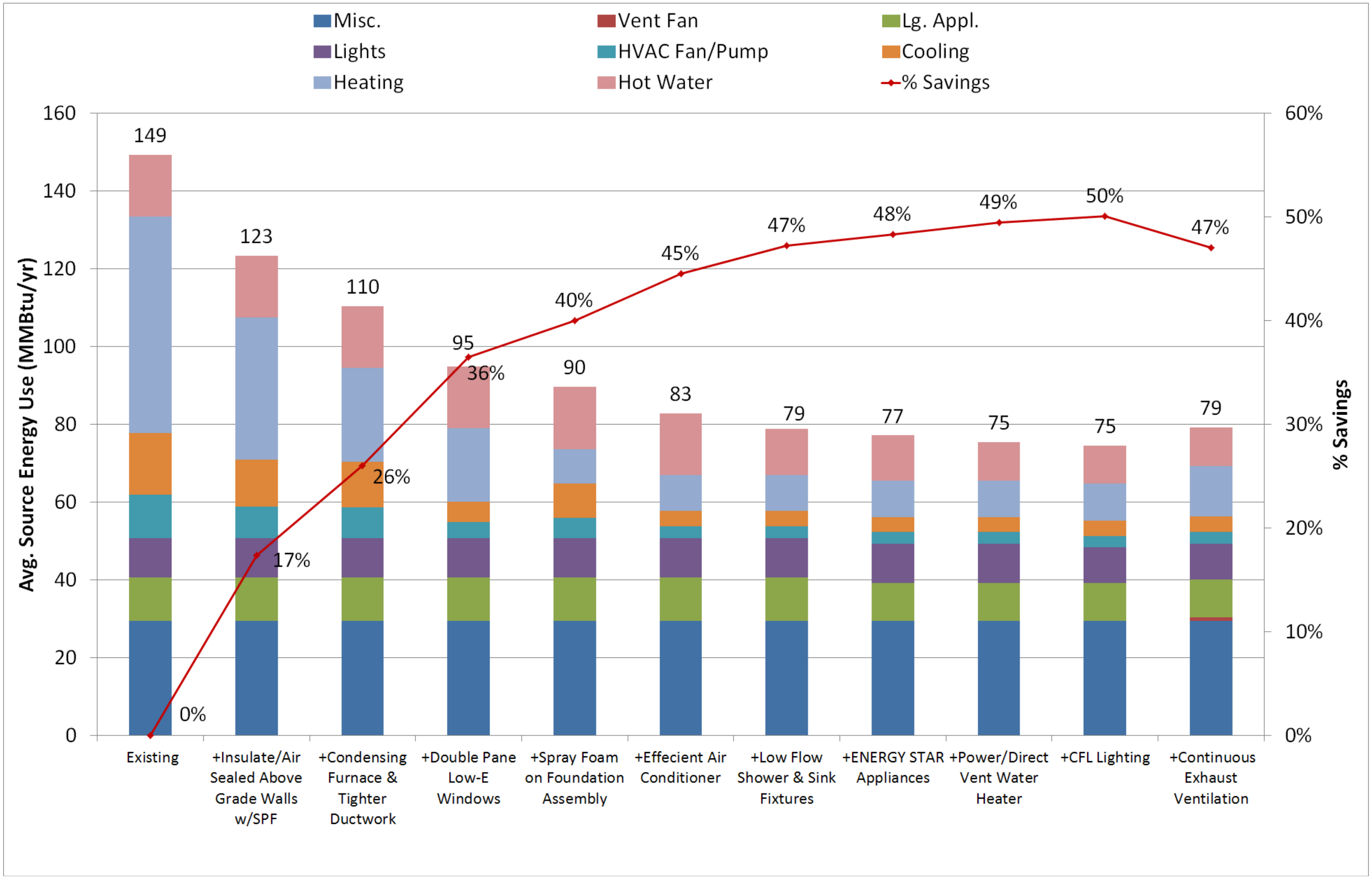

Figure 19. Cumulative contribution to total energy savings by measure and end use

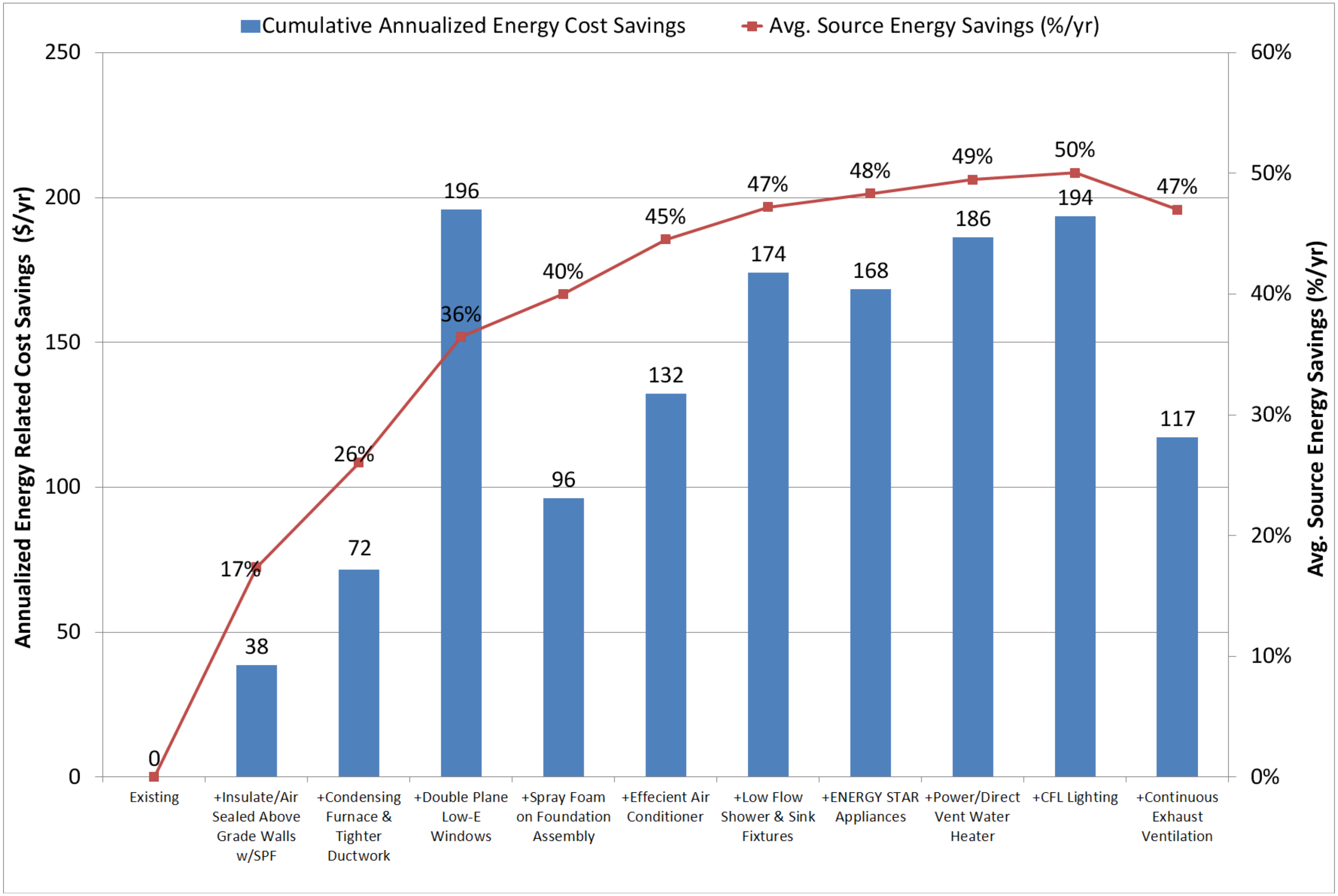

Figure 20. Cumulative contribution to total annualized cost savings by measure

4 Retrofit Solutions

After analyzing possible cost-effective solution packages and selecting the most appropriate package for this project, the project team set out to implement the recommended retrofit specification. Some key aspects of the retrofit are discussed below.

4.1 Foundation Walls

Based on CARB's experience with previous Columbus projects having high humidity levels in the basements and our initial observations of high groundwater levels in these basements, CARB suggested resolving this issue by placing a vapor barrier on the floor of the basement and pouring a rat slab on top. Then integrate the under-slab vapor barrier into the wall assembly by applying ccSPF to the rubble stone foundation. To minimize the amount of water that the foundation sees from the exterior, ensure that rain water is drained away from the foundation via extended rain gutters and proper sloping of grade. As an additional backup, installing a stand-alone dehumidifier in each basement was recommended.

Bringing the basement into the building envelope was advantageous because it keeps the first-floor apartments' ductwork, air handlers, and water heaters in conditioned space to minimize thermal losses and keep the equipment from rusting. The project team ended up implementing only part of CARB's recommendation. They insulated the foundation walls with only 3 in. of ccSPF. However, due to construction complexities and cost constraints, the builder was unable to put in the vapor barrier at the slab. CARB had concerns of potential high humidity levels in the basement due to a slab vapor barrier not being installed, so some short-term monitoring of relative humidity in the basements was performed and is discussed in Section 7.

To apply the 3 in. of ccSPF to the rubble stone foundation took a bit of effort. As water and moisture were migrating through the lower portion of the foundation wall, having proper adhesion of the ccSPF directly to the foundation was a challenge. The project team ended up attaching wire mesh to the stone foundation and using that to form a dam of sorts a couple of inches out from the wall and then just filled the space with ccSPF. A spray intumescent coating was applied to the ccSPF insulation to provide a thermal/ignition barrier.

Figure 21. Wire mesh applied to bottom of stone foundation wall to help secure ccSPF in place

4.2 Above-Grade Walls

Achieving 50% source energy savings compared to the pre-existing building performance while maintaining cost neutrality has been difficult in existing homes and becomes even more challenging in brick structures. Though viable solutions for insulating and air sealing the interior of brick façades are available and fairly well understood, typically the cost of these strategies can be prohibitive. Columbus typically utilizes ccSPF to provide a continuous air and thermal barrier that is vapor impermeable. Before the installation of interior insulation, the brick masonry wall must be inspected for the following defective conditions:

- Cracked bricks
- Loose bricks
- Spalled bricks
- Hairline cracks in mortar
- Deteriorated mortar joints
- Deteriorated or torn sealants
- Out-of-plumb (nonvertical, sagging wall)
- Efflorescence (salts left on brick by evaporation indicative of water path through brick)
- Staining
- Water penetration (check for dampness on the interior)
- Mold
- Lead paint.

If any of these defects are found to exist, they must be rectified before proceeding with the installation of insulation. All these conditions may be exacerbated by the addition of insulation, and the potential for health and safety hazards may be greatly increased. By insulating the interior, the bricks will be exposed to harsher conditions (i.e., colder temperatures), which increases freeze-thaw potential and reduces drying potential. Therefore, for any interior insulation method, the exterior brick needs to be fully tuckpointed and an appropriate water drainage strategy for the load bearing brick walls is critical to prevent water and moisture from penetrating through the brick. If effective exterior water control and shedding cannot be properly established, insulating the interior surface of the brick wall should not be attempted. For strategies to establish exterior water control and shedding, refer to Straube (2012).

In the pre-retrofit building a wood furring strip was placed between the 2 × 4 steel stud and brick wall; however, CARB suggested that the 2 × 4 steel studs at 16 in. o.c. be set 1 in. from the wall (without the wood furring strip) and the gap filled with continuous ccSPF insulation and extended into the stud cavities for an overall wall assembly of roughly R-22.

Figure 22. Above-grade wall insulation

4.3 Roof

The roof improvements for the third-floor apartments included 3 in. of polyisocyanurate insulation (R-19 continuous) placed above roof deck and 3 in. of ccSPF (R-19) on the underside of the roof deck to create a total roof assembly of R-38. A white TPO membrane was applied over the polyisocyanurate insulation to provide a reflective, “cool-roof” rated weathertight assembly.

Figure 23. (L) 3 in. of ccSPF applied to underside of roof deck; (R) 3 in. of polyisocyanurate applied over the roof deck and covered with a white TPO membrane

4.4 Windows

All windows were replaced with dual-pane, low-e windows with vinyl frames (U-0.29/ SHGC-0.22). Prior to installing the new windows, those steel angle window headers that deflected had to be replaced. In addition, most of the rough openings for the windows had to be rebuilt. Once the windows were installed, the interior surfaces were air sealed and insulated with ccSPF and the exterior surfaces were caulked.

Figure 24. (L) Rebuilt window header; (R) ccSPF applied to rough opening to air seal and insulate

5 Field Inspections

CARB made several visits to the project site to verify that the construction execution corresponded with the drawings and specifications. There were no major incongruities between design and as-built conditions; however, there were a few correctable defects that were observed and ultimately corrected.

ccSPF insulation applied to the roof deck roof was difficult in some instances due to the sequencing of the contractors. The ductwork rough-in was done prior to the roof underside insulation. In certain locations, ducts were hung close to the underside of the roof deck, making applying the ccSPF difficult (Figure 25). In addition, the complex framing typical of low-sloped cockloft-type roof cavities in older buildings was challenging. The arrangement of roof rafters, ceiling joists, and vertical compression struts connecting the two form voids and narrow gaps that are difficult to access and fill (Figure 26). CARB recommended that the schedule be adjusted in the future to allow for the insulator to come out prior to installation of the mechanical duct rough-in, so the roof deck can be insulated without any obstructions. This would allow a better line of sight and physical access for the spray gun to apply insulation.

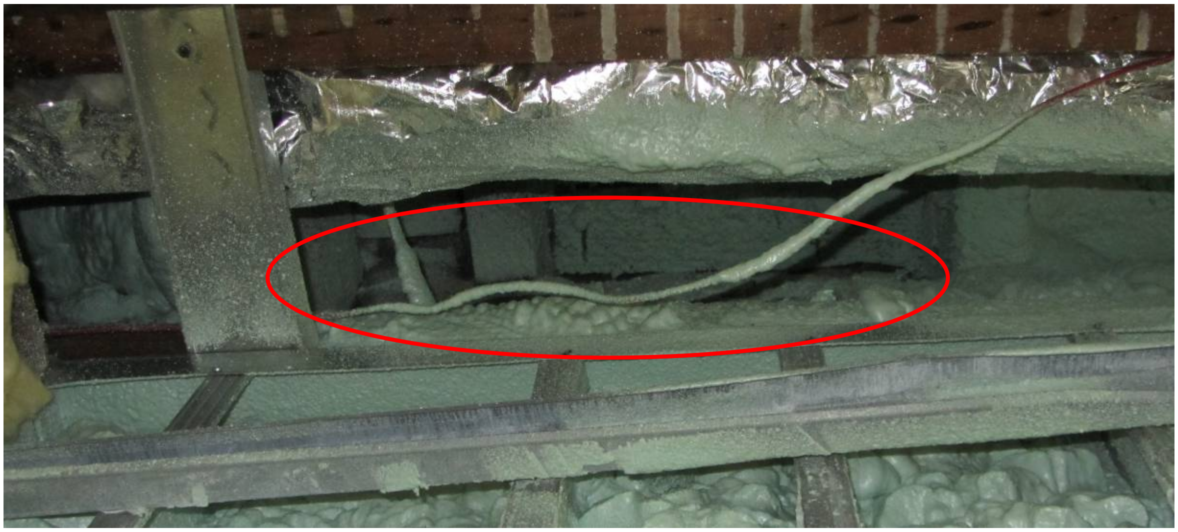

Figure 25. Minimal ccSPF insulation against the roof deck due to obstructive ductwork

Figure 26. ccSPF should be applied to the whole length of these "sister" trusses to seal gap

One of the buildings has a window bay projection (Figure 27). The overhang at the exterior window bay bump-out was insulated at the subfloor with ccSPF insulation, but no air/thermal block was installed in the floor joists where the overhang meets the exterior wall. Therefore, cold air could leak into this overhang and travel through the floor joists between the conditioned apartments. CARB recommended using rigid extruded polystyrene insulation to provide a thermal barrier. The corners of the rigid insulation were sealed with spray foam to provide a continuous air barrier.

Figure 27. (L) Location of thermal/air bypass in exterior wall bump-out;
(R) Looking from the interior ceiling out into the floor overhang of the window bay

Several of the window sills were not well insulated. As shown in Figure 28, there were uninsulated brick surfaces and wood bucks at the window rough openings. CARB recommended that the ccSPF extend the full depth of the window rough opening or rigid extruded polystyrene insulation be installed.

Figure 28. Missing ccSPF insulation around window rough opening

6 Performance Testing

Although performance testing could not be performed during the initial audit of the buildings due to lack of power to run test equipment and some demolition already haven taken place, final performance testing was performed on a sampling of apartment units at the completion of the retrofits (Table 6). On average, the apartments outperformed the initial BA model targets. The average apartment infiltration rate of 4.0 ACH50 was lower than the goal of 5.0 ACH50. The average duct leakage to outside rate of 2.6 cfm25/100 ft^2 was considerably lower than the goal of 4.0 cfm25/100 ft^2.

Table 6. Summary of Performance Testing Result of a Sample of the Apartment Units

Apartment Type (Building/Floor/Type)	Floor Area (ft^2)	Unguarded Infiltration		Duct Leakage to Outside		System Airflow (%)
		(cfm50)	(ACH50)	(cfm25)	(cfm25/ 100 ft^2)	
Building 2/ First Floor/Type I	875	650	4.1	36	4.1	6.0
Building 2/ Second Floor/Type F	999	712	4.8	23	2.3	3.8
Building 2/ Third Floor/Type F	999	706	3.8	20	2.0	3.3
Building 3/ Second Floor/Type F	999	660	3.6	38	3.8	6.3
Building 4/ First Floor/Type H	721	547	4.1	15	2.1	2.5
Building 5/ Second Floor/Type F	999	678	3.7	19	1.9	3.2
Building 5/ Third Floor/Type F	999	715	3.9	25	2.5	4.2
Building 6/ Third Floor/Type E	999	838	4.6	45	2.5	7.5
Building 7/ First Floor/Type E	999	736	4.0	15	1.5	2.5
Building 7/ Third Floor/Type E	999	647	3.5	36	3.6	6.0
Averages	–	–	4.0	–	2.6	4.5

In addition to the performance testing, CARB inspected the overall project and found the installation of the HVAC systems to be a major improvement over the pre-existing systems (Figure 29). The previous concerns of CO spillage into the mechanical closets have been eliminated with the installation of sealed combustion and power/direct vented equipment. However, a CO detector was still installed in these closets as a safety precaution. The HVAC systems for the first floor apartments have been brought within the building envelope and the ducts properly air sealed and insulated.

Figure 29. (L) The furnace and water heater do not draw combustion air from the interior and direct exhaust flue gases to the exterior, so the risk of CO spillage has been drastically reduced. (R) This HVAC system located in a basement has been brought within the thermal envelope of the building and ductwork has been air sealed and insulated.

Based on the as-built specifications and updating for performance testing averages, the first-floor Type F apartment achieved the design goal of an estimated 47% source energy savings.

7 Short-Term Monitoring

Moisture control in the basements of the apartment complex was one of the biggest concerns, as the BA recommendation for a capillary break at the foundation slab was not included in the retrofit due to budgetary constraints. Even after the ccSPF insulation was applied to the foundation walls, there was evidence of moisture wicking up through the slab and the basements remained feeling "muggy." High moisture levels in the basement could result in mold growth on susceptible surfaces, such as the wooden floor joists in the basement ceiling. According to ASHRAE Standard 160, in order to minimize the potential for mold growth, interior conditions should be maintained such that the 30-day running average surface relative humidity (RH) of the materials is less than 80% when the 30-day running average surface temperature is between 41°–104°F. ASHRAE's website states that a good range for RH in homes is 30%–60%.[3] In addition, the U.S. Environmental Protection Agency recommends indoor RH levels be kept under 50% to prevent growth of dust mites, mold, mildew, and any bacterial growth while maintaining thermal comfort.[4]

Quick Tip To Determine Presence of Slab Foundation Moisture

Seal a piece of plastic to the foundation slab (covering several square feet). If there is water on the underside of the plastic after 24 h, there is water migration up through the slab. If water droplets are on the top side of the plastic, this is from warm moist air condensing against the cooler concrete. This test should be done in each season to confirm results. See Appendix A for further guidance on retrofitting foundation slabs.

To determine if a dehumidifier would be a sufficient solution to address the high RH levels in these basements, CARB set up temperature and RH sensors in two separate basements in the apartment complex; one with a dehumidifier and the other without a dehumidifier. The dehumidifier had a maximum moisture removal capacity of 145 pints/day.

Figure 30. Stand-alone dehumidifier installed in a basement

[3] www.ashrae.org/resources--publications/free-resources/consumer-center-faq
[4] www.epa.gov/iaq/pubs/careforyourair.html

Figure 31 shows a 30-day running average for the temperature and RH data collected at the project site. The dashed lines represent temperature and the solid lines represent RH. The basement measurements are an average of data recorded at three different heights: 1 ft from the basement floor, 4 ft from the floor, and 1 ft from the basement ceiling. The legend descriptions with "wDH" are measurements in the basement with a dehumidifier and "woDH" indicates measurements in the basement without a dehumidifier. It should be noted that these two basements have different ambient air conditions. Therefore, these two cases should not be directly compared to each other, but evaluated individually as the two basements were not baselined.

The running average of the RH readings from the basement without a dehumidifier ranged from 70%–75% and temperatures ranged between 78°–83°F. Although these conditions fall outside the critical thresholds for mold growth according to ASHRAE 160, data were collected for only one month. As temperatures drop outside, basement temperatures may also fall as they are not directly conditioned and duct leakage from the first-floor apartment ductwork has been minimized. If the excess moisture is not removed, RH levels could easily climb into the ideal range for mold and fungi growth.

The running average RH levels from the basement with a dehumidifier were below 65% and appear to be continually decreasing, unlike the basement without the dehumidifier. Temperatures ranged between 73°–76°F. The data indicate that the dehumidifier is reducing the RH levels in the basement to a safer level. However, as the basement is not directly conditioned, RH levels should continue to be monitored throughout the winter to ensure they do not climb into the range where mold growth is likely. CARB requested that the property manager periodically inspect the basements for moisture and to take temperature and RH measurements. CARB intends to follow up over the coming years to determine the effectiveness of this foundation system.

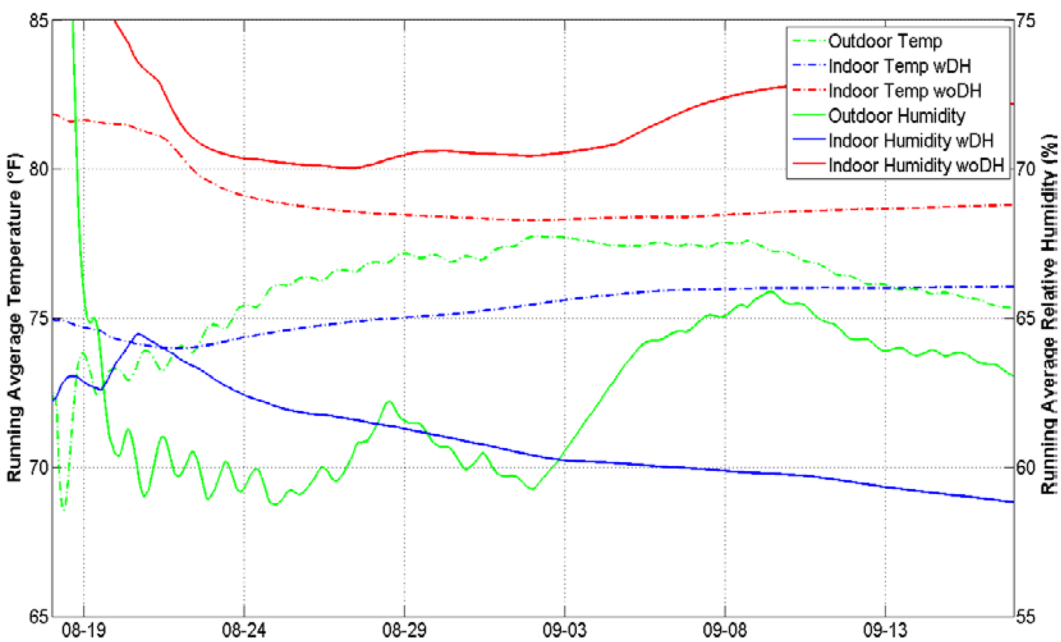

Figure 31. Temperature and RH 30-day running-average data

An alternative analysis method, condensation potential, was evaluated for the monitored period for each basement by comparing the interior air dew point temperature to the interior surface temperature of the basement walls. Interior surface temperature was predicted using THERM 6.3, a two-dimensional modeling tool used to evaluate heat-transfer effects in building components. The average daily recorded interior and exterior temperatures were used as the boundary conditions in THERM. As seen in Figure 32, over the monitoring period, there was no potential for condensation forming. The greatest potential for condensation would occur in the winter months, but to date, no signs of condensation in the basements have been observed at the site.

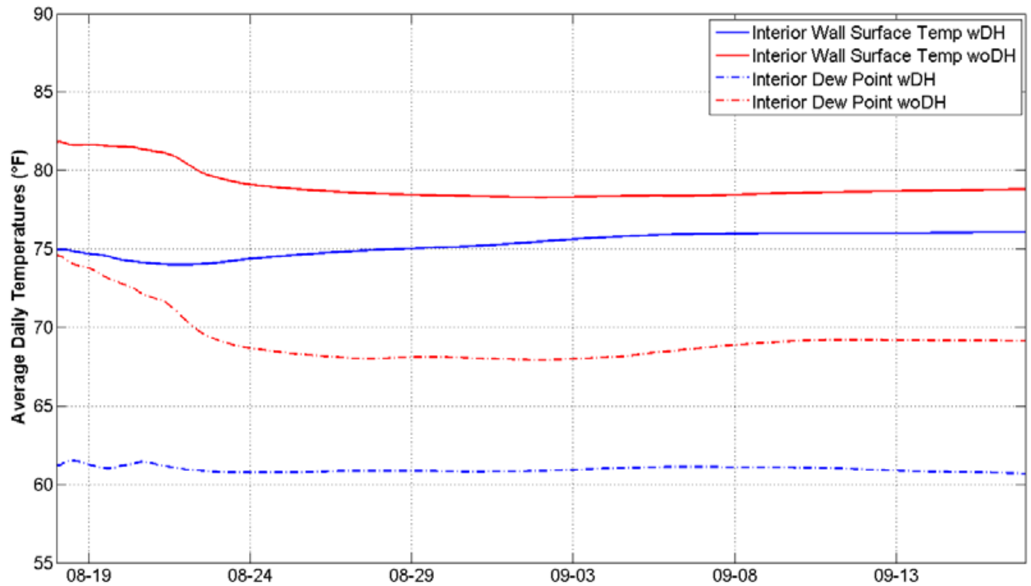

Figure 32. Measured dew point of interior air and modeled surface temperature of foundation wall

8 Project Results

Implementing all the solution measures of the BA solutions package (accounting for the measured performance test results) brings the predicted energy saving of the post-retrofit first-floor type F apartment to 47% as compared to the pre-retrofit unit. With the exception of energy use associated with ventilation, CARB's solution package reduced the energy savings and utility cost significantly. The post-retrofit reduced utility costs by \$707/yr, but increased mortgage costs by \$520/yr. The net result is a total savings of \$187/yr and source energy savings of 70 MBtu/yr, as shown in Figure 33.

The second and third floors of the same building type F were also modeled in BEopt to determine how the varying boundary conditions impacted the performance of the proposed solutions package. The source energy savings for all three apartment units fell within a relatively small range, 45%–47% with the top and bottom floors being nearly identical and the second floor having the least average source energy usage, as expected, at 77 MBtu/yr.

Lighting, appliances, and miscellaneous electric loads (LAMELs) are often grouped together as the remaining contributors to the electrical demand after space heating, space cooling, domestic hot water, and ventilation. In the pre-retrofit apartment, the LAMELs accounted for 34% of the overall energy consumption. In the post-retrofit apartment, the LAMELs now account for 61% of the remaining energy consumption. This makes achieving higher levels of energy savings difficult for this housing type and class without significantly higher annualized energy-related costs or specific energy saving solutions for miscellaneous energy loads, which is difficult as the builder typically has little control of these components.

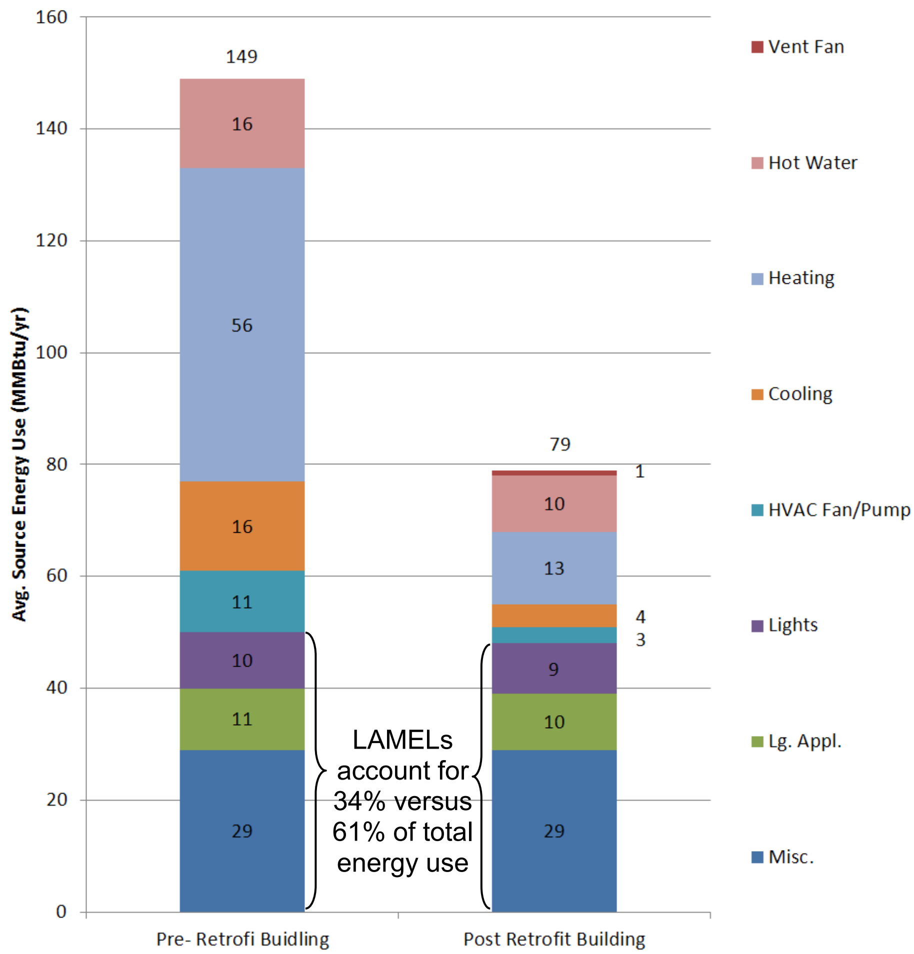

Figure 33. Pre- and post-retrofit comparison of source energy use by component

Another commonly used industry metric to quantify buildings is the Residential Energy Service Network's Home Energy Rating System (HERS) Index. This is a scale where 100 is a code-compliant new construction home and 0 is a zero-energy capable home. According to the Residential Energy Service Network, the typical resale home scores 130 on the HERS Index. These apartments had HERS Indexes ranging from 66–76.

Two common methods of determining cost effectiveness were evaluated: simple payback period (SPB) and savings-to-investment ratio (SIR). An SPB is the first cost of the implemented measures divided by annual utility savings resulting from those efficiency measures. For individual measures, a 5–10 year timeframe for the SPB is typically used when making investment decisions. When looking at an entire solutions package of measures, a more reasonable timeframe is in the 10–20 year timeframe, but the SPB metric excludes the value of improved comfort, durability, and indoor air quality associated with the implemented measures. The SPB analysis for the first-floor type F apartment is provided in Table 7.

A SIR is the annual savings resulting from energy efficiency measure for the lifetime of the measure divided by the first cost of those implemented measures. The standard is for the SIR to be 1 (100%) or greater to be deemed a cost-effective efficiency measure or package. In the case of a solutions package, there are varying lifetimes for the various measures. Most mechanical equipment has an expected 10–15-year serviceable lifespan. The SIR analysis for the first-floor type F apartment is provided in Figure 34. Again, this metric excludes the value of improved comfort, durability, and indoor air quality associated with the implemented measures.

Table 7. Cost and Simple Payback by Measure for First-Floor Type F Apartment

Component	Pre-Retrofit	Post-etrofit	First Cost Per Measure	Cumulative Annual Utility Savings	Cumulative SPB (yr)
Above-Grade Wall Assembly	Brick wall, ~R4 cavity insulation	Steel studs spaced 1 in. from brick with 3.5 in. of ccSPF	$4,403	$263	17
Building Infiltration	9 ACH50	4.0 ACH50	Included in wall assembly		–
Space Heating	Natural gas furnace (90% AFUE)	Natural gas conditioning furnace (95% AFUE)	$2,103	$398	16
Ductwork	12 cfm/100 ft^2	2.6 cfm/100 ft^2	Included in space heating	–	–
Window Glazing	Dual-pane, clear, with metal frame (U-0.76/SHGC-0.68)	Dual-pane, low-e with vinyl frame (U-0.35/SHGC-0.35)	$3,900	$547	19
Foundation Assembly	Uninsulated	3 in. of ccSPF on foundation.	$2,997	$609	22
Cooling System	2-ton A/C (SEER 8)	1.5-ton A/C (SEER 16)	$2,070	$671	23
Plumbing	Standard flow showers and sinks	Low-flow showers and sinks	–	$712	22
Major Appliances	Non-ENERGY STAR refrigerator	ENERGY STAR refrigerator	$980	$728	23
Water Heating	Natural gas tank heater (0.57 EF)	Natural gas tank heater (0.67 EF)	$850	$746	23
Lighting	CFL–LED–LFL = 50%–0%–0%	CFL–LED–LFL = 62%–0%–13%	$50	$753	23
Whole-House Ventilation	None	Exhaust 100% of ASHRAE 62.2	$120	$707	25

The SPB of 25 years is reduced if you account for the fact that even without doing a major retrofit on these apartments, the mechanical systems (furnace, A/C, refrigerator, exhaust fan, and water heater) would have needed to be replaced. If replacing with a similar 90% AFUE furnace and minimum efficiency requirements for the other mechanical, the lower incremental cost of the BA solutions package results in an SPB of 22 years.

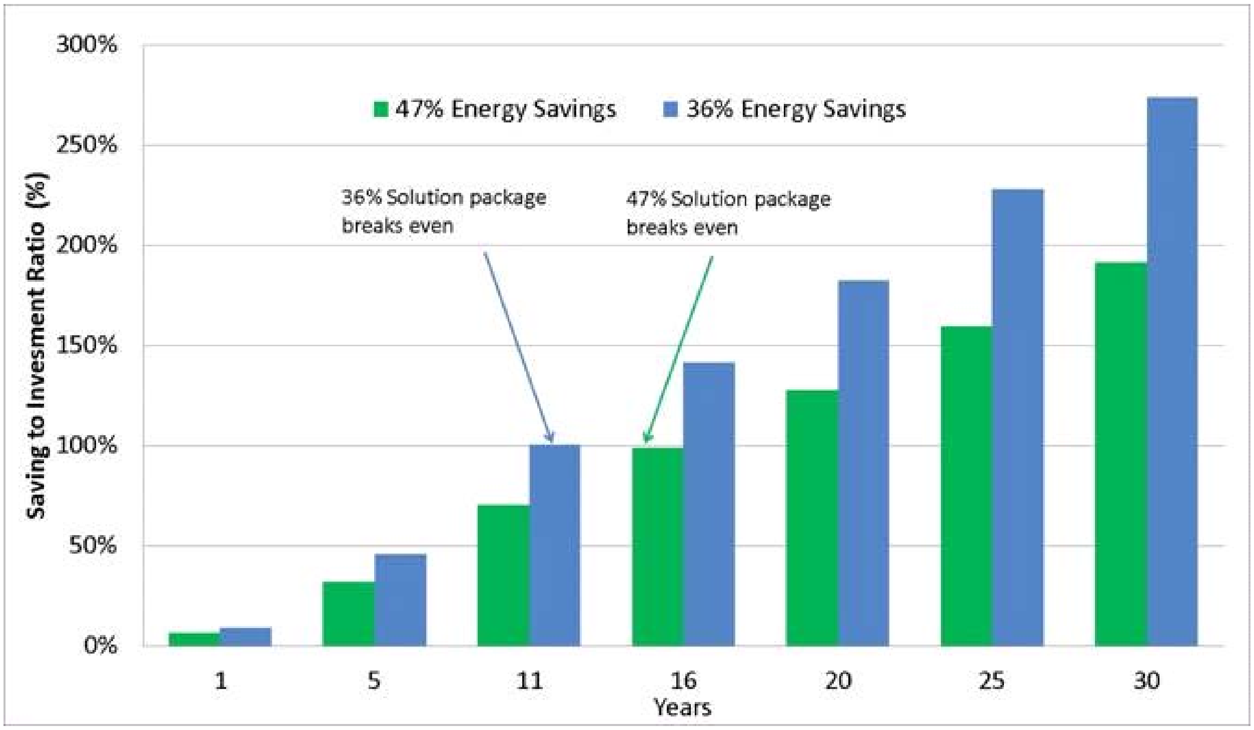

Figure 34. SIR for the 36% and 47% energy saving packages

Figure 34 shows that the SIR is neutral (= 1 or 100%) after 11 years for the 36% energy saving solutions package (improved walls, windows, and furnace/ducts only) and after 16 years for the complete BA solutions package. This is within the typical lifespan of the major implemented measures, so the modified or complete solutions packages are cost effective.

9 Conclusion

As with other gut rehabilitation projects targeting very high post-implementation energy improvements, the initial pre-retrofit building survey and energy use analysis are keys to establishing the baseline starting point. The subject of this particular retrofit, a 100-year-old urban, brick-masonry multifamily building, is also representative of other building types based on a very common attribute: a wet basement. With a non-damp-proofed stone foundation, no drainage layer or capillary break below the basement slab, and a high local water table, water entry and high RH are systemic and chronic. To button-up a high performance enclosure above a wet basement will lead to high interior moisture levels and all the associated problems. It is therefore imperative that the moisture problems be managed, if not eliminated, as part of the energy improvement package and the costs of doing so must be included in the overall cost of the project. Once these issues of health, safety, and durability are addressed, we can move on to answering the research questions focused on energy efficiency, and determining the effectiveness of the implemented solutions.

The overarching research focus was to identify and vet a viable solution package that can be readily implemented in the mixed, humid climate to existing brick multifamily buildings to achieve 50% source energy savings compared to pre-retrofit conditions? With the improvement target bar set relatively high, the only viable approaches consist of whole-building packages in which all energy uses, with the exception of MELs, are identified, quantified, and addressed. Moreover, to realistically approach the savings target, the larger energy uses must be identified and aggressively mitigated. For this building type and climate zone, space heating source energy is by far the largest component.

This requires the thermal enclosure (walls, roof, fenestration, etc.) as well as the space heating equipment be significantly upgraded, but not beyond the point of diminished returns. It also requires that the HVAC equipment be located within conditioned space, which means the basement walls must be insulated. The solution package implemented here, and suitable for a very large population of similar buildings, is 3.5 in. of ccSPF directly against the interior brick surface, and 2.5 in. of ccSPF directly against the stone foundation walls. The roof surface insulation package consists of 3 in. above-deck polyisocyanurate, and 3 in. below-deck ccSPF along with a white TPO surface completing the unvented roof assembly. Relatively inexpensive vinyl low-e windows and enclosure air sealing complete the package.

Space heating alternatives are more numerous, but since this building was converted to individual gas-fired forced-air systems 20 years ago, the duct distribution systems was improved, return air path was corrected, and higher efficiency furnaces and higher SEER A/C were installed. Hydronic heat is also a feasible alternative.

Domestic hot water is also provided individually to each dwelling through EF 0.67 gas storage tanks with existing (although improved) venting. Going with condensing equipment would require alternate venting which could be difficult to integrate in this type building. Most often this building type would be equipped with central hot water, changing the available options dramatically.

Post-implementation and test-out, BEopt analysis for multiple sample dwellings yielded performance improvements ranging from 45%–47%. The addition of whole-house ventilation after reducing the building infiltration resulted in a reduction of 3% to the source energy savings achieved, but ignoring potential indoor air quality issues to simply meet the 50% target savings goal cannot be justified. Overall, the recommended BA solutions package is deemed to be a successful outcome for this project.

Questions specific to this study:

- Is the selected solution package for these apartment buildings commercially viable?

  The best indication of commercial viability is whether a builder or developer continues the solution package in future projects. In this case, the developer has incorporated the BA recommendations as base specifications for future gut rehab projects. In addition, even with high efficiency targets being achieved in this project, all the solutions implemented in this gut retrofit were commercially available and off the shelf.

- Where are opportunities to reduce costs in the solution package?

  The 3.5 in. of ccSPF used for the above-grade walls is an expensive solution, albeit one that helps mitigate moisture issues. Lesser amounts of ccSPF, or rigid board insulation applied directly to the interior masonry surface, along with fibrous cavity fill insulation would also be effective, but with additional installation steps.

- What specific issues are there regarding quality assurance and quality control to maintain consistency throughout the project build-out?

Documenting all the enclosure areas where specific air sealing and insulation strategies are required needs to occur during the site survey. Ensuring those steps take place during application requires on-site vigilance by contractors and third party quality assurance inspectors.

- What additional risk concerns need to be addressed as a result of this being retrofit construction?

Moisture management not properly accomplished is a significant risk. Fully understanding the moisture dynamics in a 100-year-old urban building is essential to developing solutions and avoiding these risks.

- How effective is each individual energy efficiency measure at meeting its specific cost and performance targets? How effective is it when integrated into a whole-house package?

The individual energy efficiency measures range from somewhat to very cost effective, but as a whole-building package, and in particular in a building with many antiquated and obsolete components, the result was immediate positive cash flows of $187 annually. In addition, the SIR was positive after 16 years, which is well within the lifespan of the major implemented measures.

The process of examining this building, developing energy improvement alternatives, implementing solutions, and verifying results has provided usable information that can be applied directly to significant numbers of similar buildings in the Northeast and mid-Atlantic regions. It has also uncovered a need for additional research.

In order to safely implement deep energy retrofits in existing buildings either through gut-rehabs or through less intrusive methods, moisture management with regards to existing basements is paramount. Bulk moisture and moisture vapor are near-ubiquitous threats due to inadequate damp-proofing, lack of subgrade drainage, no subslab capillary breaks, poor surface drainage, and unknown soil conditions. These conditions are present in millions of existing basements, and taking a custom approach to each potential energy-upgrade project is inefficient and loaded with subjective guesswork. A specifically targeted advanced research project involving identifying these common threats and developing broad-scope solutions would have a significant impact on the market.

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Appendix A: Retrofitting Foundation Slabs

Assessment

Although it is always a best practice to have a under slab vapor barrier, in existing homes this is not present and installing a vapor barrier retroactively can be difficult. To determine if a vapor barrier is needed, verify that moisture is wicking up through the slab and not coming from foundation walls or from interior sources (more common in very humid climates).

Seal a piece of plastic to the foundation slab (covering several square feet). If there is water on the underside of the plastic after 24 h, there is water migration up through the slab. If no moisture issue is found during the first test, make sure to retest throughout the year to ensure the results, as moisture issues can be seasonal. If water droplets are on the top side of the plastic, this is likely from warm moist air condensing against the cooler concrete. If the moisture issue is related to high indoor humidity, a dehumidifier is usually is sufficient. Ensure that no dryer vents or exhaust fans are disconnected and dumping excess moisture into the basement.

Sealing

The best option would be to rip up the existing slab, install proper drainage and capillary break (if not already installed), apply a vapor barrier, and pour a new slab. This is expensive and therefore, not feasible for many retrofits. Short of this ideal solution, alternate moisture control methods must be employed.

One alternative is applying a vapor barrier directly on the existing slab and pouring an additional concrete slab on top. This will of course reduce head height, so verify that suitable head clearances are maintained if this method is pursued. Other options should be selected based on the assessed level of moisture present at the existing slab.

If foundation drainage is adequate, and moisture is predominantly vapor driven (as opposed to bulk moisture), an epoxy paint finish can be applied. If more moderate moisture control is deemed necessary to maintain a dry environment, other more aggressive measures are warranted. These include a sealed sump pit and pump to alleviate sub slab hydrostatic pressure in conjunction with a plastic dimpled drainboard and subfloor installed on top of the slab. Perforated interior perimeter drains connected to the sump pit may also be needed if perimeter foundation drainage is inadequate.

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