U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

BUILDING TECHNOLOGIES PROGRAM

Retrofitting Vegas: Implementing Energy Efficiency in Two Las Vegas Test Homes

S. Puttagunta
Consortium for Advanced Residential Buildings

April 2013

Building AMERICA
U.S. Department of Energy

Available electronically at http://www.osti.gov/bridge

Available for a processing fee to U.S. Department of Energy
and its contractors, in paper, from:
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
phone: 865.576.8401
fax: 865.576.5728
email: mailto:reports@adonis.osti.gov

Available for sale to the public, in paper, from:
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
phone: 800.553.6847
fax: 703.605.6900
email: orders@ntis.fedworld.gov
online ordering: http://www.ntis.gov/ordering.htm

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Retrofitting Vegas: Implementing Energy Efficiency in Two Las Vegas Test Homes

Prepared for:

The National Renewable Energy Laboratory

On behalf of the U.S. Department of Energy's Building America Program

Office of Energy Efficiency and Renewable Energy

15013 Denver West Parkway

Golden, CO 80401

NREL Contract No. DE-AC36-08GO28308

Prepared by:

S. Puttagunta

Steven Winter Associates, Inc.

of the

Consortium for Advanced Residential Buildings

61 Washington Street

Norwalk, CT 06854

NREL Technical Monitor: Cheryn Metzger

Prepared under Subcontract No. KNDJ-0-40342-00

April 2013

(This page left blank)

Contents

List of Figures

Unless otherwise noted, all figures were created by CARB.

List of Tables

Unless otherwise noted, all tables were created by CARB.

Definitions

AC	Air conditioner
ACH50	Air changes per hour at 50 Pascals
AFUE	Annual fuel utilization efficiency
ASHP	Air source heat pump
BA	Building America
BARA	Building America Retrofit Alliance
BEopt	Building Energy Software
Btu/h	British thermal units per hour.
CARB	Consortium for Advanced Residential Building
CFL	Compact fluorescent lamp
cfm	Cubic feet per minute
EPS	Expanded polystyrene foam
ERV	Energy recovery ventilator
HERS	Home Energy Rating System
HSPF	Heating Season Performance Factor
HVAC	Heating, Ventilation, and Air Conditioning
in. w.c.	Inches of water column
IR	Infrared
kWh	Kilowatt-hour
LAMEL	Lighting, appliances, and miscellaneous electric loads
LED	Light-emitting diode
NSP	Neighborhood Stabilization Program
RESNET	Residential Energy Services Network
SEER	Seasonal energy efficiency ratio
SPB	Simple payback

Executive Summary

In 2009, Nevada received nearly $40 million in Neighborhood Stabilization Program funds from the U.S. Department of Housing and Urban Development. The purpose of this funding was to stabilize communities that have suffered from foreclosures and abandonment. In an effort to provide guidance to local officials and maximize how effectively this Neighborhood Stabilization Program funding is used in retrofitting homes, the Consortium for Advanced Residential Buildings (CARB) provided design specifications, energy modeling, and technical support for the Building America Retrofit Alliance (BARA) team and its local partners—Better Building Performance, Nevada ENERGY STAR® Partners Green Alliance, and Home Free Nevada—for two retrofit test homes. One home was to demonstrate a modest retrofit and the other a deep energy retrofit.

The Carmen and Sierra Hills homes demonstrate how cost effectively energy-efficient upgrades can be implemented in the hot, dry Southwest climate. The homes were used as an educational experience for home performance professionals, building trades, remodelers, and the public. In-field trainings on air sealing, HVAC upgrades, and insulating were provided to local contractors during the retrofit. BARA documented these retrofits through a series of video presentations, beginning with a site survey and concluding with the finished remodel and test out.

Through this project, CARB has provided two robust solution packages for retrofitting homes built in this region between the 1980s and early 1990s without substantially inconveniencing the occupants. The Building America solution packages for the two test homes were fairly similar (though the Carmen home did have a solar thermal water heating system) and achieved the targeted energy savings (over the pre-retrofit home) of 30% or more at the Sierra Hills home and 50% or more at the Carmen home. The lower savings level at the Sierra Hills home was primarily a result of mechanical equipment updates that were performed over the past decade. The final estimated performance of these homes is summarized in Table 1.

Table 1. Final Estimated Performance of the Carmen and Sierra Hills Homes

Home	Source Energy Savings	Annual Utility Savings[a]	Annualized Energy Related Cost Savings[b]	Home Energy Rating System Index	
				Pre-Retrofit	Post-Retrofit
Carmen	51%	$1,138	$845	126	66
Sierra Hills	34%	$480	$321	98	61

[a] $0.1175/kWh +$10 monthly charge, $0.7666/therm + $9 monthly charge

[b] 30-year mortgage, 4.0% loan interest rate, 1.6% inflation rate, 3.0% discount rate (real), 0% fuel escalation rate

The solution packages focused on air sealing the building envelope where accessible and replacing windows with double-pane low-e retrofit windows. This reduced solar heat gain and allowed rough openings to be better air sealed. Another essential strategy was to simplify the design and distribution of the high efficiency HVAC systems for optimum system performance. This included bringing the ductwork into conditioned space.

Acknowledgments

Steven Winter Associates, Inc. acknowledges the U.S. Department of Energy Building America program and its funding and support of development of this technical report as well as research that informed it. A special thanks to Annette Bubak, Brandon Kephart, and Kelly Thomas of Better Building Performance, Richard Chitwood of Chitwood Energy Management, and Darren Harris, Tami Svarfar, and Don Whipple of the BARA team.

1 Introduction

In 2009, Nevada received almost $40 million in Neighborhood Stabilization Program (NSP) funds from the U.S. Department of Housing and Urban Development to stabilize communities that have suffered from foreclosures and abandonment. Nevada suffered the highest rates of foreclosure in the nation between 2008 and 2009 (see Figure 1).

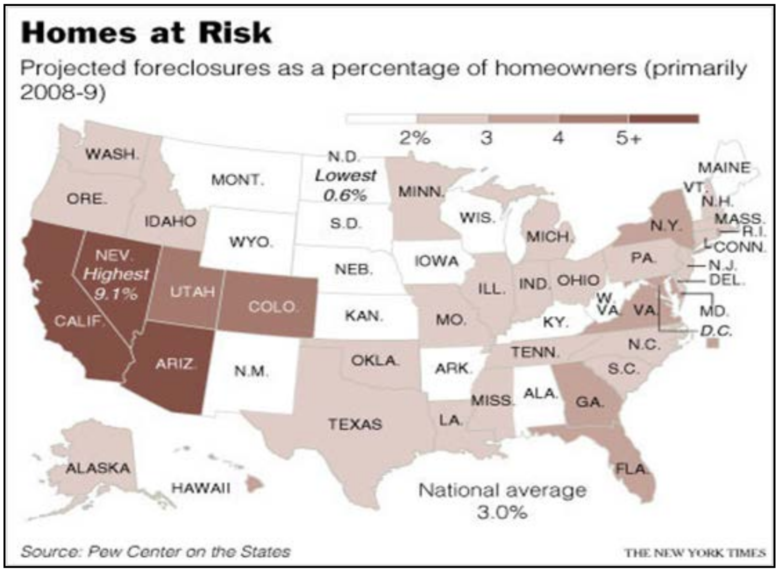

Figure 1. Projected foreclosure rates by state

Nevada used this funding to develop a renovation program that purchases foreclosed properties, performs audits on the homes to assess code compliance, energy efficiency, and health issues, and implements the recommended repairs from these inspections. These homes are then resold to qualifying buyers or held by housing authorities for rental.

A key change in the program requirements since 2011 was a focus on neighborhood-scale retrofits. The program requires that multiple homes in the same neighborhood be retrofitted. Tens of thousands of homes were built in this region over the past decades with hardly a nod toward energy efficiency. With a desire to make these homes affordable (low first cost) and sustainable (low operational costs), the focus has shifted from finishes, aesthetics, and curb appeal to home performance. Over the years, the U.S. Department of Energy's Building America (BA) program has provided support for this performance-based, whole-house remodeling approach and has educated the industry and homeowners about economically sound measures and strategies that result in energy-efficient, healthy, comfortable, and durable homes.

In an effort to maximize how effectively this NSP funding is used to retrofit homes, the Consortium for Advanced Residential Buildings (CARB) provided design specifications, energy modeling, and technical support for the Building America Retrofit Alliance (BARA) team and its local partners—Better Building Performance, Nevada ENERGY STAR® Partners Green Alliance, and Home Free Nevada—for two retrofit test homes. Two homes in the Las Vegas

NSP were selected as test homes to demonstrate how cost-effective energy efficiency upgrades could be incorporated into these retrofits. These two demonstration homes were used as an educational experience for home performance professionals, building trades, remodelers, and the public. In-field trainings on air-sealing, heating, ventilation, and air conditioning (HVAC) upgrades, and insulating were provided to local contractors during the retrofit. BARA documented these retrofits through a series of video presentations, beginning with a site survey and concluding with the finished remodel and test out.

The two test homes, the Carmen and Sierra Hills, are located in an area with one of the greatest number and highest percentage of foreclosed homes in the city. In this area, more than 11% of the existing housing stock is in foreclosure, equating to more than 8,100 homes, many of which are vacant or abandoned.

The original scopes of work and cost estimates for the proposed NSP retrofits of these two homes were provided to CARB. After doing an initial energy audit of both homes, CARB performed energy modeling of the home conditions, the NSP proposed specifications, and CARB recommended specifications to achieve 30%–50% source energy savings over the existing conditions. Though some structural and cosmetic improvements were also included, this effort focused on the energy improvements and associated costs.

1.1 Carmen

The Carmen home is a 1,521-ft^2 ranch built in 1983. This single-family detached home has three bedrooms, two baths, and an attached garage. At the height of the housing boom, it was valued as high as $285,000,[1] but now its estimated value is $97,400.[2] The price range for homes in this neighborhood is $70,000–$130,000. The home was dated, but its overall condition was livable after a thorough cleaning and repair of a couple broken windows.

Figure 2. Exterior photo of the Carmen home

[1] Based on information from www.zillow.com for July 2006.
[2] Based on information from www.zillow.com for February 2012.

Table 2 provides a summary of the Carmen home's conditions.

Table 2. Existing Conditions at the Carmen Home

Building Component	Existing Condition
Foundation	Slab-on-grade, uninsulated
Above-Grade Walls	2 × 4 wood framing @ 16 in. w/R-11 fiberglass batts (grade III)
Attic	Vented attic (gable vents), R-24 fiberglass batts (grade III) at ceiling plane
Kneewalls	2 × 4 wood framing @ 16 in. w/R-11 fiberglass batts (grade III)
Windows	Aluminum double pane, clear (assumed U-0.76, SHGC[a]-0.67)
Cooling	Roof-mounted Carrier packaged forced air furnace with cooling unit (Model 48KL042300BE), 40.5 kBtu/h cooling capacity, R-22 refrigerant, SEER[b] 8.5/EER[c] 8.0 (poorly maintained)
Heating	Roof-mounted Carrier packaged forced air furnace with cooling unit (Model 48KL042300BE), 60 kBtu/h heating input, natural gas, 76% AFUE[d] (poorly maintained)
Ductwork	R-2 ductwork in vented attic, exterior vapor barrier in poor condition and unwrapping in various locations
Ventilation	Kitchen exhausted to exterior and bathroom exhaust fans
Hot Water	Reliance 50-gal atmospheric water heater, natural gas, 0.55 EF[e] (Model 8 50 NKRTO, tank likely replaced in 1997 based on serial number)
Lighting	Mostly incandescent light bulbs except fluorescent lighting in kitchen
Appliances	Original Tappan appliances from 1980s

[a] SHGC = solar heat gain coefficient
[b] SEER = seasonal energy efficiency ratio
[c] EER = energy efficiency ratio
[d] AFUE = annual fuel utilization efficiency
[e] EF = energy factor

1.1.1 Building Envelope

The Carmen home uses 2 × 4 wood framing at 16 in. on center with R-11 fiberglass batt cavity insulation. This was not a gut rehab, so the wall insulation was evaluated using infrared (IR) thermal imaging. There was the typical leakage commonly found in residential homes. Figure 3 provides an overview of the various leakage points between the conditioned living space and the attic.

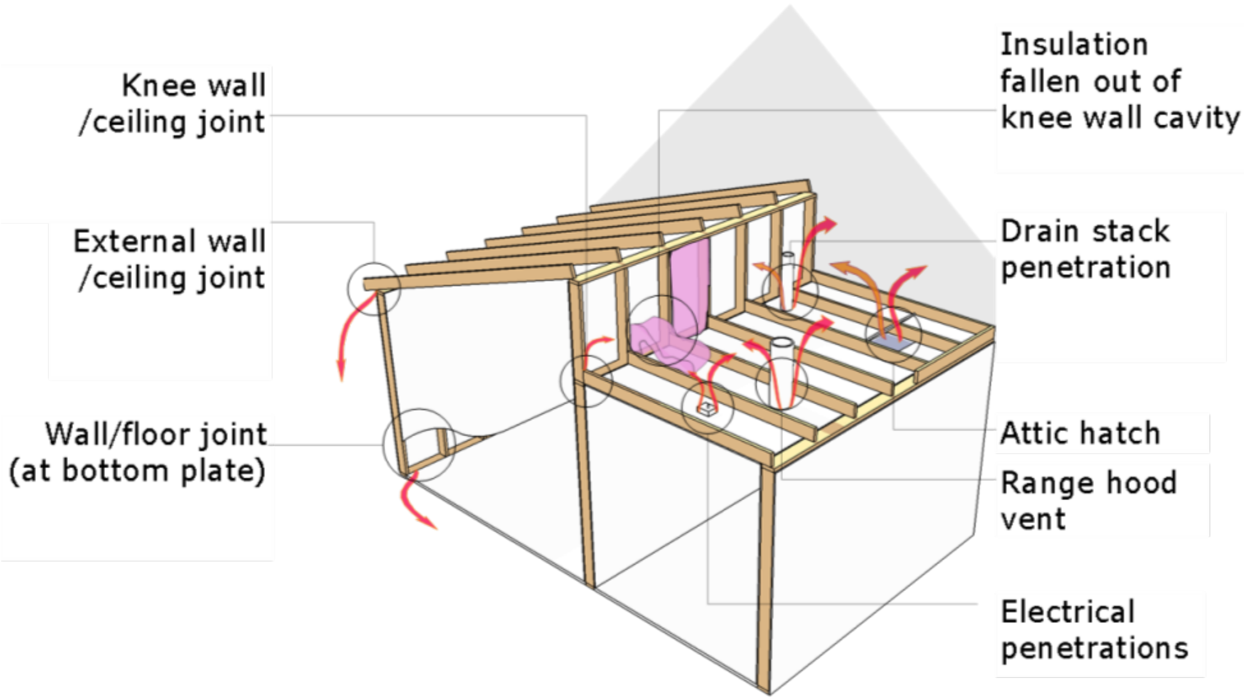

Figure 3. Ceiling leakage points at the Carmen home

IR thermal imaging revealed that many of the interior uninsulated partition walls were communicating with the attic. Penetrations in the top plates to accommodate electrical wiring were the most common culprit for this leakage pathway. Figure 4 shows two instances in which electrical wiring resulted in interior wall cavities that directly communicated with the attic air. These sections were not air sealed, and often did not have ceiling insulation, because it had been pulled or cut back.

Figure 4. Top plate of interior walls cut out for electrical runs into partition walls

The ceiling insulation was Kraft-faced fiberglass batts installed with inset stapling. This was done for ease of installation before the ceiling drywall was installed. Unfortunately, this installation technique creates an air space between the ceiling drywall and the insulation. If air does not move in this space, it can be beneficial in terms of thermal resistance, but that is nearly impossible to accomplish. The result was ceiling insulation that was performing significantly worse than its rated R-value because of the convective airflow cavity.

In general, kneewalls were performing poorly, mostly because unsupported batts had been dislodged, leaving uninsulated vertical bays. Figure 5 shows the kneewall at the transition from the kitchen to dining room. The IR camera showed that the bay to the left of the supply register had surface temperatures close to the attic temperature. Further investigation in the attic revealed that this section of the kneewall was not insulated because the fiberglass batt had fallen down. The whole top portion of this kneewall is hot, because all the batts are poorly installed and attic air is leaking between the batt and drywall, significantly reducing the insulation's performance.

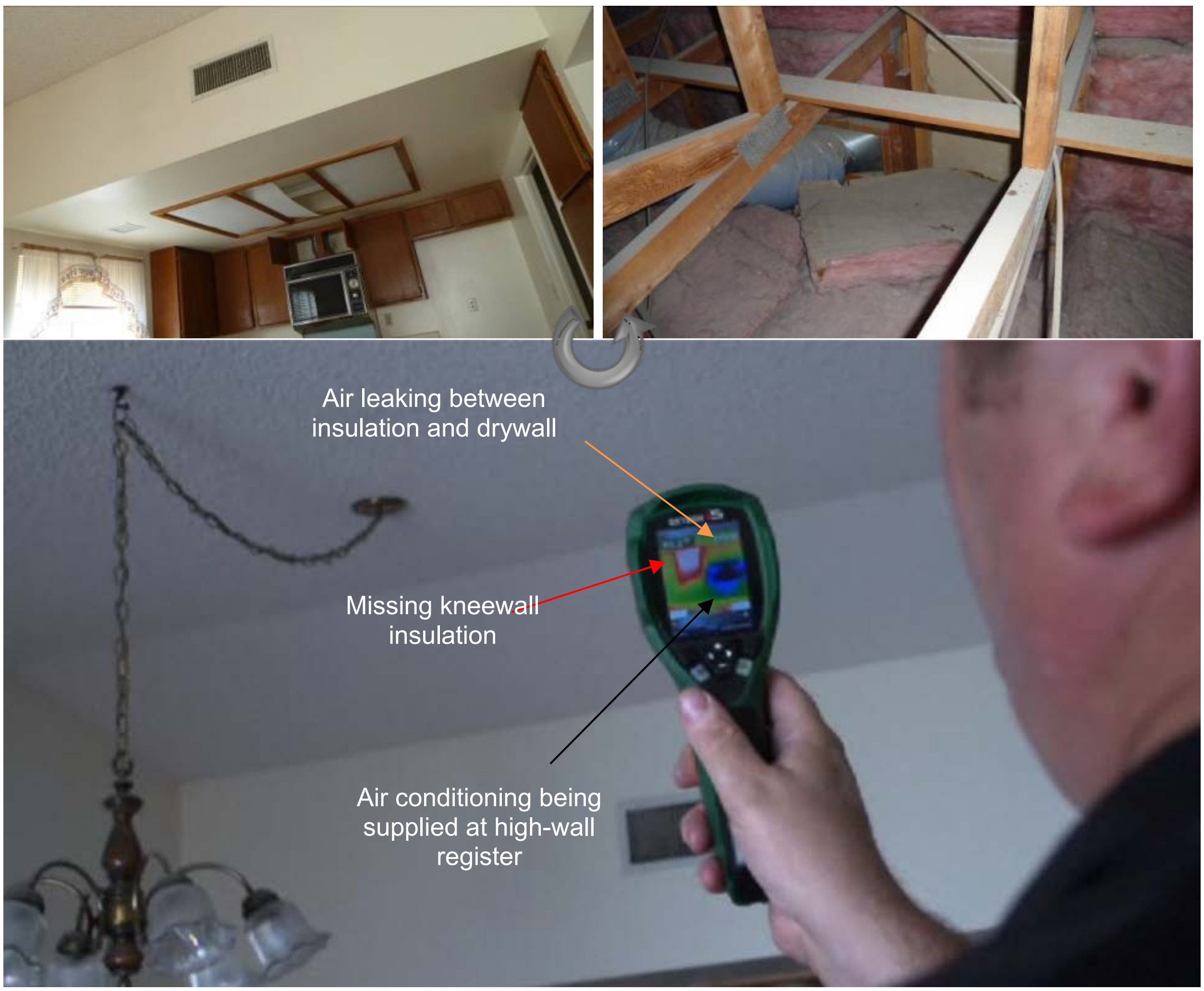

Figure 5. Discovery of poor insulation in the kitchen kneewall

The window in the front corner bedroom was broken and temporarily boarded up. Further inspection revealed that the hermetic seal of several dual-pane windows had been compromised. This broken seal creates a pathway for moist air to enter this dead air space. When the window surface temperature is lower than the dew point of the air, condensation forms. Over time, mineral deposits and a permanent white silica haze are visible (see Figure 6).

Figure 6. Haze between the window panes is evidence of a broken hermetic seal

When door trim was removed, there was no evidence of prior air sealing between the exterior door jamb and the rough opening (Figure 7). This is a common source of air infiltration. In some instances, fiberglass batts are stuffed into this opening. This adds some slight insulation value, but is still not an air barrier.

Figure 7. Lack of air sealing around exterior doors

(Image courtesy of Building Media, Inc.)

1.1.2 Mechanical Equipment

The original HVAC system in the Carmen home was a packaged furnace/air conditioner (AC) located on the rear roof. It was more than 28 years old; its effective life expectancy is anticipated to be 15–18 years, so it was well past due for a replacement.

This furnace unit had a heating capacity of 60 kBtu/h with a seasonal gas heating efficiency of 76% AFUE. On the cooling side, this 3.5-ton AC had a seasonal energy efficiency ratio (SEER) rating of 8.5 but was poorly installed and maintained, so the actual delivered efficiency was likely closer to an equivalent SEER 5 equipment rating. Ductwork was run from this exterior unit through the roof deck and was distributed throughout the home through ceiling registers located in the vented attic. The flexible ductwork was in very poor condition with significant deterioration of the exterior vapor barrier and in some instances, the insulation had unwrapped from the inner duct liner. Images of this HVAC system are shown in Figure 8.

Figure 8. From left clockwise: supply plenum located in the vented attic, roof-mounted packaged furnace/AC, and insulation unwrapping from flex duct because the exterior vapor barrier had deteriorated

The domestic hot water system is a 50-gal atmospheric, natural gas water heater located in the attached garage. The rated EF for this unit is 0.55. Based on its serial number, it was likely replaced in 1997. Though not original to the home, this unit is past its effective life expectancy of 11–13 years.

Figure 9. Atmospheric gas water heater located in the attached garage

1.2 Sierra Hills

The Sierra Hills home is a 1,131-ft^2 ranch built in 1991. This single-family detached home has two bedrooms, two baths, and an attached garage. Though dated, the overall condition of the home was livable and better than the Carmen home. At the height of the housing boom, this home was valued as high as $256,000,[3] but now its estimated value is $79,100.[4] As this home is only half a mile from the Carmen home, the neighborhood price range is the same ($70,000–$130,000).

Figure 10. Exterior photo of the Sierra Hills home

Table 3 provides a summary of the conditions in the Sierra Hills home.

[3] Based on information from www.zillow.com for March 2007.
[4] Based on information from www.zillow.com for February 2012.

Table 3. Existing Conditions at the Sierra Hills Home

Building Component	Existing Condition
Foundation	Slab-on-grade, uninsulated
Above-Grade Walls	2 × 4 wood framing @ 16 in. w/R-11 fiberglass batts (grade III) + 1 in. EPS* foam
Attic	Vented attic (gable vents), R-24 fiberglass batts (grade III) at ceiling plane
Kneewalls	2 × 4 wood framing @ 16 in. w/R-11 fiberglass batts (grade III)
Windows	Aluminum double pane, clear (assumed U 0.76, SHGC 0.67)
Cooling	Roof-mounted Tempstar packaged forced air furnace with cooling unit (Model PGF336060K00A1), 35 kBtu/h cooling capacity, R-22 refrigerant, SEER 13/EER 11
Heating	Roof-mounted Tempstar packaged forced air furnace with cooling unit (Model PGF336060K00A1), 60 kBtu/h heating input, natural gas, 79.6% AFUE
Duct Work	R-4 ductwork in vented attic
Ventilation	Kitchen exhausted to exterior and bathroom exhaust fans
Hot Water	GE 40-gal atmospheric water heater, natural gas, 0.56 EF (Model GG40T6A, tank likely replaced in 2000 based on serial number)
Lighting	Mostly incandescent light bulbs except fluorescent lighting in kitchen
Appliances	Original General Electric appliances from 1990s

* EPS = expanded polystyrene

1.2.1 Building Envelope

This home uses 2 × 4 wood framing at 16 in. on center with R-11 fiberglass batt cavity insulation and 1 in. of EPS on the exterior. This was not a gut rehab, so the wall insulation was evaluated using IR thermal imaging. There were the air bypasses typically found in existing homes at the top and bottom plates, around windows and doors, and at penetrations of lights, smoke alarms, registers, and attic hatches in the ceiling plane. The IR images in Figure 11 and Figure 12 show that the surface temperature variation across the drywall was approaching 15°F.

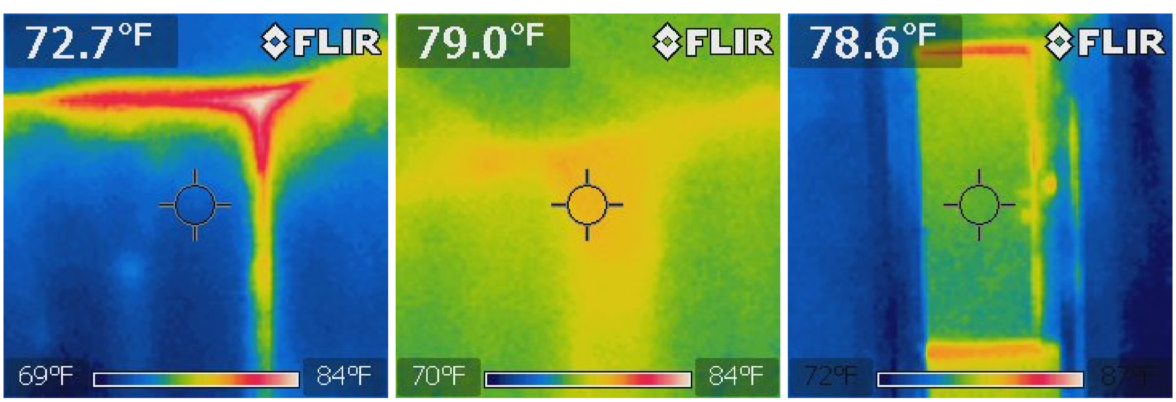

Figure 11. (Left) Top plate corner leakage; (center) kitchen exhaust ducting through interior wall without backdraft damper; (right) leakage around garage door from lack of weather stripping

Figure 12. Leakage in ceiling plane

(Image courtesy of Building Media, Inc.)

Even though the kneewalls in this home were better than the Carmen home, there still were some issues (see Figure 13). Whenever there is complicated framing, batt insulation is difficult to install effectively. In addition, to achieve the rated performance of the batt insulation, an attic side air barrier should be included to minimize air movement through or around the insulation. Once again, the framing evidenced in Figure 13 would make establishing a continuous attic side air barrier challenging.

Figure 13. Poor insulating of partially vaulted ceiling kneewalls

(Image courtesy of Building Media, Inc.)

Compared to the Carmen home, the Sierra Hills home has more variation in the ceiling plane with a mix of flat and semi-vaulted ceilings throughout the home. This has led to several interior wall cavities directly communicating with the attic air (Figure 14).

Figure 14. Interior wall cavities that are directly communicating with the attic

(Image courtesy of Building Media, Inc.)

1.2.2 Mechanical Equipment

The HVAC system for the Sierra Hills home was a packaged furnace/AC located on the rear roof. It was anticipated that the HVAC equipment would be comparable to the Carmen house system, but the packaged HVAC system was likely replaced in late 2007 or early 2008 (verified with the serial number on the unit: G071141225). For Tempstar units, the second and third number/letter of the serial number represents the year the unit was manufactured and the next two numbers represent the week of the year. This was an unforeseen challenge, as the efficiency of this unit was not suitable to achieve the energy efficiency goals of this project. Also, more than 10 years of usable lifespan remained, so the cost benefit versus the incremental savings benefit was significantly minimized.

Figure 15. Rooftop packaged furnace/AC located at the Sierra Hills home

(Image courtesy of Building Media, Inc.)

Domestic hot water was provided by an atmospheric 40-gal natural gas water heater. Again, the serial number (GENG 0700123945) of the water heater was used to estimate the install date of this equipment. For General Electric water heaters, the first two numbers refer to the month and the second two numbers refer to the year. So this unit was manufactured in July 2000. It was likely installed shortly after manufacturing, so the water heater was likely replaced in early 2001. Therefore, this unit has basically reached its effective life expectancy of 11–13 years.

Figure 16. Atmospheric water heater located in the garage of the Sierra Hills home

(Image courtesy of Building Media, Inc.)

2 Research Goals

The overarching question addressed by this research is:

- What solution package(s) can be readily implemented in hot, dry climate homes to achieve a 30% plus and a 50% plus energy savings home compared to the BA B10 Benchmark?

More specific questions:

- Is the selected solution package for each home commercially viable? Where are opportunities to reduce costs in these solution packages?
- What are the specific gaps to achieving the solution package at a production scale (cost, risk adversity, implementation complexity, etc.)?

Questions specific to this study:

- Based on the results of these test homes, what other energy efficiency measures and solution packages should be considered?
- What are the market interest and consumer reactions, developer and builder reactions and feedback loops, and stakeholder enthusiasm for replicating the package?
- How effectively does each energy efficiency measure meet its specific cost and performance targets? How effective is each when integrated into a whole-house package?

3 Design Specifications and Energy Modeling

All energy modeling was performed using BEopt (Building Energy Optimization) v1.2 software developed by the National Renewable Energy Laboratory. For the economic analysis, the economic values in Table 4 were used. In general, the NSP scopes of work focus on HVAC equipment, water heaters, kitchen appliances, and updating finishes (paint, caulk, etc.). The NSP replacement equipment typically meets or slightly exceeds the federal minimum efficiency levels.

Table 4. Inputs of Economic Analysis

Economic Variables	Modeling Inputs
Project Analysis Period	15 years
Inflation Rate	1.6%
Discount Rate (Real)	3.0%
Loan Period	15 years
Loan Interest Rate	4.0%
Electricity Rate – NV Energy	$0.1175/kWh + $10.00 monthly charge
Natural Gas Rate – Southwest Gas	$0.7666/therm + $9.00 monthly charge
Fuel Escalation Rate	0.0%

3.1 Carmen

Based on the goals of achieving 50% source energy savings over the pre-retrofit performance of the Carmen home, CARB performed optimization analysis. The primary focus was on air sealing the building shell and bringing efficient HVAC equipment within the building envelope. Based on the optimization analysis, the following specifications (see Table 5) were proposed to the project team. The building infiltration target for this home was 4.5 ACH50. The base proposed specifications resulted in a 52.2% source energy savings over the pre-retrofit conditions. If a solar thermal system is included, the source energy savings increases to 53.9%.

Because the first costs of solar thermal systems are quite high, the hot water system was evaluated with and without this feature. In addition, programmable thermostats that are set back or up during the workday and overnight were included as an additional option. Numerous studies (such as Gunshinan 2007) conclude that programmable thermostats do not save money, because homeowners do not know—or care to know—how to properly set their schedules. Therefore, the project team wanted to have the proposed base package meet the efficiency targets even if these two items were not incorporated.

Table 5. BA Proposed Specifications at the Carmen Home

Building Component	Proposed Upgrade
Above-Grade Walls	Air seal any penetrations in exterior walls with spray foam
Attic	Unvented attic, R-30 closed cell spray polyurethane foam at roof deck
Windows	Simonton vinyl double pane, low-e retrofit windows (U 0.26, SHGC 0.23)
Cooling/Heating	Lennox XP21-024 ASHP[a] with CBX40UHV-036 air handler (SEER 18.5/9.2 HSPF[b]), 25.6 kBtu/h cooling capacity, 24.2 kBtu/h heating capacity, R-410A refrigerant with TXV[c] valve
Ductwork	Compact distribution design, R-6 ductwork in unvented attic, sealed with mastic
Ventilation	Kitchen and bathroom fans exhausted to exterior, Panasonic WhisperGreen 80 cfm fans with delay off timers in bathrooms, Panasonic WhisperComfort spot ERV[d]
Hot Water	Solar thermal water heating system (40 ft^2 of collectors) with 80-gal preheat tank with tankless water heater backup (0.84 EF)
Lighting	All CFLs[e] or LEDs[f]
Appliances	ENERGY STAR appliances

[a] ASHP = air source heat pump
[b] HSPF = heating seasonal performance factor
[c] TXV = thermostatic expansion valve
[d] ERV = energy recovery ventilator
[e] CFL = compact fluorescent lamp
[f] LED = light-emitting diode

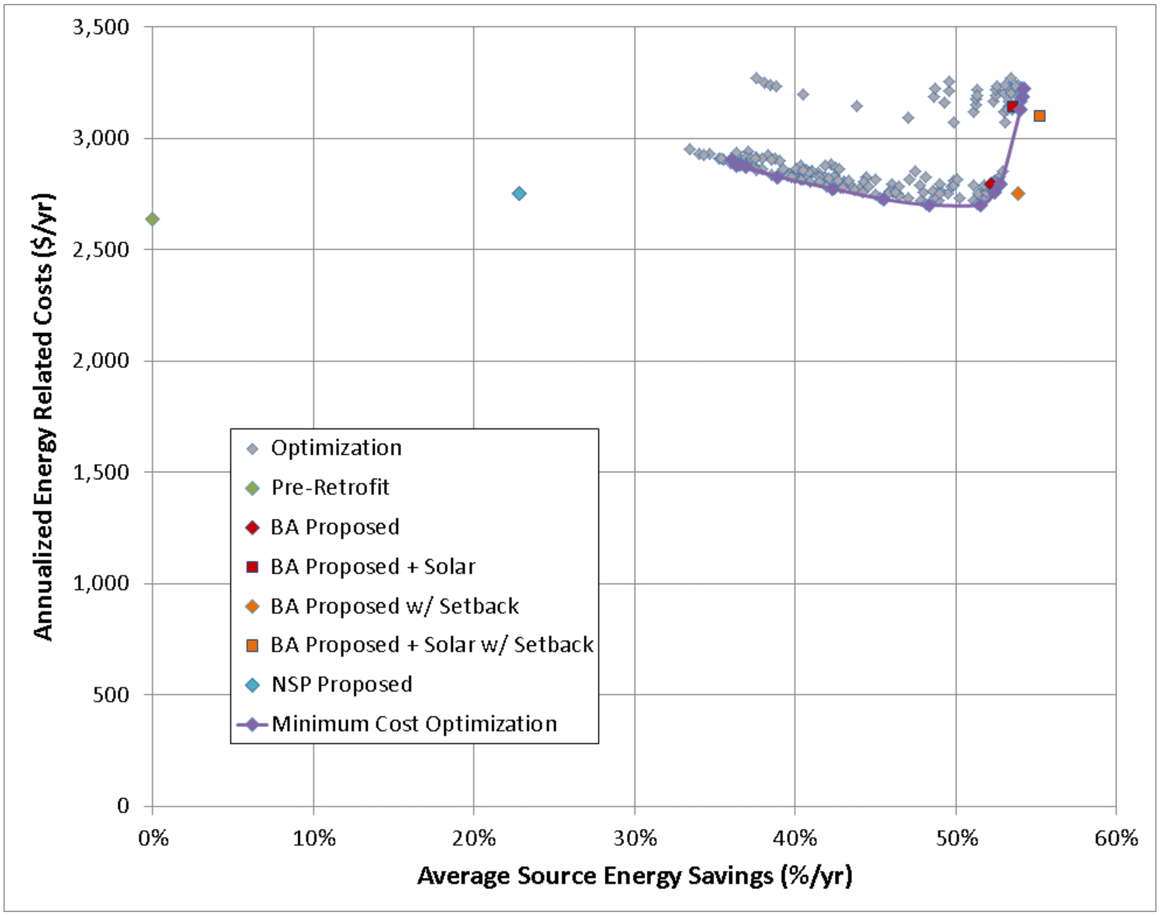

Figure 17. Specification optimization analysis during the design stages of the Carmen home

3.2 Sierra Hills

With a source energy savings target of 30%, the Sierra Hills project can more effectively be adopted in hot, dry climate zone, such as the Las Vegas retrofit market. The Sierra Hills specifications were geared to efficiency improvements that can be made to existing homes without disrupting or substantially inconveniencing the occupants. Based on the optimization analysis, the specifications in Table 6 were proposed to the project team. The building infiltration target for this home was 4.0 ACH50. The base proposed specifications resulted in a 30.6% source energy savings. Nearly identical efficiency savings would be achieved with a mini-split heat pump HVAC system.

Table 6. BA Proposed Specifications at the Sierra Hills Home

Building Component	Proposed Upgrade
Above-Grade Walls	Air seal any penetrations in exterior walls with spray foam
Attic	Vented attic, R-49 blown insulation at ceiling plane
Windows	Apply low-e film to existing windows (SHGC 0.43)
Cooling/Heating	Mitsubishi mini-split heat pump MXZ-4A36NA (SEER 16/8.5 HSPF) + 4 MSZ-(A,FD) indoor units (9,9,9,9), 35.4 kBtu/h cooling capacity, 36.0 kBtu/h heating capacity, R-410A refrigerant
Ductwork	–
Ventilation	Kitchen and bathroom fans exhausted to exterior, Panasonic WhisperGreen 80 cfm fans with delay off timers in bathrooms, Panasonic WhisperComfort spot ERV
Hot Water	Natural gas premium tank water heater (0.67 EF)
Lighting	All CFLs or LEDs
Appliances	ENERGY STAR appliances

After discussions with the project team, a couple changes were made to the design specifications (see Table 7). There was concern about the durability of the low-e film on the existing windows. Therefore, more expensive double-pane, low-e replacement windows were specified. The project team was also concerned about the aesthetics of the wall-mounted mini-split heat pumps and chose a more conventional ducted HVAC system. To minimize the energy impact of having an HVAC system in the vented attic, the air handler was to be located in a closet of the secondary bedroom. The new distribution ductwork would still be located in the vented attic, but would be properly air sealed with mastic and insulated with R-8 duct insulation.

Table 7. BA Revised Specifications at the Sierra Hills Home

Building Component	Proposed Upgrade
Windows	Simonton vinyl double-pane, low-e retrofit windows (U 0.26, SHGC 0.24)
Cooling/Heating	Lennox XP17-024 ASHP with CBX40UHV-036 air handler (SEER 17.2/9.5 HSPF), 25.2 kBtu/h cooling capacity, 22.4 kBtu/h heating capacity, R-410A refrigerant with TXV valve
Ductwork	Compact distribution design, R-8 ductwork in vented attic, sealed with mastic

If the minimum cost point on the BEopt optimization curve was the target, the specifications in Table 8 would replace those in Table 6 and Table 7. The lowest cost option with the same efficiency percentage would be achieved with no air sealing, a SEER 15/8.5 HSPF ASHP, and a tankless water heater. The fact that no air sealing is being advocated shows the limitations of modeling as the enhanced comfort achieved by minimizing drafts in the building are not accounted for in the annualized energy related cost.

Table 8. Least Cost Optimization Specifications at the Sierra Hills Home

Building Component	Proposed Upgrade
Building Infiltration	No air sealing efforts
Attic	Less attic insulation, R-30 blown insulation at ceiling plane
Windows	Keep original clear, double-pane windows
Hot Water	Natural gas tankless water heater (0.84 EF)

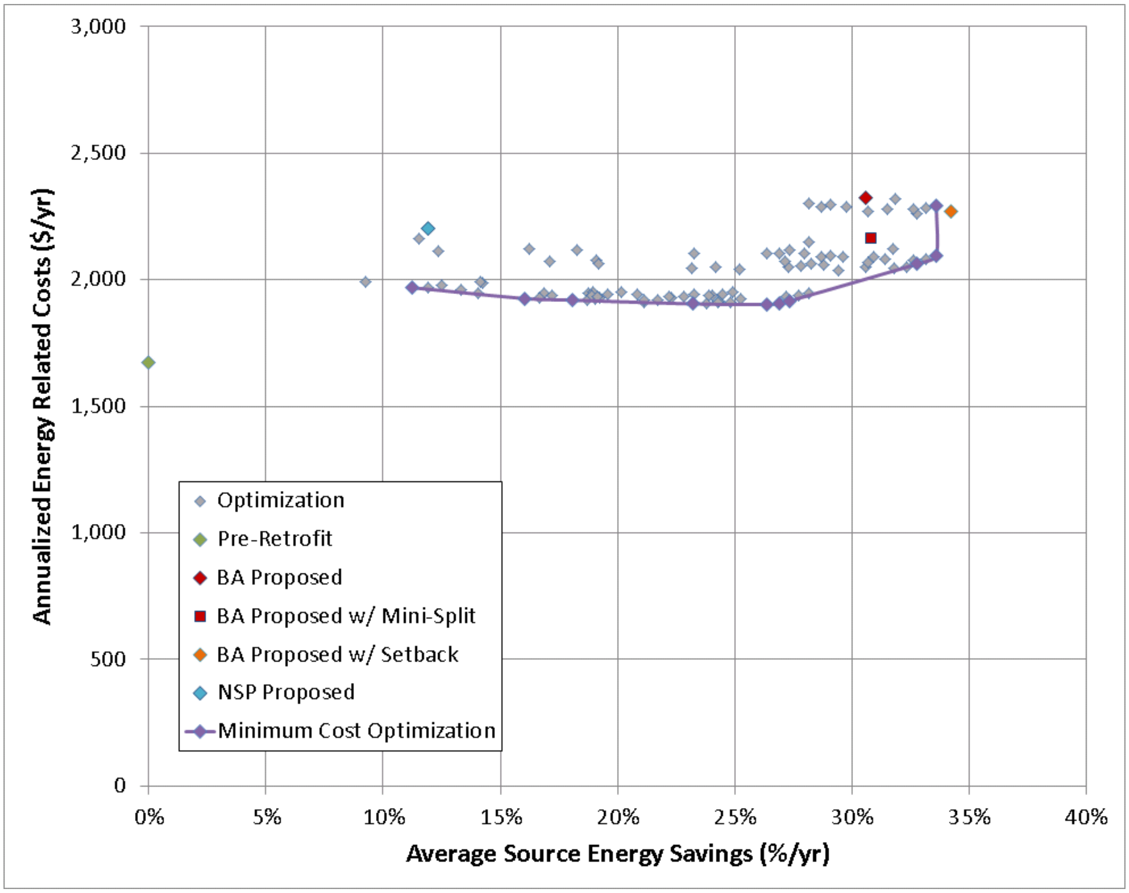

Figure 18. Specification optimization analysis during the design stages of the Sierra Hills home

After completing this retrofit, the project team is now considering evaluating mini-split heat pumps in its next retrofit project. The primary reason for this renewed interest was based on inquiries about the technology from tour visitors at the Carmen home.

4 Implementation

There is no better way of learning than by doing. Therefore, the project team partnered with Richard Chitwood, founder of Chitwood Energy Management, to provide five hands-on training sessions for local contractors. Mr. Chitwood is an expert in energy-efficient residential building construction, diagnostic testing, and performance evaluation. CARB worked with Mr. Chitwood on the content of the courses and what details to include in the training to ensure that the efficiency goals would be met.

The five sessions focused on shell sealing, HVAC, and insulation. There were two shell sealing sessions, one at the Carmen home and one at the Sierra Hills home. Similarly, there were two HVAC sessions. There was only one insulation session at the Sierra Hills home, because the Carmen home used spray polyurethane foam that was installed by a local contractor. This insulation session was essentially a follow-up to the air sealing session and focused on insulating kneewalls and vented attics. Also, there was training on maintaining proper ventilation in vented attics through the proper installation of baffles that allow airflow from soffit to rigid vent, even when high levels of ceiling insulation are installed.

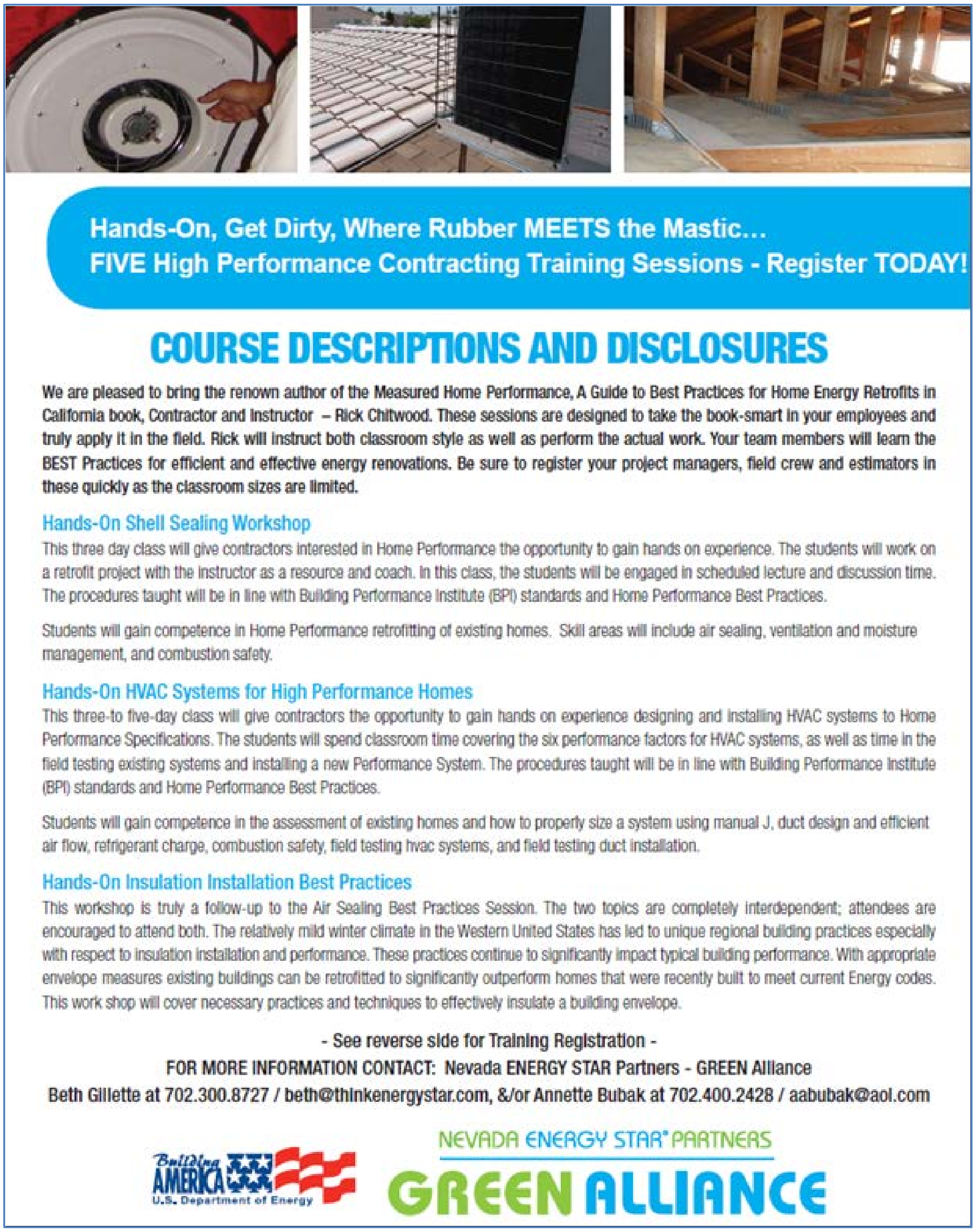

Figure 19. Field training flyer

The BARA team documented the retrofits to the two selected homes through a series of short video presentations, beginning with the initial site survey and concluding with the test-out of the finished energy efficiency retrofits.

4.1 Air Sealing

Over the two-day air sealing sessions at each project home, the attendees worked with Mr. Chitwood to air seal all accessible openings, joints, and cracks to maintain a continuous pressure boundary (see Figure 20). A blower door and an IR camera were used during the session to qualitatively identify air leakage pathways and to quantitatively measure the air sealing efforts.

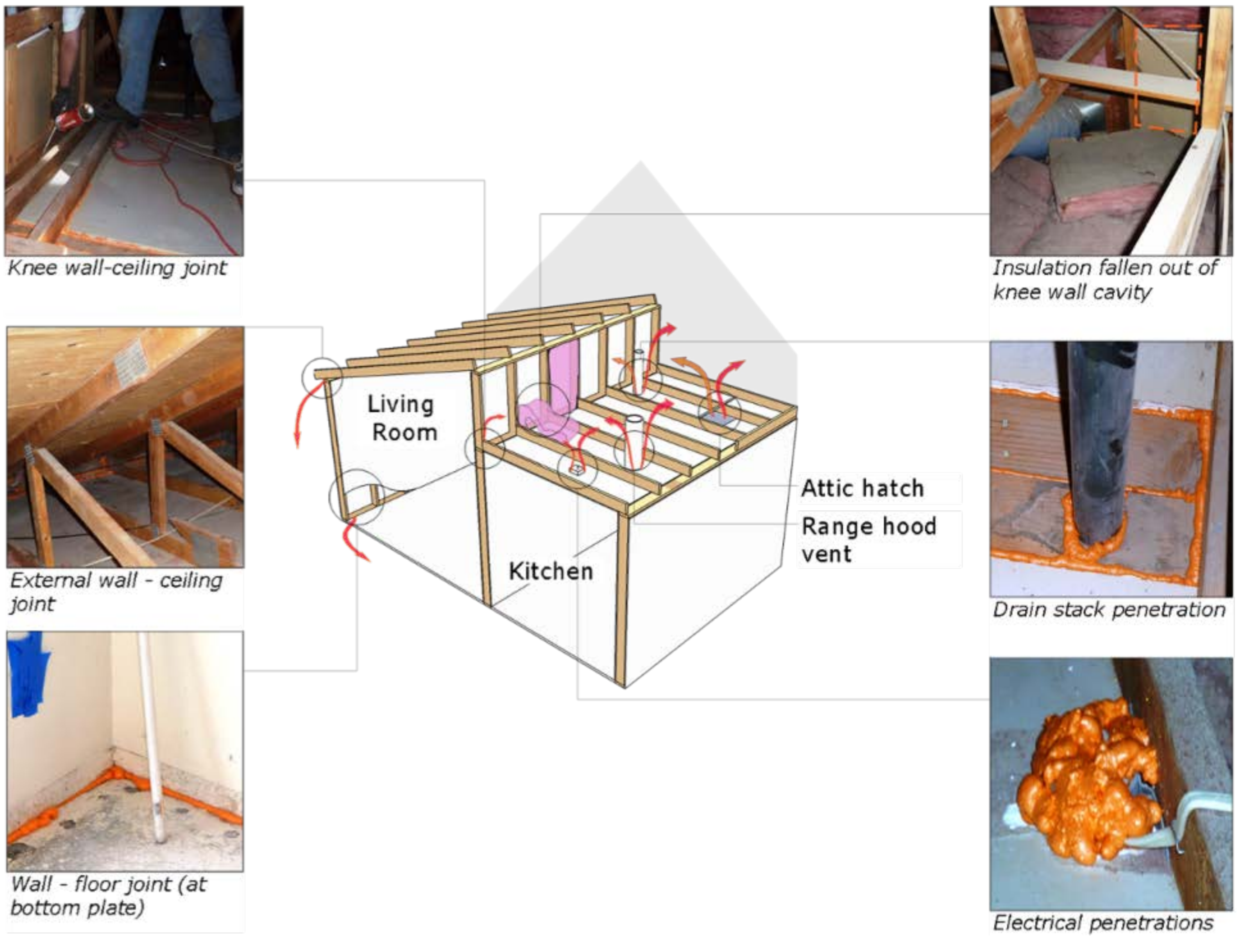

Figure 20. Examples of air sealing at the Carmen home

(Small images courtesy of Building Media, Inc.)

Even though the Carmen home was to be insulated with closed cell spray polyurethane foam at the roof deck, the ceiling plane was still air sealed to minimize the transfer of air between the actively conditioned (living space) and unconditioned (attic) areas. When testing with the blower door, the pressure of the attic space was only one third the pressure of the rest of the home. Therefore, it did not significantly add to the conditioned volume that the HVAC system needs to address, but was still within the thermal envelope negating the thermal losses associated with being in a conventional vented attic.

Table 9 and Table 10 provide the initial and final building infiltration test results, as well as the impact of specific leakage pathways to the overall leakage of these homes. As mentioned in Section 4, the Carmen home was targeting a building infiltration rate of 4.5 ACH50 and the Sierra Hills home was targeting a rate of 4.0 ACH50. Both homes were lower than the target goals at 3.2 ACH50. This level of building tightness is impressive in existing homes, considering that the exterior walls were not touched other than sealing visible penetrations through them. This level of airtightness is 36% better than U.S. Environmental Protection Agency's ENERGY STAR v3.0 Certified New Homes requirement of 5 ACH50 in climate zone 3.

Table 9. Air Sealing Results at the Carmen Home

Building Component	Building Infiltration (CFM50)	CFM Reduction
Test-In	2,241 (9.8 ACH50)	–
Range Hood Sealed	2,099	142
Dryer Vent Sealed	2,052	47
Door to the Garage Sealed	1,806	246
Fireplace Sealed	1,623	183
Front Door Sealed	1,271	352
Laundry Room Exhaust Fan & Attic Hatch	1,205	66
Patio Door Sealed	1,199	6
Miscellaneous Electrical and Plumbing Leaks Sealed	1,134	65
Converting to Unvented Attic and Replacing the Existing Windows	725	409
Test-Out	725 (3.2 ACH50)	–

Table 10. Air Sealing Results at the Sierra Hills Home

Building Component	Building Infiltration (CFM50)	CFM Reduction
Test-In	1,043 (6.1 ACH50)	-
Range Hood Sealed	1,006	37
Door to the Garage Sealed	966	40
Front Door Sealed	897	69
Three Exhaust Fans Sealed	798	99
Attic Hatch	752	46
Patio Door Sealed	729	23
Miscellaneous Electrical and Plumbing Leaks Sealed	605	124
Replacing the Existing Windows	590	15
Test-Out	590 (3.2 ACH50)	–

Additional leakage testing was performed to see how well the garages were isolated from the living space to minimize the potential for carbon monoxide from cars and atmospheric natural gas water heaters from entering the homes. Using a guarded blower door method to bring the garage to the same building pressure (50 Pascals) as the home, the leakage between the garage and living space can be determined. The leakage in this interstitial wall was minimal in both homes. For the Carmen home, only 8 cfm50 was associated with leakage to and from the garage. For the Sierra Hills home, 37 cfm50 was associated with leakage to and from the garage.

4.2 Heating, Ventilation, and Air Conditioning

CARB provided the HVAC design for both homes using the Air Conditioning Contractors of America's Manual J (room-by-room load calculations), Manual S (equipment sizing and selection), Manual T (air distribution design), and Manual D (ductwork sizing). The initial designs focused on compact distribution systems based on a central trunk and branch system. Based on typical regional installation practices, this was redesigned to a radial system with each supply duct running back to the supply plenum. Manual dampers were specified for each supply duct run so the system could be balanced after startup.

Another common regional practice is the use of a furnace/AC HVAC system combination, but this made little sense because the heating demand for homes in this climate is low. CARB recommended switching to ASHPs to provide cooling and heating through a vapor compression cycle. This also allows the heating system capacity to be better matched to the heating demand. Even the smallest capacity furnaces (40,000 Btu/h) are oversized by 200%. Two-stage and modulating furnaces add complexity to the systems (ductwork would still need to be designed for maximum capacity airflow, resulting in lower supply velocities at part load caused by oversized ductwork), and therefore were avoided in these homes.

The existing packaged furnace/AC units were located on the roofs. In the case of the Carmen home, this unit was removed with a crane, the roof was patched, and the new outdoor heat pump unit was located in the backyard. For the Sierra Hills home, the project team decided to maintain the location of the outdoor unit, by placing the new outdoor heat pump on the roof (see Figure 22). This resulted in added cost for a crane (see Figure 21), but simplified running the refrigerant line sets to the indoor air handler unit.

Figure 21. Existing package furnace/AC unit being craned off of the Sierra Hills home

(Image courtesy of Building Media, Inc.)

Figure 22. New outdoor heat pump unit being installed at the Sierra Hills home

(Image courtesy of Building Media, Inc.)

For ventilation, both homes had Panasonic 80 cfm WhisperGreen exhaust fans located in the bathrooms for local spot ventilation to remove excess moisture from showers. The kitchen ranges also had exhaust hoods that were ducted to outside to remove cooking contaminants from the home. These homes were extensively air sealed, so additional whole-house ventilation was provided in the form of a Panasonic 40-cfm WhisperComfort ERV (see Figure 23). CARB has researched this point source (Arena 2011) to verify that the units do not short-circuit (supply air is directly exhausted before being distributed throughout the home because the supply air and return air are close together).

Figure 23. Spot ERVs installed in both homes to provide balanced whole-house ventilation

(Image courtesy of Building Media, Inc.)

There has to be a reason or purpose, not just because…

CARB designed the ventilation systems for these homes without exhaust fans in the laundry rooms. The homes originally had laundry room exhaust fans, but CARB recommended removing them and patching the ceilings to eliminate unnecessary envelope penetrations.

During the training courses, the entire class said "it is code, you have to put a fan in a laundry room without a window." To prove their case, they spent the next hour looking it up. In the end they determined that it was not required. As Mr. Chitwood stated, "We so often see something over and over and think it must be code. It was a wonderful lesson for the class."

4.2.1 Carmen

During the training course, the attendees did some initial testing of the HVAC system before removing it and installing the new unit. They determined that the delivery velocity of its distribution air was very low. This allows for temperature stratification year round, which means the HVAC system runs longer in an attempt to achieve comfort in the occupied areas of the home.

The attendees were trained on the design, installation, and commissioning of the HVAC system. Figure 24 shows CARB's design of the Carmen HVAC system as a radial distribution system. Once in the field, Mr. Chitwood felt the supply air in the kitchen was not necessary and could be adequately supplied from the dining room. CARB had reservations about eliminating this kitchen supply air because of the large internal gain loads of the laundry and kitchen. Also, the dining room supply is a high wall supply (see Figure 4) throwing toward the north end of the home (which is opposite to the kitchen and laundry room) on the south end of the home. Though a mild day, testing during the training session showed little temperature difference between the kitchen and dining room.

The other field modification made to the HVAC design was to eliminate the return ductwork for the master suite. The door to the master bedroom was a 5-foot double door set, so the door undercut was calculated to provide a sufficient return air pathway. This left only the central return in the hallway outside the bedrooms. The as-installed HVAC layout is shown in Figure 25.

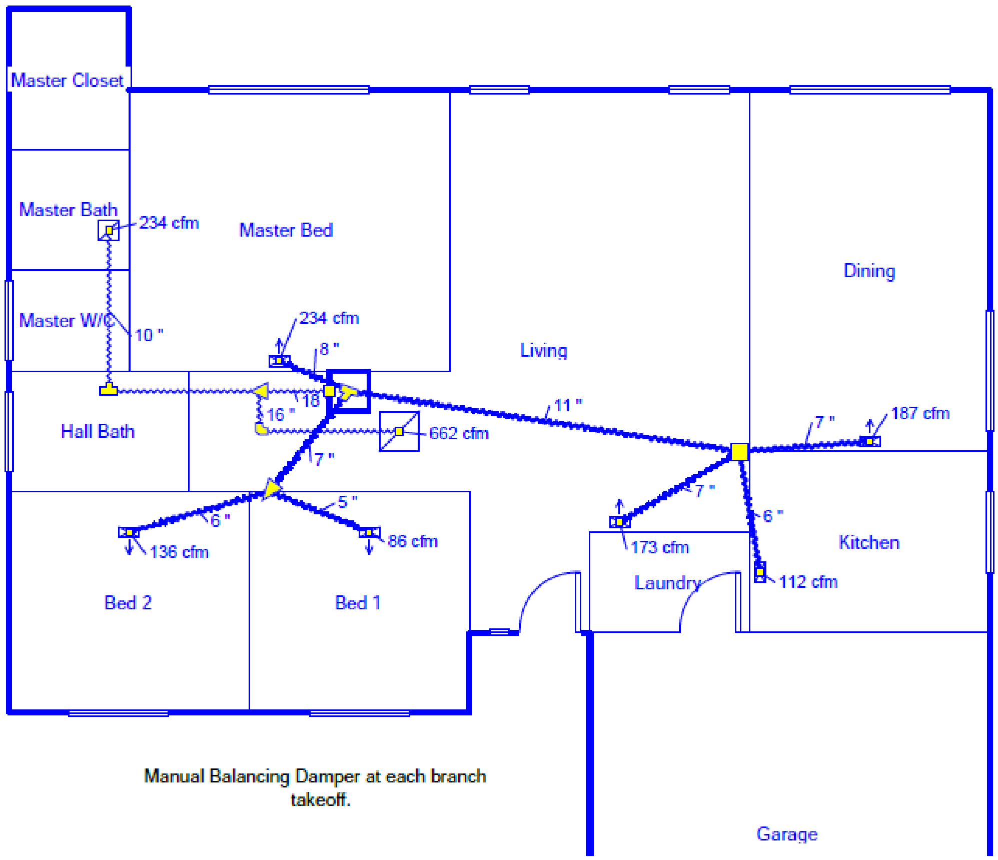

Figure 24. The radial HVAC design for the Carmen home

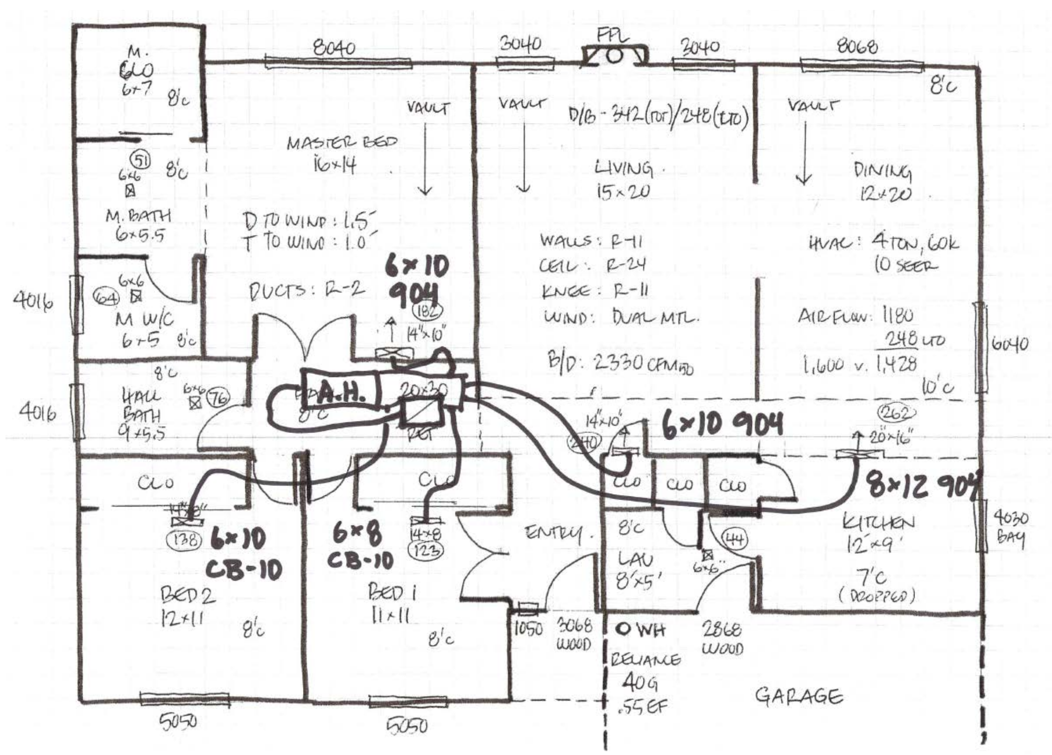

Figure 25. Radial HVAC system as installed at the Carmen home

CARB calculated the cooling and heating loads during the design process to be 19,411 Btu/h and 19,163 Btu/h, respectively. A 2-ton two-stage ASHP was specified to meet these loads. But as the retrofit was being undertaken, air sealing and building specification goals were exceeded, so the actual building loads were lower than predicted. Therefore, the two-stage ASHP was locked on first stage unless the house was 8°F from the set point, so it operates as an approximately 1.5 ton unit. The class recalculated the duct design based on the final system controls configuration (full-stage lock out) and the in-field revisions to the duct layout (elimination of the dedicated kitchen/laundry supply). Once the target airflows were determined, the attendees worked on best practice installation methods for the various HVAC components (see Figure 26).

Figure 26. Mastic being applied to inside of flexduct jacket before being slipped over and secured to a branch takeoff elbow with compression bands

(Image courtesy of Building Media, Inc.)

Session attendees extensively commissioned the HVAC system. The external static pressure drop of the HVAC system was 0.27 in. w.c., well below the manufacturer's specified maximum (0.5–0.7 in. w.c.). The lower external static pressure allows the electronically commutated fan motor to provide the required airflow with less resistance and therefore, less power draw.

The total duct leakage was measured to be 23 cfm at 25 Pascals. This equates to 2.6% leakage based on system airflow. Though the source of the remaining total duct leakage was not identified during the training, this was likely primarily around the air handler unit. The duct leakage to outside was measured to be negligible.

The individual supplies were balanced using the manual dampers at each supply branch takeoff. As shown in Table 11, overall balancing of each supply register was within ±3% of the design flow rates. This was achievable because of the compact distribution design and tight ductwork.

Table 11. Air Balancing Results at the Carmen Home

Room	Design (cfm)	Final (cfm)	Deviation (%)
Dining/Kitchen	283	278	–2
Living Room	164	168	2
Master Bedroom	181	185	2
Bedroom 2/Office	98	98	0
Bedroom 3	146	141	–3
Total	868	870	

The return air pathway for the central return system was confirmed by measuring the pressure difference between bedrooms with closed doors and the main living space. Industry standards, such as the Environmental Protection Agency's ENERGY STAR v3.0 Certified Homes program, require this pressure difference to be ≤ 3.0 Pascals or additional return air pathways installed (jump ducts, transfer grilles, etc.). The Carmen home met this requirement (see Table 12).

Table 12. Verification of Suitable Return Air Pathways at the Carmen Home

Room	Pressure Differential (Pascals)
Master Bedroom	0.9
Bedroom 2/Office	0.6
Bedroom 3	3.0

4.2.2 Sierra Hills

Similar to the Carmen home, attendees of this HVAC training session were trained on the design, installation, and commissioning of the HVAC system. Figure 27 shows CARB's initial design of the Sierra Hills HVAC system as a radial distribution system. Once in the field, Mr. Chitwood again felt the supply in the kitchen was not necessary and could be adequately supplied from the living room (as the two rooms are open to each other). CARB had reservations about eliminating this kitchen supply due to the internal gain load of the kitchen and the distance of the supply throw to adequately reach the kitchen from the living room.

The other field modification made to the HVAC design was to move the air handler unit from the bedroom closet to the hall closet. This was originally not an option based on feedback from the project team, but was deemed necessary to provide adequate clearances for ductwork. This also allowed ductwork to be moved inside the pressure boundary. The framing of the attic allowed for the pressure boundary to be relocated to the bottom cord of the scissor trusses (see Figure 28). This simplified the ceiling insulation installation (as this eliminates the varying ceiling heights caused by the kneewalls) and creates a space for the ducts to be located inside the building envelope (see Figure 29).

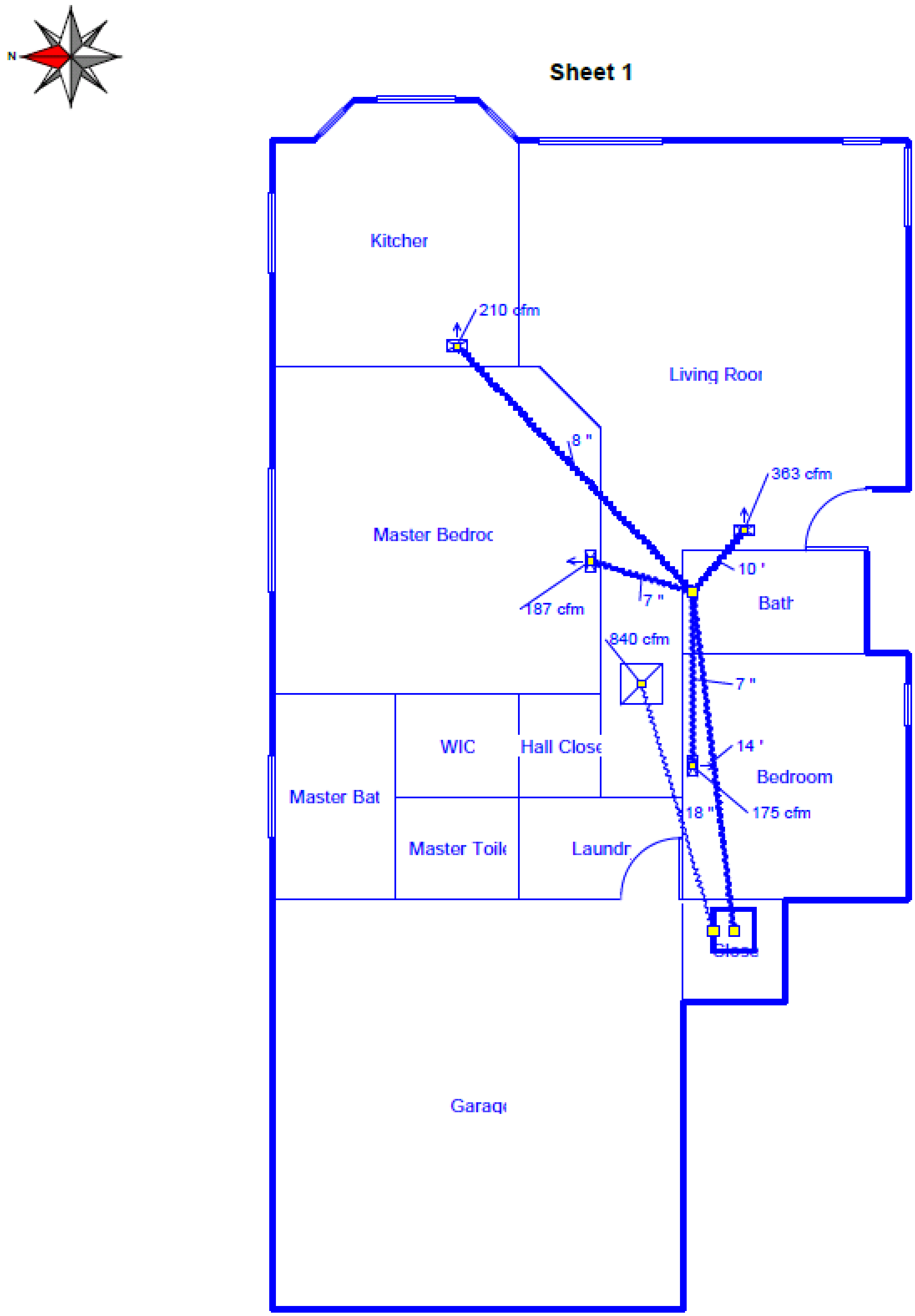

Figure 27. Initial radial HVAC design for the Sierra Hills home

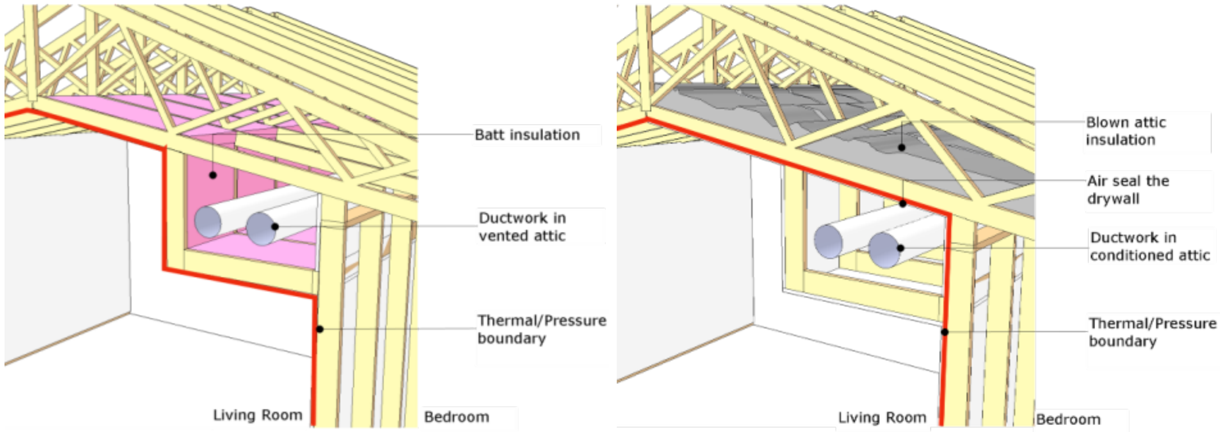

Figure 28. Relocating pressure boundary to bring ductwork into conditioned space. On the left is the existing configuration; the right image shows the new configuration.

Figure 29. Pressure boundary being moved up to the bottom of the scissor trusses to allow ducts to remain within the building envelope

(Image courtesy of Building Media, Inc.)

Session attendees commissioned the HVAC system at Sierra Hills. The external static pressure drop of the HVAC system without the supply registers was 0.11 in. w.c. The double deflection supply registers were not available during the training session, but Mr. Chitwood anticipated that the external static pressure would be no greater than 0.24 in. w.c.

The total duct leakage was measured to be 17 cfm at 25 Pascals. This equates to 1.7% leakage based on system airflow. The duct leakage to outside was measured to be negligible.

The individual supplies were balanced using the manual dampers at each supply branch takeoff. Table 13 shows that overall balancing of each supply register was within ±3% of the design flow rates. The return air pathways for the central return system were also confirmed to be acceptable by measuring the pressure difference between both bedrooms with closed doors and the main living space (see Table 14).

Table 13. Air Balancing Results at the Sierra Hills Home

Room	Design (cfm)	Final (cfm)	Deviation (%)
Living/Kitchen	699	681	–2.6
Master Bedroom	228	230	0.9
Bedroom 2	213	212	–0.5
Total	1,140	1,123	

Table 14. Verification of Suitable Return Air Pathways at the Sierra Hills Home

Room	Pressure Differential (Pascals)
Master Bedroom	1.1
Bedroom 2	2.0

5 Final Performance Modeling

Based on CARB's final performance testing, the Carmen home and Sierra Hills home achieved predicted source energy savings targets of 51% and 34%, respectively. The Carmen home slightly underperformed compared to the initial BA model, but still exceeded the 50% source energy savings goal. This was because the atmospheric natural gas water heater was used as the backup heating source for the solar thermal system, rather than switching to a natural gas tankless water heater. The Sierra Hills home outperformed the initial BA model. This was because of the changes in the building specifications (see Table 7) and because the tested building infiltration rate was lower than the goal of 4.0 ACH50.

Table 15 provides the Home Energy Rating System (HERS) Index for the pre-retrofit and finalized homes. The reference home for the HERS Index is based on the 2006 International Energy Conservation Code. An average code compliant new home has a HERS Index of 100; according to RESNET, the typical resale home scores 130 on the HERS Index.

Table 15. Pre- and Post-Retrofit HERS Indexes for the Vegas Retrofits

Home	HERS Index	
	Pre-Retrofit	Post-Retrofit
Carmen	126	66
Sierra Hills	98	61

5.1 Carmen

A summary of the specifications for the four primary cases discussed in this report for the Carmen home are provided in Table 16.

Table 16. Summary of Specifications at the Carmen Home

Building Component	Existing	NSP	BA Proposed	Final
Above-Grade Walls	2 × 4 wood framing @ 16 in. w/R-11 fiberglass batts (grade III)			
Attic	Vented attic, R-24 fiberglass batts at ceiling plane		Unvented attic, R-30 closed cell spray polyurethane foam at roof deck	
Windows	Aluminum double pane, clear (assumed U-0.76, SHGC-0.67)		Vinyl double pane, low-e retrofit windows (U-0.26, SHGC-0.23)	
Cooling/Heating	Packaged furnace/AC, 60 kBtu/h heating input, natural gas, 76% AFUE, 40.5 kBtu/h cooling capacity, R-22 refrigerant, SEER 8.5	Packaged furnace/AC, 60 kBtu/h heating input, natural gas, 78% AFUE, 40.5 kBtu/h cooling capacity, R-410A refrigerant, SEER 14	Split ASHP (SEER 18.5/9.2 HSPF), 25.6 kBtu/h cooling capacity, 24.2 kBtu/h heating capacity, R-410A refrigerant with TXV valve	
Ductwork	R-2 ductwork in vented attic (poor condition)	R-6 ductwork in vented attic	Compact distribution design, R-6 ductwork in unvented attic, sealed with mastic	
Local Ventilation	Kitchen exhausted to exterior and bathroom exhaust fans		Efficient exhaust fans with delay off timers in bathrooms	
Whole-House Ventilation	–		Spot ERV	
Hot Water	50-gal atmospheric water heater, natural gas, 0.55 EF	50-gal atmospheric water heater, natural gas, 0.59 EF	Solar thermal system (40 ft^2 of collectors facing south) with 80-gal preheat tank and tankless water heater backup (0.84 EF)	Solar thermal system (40 ft^2 of collectors facing west) with 80-gal preheat tank and existing water heater backup (0.55 EF)
Lighting	Mostly incandescent except fluorescents in kitchen		All CFLs or LEDs	
Appliances	Old appliances	ENERGY STAR appliances		
Infiltration	9.8 ACH50	9.2 ACH50	4.0 ACH50	3.2 ACH50

The finalized BEopt model in Figure 30 confirms that the Carmen home was a very successful retrofit showcasing how typical homes in the region can be improved to reduce source energy consumption by 50% or more while maintaining annualized costs roughly the same over a 15-year period (after which the retrofit is cash positive). The difference between the final BA home and the minimum cost option was the use of solar thermal with the existing water heater versus a gas tankless water heater.

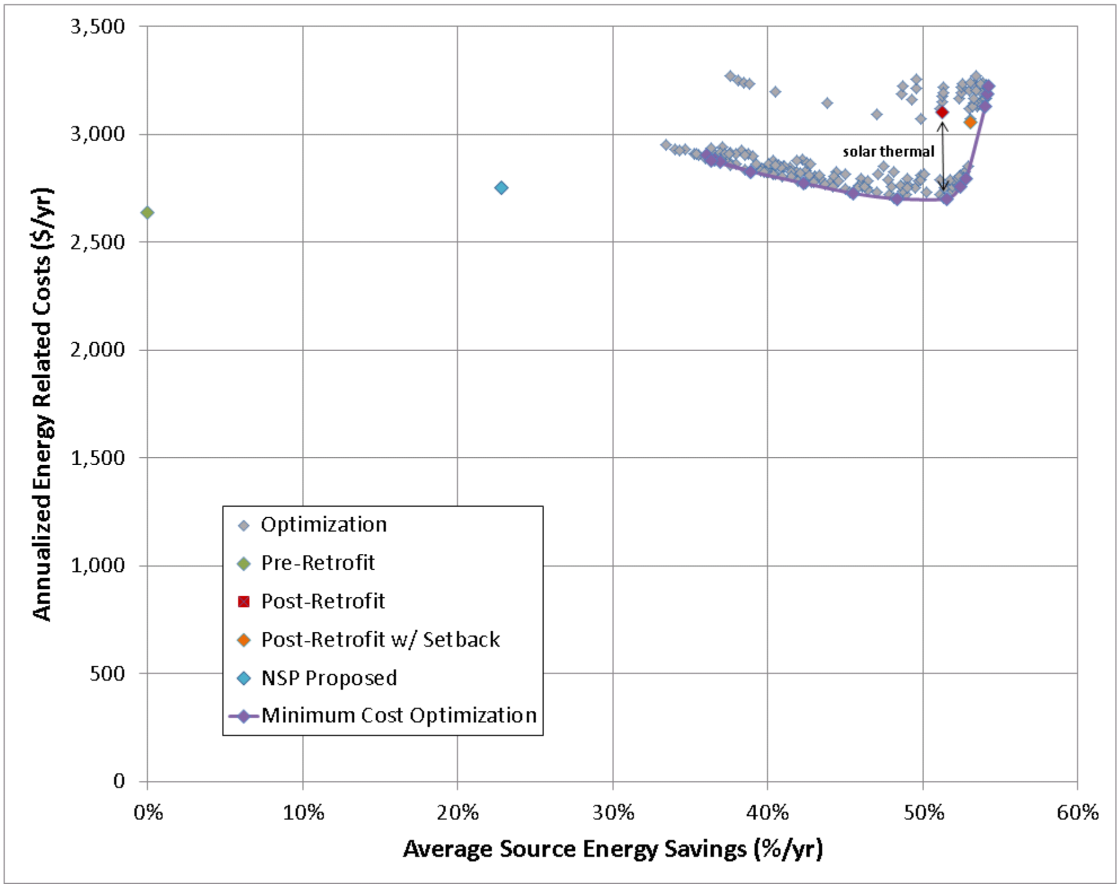

Figure 30. Final energy savings prediction for the Carmen home

To achieve the 50% level of energy savings without significantly disturbing the interior gypsum board and finishes, the team thought a solar thermal hot water system would be required. CARB's proposed specifications were for a solar thermal system and using a tankless water heater as the auxiliary water heater. The project team was interested in showcasing the solar thermal technology, but the first cost of the solar thermal system was, so it elected to leave the atmospheric tank water heater.

In hindsight, as a result of the tighter building infiltration results than anticipated, the home could have achieved similar performance at a lower first cost by switching the domestic water heating to a tankless water heater rather than a solar thermal system. Though the available solar resource is excellent in this climate region, the system was sized to only about 60% of domestic hot water design load and was installed on the west roof slope. Being nearly 90 degrees from true south may result in a 10%–20% reduction in solar thermal output. The hot water use pattern will determine the performance of the solar system, which is configured for afternoon and evening hot water use.

Figure 31 provides a look at the component end use for the various specification packages of the Carmen home. Based on the energy modeling, the predicted annual utility bill savings for the Carmen home is $1,138 ($2,543 pre and $1,405 post = $1,138) based on current utility rates (NV Energy $0.11751/kWh and Southwest Gas $0.76659/therm). This is a 45% savings in annual utility costs.

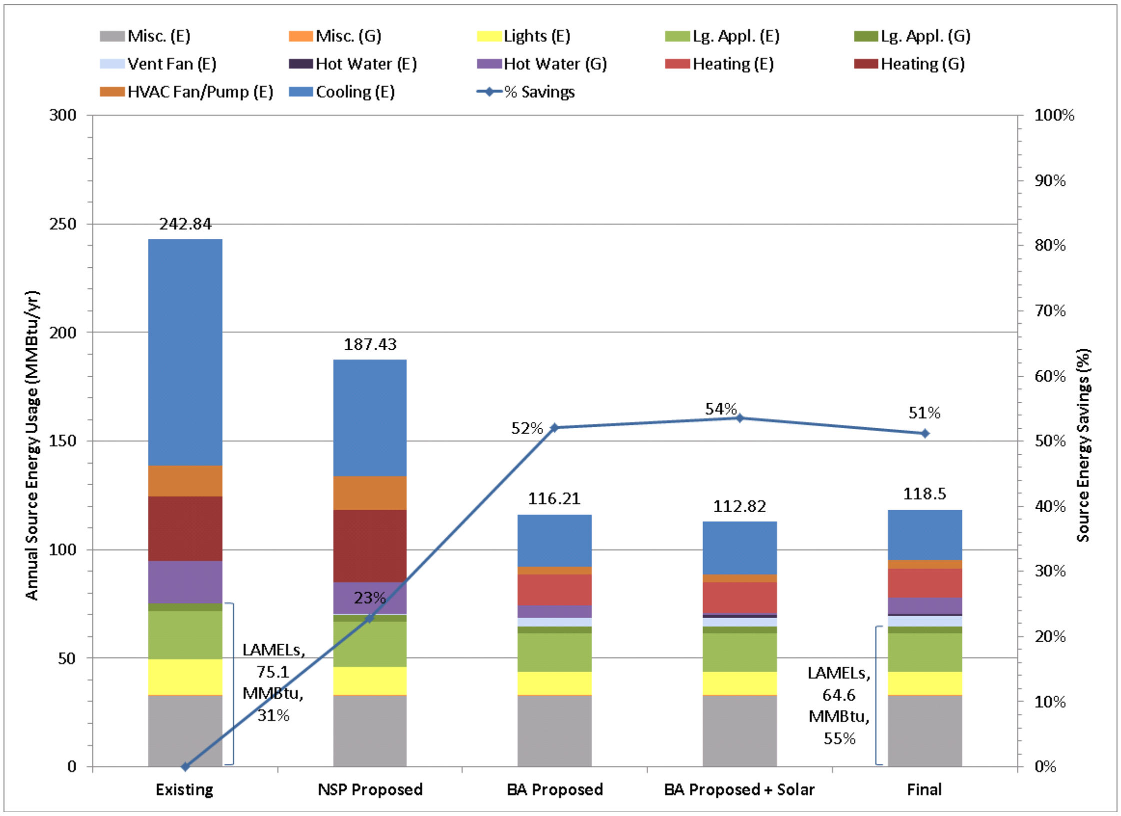

Figure 31. Cumulative contribution to total energy savings, by measure and end use, for the Carmen home

Lighting, appliances, and miscellaneous electric loads (LAMELs) are often grouped together as the remaining contributors to the total home electricity demand after space heating, space cooling, domestic hot water, and ventilation. In the existing home, the LAMELs accounted for only 31% of the overall energy consumption. In the retrofitted home, the LAMELs now account for 55% of the remaining energy consumption. These are all top of the line units (ENERGY STAR labeled, if available), so little currently can be done from a technology standpoint to reduce this use. The same is true of the fixed lights, which are all CFLs) or LEDs. Essentially, the occupants would need to alter their behavior to see a significant reduction in their LAMELs consumption.

5.2 Sierra Hills

Table 17 provides a summary of the specifications for the four primary cases discussed in this report for the Sierra Hills home.

Table 17. Summary of Specifications at the Sierra Hills Home

Building Component	Existing	NSP	BA Proposed	Final
Above-Grade Walls	2 × 4 wood framing @ 16 in. w/R-11 fiberglass batts (grade III) + 1 in. EPS foam			
Attic	Vented attic, R-24 fiberglass batts at ceiling plane		Vented attic, R-49 fiberglass batts at ceiling plane	
Windows	Aluminum double pane, clear (assumed U-0.76, SHGC-0.67)		Apply low-e film to existing windows (SHGC-0.43)	Vinyl double pane, low-e retrofit windows (U-0.26, SHGC-0.23)
Cooling/Heating	Packaged furnace/AC, 60 kBtu/h heating input, natural gas, 79.6% AFUE, 35 kBtu/h cooling capacity, R-22 refrigerant, SEER 13	Packaged furnace/AC, 60 kBtu/h heating input, natural gas, 78% AFUE, 35 kBtu/h cooling capacity, R-410A refrigerant, SEER 15	Mini-split heat pumps (SEER 16/8.5 HSPF), 35.4 kBtu/h cooling capacity, 36.0 kBtu/h heating capacity, R-410A refrigerant	Split ASHP (SEER 18.5/9.2 HSPF), 25.6 kBtu/h cooling capacity, 24.2 kBtu/h heating capacity, R-410A refrigerant with TXV valve
Ductwork	R-4 ductwork in vented attic	R-6 ductwork in vented attic	–	Compact distribution design, R-6 ductwork in conditioned space
Local Ventilation	Kitchen exhausted to exterior and bathroom exhaust fans		Efficient exhaust fans with delay off timers in bathrooms	
Whole-House Ventilation	–		Spot ERV	
Hot Water	50-gal atmospheric water heater, natural gas, 0.56 EF	50-gal atmospheric water heater, natural gas, 0.59 EF	50-gal premium water heater, natural gas, 0.67 EF	
Lighting	Mostly incandescent light except fluorescent lighting in kitchen		All CFLs or LEDs	
Appliances	Old appliances	ENERGY STAR appliances		
Infiltration	6.1 ACH50	6.0 ACH50	4.0 ACH50	3.2 ACH50

The finalized BEopt model in Figure 32 confirms that the Sierra Hills home exceeded the source energy consumption goal of 30%. The final home performance is not even on the optimization curve, because the level of airtightness achieved—though minimally invasive—exceeded what was thought to be feasible during the initial analysis. Unfortunately, as the Sierra Hills home already had equipment replaced over the past decade, any energy efficiency measures would result in higher annualized costs over the 15-year financing period (after which the retrofit would be cash positive).

In this case, the final retrofit resulted in a 28.2% efficiency improvement over the NSP-proposed specifications and reduced the annualized costs by $305/year. So if the decision has already been made to make improvements, the efficiency measures recommended by CARB can lead to lower annualized costs with improved comfort.

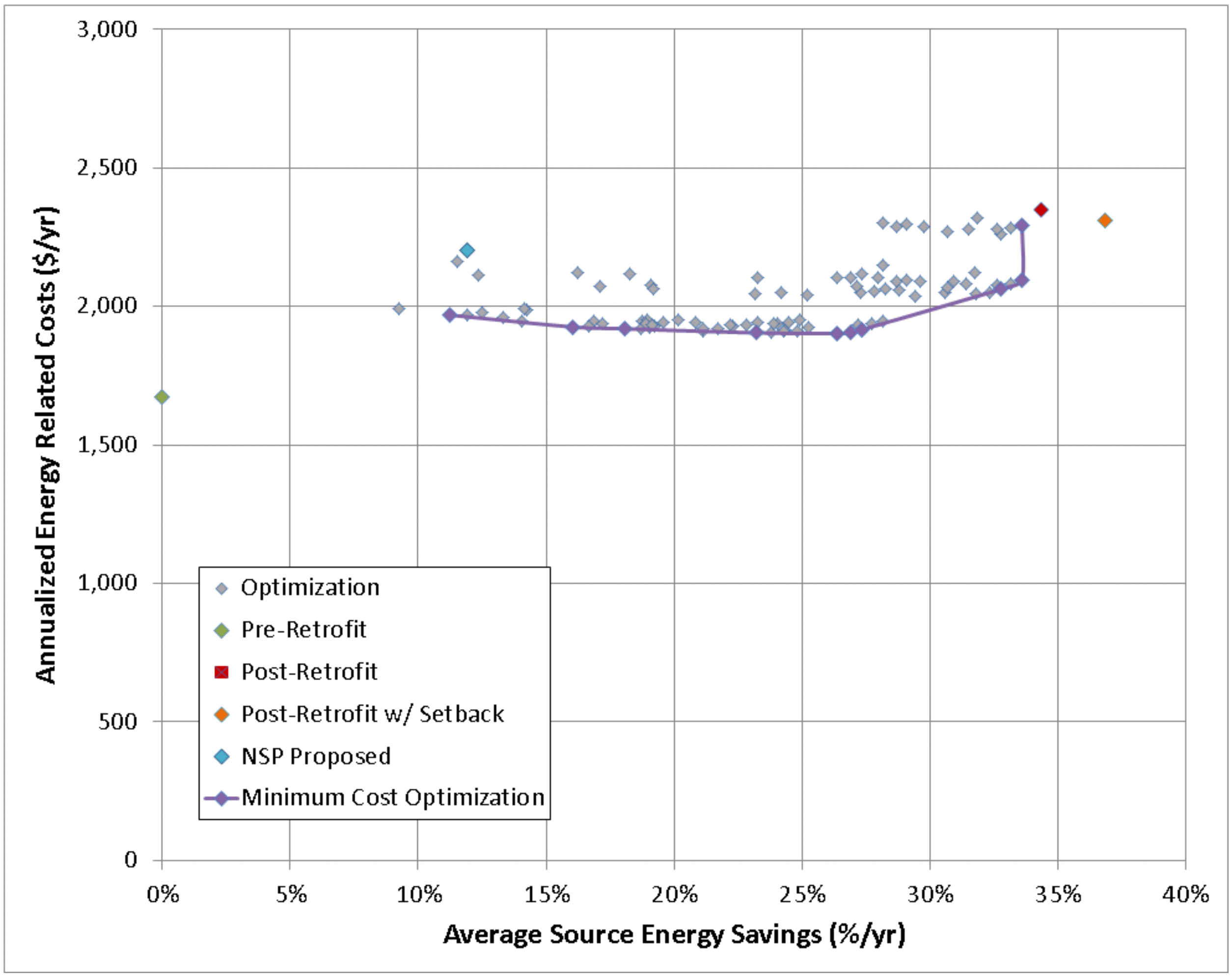

Figure 32. Final energy savings prediction for the Sierra Hills home

Figure 33 provides a look at the component end use for the various specification packages of the Sierra Hills home. Based on the energy modeling, the predicted annual utility bill savings for the Sierra Hills Home is $480 ($1,672 pre and $1,192 post = $480). This is a 28.7% savings in annual utility costs.

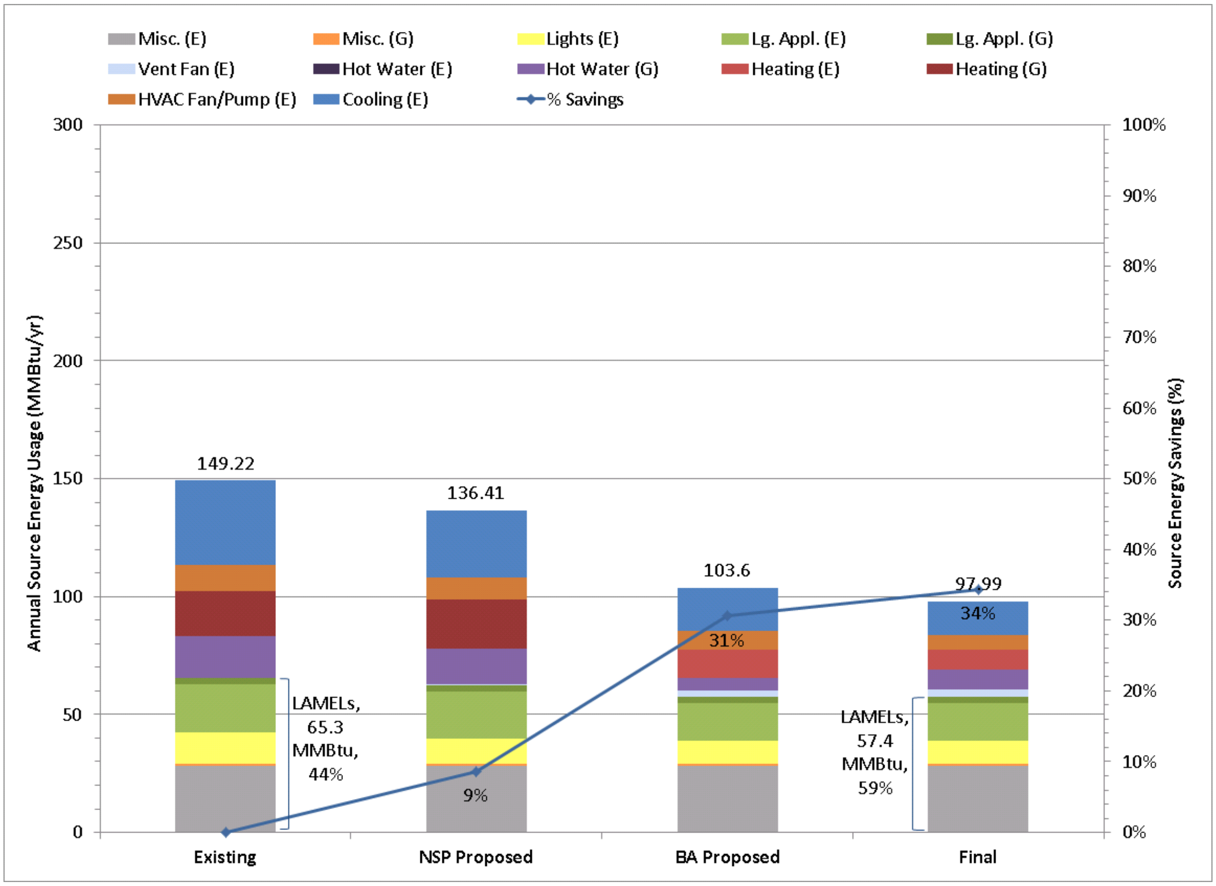

Figure 33. Cumulative contribution to total energy savings, by measure and end use, for the Sierra Hills home

In the existing home, the LAMELs accounted for 44% of the overall energy consumption. In the retrofitted home, the LAMELs now account for 59% of the remaining energy consumption. This makes achieving higher levels of energy savings difficult for this housing type/class without significantly higher annualized energy related costs.

6 Cost Analysis

When we are trying to determine whether energy efficiency measures are cost effective, the real issue is whether we have developed a compelling home for the marketplace. According to Kerry Landley, Director of Sustainable & High Performance Lending at the Real Estate Mortgage Network, homebuyers in this region can use two strategies to purchase an existing home.

- Common Strategy
  - Purchase a traditionally built home (based on market price).
  - Obtain market-based mortgage financing.
  - Pay market-based monthly utilities.
  - Pay market-based home ownership expenses (maintenance and repairs).
- Efficiency Strategy
  - Purchase a traditionally built home (based on distressed property pricing).
  - Add renovation and energy retrofit cost (based on energy saving goals).
  - Obtain optimized mortgage financing.
  - Pay discounted monthly utilities (from energy-related improvements).
  - Pay discounted home ownership expenses (maintenance and repairs).

Based on the purchaser's timeframe, the cost benefit of the efficiency strategy will also vary. The 15- and 30-year mortgages are the most common. Table 18 compares the annualized energy-related cost estimates from BEopt for the two retrofit homes based on length of a mortgage and timeframe over which the cost analysis is evaluated. This cost analysis only accounts for estimated first costs, utility bills, and potential equipment replacement costs over the analysis period. It does not take into account the potential for improved comfort, durability, and indoor air quality.

Table 18. Comparison of Annualized Energy-Related Costs Based on Length of Mortgage and Analysis Period

House (Mortgage Term/Analysis Period)	Existing	NSP Proposed	BA Final	Annualized Savings Over Existing	Annualized Savings Over NSP Proposed
Carmen (15 years/15 years)	$2,543	$2,754	$3,103	–$560	–$349
Carmen (15 years/30 years)	$2,392	$2,629	$1,565	$827	$1,064
Carmen (30 years/30 years)	$2,392	$2,614	$1,547	$845	$1,067
Sierra Hills (15 years/15 years)	$1,525	$2,202	$2,349	–$824	–$147
Sierra Hills (15 years/30 years)	$1,525	$2,011	$1,222	$303	$789
Sierra Hills (30 years/30 years)	$1,525	$1,996	$1,204	$321	$792

For a 15-year mortgage and analysis period, the implemented efficiency measures were not cost neutral over the existing home. For a 30-year mortgage and analysis period, the efficiency measures were cost beneficial over the existing home. Because of the age and condition of the home and equipment, many of these improvements, though maybe to a lesser efficiency level, would have needed to be made. The NSP proposed specifications are a good reference for the minimal needed to be done to make these homes market ready. This comparison nets the same overall results as the existing home, but the savings are higher (or additional expenses are lower) across all cases. To be cost neutral across all instances in Table 18, the solar thermal system would need to be removed from the Carmen specifications and, rather than replacing the windows at the Sierra Hills home, a low-e film should be considered.

The general contractor provided the following project specific cost information in Table 19 and Table 20 for the Carmen and Sierra Hills retrofits, respectively. In these homes, labor was provided by the training session attendees, so the labor costs in these tables are estimates. The window costs were quite similar to the BEopt estimates, but BEopt underestimated the cost of the high efficiency heat pump and solar thermal hot water system by nearly half. Whether this cost discrepancy is based on regional price variations or something else is unclear.

Table 19. First Costs of Efficiency Measures at the Carmen Residence

	Quantity	Units	Unit Price	Cost	Cost/ft^2
Installing New HVAC Distribution System					
Materials	120	LF	$ 6.25	$ 750.00	$ 0.49 /sq ft
Grills, Fittings, etc	60	EA	$ 6.25	$ 375.00	$ 0.25 /sq ft
Labor	20	HRS	$ 35.00	$ 700.00	$ 0.46 /sq ft
			Subtotal	**$ 1,825.00**	**$ 1.20 /sq ft**
Installing High Efficiency HVAC Equipment					
Air Handler Unit	1	EA	$ 3,062.50	$ 3,062.50	$ 2.01 /sq ft
Heat Pump Unit	1	EA	$ 6,062.50	$ 6,062.50	$ 3.99 /sq ft
Thermostat	1	EA	$ 156.25	$ 156.25	$ 0.10 /sq ft
Labor	31	HRS	$ 35.00	$ 1,085.00	$ 0.71 /sq ft
			Subtotal	**$ 10,366.25**	**$ 6.82 /sq ft**
Repairing Roof After HVAC Removal					
Shingles	30	SF	$ 8.00	$ 240.00	$ 0.16 /sq ft
Plywood	30	SF	$ 1.00	$ 30.00	$ 0.02 /sq ft
Materials	1	LS	$ 50.00	$ 50.00	$ 0.03 /sq ft
Labor	6	HRS	$ 35.00	$ 210.00	$ 0.14 /sq ft
			Subtotal	**$ 530.00**	**$ 0.35 /sq ft**
			HVAC Total	**$ 12,721.25**	**$ 8.36 /sq ft**
Installing New Windows					
Simonton Windows	190	SF	$ 37.00	$ 7,030.00	$ 4.62 /sq ft
Foam	13	EA	$ 2.50	$ 32.50	$ 0.02 /sq ft
Labor	32	HRS	$ 25.00	$ 800.00	$ 0.53 /sq ft
			Subtotal	**$ 7,862.50**	**$ 5.17 /sq ft**
			Windows Total	**$ 7,862.50**	**$ 5.17 /sq ft**
Converting to Unvented Attic					
Closed Cell Polyurethane (Material & Labor)	1,825	SF	$ 5.75	$ 10,494.90	$ 6.90 /sq ft
			Subtotal	**$ 10,494.90**	**$ 6.90 /sq ft**
			Insulation Total	**$ 10,494.90**	**$ 6.90 /sq ft**
Providing ENERGY STAR Appliances					
ENERGY STAR Refrigerator	1	EA	$ 1,375.00	$ 1,375.00	$ 0.90 /sq ft
ENERGY STAR Dishwasher	1	EA	$ 487.50	$ 487.50	$ 0.32 /sq ft
ENERGY STAR Clothes Washer	1	EA	$ 879.00	$ 879.00	$ 0.58 /sq ft
ENERGY STAR Clothes Dryer	1	EA	$ 817.00	$ 817.00	$ 0.54 /sq ft
Labor	6	HRS	$ 25.00	$ 150.00	$ 0.10 /sq ft
			Subtotal	**$ 3,708.50**	**$ 2.44 /sq ft**
			Appliances Total	**$ 3,708.50**	**$ 2.44 /sq ft**
Adding a Solar Hot Water System					
Solar Hot Water	1	Ea	$ 6,930.00	$ 6,930.00	$ 4.56 /sq ft
Labor	12	HRS	$ 25.00	$ 300.00	$ 0.20 /sq ft
			Subtotal	**$ 7,230.00**	**$ 4.75 /sq ft**
			Water Heating Total	**$ 7,230.00**	**$ 4.75 /sq ft**
			Total Costs of Energy Efficiency Measures	**$ 42,017**	**$ 27.62 /sq ft**

Table 20. First Cost of Efficiency Measures at the Sierra Hills Residence

	Quantity	Units	Unit Price	Cost	Cost/ft^2
Installing New HVAC Distribution System					
Materials	120	LF	$ 6.25	$ 750.00	$ 0.66 /sq ft
Grills, Fittings, etc	60	EA	$ 6.25	$ 375.00	$ 0.33 /sq ft
Labor	20	HRS	$ 35.00	$ 700.00	$ 0.62 /sq ft
			Subtotal	**$ 1,825.00**	**$ 1.61 /sq ft**
Installing High Efficiency HVAC Equipment					
Air Handler Unit	1	EA	$ 4,312.50	$ 4,312.50	$ 3.81 /sq ft
Heat Pump Unit	1	EA	$ 6,562.50	$ 6,562.50	$ 5.80 /sq ft
Thermostat	1	EA	$ 156.25	$ 156.25	$ 0.14 /sq ft
Labor	31	HRS	$ 35.00	$ 1,085.00	$ 0.96 /sq ft
			Subtotal	**$ 12,116.25**	**$ 10.71 /sq ft**
			HVAC Total	**$ 13,941.25**	**$ 12.33 /sq ft**
Installing New Windows					
Simonton Windows	180	SF	$ 37.00	$ 6,660.00	$ 5.89 /sq ft
Foam	13	EA	$ 2.50	$ 32.50	$ 0.03 /sq ft
Labor	32	HRS	$ 25.00	$ 800.00	$ 0.71 /sq ft
			Windows Total	**$ 7,492.50**	**$ 6.62 /sq ft**
Insulating Vented Attic					
Blown Fiberglass	1,131	SF	$ 0.70	$ 791.70	$ 0.70 /sq ft
Labor	32	HRS	$ 25.00	$ 800.00	$ 0.71 /sq ft
			Subtotal	**$ 1,591.70**	**$ 1.41 /sq ft**
			Insulation Total	**$ 1,591.70**	**$ 1.41 /sq ft**
Providing ENERGY STAR Appliances					
ENERGY STAR Refrigerator	1	EA	$ 1,375.00	$ 1,375.00	$ 1.22 /sq ft
ENERGY STAR Dishwasher	1	EA	$ 487.50	$ 487.50	$ 0.43 /sq ft
ENERGY STAR Clothes Washer	1	EA	$ 879.00	$ 879.00	$ 0.78 /sq ft
ENERGY STAR Clothes Dryer	1	EA	$ 817.00	$ 817.00	$ 0.72 /sq ft
Labor	6	HRS	$ 25.00	$ 150.00	$ 0.13 /sq ft
			Appliances Total	**$ 3,708.50**	**$ 3.28 /sq ft**
Replacing Hot Water System					
High Efficiency DHW System	1	Ea	$ 1,188.75	$ 1,188.75	$ 1.05 /sq ft
Labor	6	HRS	$ 25.00	$ 150.00	$ 0.13 /sq ft
			Water Heating Total	**$ 1,338.75**	**$ 1.18 /sq ft**
Total Costs of Energy Efficiency Measures				**$ 28,073**	**$ 24.82 /sq ft**

The costs for all the other alternatives run in BEopt to generate the least cost optimization curve are unknown, so CARB did not adjust the costs of various measures within this software. This would unfairly weight those alternative strategies with lower cost estimates, and translating the actual costs into BEopt would be difficult. For example, the cost for converting to an unvented attic is specified as a single cost for spray foam insulation at the roof deck, but in BEopt, this cost would have to be judiciously divided among insulation, infiltration, and ducts (bringing ducts within conditioned space).

The project team was able to obtain the cost estimate report from the City of Las Vegas Housing Rehabilitation Program for the Sierra Hills home (a scope of work had been developed for the Carmen home, but a cost estimate report had not been completed). The cost increase for the higher efficiency measures at the Sierra Hills home was about $11,000 more than what was originally intended under the NSP. However, several of the big ticket items of the NSP cost estimates seem optimistic, based on feedback from the general contractor of these retrofits. For example, it is unlikely that a completely new HVAC system, including new ductwork, can be designed, installed (unit located on roof), and commissioned per the NSP proposed scope of work for $4,500. The distribution system alone cost $1,825, so the cost of the packaged furnace/AC and the installation of that unit would need to be less than $2,675, which is unlikely.

The percent differential in costs from BEopt was used to estimate a more appropriate first cost for the NSP specifications. For the Carmen and Sierra Hills homes, the cost differential was 58% and 13%, respectively. For the Carmen home, an estimate of the NSP proposed specifications based on the BEopt cost differential would be $24,300. For the Sierra Hills home, this would mean that a potentially more reasonable estimate would be about $7,500 more than the NSP cost estimate report indicated or a difference of about $3,500 between the NSP specifications and the BA specifications cost.

As the NSP specifications would need to be done for the most part to make these homes marketable again, a simple payback (SPB) between the NSP specifications and BA specifications is provided based on the adjusted annualized energy-related cost savings potential (based on first cost differential percentages) of these homes with a 30-year mortgage and analysis period. The simple payback would be about 16.6 years for the Carmen home and about 6.4 years for the Sierra Hills home. If the solar thermal system were replaced with a tankless natural gas water heater, the SPB would be reduced to about 12.9 years. For the Carmen home, this SPB is higher than the 5- to 10-year timeframe that is typically used when making investment decisions, but the SPB metric excludes the value of improved comfort, durability, and indoor air quality of the retrofitted home.

7 Conclusions

These two test homes proved to be valuable resources in demonstrating the effort (design and implementation) and cost required to retrofit existing homes in the Southwest climate region to various BA energy saving targets. In addition to validating and vetting BA solution packages, these homes were used as training centers for local contractors and have been opened to the local community for tours. These tours focus on how energy efficiency can be effectively incorporated into other existing homes in the region. A Nevada ENERGY STAR® Partners website has been set up for this project. The site provides information on tour availability, links to video segments filmed during the project, and brief story lines of the retrofits.

The overarching research question was, "How do we determine what solution package(s) can be readily implemented in hot, dry climate homes to achieve a 30% plus and a 50% plus energy savings home compared to the pre-retrofit home (as defined by the BA B10 Benchmark)? CARB has provided two robust solution packages for retrofitting homes built in this region from the 1980s to the early 1990s without substantially inconveniencing the occupants. These BA solutions focused on air sealing the building envelope where accessible to reduce the overall space conditioning loads. Windows were replaced with double-pane low-e retrofit windows. The replacement windows reduced solar heat gain entering the homes and allowed for these rough openings to be better air sealed. Another essential strategy was to simplify the design and distribution of the high efficiency HVAC systems. This included bringing the ductwork within the conditioned building envelope. High efficiency technology is beneficial only if it is designed and installed appropriately. For more details about these solution packages, refer to Table 16 and Table 17. Whether energy savings of 30% or greater or 50% or greater are achieved depends primarily on the pre-retrofit state of the home and whether mechanical equipment updates have been performed since initial construction. The final estimated performance of these homes is summarized in Table 21.

Table 21. Final Estimated Performance of the Two Test Homes

Home	Source Energy Savings	Annual Utility Savings[a]	Annualized Energy Related Cost Savings[b]	HERS Index	
				Pre-Retrofit	Post-Retrofit
Carmen	51%	$1,138	$845	126	66
Sierra Hills	34%	$480	$321	98	61

[a] $0.1175/kWh +$10 monthly charge, $0.7666/therm + $9 monthly charge
[b] 30-year mortgage, 4.0% loan interest rate, 1.6% inflation rate, 3.0% discount rate (real), 0% fuel escalation rate

The determination of whether the selected solution package for each home is commercially viable comes down to marketability and adoption. Assessors are just starting to incorporate efficiency measures into the assessments of home values (though usually at a significant discount compared to aesthetic features, such as granite countertops). The City of Las Vegas Neighborhood Services Department is encouraged by the results of these two test homes and is working to incorporate these solution packages into its scopes of work for future NSP-funded homes. Work is also being done to incorporate these solution packages into the new EnergyFit Nevada program.

Even though there has been tremendous positive feedback from tour visitors of the Carmen home, success is based on retrofit implementation and not just interest. A homeowner's focus is most often on first cost, but when incorporating improvements in a mortgage, the key is the annualized energy-related costs. The question is whether it is better to pay a larger mortgage and pay less on utility bills annually. The answer depends on the timeframe of the investment. The longer a homeowner intends to live in a home, the more cost beneficial the energy efficiency measures are. Over a 30-year analysis period, whether a 15- or 30-year mortgage, these solution packages are cost effective.

To make these solution packages even more cost effective and achieve the BA energy savings targets, CARB determined that the solar thermal system could be removed from the Carmen specifications (replaced with a natural gas tankless water heater) and rather than replacing the windows at the Sierra Hills home, a low-e film should be considered. CARB also looked at an alternative solution at the Sierra Hills home that included using ductless mini-split heat pumps as the space conditioning strategy and found comparable performance and cost. Also, to enable large-scale implementation of these solution packages across this region, contractor training on air sealing and simplified, compact HVAC design needs to continue.

With more than 11% of the existing housing stock of Las Vegas in foreclosure (more than 8,100 homes), the potential for energy retrofit savings in this region is substantial. If even 10% of those homes implement these solution packages (5% at the 50% energy savings target and 5% at the 30% energy savings target), an energy reduction of more than 71,000 MMBtu or roughly $655,000 in annual utility bill cost for residents could be achieved.

References

Arena, L. (2011). "Evaluation of the Performance of a Spot Energy Recovery Ventilator in a Retrofit Application." Consortium for Advanced Residential Buildings, March 2011. Accessed August 20, 2012. www.carb-swa.com/articles/homepage/ERV%20Update_022811_CARBwebsite.pdf

Gunshinan, J. (2007). "Energy Star Changes Approach to Programmable Thermostats." *Home Energy Magazine*, March/April 2007. Accessed August 10, 2012. www.waptac.org/data/files/website_docs/technical_tools/energy_star/energy_star_changes_approach_to_programmable_thermostats.pdf

buildingamerica.gov

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

DOE/GO-102013-3898 ▪ April 2013

Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post-consumer waste.