

Consortium for Advanced Residential Buildings

The Consortium of Advanced Residential Buildings (CARB) – A Building America Energy Efficient Housing Partnership

Final Report

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Abstract

This final report summarizes the work conducted by the Consortium of Advanced Residential Buildings (CARB) (<http://www.carb-swa.com/>), one of the “Building America Energy Efficient Housing Partnership” Industry Teams, for the period January 1, 2008 to December 31, 2010. The Building America Program (BAP) is part of the Department of Energy (DOE), Energy Efficiency and Renewable Energy, Building Technologies Program (BTP). The long term goal of the BAP is to develop cost effective, production ready systems in five major climate zones that will result in zero energy homes (ZEH) that produce as much energy as they use on an annual basis by 2020.

CARB is led by Steven Winter Associates, Inc. with Davis Energy Group, Inc. (DEG), MaGrann Associates, and Johnson Research, LLC as team members. In partnership with our numerous builders and industry partners, work was performed in three primary areas – advanced systems research, prototype home development, and technical support for communities of high performance homes.

Our advanced systems research work focuses on developing a better understanding of the installed performance of advanced technology systems when integrated in a whole-house scenario. Technology systems researched included:

- High-R Wall Assemblies
- Non-Ducted Air-Source Heat Pumps
- Low-Load HVAC Systems
- Solar Thermal Water Heating
- Ventilation Systems
- Cold-Climate Ground and Air Source Heat Pumps
- Hot/Dry Climate Air-to-Water Heat Pump
- Condensing Boilers
- Evaporative condensers
- Water Heating

CARB continued to support several prototype home projects in the design and specification phase. These projects are located in all five program climate regions and most are targeting greater than 50% source energy savings over the Building America Benchmark home.

CARB provided technical support and developed builder project case studies to be included in near-term Joule Milestone reports for the following community scale projects:

- SBER Overlook at Clipper Mill (mixed, humid climate)
- William Ryan Homes - Tampa (hot, humid climate)

Disclaimer

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Most notably, this work could not have been completed without the active and cooperative participation of our builder partners and the technical and marketing contributions of our manufacturer partners and other collaborators. We greatly appreciate their support.

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Consortium for Advanced Residential Buildings

Introduction and Summary

This final report summarizes the activities of the Consortium for Advanced Residential Buildings (CARB) for the period Jan. 1, 2008 to Dec. 31, 2010. CARB, led by Steven Winter Associates, Inc. (SWA) since 1995, is one of several teams that are working to achieve the U.S. Department of Energy's Building America (BA) program goal of developing solutions for zero net energy homes - homes that require no net off-site energy over the year to operate - a practical, cost-effective reality by 2020.

Joining SWA as members of CARB are the Davis Energy Group, Inc. (DEG), MaGrann Associates, and Johnson Research, LLC. DEG brings 20+ years of technology development, building energy analysis, and field monitoring experience to CARB. In addition to working with several California builders, DEG identifies new product opportunities and conducts funded R&D to develop them and evaluate their potential. MaGrann Associates is a specialized energy engineering, consulting and Home Energy Rating firm that has focused on bringing applied building science to the residential housing market since 1982. They joined CARB primarily to assist with opportunities for improving the energy efficiency of thousands of homes in Levittown, PA. Russ Johnson of Johnson Research brings years of experience in monitoring ground source and, more recently, cold-climate air source heat pump systems.

CARB works with scores of professionals throughout the homebuilding industry to design, engineer, construct, and test energy-efficient homes. Several thousand of these homes have been built in communities throughout the country. Results range from a 30% improvement in energy efficiency with little or no cost to the builder, to truly "zero-net-electric" homes that consume virtually no electrical energy over the course of a year.

CARB projects start with a thorough analysis of current standard building practices and local climate conditions. The systems-engineering strategies used to build the houses assure the highest level of performance, while maintaining market appeal. The team utilizes a "build, test, rebuild, retest" methodology to develop the optimal cost-effective solution to each home design, community, region, and climate zone.

CARB's Project Management Plan organized project activity under the following seven major tasks:

- Task 1: BA System Research Management, Documentation & Technical Support
- Task 2A: Stage G1A: Integrated Solutions for Specific Climate Regions
- Task 2B: Stage G1B: System Performance Evaluations
- Task 3: Stage G2: Prototype House Evaluations
- Task 4: Stage G3: Initial Community Scale Evaluations
- Task 5: Project Closeout, Final Review of BA Communities
- Task 6: Additional Research

This report summarizes the work that was done by Task. As planned, the majority of research effort was in Tasks 2B, 3, 4 and 6.

CARB Partners

CARB is a team of designers, home builders, and product manufacturers that has joined the U.S. Department of Energy's Building America Program on a cost-shared basis.



The goal of CARB is to increase the productivity and profit of the U.S. residential building industry by constructing houses that are of higher quality, more affordable, more comfortable, and energy- and resource-efficient. CARB is building a series of attached and detached prototype houses and housing developments to test these goals in the marketplace. CARB's strategy is to focus on innovations that can be integrated in the near future. CARB projects are proceeding on two interdependent tracks: building process/technology advances and market-driven decision making. Building component and system innovations are being developed in an integrated whole-house approach. Industry team members are field-testing new products, resulting in a series of lower-risk, market-tested innovations which can be implemented on a large scale.

The following is a listing of CARB partners actively involved in research efforts during 2010. CARB's complete partner list is kept updated at <http://www.carb-swa.com> under *Current Partners*.

2010 CARB Builder Partners	
Arcadia Homes	Lennar Homes
Austin Design	Lewis Planned Communities
Carmel Partners/UC Davis	Leyland Alliance
Cecil Development Affordable Housing	Metric Development
Clarum Homes	New World Home
Evergreen Building Systems	One Sky Homes
Grupe Company	Paragon Homes
Habitat for Humanity of the Chesapeake	Rural Development Inc.
Habitat for Humanity of Greater Newburgh	Shaw Builders
Habitat for Humanity International	Struever Bros. Eccles & Rouse
Hamilton Homes	Sun Terra Homes
Ithaca Neighborhood Housing Services	William Ryan Homes - Tampa
Jonathan Rose Companies	Young+Wright Architects
La Mirada	Zeta Communities
2010 CARB Industry Partners	
Advanced Energy Products Corporation	Hallowell International
BASF Corporation	Home Automation, Inc. (HAI)
Beutler Corporation	Johns Manville
Carrier Corporation	Panasonic
CertainTeed Corporation	SunPower Corporation
Corvid Inc.	UltimateAir
The Dow Chemical Company	USG Corporation
Georgia Pacific	WaterFurnace International, Inc.
Green Builder Media	Whirlpool Corporation
2010 CARB Organizational Partners	
Building Media, Inc.	National Grid, NSTAR, Cape Light Compact
Connecticut Light & Power	PG&E
EDAW	UCD Energy Efficiency Center
Maryland State Energy Office	WPPI Energy

Task 1: BA System Research Management, Documentation & Technical Support

CARB's 2010 contributions to Task 1 are broken down into ten subtasks.

1.1 *Perform Duties as Industry Team Lead*

As Lead Team for the Hot/Mixed Dry climate, CARB was responsible for:

- Coordinating identification of BA core systems required to achieve annual performance targets
- Coordinating identification, development and review of builder project case studies,
- Coordinating writing assignments for individual sections of the annual Joule milestone report, and
- Reviewing core system recommendations with system technical leads

CARB's DEG and the BIRA team are the most active BA teams in this climate region and their G3 projects were being monitored. As the Building America program is going away from this Joule reporting format, CARB does not plan to proceed with the Hot/Mixed Dry Climate Joule report that was scheduled for 2011.

1.2 *Prepare Combined Monthly, Quarterly and Event Reports*

CARB has provided monthly summary reports of the team's activity on all of its advanced systems research activities and builder projects, prototype and community scale. Also, highlight reports have been prepared for George James and Project Tracking tables have been submitted to NETL quarterly.

1.3 *Update Building America Project Database*

CARB last updated the Project Database with information on prototype and community scale homes in October 2010.

1.4 *Participate in Working Groups*

CARB representatives actively participate in several working groups including BA Analysis and Dehumidification. CARB also led a working group on Ground Source Heat Pumps (GSHP) which developed a monitoring protocol for in-field evaluations.

BA Analysis Group

Throughout the year CARB has participated in the monthly BA Analysis working group calls and further supported this working group in development of the Building America House Simulation Protocols (dated September 2010).

Ground-Source Heat Pump

Since 2009, CARB has led the BA Ground-Source Heat Pump (GSHP) working group. A yahoo's group has been created to keep all interested parties informed and to allow the sharing of information in a central location. The address for this yahoo's group is <http://tech.groups.yahoo.com/group/BA-GSHP>. All BA teams have had representatives

participate in the group and additional participants from NREL, ORNL, Navigant, Newport, GSHP industry organizations, and GSHP manufacturers have been included in discussions.

A Ground-Source Heat Pump Monitoring Protocol was developed and peer-reviewed. It was uploaded to the BA extranet site on 2/9/2010. In addition, Tom Williams of NREL has been developing a Geothermal Heat Pump Roadmap, which CARB has been reviewing and commenting on.

Mini-Split Heat Pump Group

CARB has been working directly with NREL on development of a Mini-Split Heat Pump (MSHP) Monitoring Protocol. CARB intends to provide field evaluation of the monitoring protocol, once the lab evaluation has been completed by NREL.

1.5 Attend Quarterly Building America Meetings

The February and April multi-day quarterly meetings held in Washington D.C. were canceled. However, CARB sent multiple representatives to make seven presentations and participate in the BA team meeting held in Denver, CO (July). Four of these presentations are provided as Attachments.

- Barriers to Successful Community Scale Retrofit Programs (Attachment A).
- Affordable Housing Redevelopment: Chamberlain Heights (Attachment B).
- Lender Confidence in Energy Efficiency Retrofits (Attachment C).
- Deep Energy Retrofit: ReVISION House - Las Vegas (Attachment D).

1.6 Attend Conferences and Workshops

Conference or Workshop	Speaker/Presentation
ASHRAE Inside 2010 (Jan. 24)	David Springer/Energy and Water Waste Implications of Hot Water Distribution System Design and Use Patterns (Attachment E)
NESEA BE 2010 (Mar. 9)	Robb Aldrich/High Performance Windows for Northern Climates (Attachment F)
BEST2 Conference (April)	Robb Aldrich/ Practical, Residential Wall Systems: R-30 and Beyond (Attachment G)
National Oil Heat Research Alliance Conference 2010	William Zoeller/Getting to Zero: Residential Retrofits and New Construction (Attachment H)
California Redevelopment Association Conference (May 4-5, July 13-14)	David Springer/EERE Opportunities and Strategies in Market Rate & Affordable Housing (Attachment I)
ACEEE Hot Water Forum (May 12-14)	Marc Hoeschele /Modeling Distribution System Performance (Attachment J)
Panasonic Workshop (June)	Lois Arena & Robb Aldrich/Current Projects & Technology Gaps (Attachment K)
Norwalk Preservation Trust (July)	William Zoeller/ Insulating You Green Old House (without screwing it up) (Attachment L)
EEBA 2010 (Oct. 13)	Srikanth Puttagunta/ Building America Emerging Technologies Research (Attachment M)
Geothermal Resource Council Conference (Oct. 26)	Srikanth Puttagunta/Residential GSHP: In-Field System Performance and Energy Modeling (Attachment N)

1.7 Host and Participate in Building America Expert Meetings

CARB held an expert meeting on Oct. 28th in Albany, NY that examines the in-field performance condensing boilers and identifies the linkages to the Building America program goals of zero energy homes.

Topics covered included:

- Overview of monitored systems and research scope/objectives.
- Reviewed recommendations and installed system configuration without use of primary/secondary.
- Discussion of high flow rates, interaction of zone flows, and use of zone valves vs. zone circulators.
- The impact of “over-pumping” that commonly occurs.
- The need to consider “Distribution Efficiency” versus equipment thermal efficiency.
- Alternatives for providing hydraulic separation between the boiler and heating zones, including primary/secondary loops, buffer tanks, and specialty fittings.
- Potential for boiling within the heat exchanger at low flows, which would occur in systems without a primary loop to maintain minimum recommended flow rates; and determine optimal condensing performance with indirect domestic hot water tanks.
- Savings associated with variable speed pump technology, both Electronically Commutated Motors (ECM) and Pulse-Width Modulation
- Details related to testing standards (ASHRAE 152 – Method for Testing Distribution Systems, Chapter 7 – Hydronics), cost of certification, and how the program will be regulated and mandated
- The lack of certification and quality control programs for technicians associated with hydronic system installation and the importance of proper installation on system performance

The Condensing Boiler Expert Meeting agenda, presentations, minutes, and attendee list have been posted at www.swa.sharefile.com and are available in the following attachments.

- Agenda and Attendee List (Attachment O).
- Meeting Notes (Attachment P).
- Presentation – Meeting Intro and Objectives (Attachment Q).
- Presentation – Building America Condensing Boiler Research (Attachment R).
- Presentation – Hydronic System Performance (Attachment S).
- Presentation – Boiler Performance Testing (Attachment T).
- Presentation – Pump Efficiency Rating Systems (Attachment U).

The Condensing Boiler Final Report is included under the Advanced Systems Task as Attachment GG.

CARB representatives also attended the following Expert Meetings hosted by other BA teams or labs:

BSC's Construction Details for Deep-Energy Retrofits – March 12

1.8 Technical Reports and Presentations

In addition to the presentations previously noted under subtask 1.6, CARB has submitted technical papers that have been peer-reviewed and approved for presentation at BEST 2, GRCC, and ACEEE. Several journal articles have also been published during BP3.

California Energy Commission – Energy Aware Planning Guide (Attachment V)
BEST2 – Practical Residential Wall Systems: R-30 and Beyond (Attachment W)
ACEEE – The Last Big Leak: Exposed Slab Edges (Attachment X)
ACEEE – Zero Energy Communities: UC Davis' West Village Community (Attachment Y)
ACEEE – A Case Study in Reconciling Modeling Projections with Actual Usage (Attachment Z)
Geothermal Resource Council – Residential Ground-Source Heat Pumps: In-Field System Performance and Energy Modeling (Attachment AA)

Website

CARB prepared several white papers, case studies, and building details that address specific gaps or design questions that are frequently encountered through our various projects. A key element that CARB has been focusing on in these resources is not to discuss what the best practice is, but how builders/contractors/homeowner can practically achieve these best practices. These guidelines are available at CARB website at www.carb-swa.com. A summary of new website content is provided below:

Building Detail – Garage Band Joist Air Barrier
http://www.carb-swa.com/articles/homepage/Air_Sealing1.pdf
Building Detail – Insulation and Air Sealing II
http://www.carb-swa.com/articles/homepage/Air_Sealing2.pdf
Building Detail – Advanced Framing I
http://www.carb-swa.com/articles/homepage/Advanced_framing1.pdf
Building Detail – Advanced Framing II
http://www.carb-swa.com/articles/homepage/Advanced_framing2.pdf
Building Details – Multi-Family Air Sealing Guide
<http://www.carb-swa.com/articles/guidelines/Multi-Family%20Air%20Sealing%20Guide.pdf>
Guideline Update – Designing Forced-Air HVAC Systems (was written up in Energy Design Update's October issue)
http://www.carb-swa.com/articles/guidelines/Forced%20Air%20HVAC%20Guide%20updated%2008_31_10.pdf
Guideline – Mold: Ignorance Is Not Bliss
<http://www.carb-swa.com/articles/guidelines/Mold%20writeup.pdf>
Case Study – Revision House Mini-Case Studies
http://www.carb-swa.com/articles/retrofits/BASF_revised.pdf
<http://www.carb-swa.com/articles/retrofits/Dryvit.pdf>
<http://www.carb-swa.com/articles/retrofits/Milgard.pdf>
<http://www.carb-swa.com/articles/retrofits/MBCIfinalrevised.pdf>
<http://www.carb-swa.com/articles/retrofits/DuPont.pdf>
<http://www.carb-swa.com/articles/retrofits/energy.pdf>
<http://www.carb-swa.com/articles/retrofits/Trane.pdf>
<http://www.carb-swa.com/articles/retrofits/Rinnai.pdf>
<http://www.carb-swa.com/articles/retrofits/AmericanStandard.pdf>
<http://www.carb-swa.com/articles/retrofits/EagleSun.pdf>
<http://www.carb-swa.com/articles/retrofits/SunPower.pdf>

In addition, CARB put out three issues of the CARBNews newsletter that has a distribution list of over 14,000 subscribers.

February – Residential Wall Systems: R-30 and beyond

http://www.carb-swa.com/articles/carbnews%20articles/CARBNews_Feb2010.pdf

July – Tools for Residential Solar Analysis

http://www.carb-swa.com/articles/carbnews%20articles/CN_July2010.pdf

November – Retrofitting America: A 1970's Home Analysis

http://www.carb-swa.com/articles/carbnews%20articles/CARBNews_Nov2010.pdf

1.9 Review Draft Best Practice Case Studies Produced by NREL

CARB peer-reviewed the ***Draft Work Specification for Residential Retrofits***, a document that was a part of the National Residential Retrofit Guidelines project sponsored by DOE and EERE.

CARB also provided retrofit case study content to Gail Werren at NREL for the ***Building E2 Newsletter***.

Our Newburgh, NY retrofit case study focused on atypical use of rigid insulation within the stud cavities, so not a continuous thermal break, but as this was available to HfH as a donation, they utilized it to improve thermal resistance and air sealing of the walls and ceiling.

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_cs_retrofit_newburgh_habitat.pdf

Our Wapato, WA retrofit case study focused on exterior rigid insulation sheathing and blown cellulose cavity insulation to reduce building loads and infiltration levels.

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_cs_retrofit_yakama.pdf

Our Washington D.C. retrofit case study focused on dealing with brick exteriors. The use of rigid insulation on the interior surface of the exterior wall and air sealing was used to reduce the building load. Air sealing of rim/band joists, window openings, penetrations, bottom/top plate, and stairwells were a focus of this retrofit.

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_cs_retrofit_carb.pdf

Similar to the DC project, our Baltimore, MD retrofit case study focused on dealing with brick exteriors and air sealing.

http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_cs_retrofit_chesapeake_habitat.pdf

Our Las Vegas, NV retrofit case study dealt with retrofitting a home from the exterior.

http://www1.eere.energy.gov/buildings/challenge/pdfs/ba_builderschallengespotlight.pdf

1.10 Peer Review Activities for Stage Gates

Work under this task included two peer-reviews of reports requested by NREL through the SharePoint Administration Site.

40% Mixed, Humid Best Practices: *07-19-10 Mized Humid G3 Communities Report Compiled*
40% Hot, Humid Best Practices: *2010_jul_pmmrpt_hothumid_40_draft2[1]*

Task 2A: Stage G1A – Integrated Solutions for Specific Climate Regions

2.1 *Perform Duties as Industry Team Lead*

CARB continues to perform technology pathway analyses using BEOpt optimization software as well as EnergyGauge to investigate technology pathways that will lead to zero energy homes in all climate regions.

California 50% Savings Packages

Residential building energy efficiency has become a well recognized marketing strategy amongst production home builders in California. However, builders frequently express frustration about how to deal with the variety of overlapping programs that are offered by utilities, Energy Star, Build-It-Green, LEED, Builders Challenge, and how they relate to Title 24 standards. DEG/CARB recognized the need for a streamline approach that would allow builders to quickly review design specifications that would meet their “performance goal of choice” and that they can use to support their marketing strategy.

In this work DEG/CARB developed packages for 9 of the 16 California climates zones that meet California Tier 1 and Tier 2 incentive criteria as well as the Building America 50% milestone. These packages represent a cost-effective, current best practice design approach that can be implemented without the need for costly and time-consuming plan-by-plan analysis. The packages also report HERS indexes for Builders Challenge qualification and provide a direct comparison between Title-24 compliance and Building America Benchmark savings. Although the specifications may not produce the indicated results for all plan types, builders can use this information as a general guideline that can be reinforced with detailed analysis of specific plans.

A report on the California 50% packages development is provided as Attachment BB.

2.2 *Perform Duties as Technical Lead*

CARB has Technical Lead responsibilities for space conditioning and hot water. CARB, including member DEG, continues to be a leader in mechanical system research with several advanced system projects on space conditioning and water heating technologies. This research is reported in various forms to different audiences including DOE, the building science community, and trades.

Technologies being studied include ground source heat pumps, cold climate air source heat pumps, condensing boilers, heat pump water heaters, solar thermal water heating, advanced ventilation systems, evaporative condensers, and hybrid forced air-radiant distribution.

SWA engineer Srikanth Puttagunta recently gave a well-received 75-minute presentation highlighting much of this research at the EEBA Conference in Portland (Attachment M). This presentation was the Building America sponsored Advanced Building/Technology track. He also presented a peer-reviewed technical paper on ground source heat pump performance at the Geothermal Resource Council Conference (Attachment N). Davis Energy Group’s David Springer and Marc Hoeschele have presented their hot water research findings at ASHRAE (Attachment E) and ACEEE (Attachment J).

Task 2B Stage G1B: System Performance Evaluations

CARB continues to conduct advanced systems research on technologies important to accomplishing the BA program goals.

2.3 Envelope Technologies

High R-Wall Systems

With uncertainty of energy prices and an increased interest in sustainability, more builders and designers are striving for dramatic levels of home energy efficiency. Performance of the home's envelope is clearly critical in this endeavor. In colder climates, several builders are moving towards whole-wall thermal resistances above 30 ft²hr°F/Btu (4.9 m²°C/W). While there are numerous high-performance wall systems, CARB is focusing on three of the most practical methods to achieve whole-wall performance of R-30 or above. Working with builders in cold climates, CARB has found that these three approaches are often the most well-established, use readily available materials, and are buildable by contractors without substantial additional training or expertise:

- Double framed walls with blown or sprayed insulation;
- 2x4 or 2x6 insulated, framed walls with exterior rigid foam insulation;
- Structural insulated panels (SIPs).

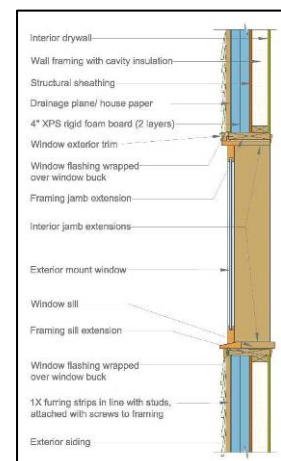
CARB submitted a paper for the 2010 Building Enclosure Science & Technology (BEST) Conference (Attachment T) that documents key components, advantages, and challenges for each wall system, including:

- Material choices and options;
- Structural issues, durability, and moisture management;
- Requirements of builders and trades (framing, insulation, plumbing, electrical, siding, etc.);
- Cost considerations.

The “best” choice for a wall system will vary with region, with fluctuating material prices, with building design and type, and with builder experience and preference. From experience working with builders using these techniques, CARB has prepared this paper to provide key considerations and guidelines for designing and building homes with walls of R-30 or higher.

The Best2 Conference Paper entitled “Practical Residential Wall Systems: R-30 and Beyond” is provided as Attachment W.

In addition, CARB continued to work with builder partners to document construction of high R-walls. CARB documented a prototype wall assembly with FinishWerks & Icon Legacy modular builders incorporating a staggered double wall with a hybrid cavity insulation system (2” of closed-cell spray polyurethane foam and fiberglass batts) and 1.5” of rigid exterior insulation. Another prototype project located in Alden, NY (the Young Residence is discussed in more depth in Task 3) incorporated a 2x6 framed wall with ccSPF on the interior side of the sheathing, blown cellulose insulation in the remainder of the wall cavity, and 3.5” of foil-faced rigid exterior insulation. In addition to documenting these wall constructions, CARB is also performing THERM (Two-Dimensional

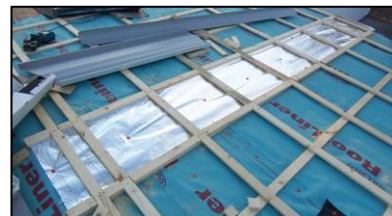


Building Heat-Transfer Modeling) and WUFI (transient hygrothermal behavior of multi-layer building components) analysis on these assemblies and a couple other more typical cold climate wall assemblies.

A draft report of this research is provided as Attachment CC.

Effects of a Radiant Barrier on Roof Cavity Temperature

The ReVision Las Vegas house is a research and training platform intended to demonstrate cost-effective, market-ready methods for achieving near-net-zero energy consumption in deep-energy retrofit projects. Significant building envelope upgrades were combined with efficient mechanical systems, and renewable energy systems. The thermal envelope improvements (walls, roof, windows, etc.) were performed primarily from the exterior, leaving the interior building finishes largely intact. Added to the deep energy-efficiency measures were significant levels of renewable energy in the form of a solar PV system and a solar-thermal hot-water system.



The roof insulation presented additional unique challenges and opportunities. Before renovation, the cooling load from the roof assembly was immense with poorly installed insulation, plenty of air-leakage paths (over a dozen non-sealed can-lights), and ineffective venting. In a hot-dry climate like Las Vegas, with its extreme summer heat and solar radiation levels near the highest in the nation, roofs are exposed to high levels of ultra violet radiation (UV) shortening life spans and increasing cooling loads.

In order to obtain the R-values desired, seal the air leaks, and not adversely affect the architectural character by adding a thick layer of insulation above the decking, closed-cell foam was specified. Working from the exterior, to leave the ceiling finishes in place, the existing roll-roofing and decking were removed exposing the 2 x 10 rafter cavities. The foam was sprayed against the gypsum board to a final depth of 8.5". Above the dropped ceiling soffits that housed the ductwork, furring strips and ledgers were added at the bottom of the rafters to support gypsum board fillers providing both a surface to foam against and the required thermal barrier for foam of this thickness. This strategy also placed the soffits and hence the ductwork within conditioned space. At a rated R-value of 6.9 per inch, 8.5 inches of foam resulted in an R-value of 58.65.

Using this strategy the ReVision House project team devised a roofing solution that is compatible with the homes architecture, but also one which has the capability of reflecting solar energy and rejecting thermal heat before it has a chance to penetrate through the insulated roof assembly and into the house. A vented "cool" metal roof was the clear choice. The product specified had a factory applied paint coating with a solar reflectance (SR) of over 0.46, and a solar Reflectance Index (SRI) of 53 or higher. Second, the manner in which this roof is installed creates a 1½" vent space below the standing seam metal but above the roof decking to direct heated air out and away from the insulated assembly.

To investigate how far this heat-rejection strategy could be effectively pursued, CARB monitored two different roof bays: one with an additional radiant barrier placed on the roof decking underlayment facing up into the vented space, and the other with no additional radiant barrier. The test bays were isolated from the remainder of the roof to prevent cross-communication of air from the rest of the roof into the test bays.

A summary of this research is provided as Attachment DD.

Unvented Roof Retrofit Evaluation

In 2009, the state of Nevada was recipient of almost forty million dollars in Neighborhood Stabilization Funds from the Department of Housing and Urban Development. With this money, Clark County has developed 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 which result from these inspections. These homes are then resold to qualifying buyers or held by the Housing Authority for rental.



During this process, all parties involved have experienced a very steep learning curve. This includes the program administrators, auditors and subcontractors. One of the biggest barriers to successful implementation of this program has been the lack of training and understanding of the HVAC industry to comply with the requirements of the Air-Conditioning Contractors of America (ACCA) for achieving a quality installation of heating and cooling equipment. Constant training and oversight has been necessary to ensure systems are properly installed. There have been instances where contractors refuse to warranty their work because they feel that the system is not large enough, is equipment they are not familiar with or will face environments that they feel will be inhospitable to the equipment. This last complaint was the basis for this introductory study.

One of the retrofits commonly being recommended is the installation of roof deck, spray-foam insulation. This is being done to increase insulation levels and to bring the mechanical system located in the attic into what would now be semi-conditioned space. In an effort to save money, the existing, inadequate insulation located on the ceiling plane was not being removed in some of the homes in Clark County. Because of this, the HVAC contractor refused to warranty the job because he felt that leaving the insulation on both the roof deck and ceiling plane would create an inhospitable environment for the AC unit. The contractor, however, did not provide any support for this claim.

In response to this, CARB proposed monitoring attic temperatures and relative humidity levels in several different homes. Four homes were finally decided upon: two with vented attics and ceiling plane insulation only, and two with unvented attics and insulation on both the roof deck and ceiling plane.

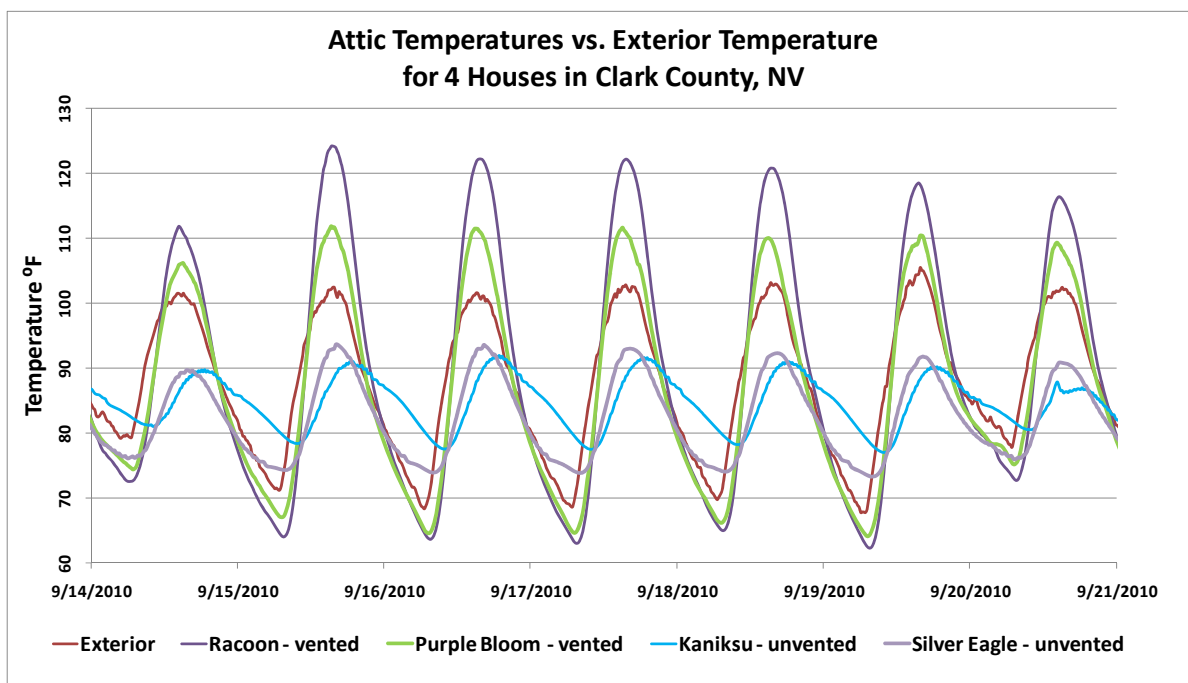
Attic sensors were zip-tied to the roof truss cross members at the height of the top of the air handler cabinet at two points in each attic – approximately 18" above the bottom cord of the trusses and in alignment with each end of the air handler. During monitoring, all homes were vacant and were kept at 80°F. Temperature and relative humidity data were recorded using HOBO U12 and U23 sensors at 15 minute intervals over a 3 week period in September of 2010. Exterior sensors were placed under overhangs on the front porch of two of the homes. These, unfortunately, needed to be attached to light fixtures as there were no other viable places to attach them. Fortunately, all four homes were unoccupied at the time and it does not appear that the exterior lights had much of an affect on the sensors. There are no temperature spikes in the evening hours that would lead one to believe that the sensors were being heated up by the lights.

The basic attic configuration in each home is summarized in the table below.

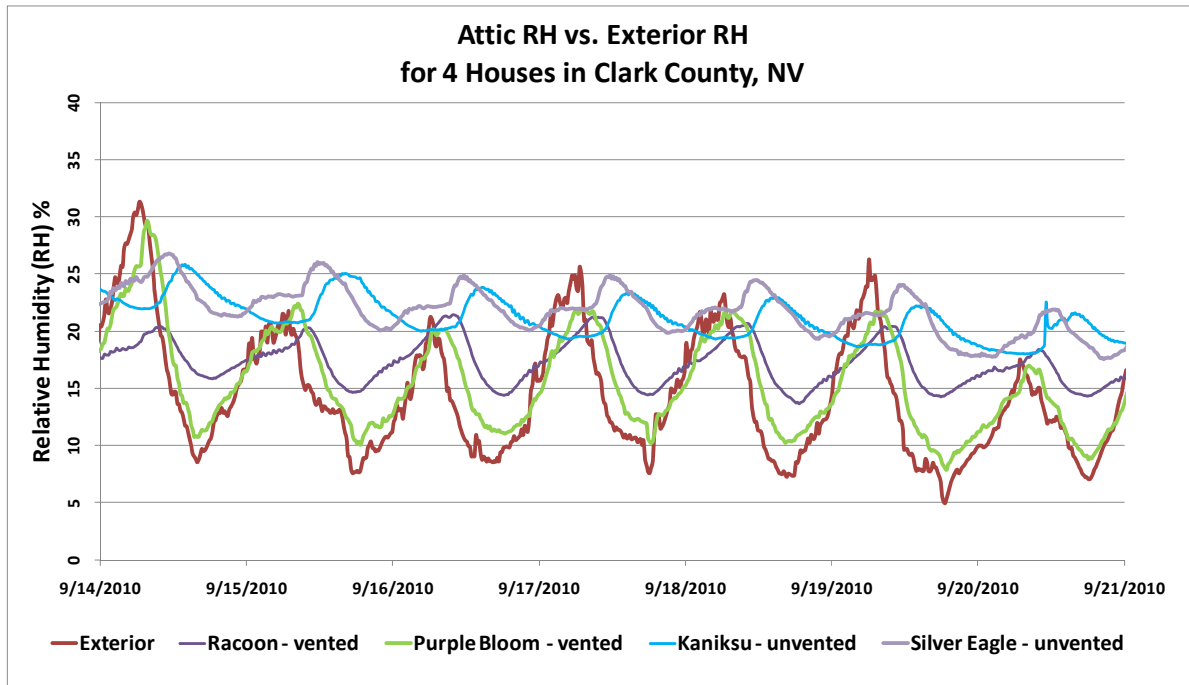
Attic Configurations for Homes Monitored in Clark County, NV

Address	Raccoon	Purple Bloom	Kaniksu	Silver Eagle
Attic space height	4'	5'	6'	2'
Roofing material	med. red tile	med. grey tile	med. grey tile	med. red tile
Roof deck insulation	n/a	n/a	R-30 – open cell	R-10 - open cell
Ceiling insulation	R-30 cellulose	R-30 cellulose	R-19- cellulose	R-25-fiberglass
Roof orientation	1/3 each: N,S & E	E/W	E/W	E/W
Venting	Vented	Vented	Unvented	Unvented
Photo				

The following graphs show the temperature and relative humidity in all four attics compared to the exterior temperatures during a one week period in September. The data displayed in each graph is the average of the two sensors in each attic. The data from the two exterior sensors was also averaged. Except for the two exterior sensors, there was less than a 2.5 degree variation between sensors in each attic.



Attic Temperatures vs. Exterior Temperatures for 4 Homes in Clark County, NV



The maximum temperatures and relative humidity levels recorded from each sensor during this three week period are listed below.

Maximum Temperature of Each Sensor During the 3 Week Monitoring Period

	Raccoon		Purple Bloom		Kaniksu		Silver Eagle	
	Temperature [°F]	RH [%]	Temperature [°F]	RH [%]	Temperature [°F]	RH [%]	Temperature [°F]	RH [%]
Attic Sensor 1	127.3	23.7	116.1	38.9	103.6	32.9	96.2	29.6
Attic Sensor 2	127.8	24.6	117.4	39.0	104.1	34.4	98.2	29.8

There is a significant difference between the maximum temperatures of the vented attics (Raccoon & Purple Bloom) vs. the unvented attics (Kaniksu & Silver Eagle). On the conservative side, there is a 13°F difference in these max temperatures if you compare Purple Bloom to Kaniksu. On the liberal side, there is a 30°F difference between the lowest max and highest max attic temperatures in the table if you compare Silver Eagle to Raccoon. The maximum outdoor temperatures were 115.1°F recorded at Silver Eagle and 107.8°F at Purple Bloom. Although both sensors were located on covered porches and were not exposed to direct sunlight, the difference in these temperatures can most likely be attributed to the fact that the porch at Silver Eagle was located on the south side of the house. There was no additional shading to that side of the home from neighboring properties or projections from the home. The porch at Purple Bloom was located on the east side of the home, was shaded by neighboring properties and its own garage. What is important to note is that the vented attics get hotter than the ambient air where the unvented attics do not.

The graphs and table clearly show that the equipment in the vented attics was subject to much more extreme temperatures during this monitoring period than that in the unvented attics with roof deck insulation. The relative humidity (RH) is relatively stable in these unvented attics, which is consistent with more stable temperatures. RH values might be different in occupied

homes with greater moisture generation potential, but it appears that insulating the roof deck of an attic in Las Vegas (while leaving existing ceiling insulation) does not create a more inhospitable environment for HVAC equipment than a vented attic with insulation on the ceiling plane. If HVAC contractors are comfortable placing the equipment in a vented attic with the insulation located on the ceiling plane in this climate, this data suggests an unvented attic should give them no extra cause for concern.

Insulating the roof deck as a retrofit measure is becoming more common in some climates. It can provide superior R-values, help air seal the home and bring the mechanical equipment into a semi-conditioned space. Considering that the retrofit market is the main focus of the building industry and the current administration's goals include increasing the efficiency of the housing stock, further investigation into this particular retrofit may be warranted.

2.4 Heating and Cooling Technologies

Non-Ducted Mechanical Systems

The Katywil development in Colrain, MA is a small community of homes that are incorporating many similar to those used by nearby developer and CARB-partner Rural Development, Inc. (RDI). The architect for both projects, Austin Design, incorporated double walls, triple-pane windows, and air-tight construction. Because one of the goals of the Katywil development was using no fossil fuels on site, these homes provide an opportunity to conduct research on other, electric-only, options for meeting modest space conditioning loads in high performance homes.



The first two homes were occupied in the mid-late 2009. The first home is heated with a ductless, mini-split heat pump with two interior fan coils; there is auxiliary electric resistance heat in three rooms in the home. The second home is heated by a combination of active solar thermal and an electric resistance boiler with radiant floor heat delivery. CARB has installed monitoring equipment to record electric energy consumption of the heating systems, several other key home loads, and outdoor temperature and humidity conditions during the winter of 2009-2010.

A summary report on this research is provided as Attachment EE.

Low-Load Heating Systems

For high performance (50%+) cold climate homes with excellent envelope performance, design heating loads are very small. Building America teams have struggled to find systems small enough to meet these loads efficiently, comfortably, and cost-effectively. At Wisdom Way Solar Village in Greenfield, MA, Rural Development Inc. (RDI) is building homes with exceptional thermal envelopes. To heat each home, a single, gas-fired, sealed-combustion room heater is located in the central living space of each home. There is no heat provided directly to bedrooms, though a modified ventilation fan is used as a simple distribution system to provide some thermal equalization. CARB has installed long-term monitoring that is on-going.



A comprehensive report on this research is provided as Attachment FF.

Condensing Boiler/Hydronic Distribution Systems

Condensing boilers are designed to higher combustion efficiencies by recovering the latent heat of condensation from the combustion process. However, to achieve this efficiency gain, requires return-side water temperatures below 130°F for gas equipment and 118°F for oil equipment. CARB has observed that most condensing boiler installations are not designed to provide the required low return-side water temperatures.



With additional funding from New York State Energy and Research Development Authority (NYSERDA), CARB continues to work with Ithaca Neighborhood Housing Services, a non-profit developer and operator of for-sale and rental affordable housing in Central New York. During BP2, existing homes were evaluated. During BP3, CARB designed the hydronic distribution for three new homes and monitoring is on-going. Two main changes in the new distribution design are the elimination of the primary loop and lower circulating flow rates.

The initial results of this monitoring were presented at an expert meeting on Oct. 28th in Albany, NY that was attended by folks from NREL, NYSERDA, and numerous boiler manufacturers.

A comprehensive report of the BP3 research on this project is provided as Attachment GG.

Ground Source Heat Pump Systems

CARB worked with contractors and homeowners in Connecticut, Wisconsin, and Virginia to monitor the true performance of residential ground source heat pump (GSHP) systems. The technical paper provided as Attachment AA provides the results of long-term GSHP monitoring at three residences to provide better understanding of the potential source energy and whole-building performance benefits of this technology. With the increase in market penetration and with federal, state, and utility incentives for the installation of these units, CARB believes it is critically important to know how systems are actually performing in order to gauge what advancements need to be made to achieve long-term Building America zero energy goals. CARB's primary focus of these evaluations was on heating performance in the cold climate zone.



In addition, CARB led a GSHP working group in 2009 through early 2010. The efforts of that group resulted in a minimum monitoring protocol for GSHPs. The goal of this monitoring plan was to develop a valid, consistent, and concise approach for use by all Building America teams to document and assess GSHP system performance. The resulting body of data will provide deeper understanding of system performance and the associated savings potential. The monitoring plan is provided as Attachment HH.

Low-Temperature Air-Source Heat Pump

A 4-ton Low Temperature Heat Pump (LTHP) manufactured by Hallowell International was installed in a residence in Madison, Connecticut in April 2009. The Low Temperature Heat

Pump is claimed to operate down to -30°F , and to supply all needed heat to a home via its compressors with very minimal use of a supplemental heat source. It claims a steady-state Coefficient of Performance (efficiency) greater than 2.0 at -10°F . “Standard” heat pumps, in comparison, lose heating capacity as the outdoor temperature drops below about $+30^{\circ}\text{F}$ and rely increasingly heavily on supplemental heat (usually an electric resistance heater).

Minimizing the use of electric resistance heat not only reduces the homeowner’s heating bill; it also reduces the heat pump’s contribution to the local electric utility’s winter peak load. Extensive metering equipment was installed in September 2009 to monitor the performance of the heat pump over the 2009 – 2010 winter. Data were collected during each minute of the winter for system and subsystem power, various temperatures, air flow, and system status.



A summary of the BP3 research on this project is provided as Attachment II.

Sleeve & Packaged-Terminal Air Conditioner

SWA has worked in the multifamily sector, particularly affordable housing, for many years. Much of this work has been in the New York City area with funding support from the New York State Energy Research and Development Authority (NYSERDA). SWA is currently providing technical support to dozens of projects and program development efforts with funding from private developers, NYSERDA, and EPA. Following research in BP2 on the concepts of “compartmentalization” and the use of “unitized” ventilation, CARB investigated the infiltration impact of through-the-wall (“sleeve AC”) and packaged terminal heat pumps and air conditioners (“PTHPs” and “PTACs”). These systems represent a permanent penetration through the building envelope. The following image shows a new townhome project on Staten Island with sleeve AC systems.



Sleeve AC Systems in a Staten Island Townhome Project

Sleeve or through-the-wall air conditioners are similar in design to window air conditioners in that they are a self-contained unit that can be installed and removed by a tenant. They are mounted in a metal sleeve that has been installed through a rough opening in the wall, typically under a window. Sleeves have been installed in buildings at the time of construction since the 1950s and may also be retrofitted in buildings that were not otherwise designed with a cooling system.



Typical Sleeve AC System

Because they must fit in a sleeve and not protrude beyond the building façade, sleeve air conditioner condenser coils are only exposed to the outside from their exterior face in the rear; they do not have louvered sides like window air conditioners do. The amount of air leakage through the sleeve may vary, depending on whether or not an air conditioner unit is installed and, if one is, whether it is a proper sleeve unit or just a window unit stuck in the opening. The air leakage can come from a few different sources: the joint between the unit and its sleeve, the joint between the sleeve and the drywall finish, and through the air conditioner unit itself.

Packaged terminal air conditioners (PTACs) and packaged terminal heat pumps (PTHPs) started to be installed in New York City buildings in the 1970s. Both types of units are mounted in a metal sleeve which has been installed through a rough opening in the wall; however, in this case only the outdoor section fits into the sleeve itself. PTACs are professionally installed at the time of construction, usually in every bedroom and living room and almost always maintained by the building owner. The indoor section extends well into the living space in a cabinet.

Air leakage through PTACs and PTHPs is similar to that of sleeve ACs: there may be gaps between the rough opening and the sleeve and between the sleeve and the unit itself. PTACs and PTHPs may also have holes within the units themselves, such as penetrations for refrigerant and electrical lines as well as dedicated outside air dampers.



Typical Packaged Terminal Air Conditioner

In order to assess the infiltration impact of these systems, CARB researchers developed a field protocol for measuring the effective leakage area in square inches of a unit using a modified “blower door” test.



Air Infiltration Testing of a Packaged Terminal Unit

Five buildings of various vintages with sleeve ACs were tested. The average leakage area for these cases was 5.2 square inches. The one installation tested with a small window AC installed in the sleeve was over twice as leaky as the average unit tested. Ignoring the case of the window AC installed in the sleeve, there is a general trend of tighter installations in older buildings, probably due to years of paint covering up any gaps around the units. This trend implies that the majority of leakage in these types of installations is around the air conditioners and not through them. Moreover, the result from Building 7 demonstrates that it is possible for a sleeve AC installation to result in almost zero leakage.

Air Leakage Test Results for Sleeve AC Buildings (with ACs Installed in Sleeves)

Test Building #	Year Built	Affordable or Market Rate	Description	Total Leakage Area (in ²)
4	2010	Affordable	Sleeve AC	7.1
5	1999	Affordable	Sleeve AC	4.6
5	1999	Affordable	Sleeve AC	5.2
6	1983	Affordable	Sleeve AC	1.9
7	1991	Affordable	Sleeve AC	0.7
8	1928	Affordable	Window AC in sleeve	11.7
Average				5.2

CARB researchers also tested five PTAC units in three market rate buildings constructed in the last 20 years. The average leakage area for all cases was 6.7 square inches.

Air Leakage Test Results for PTAC Buildings

Test Building #	Year Built	Affordable or Market Rate	Description	Total Leakage Area (in ²)
9	1990	Market Rate	PTAC Ice Cap P.DNS.2.015.C.Z.63.12AR.14.C.I.C.I	5.2
9	1990	Market Rate	PTAC Ice Cap, CTC09200 CAFLDA	5.6
10	1986	Market Rate	PTAC Retroair, RC3509A0A	4.2
11	1994	Market Rate	PTAC Ice Cap 5RSCT12WNC	11.6
11	1994	Market Rate	PTAC Ice Cap 5RSCT09WNC	7.0
Average				6.7

Evaporative Condenser Gate Evaluation

Evaporative processes provide an important vehicle for reducing cooling system energy use in very hot-dry climates such as the desert southwest. Evaporative condensers demonstrate efficiency advantages by reducing the temperature of the condensing environment from the outdoor dry bulb temperature to close to the outdoor wet bulb temperature. Energy savings, which stem from reduced temperature “lift”, are most significant when outdoor temperatures are high and when the difference between dry and wet bulb temperatures (the “wet bulb depression”) is the greatest. Evaporative condensers have achieved a measure of reliability over the relatively short length of time they have been on the market and they fill a much needed market niche for high performance cooling systems in hot dry climates.



The objective of this project was to identify the status of evaporative condensers in a stage gate context, and to evaluate improvements made during BP2 to the design of the AquaChill evaporative condenser. Residential evaporative condensers are represented by two manufacturers, AquaChill and Freus. The technology passed all gates with the caveat that they have not been on the market long enough to be assured of long term durability and reliability.

Modeling results predicted 20% cooling energy savings compared to a SEER 13 air-conditioner in hot-dry valley climates. Savings in transitional climates were lower at 9%. In abbreviated field tests the improved second generation AquaChill design showed an average EER of 15.6. The primary barrier to widespread dissemination is the high first cost. Additional implementation obstacles include sensitivity to increased water usage and uncertain maintenance requirements.

A detailed summary of this work is provided as Attachment JJ.

Hybrid Air-to-Water Heat Pump Evaluation

Radiant cooling is a relatively uncommon and understudied means of cooling delivery. The effectiveness of a hybrid forced air / radiant cooling system was evaluated in a previous Building America study, with results showing significant improvements in cooling efficiencies (DEG, 2008). Chilled water is generated from a refrigerant-to-water air conditioner and sent first to a fan coil to provide latent and sensible cooling before going to the floor, reducing the chance for condensation formation on the slab. In the DEG study, the hybrid system resulted in higher EER performance that is most likely due to the high return temperature to the evaporator, but

little in the way of seasonal energy savings because the slab underside was uninsulated resulting in delivery inefficiencies. The objective of this project is to model, implement, and monitor the effectiveness of the hybrid delivery system in another application with an insulated slab. The hybrid system in this study will utilize the Daikin Altherma Monobloc air-to-water heat pump.

The focus of this study is on assessing:

- Performance of the Daikin Altherma air-to-water heat pump in both cooling and heating and water heating operation
- Effectiveness and efficiency of the hybrid floor cooling design and the optimal mix of the two delivery systems

The home chosen for this study, the “Cana” house, is a 3,268 ft², single-story home located in Chico, CA. Chico is in a hot/dry climate (California Climate Zone 11) on the north end of the Sacramento Valley. Construction began in early May and the expected completion and occupancy date is mid 2011. Pre-wiring for monitoring equipment has been installed in the slab and interior of the home. Monitoring and evaluation of the home and the hybrid forced air / radiant cooling system will begin upon completion of the house and continue for one year.



Preliminary modeling results of the house estimate performance 60% better than the 2008 Building America Benchmark. Due to modeling limitations of the Altherma heat pump and hybrid delivery system in BEopt, extensive modeling of the hybrid delivery system is underway with a TRNSYS v17 model. DEG worked with TESS to develop an air-to-water heat pump module in order to simulate Altherma operation. Preliminary runs using the new heat pump model generated mass balance errors in the outputs. TESS is working on correcting source code errors and evaluations will continue as the problems are resolved. The completed model will be calibrated with the monitored data as that is obtained.

A summary of this research is provided as Attachment KK.

2.5 Ventilation Technologies

CARB believes evaluation and documentation of “real-world” ventilation installations is needed to provide a more accurate assessment of current technology performance and requirements. It is critically important to maintain health and comfort while making advancements needed to achieve long-term Building America zero energy goals. These evaluations are intended to identify the “best practice” strategy in varying climates and identify opportunities for technology improvements.

CARB specifies ASHRAE 62.2 compliant ventilation systems for all of its builder projects. The system specified is primarily dependent on the climate and the builder’s interest in utilizing specific systems such as energy recovery ventilators (ERVs) or integrated dehumidification systems. While it is agreed that outside air ventilation is important and necessary, there is no consensus on what method is best. CARB has and will continue to conduct research on different ventilation systems as opportunities arise

California Residential Ventilation System Effectiveness Study

As of January 2010 California joined other states in requiring ventilation systems that are compliant with ASHRAE Standard 62.2-2007. Builders and mechanical contractors have expressed concern about which systems to apply. To aid builders with this decision, DEG/CARB, with assistance from Lawrence Berkeley National Laboratory (LBNL), initiated a project to evaluate the ventilation effectiveness and energy consumption of four generic system types. Two similar Sacramento area production homes were tested with four different ASHRAE 62.2 compliant ventilation systems, including:

- *Exhaust only*, using a single continuously operating exhaust fan in the laundry room;
- *Balanced, single point supply*, consisting of an exhaust fan and a supply fan that delivered outside air to the master bedroom closet;
- *Balanced, distributed*, using an exhaust fan and a supply fan that feeds air into the heating and cooling system ducting (with a backdraft damper in the return duct); and
- *Supply, distributed*, using fan cycler type controls to operate the heating/cooling system fan and a small, dampered, outside air duct connected to the return air plenum.

Tests of two systems in each house were conducted over two two-week periods during the months of July and August 2010. Measurements included indoor and outdoor temperatures, ventilation system air temperatures and airflow rates, and ventilation fan power. Overall source energy use was calculated by combining measured net thermal energy added to or subtracted from the buildings by the ventilation systems, and fan energy use. The fan cycler system averaged 71 kBtu/day source energy use and the other three systems ranged from 13 to 14 kBtu/day.

Full year simulations of four ventilation system types were also completed using Energy Gauge. These included exhaust only, supply only, fan cycler, and HRV systems. Source energy use was also calculated for these systems. The HRV displayed the lowest energy use of 51 MBtu per year, and the fan cycler the highest at 61 MBtu per year. Energy Gauge has no explicit capability to model fan cycler systems, making the results somewhat suspect given the findings from the field tests. An economic evaluation of the HRV results showed that their increased cost is not supported by energy savings in the California climate, but they may be valuable for net zero energy programs.

Lawrence Berkeley National Laboratory, who assisted in this research, completed measurements of indoor pollutants and air exchange rates for each system tested. Formaldehyde concentrations ranged from 35 to over 70 mg/m³, which exceed most state and federal guidelines for inhalation exposure. The variation in pollutant concentrations appeared to be influenced by house tightness more than by ventilation system type. An unexpected consequence was that the balanced systems did not produce the highest air exchange rates or the lowest formaldehyde concentrations, and the distributed ventilation systems did not improve the room-to-room uniformity of formaldehyde levels. The single point balanced system, which produced the highest air exchange rate also had the lowest formaldehyde concentration.

Feedback from other researchers suggests that formaldehyde may not provide a valid indicator of ventilation effectiveness because the rate at which the sources emit formaldehyde may be inversely proportional to its concentration in indoor air. Additional research is needed to verify this equilibrium phenomenon. Given that formaldehyde is the pollutant of greatest concern,

research on controlling sources should take priority over research on the ventilation effectiveness of different systems.

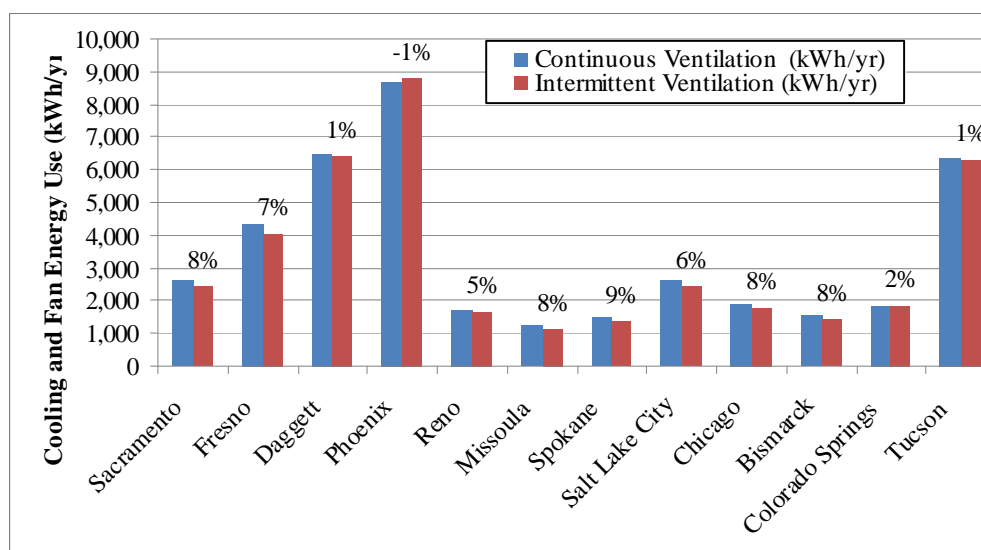
A comprehensive report of the BP3 research on this project is provided as Attachment LL.

Scheduled Ventilation in Hot-Dry Climates

The recently adopted ASHRAE Standard 62.2-2010 includes a table and equation that allows for intermittent ventilation provided ventilation rates are increased. Using the 24 hour cycle time from this table, ventilation periods can be shifted to nighttime hours such that the negative impact on cooling load can be minimized.

Algorithms for controlling the system fan in a ventilation cooling system were developed to test this hypothesis. The output of these algorithms is a vent duration that is a function of house size and number of bedrooms. Evaluations were also completed to identify the optimal “center time” around which ventilation should be applied. Three houses were identified for testing and instrumented. The inability of the controls contractor to provide the control code in a timely manner delayed field testing to a later time.

The results below were developed using a TRNSYS model to simulate the “nighttime biased” ventilation approach in a variety of climates for a high performance house. The cooling energy savings determined using the TRNSYS model and listed in the figure below account for both the reduced cooling load impact of the biased ventilation relative to continuous ventilation, and the added fan energy required to deliver the higher rate of ventilation.



Simulation data show significant (7 to 10%) cooling energy savings in all but the extreme hot climates and in one of the cold climates (Colorado Springs). Although this analysis assumed relatively dry air, energy savings are likely to be greater in humid climates as a result of lower nighttime humidity ratios. This technology can be applied using any high efficiency fan capable of moving about 200 cfm, and simple timer controls. Where this ventilation strategy can be combined with ventilation cooling (in dry climates), no additional hardware is required and fresh air ventilation overlaps with night ventilation for cooling, reducing fan energy impacts.

A summary report of the BP3 research on this project is provided as Attachment MM.

2.6 Water Heating Technologies

Water Heating Best Practices Design Guide

The goal of the water heating design guide is to provide a comprehensive review of the issues that need to be addressed in developing a high performance water heating system in both new and existing homes. The systems approach integrates latest research findings on high efficiency water heaters, distribution system research, and end use fixtures. By applying the latest research findings, designers can make intelligent climate-appropriate decisions that optimize domestic hot water energy and water use.

Nationally, water heating represents roughly 16% of residential building energy use. In mild climates, such as California, it represents nearly half of the average residential customer's gas bill. Achieving a 30% reduction in national domestic water heating energy use would reduce the country's energy consumption by 0.75 quads annually. A 30% reduction is certainly achievable in new construction, but emphasis must be placed on upgrading the existing building stock. To achieve high performance water heating systems, the following steps should be taken:

- New construction should focus on intelligent building design that brings the water heater close to all hot water fixtures. Current design practice pays no attention to this issue resulting in high first cost and inefficient distribution systems.
- Climate and local utility rates should be a key factor in determining water heater system types. Heat pump water heaters will perform best in mild to hot climates with low electric rates. Solar can be a valuable tool in many climates, if properly installed.
- Many new water heating products have entered the market in the past few years. These include EnergyStar gas storage water heaters, hybrid gas water heaters (combining elements of gas tankless and storage water heaters), and heat pump water heaters (HPWHs). All of these offer promise, but currently have high first costs.
- Training for builders, plumbers, and homeowners is critical. Understanding what constitutes an optimal installation is the first step, but installing and using it properly are critical in obtaining the desired performance.
- Selection of efficient fixtures (e.g. WaterSense showerheads), appliances, and drain heat recovery devices will reduce the hot water load and resulting energy use. Load reduction has benefits for technologies such as HPWHs which should experience less supplemental resistance heat operation when loads are reduced. Other technologies, such as conventional gas storage and electric storage water heaters, will see reduced annual efficiencies as the reduced load contributes to greater standby operation.

This water heating design guide is provided as Attachment NN and represents a first step in integrating current information in one document. This design guide is an evolving document that will continue to be updated as new information becomes available.

Solar Thermal Water Heating Systems

In designing their latest community in Greenfield, MA, Rural Development, Inc. (RDI) wanted to create homes that used as little outside energy as possible – getting closer to zero net energy goals. To do this, RDI built very efficient envelopes, installed solar electric systems (which provide all of the electricity needs for most homes), and installed solar thermal systems to provide most of the water heating energy needs.

There were several challenges during the design and construction of the development. The ideal windows were hard to procure, there were some surprises in coordinating venting in the double-wall system, and the building department was not familiar with some of the proposed features. Perhaps no other system, however, provided more challenges than the solar thermal systems.

The systems consist of flat-plate, serpentine collectors coupled with 110-gallon storage tanks. In each system, a small PV module (20-30 Watts) powers a DC circulator which moves a propylene glycol solution between the collectors and storage tanks. Auxiliary heat is provided by a tankless gas water heater. Through the design, construction, and trouble-shooting processes, CARB worked with RDI, the solar contractor, the plumber, and others to overcome several challenges.



The results appear quite good; the solar thermal systems are providing most of the water heating energy to the homes. Many homeowners turn their gas heaters off entirely during the summer. CARB was able to install monitoring equipment on one system to evaluate performance over the course of 1-2 years. During the four months monitored (August – November 2010), the solar thermal system has provided 96% of the water heating energy in this home.

A detailed summary of this work is provided as Attachment OO.

GSHP Water Heating Systems – WPPI’s GreenMax 1 Demonstration

This project included a horizontal closed loop, pressurized slinky GSHP system consists of two 300 foot trenches at a depth of 8 feet and separated by 8 feet. Environol 1000 solution (21.4% ethanol) is circulated between the ground coils and a 3-ton dual capacity Water Furnace Synergy 3-D heat pump (model SDV038A121CTL). This unit has a third mode of water heating that goes to a 50 gal buffer tank prior to the 80 gal electric water heater. A desuperheater runs directly to the electric water heater. There is also a drain water heat recovery unit installed.



Over the 15 month monitoring period, this 3rd-mode for water heating has provided a 2.4 DHW COP when running at steady-state. The drain water heat recovery unit provided 5.7% of the DHW Btus. The auxiliary electric resistance tank water heater only provided 17.7% of the DHW Btus. The remaining 77% of DHW Btus was provided by the GSHP’s 3rd-mode and desuperheater.

According to the 2000 Energy Center of Wisconsin’s “Energy and Housing in Wisconsin” Study, the average Wisconsin home (28% of homes have electric water heaters) uses 3,250 kWh/yr to heat hot water. The GreenMax home utilized 1,149 kWh (energy usage of electric water heater, DHW mode of GSHP, and desuperheater pump) over the initial twelve months to heat water. This is roughly a 65% reduction in electrical consumption for water heating over typical Wisconsin homes.

GSHP Water Heating Systems – WPPI’s GreenMax 2 Demonstration

This project included a horizontal closed loop, pressurized slinky GSHP system consists of two 110 foot trenches at a depth of 8 feet and separated by 15 feet. Environol 1000 solution (21.4% ethanol) is circulated between the ground coils and two GSHPs located in the unfinished portion of the basement: a WaterFurnace Envision 3-ton dual speed (NDV038) heat pump for space conditioning and a WaterFurnace ESeries 2-ton (EW020H) for water heating. A desuperheater runs from the Envision to a 50 gal pre-heat storage tank. The ESeries runs to an 80 gal primary tank. There is no auxiliary water heating source.

For the initial four month period, the steady-state hot water COP was 2.04. To get a complete view of hot water heating, the pre-heat tank needs to be accounted for as well. The 50 gal pre-heat tank is feed by the main water line that runs through a drain waste heat recovery unit to capture some of the energy from hot water running down the drain. The pre-heat tank is connected to the space conditioning GSHP desuperheater via an internal heat exchanger. The table below shows the energy supplied by these additional sources and their overall contribution to the water heating. Just note that standby heat loss of the storage tanks is not accounted for.



Water Heating Source	Energy Supplied [MMBtu]	DHW Contribution
Desuperheater	969	19%
DHW GSHP	3,579	69%
Drain Waste Heat Recovery	615	12%

Task 3: Stage 2 – Prototype House Evaluations

Throughout BP3, CARB worked on various stages of several Stage 2 prototype house evaluation projects. The primary objective of Stage 2 research is to evaluate the ability to integrate advanced systems with production building practices. Prototype homes are modeled, constructed, and tested to confirm quality and performance. Most of the prototype homes are expected to achieve greater than 50% energy efficiency savings over the BA Benchmark. The following table summarizes the active Stage 2 projects reported on in this BP3 Progress Report.

Builder/Project Title	Climate	Location	Target Savings	System Opportunity	Status
New World Home – Country Living’s 2010 Home of the Year	Cold	Hardyston, NJ	41%	Modular, High-performance envelope, high efficiency HVAC	Construction complete
Young Residence	Cold	Alden, NY	51%	High-R Wall, Boiler for Radiant Floor, Passive Cooling, PV	Construction complete
Austin Design / Katywil 1 & 2	Cold	Colrain, MA	55%+	Double wall, triple pane windows, MSHP or solar radiant floors, solar thermal	Construction complete
Shaw Builders/ GreenMax2	Cold	Stoughton, WI	61%, net-zero with PV	GSHP, DHW GSHP, ERV, Drain Water Heat Recovery, PV	Construction complete, monitoring
All American Lumber/ GreenMax1	Cold	Black River Falls, WI	69%, net-zero with PV	GSHP, HRV, Drain Water Heat Recovery, PV	Construction complete, monitoring
Devens	Cold	Fort Devens, MA	52%	Double wall, high efficiency ASHP, ERV	Design complete.
Paragon Homes – Partlow Residence	Mixed Humid	Ashburn, VA	61%+	Mini-split heat pumps, Verve Living Systems wireless outlet/lighting controls	Under construction
IBS Demonstration Home/ReVision	Hot/Mixed -Dry	Las Vegas, NV	68%, net-zero with PV	Deep energy retrofit	Construction complete, monitoring
La Mirada	Hot/Mixed -Dry	Tucson, AZ	59%, 80% with PV	SIP walls and roof, Altherma air-to-water heat pump system, ERV, solar thermal, PV	Under construction
One Sky	Marine	San Jose, CA	57%, 90% with PV	Passive House design principles, ERV, solar thermal, PV	Under construction

3.1 Cold Climate – New World Home

This prototype project was a New World Home showcase home. It was featured as Country Living's 2010 House of the Year. From June 4-17, 2010 this modular home was temporarily set in the World Financial Center in New York City as an educational experience for visitors. The home incorporated energy efficiency, durability, sustainability, and classic country cottage aesthetics in a 1,600 square foot package. The home was later permanently set in Hardyston, N.J. This home is also in the process of being certified under the following rating programs: EPA's ENERGY STAR Qualified New Home, USGBC's LEED for Homes Platinum, NAHB's National Green Building Standard Emerald, EPA's ENERGY STAR Indoor airPLUS, EPA's WaterSense, and DOE's Builders Challenge.

The home featured Superior Walls System Foundation, R-21 of closed-cell spray polyurethane foam in the rim/band joists and below-grade wall cavities, R-10 under slab insulation, R-19 fiberglass batts in above-grade walls, double pane low-e windows (U-0.32, SHGC-0.30), R-36 open-cell spray polyurethane foam at rafters (unvented attic), a condensing furnace (94.1 AFUE), a high efficiency air conditioner (SEER 19.5), 87% compact fluorescent lighting, a heat recovery ventilator in compliance with ASHRAE 62.2 ventilation standard, and all ductwork located in the building envelope. Though this home was 2x6 framing, it was built at 16" on center due to concerns from the modular plant about shipping the modules. This prototype was 41.2% better than the Building America reference home (Benchmark version 12/19/2008) using BEOpt v0.9. In terms of ENERGY STAR, this home achieved a HERS Index of 49.



There has been significant press about New World Home's Country Living 2010 House of the Year project. Links to various media is provided below:

- To follow New World Home's blog on this project, click [here](#).
- A photo tour through the prototype home, click [here](#).
- A NBC-NewYork video on this home, click [here](#). Shows time lapse of the module setting at World Financial Center.
- A NYDailyNew.com article on the prototype home, click [here](#).
- A NJHerald.com article about the move to the final home site, click [here](#).

A comprehensive report on this BP3 effort is provided as Attachment PP.

3.2 Cold Climate – Young Residence

CARB completed work with Young + Wright Architectural on a 50+% cold-climate prototype residence located in Alden, NY (near Buffalo). The primary focus was to design a highly efficient building envelope (high-R wall assembly, unvented attic, etc.) that can be effectively conditioned by radiant heating and passive cooling (clerestory windows at top of open living space enhance cross ventilation and provide daylighting to the interior of the home). The combination of a hybrid wall cavity insulation and exterior rigid insulation led to a highly efficient wall assembly (as reported in Attachment CC). The construction of the wall assembly was:



- 2x6 wood frame construction (in-line framing) @ 24" o.c. with ½" OSB sheathing
- 2" of closed-cell spray polyurethane foam applied to the interior of the OSB sheathing.
- R-13 fiberglass batts filling the remainder of the wall cavity
- On the exterior, 2" of SEI's ShelterSheath (R-4.35/in) against the exterior of the OSB sheathing (Tyvek DrainWarp was installed between the sheathing and rigid insulation). This was followed by 1.5" of DOW's Tuff-R (R-6.5/in). The 2" insulation was secured with three inch roofing nails and then the 1.5" insulation was secured with furring strips and 6" screws.

Estimated source-energy savings over the Building America Benchmark was 51% and 44% versus the 2006 IECC reference building. These savings do not include site electric generation (PV), but do include an anticipated solar hot water system (which accounts for ~2% of the source-energy savings).

A final report on this BP3 effort is provided as Attachment QQ.

3.3 Cold Climate –Austin Design's Katywil 1& 2

Developers/Designers of the Katywil development in Colrain, MA are in part building on successes achieved by nearby developer and CARB-partner Rural Development, Inc. (RDI). The architect for both projects, Austin Design, incorporated many similar systems in the Katywil homes, most notably the double wall system.



Designers were also eager to incorporate simple mechanical systems in these new homes. Because one of the goals of the Katywil development was using no fossil fuels on site, designers chose mini-split heat pumps to meet the modest loads in the first of these homes. The second home is heated by a combination of active solar thermal and an electric resistance boiler with radiant floor heat delivery. Both homes also have wood stoves to provide some space heating and they take advantage of passive solar gains to varying degrees.

The first two homes were occupied in mid-late 2009. CARB saw an opportunity to evaluate the mini-split heat pumps as part of its research of simple mechanical systems in low-load homes. CARB installed monitoring equipment to record electric energy consumption of the heating systems, several other key home loads, and outdoor temperature and humidity conditions during the winter of 2009-2010. Electric energy monitoring will continue through the winter of 2010-2011. This advanced systems research and whole-building design are discussed in Attachment EE.

3.4 Cold Climate – Shaw Builders/GreenMax 2 Demonstration Home

GreenMax 2 is a WPPI Energy-supported research project to demonstrate cost-effective, market-ready methods for achieving near-net-zero energy consumption in typical Wisconsin home styles. CARB focused on developing a cost-effective technology package that would achieve 50+% source-energy savings over typical mid-1990's construction. Key features of this home built in Stoughton, WI included 2x6 wall construction, two GSHPs (a water-to-air for space conditioning and a water-to-water for domestic water heating), exterior rigid insulation (R-5 above

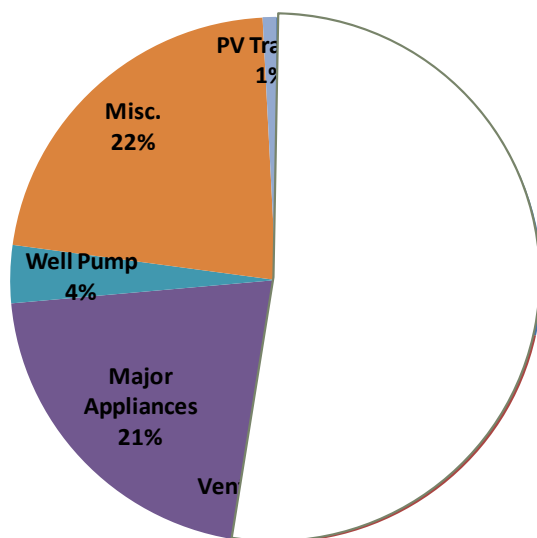


grade and R-10 below grade), R-10 rigid insulation under slab, and a 5.76 kW dual tracking solar PV system. Construction was completed in December 2009. Monitoring of the home's systems has been going on since May 2010 and can be viewed on WPPI's GreenMax website (http://www.greenmaxhome.com/projects/index.php?category_id=4463&subcategory_id=6977).

Based upon the building specifications, this prototype home is estimated to achieve 60.5% less source energy to operate than a typical mid-1990s home. With PV generation included, the source-energy savings would increase to 81.7% based on energy modeling with EnergyGauge USA v2.8.03. Though preliminary monitoring data suggests that this home will be a net-zero energy home. So it is likely that the homeowners are more energy conscious than the average homeowners/occupants that were modeled for this analysis.

Though every electrical breaker is not being monitored in this home, all major equipment beyond lighting and outlets are being monitored. Looking at just the Lighting, Appliances, and Miscellaneous Electric Loads (LAMELs), the major appliances account for 44% of the electrical consumption outside of heating, cooling, ventilation, and hot water. The major equipment (see table below) accounts for 57% of the LAMELs for this home. Those items specific to the kitchen account for 33% of the LAMELs. These major appliances are all top of the line units (Energy Star labeled, if available), so there is little that can currently be done from a technology standpoint to reduce this usage. The same is true of the lighting, which is nearly all LED lighting. Essentially, the homeowners would need to alter their behavior to see a significant reduction in their LAMEL consumption.

LAMELs	Energy Totals [kWh]						% of LAMELs
	May	June	July	August	Sept	Total	
Induction Cooktop	18.9	14.3	17.3	17.6	21.8	89.9	4%
Oven	23.8	19.2	26.2	36.1	27.2	132.5	6%
Microwave Oven	5.7	6.2	5.6	5.8	5.7	29.0	1%
Clothes Washer	3.3	3.3	3.1	2.9	2.7	15.2	1%
Wine Cooler	1.3	1.3	1.4	1.3	1.4	6.7	0%
Clothes Dryer	50.0	50.0	50.0	50.0	51.8	251.8	12%
Refrigerator & Island Outlets	68.4	65.7	72.5	73.1	72.4	352.1	17%
Garbage Disposal & Dishwasher	7.3	4.9	6.0	8.3	5.9	32.5	2%
Kitchen Outlets	8.8	9.2	9.5	9.9	9.2	46.6	2%
Septic System	2.5	1.8	2.2	2.2	2.1	10.8	1%
Well Water Pump	36.7	26.5	31.1	30.8	28.3	153.3	8%
PV System Tracking Unit	7.1	6.8	7.0	7.0	6.8	34.9	2%
Miscellaneous	172.4	138.7	182.5	194.0	199.4	887.1	43%
Total	406	348	414	439	435	2,042	100%
Kitchen Total	133	120	137	151	142	683	33%



Appliance	% of Energy Usage Not Associated with HVAC/DHW
Induction Cooktop	4%
Oven	6%
Microwave Oven	1%
Clothes Washer	1%
Clothes Dryer	12%
Refrigerator	17%
Dishwasher	2%
Total	44%

Misc. includes:

- Lighting
- Outlets
- Beer/wine fridges
- Steam Shower/Whirlpool Tub
- Water Treatment

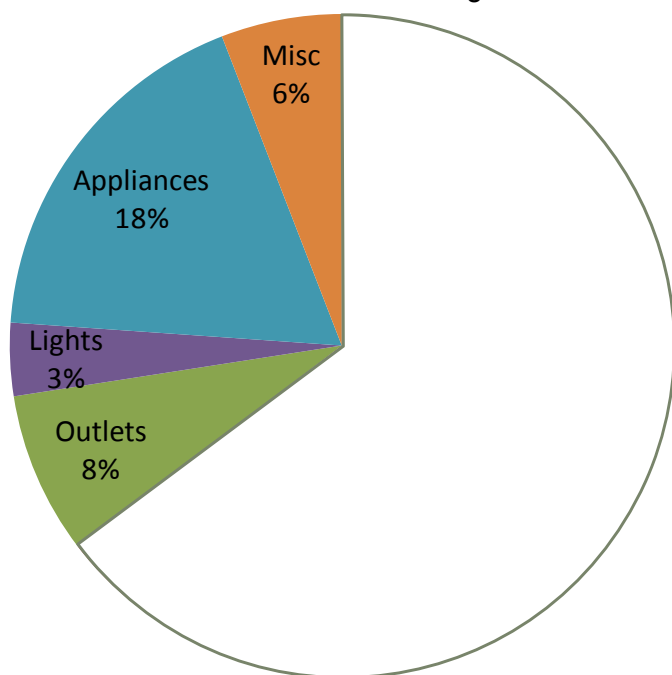
A summary monitoring report on this BP3 effort is provided as Attachment RR.

3.5 Cold Climate – All American Lumber/GreenMax 1 Demonstration

The first GreenMax project was located in Black River Falls, WI. CARB has been monitoring this demonstration home since late May 2009. Key features of this home include 2x8 wall construction, a 3-mode GSHP (heating, cooling, hot water), exterior rigid insulation (R-5 above grade and R-10 below grade), and a 5.76 kW dual tracking solar PV system. For monitoring data and additional information, go to: http://www.carb-swa.com/articles/near%20zero%20energy/GreenMax_One%20Year_Summary.pdf



Looking at just the Lighting, Appliances, and Miscellaneous Electric Loads (LAMELs), the major appliances account for 51% of the electrical consumption outside of heating, cooling, and hot water. These are all top of the line units (Energy Star labeled, if available), so there is little that can currently be done from a technology stand-point to reduce this usage. The same is true of the lighting, which is nearly all compact fluorescent lighting. Essentially, the homeowners would need to alter their behavior to see a significant reduction in their LAMEL consumption.



Appliance	% of Energy Usage Not Associated with Heating/Cooling/DHW
Dishwasher	4%
Speed Oven	2%
Induction Cooktop	6%
Coffee Maker	5%
Clothes Washer	4%
Clothes Dryer	10%
Refrigerator	19%
Total	51%

In terms of appliance specifics, the refrigerator consistently uses the most energy on a monthly basis (though data for this appliance has only been available since March 2010, gray box in chart shows estimated usage over the entire monitoring period). The clothes dryer uses the second largest amount of energy.

Monthly Appliance Electrical Usage [kWh]								
Month	Dish-washer	Speed Oven	Induction Cooktop	Coffee Maker	Clothes Washer	Clothes Dryer	Refrige-rator	LAMELS
Jun '09	14	4	10	11	10	30	N/A	217
Jul '09	5	0.5	8	7	4	9	N/A	139
Aug '09	10	2	18	14	13	34	N/A	262
Sept '09	8	5	14	13	12	19	N/A	240
Oct '09	7	8	10	13	9	26	N/A	227
Nov '09	11	13	17	15	15	45	N/A	299
Dec '09	7	7	10	12	4	23	N/A	241
Jan '10	9	9	26	15	13	41	N/A	309
Feb '10	8	5	20	14	9	31	N/A	269
Mar '10	7	5	15	13	18	18	40	232
Apr '10	9	6	13	13	12	26	42	243
May '10	9	7	13	12	11	23	46	238
Jun '10	9	5	15	12	14	31	46	285
Jul '10	4	2	8	8	7	18	47	184
Aug '10	11	7	17	13	9	19	52	241
Sept '10	11	5	18	13	9	12	50	247
Total	139	91	232	198	169	405	738	3,873

As mentioned previously, the Energy Guide Label for the installed refrigerator estimates electrical usage at 470 kWh/yr, but based on the average monthly electrical consumption of the actual refrigerator, it is likely will be closer to 554 kWh/yr.

The July 2009 data when the Chambers weren't home actually provides some interesting information about the electrical usage of the various appliances when not operating. Essentially this is the daily standby-by energy usage. If an electric rate of \$0.10/kWh is assumed, this standby energy amounts to a \$15 additional per year for the appliances.

Appliance	Daily Standby Watt-hours
Dishwasher	37
Speed Oven	5
Induction Cooktop	190
Coffee Maker	155
Clothes Washer	25
Clothes Dryer	0
Total	411

A final summary monitoring report on this BP3 effort is provided as Attachment SS.

3.6 Cold Climate – Devens

In 2009 Metric Development formed a team that included CARB and Cambridge Seven Architects, Inc. (C7), to respond to a Request for Qualifications/Devens Sustainable Housing RFQ that was sponsored by MassDevelopment, the Massachusetts agency which owns the Devens Regional Enterprise Zone in Massachusetts. The Purpose of the RFQ was to identify development teams suitable for the creation of moderately priced high-efficiency homes on two sites within the enterprise zone (Devens) formerly Fort Devens Army Base. The project aims to produce a replicable example of current and innovative sustainable building practices with a near-zero energy potential. The Metric team was invited to respond to subsequent Request for Proposal (RFP) by MassDevelopment for the actual design and construction of the low-energy market-rate housing at Devens. The Metric team was one of two teams ultimately selected to proceed with the project. MassDevelopment had decided to have Metric build attached homes with the other bidder being tasked with detached dwellings.

The key to very low-energy buildings starts with simple forms and high floor-area to envelope area ratios. Because the objective is to get the heating and cooling loads as low as practical, a high performance envelope is critical. Lower envelope areas for a given useful floor area, allows more economical upgrades to the envelope area. Thus, starting with a simple box form, CARB explored optimal thermal performance values using REM/Rate v12.85 software (this software

was used due to the teams desire to target HERS Index of 40 prior to the application of any on site renewables. Having worked on a similar project in the same climate recently (RDI's Wisdom Way Solar Village), CARB developed envelope specifications based on the success of that previous project. The end result of the cost-benefit analysis was R-42 walls, R-59 ceiling, and R-13 foundation walls being initially specified. Window and door options were explored with the design team looking at cost, performance, function and marketing concerns. Ultimately selected were "Paradigm" double-hung low-e vinyl units with a 0.26 U-value, and a 0.30 SHGC. With the envelope performance characteristics optimized on a cost-performance basis, the team began to look at HVAC and domestic hot water options. Unlike Wisdom Way, a far more conventional approach was selected: a conventional, albeit very small, high-efficiency ducted HVAC system using a gas-condensing furnace, and a SEER 16 outdoor unit. Additionally, the homes are planned to use full-span open-web truss floors to allow complete integration of the ducts into the floor assemblies, and therefore all ducts in conditioned space.

Based upon the building specifications, this prototype home is estimated to achieve 52% less source energy to operate than a typical mid-1990s home.

A design summary report on this BP3 effort is provided as Attachment TT.

3.7 Mixed Humid Climate – Paragon Homes' Partlow Project

This prototype home is an opportunity for Paragon Homes to investigate new technologies to further enhance their current building standards (which meet the 40+% BA source-energy savings target) and to assess strategies to bring them closer to a near-zero energy building package. Through the design process, the builder has been able to explore several varying HVAC systems to achieve the target energy savings goal. After extensively exploring ground-source heat pump designs and contractors, mini-splits offer Paragon Homes an alternative that is more cost-effective, eliminates past issues with distribution leakage, and provides their homeowners with the zoning capabilities that they desire.



EnergyGauge USA v2.8.03 was used to perform a cost-benefit analysis and generate the optimal package of measures to improve the energy performance of the Paragon homes. Based upon the originally proposed design specifications, this prototype home is estimated to achieve ~61% (~78% if PV generation is included) less source energy to operate than a typical mid-1990s home. Since then, Paragon Homes is intending to extensively use spray foam throughout the home to improve the performance of the thermal envelope, which will increase the potential source energy savings further.

The Partlow prototype design specifications includes: 2x6 wood framing spaced at 24" on center, optimum value engineering (two-stud corners, ladder framing, headers in floor system), extensive air sealing (caulking all seams where two framing members meet, spray foam all rim/band joists, etc.), low-e windows, blown-in cellulose insulation, properly sized HVAC equipment, a solar thermal water heater, all Energy Star® appliances, and a balanced ventilation system capable of complying with ASHRAE Standard 62.2. All mechanical equipment and fireplace are sealed combustion and direct-vent, to meet or exceed the minimum requirements of the National Energy Star Qualified Homes Program.

A summary report on this prototype home project is provided as Attachment UU.

3.8 Hot/Mixed Dry Climate – IBS Demonstration Home, ReVision

The ReVision Las Vegas house is a DOE-supported research and training platform intended to demonstrate cost-effective, market-ready methods for achieving near-net-zero energy consumption in the context of a typical 1960's southwestern ranch style home. The deep-energy retrofit project combined significant building envelope upgrades with efficient mechanical systems and renewable energy systems. CARB provided technical support for this demonstration home including baseline performance testing, energy modeling, and specifications development.



Using EnergyGauge USA 2.8.03, multiple parametric analyses were conducted to determine the optimal balance of wall and roof insulation values, glazing U-factors and solar heat gain coefficients (SHGC), and envelope tightness levels, again with the intent of minimizing, to the degree practical, space heating and cooling loads. Exterior walls are 2x4 framing, and with the interior finishes to remain, additional space for insulation cannot be obtained toward the interior, so an exterior foam sheathing solution was developed. Closed-cell spray polyurethane foam (ccSPF) and open-cell spray polyurethane (ocSPF) were looked at for the cavity fill while an EIFS solution was selected for the foam sheathing and exterior finish. Based on the optimization study and the required R-value in the R-21 range, ocSPF was selected as the fill insulation, with 2" EPS foam for the EIFS.

Estimated source-energy savings over the Building America Benchmark was 68%. These savings do not include site electric generation (PV), which would push it to net-zero source energy.

A final comprehensive report on this BP3 effort is provided as Attachment VV.

3.9 Hot/Mixed Dry Climate – La Mirada “SEED” Home

The “Super Energy Efficient Designed” (S.E.E.D.) home is a 1,935 ft², single-story spec home located in Tucson, Arizona. The builder, Michael Ginsburg of La Mirada Homes, wants to be able to offer affordable energy efficient homes that minimize the need for mechanical cooling. The evaluation objective of this study is to determine how effectively a radiantly delivered cooling system can perform within a high performance home in a hot-dry climate.



The design incorporates efficiency measures such as SIP walls and ceiling, high performance windows with a low solar heat gain coefficient (SHGC), appropriate shading, significantly downsizing the mechanical system which includes radiant floor heating and cooling, an air-to-water heat pump and fan coils for dehumidification, solar water heating with electric backup, and rooftop PV. A benchmark analysis estimated 60% source energy savings. The house is currently in the construction phase with an expected completion of early 2011. Extensive monitoring equipment will be installed to evaluate the performance of the hybrid coil/floor cooling system in a hot dry climate. The seasonal cooling efficiency of the equipment as well as the annual cooling energy use will be calculated. Monitoring will be conducted for a full year after occupancy.

A summary report on this BP3 effort is provided as Attachment WW.

3.10 Marine Climate – One Sky Homes

The Cottle Zero Energy Home is a 3,170 ft², two-story spec home to be located in San Jose, CA. The project was developed by California builder Allen Gilliland of One Sky Homes. The design is guided by Passive House principals and Davis Energy Group identified a unique opportunity to evaluate Passive House strategies in a Marine climate. The evaluation objective of this study is to determine how effectively Passive House design features can contribute to approaching zero net energy performance, how they fit into Building America performance goals, and which of the Passive House measures have cost effectiveness potential in a Marine climate.



The design incorporates efficiency measures such as 2x6 advanced frame exterior walls, high performance triple pane windows, significantly downsizing the mechanical system which includes a high efficiency heat pump, heat recovery ventilator, and ventilation cooling, high efficiency gas storage water heater with solar water heating system, and rooftop PV. A benchmark analysis estimated 57% source energy savings. The house is currently in the construction phase with an expected completion of early 2011. Extensive monitoring of indoor and outdoor conditions will be performed for a full year once the home is occupied.

A summary report on this BP3 effort is provided as Attachment XX.

Task 4: Stage G3: Initial Community Scale Evaluations

During BP3, CARB has supported several community scale projects at various phases of completion. The current housing market has slowed construction levels down in many of these projects, but the completion of these community scale project case studies is still viable for future case study reports.

Builder/Project Title	Climate	Location	Target Savings	System Opportunity	Status
Rural Development Inc. / Wisdom Way Solar Village (affordable)	Cold	Greenfield, MA	57%, 77% with PV	Double walls, triple pane windows, non-ducted unitary heater, solar thermal, PV	Construction complete (20 units)
Chamberlain Heights (retrofit)	Cold	Meriden, CT	45%	Retrofit expanded wall assembly, foamed over buried ducts	Under construction (122 units)
Hunting Ridge Properties LLC	Cold	Middlebury, CT	50+%	High-R wall, solar thermal, PV	Solar design complete (23 units)
Evergreen Building Systems / Mason Island	Cold	Mystic, CT	65%	2" ccSPF with R-13 FGB in 2x6 walls, unvented attic, GSHP, ERV	Under construction (2 of 10 units completed)
Wilcox Lane (retrofit)	Cold	Canandaigua, NY	40%+	Magic Pak HVAC	Under design (120 units)
Coburg Village	Cold	Clifton Park, NY	40%+	Non-ducted HVAC	Under design (78 units)
Struever Bros. Eccles & Rouse / Overlook at Clipper Mill	Mixed, Humid	Baltimore, MD	43%	properly sized HVAC equipment, tight envelope	Under construction (13 of 38 units completed)
Paragon Homes / Broad Run & Potomac Farms	Mixed, Humid	Sterling, VA & Ashburn, VA	50%+	Foamed over buried ducts, 1" exterior XPS, ccSPF air sealing & rim/band	6 units completed to date
William Ryan Homes	Hot, Humid	Tampa, FL	47%	Right sized HVAC system and ducts sealed with mastic	Construction complete (78 units)
West Village	Hot, Dry	Davis, CA	53%	Exterior foam sheathing, feedback devices, HPWH	Under construction (27 buildings, 648 units)
Willowbank	Hot, Dry	Davis, CA	47%+	Exterior foam sheathing, tankless water heater, ventilation cooling	Under construction (27 units)

4.1 Cold Climate – Rural Development, Inc.

Throughout BP3, CARB continued to provide technical support during the construction and as homeowners occupy the duplexes at RDI's Wisdom Way Solar Village in Greenfield, MA. This community scale project of affordable housing is a direct follow-on from the Colrain prototype home completed in 2007.



RDI has incorporated double wall construction, triple-pane windows, solar domestic water heating systems, and other strategies to meet the 40% energy goals cost effectively. Benchmark analyses shows that one of these RDI homes will require 57% less source energy to operate than a comparable home built to benchmark standards (77% less source energy when including PV system generation). The total incremental cost of the energy improvements was \$12,206, and the predicted energy savings to the homeowner – at current energy rates – are \$2,192 per year (both values do not include PV). The result is a net positive cash flow of \$1,110 per year.

Because of the superb envelope, the design heat load of the units is very small – 10,000-13,500 Btu/hr. With the very small loads, RDI chose a very small, simple heating system: a sealed-combustion, natural gas-fired room heater located in the central area on the first floor of every unit. The unit is a Monitor Products model GF1800; capacity is 10,200 Btu/h at low fire, 16,000 Btu/h on high fire, and the AFUE is 83%.

CARB has discussed comfort in the homes at length with RDI. To alleviate concerns about temperature differentials – and to improve ventilation performance – CARB worked with RDI to design a very simple air distribution system. Each home contains a Panasonic WhisperGreen fan which “exhausts” air from the ceiling of the first floor and distributes a small amount of air (20-25 CFM) to each bedroom.

In conjunction with NREL, CARB performed multi-point tracer-gas testing to evaluate air changes throughout the homes. Results showed that the simple air distribution system truly does improve mixing of fresh air. During one tracer gas test when all interior doors were closed and the distribution system was turned off, the reciprocal average age of air ranged from 0.15 hr⁻¹ in one bedroom to 0.30 hr⁻¹ in the living room. When the distribution system was turned on, reciprocal average age of air ranged only from 0.27 hr⁻¹ in one bedroom to 0.32 hr⁻¹ in the living room.

While not all homes are occupied, CARB did receive preliminary utility data from the first several homes. Of the seven homes that had been occupied for at least 300 days, six of the homes are net generators of electricity (and have a net credit from the electric utility). CARB also obtained some gas utility data for seven homes occupied during the winter of 2009-2010. On average, these homes paid \$284 for gas during the 6-month heating season.

The comprehensive case study report, including QA documentation, is provided as Attachment YY.

4.2 Cold Climate – Chamberlain Heights

Chamberlain Heights is an existing community of 122 residential dwellings and is part of the Housing Authority of the City of Meriden's portfolio of housing serving low-income inhabitants in the region. The community consists of 36 duplexes and quad-plexes on 22 acres located within

two miles of downtown Meriden, CT. The existing homes, built in the early 1950's are wood frame with poured concrete foundations. Most of the dwellings are two-story, with a few accessible one-story dwellings. The 122 homes are to be essentially gutted, down to framing, board-sheathing and foundations. All existing mechanical systems, including plumbing, heating, and electrical will be replaced.



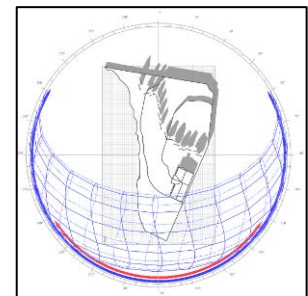
Most limiting is the 2 x 4 exterior wall framing and the existing first floor brick veneer which is to remain in place. Predicated on these limits the design team identified potential solutions for high-performance insulation within the bounds of the 3.5" space provided, and which could be installed from the inside in the case of the first floor walls. An early solution which satisfied both the R-value requirement, and the cost/constructability requirement was 3" of closed cell spray-polyurethane-foam (ccSPF) for the first floor (R-19.5) and 3-1/2" of dense pack cellulose plus 2" exterior XPS (R-22.5) on the second floor walls.

Because of multiple crew requirements and concerns regarding cement board siding attachments, the development team requested an alternative wall assembly without the use of exterior foam sheathing. Following confirmation by the architect that it would be possible and practical to furr the exterior walls 1-1/2" to the interior, a second strategy was developed. This alternative assembly would be comprised of 1" ccSPF sprayed against the interior side of the spaced-board sheathing on all exterior walls, with dense-pack cellulose applied to the remaining 4-1/2" space. With this multiple objectives are achieved: all exterior assemblies are the same simplifying construction; ccSPF use is reduced, decreasing cost; R-22.3 is achieved for all walls; air-sealing the spaced board sheathing is accomplished; and moisture control for the inaccessible space behind the brick veneer is accomplished.

A summary report, including quality assurance efforts, on the work to-date is provided as Attachment ZZ.

4.3 Cold Climate – Hunting Ridge Estates

In early 2010, CARB began work with Hunting Ridge Properties LLC on a community scale development located in Middlebury, CT. The project is in its schematic design phase and CARB had an opportunity to analyze potential passive design strategies and on-site solar generation. The site is located on a heavily contoured and wooded piece of land which makes siting and orientation a top priority – not only to maximize on winter solar heat gain and rooftop insolation but also to minimize disturbance to the trees. 23 houses are proposed to be built, all of which are 4 bedroom houses with attached garages.



A summary report of the solar analysis is provided as Attachment AAA.

4.4 Cold Climate – Evergreen Systems' Mason Island Landing

In 2009, CARB partnered with Evergreen Building Systems LLC on a 50+% cold-climate initial-community scale project located on the Mystic River in Mystic, CT. The completed development will consist of five duplex condominium buildings (10 units) and three single-family homes. The primary focus of this project was on designing highly durable (due to marine conditions), efficient building envelopes for the duplexes and the incorporation of ground-source heat pumps

for space conditioning. Though these homes will not include solar thermal or electric systems from the builder, they were designed/constructed to be “solar ready”. To date, one duplex has been completed. The rest of the duplexes will be constructed as they are sold.

A site solar evaluation report is provided as Attachment BBB and a summary report on the work completed to date, including QA documentation, is provided as Attachment CCC.



4.5 Cold Climate – Wilcox Lane

Wilcox Lane is an existing three story, 120 unit, affordable residence for independent living seniors in Canandaigua, New York (Zone 5). The existing apartments will receive a renovation of the kitchen, bath, lighting fixtures, appliances, and upgraded through the wall heating and cooling (Magic Pak). CARB is working with the developer to address those items that will have a bigger cost savings benefit such as; domestic hot water units, ceiling insulation, and an alternative to HVAC. An addition of 18 new, three story units was planned to the existing facility but funding has not been appropriated so this phase of the project has stalled.

4.6 Cold Climate – Coburg Village

This cold climate, independent living community for seniors will offer one & two bedroom rental apartments (78 units total) in a three story wood frame building. The new apartments will link to the existing 210 apartments owned by Wartburg Lutheran Services in Clifton Park, NY. CARB is working with the project team to better define the thermal envelope, mechanical closets (designed to be located in common halls), and fresh air delivery for common spaces. Reducing ductwork is a project goal and alternatives to central a/c are being investigated.

4.7 Mixed Humid Climate – SBER’s Overlook at Clipper Mill

Overlook at Clipper Mill will contain 19 contemporary park home duplexes (38 units) designed primarily to meet green building standards. As built, the majority of these units require 43% less energy to operate than a typical mid-1990s home. In comparison to today’s standards, these units are estimated to save 35% over code-compliant new construction homes. Annual utility bills should be in the range of \$2,000-\$2,500 based on national homeowner occupancy behavior.



As of August 2010, 13 homes had been completed and an additional 3 homes were ~90% complete (the majority of the remaining homes were under some stage of construction). Due to financial difficulties, the remaining units were to be sold through a foreclosure auction. One of the previous SBER partners (and homeowner in this community) started his own company and convinced the bank, BB&T, to allow him to finish the remaining houses at the Overlook. They are continuing the energy conservation measures recommended by CARB and certifying all homes under LEED for Homes and Energy Star.

The finalized case study report that was included in the 40% Mixed Humid Joule Milestone report is provided as Attachment DDD.

4.8 Mixed Humid Climate - Paragon's Broad Run & Potomac Farms

CARB continues to provide technical and construction oversight services to Paragon Homes' Broad Run & Potomac Farms development in Ashburn, VA. The inspections and performance testing of the initial six homes that have been built show excellent quality control throughout the community build out. But with current market conditions, Paragon Homes is not building additional homes within the communities unless they have a signed contract with a homeowner.

Here are the building infiltration results for the six homes completed under the Building America program¹:

Home	CFM50	ACH50	ACHnatural	ELA	SLA	ELA/100 sf shell
45396 Winding Road	1,630	2.51	0.14	89.5	0.00013	0.94
20256 Redrose Drive	1,978	2.22	0.12	108.6	0.00012	0.92
39502 Quarter Branch Road	3,159	4.76	0.26	173.4	0.00032	1.75
19547 Smith Circle	2,052	3.25	0.18	112.7	0.00017	1.30
45449 Mallard Street	2,087	2.98	0.16	114.6	0.00016	1.35
19929 Smith Circle	2,355	2.13	0.11	129.3	0.00012	1.00

Here are the duct leakage to the outside results for the six homes:

Home	CFM25	CFM25/CFMfan	CFM25/CFA
45396 Winding Road	97	6.06%	2.1%
20256 Redrose Drive	95	5.28%	1.6%
39502 Quarter Branch Road	40	6.25%	1.1%
19547 Smith Circle	97	5.39%	2.2%
45449 Mallard Street	88	5.50%	1.8%
19929 Smith Circle	75	3.75%	1.0%

Here are the energy performance results for the six homes:

Home	HERS Index	kBtu/ft2/yr
45396 Winding Road	67	21.3
20256 Redrose Drive	60	20.4
39502 Quarter Branch Road	66	26.4
19547 Smith Circle	70	23.4
45449 Mallard Street	68	21.9
19929 Smith Circle	53	15.0

CARB has been working with Paragon Homes since the later part of 2007. Over that period, CARB has assisted with design, training, inspection, and testing of energy efficient homes built by Paragon Homes. A key component to the builder development was integrating quality

¹ The Quarter Branch Road project had higher leakage (as was expected) due to the roof configuration.

control measures into their standard builder practices. The first step in that process was to educate the builder in the specific details that need to be implemented to ensure an efficient, durable, and comfortable home. Not just informing them of the details, but why it is important and how to best go about achieving the specification. The builder needs to have a solid understanding of building science to truly comprehend the importance of maintaining quality control. Once they understand its importance to their bottom dollar (reduced call backs, happier homeowners, etc.), it doesn't become a hindrance to them completing a home, but rather a tool to complete a quality home. To ensure that there aren't oversights on a home, CARB worked with Paragon Homes to expand upon their builder checklist and contractor scopes of work.

The summary report, including QA documentation, is provided as Attachment EEE.

4.9 Hot Humid – William Ryan Homes

CARB first worked with William Ryan Homes (WRH) in Chicago in the summer of 2002. That work led to Steven Winter Associates (SWA) being asked to conduct performance testing for numerous William Ryan developments in their newly formed Tampa division. Performance testing began in June 2005 in Tampa and expanded to Orlando in October 2006. When the contract ended in March 2009, over 650 houses had been tested by SWA for infiltration levels, duct leakage, supply airflow and bath fan performance.



Based on these results, SWA met with William Ryan Homes' superintendents and executives in March 2006, and took the opportunity to suggest developing an energy efficient preproduction prototype home that would meet the Building America 30+% whole-house source energy savings target and potentially be adopted by WRH as standard practice. This prototype was completed in December 2006 and qualified for the ENERGY STAR homes label, through the EPA's Builder Option Package. However, due to poor market conditions and cost restraints in 2007 and 2008, this prototype home was not adopted as standard practice.

Changes in the Florida Building Code and a company-wide "green" initiative in the fall of 2008 gave WRH the push they needed to implement energy-efficient measures as standard practice, regardless of market conditions. The decision was made that each home was to be ENERGY STAR labeled and certified as "green". WRH became a partner of the Florida Green Building Coalition (FGBC) and looked to SWA to provide certification services for each home, in addition to the performance testing already being conducted. Unable to provide these services cost-effectively, a local certifying agent was identified and SWA's performance testing contract was ended. CARB continued to work with WRH as a Building America builder partner and based upon WRH approval of updated specification recommendations, determined that they would meet the 40% whole-house source energy savings target for the hot, humid climate region for Community Scale projects.

The finalized case study report that was included in the 40% Hot Humid Joule Milestone report is provided as Attachment FFF.

4.10 Hot/Mixed Dry – UCD West Village

West Village is a \$280 million 200 acre mixed use development project located at the University of California, Davis (UC Davis). The development, which started construction in early 2010, combines building energy efficiency measures and on-site solar resource energy collection and

use to reduce the development's demand on grid supplied energy. The key planner, Carmel Partners, in conjunction with UC Davis, has laid out the development to provide student housing, residential housing, mixed use commercial space, mixed use residential, leasing space, and community college space. Chevron Energy Solutions (CES) and Davis Energy Group (DEG) were brought in to evaluate and recommend the energy efficiency and renewable energy strategies for the community. Carmel Partners partnered with Building America to implement energy efficient designs into their proposed residential units.

Initial planning for West Village was completed with the goal of a net zero energy development. Net zero energy use was analyzed by planning the development as an energy system that used building energy-saving measures to reduce energy demand and a sophisticated small scale utility network. The West Village utility network included centrally located photovoltaic (PV) and biogas fuel cell energy conversion systems with smart-metering grid distribution. Complications with establishing a small-scale West Village utility district made the application of central energy generation and distribution unfeasible. At present, the developer is pursuing the traditional net metering model with the local utility, with individual PV systems sized for each apartment. The centrally located PV system has been redesigned for individual apartments and moved to the apartment roofs.

During 2010, design was completed and construction started on Ramble A and B; student apartments which consist of two 3 story building designs. In the first phase of construction, 13 Ramble A and 3 Ramble B buildings are being built for occupancy by fall of 2011. DEG assisted planners with design of Ramble A and B through: design recommendations and energy use/savings analysis, estimated cost and neutral cost analysis, gap analysis, and quality assurance.



DEG's design recommendations and energy/use savings analysis for Ramble A and B included the evaluation of space conditioning, solar hot water heating, building envelope insulation, and exterior shading. DEG investigated seven different building mechanical systems: central electric boiler for water heating, central gas boilers for both space and water heating, individual tankless water heating for both space and water heating, and central heat pump water heating. Additionally, several solar water heating options were evaluated with select energy efficiency packages. As a result of DEG's analysis, the Ramble final designs included building envelope improvements, high efficiency space conditioning heat pumps, central heat pump water heating, as well as energy efficient lighting and miscellaneous electrical load controls. Central solar water heating was evaluated and recommended to further lower hot water energy use, but due to high incremental costs and limited roof space Carmel Partners elected not to include it in the final design.

DEG's neutral cost analysis included the individual break out of energy conservation measures (ECMs) in addition to combined packages of ECMs based on incremental costs provided by Carmel Partners. Breaking out and combining individual ECMs were used to illustrate the system interactions due to individual ECMs.

DEG conducted gap analysis during the construction process to identify construction methods that 1) have the potential to negatively impact energy savings and 2) create barriers to the implementation of energy efficient measures. Gap analysis identified the following items: large window glazing areas that increase building energy demand and builder cost, builder reluctance to add foam sheathing to the building exterior, envelope siding design issues that limited foam sheathing to one-half inch, educating the builder in advanced building energy efficient designs

and efficiency systems (DEG undertook the task of educating and explaining the benefits of energy efficient measures), and teaching the construction crew envelope construction methods that reduce building air leakage.

Third party quality assurance has been contracted to Quality Built, LLC. Quality assurance inspection items to be completed during the construction of Rambles A and B are: slab on grade reinforced steel, concrete placement, floor framing and sheathing, window and door attachments, wall framing and sheathing, installation roof framing and sheathing, vapor barrier, laps, penetrations, roofing process and final barrier installation, and window and door caulking and impermeability. Additionally, Carmel Partners have been consulting with DEG for LEED certification of Rambles A and B, as well as third party verification of Home Energy Rating System (HERS) measures including quality insulation installation, Thermal Bypass Checklist, and duct testing.

A comprehensive report on this research and analyses findings is provided as Attachment GGG.

4.11 Hot/Mixed Dry– Willowbank Park

The Willowbank Park development is located in Davis, California and consists of 27 one and two story single family detached residences, among four plan types. The developer/ builder, Brix and Mortar Partners, has been working with Davis Energy Group (DEG) to qualify their development for both Builders Challenge and Building America (BA). DEG consulted with Brix and Mortar to provide quality assurance (QA) training on insulation and sealing as well as moisture management strategies.



The worst performing model performs 47.4% better than the Building America Benchmark (BAB), with the other models 49-50% than the BAB. DEG recommended the addition of ventilation cooling and 60% hard-wired fluorescent fixtures to get the models over the 50% BA target for hot/mixed dry climates Joule. The builder added ventilation cooling but is still resistant to add more fluorescent lighting due to preconceived notion of poor light quality. HERS index values are between 59 and 60.

Through the Builders Challenge program, DEG worked with the builders on QA measures, including reviewing moisture management strategies, insulation and air sealing training with builder and contractor, HVAC equipment sizing, and equipment selection. A checklist was developed and provided to the builder with the Builders Challenge construction requirements. Four models are under construction now, with expected completion to be in early 2011.

A comprehensive report on this research and analyses findings is provided as Attachment HHH.

4.12 Additional Community Project Opportunities

Zeta Communities

Zeta Communities is a young, innovative, factory home builder based in San Francisco with production facilities in Sacramento. Their target market is net zero energy multifamily housing and mixed-use structures for sustainable communities, focusing on urban infill, transit-oriented

development, public land development, and educational campuses. They have a number of projects in the planning stages in both the bay area and the Sacramento valley. In 2010 DEG/CARB provided ZETA with design assistance for three communities: a mixed use building in Palo Alto, a residential development in Sacramento, and multifamily lofts in San Francisco. DEG/CARB also assisted with development of design specifications that would define standard packages for them to offer.

4073 El Camino Real

The 4073 El Camino Real project is a mixed use building in Palo Alto with two 1,800ft² residential units above retail space. The designer initially wanted to eliminate mechanical cooling; however, the original design incorporated a substantial amount of glazing and simulations predicted considerable summer cooling loads. We provided Zeta with a package of recommended ECMs that included the following:

- R-21 wall insulation w/R-5 continuous wall insulation
- Cool roof
- R-30 ceiling insulation and R-20 at the roof deck
- Windows with 0.173 U-value / 0.267 SHGC
- 15SEER / 8.5HSPF heat pump for heating and cooling
- Ducts in conditioned space
- Heat pump water heater with the option for solar water heating.
- Energy Star refrigerator, clothes washer & dishwasher
- 100% fluorescent lighting

Table 1 lists source energy use by end use for the Benchmark building, and two design packages for one of the residences, Residence 1. The table below shows overall energy savings of 52% and 58% without and with a solar water heating package, respectively.

Table 1: Zeta-El Camino Real Prototype Source Energy Savings

	Benchmark (MBtu/yr)	Package A – no solar DHW (MBtu/yr)	Package B – w/ solar DHW (MBtu/yr)
Space Heating	44.3	13.8	13.8
Space Cooling	21.5	7.6	7.6
DHW	40.7	13.6	3.2
Lighting	24.7	6.9	6.9
Appliances + Misc./Plug Loads	56.6	52.5	52.5
Total Usage	197.9	94.3	83.9
Total Savings over Benchmark		103.5	114.0
% Savings over Benchmark		52%	58%

Through conversations with ZETA and the designer we were able to successfully convey the windows' contribution to the total building cooling load. They are currently re-assessing the design to see how the glazing area can be reduced while maintaining the desired architectural features.

2500 R Street

Zeta is proposing 30 single family homes at 2500 R Street in Sacramento, CA. All of the homes are 2 stories with 3 bedrooms, and approximately 1,300 ft². Zeta has been aggressive in seeking out participation in energy efficient programs. In addition to participation in Building America they are also trying to achieve Sacramento Municipal Utility Districts (SMUD) Solar Smart criteria as well as have 2 test homes participate in the SMUD Home of the Future program.

The objective for Zeta is to provide energy efficiency options to their clients. We helped to formulate these packages by providing energy consumption data and energy milestone criteria for each of their options.

The Zeta base case package goal is to reach at least 15% better than 2008 California Title-24 code. The specifications for the home include:

- R-19 wall insulation with R-5 rigid exterior foam
- R-30 ceiling insulation
- 0.31 U-value/0.32 SHGC windows
- 90 AFUE furnace
- 14 SEER/12 EER AC
- 30% fluorescent lighting

SMUD Solar Smart program (www.smud.org/en/residential/solarsmart) certifies that homes and communities reach energy efficiency goals prior to the installation of roof top PV. In general, the homes perform 35-40% better than 2008 California Title-24 code. All SMUD Solar Smart homes have at a minimum:

- Rooftop Solar System
- Radiant barrier
- 90 AFUE Furnace
- 100% Fluorescent lighting fixtures
- Energy Star windows
- Third-party certification and SMUD quality assurance inspections.

SMUD Home of the Future (HOF) program (www.smud.org/en/residential/homeofthefuture/) is a more rigorous program that tries to reach >45% better than 2008 California Title-24 code. HOF encourages cutting edge technology to achieve maximum energy savings. The specifications that were considered for the ZETA HOF includes:

- Advanced wall framing with EcoBat R-21 HD and R-5 rigid exterior foam
- R-30 Open cell spray foam in the ceiling with R-20 rigid foam at deck.
- Serious Fiberglass 925 Series windows (0.15 U-Value, 0.17 SHGC)
- CRRC cool roof product
- 94 AFUE furnace
- 15 SEER/12.5 EER AC unit
- Ducts in conditioned space, tested
- ACCA manual J and D sizing
- 2.0 SLA, tested
- Conditioned crawl space
- 0.82 EF Tankless water heater
- 2.9 kW DC PV system.

Table 2: Zeta-2500 R St Prototype Performance Relative to Benchmark, Source Energy Basis

	% better than 2008 CA T-24 Code (no Solar)	% better than BA Benchmark (no Solar)	% better than BA Benchmark (w/Solar)
Zeta-Base Case	15.8%	40.8%	n/a
Solar Smart Home	35.3%	54.6%	60%
Home of the Future	45.2%	58.6%	82.2%

The project is currently in the process of securing funding in order to begin construction.

36-38 Harriet Street

Zeta is proposing a nano-loft multi-family development at 36-38 Harriet in San Francisco, CA. The building would be 4-stories with 22 units between 325ft² and 340ft². We provided Zeta with a package of recommended ECMs that included the following:

- R-19 wall insulation w/R-5 continuous wall insulation
- Cool roof
- R-40 ceiling insulation w/ R-6 at the roof deck
- Windows with 0.31 U-value / 0.50 SHGC
- EccoPanel electric resistance heating
- No cooling system
- Central 3.4COP heat pump water heater w/ solar thermal and recirculation loop
- Energy Star clothes washer & dishwasher
- 100% fluorescent lighting
- 1.7SLA tight envelope

Table 3 lists source energy use by end use for the Benchmark (baseline) building and the prototype, and shows overall energy savings of 56%, well above the targeted 50%. "Lighting" includes common area, exterior, and unit lighting.

Table 3: Zeta Harriet St Prototype Performance Relative to Benchmark, Source Energy Basis

	Benchmark (MBtu/yr)	Prototype (MBtu/yr)	Savings % of End Use
Space Heating	173.8	75.2	57%
Space Cooling	8.0	0	100%
DHW	903.1	286.3	68%
Lighting	981.4	269.3	73%
Misc./Plug Loads	604.4	440.9	27%
Appliances	657.4	405.1	38%
Total Usage	3,328.1	1,476.8	56%

This project recently completed the approval process through San Francisco. Zeta is finalizing design for manufacturing and construction should start in 2011.

Quarry Village

Quarry Village is a proposed, transit oriented twenty-two acre community in the Hayward hills near California State University. The proposed development is on the site of a now abandoned and undeveloped rock quarry and will encompass approximately 950 three story townhouses. The design will be focused on providing a healthy, safe, affordable place to live, with less dependence on cars, easy access to transit, and a high quality of life.

DEG/CARB has provided estimates of annual energy needs for the 2 and 4 bedroom units based on all electric and electric / gas scenarios, in order to determine the renewable energy requirements and the associated costs. DEG also evaluated building envelope, glazing and mechanical system alternatives and made recommendations on potential strategies.

Table 4 shows source energy savings for the 944 ft² 2 bedroom home which incorporates an ECM package recommended to the builder by DEG/CARB. Source energy savings exceed the 50% Building America milestone. The developer is also proposing to include sufficient PV capacity to become a zero net energy community. Building components included in the ECM package include the following:

- R-21 wall insulation w/R-4 continuous wall insulation
- R-38 ceiling insulation w/ R-25 at the roof deck
- Perimeter slab insulation
- Windows with 0.32 U-value / 0.23 SHGC
- 15SEER / 8.5HSPF heat pump for heating and cooling
- Ducts in conditioned space
- Solar water heating w/ electric backup
- Energy Star refrigerator, clothes washer & dishwasher
- 100% fluorescent lighting
- 1.5SLA tight envelope

Table 4: Quarry Village Prototype Performance Relative to Benchmark, Source Energy Basis

	Benchmark (MBtu/yr)	Prototype (MBtu/yr)	Savings % of End Use
Space Heating	26.8	12.3	54%
Space Cooling	5.2	.3	95%
Ventilation	1.9	1.2	40%
DHW	35.8	3.9	89%
Lighting	15.2	7.3	52%
Misc./Plug Loads	22.1	17	23%
Appliances	24.4	20.0	18%
Total Usage	131.4	62	53%

The developer is in the process of drafting a pro-forma to interest investors in the development. The developer is also in discussion with Zeta Communities to identify whether the townhouses would be a good application for modular construction.

Lennar Urban

Lennar Urban is spearheading a massive residential development with plans on developing between 5,000 and 6,000 multi-family units over the next 15 years at Hunters Point Shipyard. The site is located on an old military base in San Francisco, CA. Hunters Point is an urban infill

project and partial brown-field remediation project. The construction of the units will be in phased blocks with the first four blocks scheduled to start construction in 2010 with occupancy by 2011. Lennar Urban has taken significant strides towards energy efficiency and green design. The project is participating in LEED and LEED Neighborhood Development as well as Build-It-Green's Green Point Rated program.

The four current blocks of development all have approximately 193 town home style buildings that qualify for Building America assistance. Davis Energy Group chose to analyze Unit D of Block 50, a 3 story end unit. Unit D is one of the largest end units. DEG/CARB evaluated preliminary energy efficient packages in order to reach the 50% Building America milestone. The upgrade packages would have to include:

- Advanced framing
- R-21 wall insulation w/R-4 continuous wall insulation
- Blower Door of \leq SLA
- Cool Roof
- R-49 Ceiling insulation
- 8.5 HSPF Heat Pump Heater
- No AC
- Condensing Tankless water heater
- Windows with 0.35 U-value/0.5 SHGC
- Energy Star dishwasher, fridge, and clothes washer
- 100% CFL Hardwired lighting.

Analysis completed on three buildings using Building America benchmark methods show that energy savings in the range of 46-48% can be expected. Table 5 shows savings for a sample building, Building 10. These savings are just short of Building America's target milestone for Marine climates of 50%. Measures such as the addition of 1" exterior foam insulation and improving water heating energy factor can be used to exceed the 50% target and are recommended on future blocks. Condensing tankless water heaters in combined space and water heating systems are also being investigated as a means of increasing usable floor space and reducing gas piping costs.

Table 5: Lennar Urban Building 10 Prototype Performance Relative to Benchmark, Source Energy Basis

	Benchmark (MBtu/yr)	Prototype (MBtu/yr)	Savings % of End Use
Space Heating	239.8	74.1	69%
Space Cooling	16.4	-	100%
DHW	202.5	91.4	55%
Lighting	189.4	52.8	72%
Appliances + Misc./Plug Loads	400.5	386.1	4%
Total Usage	1,048.7	604.3	42%
Net Energy Use with Size Adjustment	1,162.7	604.3	48%

Since no air conditioning is provided, installation of ceiling fans and tenants education will be used to address potential comfort issues that might occur during hot weather spells.

To realize electrical energy savings DEG/CARB is also recommending that Lennar provide sufficient hard-wired fluorescent fixtures to adequately illuminate all spaces (to minimize

occupant-supplied lighting), and that devices for reducing electric use from consumer electronics and other phantom loads be investigated.

Pulte Homes

Pulte Homes approached DEG with interest in participation in Building America for future developments. We conducted energy modeling on one of their existing single family developments in Elk Grove, CA. The development has six floor plans ranging from 1257 ft² to 2252 ft². Analysis of the homes as-designed predicted source energy savings of around 40%. Additional measures were evaluated using Pulte's Plan 6 to see how these measures performed individually and how they would impact energy savings and compliance with Building America savings goals. No single measure could be applied to meet the 50% benchmark goal; therefore, two packages were recommended that would achieve 50% savings. Table 6 shows the components of the two packages that were recommended to the builder for implementation. Both packages result in source energy savings greater than 50%.

Table 6: Pulte Recommend Packages w/ ECMs to Improve Performance

Package 1 – Envelope Improvements	Package 2 – Solar Water Heating
<ul style="list-style-type: none"> • Wall construction: 2x6 framing with R-21 insulation + R-4 exterior foam • Ceiling insulation: R-50 • 100% Fluorescent Lighting • AC: 15 SEER/ 12.5 EER • Tight Envelope: 2.6 SLA • Improved Furnace: AFUE 94 • Better Windows: 0.30 U-Factor/0.22 SHGC • Water Heating: Condensing Tankless (0.93 Energy Factor) • Appliances: Energy Star Refrigerator 	<ul style="list-style-type: none"> • Wall insulation: High density insulation: R-15 + R-4 exterior foam (2x4 walls) • Ceiling insulation: R-50 • 100% Fluorescent Lighting • AC: 15 SEER/ 12.5 EER • Tight Envelope: 2.6 SLA • Water Heating: Tankless WH (0.82 Energy Factor) + Solar Water Heating

Package 1 requires more significant investment into building envelope performance than Package 2. Package 2 assumes a solar water heating system to provide a minimum of 35% of the homes hot water needs. Pulte has not committed to either package as yet, but DEG plans to continue to work with them on specific communities.

Task 5: Project Closeout, Final Review of BA Communities

The project closeout stage is used to gauge how successful a production home builder was at incorporating energy efficient designs proposed in Stage 3, and to determine whether the projected energy savings materialized. This task evaluates post-construction energy consumption with analysis of occupied home utility bills, homeowner surveys, and modeling simulations.

5.1 *Mixed Humid - HfH of the Chesapeake, East Fayette Street*

CARB has an enduring partnership with Habitat for Humanity of the Chesapeake (HfHC) and its efforts to produce efficient, affordable rehabilitated and new housing in the Baltimore area since 2005. CARB has worked with HfHC on energy improvements and giving its work force hands-on training with their rehab programs. Prior to HfHC's participation in Building America, HfHC was in phase 1, "Historical Baseline", of energy efficiency retrofits. These homes included high efficiency furnaces, increased insulation levels, and Energy Star appliances. Seven row homes were completed between January 2004 - June 2005. CARB worked with HfHC to develop phase 2, "Stepped-Up Efficiency", building specifications. These included low-e windows, tankless water heaters, mastic sealed ductwork, improved air sealing techniques, and compact fluorescent lighting. Fourteen row homes were completed between June 2006 - June 2008. From October 2008 - May 2009, CARB took a back seat in this partnership as HfHC worked with a local rater on phase 3, "Energy Star". Fifteen row homes were completed over this period. CARB began actively working again with HfHC in 2009 on their modular East Fayette Street Project.

HfHC worked with Baltimore Gas & Electric and Brandon Little, a graduate student from Duke University, to quantify the benefit of their energy efficient affordable housing efforts compared to other row homes of similar size in Baltimore. An analysis of variance (ANOVA) confirmed that there was a statistically significant difference in mean daily energy performance between the HfHC group and the control group. This was extremely important to HfHC due to a December 2007 study by Oak Ridge National Laboratory that found that from 2001 to 2005, the average residential energy burden (ratio of energy expense over household income) rose for low-income households from 12.6 to 14.6% of income, while the burden for non-low income households rose from 3.1 to 3.2%. The results from Ms. Little's analysis showed the following savings benefits from the various phases (table to right).²

	Electricity	Gas
All HHC	25%	33%
Phase 1	11%	17%
Phase 2	32%	55%
Phase 3	25%	29%

It is interesting to note that Phase 2 homes demonstrated the greatest energy efficiency. More important, is that Phase 2 and 3 show the least amount of variance between homes. This demonstrates that quality control were excellent during these phases.

CARB built upon the analysis of Ms. Little to provide this BA community final review/evaluation, provided as Attachment III.

² *Energy Consumption Study for Habitat for Humanity of the Chesapeake* by Brandon Little, Duke University

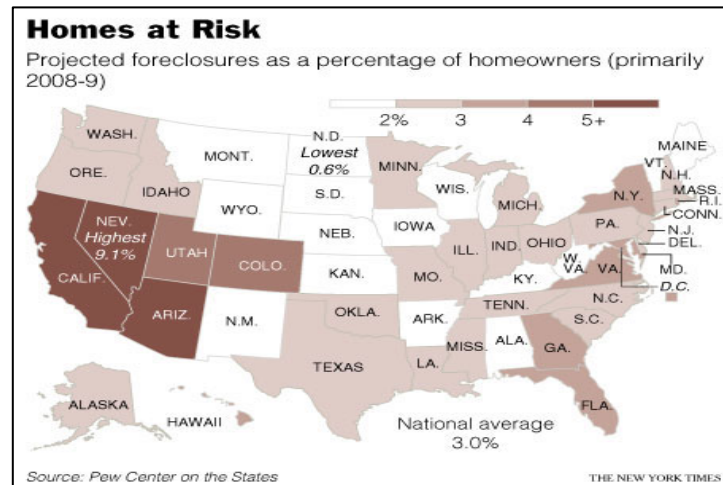
Task 6: Other Research Activities

This section focuses on CARB's existing housing research.

6.1 Hot/Mixed Dry Climate –Clark County Neighborhood Stabilization Program

In February of 2010, CARB entered into a partnership with the Community Resources Management office in Clark County, NV to provide technical assistance and program evaluation for their residential rehabilitation program funded through the Neighborhood Stabilization Program (NSP).

The Neighborhood Stabilization Program is administered by the Department of Housing and Urban Development (HUD) and was established for the purpose of stabilizing communities that have suffered from foreclosures and abandonment. Specific goals of this program include stabilizing the housing market, providing durable, low cost homes, providing down payment assistance and creating jobs in the construction industry. Because foreclosure and abandonment rates in Nevada were among the worst in the nation, Clark County received approximately 30 million dollars in state and federal funding under the NSP.



NSP grantees must use at least 25 percent of the funds appropriated for the purchase and redevelopment of abandoned or foreclosed homes or residential properties that will be used to house individuals or families whose incomes do not exceed 50 percent of the area median income (AMI). In addition, all activities funded by NSP must benefit low- and moderate-income persons whose income does not exceed 120 percent of area median income. In Clark County, NV, the AMI is \$75,000 for a family of 4.

The funds can be used in a number of ways including:

- establishing financing mechanisms for purchase and redevelopment of foreclosed homes and residential properties;
- purchasing and rehabilitating homes and residential properties abandoned or foreclosed;
- establishing land banks for foreclosed homes;
- demolishing blighted structures;
- redeveloping demolished or vacant properties.

In Clark County, the majority of the funds were used to purchase and rehabilitate single family homes for resale and rental. The remainder of the funds was primarily allocated for homeowner counseling and purchasing assistance.

BA Involvement

Clark County's specific goals included rehabilitating 300 - 400 homes. All homes were to be built to Home Performance Specifications for Warm Climates (HPWC) and achieve a HERS index of 50 or better. To aid in achieving these goals, CARB offered energy modeling services along with technical support for the auditors.

Energy Modeling: CARB analyzed the viability and energy savings of over thirty different upgrades for typical homes in Clark County taking into account age, as-built construction, familiarity of the industry with each upgrade and cost-effectiveness. Although NSP funds are not subject to cost-effectiveness evaluation in order to be implemented, CARB, along with several of the auditors, felt that this was the best path for analysis.

The preliminary analysis was conducted in both REM/Rate and EnergyGauge and is summarized in the tables below. In addition to a few standard recommendations as listed below, three different HVAC combinations were analyzed:

1. 94 AFUE gas furnace w/ 16 SEER a/c;
2. 9 HSPF/16 SEER air source heat pump;
3. 94 AFUE gas furnace with an evaporative cooler.

Each of the above cases analyzed also included the following improvements which were found to be the most cost-effective and easily implemented:

- Instantaneous natural gas water heater (0.82 EF);
- 90% fluorescent lighting;
- ENERGY STAR® refrigerator, dishwasher and clothes washer;
- Exhaust only ventilation using Panasonic WhisperGreen bath fans at 50 cfm continuous flow.

EnergyGauge Results for Clark County, NV

SPECIFICATIONS	94 AFUE & 16 SEER A/C		9 HSPF & 16 SEER A/C		94 AFUE & 85% Evap. Cooler	
	kWh/yr	MMBtu/yr	kWh/yr	MMBtu/yr	kWh/yr	MMBtu/yr
Total cooling (kWh)	2326	7.9	2326	7.9	1064	3.6
Heating fan/pump(kWh)	117	0.4	1458	5.0	133	0.5
Lighting (kWh)	688	2.3	688	2.3	688	2.3
Appliances (kWh)	1939	6.6	1939	6.6	1939	6.6
MEL's (kWh)	2435	8.3	2435	8.3	2435	8.3
TOT. ELECTRIC	7505	25.6	8846	30.2	6259	21.4
NATURAL GAS LOADS	therms/yr	MMBtu/yr	therms/yr	MMBtu/yr	therms/yr	MMBtu/yr
Total Heating	143	14.3	0	0	143	14.3
Hot Water	100	10	100	10	100	10
TOTAL GAS	243	24.3	100	10	243	24.3
ANNUAL ENERGY USE (MMBTU)	49.9		40.2		45.7	
Utility Bills**	\$1,241		\$1,202		\$1,092	
Annual Savings \$			\$39		\$149	
HERS Index (2006)	59		61		61	

*Energy Gauge score - couldn't model indirect, only direct evaporative cooling.

**Assumes \$1.4/therm & \$0.12/kWh

REMRate Results for Clark County, NV

SPECIFICATIONS	94 AFUE & 16 SEER A/C		9 HSPF & 16 SEER A/C		94 AFUE & 30 EER Evap. Cooler	
	kWh/yr	MMBtu/yr	kWh/yr	MMBtu/yr	kWh/yr	MMBtu/yr
Total cooling (kWh)	2431.9	8.3	2490.5	8.5	1611.5	5.5
Heating fan/pump(kWh)	52.6	0.2	2865.4	9.6	52.6	0.2
Lighting (kWh)	941	3.2	941	3.2	941	3.2
Appliances (kWh)	2010.6	6.9	2010.6	6.9	2010.6	6.9
MEL's (kWh)	2641	9.0	2641	9.0	2641	9.0
TOT. ELECTRIC	8077	27.6	10948.5	37.2	7256.7	24.8
NATURAL GAS LOADS	therms/yr	MMBtu/yr	therms/yr	MMBtu/yr	therms/yr	MMBtu/yr
Total Heating	268	26.8	0	0	268	26.8
Hot Water	110	11	110	11	110	11
TOTAL GAS	378	37.8	110	11	378	37.8
ANNUAL ENERGY USE (MMBTU)	65.4		48.2		62.6	
Utility Bills**	\$1,511		\$1,468		\$1,413	
Annual Savings \$			\$43		\$98	
HERS Index (2006)	55		59		48	

**Assumes \$1.4/therm & \$0.12/kWh

Technical Assistance: In an effort to provide on-going support to Clark County, CARB has provided services beyond energy modeling. CARB has attended in person or via conference call several meetings with the auditors and program administrators to provide advice and guidance on the most affective upgrades for their climate and answer any technical questions that arise. A substantial portion of this assistance was provided in response to contractor resistance to performing certain tests, calculations or improvements.

For example, HVAC contractors were reluctant to warranty their new installations in attics if roof deck insulation was being applied and the existing ceiling plane insulation was not being removed. CARB monitored four different attics for a couple of weeks during the height of the summer to evaluate the conditions of these attics and to try to determine if the attics with roof deck and ceiling plane insulation were in fact less hospitable environments than homes with just ceiling plane insulation. The results of this study were included in the Section 2.3.

Development of Supporting Documents: One of the requirements of the HPWC program that Clark County adopted is that the HVAC contractors comply with the Building Performance Institute's (BPI) "Technical Standards for the Air Conditioning and Heat Pump Professional". It quickly became evident that local contractors lacked the skill and training to successfully comply with this standard. CARB assisted Clark County by creating training materials, field checklists and guidelines for successful implementation of this standard. See Attachment JJJ for the guideline and checklists. Several meetings were held with the field auditors and experienced HVAC professionals during the development of these materials to ensure accuracy and to tailor them to Clark County's needs.

CARB continues to respond to requests for advice on technical problems and answer questions from the auditors and contractors.

Barriers to Success

Throughout the first phase of this program, Clark County staff encountered numerous barriers to reaching their goals. Inspection costs and remediation of non-energy related problems like the presence of asbestos and lead ate into the allotted budgets for each home. The table below lists the minimum inspections required for each home in the program and the associated costs.

Inspections Required and Associated Costs	
Inspections	Cost
Environment Hazards (pre-purchase)	\$200
Code Compliance Inspection	\$350
Asbestos (any age)	\$400
Lead (1978 and earlier)	\$400
Infrared Scan	\$225
Initial Energy Audit	\$800
Work Scope	\$800
Final Audit	\$300
Total Inspection Costs:	\$3,475

In some cases, remediation has cost over \$20,000 per home in homes that have tested positive for asbestos.

Inaccurate estimates (especially in the earlier months) have been common. In some cases, the bids are much too low because the subcontractors do not understand the extent of the work required and are underbidding those contractors that are experienced. This has lead to numerous change orders and delays in completion. In other cases, requests to perform work or install systems that the contractors are unfamiliar with have lead to serious overbidding. To deal with these problems, the County has been providing regular and extensive training classes for everyone from the HVAC contractors to city employees. BPI training, advanced HVAC design and basic building science courses have all been offered over the past several months, and several more are scheduled.

Finally, the paperwork involved and the reporting requirements of this program on the federal, state and county level have been quite onerous. The paperwork for one house alone can fill more than one 3" binder. The manager of the program has been working diligently with all offices involved to streamline the process and reduce the amount of reporting required.

Future Work

Clark County has been awarded another round of NSP funding for 2011. CARB will evaluate the program's success to this point by reviewing actual vs. predicted HERS indices, costs of improvements, lessons learned and any changes in procedures that have occurred over the past year. Recommendations for improvements will be made after this evaluation.

CARB will also discuss Clark County's future needs with program managers and develop scopes of work to address these needs.

6.2 Hot Humid Climate –BASF Duct Retrofit

CARB partnered with BASF, a major manufacturer of closed-cell spray polyurethane foam (ccSPF) insulation, on a demonstration project in Jacksonville, Florida. Building upon past CARB research on "Buried Ducts", this demonstration project explores the application of an encapsulated, insulation-buried duct strategy for existing homes in a hot/humid climate (Climate Zone 2).



Previous CARB research projects conducted in humid climates have established the need for encapsulating the ductwork prior to burying it beneath the insulation to avoid condensation

problems. The encapsulation with ccSPF also seals the gaps and cracks in the ductwork, while providing the minimum required insulation R-value for the ductwork in a thin 1.5 inch layer on each surface of the ductwork. For existing homes with space constraints, this is critical for facilitating duct routing through trusses and tight against the attic floor in order to maximize the amount of insulation that can be installed over the ductwork.

The three test sites were pre-screened and selected from a larger pool of BASF employee homes located in the Jacksonville area, close to a BASF corporate office. BASF will provide the ccSPF materials needed to encapsulate the ductwork for the test houses. In addition, they will fund up to \$5,000 per home to cover the costs of labor and materials associated with the retrofits through their “Neighborhood Energy Efficiency Drive” Program (NEED). The NEED Program offers BASF employees programs and products that increase the efficiency, sustainability, and comfort of their homes.

CARB developed a Test and Monitoring Plan for the project. In accordance with the plan, CARB installed monitoring equipment to assess the pre-retrofit performance of each home. Sensor installation and baseline performance testing were conducted from July 13-15, 2010. CARB plans to return to retrieve the sensors and perform detailed take-offs for the ductwork in each home during the first week of February 2011. That information will be assessed and used to develop designs for the duct reconfiguration. It is anticipated that the ductwork will be reconfigured and buried in May 2011, followed post-retrofit monitoring period.

The Test and Monitoring Plan are provided as Attachment KKK.

6.3 *Mixed Humid Climate –Levittown*

The objective of this scoping study is to assess the opportunity for energy conservation retrofits in the 17,311 homes built by Levitt and Sons in the mid 1950’s in Levittown, PA. In order to accomplish this, comprehensive energy audits are being performed on a representative sample of the six model types. Data is being gathered to determine construction characteristics of the current housing population in Levittown and assess commonalities. Energy upgrades are being modeled for all audited homes with the goal of achieving a minimum of 20% energy savings. Upgrades will be examined across the sample set and within each model type to develop cost effective retrofit packages that can be implemented throughout the community. Additional goals include identifying barriers to specific technology, upgrades or implementation within the community. Finally, the intent is to engage local community groups that will be able to move this project toward the ultimate end of actual installation of retrofits on a large scale across Levittown, PA.

The progress towards the goal of creating template energy efficiency upgrades for the Levittown community has been slower than predicted. Recruiting potential participants has been more challenging than was originally anticipated and obtaining utility data even more difficult. The modeling process has been more complicated than anticipated largely due to the fact that the homes predominantly use fuel oil for heating. Fuel oil is delivered in bulk, which makes determining actual usage over a specific time period difficult. Creating a robust process for this which allows for building models to be adjusted to match usage and implementing it consistently has also required additional modeling time.

Despite the challenges, much has been accomplished since the project’s kickoff. Eleven audits have been completed and baseline energy models have been created for each of the five unit types that have been audited. A comprehensive list of viable energy upgrades that are common

to the Levittown community is well under way. A lot has also been learned about the existing housing stock in Levittown. A majority of the homes have been modified in significant ways from their original construction. Although we originally saw this as an obstacle, it has become evident that many of the alterations have been consistent throughout the community (for example: switching heating distribution from radiant floor to baseboard radiators). Additionally the basic energy upgrade recommendations are the same across the various model types and additions or modifications.

Completion of the main task lies ahead. Creating solution sets for each model type or across all models with energy savings and costing information is in progress. Although many lessons have already been learned about community wide energy auditing of production homes, the heart of the project is establishing consistent and replicable upgrades and starting the process for large scale implementation. The team looks forward to dedicating itself to completing this work and reporting on the findings in the new year.

The Community Scale Energy Retrofit Scoping Study is provided as Attachment LLL.

6.4 Exelon & Habitat for Humanity International Weatherization Pilot

In September 2009, Exelon Corporation (Exelon), a US-based utility services holding company, and Habitat for Humanity International (Habitat), a Christian ministry dedicated to providing simple, decent and affordable homes to those in need, launched a pilot program to weatherize 70 low-income households, helping to reduce energy use and utility bills for the homeowners. The partnership was the first Habitat program to improve the energy efficiency of existing houses belonging to low-income homeowners – traditionally, Habitat volunteers have built new homes for families, with their assistance or “sweat-equity”. The pilot program provided training for volunteers to install cost-effective energy-saving features into existing houses for homeowners in Illinois, Pennsylvania and Texas, with the goal of reducing energy usage and lowering their utility bills between 12 percent and 25 percent. Weatherization projects were estimated to cost \$2,000 to \$8,000 per home and potential improvements included weather stripping, caulking, adding or replacing door seals, installing water-saving toilets, replacing showerheads, replacing water heaters and furnace filters, installing CFL bulbs, and insulating attics, basements and outer walls.



In addition to donating \$300,000 to fund the program, Exelon provided technical expertise and donated an estimated 7,000 Exelon employee volunteer hours for the program. Partnerships with DOW Chemical Co. and Whirlpool Corp. resulted in donations of insulation and energy-efficient appliances. Exelon and Habitat for Humanity International intend for the pilot program to serve as a model for similar programs in other US cities.

Since the September launch, Habitat and Exelon have designed the projects and developed training programs for volunteers and Habitat partner families across Exelon's service territories of northern Illinois, southeastern Pennsylvania and Texas. Of the more than 70 projects, 35 to 40 projects are located in northern Illinois, about 30 are from southeastern Pennsylvania, and five are in the Dallas-Fort Worth area. Since the existing housing market presents significant opportunities for improving energy efficiency and reducing the nation's energy use, CARB has been supporting Habitat in its efforts by providing energy efficiency guidance, in the form of weatherization training, energy audits, and construction management, to three Habitat affiliates

around southeastern Pennsylvania, HFH-Chester County, HFH-Philadelphia, and HFH-Southern Ocean County. The goal: to develop a case study based on the results and lessons learned from this pilot program that can be used at other Habitat affiliates as other weatherization programs are implemented across the nation.

A summary of this work is provided as Attachment MMM.

6.5 Sonoma Deep Energy Retrofit

CARB/DEG is participating in a research project to assist with the design and evaluation of a “deep” retrofit house built to Passive House standards. Built by Solar Knights Construction, the Sonoma house is the first certified Passive House to be built in California, and the first Passive House retrofit in the U.S.



Davis Energy Group adopted the project as a Building America deep retrofit opportunity to identify and evaluate “deep” retrofit measures that are practical and potentially cost-effective for the retrofit market, as well as to review the Passive House design approach as a Building America strategy. The major objective of this research is to determine how practical the Passive House design approach is in the Building America context and to identify possible take-aways from the Passive House design approach. This research will compare whole house energy usage from simulations to monitored performance, and will identify possible individual measures taken that may be applicable to Building America retrofit practices. A savings analysis was performed, but several of the design features, including a reflective air space built into the walls and a solar thermal system coupled to the ERV could not be modeled. Energy Gauge projects source energy savings of 54% without PV and 58% with PV are projected vs. the original design.

Originally built in the 1960’s, the Sonoma, California house has a remodeled floor area of 2,380 ft². The house is fully monitored in a cooperative arrangement with Lawrence Berkeley National Laboratory and was completed and occupied in November 2010. The house includes a unique vented wall assembly, extremely tight and high quality construction, solar thermal water heating and space heating, and a PV system. Sonoma is within the Marine climate zone.

A summary of this work is provided as Attachment NNN.

List of Attachments

- A. BA Quarterly Presentation – Barriers to Successful Community Scale Retrofit Programs
- B. BA Quarterly Presentation – Affordable Housing Redevelopment: Chamberlain Heights
- C. BA Quarterly Presentation – Lender Confidence in Energy Efficiency Retrofits
- D. BA Quarterly Presentation – Deep Energy Retrofit: ReVISION House - Las Vegas
- E. ASHRAE Conference Presentation – Energy and Water Waste Implications of Hot Water Distribution System Design and Use Patterns
- F. NESEA Conference Presentation – High Performance Windows for Northern Climates
- G. BEST2 Conference Presentation – Practical, Residential Wall Systems: R-30 and Beyond
- H. NORA Conference Presentation – Getting to Zero: Residential Retrofits and New Construction
- I. California Redevelopment Association Presentation – EERE Opportunities and Strategies in Market Rate & Affordable Housing
- J. ACEEE Hot Water Forum Presentation – Modeling Distribution System Performance
- K. Panasonic Workshop Presentation – Current Projects & Technology Gaps
- L. Norwalk Preservation Trust Presentation – Insulating Your Green Old House (without screwing it up)
- M. EEBA Conference Presentation – Building America Emerging Technologies Research
- N. GRC Conference Presentation – Residential GSHP: In-Field System Performance and Energy Modeling
- O. Condensing Boiler Expert Meeting – Agenda and Attendee List
- P. Condensing Boiler Expert Meeting – Meeting Notes
- Q. Condensing Boiler Expert Meeting Presentation – Meeting Intro and Objectives
- R. Condensing Boiler Expert Meeting Presentation – Building America Condensing Boiler Research
- S. Condensing Boiler Expert Meeting Presentation – Hydronic System Performance
- T. Condensing Boiler Expert Meeting Presentation – Boiler Performance Testing
- U. Condensing Boiler Expert Meeting Presentation – Pump Efficiency Rating Systems
- V. Technical Paper – Energy Aware Planning Guide
- W. Technical Paper – Practical Residential Wall Systems: R-30 and Beyond
- X. Technical Paper – The Last Big Leak: Exposed Slab Edges
- Y. Technical Paper – Zero Energy Communities: UC Davis' West Village Community
- Z. Technical Paper – A Case Study in Reconciling Modeling Projections with Actual Usage
- AA. Technical Paper – Residential Ground-Source Heat Pumps: In-Field System Performance and Energy Modeling
- BB. California 50% Savings Packages Report
- CC. Evaluating the Heat and Moisture Performance of High-R Walls Research Report
- DD. Effects of a Radiant Barrier on Roof Cavity Temperature Research Report
- EE. Non-Ducted Mechanical Systems Research Report
- FF. Low-Load Heating Systems Research Report
- GG. Condensing Boiler/Hydronic Distribution Systems Research Report
- HH. Ground-Source Heat Pump Systems Monitoring Protocol
- II. Low-Temperature Air-Source Heat Pump Research Report

- JJ. Evaporative Condenser Gate Evaluation Report
- KK. Hybrid Air-to-Water Heat Pump Evaluation
- LL. California Residential Ventilation System Effectiveness Study
- MM. Scheduled Ventilation in Hot-Dry Climates Report
- NN. Water Heating Best Practices Design Guide
- OO. Solar Thermal Water Heating Systems Report
- PP. Cold Climate Prototype Case Study Report – New World Home
- QQ. Cold Climate Prototype Case Study Report – Young Residence
- RR. Cold Climate Prototype Evaluation Report – Shaw Builders/GreenMax 2
- SS. Cold Climate Prototype Monitoring Summary Report – All American Lumber/GreenMax 1
- TT. Cold Climate Prototype Design Report – Devens
- UU. Mixed Humid Climate Prototype Update Report – Paragon Homes’ Partlow Project
- VV. Hot/Mixed Dry Climate Retrofit Prototype Case Study – ReVISION IBS Demonstration Home
- WW. Hot/Mixed Dry Climate Prototype Case Study – La Mirada “Seed Home”
- XX. Marine Climate Prototype Case Study – One Sky Homes
- YY. Cold Climate Community Scale Case Study – RDI’s Wisdom Way Solar Village
- ZZ. Cold Climate Community Scale Retrofit Summary Report – Chamberlain Heights
- AAA. Cold Climate Community Scale Solar Evaluation Report – Hunting Ridge Estates
- BBB. Cold Climate Community Scale Solar Evaluation Report – Evergreen Systems’ Mason Island Landing
- CCC. Cold Climate Community Scale Summary Report – Evergreen Systems’ Mason Island Landing
- DDD. Mixed Humid Climate Community Scale 40% Joule Report – SBER’s Overlook at Clipper Mill
- EEE. Mixed Humid Climate Community Scale Summary Report – Paragon Homes’ Broad Run & Potomac Farms
- FFF. Hot Humid Climate Community Scale 40% Joule Report – William Ryan Homes
- GGG. Hot/Mixed Dry Climate Community Scale Case Study – UCD West Village
- HHH. Hot/Mixed Dry Climate Community Scale Case Study – Willowbank Park
- III. Mixed Humid Climate Project Closeout – HfH of the Chesapeake
- JJJ. Guidelines for Complying with BPI’s Technical Standards for the Air Conditioning and Heat Pump Professional
- KKK. Hot Humid Climate Retrofit Duct Evaluation
- LLL. Community Scale Energy Retrofit Scoping Study - Levittown
- MMM. Exelon and Habitat for Humanity’s Weatherization Pilot Report
- NNN. Sonoma Deep Energy Retrofit Summary Report