Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

Research that Works

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Building America System Research Results: Innovations for High Performance Homes

U.S. Department of Energy
Energy Efficiency and Renewable Energy
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Building Technologies Program

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Executive Summary

For innovative building energy technologies to be viable candidates over conventional approaches, it must be demonstrated that they can cost-effectively increase overall product value and quality while significantly reducing energy use and use of raw materials when used on a production basis. Building America's industry team-based systems research projects evaluate opportunities for cost and performance trade-offs that improve whole-building performance and value while minimizing increases in overall building cost.

Systems research is conducted at multiple scales, including individual test houses, pre-production houses, and community-scale developments. Systems research includes analysis of system performance and cost tradeoffs as they relate to whole-building energy performance and cost optimization, including interactions between advanced envelope designs, mechanical and electrical systems, lighting systems, space conditioning systems, hot water systems, appliances, plug loads, energy control systems, renewable energy systems, and onsite power generation systems.

Building America's system research also evaluates process innovations that improve efficiency and flexibility of housing production to increase value, reduces risks, reduce barriers, and accelerates adoption of new technologies by increasing integration between the design and construction process, increasing system performance, increasing system cost effectiveness, and increasing system reliability and durability.

The Building America Program has focused for the past ten years on accelerating the development of high performance energy systems for new homes, with the ultimate goal of developing homes that use an integrated combination of energy efficiency and renewable energy to produce as much energy as they use on an annual basis.

There are three levels of market maturity that must be met before a new system can have a broad market impact on new homes:

1. The system must meet minimum builder and contractor performance and reliability requirements to be used in new homes.
2. Design and construction details for integration of the new system into homes must be understood and validated.
3. Training, quality assurance and quality control requirements for the system must be understood and implemented so that homes using the system can be built on a production basis.

Each maturity level establishes go/no-go requirements that must be met before a system can move on to the next level of maturity. The first level of maturity must be reached before the technology can be included in research projects with builders. The second level of maturity must be met before the technology can be included in pilot production homes. The third level of technology maturity must be reached before the technology can be successfully implemented by production builders.

This report provides a summary of key lessons learned from the first ten years of the Building America program and also included a summary of the future challenges that must be met to reach the program's long term performance goals.

More information about the industry research teams that participate in the Building America program and additional publications and research results can be found by visiting www.buildingamerica.gov.

The Three Levels of Residential Technology Maturity that Must be Met to Successfully Integrate Advanced Systems into New Production Homes

1. Meets Minimum Residential Performance Requirements:
   Technology meets minimum availability, reliability, O&M and durability requirements and provides high potential value to builders, contractors, and homeowners.

↓

2. Can Be Integrated with the Residential Construction Process:
   Best practice design details and construction sequencing are known and accepted by builders, contractors, and local code officials. Costs and benefits have been validated based on construction of one or more pilot homes.

↓

3. Can Be Built on a Production Basis:
   Quality assurance requirements, quality control requirements, and training requirements are understood and individual responsibilities are accepted by suppliers, builders and subcontractors.

Introduction

Over the past 10 years, the Building America program has worked with more than 120 builders that have completed more than 30,000 homes in all major climate regions in the United States. Building America's first 10 years of research have led to a large body of technical information, industry experience, and lessons learned that have been instrumental in moving the residential building industry to higher performance practices and products. This report chronicles the how and why of key Building America research results. It is organized in the context of what the Building America research teams have learned from working with their building industry partners.

This report is organized into three major sections:

- System Research Results This section reviews key contributions that have been made by the Building America Program and its research partners
- Lessons Learned: Approaches for Creating Effective Builder and Industry System Research Projects This section the key steps in the system research process based on lessons learned from Building America research projects
- Future Challenges: Remaining Market and Technical Barriers This section reviews future system research challenges and current progress in problem areas that need additional work.

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System Research Results

High-Performance Walls, Roofs, and Foundation Systems

Advanced-Framing Systems and Packages

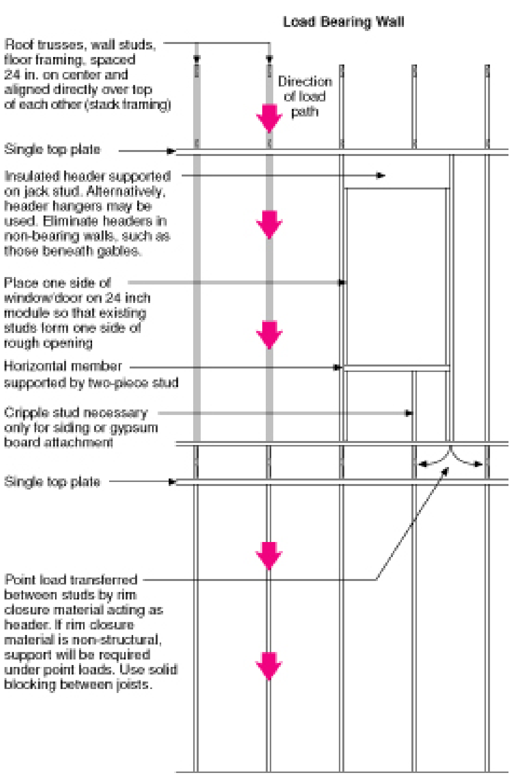
Advanced framing is a pillar of the Building America systems-engineering approach. Rarely are changes in design and construction so universally compelling as advanced framing. Benefits include the following:

Lesson Learned

BSC staff members hate to say this about advanced framing, but half a cup is better than none. Advanced framing has been around for more than 25 years. BSC should not be surprised that it will take more than 5 years to move the second half of BSC production builders to advanced framing, given that the industry as a whole is taking more than five times as long for any significant market penetration of this approach.

- Improved thermal performance
- Reduced call-backs (particularly drywall cracking)
- Reduced materials costs (less material in the framing package)
- Reduced labor costs
- Easier accommodation of mechanicals (particularly HVAC ducting in floor assemblies)
- Reduced waste disposal costs.

BSC is proud of the fact that approximately half of BSC builders and their developments embrace advanced-framing systems, but it's difficult to reconcile its absence in the other half. Despite the professional technical assistance offered to every BSC Building America builder, there are more than a few that choose to stick with conventional framing. Each of the obstacles below is more an issue of perception or interpretation than an issue of substance:



- **Resistance from the framing contractor** Although the inability to make the change (crews that either do not understand or cannot read detailed framing plans) is not uncommon, more frequently it is unwillingness rather than inability to employ advanced framing.
- **Resistance from the sales staff/homebuyer** "Wood is good; therefore, more wood must be better," makes it difficult to convince the consumer of the benefits of advanced framing, particularly on interior walls, where there is no quantifiable energy benefit.
- **Resistance from local building inspectors** Despite the fact that fewer and fewer local codes actually preclude many advanced-framing techniques, every builder must still convince the inspector on the job or reviewing the plans about advanced framing.

Builders

Pulte Homes — Houston, Phoenix, Tucson, Northern California, Sacramento, Southern California

Prairie Holdings Corporation — Grayslake, Illinois

Town & Country Homes — Vernon Hills, Illinois and Minnesota

Venture, Inc. — Flint, Michigan

Artistic Homes — Albuquerque, New Mexico

Lee Homes — Los Angeles, California

Habitat for Humanity — Orlando, Denver

Resources

www.buildingscience.com/resources/misc/wood_efficiency.pdf

Basement Insulation Systems

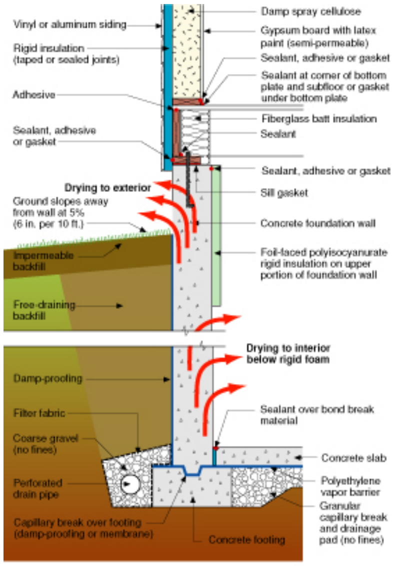
Lessons Learned

A focus on just one performance attribute of a material is antithetical to systems thinking, yet this approach is pervasive in construction practice, product manufacturing and marketing, and building codes. Basement insulation is a perfect example. A systems approach applies as well to material selection as it does to design. This is a lesson we should not be relearning but, too often, do.

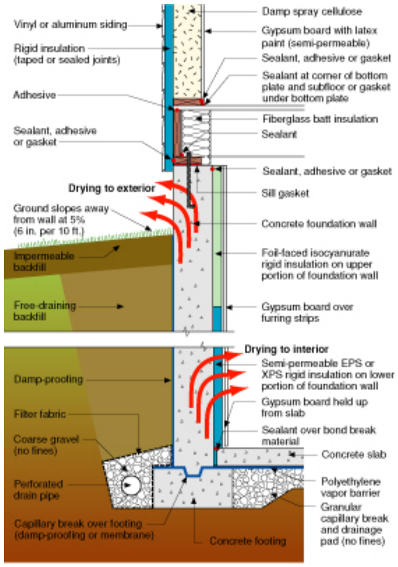
For a variety of cost and ease-of-construction issues, many if not most basements in new homes are insulated on the interior. And homes that start out with no basement insulation always end up with interior basement insulation when the basement is finished off and converted into full living space.

The addition of interior insulation (often with a vapor retarder or barrier interior face) along with other components—vapor barriers, wood framing, drywall, paint, etc.—have led to significant changes in the way that heat and moisture move through the basement wall assembly. And these changes are almost always for the worse. Mold, rot, and odor problems exist in new energy-efficient homes with what BSC contends are inappropriate insulation or wall assemblies in basements.

To address this issue, BSC has developed code-compliant (in terms of fire rating) interior insulation strategies that permit moisture from the soil and curing concrete to move through and out of the concrete and the interior insulation. In this way, high-performance homes maintain their energy performance; basements can be finished off as living space; and moisture, mold, and odor problems are controlled.



Unfinished Basement — Half-height insulation
- Lower portion of wall dries to the interior
- Upper portion of wall dries to the exterior



Finished Basement
- Drying continues to the interior
- Drying to the exterior

Builders

Pulte Home Corporation — Detroit, Michigan

Resource

www.buildingscience.com/resources/foundations/basement_insulation_systems.pdf

Cool Roofs

Improving attic thermal performance is fundamental to controlling residential cooling loads in hot climates. Research shows that the influence of attics on space cooling is not merely the result of the change in ceiling heat flux. It is often caused by the conditions within the attic and their influence on duct system heat gain and building air infiltration.

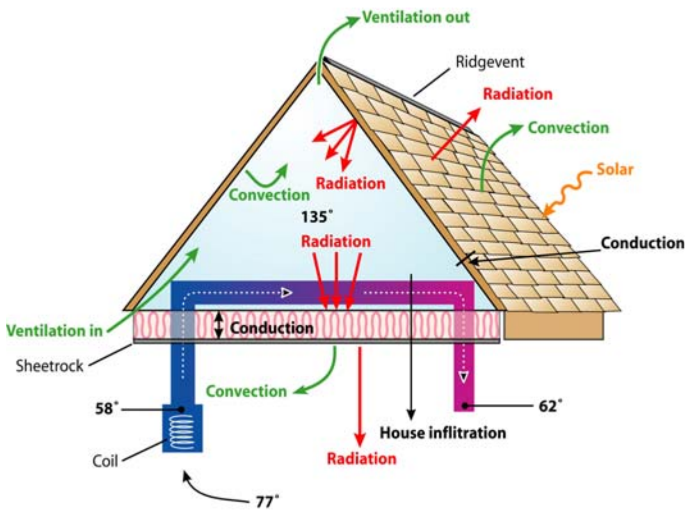
To comparatively evaluate performance, BAIHP uses its Flexible Roof Facility (FRF) to simultaneously evaluate five roofing systems against a control roof with black shingles and vented attic. The testing evaluates how roofing systems impact summer residential cooling energy use and peak demand.

Research over the past 5 years has achieved industry-changing results:

- Established the large influence of roof reflectivity on attic thermal performance regardless of roofing type (shingles, tile, metal)
- Demonstrated long-term performance of painted and unfinished metal roofing systems
- Demonstrated the potential of infrared-reflective, spectrally selective pigments leading to innovation of "cool colors" by the roofing industry (BASF, Shepard Paints)
- Provided research that underscores the need for more reflective shingles, leading to industry innovation (Elk Corporation, Cool Shingles)
- Compared performance of different attic ventilation levels on thermal performance and attic humidity
- Demonstrated the performance of sealed attic construction with roof deck insulation, showing the powerful combination of this method when combined with more reflective roofing.

Lessons Learned

- Reflectivity is fundamental.
- Spectrally selective products show excellent promise.
- Long-term reflectance of metal products is generally superior.
- Sealed attic constructions should emphasize reflectance for best performance.



Vented attic thermal processes schematic

Resources

Parker, D., Sonne, J., Sherwin, J. "Flexible Roofing Facility: 2004 Summer Test Results." Prepared for the U.S. Department of Energy Building Technologies Program, July 2005.

Parker, D.S., Sherwin, J.R., and Sonne, J.K. "Cooling-Related Performance of Finished and Unfinished Metal Roofing Systems," Proceedings of the 2004 ACEEE Summer Study on Energy Efficiency in Buildings, Vol. 1, Residential Buildings, Technology, Design, and Performance, American Council for an Energy Efficient Economy, Washington D.C.

Development of an Energy-Efficient Precast-Foundation Panel System

CARB has been working with Oldcastle Precast, Inc., a leading precast concrete company, to research and develop residential precast foundation wall systems. Oldcastle representatives first became interested in creating a finish-ready precast basement panel after attending a June 2004 Building America Expert Meeting on Advanced Concrete Construction organized by CARB.

Lessons Learned

- Market need was generated by virtue of few and expensive insulated basement alternatives. Exterior insulation is costly with durability issues. Most current interior insulation systems can present moisture/mold problems.
- Required wall R-values (code prescriptive) do not take moisture control into account. Critical design conditions occur at above-grade portions of wall.
- Thermal bridging, surface condensation, and lack of drying ability must be avoided.
- Precast-foundation systems have shorter production times, reduced construction waste, can be assembled in one day on-site, are more energy efficient (whole-wall R-20), and have better moisture resistance resulting in mold control and improved IAQ.

Precast systems generally have better quality control, decreased construction time with increased durability, better water tightness, can be set in cold weather, and do not need poured footings. Past CARB research has illustrated a number of alternatives for creating well-insulated unfinished basements, but creating finished space in the cool, damp basement environment presents other problems.

Researching the best available technologies of precast-foundation wall systems, CARB found that some systems with non-continuous insulation results in thermal bridging, which mitigates energy performance and can cause condensation and moisture problems. Some systems offer minimal insulation value and are not cost competitive with on-site construction. For finished basements (a big selling point with homeowners) builders are required to fur out the basement panels to install interior finished walls. CARB worked with Oldcastle to evaluate existing systems, installations, and construction methods and to develop new precast-foundation walls to cost-effectively boost energy performance while simultaneously defeating moisture condensation.

Their new product, Castle-Wall, consists of pre-insulated interlocking panels set on a gravel pad. Each panel consists of a 2-in.-thick concrete shell supported by concrete ribs that are 2 feet on-center, with concrete flanges at the top and bottom of the panel. Blocks of EPS foam 7½ in. thick fill the space between the ribs. A 1/2-in. layer of insulation also covers each rib, mitigating thermal bridging and providing a continuous insulation surface for an impressive whole-wall insulation value of R-14. Each EPS block also contains a vertical chase for installing electrical wiring. Laminated to the surface of the EPS is DensArmor Plus, a moisture-resistant paperless drywall product manufactured by Georgia Pacific, also a CARB partner. Glass mat facing replaces paper on the drywall to prevent the mold growth that can occur on organic materials. The wall system is "finish-ready" requiring only joint compound, tape, and paint for a finished interior surface, but a moisture-resistant, well-insulated space is created as soon as the panels are set into place.

Oldcastle claims that a Castle-Wall basement can be erected in one day under a wide range of weather conditions, offering builders more flexibility and control of project schedules than traditional cast-in-place foundation walls. The Castle-Wall product is now a standard offering. Oldcastle is currently planning a fully dedicated manufacturing plant in Pennsylvania to meet the predicted market need.

Builder/Partners

Oldcastle Precast (North Brookfield, Massachusetts)

Resources

www.oldcastleprecast.com/

carb-swa.com/PDF%20files/CNJune05.pdf

www.carb-swa.com/PDF%20files/CNAugust05.pdf

Field Research for Insulation Solutions to Beat Basement Moisture

CARB has been working with Cambridge Homes – a division of DR Horton in the Chicago area – to help improve the energy performance of their homes. In 2001, Cambridge completed the first phase of its first ENERGY STAR® development. SWA informed the builders that basement insulation was the key to reach ENERGY STAR levels. Exterior foundation wall insulation (generally rigid foam) is often desirable for thermal performance, but protecting this insulation at and above grade can be challenging. For this reason, many builders, including Cambridge Homes, choose to install insulation on the inside of basement walls. However, this insulation strategy can lead to problems with moisture accumulation.

Chicago side-by-side testing

In the fall of 2002, Cambridge completed a model home near Chicago that CARB was able to use for insulation research. The goal: to assess the thermal and moisture performance of eight production-friendly, code-compliant interior basement insulation systems. The systems tested included two fiberglass blanket systems, two rigid-foam systems, and four framed-wall systems. From October 2002 to October 2004, CARB monitored the temperature and relative humidity (RH) of these eight systems.

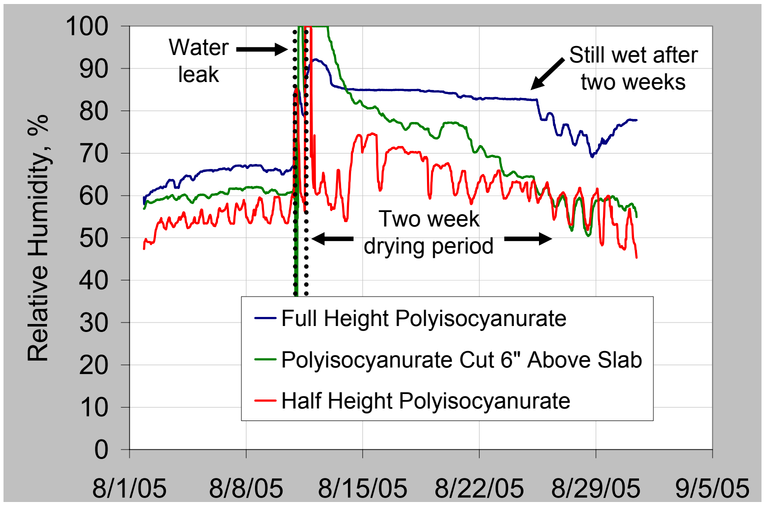
The results of the research indicate that air movement is a significant moisture transport mechanism in many of the systems studied. The resulting moisture performance of these assemblies with air movement was surprising and is in some cases counter to conventional building science wisdom. The research also showed that rigid foam attached directly to foundation walls is one of the best-performing systems. For more details on this research and specific construction details, see "Field Performance of Different Interior Basement Insulation Systems" (*Proceedings from ASHRAE Buildings IX*, 2004).

Lessons Learned

- Basement air easily moves behind 2x4 stud wall systems, resulting in the potential for condensation on cold foundation wall surfaces. Air movement is the dominant moisture transport mechanism in this case – doesn't matter if there is a vapor barrier or not.
- Stud wall systems in basements should be avoided. Rigid insulation attached directly against the wall is the way to go.
- More permeable rigid insulation systems only allow significantly more drying when the basement air is dry (i.e., if basement air is very humid during the summer, perm rating doesn't matter much).
- Results seem to indicate that foil-faced polyiosycanurate insulation installed directly against the foundation wall can be an effective alternative (not trapping moisture) as long as it is trimmed ~6 in. above the slab.

Continuing the work with Cambridge Homes, further research on the moisture performance of production-builder-friendly basement insulation systems was conducted by CARB in a Magna, Utah, prototype house with the Community Development Corporation of Utah. Results from CARB research with Cambridge Homes indicated that foil-faced polyisocyanurate is promising from a performance standpoint because it is the only commercially available rigid-board product that does not need to be separated from interior space by a 15-minute thermal barrier (i.e., ½-in. gypsum board) to meet fire code. Because the foil facing does not allow significant foundation wall drying to the inside, CARB cut the insulation 6 in. above the slab in the Cambridge house to allow some drying to the inside through the exposed concrete and to provide for better drainage in the case of water leakage through cracks in the foundation wall.

The field evaluation of this system in the Utah prototype house was designed to better assess the importance of the exposed concrete gap at the bottom of the foundation wall to moisture performance. In this house, CARB is evaluating three side-by-side polyisocyanurate systems: full-height, trimmed 6 in. above the slab, and half-height. Similar to the Cambridge House results, after 1 year of monitoring, there has been no condensation (or near condensation) resulting from the drying of the freshly poured concrete wall behind any of the systems in Utah. In order to create a more severe test, CARB engineers created a water "leak" behind each of these systems with a water bottle. While not a controlled lab experiment, relative humidity measurements behind these systems do indicate that cutting foundation insulation just a few inches above the slab can significantly shorten drying time. And the improved moisture performance benefits resulting from this small detail come without a significant energy penalty or increase in installed cost.



Utah results

Chicago House

Builder/Partners

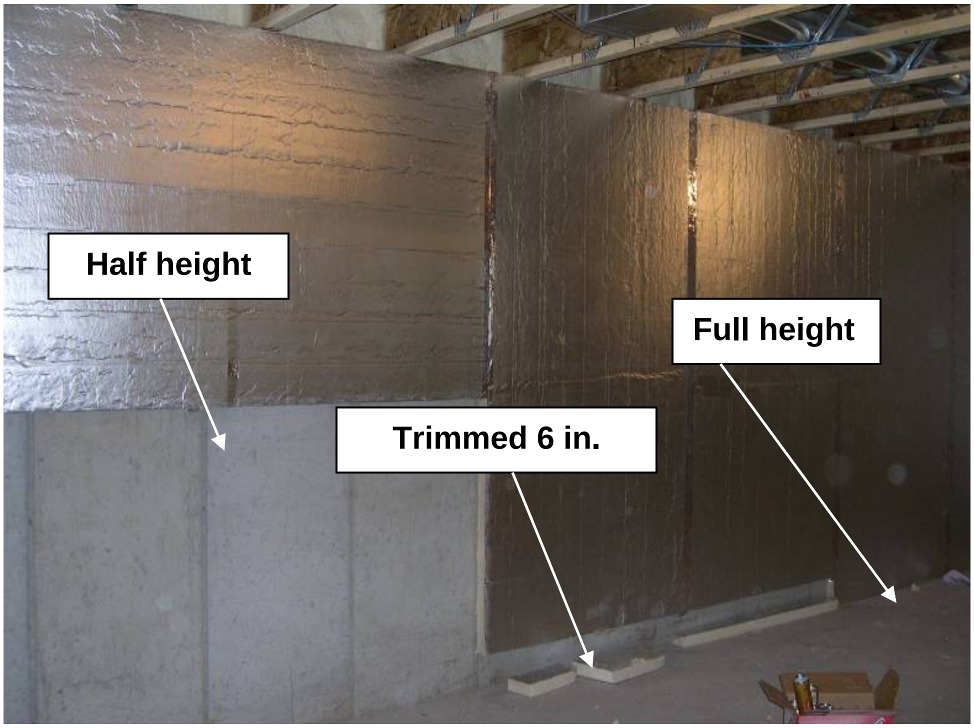
Cambridge Homes (Chicago, Illinois)

Resources

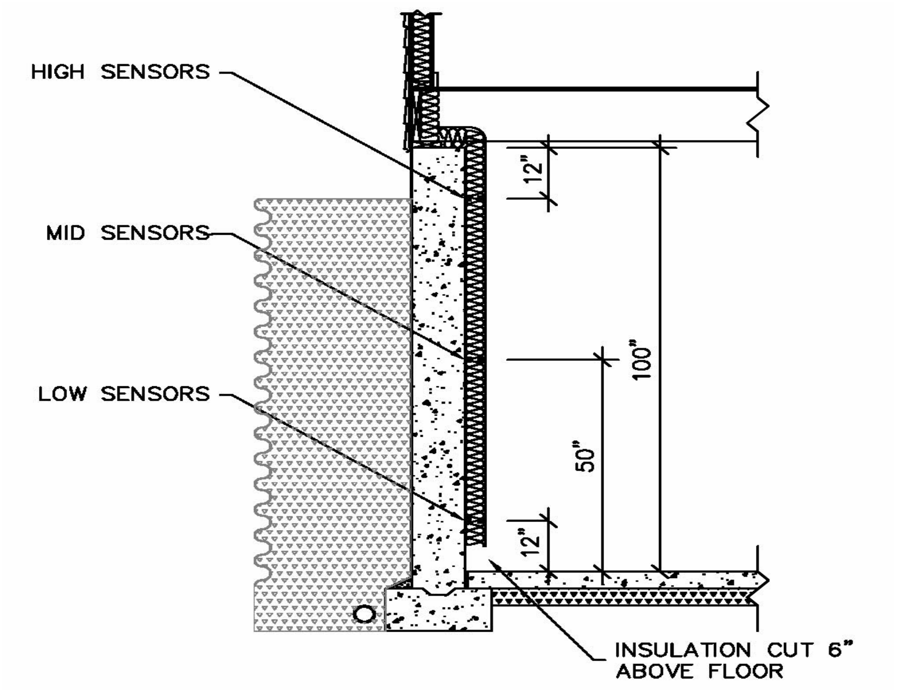
http://carb-swa.com/PDF%20files/CNSeptember03.pdf

Home Energy Magazine, Jan/Feb 2006

"Field Performance of Different Interior Basement Insulation Systems." *Proceedings from ASHRAE Buildings IX,* (2004).



Utah systems evaluated



Chicago sensor placement

Insect Control and Foam Insulation

Lesson Learned

An integrated approach—in this case one involving insect-resistant design, construction details, treated building materials, and a new termiticide—will almost always generate the most effective and economical solution to a building problem. It certainly helps when a product breakthrough, such as Termidor, completely resets the stage!

Insect control issues, particularly in the southeast, have taken a significant "bite" out of the construction of insulated foundation systems. Most notably, model code agencies have banned below-grade rigid insulation in the most severe termite zones in the United States.

The key to insect control and the use of rigid-foam insulation is a multi-pronged approach—proper chemical management at the building perimeter, borate-treated foam and wood products, and proper water and moisture management in terms of design and construction details. BSC worked with builders and product manufacturers on two projects to develop and implement this multi-pronged approach. In one instance, an innovative perimeter slab insulation detail was developed using borate-treated foam, metal flashing, and cement board. With partner Louisiana State University Agricultural Center and manufacturers LP and US Borax, BSC worked on design and construction details for LaHouse, an educational resource facility that will serve as a model for insect-control residential construction details throughout the Southeast.

In a related but separate development, the successful commercial introduction of the termiticide, Termidor, is likely to have the most dramatic effect on the use of at-grade and below-grade foam insulation in termite-prone areas of the country. The effectiveness and environmentally benign nature of this new termiticide are likely to bring about re-acceptance of the use of foam insulation for foundations.

Fairburn Commons slab foundation detail

Builders

Health-E Enterprises, Fairburn Commons — Atlanta, Georgia

La House — Louisiana State University

Moisture Control and High-R Assemblies

The most commercially viable high-thermal-resistance wall assembly is a wood-framed wall with insulating sheathing. The practical limitation to the wood-frame thickness is 5.5 in. (the width of a 2x6). Insulating sheathing thickness is currently limited by constructability issues to 2 in.. Insulating sheathing often results in an exterior vapor barrier. Therefore, an interior vapor barrier should be avoided. This has significant performance implications in cold climates.

Rain control is a critical core issue that impacts the construction of energy-efficient and durable building envelopes. Rain is the most significant wetting mechanism affecting building envelopes. Therefore, it is the single most important factor affecting building envelope durability. However, as thermal insulation levels are increased, the rate of building envelope drying decreases. Traditional rain control has been shown to be ineffective in highly insulated and airtight building envelopes.

In the past 10 years, several experimental test huts have been constructed where numerous configurations of building papers, sheathings, and claddings have been evaluated for rainwater and vapor control. This test hut work has led to the development of recommendations on rainwater control for insulating sheathings, non-insulating sheathings, building papers, house wraps, and other water resistant barriers (WRBs). In addition, data from instrumented test walls in key climate zones were used to determine boundary conditions for hygrothermal modeling to develop climate specific recommendations for vapor control with the use of insulating sheathings. These recommendations are currently being drafted into code language and will be submitted as a code change proposal by DOE for the 2008 ICC code development cycle.

Lessons Learned

One of the major problems in current building design and construction is the focus on the rate of wetting rather than a balance between the rate of wetting and the rate of drying. Many techniques that reduce wetting also reduce drying – and that is a disaster. For example, the installation of a polyethylene vapor barrier on the interior of a building assembly reduces winter "wetting" from the interior but also reduces summer "drying" to the interior. In almost any building with air conditioning the installation of this type of a "plastic" vapor barrier causes far more problems than it solves. The key is to reduce wetting, without reducing drying – or even better, reducing wetting while increasing drying. Eliminating interior vapor barriers is a priority for highly insulated assemblies.

Partners

- Building Science Consortium
- Pulte Home Corporation
- Artistic Homes
- Tamyln
- U.S. GreenFiber
- Icynene
- David Weekly Homes
- Town and Country Homes
- Dow Chemical Company
- U.S. Army Corps of Engineers
- CertainTeed Corporation

Resources

www.buildingscience.com/resources/walls/Vapor_Barriers_Wall_Design.pdf

www.buildingscience.com/resources/articles/Understanding_Vapor_Barriers_ASHRAE_2004_08.pdf

www.buildingscience.com/resources/moisture/Moisture_Control_for_Buildings.pdf

Scrap-Engineered Environmental (SEE) Stud

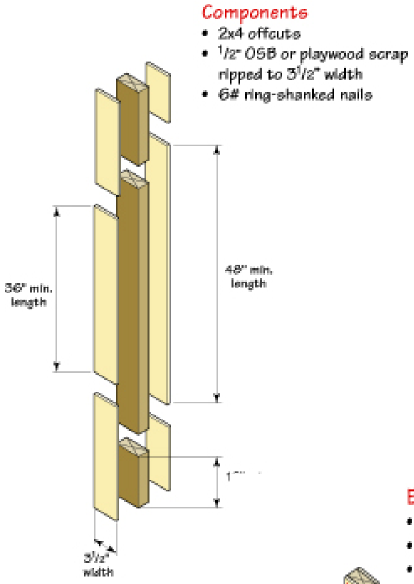
Lesson Learned

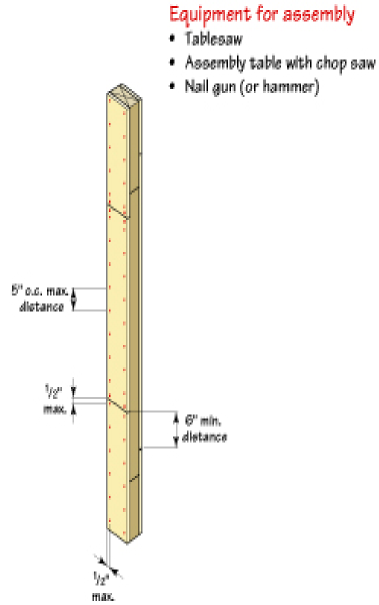
If steel can be gauged for optimal value engineering of non-load-bearing studs, why can't wood? In a sense, this is what the SEE stud does. But just as with any innovation, it must pass muster from a practicality, economic, and code standpoint.

One of BSC's Building America builders, Artistic Homes, lost its only outlet for its company-wide wood recycling program. Artistic contacted BSC, feeling that there must be some way of using, rather than discarding, the scrap OSB and 2x4s. Artistic's home designs generally take all loads to exterior walls, leaving all interior wall-framing members as non-load bearing, hence, technically non-structural. What if the scrap OSB and two-by materials could be used to build non-structural framing members (in a OSB face [2x4 core] OSB face sandwich; see diagram), reducing waste and lumber purchase?

The feasibility of SEE studs depends on a combination of technical, regulatory, and economic issues. While the technical specifications for SEE studs have been developed, the various codes do not address non-load-bearing walls and framing members in nearly the same way. Little progress has been made to date on code acceptance of SEE studs for Artistic Homes (under the Uniform Building Code), but a sample wall has been built for building code official review for the Building America project at the EcoVillage Townhomes at 58th St. in Cleveland Ohio (under BOCA).

It is ironic that scrap lumber and sheathing waste for Artistic Homes and the EcoVillage project—both using a comprehensive advanced-framing package—provide an insufficient supply of wood waste to meet the demand for non-load-bearing studs. The economic feasibility of on-site SEE stud production is dependent on the economies of scale that a production building setting provides. It is likely that real-scale production of SEE studs will require the even greater economies of scale that shop manufacturing provides at some collection point, such as a C&D recycling facility, truss or panel plant, or lumber supply center.





Builders

Artistic Homes — Albuquerque, New Mexico
DAS Construction — Cleveland, Ohio

Resource

www.buildingscience.com/resources/walls/SEE_stud_specs.pdf

Unvented Conditioned Attics

There are two basic ways to achieve the BSC Building America performance target of locating all ducts in conditioned space—move the ducts or move the conditioned-space boundary. Although not BSC's first choice, keeping HVAC equipment and ducts in attic space is a fact of life in some markets, driven by floor space and noise considerations. So BSC developed, modeled, tested, refined, and implemented the relocation of the conditioned-space boundary from the top-floor ceiling line to the roof line of homes, creating an unvented attic space conditioned either directly with supply registers or indirectly by duct leakage. There were a host of issues to consider in making this change:

- Energy performance for both heating and cooling in comparison to vented attic assemblies
- Peak temperatures achieved by various components of the roof assembly—exterior cladding, sheathing, etc.
- Building code and building department officials' assessment or acceptance of this new assembly
- Suitability and performance of the assembly in each of the six climate zones (for example, location of first condensing surface for different climate zones).

For each issue, the Building America process (modeling, pilot testing in one or two homes, analysis, refinement, and then implementation in production homes in a subdivision) led to performance that satisfied the builder, the building officials, and ultimately, the customer.

Builders

Pulte (Las Vegas, Tucson, Houston, Banning, Sacramento, Tracy, Phoenix)

Resource

www.buildingscience.com/resources/roofs/unvented_roof_summary_article.pdf

Lesson Learned

Unerring attention must be paid to construction details as a new approach is moved from one builder to another, particularly from one hygro-thermal region to another. Both examples below involved a change from a hot-dry to a hot-humid climate.

Example 1: A change from an air-tight stucco soffit to a clad soffit led to a breach in the air barrier, with subsequent moisture and condensation problems at this point of entry. This situation was resolved by using professional spray-applied air sealing to this area of the envelope assembly.

Example 2: A change from clay or cement-tile roof cladding to asphalt shingles led to wicking of exterior liquid moisture (rain or dew) between roofing shingles with subsequent solar drive of this moisture into the thermal envelope below.

The lesson here is that any change in technique or materials must be evaluated for the way in which air, liquid, and vapor moisture and heat move on and through the envelope assembly, particularly when there is a change in location that involves climate or standard construction details.

Unvented Conditioned Crawlspaces

Lessons Learned

There are actually two lessons in this work. The first one is—always start with the larger question. In this case, why do you really want a crawlspace? BSC has worked with builders on substituting slab-on-grade construction for crawlspaces in many areas of the country where the real reasons for utilizing crawlspace foundations are perceived mechanical needs or market demand that may, in fact, not hold true.

The second lesson has to do with accomplishing change in the building industry. A large part of working with the building community is working with the local building officials. Bringing building science into the building industry means educating builders and local building departments.

A little more than one-sixth of new homes in the United States are built on crawlspace foundations. Typical crawlspace construction calls for passive venting to the outside with cavity insulation for the first floor. No one is sure how this situation came about, but it certainly is not a basement configuration based on sound building science. A continuous air barrier and thermal envelope at this plane are nearly impossible because ducts and other utilities typically penetrate this plane and extend into the unconditioned crawlspace. In addition, research has shown the location, number, and total area of the typical crawlspace vents provide highly unreliable and often inadequate air exchange.

BSC worked out the details for converting this space to conditioned space, encouraging the building community (including code officials) to think of crawlspaces as simply "short" basements. In this way, all of the most common problems with crawlspaces—moisture and mold, radon and other soil gases, and heat loss from crawlspace ducting and discontinuous first-floor air barrier and thermal envelope—are resolved. In other words, it is possible to satisfy BSC Building America performance targets if the crawlspace is unvented and conditioned.

BSC also conducted work under Building America on structural sub-basement crawlspaces typical of the Metro Denver area, where the combination of expansive clay soil conditions and full basements have led to moisture and performance problems. Applying principles of building science and working with Building America builders in the Denver area, BSC developed and tested sub-basement structural crawlspace treatments that integrate the need for control of soil gas and sub-basement moisture. The result is the most energy-efficient, healthy, and comfortable method—continuous poly barrier on the sub-basement crawl floor and a continuous 50-cfm exhaust fan with transfer grilles between the sub-basement crawlspace and full basement. The BSC approach uses less energy and achieves better air quality throughout the entire structure than any of the systems utilized or approved by local code.

Builders

Hidden Springs — Boise, Idaho
Prairie Crossing — Grayslake, Illinois
Habitat for Humanity — Denver, Colorado
Engle Homes — Denver, Colorado
GreenBuilt Homes — Cleveland, Ohio
Venture, Inc. — Flint, Michigan

Resource

Please see the BSC Web site (www.buildingscience.com/what's_new) for the latest information.

System Research Results

Design Guidelines and Strategies

Durability Guidelines

A comprehensive review of the durability of building constructions was undertaken and guidelines and recommendations were developed. The current building industry focus on durability is in part a reaction to the current perceived lack of it. Warranty claims and callbacks are viewed as increasing. Litigation and insurance costs are felt to be rising as a result.

Another reason for the current focus on durability is the recognition that sustainability is not possible without durability. If you double the life of a building and you use the same amount of resources to construct it, the building is twice as resource efficient. Therefore, durability is a key component of sustainability.

It seems that one thing that both the development community and the environmental community can agree on is that durabiltiy is a good thing.

What do we know about durability, and how do we know it? The lessons of durability have come principally out of failure. Engineering is an iterative process of design by failure. Buildings are constructed. Problems are experienced. Designs and processes are changed. Better buildings are constructed.

The building industry is in essence a reactive industry, not a proactive industry. It can be argued that the industry continues to do things until they become intolerably bad and then the industry changes. Examining failures gives us guidance on increasing the durability of building constructions.

Examining failures provided the framework for the durability guidelines.

Lesson Learned

The following is a list of the key damage functions affecting durability (presently known and understood):

Damage Function	Control Method	Damage Function	Control Method
Wind	IRC/FEMA	Chlorides	IRC/FEMA/Not addressed directly (water interdependency)
Flood	FEMA	Sulphates	IRC/FEMA/Not addressed directly (water interdependency)
Earthquake	IRC	Loading/Abrasion/Fatigue	Addressed by the guidelines
Gravity	IRC	Material Incompatibility	Not addressed
Soil movement	IRC	Oxides (NO_2, SO_2)	Not addressed
Water	Addressed by the guidelines	Ozone	Not addressed
Heat	Addressed by the guidelines	Oxidizing agents (acids)	Not addressed
Ultraviolet radiation	Addressed by the guidelines	Solvents	Not addressed
Insects	Addressed by this document		

From this listing of damage functions, the first five are structural and natural disaster in nature and are arguably addressed extremely well by the existing model building code (IRC — International Residential Code) and FEMA (Federal Emergency Management Agency). They are not addressed further beyond the following: “Follow the IRC building code and FEMA recommendations and you will not have structural related or disaster related durability problems.”

The next four (water, heat, ultraviolet radiation, and insects) are the main focus of the durability guidelines and arguably address more than 90% of the current industry durability issues.

Chlorides and sulphates are also arguably addressed extremely well by both IRC and FEMA (Coastal Construction Manual). The risks associated with both of these damage functions are also

continued

Lesson Learned (Durability Guidelines continued)

dependent on water. Therefore, addressing the water-damage function further reduces the risks associated with chlorides and sulphates. They are not addressed further beyond the following: "Follow the IRC building code and the FEMA recommendations (and the water damage function control methods) and you will not have chloride and sulphate related durability problems."

Loading/abrasion/fatigue were addressed by the guidelines with the following limitations. This damage function is arguably a maintenance issue associated with "wear and tear." It is also typically the purview of durability standards and risk-assessment protocols for the developers and manufacturers of materials, components, and equipments. It is not typically the purview of designers, engineers, architects, and contractors except in the following context.

Many components will need to be replaced, serviced, and maintained during the useful service life of the building. The ease of replacement, service, and maintenance is within the purview of designers, engineers, architects, and contractors. The building components that experience the greatest loading/abrasion/fatigue stress and that need regular replacement or maintenance or servicing are typically floor coverings—and their selection is within the purview of designers, engineers, architects, and contractors.

The remaining damage functions (material incompatibility, oxides, ozone, oxidizing agents, and solvents) were not addressed. It is argued here that they are not significant enough issues to consider at this point in time for inclusion in a "practical" durability standard or risk-assessment protocol for use by designers, engineers, architects, and contractors. However, these damage functions are key to durability standards and risk-assessment protocols for the developers and manufacturers of materials, components, and equipment.

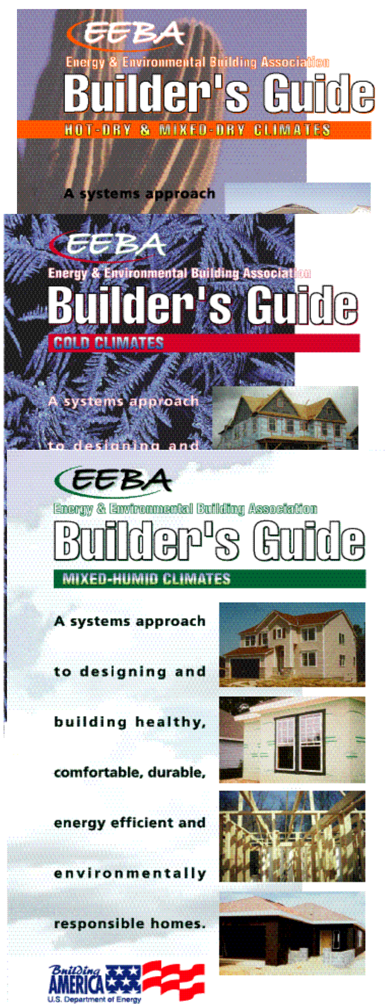
The four key non-structural or natural-disaster damage functions of water, heat, ultraviolet radiation, and insects were discussed in terms of specific guidance and recommendations applicable to designers, engineers, architects, and contactors. Additional discussion on the loading/abrasion/fatigue damage function within the context of replacement, servicing, and maintenance were also discussed.

The EEBA Builder Guides

Lessons Learned

"Show me" is a very common request from builders. BSC takes many calls a week on construction details for high-performance, durable envelope assemblies that can now be handled by referral to the climate-appropriate EEBA Builder's Guide. The *EEBA Builder's Guide - Cold Climate* was also used extensively in the Project Specifications for the EcoVillage Cleveland Building America project.

Another lesson learned was applied to the *Houses That Work* section of the BSC Web site (*www.buildingscience.com/housesthatwork/default.htm*). In this section, builders can freely access a single complete climate-appropriate envelope assembly. The lesson here is "Show me—in just one example, please."



The most successful tool for moving builders, trade contractors, and product manufacturers to climate-specific systems thinking in the design and construction of homes is the *EEBA Builder's Guide* (for each of the six climates, see www.eeba.org/mall/builder_guides.asp). Details from this guide can be found throughout the major trade publications, laminated and posted at job sites, and even translated into Spanish for field use. The guides contain both the language and the images required to move building science theory into application by both design and field professionals.

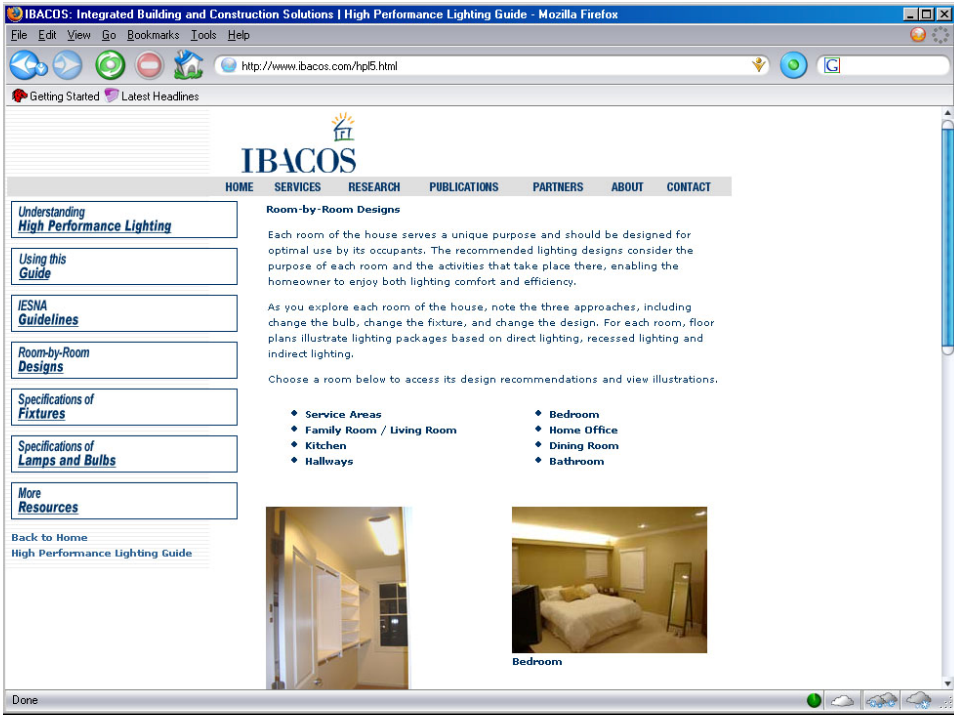
High-Performance Lighting Guide

Lessons Learned

The importance of efficient lighting systems in high-performance homes with significantly reduced electrical loads has been recognized. High-quality, efficient, hard-wired lighting solutions are possible in today's production housing; however, cost and concerns about customer dissatisfaction are still major barriers. Negative perceptions based on historical or anecdotal experience by builders is another major barrier to widespread acceptance, as is the limited availability of reasonably priced residential fluorescent downlight fixtures. The selection of efficient lighting requires the builder and homeowner to make decisions that go well beyond the current light-fixture selection process. To realize the full benefits of advanced lighting systems, further characterization of typical builder hard-wired lighting performance and occupant-use patterns is imperative.

As a single end use, lighting accounts for up to 18% of the whole-house source-energy use. The research effort focuses on establishing best practices with existing technologies and identifying and resolving barriers to further advances in savings. This must take into account whole-house interactions, including impacts on heating and cooling loads, while at the same time providing adequate lighting quality. This includes fixtures that are readily available to the builder and are easy to specify and install.

IBACOS has developed a web-based High Performance Lighting (HPL) Guide (www.ibacos.com) to offer energy-efficient lighting strategies for residential builders and lighting professionals, making it easier for them to discuss lighting options with their customers. This guide covers approaches for providing ambient light levels for various rooms/spaces in residential buildings, in conformity with the guidelines of the Illuminating Engineering Society of North America (IESNA).



On-Site Grinding and Land Application of Clean Construction Waste

Lesson Learned

The Building America principle of improved efficiency and cost savings applies as well to the tail pipe (waste management) as it does to the front end (advanced framing) of residential construction.

About two-thirds to three-quarters of the construction waste from any residential construction project is clean wood, clean gypsum board, and clean cardboard waste. That's by weight or volume. Everyone agrees that it's a shame to send that material to the landfill, both from a cost and environmental standpoint. But recycling infrastructure and markets are poorly developed in all but a very few areas of the country for wood and gypsum board waste, and markets for old corrugated cardboard (OCC) have been volatile with collection infrastructure often poorly suited to construction sites.

Working with BSC Building America partner Packer Industries, ground wood waste (often with OCC mixed in) is being used as a material for soil erosion control, and ground gypsum board is being used as a soil amendment. Landfill capacity is conserved, wastes are turned into site resources, and disposal cost savings are captured by production builders. Packer Industries provides not only a technological solution, but assists the builder with both environmental and regulatory hurdles as well. In a particularly interesting turn of events, Packer Industries (with a vested interest only in waste production and processing) is taking the Building America systems-thinking approach and promoting wood-waste reduction as the first element of waste management.

Builders

Artistic Homes — Albuquerque, New Mexico

Pulte (Minnesota) — Minnesota

Hans Hagen — Minnesota, Wisconsin

Resource

www.buildingscience.com/resources/misc/wood_efficiency.pdf

Strategies for Energy-Efficient Remodeling Projects

The NAHB Research Center has completed a report under the Strategies for Energy Efficiency in Remodeling (SEER) project, supported by the DOE Building America Program through the National Renewable Energy Laboratory (NREL). This project was to provide a knowledge base to remodelers and consumers about opportunities to increase home energy performance. The report examines the technologies and methods of implementing a wide range of energy efficiency strategies and provides detailed economic analyses. Also presented in this report are the opportunities to further reduce the energy costs using renewable energy systems.

Lessons Learned

There is a wide spectrum of opportunities to cost-effectively integrate energy efficiency strategies in home remodeling projects. The benefits of taking such measures extend beyond energy savings, as they also positively impact the indoor comfort level, environmental performance, durability, and affordability of the homes. By illustrating these opportunities, the SEER project is intended to meet the need for a constantly evolving knowledge base, from which the remodeling professionals and homeowners can benefit.

This report also addresses the benefits of implementing energy efficiency measures in home remodeling projects. These benefits include improved comfort and indoor air quality for occupants, mitigated durability issues associated with the building materials and mechanical systems, improved environmental performance, and increased affordability.

Partners

Asdal Builders, AstroPower, Bergy Windpower, Crane Performance Siding, Eastern Insulation, Energy Services Group, Fineline Energy Solutions, New Jersey Clean Energy Program, Rheem, SETS Systems, Simonton Windows, Solargenix Energy, Tamarack Technologies, Tech-Built Systems, Therma-Tru Doors, U.S. GreenFiber, VanNatta Mechanical, Vanguard Piping Systems, Waterfurnace International, Whirlpool Corporation

Resources

www.nahbrc.org/

www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1534&DocumentID=4565

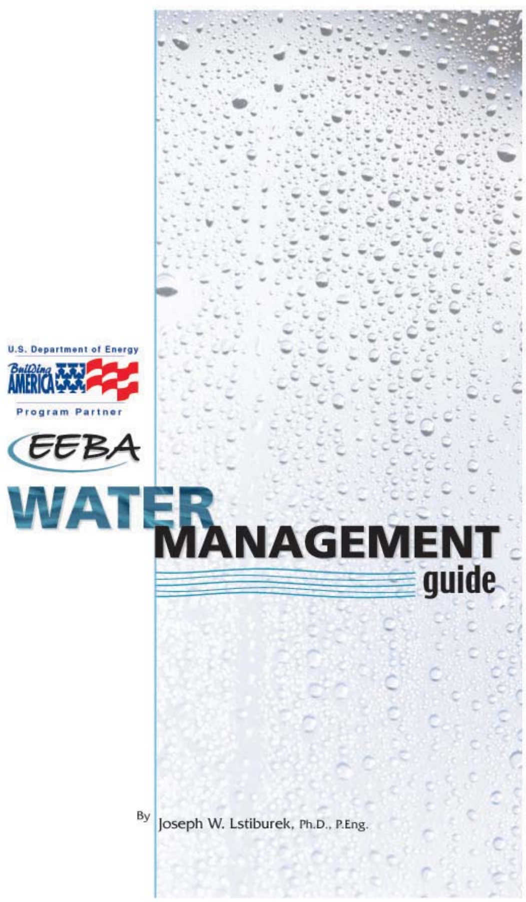
Water Management Guide

Stemming from work on rigid insulation joint details with Dow Chemical, additional Building America partners—DuPont, Andersen Windows, and Fortifiber—expressed interest in the development of a technical information resource focusing on drainage plane details, addressing water as a liquid on the building shell. The result is a graphics-rich, step-by-step manual for handling water ("down and out") from rooftop to site—*The EEBA Water Management Guide*.

This effort has led to planned production for a series of five management guides; the other four will focus on moisture management (airborne, diffusion and capillary), air management, source management (material pollutant sources), and project management (systems-thinking approach).

Lessons Learned

There is a continual tug-of-war between weaving complex principles together to show a systems-thinking or integrated perspective and breaking building-science phenomena down into separate issues for clarity. Now that both the *EEBA Builder's Guides* (full integration at the climate-specific level) and *EEBA Water Management* series (specific principle shown in a full series of graphic details) are available, energy-efficient/resource-efficient/durable design and construction are presented for builders from both perspectives.



Water Management Implementation

Lesson Learned

Good ideas and good research by themselves are not enough. Getting the information to the users in a form that can be easily used and understood is also necessary. Having a series of natural disasters (four hurricanes in 45 days in Florida) also helps focus the mind on a particular problem that needs to be addressed.

The work done on water management and the Water Management Guide has lead to a revolution in the installation of windows and doors throughout the nation. Pan-flashing opening has gone from a "fringe approach" to the mainstream. All of our production builder partners now use the Water Management Guide as the basis for rainwater control, and pan-flashing windows is now the norm not the exception. This has put tremendous pressure on ASTM to revise its window installation standards and window manufacturers to adopt pan-flashing techniques as the basis for their own recommended installation practices. The widespread window water leakage failures during the 2004 hurricane season lead to changes in the Florida Building Code where specific details from the Water Management Guide were referenced. Dozens of specialty manufacturers now offer pre-made, pre-fabricated pan-flashing systems, specialty flashings, and components as a result of the water-management work done under the program.

Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

System Research Results

Market Transformation

Adoption of Building America Performance Targets by Industry Training Programs

Lesson Learned

Builders seek and respect clarity in terms of the meaning and level of commitment a program requires. The performance targets have enhanced the credibility of both BSC and Building America.

Every term in this phrase is critical to the concept of providing builders and other building-industry members with criteria for design and construction that define exactly what it means to participate in BSC's Building America team. These criteria are mandatory for BSC builder partners and are as follows:

- Specific to the goals of the Building America program in terms of resource- and energy-efficiency
- Performance-based so that builders can use a systems-thinking approach to achieve an end, as opposed to prescriptive criteria that can discourage a systems-thinking approach
- Expressed in such a way as to distinguish between criteria that **must** be met and criteria that are strongly recommended. Embodied in these criteria are the inextricable links among standards of energy performance, indoor air quality, and durability. The systems approach that drives the Building America program is fully expressed in the BSC Building America Performance Targets (www.buildingscience.com/buildingamerica/targets.htm).

BSC developed these targets and posted them on its Web site to inform both participating and inquiring builders. The success of these criteria is demonstrated by their adoption or use in the following building industry programs:

- The Platinum level of the Masco Environments for Living program (www.eflhome.com)
- The building criteria for the Energy and Environmental Building Association (EEBA, www.eeba.org/technology/criteria.htm)
- The American Lung Association's Health House criteria (www.healthhouse.org/iaq/tourtext.htm#Building_Criteria)
- The Building America green builder program in Central New Mexico (www.bapartner.org) in partnership with BSC member, EEBA.

Building America Cost Performance Trade-Offs

The "break points" or cost trade-offs approach is one of the greatest factors behind the successful deployment of Building America technologies. During systems-engineering analysis of the residential construction process, "break points" are identified.

An extension of this approach is the "value rules" phenomenon. Several BSC Building America builders have experienced the following: selling more homes at a slightly higher cost to build, at a slightly higher selling price, with a slightly higher profit margin. The key is that if homebuyers are convinced of higher value, they will accept that a higher-priced home.

Lesson Learned

Builders like balance sheets. When they see the changes they must make to achieve high-performance homes expressed in specific costs and savings, it's easier for them to consider making the jump to Building America performance targets. It certainly helps when slightly higher costs of construction can be covered by the sales division being able to sell the **value** of a high-performance home.

The break points are costs of warranty and call-back reduction strategies as well as energy-efficient features balanced by the reductions of other construction costs. These "break points" involve construction strategies or levels of energy efficiency that allow a specific component of a building to be downsized or deleted. For example, construction costs can be increased by changes and improvements to the building envelope that reduce warranty and call-back expenses, as well as reduce heat gain and heat loss. The improved building envelope performance allows the mechanical equipment to be downsized. The initial construction cost increases are offset by the reduced costs associated with the downsized mechanical system.

Example Cost Summary
Building America Metrics

Hot Dry Climate

Unvented roof	+ $750
NOT installing roof vents	- $500
High-performance windows	+ $300
Controlled ventilation system	+ $150
Downsize air conditioner by 2 tons	- $1,000
Sealed combustion furnace	+ $400
TOTAL PREMIUM	+ $100

Example Cost Summary

Building America Metrics

Severe Cold Climate

Advanced Framing	- $250
High-performance windows	+ $250
Controlled ventilation system	+ $150
Power vented gas water heater	+ $300
Simplified duct distribution	- $250
Downsize air conditioner by 1 ton	- $350
TOTAL PREMIUM	- $150

Building Code and Building Practice Changes

Lessons Learned

Code changes are never easy. Stakeholders need to be involved in the process early and kept up-to-date in a timely manner. Numerous methodologies and approaches to defend the code changes are necessary. Although modeling can often be used to defend a recommended change, by itself this is not enough. Similarly, for test-hut and test-house construction, monitoring and demonstration are necessary as well as laboratory experimental work. All approaches must work in concert. The success of the code changes would not have been possible without industry partners, ORNL, test huts, test houses, monitoring, demonstration and experimental work.

Work done on moisture control and high-R assemblies identified the need to alter the building code and building practices to facilitate the construction of energy-efficient building enclosures.

As thermal resistance increases, heat flow across the assembly decreases. This is a desirable result from the perspective of energy efficiency. However, it is a liability form the perspective of durability. As the thermal resistance of building enclosures increases, the ability of the assemblies to dry decreases. This has lead to an unfortunate linkage between mold, decay, and high levels of thermal resistance.

It has been clear that if drying potentials decrease as a result of increases in thermal resistance, some other means of increase in drying potentials must be provided. Additionally, decreasing wetting potentials must also be provided.

The more vapor open (permeable) the interior and exterior linings of building enclosures, the greater the drying potential of the building enclosures. Installing interior vapor barriers that prevent inward drying is a serious problem that was identified by the work done on moisture control and high-R assemblies.

Additionally, insulating sheathings were identified as one of the most cost-effective means of significantly increasing the thermal resistance of building enclosures. However, most insulating sheathings have low vapor permeance and inhibit outward drying. Hence, the ability to dry inwards is a critical requirement for the use of insulating sheathing. Unfortunately, the model building codes require the installation of interior vapor barriers and vapor retarders.

In order to permit the widespread adoption of high-R assemblies with insulating sheathing and high-R assemblies in general, the building code requirements governing interior vapor barriers and vapor retarders needed altering.

The work done over the past four years with test hut construction and monitoring, computer simulation work and field investigations and demonstration culminated in an alteration of the 2006 IRC and IECC deleting the requirement for interior vapor retarders and vapor barriers in one half of the nation (Zones 1 through 4). A pending code modification for Zones 5, 6, and 7 will result in allowing the construction of high-R assemblies without interior vapor retarders or vapor barriers. This will affect in a positive manner every building enclosure constructed in the nation.

The work done over the past 4 years also identified the need for “smart membranes and smart linings” that change their vapor permeability characteristics over time (as a result of temperature, relative humidity, and other control factors). The work on such smart membranes and smart linings promises to revolutionize building enclosure design and performance. It will allow walls and roofs to dry outward and inward based on the optimum driving forces acting on the assembly at the time.

Commercialization of Building America Results

Lessons Learned

Building America teams and builder partners will continue to demonstrate integrated solutions to achieving residential constructions that offer durability, comfort, and safety while saving energy. However, the broad market will only move when there is a perception that the customer will demand the increased performance. Effective dissemination of the Building America research results is critical to a widespread adoption of the Building America best practices. Integrating Building America research results into market-based educational and media businesses is a major step in achieving this objective because these businesses can reach not only the residential building designers and construction professionals but potentially millions of homeowners as well.

A major challenge in market transformation toward higher performing homes is to build customer demand and overall market awareness. Building America's research focus precludes major activities in this area; however, opportunities exist for others to use information generated by the Building America program and disseminate it to a wider audience. IBACOS has developed strong relationships with two companies, BuildIQ and Scripps Networks, to accelerate the flow of Building America research results into the marketplace.

BuildIQ is devoted to packaging and disseminating information that results from research activities at IBACOS and other Building America partners. BuildIQ provides builders with valuable materials through sale of on-line courses to production builders on various aspects of residential design, construction, and marketing process, including HVAC, insulation, water and moisture management, all of which are important to the Building America whole-building approach and to good residential construction. By tapping into the knowledge base of the Building America teams, BuildIQ enables builders to successfully adopt Building America best practices.

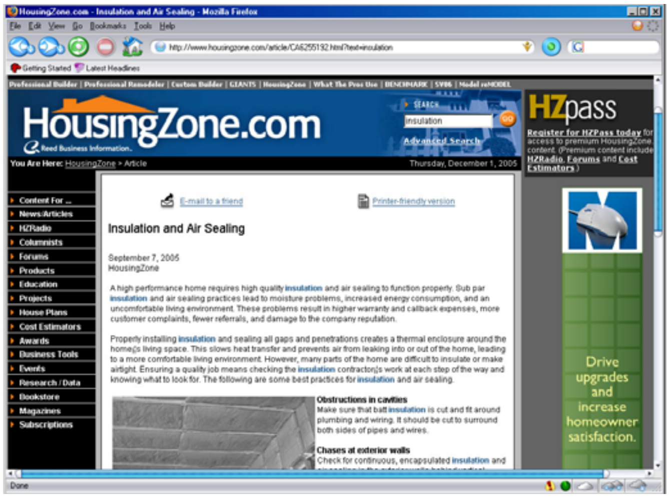
Partners

Build IQ

HGTVPro.com, DIY Network

Resources

www.buildiq.com/



BuildIQ's partnership with Scripps Network (HGTVPro and DIY) has also provided an effective conduit of structured information for educating builders and remodeling professionals through videos and other multimedia means. By using television expertise, this partnership was instrumental in presenting a number of Building America pilot homes built to achieve the 30%-40% energy-savings level.

Energy Bill Guarantee Programs

Lesson Learned

There is nothing more powerful than a market-based performance standard—a financial commitment links design, construction, and operation. Every party—builder, trade contractor, material supplier, and homeowner—has an investment in performance.

ENGINEERED FOR LIFE
BUILDING WITH SCIENCE FOR QUALITY HOMES

Environments for Living

BSC worked with three consortium partners on the development of energy bill guarantee programs—Masco (Environments for Living), GreenFiber (Engineered for Life), and Artistic Homes (The Energy Use and Comfort Guarantee). In each case, the partner firm relied upon BSC's Building America performance targets in the development of their criteria for builder program participation.

They relied upon BSC energy modeling to establish the specifics of their financial guarantees. And, most importantly, all three programs explicitly recognize the inextricable connection among the Building America attributes of energy efficiency, indoor air quality, and durability. These programs have done more to deliver market value to the builder and the homebuyer (and product manufacturers!) than any other single element of the Building America program.

Partners

- Pulte Home Corporation
- Artistic Homes
- Ryland Homes
- Lee Homes
- Habitat for Humanity

Resources

www.eflhome.com/efl_index.asp

www.us-gf.com/engineered.asp

www.artistichomessw.com/guarantee.htm

Energy Value Housing Award

The Energy Value Housing Award (EVHA), primarily funded by the DOE Building America Program (BA), honors builders that voluntarily incorporate energy efficiency into new home construction. EVHA Winner Magazine, which is published annually, provides a snapshot of the EVHA award-winning homes and their best practices for various building and climate categories. The awards are presented to progressive builders who differentiate themselves from the competition through their commitment to building high-quality and energy-efficient homes.

A notable commonality among the progressive builders is the implementation of a systems approach, as promoted by the Building America Program. In the history of the EVHA, significant differences among the home builders have been observed with respect to achieving high-efficiency goals. These differences are generally a result of variations in the local market needs and the climates. Showcasing all major features of the winning homes has been a part of the EVHA education and outreach activities.

Unveiling the EVHA winners at the International Builder's Show (IBS), the world's largest annual construction tradeshow, along with the EVHA Magazine and other publications, has provided an excellent opportunity to promote the best practices for building high-quality and energy-efficient homes.

This show attracts a broad spectrum of participants (approximately 200) from the building industry every year. The rising number of applicants for EVHA (on average), the continued interest in the concept of the energy value, and the steady improvement of energy performance of the EVHA entry homes are attributed to the success of the EVHA.

Partners

Sponsors in 2005 were AAMA Vinyl Material Council, BuildingGreen, Fannie Mae, Icynene, and the Vinyl Institute.

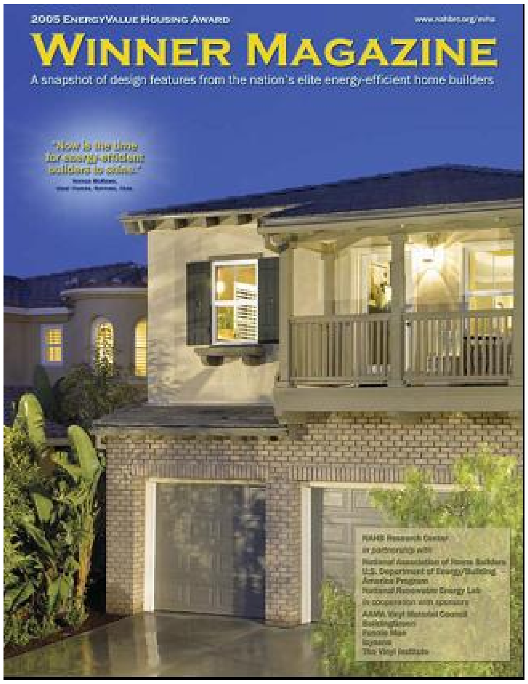
Resources

www.nahbrc.org/

www.nahbrc.org/evha/winners_year.html

Lessons Learned

The EVHA has stimulated interest in the builders to embrace the concept of the energy value and best practices in their design and construction strategies. Showcasing the EVHA activities through web-based articles and participation at other events, such as EEBA trade shows and ICEEE conferences, will lead to a more successful EVHA program. Revising the EVHA application criteria based on regular feedbacks from the BA research activities should also be emphasized to further promote the Building America goals.



High-Performance Homeowner Manual

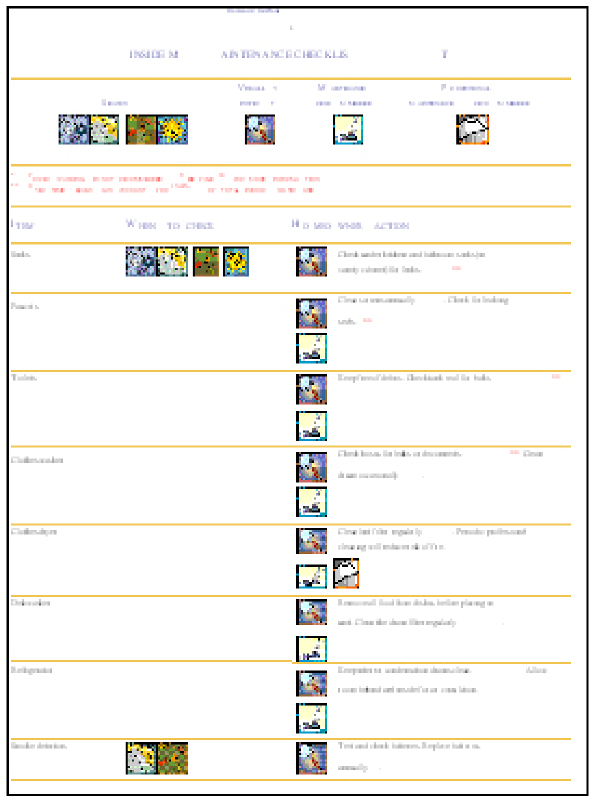
Lessons Learned

Education and training for the high-performance homeowner is a key part of any comprehensive systems approach.

More than one BSC Building America builder has requested a homeowner manual tuned to their high-performance products. BSC developed such a manual. Some of its elements that are specific to high-performance homes are as follows:

- Operating guidance on programmable thermostats, particularly with regard to the difference between setback strategies for cooling versus heating
- Operating guidance for mechanical ventilation, specifically the AirCycler
- Layman explanation of right sizing and run times for high-efficiency HVAC equipment
- Listing of building features that promote durability and service life
- Guidance on the importance of matching paint, stain, and sealant properties to the material(s) to which they are applied
- Explanation and guidance on the importance of water and moisture management inside and outside the home.

BSC expects that requests for comprehensive, performance-based homeowner manuals will only increase, as builders increasingly discover manuals as another tool in the kit of managing homeowner performance expectations and managing builder liability.



Reduced Call-backs

Although anecdotal reports of reduced call-backs for Building America homes abound, few builders have been willing to actually analyze for this phenomenon or publicly report on it. One builder, however, Pulte Homes of Tucson, has been very forthcoming about the impact that Building America has had on their call-backs. This division of Pulte Homes moved from warranty and call-back struggles that made the local news in the late 1980s to *NAHB's Builder of the Year* and the *Energy Value in Housing Award* in 2001.

Pulte Tucson accomplished this turnaround in large part as a result of the following changes under the Building America program:

- Conditioned attic with all ducts and HVAC equipment in conditioned space
- 24-in. OC 2x6 framing with R4 EPS continuous insulating sheathing
- Low-e^2, spectrally selective, high-performance windows
- Post-tensioned slab (to deal with issues related to unstable soils)
- 90%+ sealed-combustion gas furnace and high-efficiency water heater in garage
- Mechanical ventilation with room-to-room air exchange.

The first-year call-back categories analyzed—selected HVAC and drywall specifically related to Building America program changes—yielded a modest, but significant, call-back reduction of just under 10%.

It should be noted here that the most dramatic HVAC call-back reductions reported by Building America HVAC contractors come from incorporating commissioning procedures (Sierra Air working for Pulte Homes in Las Vegas). They use key elements of the HVAC commissioning program, Check Me (www.proctoreng.com/checkme/what.html). As a result of this BSC work with Sierra Air, BSC developed HVAC commissioning procedures. These procedures are recommended as part of the Building America program performance targets, but only employed company-wide by one BSC builder, Artistic Homes.

Lessons Learned

Sometimes the most significant financial advantage is the less obvious, indirect one. In this case, the biggest financial boosts to the production builder from a change to Building America practices were the reduction in call-backs and increased customer referrals, both well worth their weight in any increased first cost.

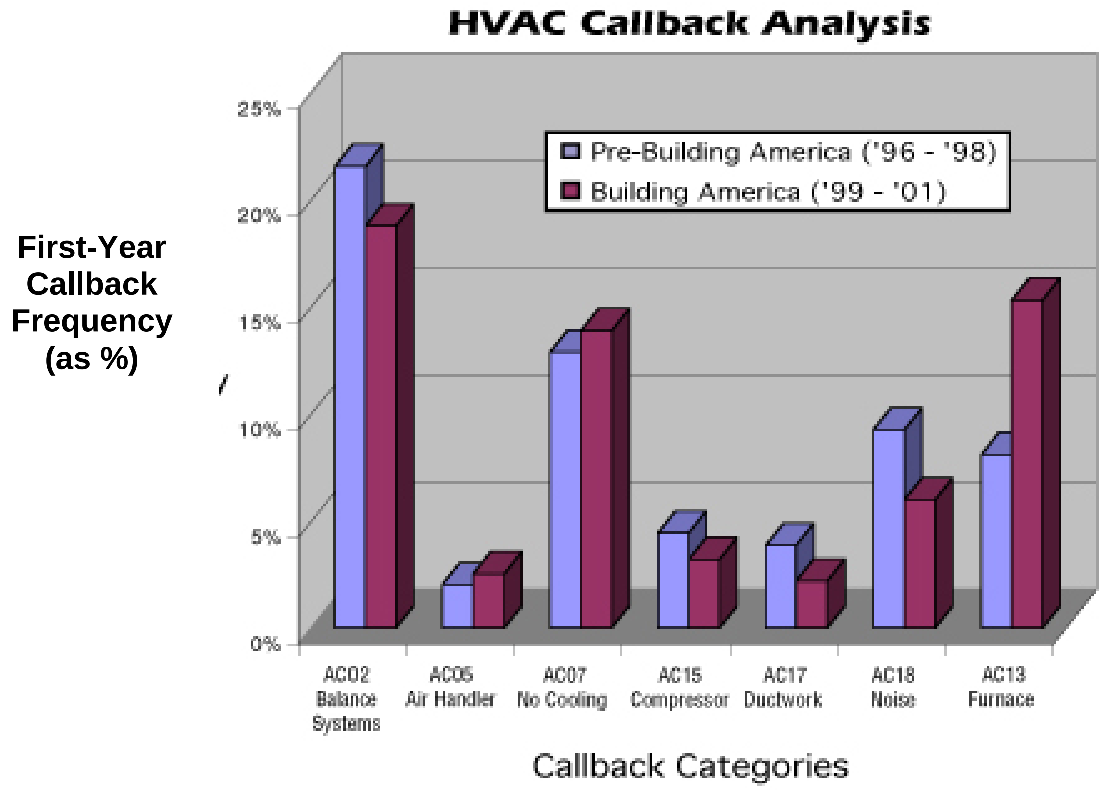
This research with Pulte Tucson has really only scratched the surface of the call-back reduction phenomenon under the Building America program. Additional research is needed, particularly to assess the impact of comprehensive HVAC commissioning and comprehensive advanced framing on call-backs related to Building America.

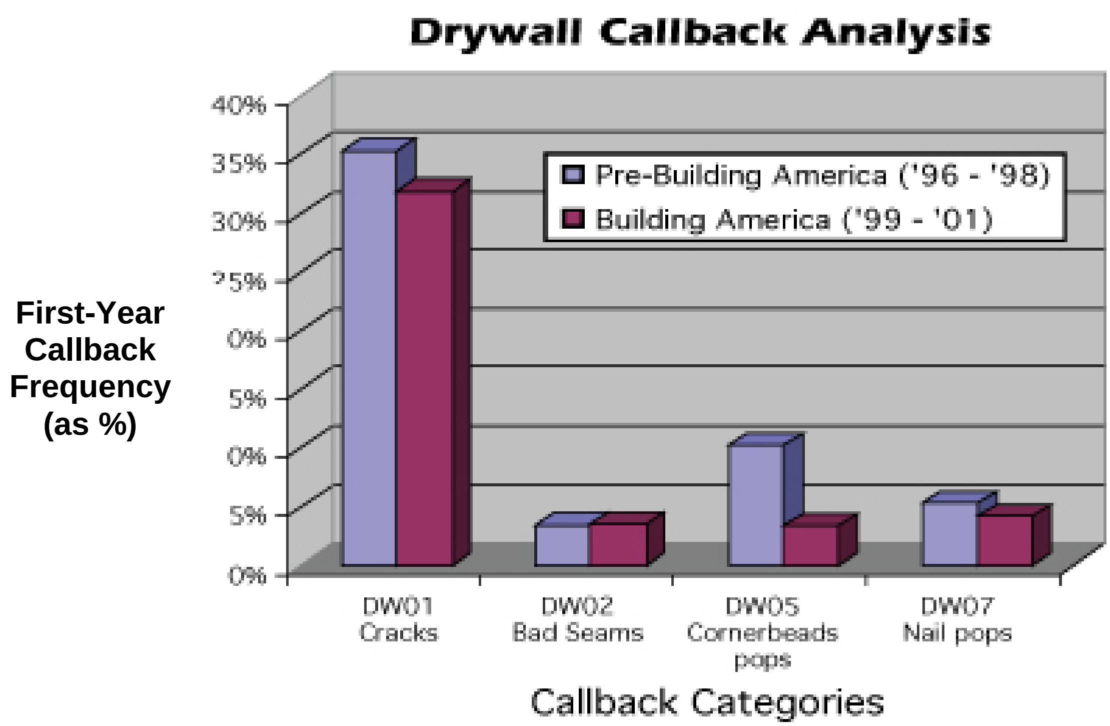
Builder

Pulte Homes – Tucson

Resource

www.buildingscience.com/resources/mechanical/air_conditioning_equipment_efficiency.pdf


HVAC Callback Analysis
First-Year Callback Frequency (as %)
25%
20%
15%
10%
5%
0%
Pre-Building America ('96 - '98)
Building America ('99 - '01)
AC02 Balance Systems
AC05 Air Handler
AC07 No Cooling
AC15 Compressor
AC17 Ductwork
AC18 Noise
AC13 Furnace
Callback Categories


Drywall Callback Analysis
First-Year Callback Frequency (as %)
40%
35%
30%
0%
5%
0%
5%
0%
Pre-Building America ('96 - '98)
Building America ('99 - '01)
DW01 Cracks
DW02 Bad Seams
DW05 Cornerbeads pops
DW07 Nail pops
Callback Categories

System Research Results

High-Performance Space-Conditioning Systems

Air Mixing in High-Performance Homes

Lessons Learned

Maintaining uniform comfort has proved to be challenging for high-performance homes in cold climates. This is partly a result of the complexity of the interrelationships among the design variables/parameters, such as supply air properties and location of diffusers, because of the reduced design flow rates in such homes. Certain supply- and return-air locations and ducting strategies are promising but need further evaluation and may require different types of heating equipment than what is currently available on the market. Special temperature disparities caused by solar heat gains in high-performance homes poses another comfort issue that cannot be overcome by conventional forced-air systems. These are some of the challenges that are addressed in the current collaborative research efforts in the BA program.

Over the past 10 years, IBACOS has been researching the interrelationship between an improved thermal enclosure, the type of air distribution system and associated registers, and the thermal comfort of the occupant. The heating and cooling of a building is a very dynamic process, and maintaining uniform temperature distribution throughout the building is very challenging. Historically, the HVAC system has had to overcome the deficiencies of the thermal enclosure, but with high-performance houses traditional strategies and "rules of thumb" no longer apply. This research helps achieve cost trade-offs and assures comfort for occupants in energy-efficient homes.

IBACOS's work in this area has been focused on evaluating houses with various duct strategies to help quantify appropriate design solutions for high-performance homes. In 2003 and 2004, IBACOS developed a Short-Term Room Air Temperature (STRAT) test method that has been used to quantify room-to-room and whole-house comfort in several test homes. A methodology for using STRAT test measurements to correlate to ASHRAE Standard 55 comfort conditions has also been developed. A paper describing the test method and examples of test home results have been accepted for inclusion in the Third International Building Physics Conference in 2006.

IBACOS has also been looking at floor-to-floor temperature variations in zoned and non-zoned homes and the impact of return-air locations. Interim results from studies have been published as part of ASHRAE conference proceedings in 2004 and 2005. IBACOS is currently working with NREL and industry partners to evaluate various strategies for supply-air diffuser placement in four cold-climate test houses.

Partners

Builders

- Aspen Homes of Colorado
- Fortis Homes
- Hedgewood Properties
- Medallion Homes and Montgomery & Rust, Inc.

Manufacturing

- Amana
- Broan/Nutone
- Cardinal Glass
- Carrier Corporation
- Fantech, Goodman
- Lennox
- Trane
- Tamarack Technologies
- RenewAire
- Dias Analytic

Resources

www.eere.energy.gov/buildings/building_america/publications.html

Attic Ducts Buried Beneath Blown-in Insulation

Lessons Learned

HVAC Design

- Duct runs should be kept as short as possible.
- Duct systems should be small, compact, and efficient
- Duct crossings should be minimized.
- Ducts should run parallel to truss chords and framing and kept close to the attic floor

Builders

- Homebuilders and construction supervisors need to be aware and informed of buried-duct specifications and must take the responsibility of ensuring that HVAC personnel install ducts accordingly. Lack of communication appears to be the largest obstacle to achieving good buried-duct installation.
- Builders also need to take responsibility for determining whether or not an attic is suitable for buried-duct systems.

HVAC Installation

- HVAC installers need to be aware of buried-duct approach and install short, compact, low-profile ducts per designs and specifications.
- To effectively install ducts against the ceiling, HVAC personnel may need to hang them initially and move them to the ceiling once drywall is installed.

Installing Insulation

- Low-profile ducts might create barriers that block the path of blown insulation to parts of the attic.
- Ducts installed on the attic “floor” can prevent proper depth of ceiling insulation; this is a relatively small effect and can be mostly eliminated by good burial.
- More time may be needed to maneuver (people and equipment) around the attic to effectively insulate all areas.

Over the 10-year history of the Building America program, CARB has explored many ways to reduce the significant energy liability caused by heating and cooling distribution ducts located in attics. While there are many ways to reduce this load (such as moving ducts within conditioned space, insulating roofs instead of ceilings, using non-ducted systems for heating and cooling, etc.) all typically require significantly more time, materials, and/or money to implement. Over the past 8 years, CARB has been investigating the potential of a simpler approach in dry climates: "burying" ducts beneath blown-in attic insulation.

Heat-transfer modeling of this approach gave CARB very consistent and straight-forward results. To summarize and simplify the results, CARB developed a table showing "effective" R-values for ducts buried to different levels beneath blown-in insulation. These different levels are shown in the diagram on this page.

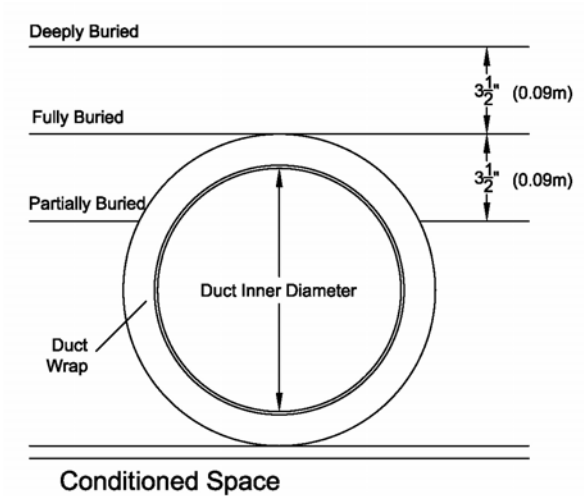


Diagram showing levels of duct "burial"

The corresponding effective R-values are in shown in the table on this page. Based on these findings, the California Energy Commission included buried ducts as one way to comply with duct efficiency standards in the 2005 state energy code.

The values in the table – which are quite conservative for several reasons – show that there is significant potential for energy savings *if* ducts can be effectively buried.

CARB worked with several builder partners and other Building America teams to inspect several attics to assess the quality and effectiveness of buried-duct installations. Based on these inspections, CARB realized that simply specifying "buried ducts" was not always effective. While the concept is very simple, there seemed to be consistent problems with the implementation.

Effective R-values for R-4.2 ducts buried beneath blown-in insulation

Loose Fill Insulation Type	Buried Duct Classification		
	Deeply	Fully	Partially
Fiberglass	25	13	9
Cellulose	31	15	9

Ducts in the attic of a model home. Although buried ducts were specified, only one branch is buried to any degree. Most ducts are hung or otherwise above the insulation.

Ducts in a California home moved to the attic floor.

Builder/Partners

Premier Homes (Sacramento, California)

Beazer (Southern California)

Beazer (Sacramento, California)

Monley-Cronin (Woodland, California)

Resources

California Energy Commission. Residential Alternative Calculation Method (ACM) Approval Manual for the 2005 Building Energy Efficiency Standards for Residential and Nonresidential Buildings. Effective October 1, 2005.

Griffiths, D. and Zuluaga, M. 2004. “An Analysis of the Effective R-Value for Insulation Buried Attic Ducts.” ASHRAE Transactions.

Griffiths, D. et al. 2004 “Insulation Buried Attic Ducts – Analysis and Field Evaluation Findings.” ACEEE Summer Study on Energy Efficiency in Buildings.

www.carb-swa.com/PDF%20files/CNMay03.pdf

www.carb-swa.com/PDF%20files/CNAugust03.pdf

Central-Fan-Integrated Supply-Ventilation System

Lesson Learned

Systems-thinking fosters innovation. Just because a cost-effective technology or building component does not exist, does not mean that it is not possible. The Building America program provided the conditions for the development and eventual successful commercialization of a key component of production in high-performance homes, the AirCycler.

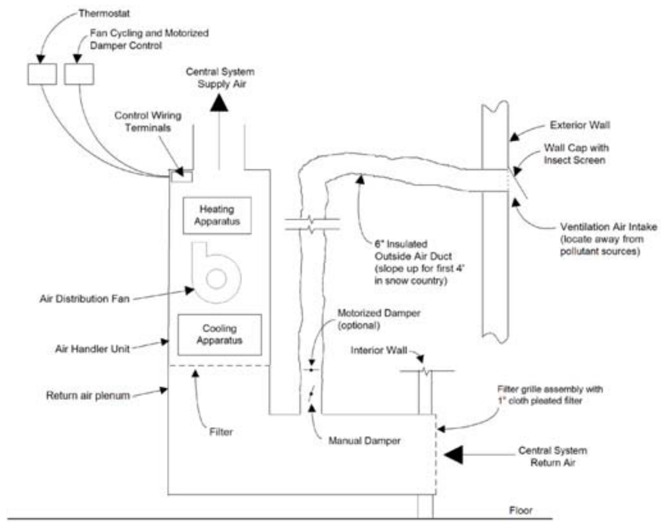
When BSC began designing high-performance homes, two things were clear:

- High-performance homes require mechanical ventilation for dilution of internal pollutants, as well as moisture
- Cost-effective, reliable systems for mechanically introducing fresh air did not exist.

BSC was attracted to an outside air duct connected to the return side of the plenum because it achieved good distribution utilizing existing ducts. This type of system would, however, rely upon central fan operation for effectiveness, and this raised issues of controlling fan operation so that it would not

- under-deliver fresh air during shoulder season conditions (reduced or no delivery of conditioned air)
- over-deliver fresh air during periods of more consistent or continuous central fan operation (particularly problematic during cooling in hot humid climates in terms of increasing latent loads
- Cycle in such a way that was energy inefficient or that shortened central fan service life.

So, a BSC engineer developed and eventually commercialized a central-fan-integrated controller. The science of efficient operation of this system involves a lot more than a smart controller, it requires the right-sized duct, introduced at the optimal location in the return plenum, and in many climates requires the integration of a motorized damper on the fresh-air duct. This system today represents the simplest, most cost-effective method to consistently deliver the right amount of fresh air for human health and safety in all homes, but particularly, in high-performance Building America homes.



Builders

Central-fan-integrated supply ventilation systems are employed in nearly every BSC Building America home. The system is also being used by other Building America builders, particularly builders working with Building America team leader, IBACOS.

Resources

www.buildingscience.com/resources/mechanical/ventilation_centralfan.htm

www.buildingscience.com/resources/mechanical/aircycler_freshair.htm

Combo Heating Systems

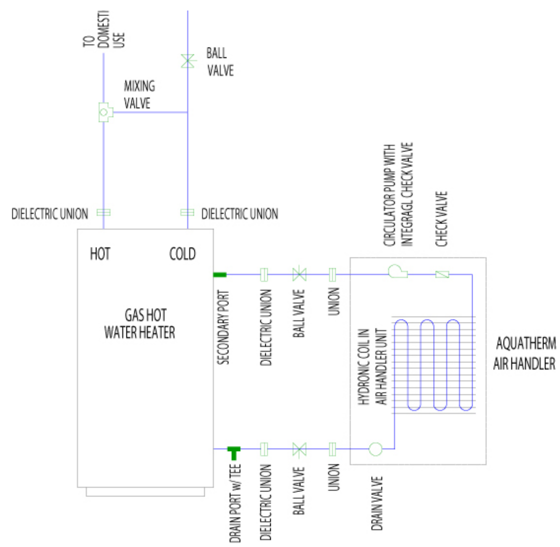
Lessons Learned

There are a couple of lessons here. Systems that involve more than one trade (plumbing and HVAC) present a bigger project management and coordination challenge than systems that involve only one trade. For Artistic Homes, this meant actually taking their trade contractors to Las Vegas to see combo systems in Pulte homes and having their contractors talk to Pulte's. The Artistic trades eventually went from the biggest skeptics to the biggest proponents of the system, but not without time and digestion and accumulated experience.

Sometimes the builder is ahead of the manufacturer. The concept of combo systems is an elegant one but the key components and the way in which they must work together are still not fully developed.

If the space-heating loads are reduced via good building design (not uncommon in affordable, high-performance production homes or townhomes), using one system to handle space-heating and hot-water loads is possible. A conventional tank water heater can be fitted with a heat-exchanger coil for delivery of forced hot air. Special t-stat controls govern demand draw, ensuring that the more immediate need for domestic hot water outranks space-heating demand when coincidental combined load approaches the delivery capacity of the tank water heater. The keys to this approach are a thorough systems analysis of the loads involved and exacting installation follow-through.

Because this is a non-standard system, home combo systems present significant design, training, and installation issues exacerbated by the lack of technological development and technical support for key components of the system. Only the most sophisticated and diligent of production home builders can successfully manage this system.



Builders

Artistic Homes — Albuquerque, New Mexico

Pulte Home Corporation — Las Vegas, Nevada (Cypress Point) and Houston, Texas (Creek Bend Estates)

Lee Homes — Village Green, Los Angeles, California

Hans Hagen – Townhomes — Minnesota, Wisconsin

Resources

www.buildingscience.com/resources/mechanical/combo_systems.pdf

Dehumidification Systems

The issue of part-load humidity control in hot-humid and mixed-humid climates has been particularly vexing. The more energy efficient the building enclosure and the air-distribution system, the less time the air conditioner operates. The less time the air conditioner operates, the less dehumidification is needed. One might think the solution should be easy — just install a smaller air conditioner to make it run longer. The problem is that even the smallest air conditioners still do not run often enough — and if they are sized too small in order to run longer, they are no longer large enough to cool during peak load periods. As the "sensible" load is decreased, the less often the air conditioner is energized because it takes a greater environmental load to change the indoor temperature conditions. The air conditioner on-time is mostly related to the air-conditioner size and the thermal distribution efficiency, but the air-conditioner off-time will be increased with more thermally efficient building enclosures causing an overall decrease in air-conditioner run time.

The part-load problem is made worse when outside air is provided to meet ASHRAE 62.2 ventilation flow rates. The outside air brings in more moisture, increasing the "latent" side of the load more than the sensible side. In energy-efficient building enclosures with controlled ventilation, as the sensible load is decreased the latent load fraction is increased. This skewing of the sensible-latent ratio has made the typical air conditioner obsolete for high-performance homes in humid climates. Even air conditioners with variable-stage compression and variable-speed fans are not able to handle the part-load humidity-control challenge. Supplemental dehumidification is required.

The first approach taken was to integrate stand-alone commercially available dehumidifiers with existing air-conditioning systems and controlled ventilation. Over the past 4 years the "bugs" and "kinks" have been worked out of the approach and it is being successfully introduced by production builders in the southeast hot-humid climate region.

The second approach taken was to modify an existing air conditioner to also make it operate as a dehumidifier. This involved adding an additional coil to the existing air conditioner plus the necessary controls. The advantage of this approach over the first approach is that only one piece of equipment now needs to be installed. A prototype unit was constructed and tested in the laboratory. Field trials of the unit are now planned.

Lessons Learned

Even the simplest concepts need field testing and pre-production monitoring. Initial production roll out also needs to be carefully monitored. Occupants do not often behave predictably. Noise and heat were issues that were identified only during the initial production roll out. The occupant feedback during the initial field testing was different from the occupant feedback during initial production roll out. Also, packaging and appearance are not typically engineering considerations during field testing but are important considerations during production roll out.

ACDM Description

Standard residential cooling equipment responds to a sensible load, as registered by a thermostat, activating a forced-air cooling system that transfers interior heat to a direct-expansion refrigerant evaporator and rejects that heat to outdoors via an air-cooled refrigerant-condensing unit. These standard cooling systems often do not provide adequate moisture control in low sensible-gain houses in humid climates. Modification of a standard cooling system to include an additional refrigerant condensing-coil in the indoor air stream can yield a dual-mode system providing (a) standard cooling with incidental dehumidification and (b) dehumidification only, without overcooling the space.

An enhanced dehumidifying air conditioner has been developed and bench-top tested. Test results showed good moisture-control capacity and efficiency.

Bench-top testing of an advanced air conditioner with dehumidification mode (ACDM) in 2005

Efficient and Effective Ventilation for Small, Northern Homes

Over the course of the winter, the homes with the AirCycler system and the exhaust fans both showed *less* variation in CO_2 concentrations throughout the home than the home with the ERV, yet only the AirCycler actively distributed any air. These two homes also tended to have the lowest CO_2 concentration peaks.

Lessons Learned

- Ventilation systems should be commissioned – none worked properly initially.
- The three ventilation systems tested all provided acceptable air distribution, but there were tremendous differences in operating costs.
- The high energy costs for the Air Cycler and ERV systems would have been significantly reduced with electrically efficient, well-sized furnaces, or especially (in the case of the ERV) with a dedicated duct system for ventilation.
- Exhaust-only systems are not appropriate for all applications. However, they *can* be a very effective, low-cost ventilation strategy.

In South Chicago, Illinois, CARB partnered with Claretian Associates and South Chicago Workforce to evaluate the performance of new sustainable, healthy, and efficient homes. The homes were constructed using structural insulated panels (SIPs) and heated with condensing furnaces.

Because the homes are so air-tight (blower door tests showed 300-350 CFM_{50}), effective ventilation was a prime concern. In the first three South Chicago homes, the builder installed three different ventilation systems:

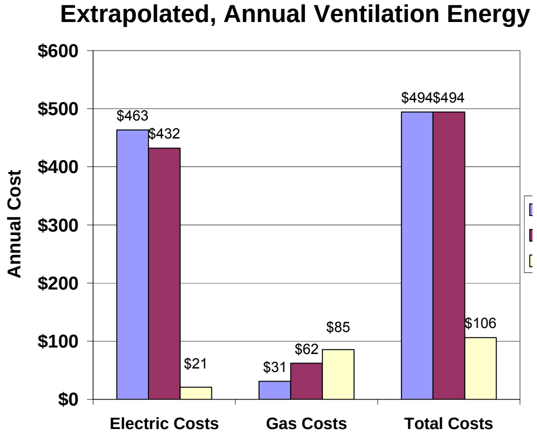
- Energy Recovery Ventilator (ERV) with fresh air distributed by the central air handler
- Air Cycler supply-only ventilation (which also uses the central air handler)
- Exhaust-only ventilation using two efficient, bathroom exhaust fans on timer controls.

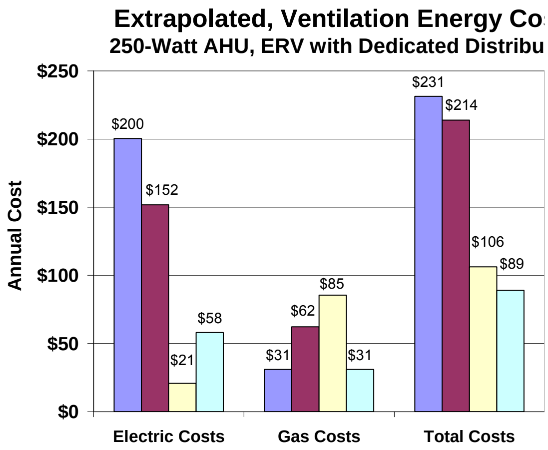
All systems were programmed to meet ventilation requirements of ASHRAE 62.2. CARB monitored both fan electricity and gas needed to heat ventilation air, as well as the temperature, humidity, and carbon-dioxide concentrations outside and at three points within each home. All three homes were occupied, and the systems were fully operational by the fall of 2004. Data was analyzed for 6 months in the winter.

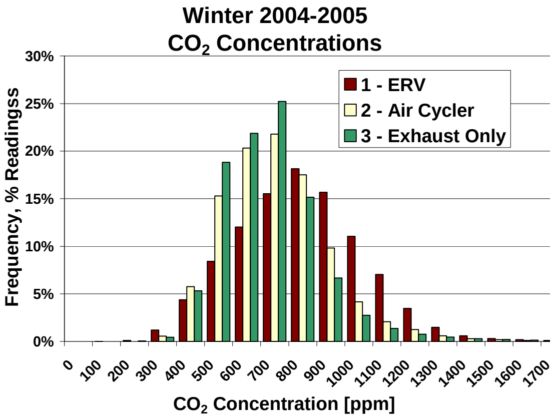
Similar to research conducted in 2000 with CARB member McStain Enterprises, the goal of this study was to evaluate the ventilation systems' performance with respect to fresh-air distribution effectiveness and to energy consumption and operating costs.

Energy results, however, favored the simple exhaust-only ventilation strategy. Although the furnaces in these homes were very efficient in using gas (92.5%), their fans were very inefficient at moving air. The furnace fans drew 700-800 Watts when simply moving air; more efficient air handlers could have used one-third of this power. The city-mandated oversized furnaces exacerbated the problem—smaller furnaces would have run much more frequently during the winter and much less operation would have been required for ventilation alone.

Among the systems monitored, it is clear that the exhaust-only system is the least costly to operate; costs were less than 50% of those of the other systems. Looking at carbon-dioxide concentrations and air distribution, data showed that the exhaust system did provide adequate distribution and was the most appropriate system for these particular homes. Based on CARB research results, revisions are being made to the Illinois affordable green-building program.







Builder/Partners

Claretian Associates (Chicago, Illinois)

South Chicago Workforce (Chicago, Illinois)

McStain Enterprises (Boulder, Colorado)

Resources

www.carb-swa.com/PDF%20files/March2000.pdf

www.swinter.com/WinterGREEN/WGAugust05.pdf

hwww.swinter.com/WinterGREEN/WGSeptember05.pdf

Home Energy Magazine

Integration of HVAC System Design

In a typical Building America research house, IBACOS engineers the HVAC system specifically for the house and coordinates the HVAC system design with the structural and plumbing systems in the house, while working with the builder or architect to accommodate room layouts and aesthetic requirements. By minimizing spatial conflicts between systems in the design stage, IBACOS aims to optimize the performance of the house as a whole, while at the same time streamlining construction of the system in the field. In other words, IBACOS does not design the HVAC system in a vacuum, ignoring the interactions between this system and the structural system, thermal envelope of the house, and plumbing system, etc. Instead, the real interactions between these systems are acknowledged and engineered, creating an integrated solution that increases whole-house performance and optimizes whole-house construction costs.

Builders

Kacin Construction – Pittsburgh, Pennsylvania

Montgomery and Rust – Pittsburgh, Pennsylvania

Hedgewood Properties – Atlanta, Georgia

Merlin Contracting – Las Vegas, Nevada

Goehring and Morgan Construction – Orlando, Florida

Hannigan Homes – Orlando, Florida

Tindall Homes – Mansfield, New Jersey

Resources

www.ibacos.com/pubs/Factsheets/HVAC%20Optimization%20Strategies.pdf

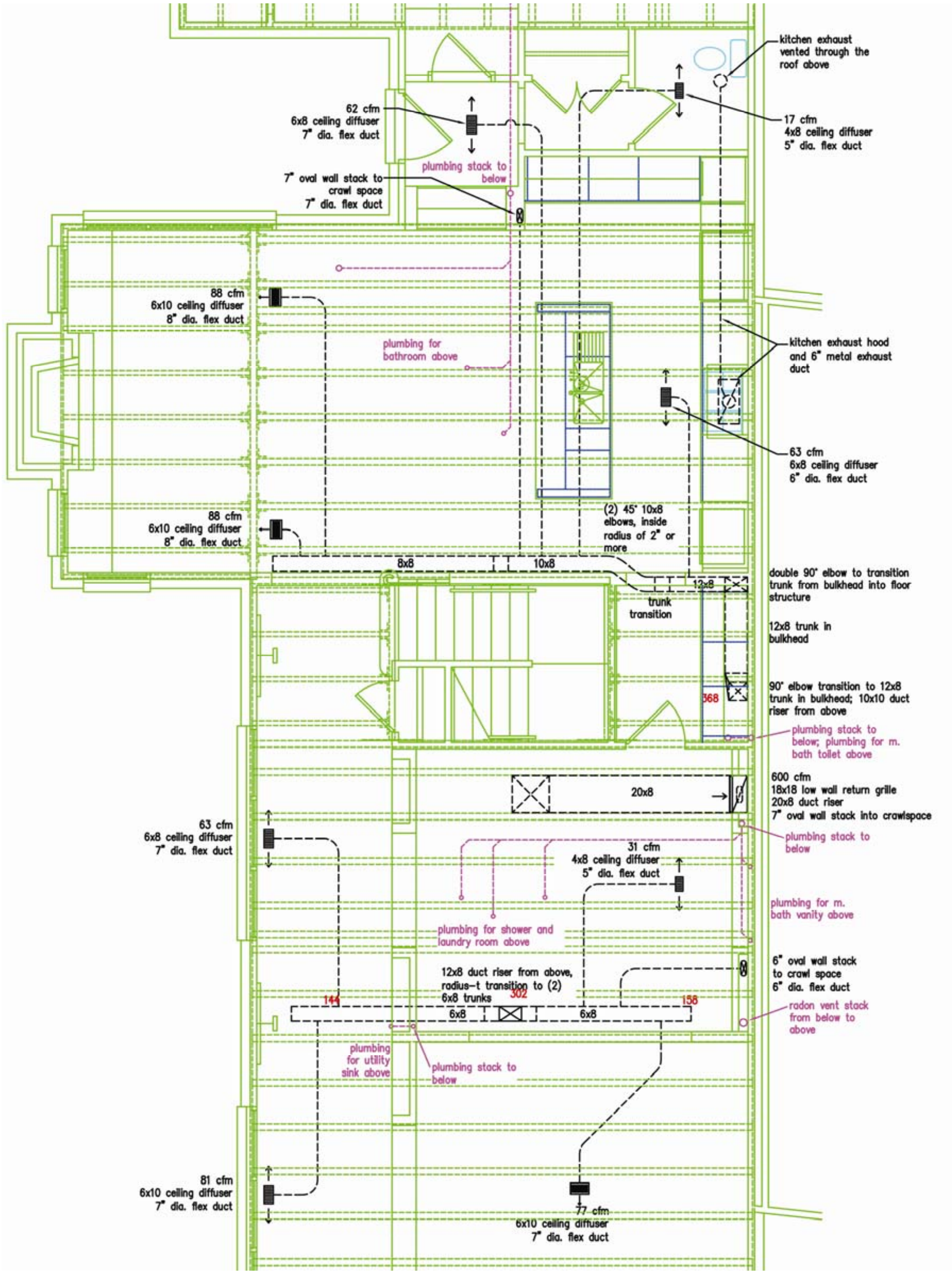
www.ibacos.com/pubs/Factsheets/Comfort.pdf

Lessons Learned

The main lesson learned when doing an engineered HVAC system design was that that obtaining accurate and timely design information from all key subcontractors involved is essential to foregoing on-site problems. A final framing plan for each floor must be obtained as soon as possible in the design process because it is the plan that dictates the possible positioning of ductwork and air-handling equipment. If the house is a new design, the builder and/or architect need to obtain a framing design quickly, often with a structural engineer involved. Design problems can occur on-site when the framing plan is changed at the last minute or at the site, often to accommodate an architectural change.

Therefore, it must be stressed to the builder that the framing plan upon which the HVAC system design is based on should be considered as the final version (whenever possible). Plumbing system design information is added next. Our experience is that plumbers need to be approached early and often for this information. Often they are reluctant or unable to give this information before going on site and we have often relied on our own in-house plumbing experience to fill in the blanks on the location of piping in this system.

The benefits of this approach to system design on a production basis include a high level of consistency for long-term warranty and uniform pricing from multiple vendors who do the work. One challenge is recognizing that the individual initially installing the system design may not necessarily be familiar with it, and site supervision and good communication with the trade organization is critical to successful implementation.



Example of engineered HVAC design fully integrated with structural layout and plumbing system

Moving Ducts/Equipment into Conditioned Space

Ducts and equipment outside of the conditioned space create three problems. One, they make it challenging, if not improbable, to achieve high HVAC system efficiency. Two, they often lead to pressure imbalances that can affect health and safety of occupants. And three, these same pressure imbalances can affect building durability by introducing moisture into building assemblies.

Lesson Learned

It often takes "outside-the-box" thinking on the part of several members of a building team to accomplish the desired result: systems engineering, systems design, systems installation, or field work. It's only when all team members "get the picture" and "build the vision" that the most elegant solutions rise to the top.

On the other hand, fitting the duct system within conditioned space presents design and engineering challenges. But herein lies the beauty of the Building America approach—when you combine a high-performance envelope with an innovative framing system, the engineer and the architect are freed from key constraints of conventional construction and the resulting simplified duct distribution system makes it much easier to move ducts and equipment into the conditioned space.

Artistic Homes took the Building America systems-thinking approach one step further in the field. They were having trouble getting the desired duct air sealing on the trunk duct tucked into the main hallway soffit. So, they decided the only way to keep this duct in conditioned space and seal it tight all the way around (the top side is nearly impossible to get to) was to assemble and mastic the trunk duct at ground level and then install it in the soffit. They accomplished this by getting the framer to build—but not install—the two 7-ft end-of-hallway partitions. After the trunk duct has been assembled and sealed with mastic and hung in the soffit, framers come back later and install the set-aside partitions. These partitions are clearly marked on the plans as "set-aside," and the actual partitions and their locations are marked with spray paint to remind all trades as to what they are, why they are not installed, and where they go when they finally are installed.

Builders

Pulte Home Corporation — Minnesota

Artistic Homes — Albuquerque, New Mexico

Resources

www.buildingscience.com/buildingamerica/casestudies/oakbrooke.htm

www.buildingscience.com/resources/misc/wood_efficiency.pdf (particularly pages 2, 3, and 5)

Night Cooling with Thermal Mass

In climates with a large diurnal swing, having hot days and cool nights, a night ventilation system that is integrated with the HVAC system can substantially reduce the cooling demand on mechanical air conditioning. When the outside temperature falls below the indoor temperature at night, the outside air can be used to both ventilate and cool the home. Furthermore, if the home has substantial thermal mass, the mass can be cooled using the outside air. Building materials like thicker (5/8-in.) drywall, interior stucco, interior brick, or concrete walls are said to have high heat capacity in that they have the ability to absorb large amounts of heat compared to lighter construction materials. When thermal-mass walls and floors are cooled at night, they can act as a heat sink during the day. They will also provide a lower mean radiant temperature. Both processes reduce the amount of mechanical cooling that will be required the next day.

Lesson Learned

Night cooling coupled with good envelope design and construction can result in a reduction of 1-2 tons in HVAC design.

Night cooling results in increased energy efficiency, comfort, and cost savings.

Night cooling with Thermal Mass in Areas with Summer Diurnal Swings

Earlier BIRA research showed both energy savings and cost benefits of using high thermal mass and PV systems with a Time-of-Use (TOU) rate structure. The total cooling energy savings were found to be as much as 33.3%, and the peak cooling energy reduction was 43.3% for a high-thermal-mass house over a house with a standard wood-frame construction. The cost savings with a TOU rate structure were 35.5% for a high-thermal-mass house.

A high thermal mass (walls and floor) coupled with night-time cooling to recharge the mass, can result in significant energy and cost savings. As Givoni, explains—the hourly cooling loads in residential buildings is generated mainly by heat flow through the envelope, which the mechanical system has to accommodate, and to a smaller extent also by the solar gain through the windows. The hourly pattern of the cooling load can be significantly affected by the thermal mass of the building, especially in the residential buildings with small internal heat generation.

Givoni explains further how the hourly heat flows through walls of different orientations have varying patterns in low-mass and in high-mass buildings. In a low-mass building, the heat flow from the internal surface of the envelope elements to the indoor air, which generates the "external" cooling load, closely follow the sol-air temperature patterns at the external surfaces. The direct solar gain through the windows also follows a similar pattern. Generally, in a building with a low-mass envelope, the resulting diurnal cooling load will have a large amplitude, meaning a high peak cooling load and high peak energy consumption by the mechanical system. The peak in such buildings usually occurs in the early afternoon hours.

Studies have shown the usefulness and applicability of using night ventilation in conjunction with the HVAC system. The following chart shows the results of a monitoring study for a 3,500-ft^2 two-story house in Gilroy, California, where the external and internal temperature of the house were monitored.

The graph shows the outside air temperature at various times of the day and the indoor temperature, which is controlled by the HVAC system. Thus, cooling loads can be met by natural ventilation for almost 15 hours of the 24 hours in a day—from 8 pm to 11 am—when the outside air temperature is lower than the thermostat lower limit, resulting in substantial energy and cost savings.

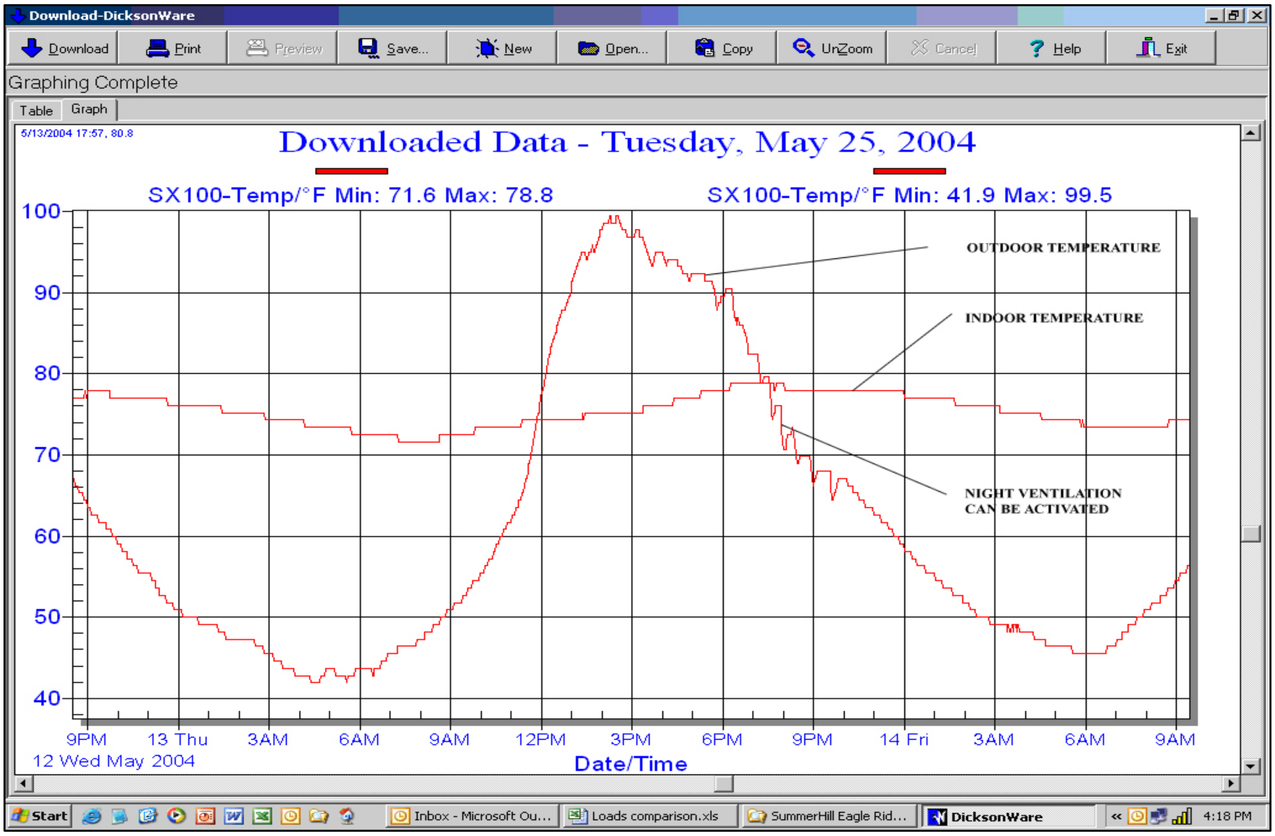
A building with a high thermal mass can significantly suppress the amplitude of the cooling load and delay the peak for several hours, until the evening. This suppression of the peak can result in a significant reduction in the size of the cooling system. Furthermore, the peak may be delayed until the outdoor temperature drops sufficiently, so that natural ventilation could replace mechanical cooling. Because of this reduction in peak loads when using high thermal mass and night-time cooling, switching to TOU rates can have high cost benefits.

Even in climates where the diurnal swing in temperatures is insufficient to cool off thermal mass, off-peak air conditioning can be used to cool thermal mass to reduce or avoid on peak use of air conditioning.

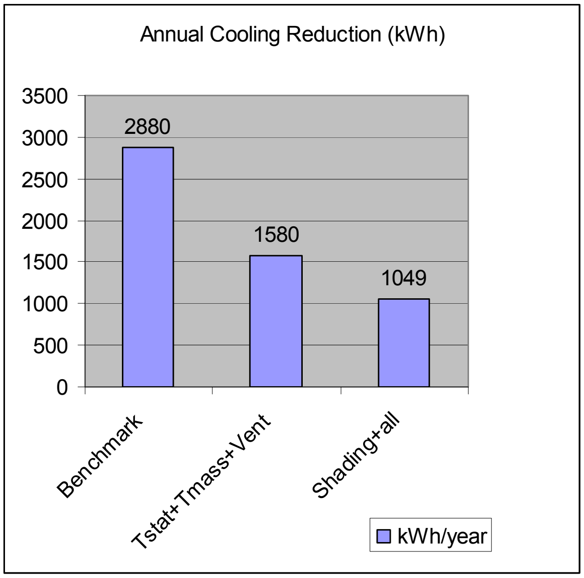
The analyses showed significant benefits of using shading and high thermal mass for the wall system and the floor in conjunction with summer night-time cooling. The benefits include total cooling load reduction, peak cooling load reduction, and significant cost benefits for the high thermal mass home with shading, compared to the house with a standard wall construction.

Total Cooling Load Reduction

Increasing the thermal mass characteristics of the home reduces the cooling load by 63.5% annually through programming the thermostat, summer night ventilation, and shading the glazing. The high-thermal-mass house with programmed thermostat and night ventilation has annual cooling loads of 1580 kWh compared to 2880 kWh cooling loads for the standard wood-construction house. The cooling load reduction is 45% for the high-thermal-mass (with no shading) home over the benchmark case.



Monitoring result for a house in Gilroy, California. The graph shows the outdoors and indoors temperature swings.



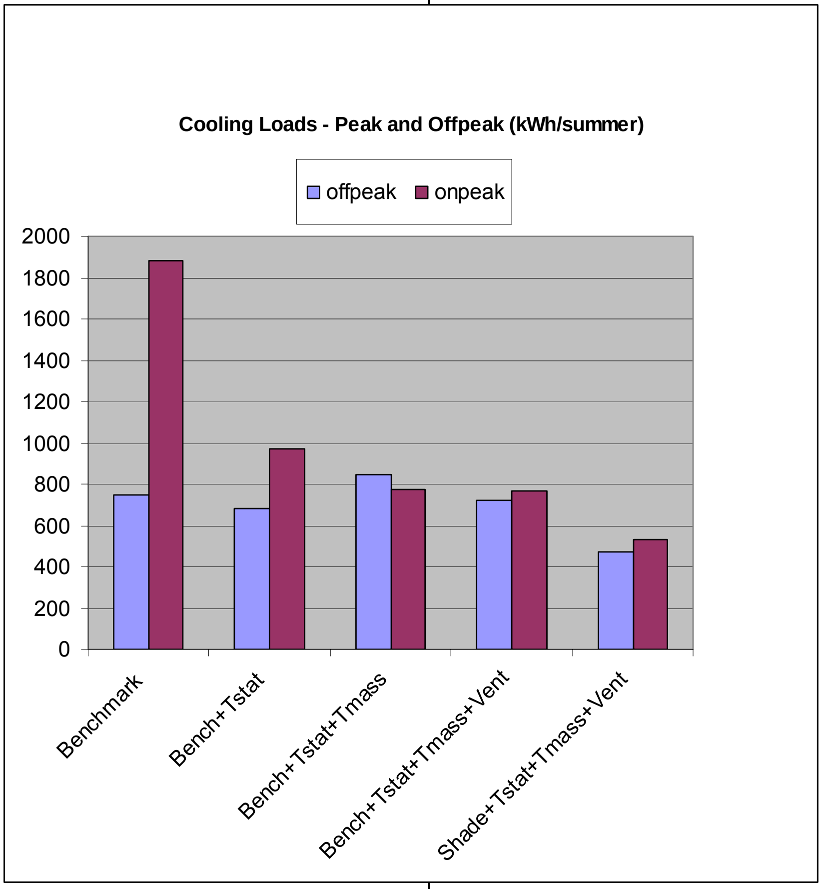
There is an annual cooling load reduction of 63.5% for a high-thermal-mass house with shading, programmed thermostat settings, and night ventilation.

Peak Cooling Load Reduction

The high thermal mass offsets the cooling loads in the house to off-peak hours resulting in a significant reduction in peak cooling loads. Adding shading shifts the cooling loads further to off-peak hours. The figures on this and the next page show the summer monthly peak for all the six cases. These results have been derived from the daily hourly outputs from the DOE 2.2 energy simulations

The simulation results show how each parameter (Shading, Night Ventilation, High Thermal Mass, and Thermostat settings) not only reduces the total cooling loads over the summers by 62% but also offsets the loads to off-peak hours by up to 32% over the benchmark case.

The chart below summarizes the results and showcases the peak and off-peak cooling loads for the summer.

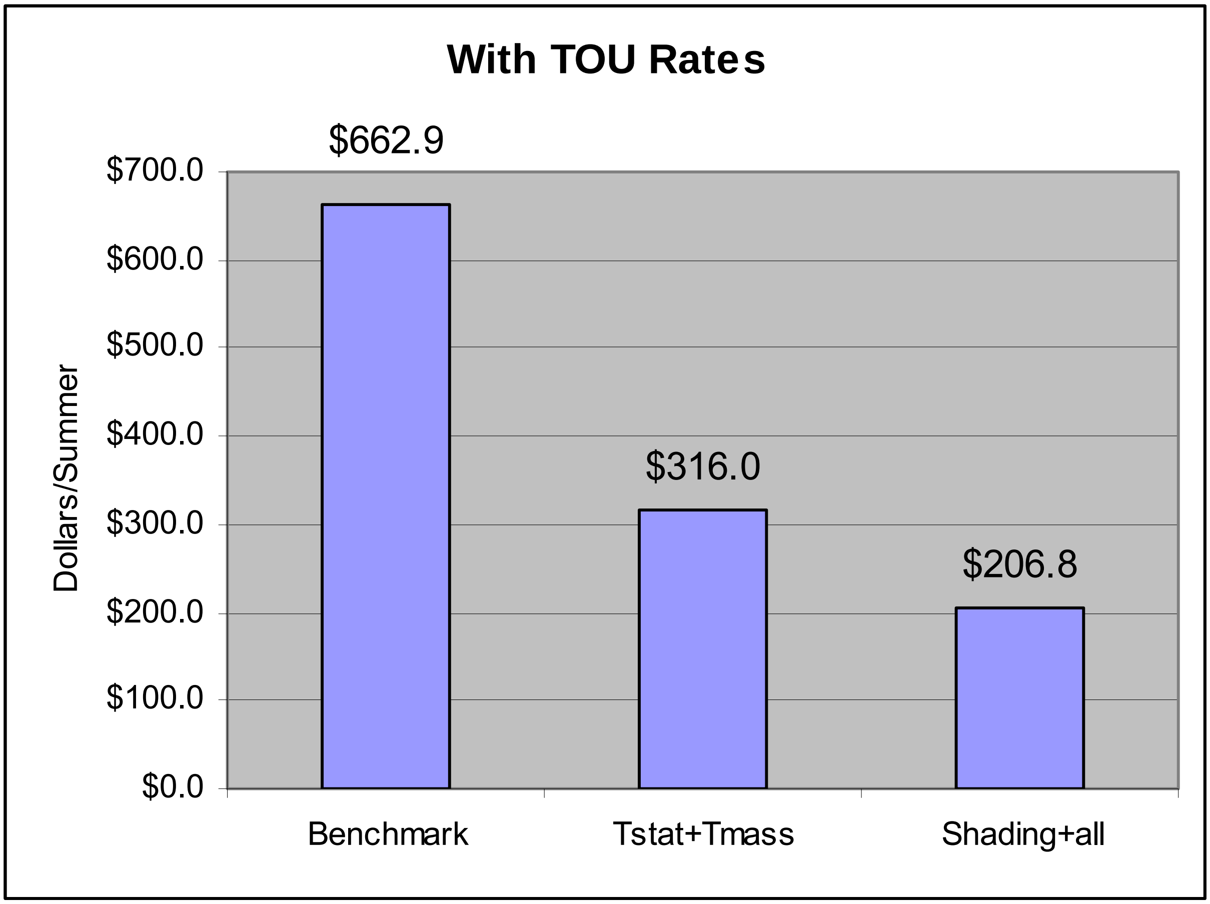


There is a 62% reduction in summer cooling loads over the benchmark case by just using the above parameters. Also, the peak cooling loads are offset to off peak hours by up to 32%.

Cost Reduction

Because of the reduction in annual peak cooling loads in the case of a high-thermal-wall house, cooled during the summer nights, there are significant benefits when using TOU rate structure. The TOU rates for peak hours in summers are almost four times those for off-peak hours in summers. Thus, by offsetting the peak cooling loads to off-peak hours when the costs are much lower, the cost benefits are high when using high thermal mass and shading.

Results show a 68.7% reduction in cooling costs when using a high-thermal-mass wall with shading over the benchmark case. The costs reduced from $663 to $207 for the summers.



There is a 68.7% cost reduction for summer cooling using the above parameters alone over the benchmark case, following a Time of Use rate structure.

Nighttime Ventilation Cooling

Lessons Learned

Two demonstration homes were built in California to evaluate integrated ventilation cooling. Both were production homes, one in Livermore (hot central valley) and one in Watsonville (mild coastal). The Livermore house was also an NREL Zero Energy Homes program demonstration. Both houses exceeded California's Title 24 standards. The Livermore house included two 2-ton air conditioners, and the Watsonville house used only ventilation cooling. Monitoring data from the Livermore demonstration house indicated substantial energy savings and peak load reduction. The 2-ton air conditioners at the 3080-ft² Livermore house operated a total of 9 hours during the summer of 2003, which included 5 days with outdoor temperature over100°F. Ventilation cooling, enhanced thermal mass, a 3.6-kW PV system, and other energy features combined to make the Livermore house a net electrical energy producer (the owners have not been charged for electrical use since they took occupancy in 2002). Energy savings for the Watsonville house were negligible because of the mild climate, and the owner's use of windows for ventilation and tolerance for warm temperatures.

Despite the Livermore success, production builders have not been receptive to using the hydronic-based integrated ventilation cooling system in their developments because of their lack of experience with combined heating-hot water systems. Further, the larger builders are reluctant to install heating-cooling systems that are not produced by a major manufacturer. To address these barriers, a version of the system has been developed that functions with variable-speed furnaces. This system, which also includes zoning capability, is being installed in two California developments.

Data obtained from the demonstration houses and simulations were used to make the case for ventilation cooling builder incentive and demonstration programs for ventilation cooling. Pacific Gas & Electric began offering a $500 incentive for variable-speed ventilation cooling in 2006 and will be monitoring performance on a number of homes. Southern California Edison is sponsoring a 150-home demonstration in their service territory.

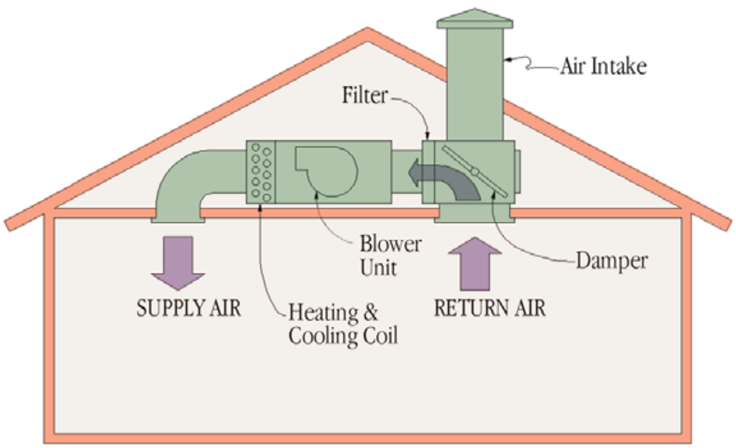
As a representative energy-efficient technology, ventilation cooling has defined some of the barriers to the introduction of new technologies needed to meet Building America goals. After a product is developed and technically proven, it must be licensed to a manufacturer who is strongly committed to manufacturing, marketing, and distribution. Alternately, investors must be convinced that the product has adequate patent protection and will yield returns, capital must be secured, and a new manufacturing and marketing enterprise must be launched to support the product. Distribution chains must be identified and contractors must be trained to ensure proper application and installation. The future of ventilation cooling and other new technologies applied to production homes hinges on overcoming these barriers.

Natural cooling, obtained by opening windows at night and closing them during the daytime, has long been employed as a means of keeping homes cool, and prior to the 1950s was the only resource most people had for maintaining indoor comfort in summer. The home-buying public has come to expect air conditioning as a standard feature in new homes, even in climates where it may only be required a few weeks of the year, as in the coastal-influenced climates of California and many other areas of the west. Because of increasing demand for comfort, security concerns related to open windows, and less free time for managing windows, air conditioning is increasingly relied upon for maintaining comfort. This trend has caused air conditioning to be responsible for about 45% of California's residential summer peak load but only 7% of its annual energy use.

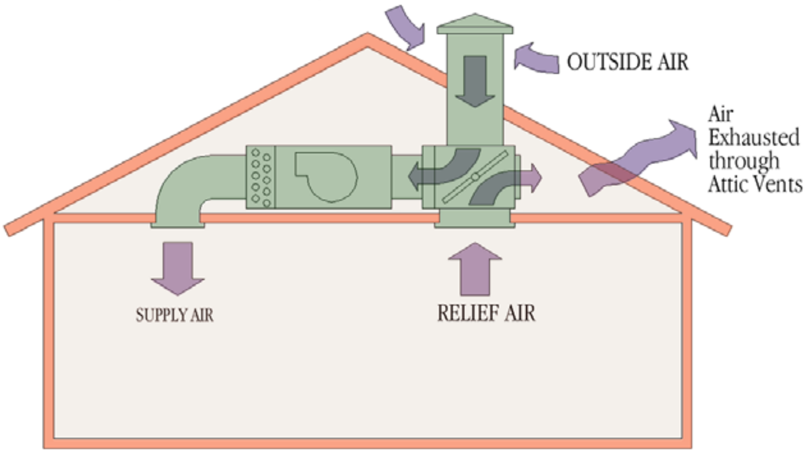
The objective of ventilation cooling is to convectively transfer heat from building mass elements (wall board, masonry, and furnishings) to cool ventilation air and to discharge it from the house. Of course, this can only occur while outside air is cooler than indoor air. During the daytime, the cool mass absorbs heat from the air, moderating the rise in indoor temperature. Provided the indoor air temperature does not rise above the thermostat cooling setpoint, air-conditioner operation can be averted.

The Alternatives to Compressor Cooling (ACC) project was initiated in 1994 to address the problem of worsening residential peak loads as a result of the proliferation of air conditioners in California's relatively mild climates. Completed in 2004, the final phase of the project developed an integrated system that provides heating, air-conditioning, ventilation cooling, and fresh-air ventilation. This "NightBreeze" system includes a variable-speed hot-water air handler, damper, and controls, and automatically delivers filtered outside air during summer nights. The cool air lowers the temperature of the building mass and offsets or eliminates air-conditioner operation the following day. The damper provides relief, eliminating the need to open windows, thereby assuring home security. The controls automatically operate the system, varying both the air volume and the minimum indoor temperature to assure optimal cooling while maintaining comfort. In winter the system also delivers fresh air to maintain indoor air quality.

To estimate energy savings and demand reduction for other houses and other climates, monitoring data from a demonstration house located in Livermore, California, were used to calibrate a DOE-2 simulation model that was then used to evaluate ventilation cooling in all 16 California climate zones and ten cities in the United States. In many locations, the outside nighttime air temperature may be low enough to provide cooling, but because of high relative humidity, the enthalpy of outside air is higher than that of indoor air, making ventilation cooling a poor choice. The table on the next page lists energy and demand savings for an 1860-ft² California Title 24-compliant house maintained at 76°F. The table also lists the number of days during which a humidity ratio of 0.013 was exceeded (about 68% relative humidity). The best climates for ventilation cooling are those with relatively dry conditions and diurnal temperature swings of 20°-30°F.



Heating & Air Conditioning



Ventilating

The following are features of the ventilation cooling system that is being applied to Building America projects:

Integration with heating and air conditioning. Using the HVAC system fan and ductwork to deliver ventilation air reduces cost by conserving equipment and assures that cool outside air is properly distributed. Integrating heating, cooling, and ventilation controls simplifies operation.

Automatic operation. It is not reasonable to expect that homeowners will always turn the ventilation system on and off at the appropriate times. The fan and damper automatically operate when it is cooler outdoors than indoors. Controls use temperature data from prior days to predict cooling requirements and vary both the indoor temperature low limit and the ventilation rate so as to provide adequate ventilation while preventing overcooling and conserving fan energy.

Positive house pressurization. Positive pressurization facilitates filtration of outside air and allows the source of makeup air to be controlled.

Filtration. Both return air and outside air are filtered. The control indicates when the filter should be changed.

Selectable airflow. Project studies identified an optimal maximum airflow rate of 0.6 cfm per ft^2 of conditioned floor area. Control settings allow the maximum airflow rate to be precisely selected, and the variable-speed fan maintains the correct airflow. This feature conserves fan energy and assures adequate ventilation cooling while conserving fan energy.

Easy-to-understand controls with diagnostics. Control design carefully considered human factors so as to simplify operation and to nurture an understanding of the principals of ventilation cooling. Diagnostics alert the homeowner when it is time to change the filter and provide notification and identification of component failure.

High reliability. Integrating ventilation cooling with HVAC systems requires automatic dampers, and damper failure may not be apparent to the homeowner. Dampers and other components should have a lifetime comparable to that of the other HVAC components.

Installability. Most residential HVAC systems in the western states are installed in attics, where space can be limited by vaulted ceilings, trusses, and other structural members. The damper is designed to fit between trusses.

Fresh-air ventilation. Indoor air quality is maintained during the summer by ventilation cooling. During the winter, the system fan and outside air damper are operated to provide outside air at a rate that can be directly selected from the thermostat. This feature provides 100% outside air rather than mixing outside air with return air, thereby reducing fan energy.

Projected Energy and Demand Savings for Ten U.S. Cities

Location	kWh/yr Savings	% Savings	Kw Peak Reduction	Number of Days Exceeding 0.013 Humidity Ratio
Sacramento, California	537	35%	0.3	0
Chicago, Illinois	597	24%	0.3	16
Ft. Wayne, Indiana	657	27%	0.3	24
Salt Lake City, Utah	356	19%	0.3	0
Tucson, Arizona	872	15%	0.2	5
Philadelphia, Pennsylvania	286	17%	0.2	0
Jacksonville, Florida	464	12%	0.2	60
Albany, New York	588	27%	0.3	11
El Paso, Texas	900	19%	0.2	10
Bismarck, North Dakota	734	33%	0.5	5

Builders

Centex Homes (Livermore, California)

Clarum Homes (Watsonville, California)

Monley-Cronin Construction (Woodland, California)

The Grupe Company (Rocklin, California)

Habitat for Humanity (Westminster, California)

Resources

www.energy.ca.gov/pier/final_project_reports/500-04-009.html

www.energy.ca.gov/pier/final_project_reports/500-03-096.html (Attachment 9)

www.davisenergy.com/nb_page.htm

www.toolbase.org/techinv/techDetails.aspx?technologyID=202#nightbreeze

Development and Testing of an Integrated Residential Night Ventilation Cooling System. D. Springer, L.I. Rainer, B.I. Dakin. ASHRAE Transactions 2005, Vol. 111, Part 2.

Quantifying Comfort in High-Performance Homes

The current residential construction industry has been optimized to deliver housing at lowest first cost, while meeting code minimums. They establish cost control by making only small changes to incrementally reduce costs. Builders do not currently have replicable models of how to manage their operations to most effectively deliver houses that perform to the standards established by the Building America program. Builders are also reluctant to adopt the technical performance packages without understanding their potential impact on their businesses as a whole and without being given successful business models to help guide implementation of the technical packages.

IBACOS has been studying this issue since 1998, beginning with work in large-scale master-planned community developments with multiple builders who all were required to achieve Building America metrics of performance. Through working with developers and through work in individual pilot homes, it became apparent that most builders view energy efficiency and higher performance housing as an additive, rather than a systems-based approach.

From this finding, IBACOS began a more detailed investigation of builders who have fully integrated higher performance housing into their operations. This is an effort to identify best practices and compare their process to that of a typical process IBACOS would undertake in a Building America pilot home or community-scale project.

Partners

Oakwood Homes

Hedgewood Homes

Resources

www.ibacos.com/

Lessons Learned

Through literature searches and working with partners, several key findings have emerged. First, a home-building company should be set up for operational excellence and continual improvement if high-performance homes are to be implemented at the lowest cost.

Feedback loops, quality assurance, and a culture that empowers the employee are all key factors for success. New trade relationships will need to be developed as well. Additionally, there should be a mechanism in the company that can track full life-cycle costs from design through final warrantee stages to fully evaluate the benefits of construction of higher performance homes.

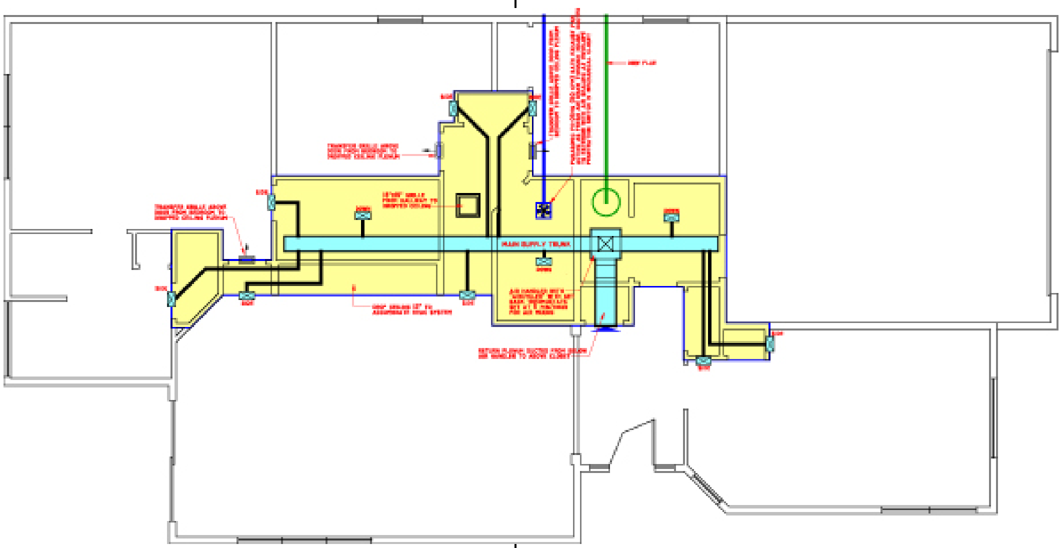
A design process that integrates the design and construction teams helps to assure that the key systems that comprise a higher performing home (advanced thermal enclosure, rational advanced-framing, integrated mechanical systems) are considered and planned before construction begins and that he cost tradeoffs for key design, structural and systems strategies are weighed.

Key outputs have been final reports posted to IBACOS' website (www.ibacos.com) and presentations on this topic at key industry conferences such as RESNET and EEBA.

Simplified Duct Distribution Systems

Lesson Learned

Good design and engineering often lead to a system that is simpler, less expensive, and of higher performance.



One of the most common callback complaints experienced by production builders has been comfort. Systems-engineering analysis identified leaky ductwork, particularly on the return side, as the most significant cause of comfort complaints. BSC systems engineering came up with the solution—a hard-ducted central return with pressure-relief transfer grilles or jump ducts.

A key part of the design is the 12- to 18-in. horizontal off-set, with two 90-degree changes in direction, which provide excellent sound and vibration dampening. Note that a high-performance building envelope is the starting point for considering an innovative simplified duct distributon system.

Builders

Town & Country Homes — Chicago, Illinois

Pulte Home Corporation — Minnesota

Engle Homes — Denver, Colorado

Artistic Homes — Albuquerque, New Mexico

Hans Hagen Homes — Minnesota, Wisconsin

Resources

www.buildingscience.com/resources/mechanical/transfer_grills.htm

www.buildingscience.com/resources/mechanical/509a3_cooling_system_sizing_pro.pdf

System-Integrated Dehumidification

Lesson Learned

It's nice when your intuition is supported empirically. In this case, research supported the suspected solution, a solution that provided the best overall value:

- Lowest first cost
- Good moisture control performance
- Reasonable operating costs.

The Building America performance targets call for a more thermally efficient envelope and a reduction in uncontrolled air leakage. In order to compensate for a reduction in air leakage, controlled ventilation is provided. In hot/humid climates, the simultaneous reduction in heat gain and addition of controlled ventilation leads to a reduction in sensible load and an increase in the latent (moisture) load as a fraction of total cooling load. The resulting sensible-to-latent-heat ratio cannot be comfortably managed with currently available air conditioning equipment. This can lead to humidity problems and issues of comfort, occupant health, and durability.

Some form of supplemental dehumidification is necessary in homes with thermally efficient building envelopes in hot and humid climates. The most promising technological approach is the integration of dehumidification with ventilation. BSC set up field research to test six different dehumidification set-ups, including both integrated and stand-alone systems, in terms of their performance, installed costs, and operating costs. The results of this research are encouraging—relatively low-tech, low first-cost set-ups have provided good dehumidification and reasonable operating costs.

Builder

Pulte Home Corporation — Houston, Texas

Resource

Please see the BSC Web site (www.buildingscience.com/resources/mechanical/conditioning_air.pdf) for the latest information.

System Research Results

Zero Energy Homes

How Close to ZERO Energy can We Really Get?

Lessons Learned

- Homeowners require conservation education and consumption feedback in order to change energy usage habits and to achieve truly "zero-energy" homes.
- Ventilation, heating and cooling distribution and equipment, lighting specification and design should be optimized *before* more expensive renewable energy systems are considered.
- Using cutting-edge technologies will require commissioning to achieve desired energy performance.

CARB has worked with builders and utilities across the nation in efforts to approach "zero-energy" homes. Improvements in energy efficiency have been achieved through CARB's recommendations on design, installation practices, and selection of HVAC equipment, lighting, appliances, and windows. Results of testing and monitoring have shown that grid-tied homes can show dramatic energy reductions, but these depend highly on the efficiency of the building envelope, occupant behavior, equipment selection and commissioning, and construction practices in the field.

West Coast

In 2003, Beazer Homes, a CARB partner, completed construction of several high-efficiency homes in Sacramento, California. The homes feature roof-integrated solar electric systems (3.3-kW), which were procured through the Sacramento Municipal Utility District (SMUD). SMUD had teamed up with area homebuilders to reduce demand placed on the utility through energy efficiency and renewable energy.

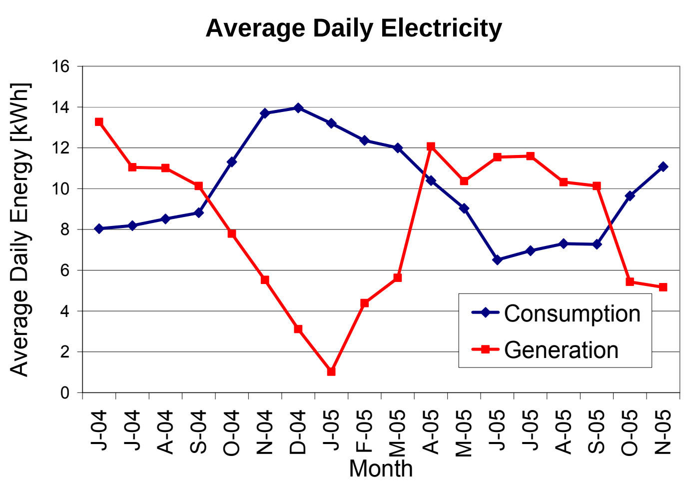
Throughout 2004, SMUD compiled the electricity consumption and PV generation data for 11 solar homes in one Beazer development. Findings show that two of the Beazer homes did, in fact, reach the zero electricity goal. A closer look at the net usage chart shows significant differences between electric bills in similar homes. These differences show that while builders and designers can do a great deal to improve efficiency of homes, the ultimate responsibility in attaining "zero energy" lies with the user.

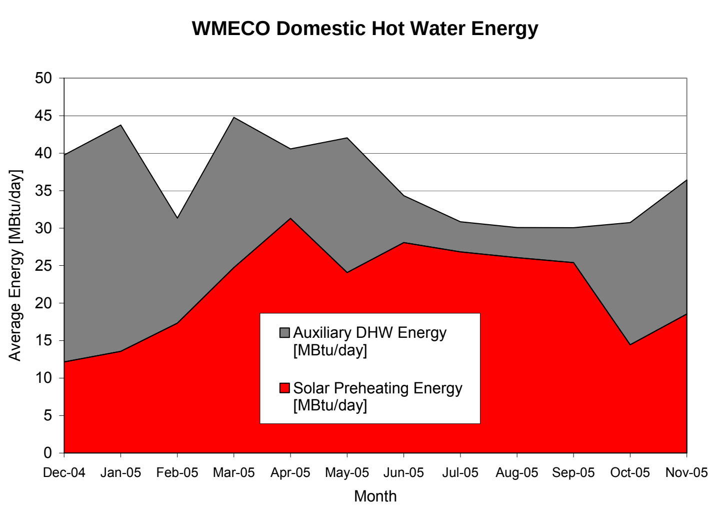
East Coast

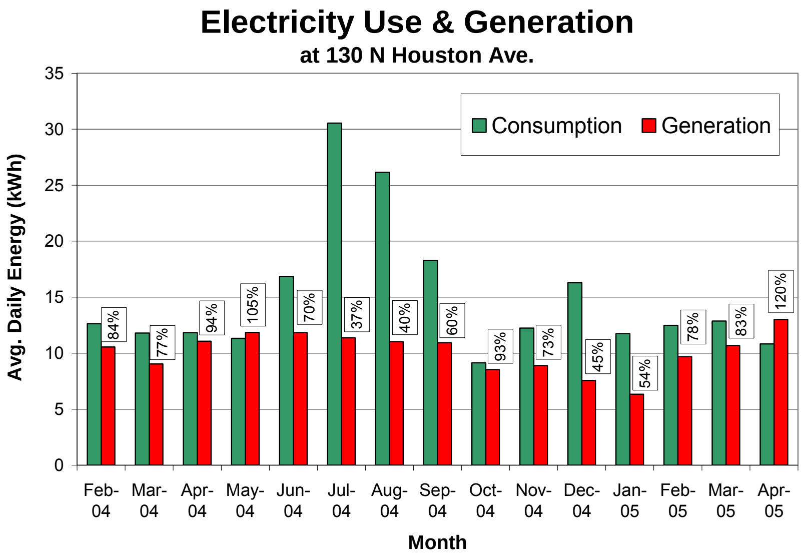
In Atlantic City, New Jersey, the Casino Reinvestment Development Authority (CRDA) built six modular homes that featured passive and active solar systems along with efficient envelopes. CARB partnered with CRDA to monitor the energy performance of an occupied home, and over the course of 1 year the solar electric system generated 67% of the electrical energy used in the home.

Like SMUD, Western Massachusetts Electric Company (WMECO) is a utility interested in combining efficiency and renewable energy generation to approach "zero energy" use in homes over the course of a year. As part of a utility research program, CARB assisted in the testing of a prototype house in Hadley, Massachusetts. Over the course of an entire year, the 2.6-kW PV system on this home generated an average of 7.3 kWh each day and provided 76% of the home's electrical consumption.

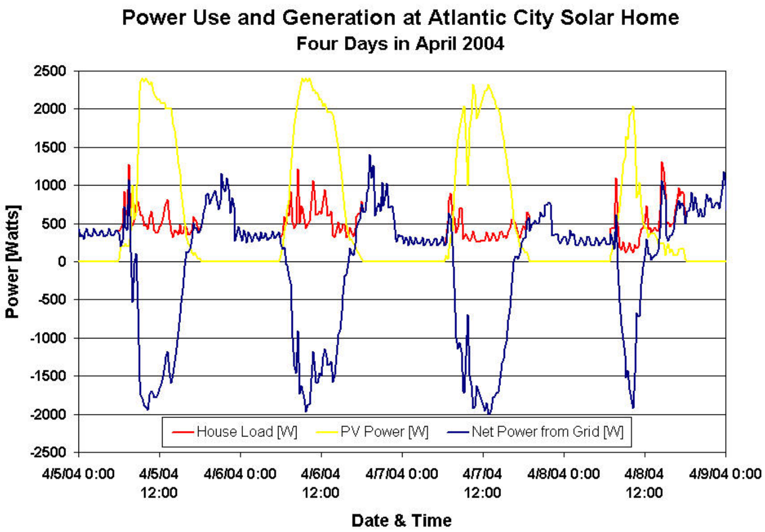
The solar thermal hot-water system met 62% of the home's domestic hot-water energy needs. WMECO hopes to build on this concept and explore a pilot incentive program to promote the cost-effective combination of energy efficiency and renewable energy.

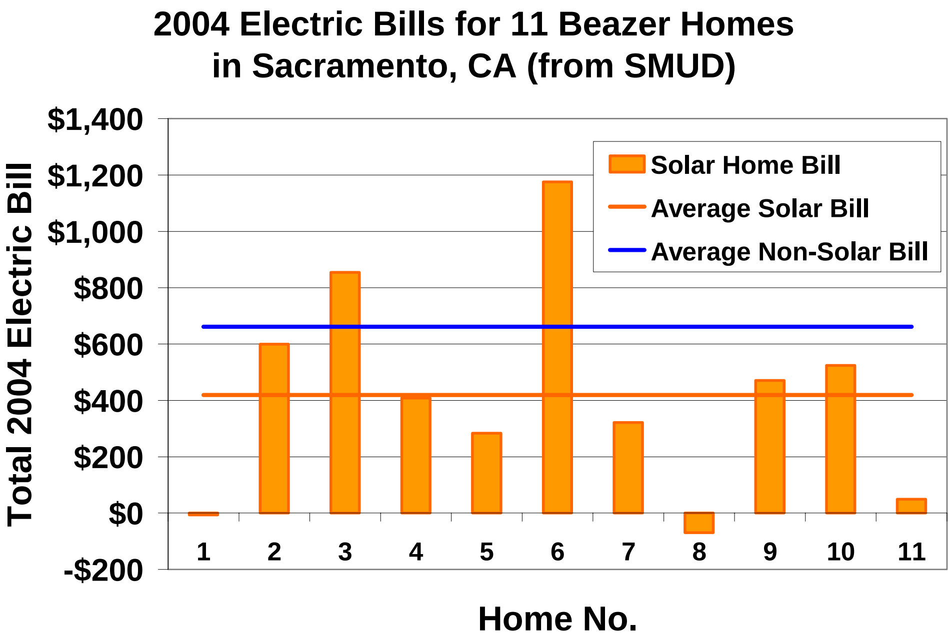

Average Daily Electricity
Average Daily Energy [kWh]
Month
Consumption
Generation
J-04
J-04
A-04
S-04
O-04
N-04
D-04
J-05
F-05
M-05
A-05
M-05
J-05
J-05
A-05
S-05
O-05
N-05


WMECO Domestic Hot Water Energy
Average Energy [MBtu/day]
Auxiliary DHW Energy [MBtu/day]
Solar Preheating Energy [MBtu/day]
Dec-04
Jan-05
Feb-05
Mar-05
Apr-05
May-05
Jun-05
Jul-05
Aug-05
Sep-05
Oct-05
Nov-05
Month



CRDA (Atlantic City, New Jersey)





Piazza de sol

Builder/Partners

WMECO (West Springfield, Massachusetts)

SMUD (Sacramento, California)

Beazer Homes (Sacramento, California)

CRDA (Atlantic City, New Jersey)

Resources

swinter.com/WMECO/ZeroEnergy.html

carb-swa.com/PDF%20files/CNSeptember04.pdf

carb-swa.com/PDF%20files/CNMarch05.pdf

carb-swa.com/PDF%20files/CNJuly05.pdf

Pulte Low-Energy Home

Lesson Learned

To test the marketability of a high-performance home, there must be equivalence in non-energy features. In this case, the low-energy home carried the following unique marketing burdens:

- A three-car garage option, rather than the den (the den has proven to be highly preferred in this development)
- Property lines shared with five other homes (all other homes in the subdivision share property lines with two, three, or four homes, but none share as many as five)
- Location in development, such that headlights from cars entering the development shine directly into the front bedroom window.

Two nearly identical homes were constructed for side-by-side evaluation at the Pulte Homes La Terraza community in northwestern Tucson. One home, the reference house, was constructed according to BSC's minimum Building America metrics. The other—the low-energy home—had the following additional energy features: Polaris 94% efficient combo water /space heater; 15 SEER A/C unit and air-handler with a more efficient electronically commutated motor (ECM); ENERGY STAR refrigerator, dishwasher, clothes washer; and compact fluorescent interior lighting package.

These features totaled a builder-reported additional cost of approximately $7,600. Collectively, these features had a target performance of approximately 20% greater energy efficiency than the more conventional Building America house. Energy modeling predicted that the low-energy home would demonstrate about 44% energy savings in comparison to a conventional home, for an annual savings of about $759. Using Fannie Mae's net present value calculation, this would result in adding between $8,500 and $10,500 to the appraisal value of the home.

Builder

Pulte Home Corporation, La Terraza — Tucson, Arizona

Resource

11.A.4 Report: Higher Performance Building Systems

Pushing the Limits: ZEH Pilot Projects

The NAHB Research Center has been working with homebuilders in the United States on a number of near-Zero Energy Home (ZEH) or net ZEH projects. There are two major aspects to the concept of ZEH: (1) reducing the building energy consumption through energy efficiency measures and (2) utilizing renewable energy to offset the electrical energy supply by the utility company on an annual basis. To achieve annual net-zero energy consumption, the NAHB Research Center has adopted a strategy that focuses on maximizing the efficiency of all-electric homes subject to economic constraints, providing solar-thermal systems to offset hot-water and space-heating energy consumption, and incorporating PV systems to meet the remainder of the electric load.

As part of its research efforts, the NAHB Research Center has worked with John Wesley Miller Companies to develop near-ZEH projects in Tucson, Arizona. The renewable system of the first Tucson ZEH project is expected to supply over 90% of the home's total energy consumption. NAHB Research Center is also working with the Maryland Energy Administration and Bob Ward Companies to investigate the feasibility of the ZEH concept in Maryland, which is located in the mixed-humid climate zone. Implementing the net ZEH concept is particularly more challenging for this climate because of a more limited availability of solar energy in comparison with the hot-dry climate.

The NAHB Research Center's efforts in ZEH are not limited to new constructions. Helping to transform a dilapidated property in New Jersey into a historic bed and breakfast facility, classified as a ZEH, is an example. This project retrofitted state-of-the-art technologies, including PV panels, an active solar hot-water system, and a ground-coupled heat-pump system for space conditioning. The properly designed systems, along with the incentives offered by the state's clean Energy Program (NJCEP) for PV systems, have contributed to the economic viability of this project.

Based on the findings from the ZEH projects, the NAHB Research Center has developed websites to help builders and consumers to better understand the ZEH concept and to learn about methods for achieving the ZEH goals.

Lessons Learned

The economic feasibility of the ZEH concept depends in part on the climatic conditions and the availability of financial incentives for renewable technologies. Currently, net ZEH performance is achievable at a very high first cost in many areas. To promote ZEH, it is imperative to educate builders, homeowners, and the real state and appraisal industries about the concept and its significance to the overall value of the home.

Partners

John Wesley Miller Companies, Tucson Electric Power, Asdal Builders, Bob Ward Companies, Maryland Energy Administration

Resources

www.nahbrc.org/

www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=1979&DocumentID=4777

The Zero Energy Cottage

Lessons Learned

This project abounds in Lessons Learned:

- Systems integration and donation-driven demonstration project is nearly a contradiction in terms. Any zero-energy building by definition must be finely tuned, with each element of design and specification critical to overall performance.
- Current modeling tools can't handle all of the elements that are key to zero-energy buildings: passive design for heat gain and heat avoidance, natural ventilation, daylighting, and active solar (PV and solar water).
- Once a super-efficient envelope and HVAC system have been integrated with a low-energy design, the energy performance of the home is driven by hot-water consumption, appliances, and plug loads. In general, these loads are out of the builder/designer's hands and lie squarely in the homeowner's. Occupant behavior/awareness/tolerance can make or break the zero-energy building.
- Although the solar industry has done a great job of packaging individual components—panels, mounting racks, inverters, and battery systems—into solar energy systems, there are still areas for improvement. For example, there was no clear system or contractor responsibility for securing either PV or solar water rooftop panels to SIPS roof panels.
- There is a lot of tension between breaking new ground with new technology and delivering reliability and service life on projects that push the envelope. For example, heat-pump water heaters were considered for this project in this climate, but the lack of product selection and track record made it a tough choice.

BSC designed an ultra-efficient vacation or second home for the non-profit environmental organization, the Captain Planet Foundation. BSC also provided technical assistance in the outfitting of this home for two of its traveling venues—the Atlanta Home Show and the National Park Service Sustainability Fair.

BSC identified four key elements of the Zero Energy Cottage—performance of the envelope and HVAC equipment, solar power supply from photovoltaic and solar water panels, high efficiency appliances and lighting, and homeowner load management. One of the toughest challenges of any zero energy building is selecting and integrating loads from space heating, space cooling, dehumidification, and domestic hot water.

Along with building design, the optimal combination of equipment to meet these needs is heavily dependent on climate. This is particularly true in terms of passive solar design, design for natural ventilation and daylighting, and integrating hot water with either space heating or cooling. The Zero Energy Cottage for the Captain Planet Foundation represents the BSC vision and deployment for a mixed humid climate.

Builder

Certified Living, Inc.

Resource

www.buildingscience.com/buildingamerica/casestudies/zero_energy.pdf

System Research Results

Disaster-Resistant Construction

Energy Efficiency and Hurricane Resistance

Lessons Learned and Successes

Hurricane codes refer predominantly to structural concerns and wind-storm resistance, with little regard for water intrusion (typically the cause of most hurricane damage). Applying simple systems-level approaches to manage the most common avenues of wind-driven water entry, building envelopes can affordably be made to resist most wind-driven water damage.

Following the hurricanes that struck Florida in 2004, CARB surveyed damage to builder/partner homes in the affected areas. Water damage was found to be most common and improving the most susceptible components, roof vents, soffits, windows, in-swing doors, and stucco coatings, led to a substantially more resistant building, without negatively affecting energy efficiency or affordability.

Builder and superintendent training and guides for the correct implementation of the improvements are necessary to achieve the intended benefits.

CARB, in cooperation with the University of Florida Extension Service, is being used for course curriculum in Florida required continuing education programs for licensed builders.

The improvements to the Mercedes Homes have resulted in a slight cost increase, but also have resulted in higher market share for the builder.

Virtually no waste with the site-poured concrete walls (as opposed to CMU, which typically produces a great deal of waste).

As a result of the costly hurricane seasons of 2004 and 2005, homebuilders, homeowners, and insurance agencies are all searching for ways to increase the storm resilience of their communities. In evaluating the aftermath, researchers from University of Florida's Energy Extension Service (FEES) and CARB found that cast-in-place concrete homes performed exceptionally well in resisting wind-blown debris and hurricane-induced lateral loads. However, most damage to buildings throughout the region resulted from wind-driven *rain*, not excessive wind loads.

As part of its ongoing support to Building America's builder partners, CARB worked with Mercedes Homes to develop an energy-efficient hurricane-resistant home. With funding from the Federal Emergency Management Agency (FEMA), a Mercedes prototype was completed in early 2005 that combined a number of advanced building technologies with their solid wall system. These improvements offered homeowners three levels of hurricane protection: superior structural strength, greater resistance to wind-driven rain, and improved post-storm recovery.

The structural superiority of the new model comes primarily from the cast-in-place reinforced concrete wall system that evenly distributes point loads from wind-driven debris across the structure. This system withstands debris up to 200 mph! The roof is tied to the wall system by wet-set hurricane straps embedded every 2 ft in the concrete walls, and the reinforced cage is secured to the footings with steel.

Wind-driven rain can enter the home at vulnerable points in the building envelope, such as the doors, walls, and the roof. Recessed seats were designed in the foundation slab to prevent rain from being driven into the home under the exterior doors and walls. Out-swing entry doors replaced conventional in-swing entry doors to avoid water and debris damage and even changes in pressure that contribute to roof uplift and significant structural damage. Exterior walls are protected with elastomeric sealant and are finished with stucco topped with a high-performance acrylic coating to prevent the absorption of water during heavy rain storms. To provide extra protection in the case of lost or damaged shingles, a continuous peel-and-stick underlayment product is applied beneath the roofing material to create a secondary roof drainage plane.

A continuous drainage plane also covers roof trusses on gable ends to prevent sheeting water from entering the building assembly at the truss-to-wall transition. To prevent sheeting water from spilling down the fascia board and being driven by wind or surface tension into the soffit vent opening, a redesigned fascia extends 1 in. below the soffit to form a drip edge, directing water down and away. A new soffit board product with recessed openings limits water intrusion while encouraging greater air circulation (and faster drying) within the eave assembly.

Besides wind-driven loads and rain damage caused during a storm, a truly hurricane resistant home needs to address post-storm recovery issues. Mold can grow undetected within the home for long periods of time, compromising indoor air quality and causing significant long-term damage to the home. Water damage and mold growth become more severe when power outages prevent homeowners from drying out their homes quickly following a storm. Mercedes Homes plans to offer a generator-ready exterior electrical service panel that can be easily connected to a portable generator so that homeowners can use fans immediately after the storm. Another strategy for preventing post-storm mold damage is the use of non-organic building products. Because mold grows particularly quickly on paper, adhesives, and other organic matter, the prototype utilizes a new paperless drywall product that uses glass reinforcing mat facing over gypsum.

These hurricane-resistant improvements, along with energy-efficient measures, were featured on the nationally syndicated television show *Bob Vila's Home Again* in the fall of 2005. Mercedes Homes and CARB were part of a team that worked to build a new home for a couple from Punta Gorda, Florida, who had lost theirs during Hurricane Charley. The demonstration home incorporated the hurricane resistant package developed for the Mercedes prototype and included impact-resistant, low-E windows, properly sized, high-

efficiency HVAC equipment, an engineered duct system, foamed over buried ductwork, SEER 14 air conditioning, a tight envelope, a programmable thermostat, fluorescent lighting, and an ENERGY STAR appliance package.

Not only is this home hurricane resistant, the results from the energy-modeling analysis showed a 48% *total energy savings* of this prototype design over the Building America Benchmark reference home. The demonstration home also only needed about a third of the tonnage for space cooling compared to the reference home. Testing results showed a tight building envelope (ACH_{nat} = 0.18) and tight ductwork (leakage of 4% to the outside).

Mercedes has adopted the new specifications across the board in those divisions using the solid wall system, which represents more than 1,000 homes a year. Following Hurricane Wilma in 2005, of the 300+ homes constructed using the hurricane-resistant upgrades, less than 4% reported any water intrusion.

Builder/Partners

Mercedes Homes (Melbourne, Florida)

Resources (websites for references):

carb-swa.com/PDF%20files/CNMarch05.pdf

carb-swa.com/PDF%20files/CNJune05.pdf

www.carb-swa.com/PDF%20files/CNAugust05.pdf

www.bobvila.com/BVTV/Bob_Vila/Project-0101.html

Professional Builder, July 2005, “Building for Survival in Hurricane Country”

Professional Builder, October 2005, “Shelter from the Storm”

Innovative Shear Panels

Lesson Learned

Sometimes thinking "outside the box" actually means thinking "inside the box." The inset shear panel is yet another systems-engineering solution that furthers Building America performance targets, even when environmental conditions place additional structural constraints.

There are many areas of the country where wind shear forces necessitate structural sheathing on exterior walls and other areas where earthquake shear-resistance requirements essentially mandate costly, proprietary shear components. Often, these same shear requirements preclude two important Building America concepts—continuous rigid exterior insulating sheathing on exterior walls and advanced framing (24-in. OC spacing and single top plates) of exterior walls.

BSC was convinced that a low-cost shear panel could be developed that would accommodate continuous rigid insulating sheathing in place of structural sheathing and advanced framing. Working with the Civil Engineering Research Laboratory, various panel configurations were lab-tested under the most stringent, up-to-date, and realistic stress protocols. The result was an inset shear panel made up of readily available building materials that can be either site- or shop-manufactured and provide shear resistance for areas with seismic and high-wind shear requirements. Currently, BSC has filed for an ICBO Evaluation Service report, the first and most important step toward broad-based code approval.

Builders

Pulte (Tracy, California)

Morrison Homes (NAHB 2001 Builder Show home)

Health-E Enterprises (Fairburn Commons — Atlanta, Georgia)

Spruce Construction (Juneau, Alaska)

Resource

www.buildingscience.com/resources/walls/shear_panel_test_results.pdf

Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

System Research Results

High-Performance Hot-Water Systems

Domestic Water-Heating and Distribution Systems

Lesson Learned

Tankless Water Heaters

- Increase Energy Efficiency – Energy Savings of up to 30% over storage tank water heater
- Have a high life expectancy of up to 15-20 years, zero recovery time, and saves space
- Can be retrofitted in existing homes.

Tankless Water Heaters

Energy for residential water heating accounts for approximately 20% of overall energy use in homes in the United States. There is also a substantial loss of water while the user waits for the desired water temperature to be reached. There exits an enormous opportunity to save both energy and water by using efficient alternative water-heating and distribution systems.

This research investigates the available advanced technologies in the market, for hot-water heating and distribution—focusing on their usage, installation, energy and water savings and benefits, overall effectiveness, and associated costs.

Tankless Water Heaters

Three fully modulating, gas tankless domestic hot-water heaters currently existing in the market—Noritz, Rinnai and Takagi—were evaluated. The existing tankless water heaters in the market were found to have significant energy and cost benefits over the regular storage tank water heaters. For example, Rinnai tankless water heaters have a high energy efficiency of up to 90% and show energy-cost savings of 35.5% for a natural-gas tankless water heater compared to a natural-gas storage tank water heater.

In addition, the tankless water heaters have a higher life expectancy (15 to 20 years vs. 9 years for storage tank water heaters), zero recovery time, save space, are hygienic, and are a cleaner option compared to a storage-tank water heater.

On-demand Water Recirculation Distribution Systems

The research focused on the Metlund on-demand water recirculation system available in the market. On-demand recirculation systems, with and without a dedicated return line, were studied for energy and cost benefits.

The Metlund system saves up to 1,689 kWh electricity, 78 therms of natural gas, and 7,300 gallons of water saved according to the manufacturers. In addition, the on-demand water system reduced the wait time, extended the life of the water heater, and reduced sewage pollution.

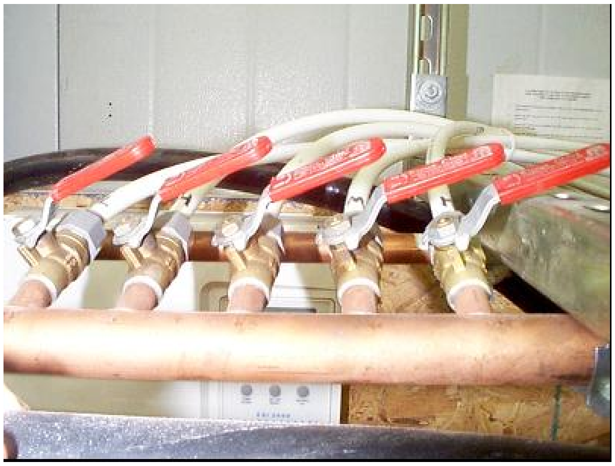
Rinnai tankless water heater

Hot-Water Distribution Systems

NAHB Research Center has completed a two-phase research on domestic hot-water (DHW) systems. A TRNSYS simulation constitutes the first phase followed by an experimental verification, which is the second phase. The research, sponsored by NREL, was undertaken to evaluate the energy performance of two different types of electric water heaters, tank-type and tankless (demand), for two hot-water distribution scenarios: copper piping in a tree configuration and cross-linked polyethylene (PEX) piping in a parallel configuration. The performance of an electric DHW system incorporating multiple demand heaters distributed at the outlets was also evaluated. In the analyses, high- and low-water-usage patterns were considered for each system arrangement.

The research results reflected an annual electrical energy savings of about 14% for the demand-type DHW system with a parallel-piping distribution over the tank-type system incorporating a tree distribution for the high-usage pattern. The energy savings was estimated to be about 34% for the low-usage pattern. Regardless of the heater type, the parallel-piping configuration resulted in 6% and 13% energy savings for the high- and low-usage patterns, respectively. When multiple demand (tankless) heaters are distributed at the outlets, minimizing the piping losses, the annual energy consumption can be reduced by approximately 28% and 50% for the high- and low-usage patterns, respectively.

Any improvement to the energy performance of a DHW system can also result in a reduction in water use, especially when the response time for hot-water delivery at the outlets is minimized via a well-designed distribution system.



Lessons Learned

DHW systems incorporating a demand water heater and a parallel distribution configuration offer a potential for significant energy savings, especially for homes with low hot-water use. Systems with distributed tankless heaters offer even higher energy savings. Reduction in water use is generally expected to accompany such energy savings.

Designing an optimum DHW system for a home requires close attention to the plan for the plumbing outlets as well as to the usage pattern. When feasible, development of architectural plans should be influenced in part by the lessons learned for efficient DHW distribution systems.

Partners

For completed activities: N/A

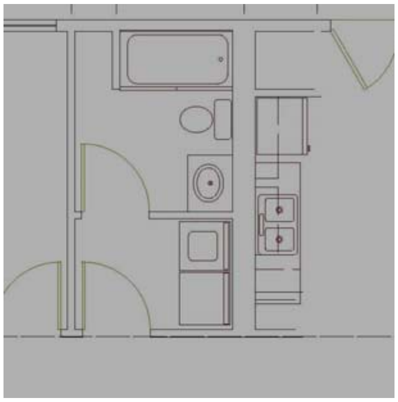
For current activities: Plastic Pipe Institute and HUD's Partnership for Advancing Technology in Housing (PATH)

Resources

www.nahbrc.org/

Hot-Water Recirculation Systems and Their Impact on Energy Efficiency

Builders are increasingly interested in reducing hot-water wait times for their customers. One of the approaches they have shown interest in using is a system that continuously circulates hot water through the entire piping system, by using a high-performance water pump and an aquastat to monitor hot-water temperature. This is usually the least expensive method for reducing hot-water wait times.



Floor plan with major hot-water uses in close proximity: bath, laundry and kitchen

Lessons Learned

The continuous circulation of hot water can result in significant water heat loss, possible performance problems, and wastage of electrical energy because of the continuous operation of the pump. One performance problem we observed in this system was water temperature fluctuations during a shower. The aquastat for the system was not installed on the correct pipe location and was not reading a water temperature that included recirculated hot water and incoming cold water thereby fooling the system into believing there was a constant supply of hot water. This problem could have been avoided if manufacturer's installation instructions for the aquastat were completely followed.

This lesson highlighted that an on-demand hot-water circulation system is a better overall option since it is a less complicated approach and operates only when needed. This system shortens the wait for hot water because the circulating pump moves hot water quickly to the location it is demanded when the homeowner presses a remote switch. This system does not save energy directly in the home, but it does save water.

Another strategy for reducing hot-water wait times is to design "mechanical cores" where the water heater is located in close proximity to the hot-water use area (kitchen, bath, laundry, etc.) This is an issue that must be integrated at the schematic design phase. With the growing availability of higher efficiency tankless water heaters, remote baths like master suites can be serviced by a separate unit, and units can be located in closets without sacrificing a significant amount of space.

Builders

Kacin Construction – Pittsburgh, Pennsylvania

Montgomery and Rust – Pittsburgh, Pennsylvania

Green Street Properties – Atlanta, Georgia

Resource

www.ibacos.com/pubs/Factsheets/Integrated%20Systems%20Design.pdf

www.ibacos.com/pubs/SavWater&EnergyinResHWDistr.pdf

www.ibacos.com/pubs/HotWaterRecirCaseStudiesWR.pdf

www.ibacos.com/pubs/HWDistSystemsBW.pdf

Strategic design can minimize hot-water piping runs and, with the water heater in close proximity, can eliminate the need for hot-water recirculation systems. This wall services bath, laundry, and kitchen sink.

Solar Water-Heating Systems

Solar hot-water systems are one of the domestic water-heating approaches that are expected to be required to achieve cost-effective energy savings greater than 50% in most climates. Hence, in FY2005, NREL developed a solar domestic hot-water (SDHW) sizing tool to help support successful integration of solar hot-water systems in Building America research projects. The user-friendly TRNSED tool, built on the TRNSYS energy-simulation program, provides performance evaluations based on climate, system type, building hot-water loads, and use of SRCC-certified packaged solar hot-water systems. The simple tool assists users with solar collector and storage tank sizing, selection of system type, and integration with back-up systems.

NREL developed an annotated bibliography of SDHW system information for distribution to the research teams in the Building America Program. The bibliography provides links or other access to SDHW information that is deemed potentially useful to team engineers, architects, and builders considering offering SDHW systems on their buildings. NREL also provides updates on solar hot-water technology developments, including distributing reports on solar hot-water system analysis and providing Building America teams with expert information about best practices in solar hot water. Recent reports have highlighted issues with sensor placement and controls.

In FY06, NREL is coordinating field testing of innovative, low-cost, solar water heaters for mild climates that have been developed by Davis Energy Group and SunEarth, Inc.—a U.S. solar collector manufacturer—under funding from the DOE Solar Heating and Lighting research program. The low-cost system, made of polymer materials and copper heat-exchanger piping, has gone through three stages of product development over the past 6 years and is now ready for wider field trials.

Partners

Thermal Energy System Specialists

SunEarth, Inc., and Davis Energy Group

Resources

ftp.nrel.gov/pub/solar_waterheat-out/

www.solar-rating.org/

Lessons Learned

Solar water-system certification is the one means through which builders are assured that the product meets minimum standards for safety, durability/reliability, and performance. In the United States, both the Solar Rating and Certification Corporation (SRCC) and the Florida Solar Energy Center (FSEC) certify and rate solar water-heating systems and equipment. Standards for combined water and space-heating systems will be needed in the near future as more aggressive savings levels naturally lead to use of solar combined domestic water and space-heating systems.

To keep up with the increasing energy-savings requirements of the Building America program, higher energy-savings levels for water-heating systems have to be realized. Certified solar water-heating systems, when installed properly, are capable of meeting or exceeding these energy-savings levels in most climates. However, the current cost of solar water heating discourages some homebuilders. Lower-cost systems—with similar levels of energy performance—are necessary for increased penetration into the residential construction market in the United States.

Tankless Gas Water-Heater Performance

Lessons Learned

Tests were completed by Davis Energy Group-CARB to compare efficiency of a storage type gas water heater (0.60 EF) and a tankless water heater (0.82 EF). The test site was an existing home occupied by two people. The existing storage water heater was monitored for about two weeks to measure hot water supplied and gas consumed. The existing water heater was replaced by a tankless water heater and again monitored.

Results showed that tankless water heater efficiency correlates with daily usage (gallons per day), but correlates better with the individual draw volume (gallons per draw). After a hot water draw the heat exchanger and the small volume of water it contains will gradually cool down. If there is a long enough delay before the next draw, the heat contained in the heat exchanger will not be conserved. The same amount of energy will be lost after small draws as large draws, thus the larger the draw the greater the efficiency. Above a volume of about 10 gallons per draw the efficiency approaches the rated energy factor.

Because of the disparate behavior of the two water heater types, energy savings are not linear with hot water use. The greatest energy savings occurs at a daily use quantity of about 50 gallons.

These results are useful for estimating energy savings resulting from replacement of storage type with tankless water heaters, and can provide a basis for the development of a separate federal test standard for tankless water heaters.

Tankless gas water heaters are receiving considerable attention for their significant efficiency benefits over storage type water heaters and are increasingly applied by Building America builders as a way of meeting performance goals. The energy factor for a typical tankless water heater of 0.8 suggests a 33% reduction in gas use relative to a typical 0.6 energy factor storage water heater. Recent improvements in tankless water heater technology allow them to deliver large quantities of hot water under changing load conditions and at a relatively constant temperature, in other words, to mimic the behavior of large storage water heaters, but without suffering the standby loss (pilot light and tank heat loss) of the former.

Federal test procedures for developing gas water heater energy factors for tankless water heaters are the same as those applied to storage type heaters. The direct relationship between use quantity and efficiency of tankless water heaters has long been recognized, and is implicit in the California Title 24 standards. The question asked by Building America researchers is, does tankless water efficiency also vary with hot water use?

or

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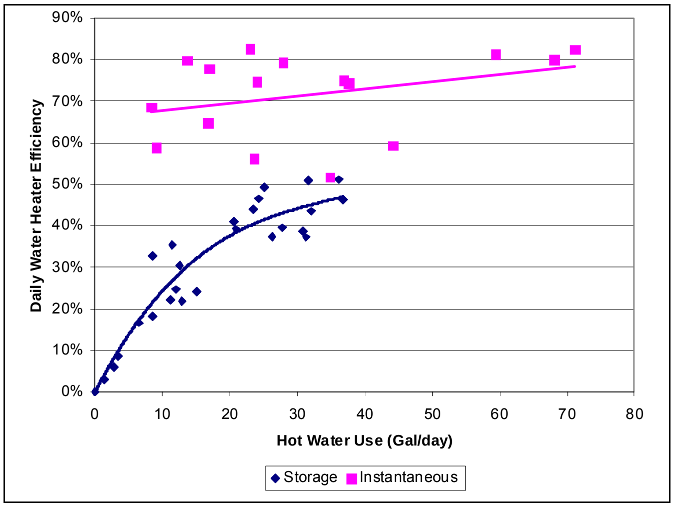
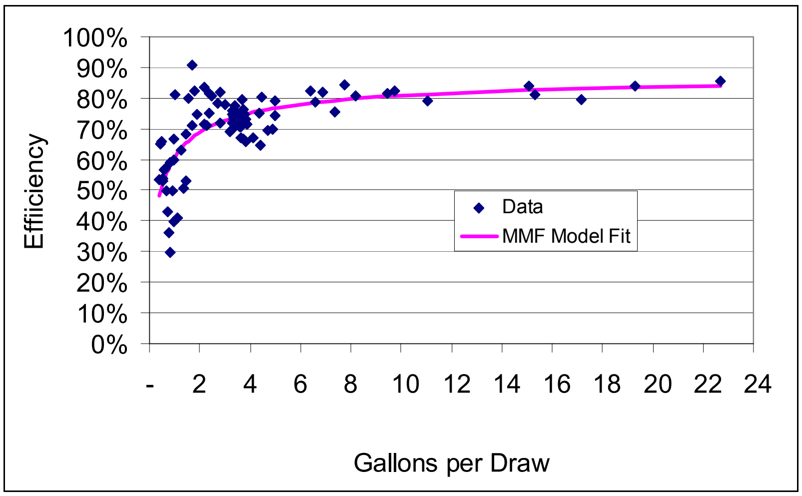
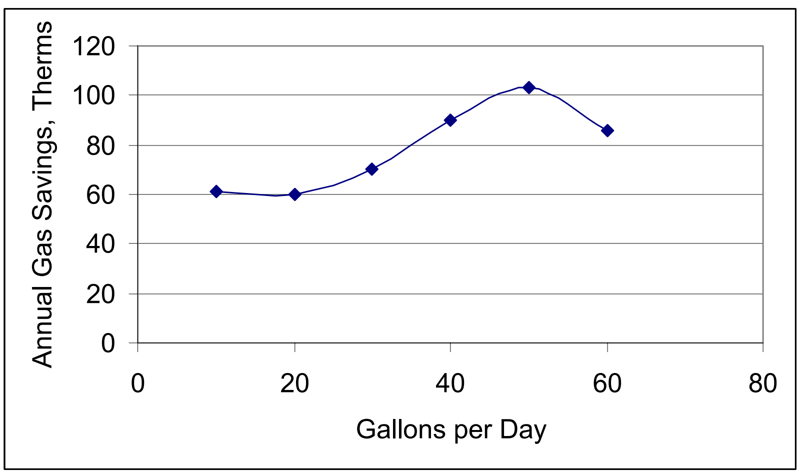


Measured Performance of Storage and Tankless Gas Water Heaters as a Function of Daily Hot Water Use

Performance of a Tankless Gas Water Heater as a Function of Draw Volume





Approximate Annual Energy Savings as a Function of Daily Hot Water Use

Resources

Tankless Option Improving. Home Energy Magazine, July/August 2005.

www.eere.energy.gov/consumer/your_home/water_heating/index.cfm/mytopic=12820

Tankless Hot-Water Integration

The Building America domestic hot-water (DHW) research focuses on developing strategies for hot-water production, distribution, and heat recovery that reduce energy and water consumption without compromising the availability of hot water to the occupants. The importance of this research is particularly realized for high-performance homes where the residential hot-water energy use accounts for a higher percentage of the total residential energy consumption compared to the standard-practice homes.

As part of the ongoing research activities, field studies were performed on various solar-assisted tank-type DHW systems in an Arizona community. A number of these systems provided space heating as well. These studies were designed to investigate the impacts of the water-heater type (electric vs. gas-fired), hot-water recirculation (with and without on-demand control), and pipe lengths on the overall system performance.

Lessons Learned

To keep the pace with the increasing requirements of the Building America program, higher energy savings levels for DHW systems have to be realized. However, this will not be feasible without implementing non-conventional energy saving measures, such as heat recovery from waste water, heat-pump water heating, integration of DHW systems with space-heating and cooling systems, and renewable strategies. For some of these concepts, the product cost appears to be a major market barrier, leading to a strategy of integrating them with the heating and cooling system to capture cost synergies.

To meet the Building America multi-year goals, it is imperative to explore other energy-saving measures for DHW systems. In doing so, IBACOS has worked with builders to integrate high-efficiency tankless water-heating technologies in current test houses and communities. IBACOS has also initiated studies to examine the potential of heat recovery from drain (grey) water using thermal storage and heat-pump technologies. Initial TRNSYS simulation results indicate electric energy savings of about 30% for hot-water systems can be achieved through passive heat recovery from grey water. Active heat-recovery systems incorporating heat-pump technology, as well as thermal storage are also available. Electric energy savings of about 60% to 72%, depending on the water-heater tank size and the inlet cold-water temperature, have been reported for DHW systems implementing active heat recovery from drain water. Further studies are needed to fully account for the impact of coincident and non-coincident hot-water uses. Also included in the research plan is evaluation of methods of integrating DHW systems with space-heating and cooling systems.

Partners

Builders

Amland Development,

Aspen Homes of Colorado

Civano, Geohring, and Morgan Construction

Montgomery & Rust, Inc.

Manufacturing

Florida Heat Pump

Steibel Eltron

Nyle Special Products

Noritz America Corporation

Rinnai

ECR International

Resources

www.eere.energy.gov/buildings/building_america/publications.html

Included in the guide are HPL principles, room-by-room lighting design approaches, and specifications of fixtures and lamps. The guide also provides additional resources on HPL. In addition to energy efficiency, the guide addresses other aspects of lighting systems, including lighting quality and architectural considerations. The HPL Guide is updated and enhanced as more information on efficient lighting systems becomes available through research in collaboration with DOE/NREL and other partners.

Partners

Builders: Aspen Homes of Colorado, Green Street Properties, Hedgewood Properties, Kacin General Contractors, and Montgomery & Rust, Inc.

Manufacturing: Lithonia, GE, Seagull, Progess, Alkco

Resources

www.ibacos.com/hpl1.html

Water-Distribution Systems

On-Demand Hot-Water Recirculation Systems

A hot-water recirculation system saves energy when activated by re-circulating the hot water through the water heater until the desired hot-water temperature is reached. It also saves on water, which is lost otherwise, while waiting for the hot water at set temperature to arrive in the fixture.

Two Main Types of Hot-water Re-circulating Systems

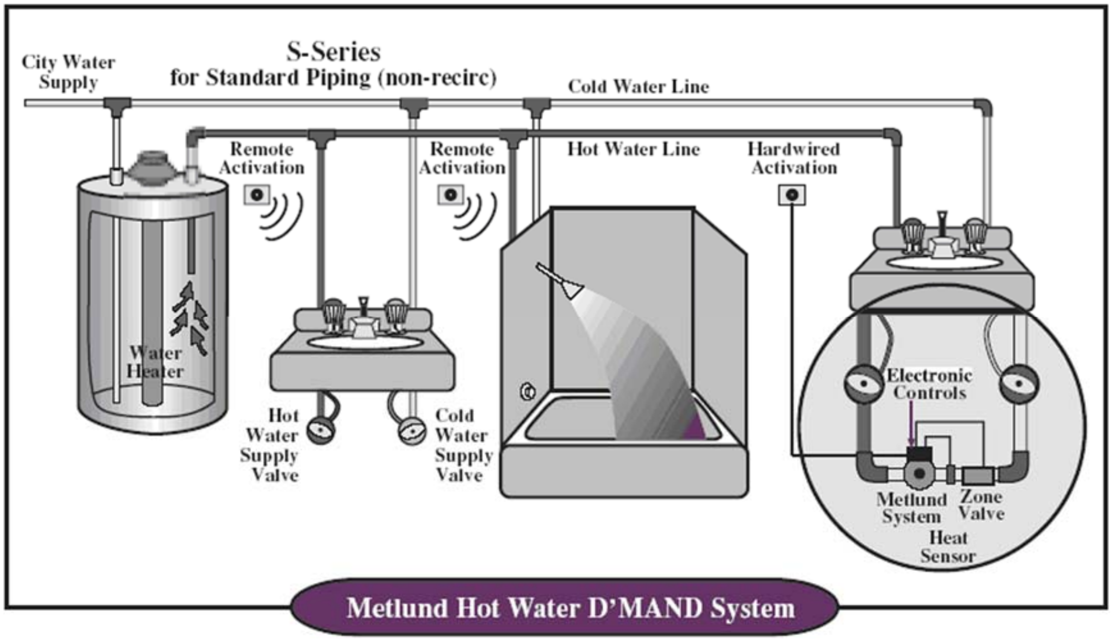
Re-circulating System without Dedicated Return Line

This is a cheaper alternative, suitable for retrofitting an existing house. The last hot-water fixture (all fixtures attached in series) is directly attached to the cold-water line through a sensor, valve, and a pump. This prevents the loss of hot water down the drain and it re-circulates the hot water pumping it into the cold-water line, until the hot water at the desired temperature reaches the last hot-water fixture (ascertained by the sensor). The valve is then shut down, and the pump stops re-circulating the hot water. This system saves water, but is not very energy efficient.

Lesson Learned

On-Demand Water Recirculation System

- Water savings of up to 7000 gallons in a year/household
- Energy savings (for on-demand recirculation system with proper controls)
- Proper layout—ensures reduced wait time and reduced energy and water losses
- Can be retrofitted in existing homes
- Must have on / off controls, like motion sensors, and not operate continuously



Re-circulating system without dedicated return line

Re-circulating System with Hot-water Dedicated Return Line

This is a more energy-efficient system that not only prevents the loss of water, but is also energy efficient. The last hot-water fixture is attached through a dedicated return line to the water heater, via a pump, sensor, and a valve. When the re-circulation system is activated, until hot water at the desired (set) temperature reaches the last hot-water fixture, the hot water (at lower temperature compared to the set temperature) is re-circulated to the water heater. This system saves energy because the water heater has to heat the incoming water through a smaller temperature difference (Δ t = set temp – incoming temperature).

Metlund D'Mand system, a subsidiary of the Advanced Conservation Technologies, has developed an efficient plumbing system using the dedicated return line—called Structured Plumbing. According to the Advanced Conservation technologies, in Structured Plumbing, the Hot Water D'MAND System is installed with a positive closing valve at the last fixture, stopping the hot-water flow and not allowing hot water to be lost in the return line to the water heater. The hot-water line goes in series from the water heater, fixture to fixture, until the furthest fixture is reached. The distance from this main line to each fixture is, ideally, kept to less than 5 ft (Larry Acker, CEO, Advanced Conservation Technologies, Metlund D-Mand System, gothotwater.com/D"MAND/structured.asp).

Controls are critical to energy efficiency

Any recirculation system will waste an enormous amount of energy if they operate all the time or when significantly longer than when hot water is actually needed. On/off switches can be used, but can be forgotten in the on position. An on-switch with timers or motion sensors with timers set for reasonable use times can also be used.

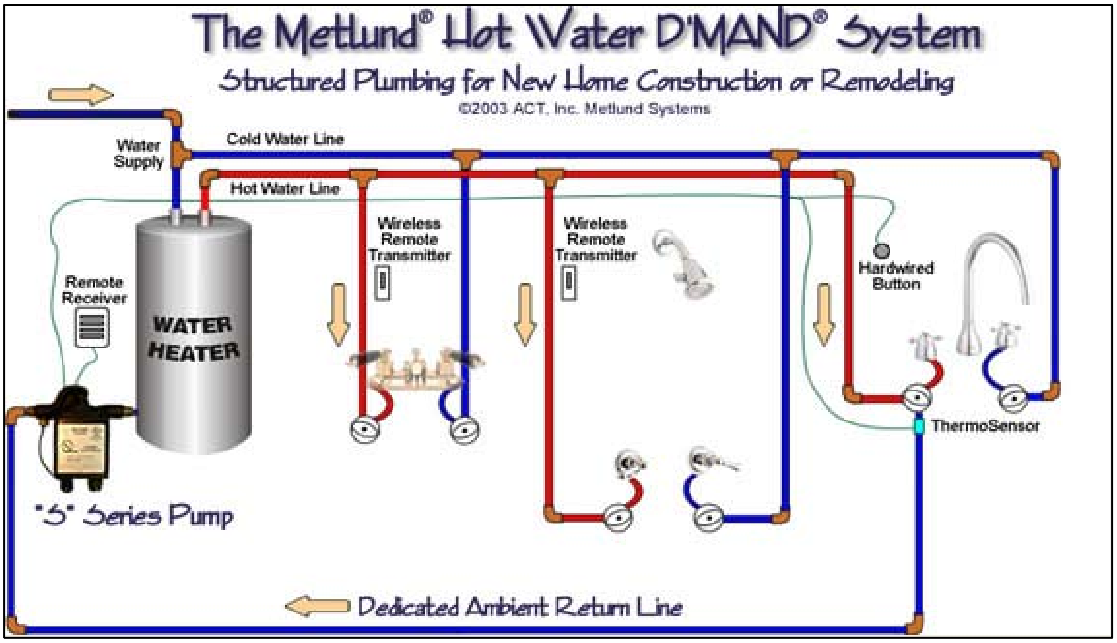
Tankless Water Heater and On-Demand Recirculation Systems

Real-world Usage

Home builder-developers working with Consol/BIRA have been successfully using both the tankless water heater, as well as the on-demand recirculation system to meet the Building America and Zero Energy Homes goals. For example, 257 homes in Vista Montana (Watsonville, California) and 95 homes in Premier Gardens (Rancho Cordova, California) use tankless water heater. The Ultimate Family Home in Nevada Trails (Las Vegas) has two Rinnai tankless water heaters in conjunction with a S-02 D'Mand recirculation system.

Further research

The next stage of the research deals with developing guidelines for home builders for an alternative advanced hot-water heating and distribution systems. This is aimed at educating the home builders about the various alternatives available and allowing them to make informed decisions when choosing and installing these advanced alternate hot-water heating and distribution systems in homes.



Structured plumbing with dedicated return line

Building America
U.S. Department of Energy
Research Toward Zero Energy Homes

System Research Results

Affordable Housing

Affordable Approaches to Existing Building Rehabilitation

In 2003, as part of the Existing Residential Buildings Program (ERBP), CARB partnered with Habitat for Humanity of Greater Newburgh (HfHGN) to develop innovative, yet affordable, system-engineering research strategies for retrofit housing. One goal of this partnership was to increase an existing house's overall product value and quality while significantly reducing its use of energy and finite resources. It was also of great importance to maintain low first costs and reduce operating costs in order to make the houses truly "affordable" for low-income homeowners.

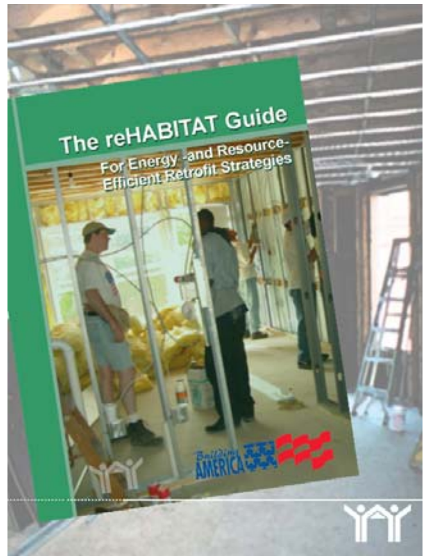
Lessons Learned

- In affordable housing projects, it is very important to help the developer or builder understand the long-term benefits of making homes truly affordable for low-income families and the impact on first costs.
- To achieve the energy goals, climate-specific research is needed to identify the most cost-effective energy-efficiency measures.
- Simple and inexpensive measures, like air sealing, better windows and insulation, can result in large energy savings.
- There is a steep learning curve before a technique truly becomes replicable.
- There is no substitute for a site visit. Not only can you better convey the information, it gives you a clearer understanding of how the project is being run and how well the recommendations are being implemented.
- Educating the builder and/or developer about the increased project scope and holding a pre-bid conference to outline the new expectation proved to be a valuable exercise. Understanding the areas where extra effort is needed is critical to a successful project.
- The housing quality and, in turn, energy efficiency can only be impacted in a true gut rehab scenario. Builders and homeowners must be informed that a completely aesthetic rehab offers very little opportunity to improve quality, durability, or energy-efficiency.

CARB suggested new technologies and advanced engineering techniques and provided hands-on training of these retrofit strategies. CARB consequently published ***The reHabitat Guide***, a set of rehab guidelines that would help construction managers incorporate energy-efficient strategies cost-effectively in future affordable housing retrofit projects. CARB also conducted a full-scale performance evaluation for the houses developed under the retrofit program.

In May 2004, Habitat for Humanity, with the assistance of CARB, completed the rehabilitation of a two-story, semi-attached home in Newburgh, New York. This unit was completely gutted and now includes advanced framing (which reduces the amount of framing lumber required), low-voc paint, and mechanical ventilation (which both result in better indoor air quality), advanced air-sealing techniques (keeping those air ducts from leaking), compact fluorescent lighting, ENERGY STAR appliances, an energy-efficient combination boiler and hot-water heater, low-e windows, R-15 walls, and an R-40 roof. Taking advantage of national partnerships helped lower first costs: Whirlpool donated an ENERGY STAR refrigerator, Dow Chemical Company donated the rigid insulation, and the bathroom exhaust fans from Panasonic were obtained at a discount price through Energy Federation, Inc. The resource-efficient rehab resulted in a home with a HERS score of 89.7, which qualified the home for the New York ENERGY STAR homes program.

Original Rear Elevation of 85 Nicoll St



Habitat for Humanity Rehab in Newburgh, New York

Builder/Partners

Habitat for Humanity of Greater Newburgh, HfHGN (Newburgh, New York)

Resources

www.eere.energy.gov/buildings/building_america/pdfs/36057.pdf

carb-swa.com/PDF%20files/CNNovember04.pdf

Affordable Housing with Habitat for Humanity

Building America partners with Habitat for Humanity International (HFHI) to improve affordability, durability, and energy efficiency of the homes built by HFHI's 1600+ domestic affiliates. The BAIHP team has partnered with Habitat since 1995 when HFHI kicked off its Environmental Initiative providing technical assistance in the design, specification, and construction of 420 ENERGY STAR Habitat homes and 260 near-ENERGY STAR homes.

The partnership has generated a rich body of collective experience from "blitz" builds, as well as a cohesive set of Web-based and hardcopy documents that give HFH affiliates practical guidance on energy efficiency, indoor air quality, combustion safety, moisture mitigation, and "green" building. In 2003, Habitat International adopted ENERGY STAR certification as one of only two "Construction Best Practices," an indicator of commitment from the highest levels of Habitat International.

Building America researchers also provide training to Habitat volunteers and construction staff at Habitat conferences and fast-paced "blitz" builds including the 1997, 1998, 2000, 2003, and 2005 Jimmy Carter Work Projects.

BAIHP energy efficiency recommendations for Habitat homes need to meet four criteria to be successfully integrated into Habitat's construction process. They must be

- cost effective and proven
- volunteer friendly
- readily available in current market
- easily maintained and repaired.

Habitat volunteers at the 2003 Jimmy Carter Work Project in LaGrange, Georgia

Lessons Learned

Many of Habitat's passionate volunteers want to build the best houses possible. However, the affiliate must balance enthusiasm with fiscal responsibility. It is essential to engage all of the decision makers in the systems-engineering process to develop sustainable solutions.

We have observed that when the Building America systems-engineering goals support the builder partner's basic mission and business model, any identified improvement needs become imperative to the builder because it supports their organizational mission. Conversely, when the builder's mission and philosophy are either loosely defined or counter to the Building America goals, no amount of thinking, talking, or training will transform their product into Building America homes.

Builders

50 Habitat for Humanity Affiliates in Alabama, California, Connecticut, Delaware, Florida, Tennessee, Georgia, Louisiana, Michigan, New Mexico, New York, North Carolina, Ohio, Oklahoma, Oregon, Pennsylvania, Texas, Virginia, Washington, Washington D.C., and West Virginia

Resources

Examples of ENERGY STAR packages for typical Habitat construction: www.fsec.ucf.edu/bldg/baihp/casestud/HfH_EStar/index.htm

Support of Habitat for Humanity International's Congress Building America program www.fsec.ucf.edu/bldg/baihp/casestud/hfh_partner/index.htm

Building America Improving Attached Affordable Housing in New York City

Lessons Learned

- Panelized construction leads to faster construction and very air-tight buildings
- Tight homes and efficient systems lead to increased comfort and much lower utility bills, making them truly affordable
- Improved performance leads to fewer call-backs and associated headaches

Housing Partnership to improve affordable housing in the South Bronx. The first result: Melrose Commons II, the first affordable three-family housing to receive the ENERGY STAR rating in New York State. CARB also created a design guidebook for developers on meeting and exceeding ENERGY STAR in affordable housing.

Working with Blue Sea and Danois Architects, CARB studied the designs for opportunities to introduce energy conservation technologies, materials, and techniques. The project scope was 30 three-family homes, with a ground-floor accessible apartment for the owner, and two apartments above. As the design and construction of these 90 units moved forward in 2001, CARB determined ways to make the units more energy and resource efficient. When the project began, concrete block and plank row-housing was the norm for the developer. However, in an effort to reduce infiltration rates, labor costs and construction time, a panelized concrete exterior wall system by Old Castle Precast was chosen to replace the traditional block-and-plank townhouse construction. CARB analyzed the pre-fabricated exterior wall panel for energy efficiency and discovered that the steel studs were permitting excessive heat loss through the wall. A more efficient assembly was developed, mitigating the thermal bridging problem.

To increase the efficiency, durability, and comfort of the homes, CARB also suggested higher insulation levels, better glazing than typical affordable housing, as well as sealed combustion boilers that also generate domestic hot water in a separate, insulated storage tank. Energy models indicated that heating usage at Melrose Commons II would be less than 5 Btu/ft^2/HDD. The units also featured ENERGY STAR lighting fixtures and appliances throughout, resulting in electricity usage well below the per-unit average in the Big Apple.

In the Fall of 2002, construction was completed on the 30-building Melrose Commons II development in the South Bronx. With the success of these homes, the developer committed to continue—and to improve upon—the efficient, affordable construction practices in his next three projects. Neighboring the Melrose II development in the Bronx, 40 Melrose Commons III homes have already been constructed; one even has a solar electric system on the roof. In Brooklyn, Blue Sea completed over 72 family buildings using the same Building America principles.

Typically, affordable housing in New York City is built with regard to first cost only resulting in maintenance and energy costs that can become burdensome to homebuyers. Melrose Commons II is the first ENERGY STAR affordable housing project in New York City. The homes were not only designed for low first-cost, but also for low maintenance and energy bills, resulting in units that are truly affordable.

Builder/Partners

Blue Sea Construction (New York City, New York)

OldCastle Precast (North Brookfield, Massachusetts)

Resources

www.carb-swa.com/PDF%20files/June2000.pdf

www.carb-swa.com/PDF%20files/October2000.pdf

www.carb-swa.com/PDF%20files/December2001.pdf

www.carb-swa.com/PDF%20files/May2002.pdf

www.carb-swa.com/PDF%20files/October2002.pdf

www.carb-swa.com/PDF%20files/CARBNewsFeb03.pdf

carb-swa.com/PDF%20files/CNOctober03.pdf

Habitat Congress Building America Case Studies

> **Lesson Learned**
>
> More information is not necessarily better. The quality of the information and the order/logic of its presentation are more important than the quantity of information. Clear and concise packages that allow easy user modifications of “non-critical” parameters proved popular.

Assembling all of the necessary information to construct a high-performance house in a useful manner is necessary in order to encourage the construction of such houses. A set of four case studies were developed that included complete architectural descriptions of each house from the foundations to the roof:

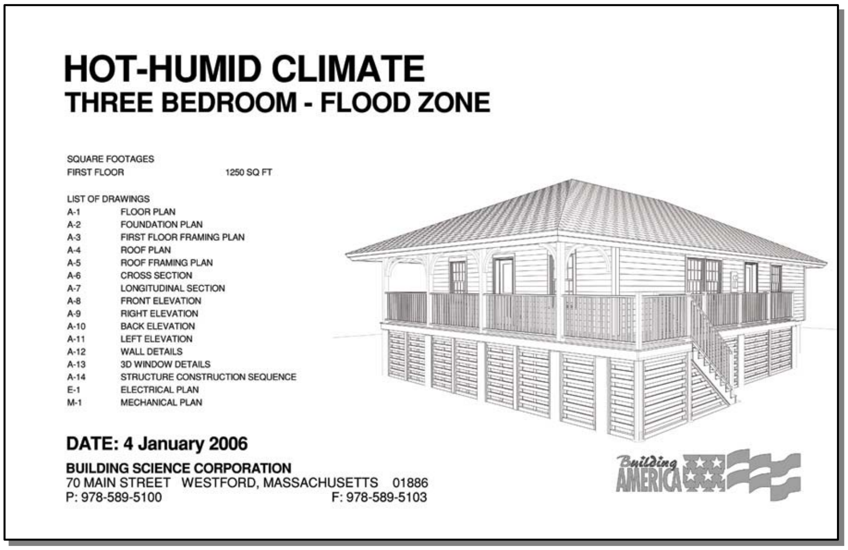
Hot-humid climate: **New Orleans, Louisiana**

Mixed-humid climate: **Haymount, Virginia**

Cold climate: **Pontiac, Michigan**

Very cold climate: **Juneau, Alaska**

The case studies included plans that described the house framing systems in detail, as well as electrical and mechanical drawings. Lighting, ventilation, space heating, and domestic water-heating system designs were provided that considered the building enclosure and climate locations. Trade-offs were made to get the best performance while keeping the systems affordable.



Implementing Systems Engineering in HUD-Code Manufactured Housing Factories

At the request of HUD-code home manufacturers, BAIHP researchers have conducted reviews and consulted on ways to make the home's systems work better together with six HUD-code home manufacturers. BAIHP consultation, recommendations, and training led to sweeping changes at four manufacturers' factories that resulted in more than 106,000 energy-improved homes built in the past 5-1/2 years. Changes included the following:

- Switching from tape to mastic duct sealing
- Improved duct cutting, mating, and strapping practices
- Testing of duct systems produced in the factory
- Addition of through-wall or jump duct return air pathways to private rooms.

BAIHP worked with manufacturers to test the duct systems (and other performance indicators) in 101 houses representing 190 individually manufactured "sections." The data was collected during 39 factory visits to 24 factories of six manufactures over a period of 6 years (1996- 2003), and it showed robust correlation between duct leakage to the outside in completed houses (which can only be measured after the house is fully assembled) and total duct leakage (which can be measured in each section while it is on the production line– see photo) as well as evidence that substantially air-tight duct construction with mastic could be cost-effectively achieved in the HUD-code home-manufacturing environment.

Based on this data, the National Fire Protection Association's (NFPA) approved a new standard on duct tightness, as well as a refined duct-testing protocol. Typically, standard NFPA-501 is incorporated into the HUD Code, which governs the construction of more than 250,000 HUD-code homes each year.

BAIHP work with HUD-code manufacturers also resulted in indoor air-quality studies facilitated with LBNL and in many factories becoming ENERGY STAR certified.

Lessons Learned

BAIHP has found that using building science and the systems-engineering approach to help Industry Partners solve difficult problems develops a strong working relationship and increases the likelihood of the Partner incorporating concepts central to achieving Building America goals, such as sealed and tested ducts, right-sizing air conditioning, and moisture management.

Duct testing rig at Palm Harbor Homes, Plant City factory, Florida

Factory Builders

Cavalier Homes

Clayton Homes

Fleetwood Homes

Palm Harbor Homes

Southern Energy Homes

Redman Homes (defunct)

Resources

Chasar, D., Moyer, N., McIlvaine, J., Beal, D., and Chandra, S. (2004). "Energy Star Manufactured Homes: The Plant Certification Process," Proceedings of ACEEE 2004 Summer Study, American Council for an Energy Efficient Economy, Washington, D.C., August 2004.

Hodgson, A.T., Apte, M.G., Shendell, D.G., Beal, D., and McIlvaine. J.E.R. 2002. Implementation of VOC source reduction practices in a manufactured house and in school classrooms. In Levin, H. (Ed.), Proceedings of the 9th International Conference on Indoor Air Quality and Climate. Indoor Air 2002, Santa Cruz, California, Vol. 3. pp. 576-581.

Hodgson, A.T., D. Beal, and J.E.R. McIlvaine. 2002. Sources of formaldehyde, other aldehydes, and terpenes in a new manufactured house. Indoor Air 12: 235-242.

Hodgson, A.T., A.F. Rudd, D. Beal, and S. Chandra. 2000. Volatile organic compound concentrations and emission rates in new manufactured and site-built houses. Indoor Air 10: 178-192.

McIlvaine, Janet, David Beal, Neil Moyer, Dave Chasar, and Subrato Chandra. 2004. Achieving Airtight Ducts in Manufactured Housing. Symposium on Improving Building Systems in Hot and Humid Climates, Richardson, Texas, May 17-19, 2004.Report No. FSEC-CR-1323-03.

Solving Moisture Problems in HUD-Code Manufactured Housing

Over a 5-year period, BAIHP researchers conducted diagnostic and systems evaluations in 98 moisture damage homes at the request of four home manufacturers. All of the homes were less than a year old and, thus, still under warranty. These homes were on the brink of failure from moisture intrusion that their service teams could not resolve. Typically, service crews would have eliminated normal moisture problem sources, such as plumbing and roof leaks and replaced materials at least once, sometimes twice before requesting technical assistance from BAIHP. This represented tens of thousands of dollars in labor and material with the potential of having to replace the whole house if the problem remained unsolved.

Using blower doors, duct testers, digital pressure gauges, infrared cameras, moisture meters, and a series of diagnostic tests, BAIHP researchers identify unintentional air-flow paths, pressure imbalances, and moisture sources that drive moisture problems unresponsive to standard service procedures. BAIHP makes for solving the underlying problems often related to duct leakage, inadequate return-air pathways, surfaces at extreme temperatures, and unexpected moisture sources. After BAIHP recommendations were implemented, manufacturers reported an overwhelming reduction in moisture problems achieved at a very low cost. BAIHP continues to work with manufacturers regarding crawlspace moisture sources.

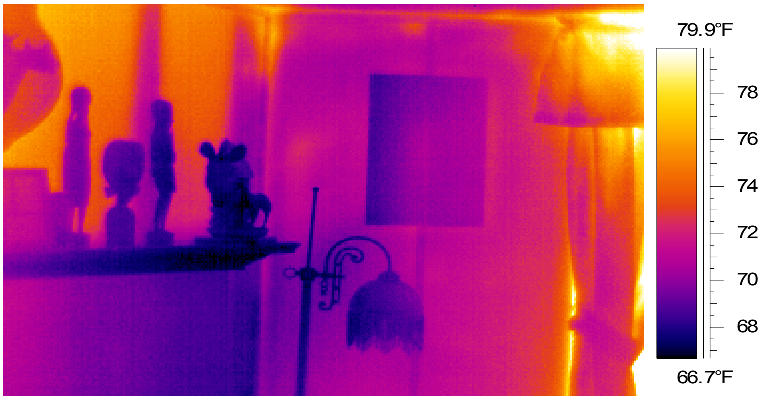
Once the service crews and managers saw and understood the building-science techniques, they were eager to learn and add them to their standard procedure, thus saving thousands of man hours and dollars in avoided cost. BAIHP conducted field and classroom training in teaching the underlying building-science principles as well as the practical skills.

Lessons Learned:

Building science can be used to cost effectively identify and solve moisture problems beyond the usual plumbing and roof leaks. And these techniques can be widely embraced by industry, in this case HUD Manufactured Home service managers and crews.

Building science skills can be integrated into standard service procedures if managers and crews are motivated by need.

Building science problem solving in existing housing can lead to change in design and production processes.



Infrared image of vinyl covered gypsum that is being cooled by the throw of air from the air-conditioning floor duct. Note the rectangle in the center of the image (a picture frame) is about 68EF. This image was taken in August around noon when the outside dewpoint was in the low 70EF range.

After the service teams were successful in using building science in existing houses, they communicated with factory managers the need to change the production processes to prevent recurrent moisture problems and associated service costs (*see Implementing Systems Engineering in HUD-Code Manufactured Housing Factories*).

Factory Builders

Cavalier Homes

Fleetwood Homes

Palm Harbor Homes

Southern Energy Homes

Resources

Moyer, N., Beal, D., Chasar, D., McIlvaine, J., Withers, C, & Chandra, S. 2001. "Moisture Problems in Manufactured Housing: Probable Causes and Cures." ASHRAE - IAQ 2001 Conference Proceedings, San Francisco, California

Subrato Chandra, Danny Parker, David Beal, David Chasar, Eric Martin, Janet McIlvaine, Neil Moyer. Alleviating Moisture Problems in Hot, Humid Climate Housing. Position Paper for NSF Housing Research Agenda Workshop, UCF Feb. 12-14, 2004.

Building AMERICA
U.S. Department of Energy
Research Toward Zero Energy Homes

System Research Results

High-Performance Lighting, Appliances, and Miscellaneous Electric Loads

The Impact of Miscellaneous Electrical Loads

Although its title might make one think it's an insignificant issue, miscellaneous electric loads (MELs) can, in an average household, make up 14% of electrical use. As implied by its title, miscellaneous electric loads includes all loads not categorized by heating, cooling, hot water, lighting, and major appliance (dishwasher, clothes washer, clothes dryer, refrigerator, and oven/range) use. Therefore, the energy used by any device plugged into an electric socket, such as computers, TVs, audio equipment, microwaves, curling irons, etc., is accounted for in this category. We suggest to our builders that they recommend to their customers that they purchase ENERGY STAR appliances wherever possible. Computers, TVs, DVDs, cordless phones and audio equipment are all devices that are available as ENERGY STAR products.

Growing saturation of miscellaneous electric loads, such as plasma-screen TV's and home-entertainment systems, are adding to the overall energy consumption in today's more energy-efficient homes.

Lessons Learned

In a pilot home, IBACOS worked on in the hot-dry climate, an examination of the utility bills of a 5,180-ft^2, custom, energy-efficient home revealed that the house consumed an average of 8,040 kWh per month over the summer—twice as much as initially estimated. After analyzing detailed monitored data and conducting an on-site audit, we concluded that the HVAC systems appeared to be operating properly and was in line with energy-consumption predictions generated by our energy modeling (37% of total electrical energy use). The site audit revealed that much of the excess energy usage was attributed to MELs and, in particular, luxury features in the design of the home, including two pool pumps, pool lighting, landscape lighting, and audio-visual equipment.

Monthly energy needs were reduced by approximately 1,800 kWh/mo by reducing the runtime of the pool pumps from 24 to 6 hours/day. Other large discretionary uses of energy, such as landscape lighting (125 kWh/mo), pool lighting (45 kWh/mo), and A/V equipment standby (482 kWh/mo) could also be reduced if desired by the homeowner. The balance of energy savings would be obtained by using interior lighting only when needed. The lesson learned here was that homeowner purchasing and operating decisions and architectural design decisions can greatly affect energy consumption, negating energy efficiency measures achieved by the builder through improved thermal enclosure elements, and high-efficiency space-conditioning and water-heating systems. It is critical that consumers be educated about efficient electric consumer products to assure maximum energy savings. This is challenging because it adds another layer of complexity to the builder's sales and homeowner education process. In addition, advanced control or occupant feedback strategies for managing MEL's will be needed to achieve higher levels of energy savings in high-performance houses.

Builders

Merlin Contracting – Las Vegas, Nevada

Goehring and Morgan Construction – Orlando, Florida

Hannigan Homes – Orlando, Florida

Resources

www.fsec.ucf.edu/bldg/baihp/presentations/miscelLoads/BAIHP_MiscelLoads_Jan2006.pdf

Implementing Energy-Efficient Lighting

High-performance lighting (HPL) is lighting of excellent quality that is also very energy efficient. It is principally based on the use of new and improved fluorescent lighting technology. We approached our builders with a strategy to get them to adopt HPL that centered on developing a complete lighting design for each room in the home. This approach includes incorporating as much hardwired fluorescent lighting as possible to minimize the amount of portable lighting used in the house, which is usually incandescent. This approach was favored over a bulb or fixture-replacement strategy because it would be a more permanent approach than just changing bulbs, and it ensured better lighting quality than a one-for-one fixture substitution approach.

The goal of the lighting design was to achieve the ambient lighting needed for each space and, in some rooms, incorporate fluorescent solutions for task lighting, or even accent lighting. We worked with the builder's electrician in developing the design to ensure that it was as feasible and cost effective as possible and with their carpenter to build architectural millwork if cove trim was necessary.

Builders

Kacin Construction – Pittsburgh, Pennsylvania

Mongomery and Rust – Pittsburgh, Pennsylvania

Green Street Properties – Atlanta, Georgia

Tindall Homes – Mansfield, New Jersey

Resources

www.ibacos.com/hpl1.html

www.ibacos.com/pubs/Factsheets/Advanced%20Lighting%20Design.pdf

Lessons Learned

We found that a complete lighting design, including a drawing layout and equipment specification, when first done on a specific house plan, requires significant design time and continuous feedback from the builder and their subcontractors before the final layout and specifications are produced. We learned that by developing standardized lighting designs (Builder Packages) based on previous design experience and prepared for specific rooms (such as kitchen, dining room, master bedroom), a HPL design could be more easily incorporated.

The standardized Builder Package offers the potential for substantial predictability and control of the energy efficiency of residential lighting, while making HPL implementation less onerous and more predictable for the builder from cost and time perspectives.

The main challenge with HPL at this point is the high price of compact fluorescent fixtures, most of which are commercial grade and not targeted to the residential market. It is anticipated with the changes in Title 24 in California, a greater range of residential fixtures will become available over time; however, it is unclear if price advantages will be able to be achieved by builders outside of the California market. IBACOS has also experienced significant resistance on the part of interior designers to consider HPL solutions, as their perception of fluorescent lighting is typically based on poor quality lamps and older technologies.

Architectural cove lighting utilizing low-cost T-8 strip fluorescent fixtures for high-quality, energy-efficient, ambient lighting in a bedroom.

Residential Lighting Controls

Lessons Learned

- Use quality fixtures for increased light quality and life span
- For good design, use the same number of fixtures, but with a lower wattage
- Use multiple lamps per ballast
- Use lighting controls with high-efficacy fixtures (CFLs)

Overview

Electric lighting is a significant contributor to overall residential energy usage and should be carefully considered when designing and building new energy-efficient homes. Various studies have found that lighting accounts for 10%-30% of residential energy usage. Moreover, lighting is very appealing for residential energy savings because of the abundance of opportunities it presents. Residential lighting offers a wealth of "low-hanging fruit" when looking for energy savings.

New homes primarily utilize inefficient incandescent light sources with little or no application of energy-saving control systems. This presents significant energy-saving opportunities that are only magnified when considering the technological advances that have been made recently in energy-efficient lighting.

Residential-grade fluorescent and compact fluorescent (CFL) technologies have steadily improved in quality over the past several years, while consumer prices for these technologies have dropped significantly. These energy-efficient light sources are now fairly well understood by homebuilders and are anticipated to continue to see market growth in new home applications. The focus of this paper is on a lesser known, though no less promising, opportunity that is now offered by residential lighting controls.

BIRA Partner

California Lighting Technology Center,
University of California, Davis

Residential Lighting Controls

Residential lighting controls represent an intriguing emerging opportunity for energy savings. Lighting controls generally refer to technologies that turn off (or turn down) lighting systems when they are not needed. Examples include occupancy sensors, photosensors, dimmers, and timers.

Lighting controls are commonplace in commercial applications, where they are widely recognized for their potential to provide cost-effective energy savings. But their application in the residential sector is much more limited. This is expected to change, as residential controls have the potential to become significant factors in energy savings for a variety of technological, market-based, and code-based reasons.

Technologically, residential controls have improved greatly over the lpst several years, both in terms of the types of control options available as well as their quality and functionality. As the cost of these systems is reduced by increased demand for commercial applications, they become increasingly attractive for cost-effective residential applications.

Recognizing these technological and market advances, as well as the potential energy savings of these technologies, energy-code officials have begun to look more closely at residential lighting controls. The new 2005 Title 24 California Building Code, which went into effect October 1, 2005, includes alternative options for homebuilders to utilize occupancy sensors, photosensors, and dimmers. In fact, many market watchers now anticipate that homebuilders will choose lighting control alternatives over energy-efficient luminaires to comply with this new code because the control approaches can be less expensive and may be as cost effective.

Residential Lighting Studies Overview

A number of state-, federal-, and utility-funded studies have been conducted over the past decade to characterize the lighting energy usage in the residential sector. These studies have been utilized to help identify end-use applications and energy-saving technologies that should be focused to promote energy efficiency in homes.

These studies have estimated lighting to account for 10%-30% of overall residential energy costs. Unfortunately this extremely wide range leaves much room for interpretation and has led to significant debate over how much lighting *really* contributes to the overall energy usage in homes. This range is partially, but perhaps not entirely, explainable by climate differences. While lighting usage is fairly constant, heating and cooling costs vary greatly in different climates. Lighting is generally found to be a smaller percentage of the overall energy usage in climates with large heating and cooling loads and a larger percentage of the overall energy usage in more moderate climates.

Many of these studies provide information about hours of operation in various residential applications and provide energy-saving estimates based on replacing incandescent lighting with fluorescent lighting. This is a fairly straightforward estimate, because the usage pattern is assumed constant as the load changes. Energy savings are calculated by taking the difference in load between the incandescent and equivalent fluorescent lighting system and multiplying by the hours of operation for that application.

While sufficient for load-change energy-saving estimates, this approach is not sufficient for consideration of lighting control systems, where typically the load remains constant while the usage pattern varies. To quantify the potential energy savings of residential lighting controls, we need new studies that focus on lighting usage patterns in residential applications.

It is also important to note that all of the major residential usage studies that have been conducted have focused on the residential market as a whole, rather than on new homes. It is difficult to utilize these studies to definitively identify issues and opportunities that are pertinent to homes currently being built when the data may be affected by the potentially obsolete technologies and out-of-style trends that might be found in older homes. To gain a clearer picture of the usage patterns in new homes, a study would need to contain a statistically significant number of new homes in its sample.

Technology Summary

Lighting controls have a great potential for cost-effective application in many residential settings. Occupancy sensor switches can be installed in place of standard wall switches to reduce lighting usage during unoccupied periods. Dimmers have the unique benefit of providing an added amenity to consumers in a manner in which energy savings is a positive by-product. Daylight sensors turn off luminaires that are unnecessarily left on during daylight hours. These technologies cost between $10 and $40 per electrical circuit and offer the potential for very attractive payback periods.

It is difficult to make generalized statements about the energy savings and paybacks for these technologies because the existing data in residential usage patterns is very limited and the savings will very greatly depending on the specifics of the applications. For example, an occupancy sensor may save 10 times as much energy and have 1/10th of the payback for a connected load of ten 65W downlights, than for a single 60-W luminaire.

System Research Results

Enabling Onsite Power Systems

Solar Electric and Energy Efficiency

Lessons Learned

Photovoltaics (PV) are cost effective with buy-down and state rebates.

Solar electric can drive the energy efficiency side – improves the marketability of energy efficiency

BIPV – building integrated photovoltaic products have increased the marketability of PV systems. BIPV are aesthetically pleasing – PVs are not limited to the back of the house – and can now be oriented (including front of the home) to maximize energy generation or peak demand reduction

Marketing and Media Success

Beginning with a Grand Opening in April 2004, Premier Gardens has been a marketing and sales success beyond Premier Homes expectations. The media coverage was local, national, and even international. The homes have sold, and the company had developed new business relationships positively influenced be rapid sales and notoriety of the project.

Energy Features and Paybacks

The combination of energy efficiency and the BIPV seem to be a winning combination. Research is being conducted to learn more from this project.

The energy features include

- higher levels of insulation in walls, R-38, and ceiling, R-17
- air sealing of the building shell and ducts and testing to ensure air tightness
- efficient dual-pane vinyl-frame windows with spectrally selective glass,
- 92% efficient furnace
- 14 SEER air conditioner with TXV valves
- tankless water heaters
- hot-water pipes insulated
- all fluorescent lights
- 2.4-kW DC PV system.

The total cost of these systems, after rebates for the PV system, are $11,314. Taking into account all of the energy savings of the above listed features, the payback is 15.7 years.

Building-integrated PV in Premier Gardens

At ground level, BIPV blend in well with roof tiles.

Total Costs for the System

	Monthly				
Gas Savings	**Electricity Savings**	**Total Savings**	**Yearly Savings**	**Cost of Features**	**Payback Period**
$9.17	$50.74	$59.91	$718.87	$11,314.30	15.7

Solar Orientation of Photovoltaic Panels

Lessons Learned

- South orientation of PVs maximize annual energy saved
- West orientation of PV maximizes summer afternoon performance and can be helpful to local utilities in reducing peak demands for electricity and can be most economical where utilities provide Time of Use (TOU) rates.

PVs with South, East, and West Orientation

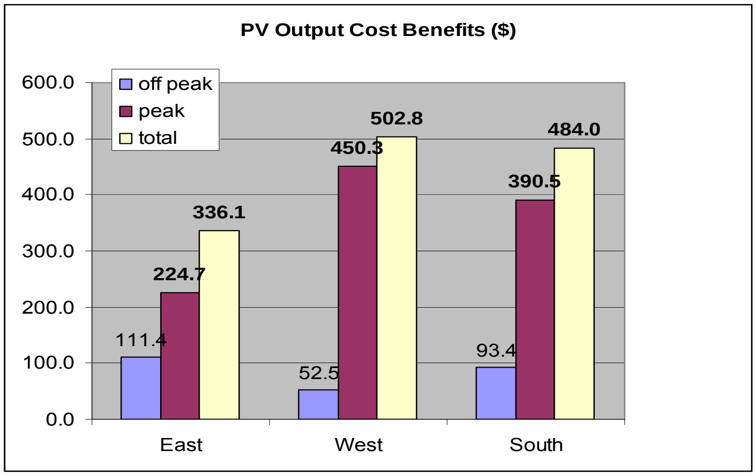
South-facing PV systems maximize annual output, and east- and west-facing PVs only reduce annual performance by approximately 15%.

Economic Benefits of PVs with West Orientation

West-facing PV systems maximize their electrical output on summer afternoons when many electric utilities reach their system peak demand for electricity. This summer afternoon performance can be most cost effective if the utility offers a TOU rate structure. The following summarizes the positive cash flow generated by the PV system with three different orientations. The west-facing PV system becomes an equally viable option compared to a south-facing PV system. It has a much larger peak generation capacity and, hence, a higher cost benefit compared to the south-facing PV system.

Premier Gardens Example

Establishing criteria early in the land development and home-design process that affect orientation of PVs can be a key to reducing peak demand. As with many electric utilities, SMUD has an interest in reductions in peak demand; however, peak reduction was not considered in the design of lots, the design of the homes, nor roof designs in Premier Gardens, a near-ZEH development in the Sacramento, California, area (Rancho Cordova).



Using a west-facing PV results in higher cost savings compared to a south-facing PV system using a TOU rate structure.

As a result, cost and ease of installation determined the orientation of the PV panel: east, south or west. Of the 95 homes in Premier Gardens, the PV systems of 54 (57%) face south, 23 (24%) face east, 17 (18%) face west, and one (1%) faces southwest. If the criteria had been established before the homes were designed, presumably all PV systems could be oriented facing only south or west (and southwest), or even with an emphasis on west to maximize later afternoon solar electric production to maximize reduction in SMUD's late-summer afternoon peak. Further studies of this nature are an important part of California's ZENH program and will be reported to BAP.

Orientation of PV Systems at Premier Gardens

	Actual of all 95		SMUD's Sample of 18	
	#	%	#	%
SW	1	1		
S	54	57	11	61
E	23	24	5	28
W	17	18	2	11
Total	**95**		**18**	

Lessons Learned: Approaches for Creating Effective Builder and Industry System Research Partnerships

Perhaps the most important factor contributing to success under the Building America program has been the strength of Building America's builder partnerships. The key elements of that success include the following:

- **Under-promise and over-deliver.** From the beginning, Building America adopted the philosophy with its builders of exceeding expectations, particularly in terms of technical assistance. It is often tough to overcome the builder preconception of a government industry initiative—"We are from the government and we are here to help you." BSC won its builders' respect and trust by delivering on commitments to find ways to reduce or maintain first costs, increase value, and achieve energy savings.

- **Provide real-world technical assistance.** Another key element of winning builder partner respect and trust is the technical and field experience of the Building America industry teams. Building America builder partners have come to expect that anyone from Building America sent out into the field on a job site has the technical credibility and field experience to hold their own with superintendents, trade contractors, and technicians. It's easy to overlook how important this "job-site" credibility is with builders.

- **Match expectations to technical feasibility** – When working with builders on innovations and changes to the way they build, the best way to attain a "can-do" attitude—as opposed to a "you-want-to-do-WHAT?" attitude—is to know the line between challenging and daunting. This only comes from experience in both building science and home construction, and the Building America teams have both.

- **Meet Builder Schedules.** It's easy for consultants to be less than sensitive to the scheduling demands of the home building business. Building America teams know on what issues builders had scheduling leeway and what issues they needed immediate delivery. Examples include plan review, energy modeling results, installation specs, etc.

- **Support broad-based expertise and capabilities.** Building America teams have expertise in enough arenas of construction that builders felt that they could rely on sound guidance or assistance on everything from design to energy modeling, from moisture dynamics to construction waste management.

- **Hang in when the going gets tough.** When an innovation does not work quite the way that the builder or the consulting firm intended or expected, builders respect firms that follow through and stick with the situation until it is resolved. In our case, there were times when this even meant using non-Building America company resources to correct problems in prototype housing. But once again, builders will hang tough with you, if you hang tough with them.

- **Deliver value to homeowners via energy bill guarantee programs.** This is perhaps the most important partnership development within the Building America program. These programs are market-based, building science-based programs that deliver real value to the builder (both in terms of technical information and marketing) *and* have a life of their own. The strength and rigor of these programs is based upon the science, experience, and data that Building America has developed with the industry.

- **Network with other building science programs** – The network of local and regional building science service providers that Building America teams work with extends the reach of the program with little loss in efficiency, given the depth and consistency of interaction between these firms and the Building America teams. Examples include Advanced Energy Corp. (North Carolina), Southface Energy Institute (Georgia), Florida Solar Energy Center (Florida), BCI Testing (Arizona), Shelter Supply (Minnesota), and LDC Consulting (New Mexico).

Technical Support for Professional Builder Organizations

- **The EEBA Builder's Guides.** This resource is a key element of the process BSC has for developing a relationship with builders. It connects and grounds all of the training and builder education efforts that are the heart of the Building America program. And again, builders trust and respect a firm that created and continues to update a resource well-tailored to their needs in the design office, at the superintendent's trailer, and out on the job site.
- **The Building America whole house energy performance targets.** It's a lot easier for both the builders and the consulting firm to set and meet expectations when the "requirements" for participation are clear-cut. BSC over the years has worked hard to make these performance targets explicit so that builders know exactly where they stand in terms of making a Building America commitment. Again, builders respect this straightforward, meaningful approach to building high-performance homes.

In many ways, the approaches that prove successful with builders are no different than the approaches that prove successful with industry partners. The 10 bullets listed above apply equally well to industry partners such as building product manufacturers. What is most interesting is the increasing need for the team approach that Building America embodies. At a time when an unprecedented number of new building products and systems are being introduced to the residential building industry, many if not most manufacturers have reduced their technical support and field presence. Building America has found that manufacturers are just as hungry as builders for "third-party" qualified analytical field and technical support and analytical perspective.

Manufacturer interest in the building science that Building America embodies is being driven by both positive and negative market forces—homebuyers want energy savings and don't want mold and moisture problems. More and more manufacturers, as well as builders, are beginning to understand that a systems thinking approach will give them the positive public exposure they desire and go a long way towards avoiding the negative press they so ardently seek to avoid.

The most promising development under the Building America program for applying private sector resources toward a systems approach to energy efficiency has been the energy bill guarantee program. Nothing has solicited more comprehensive industry partnerships than this development. It is the most elegant way to bring about builder/trade contractor/manufacturer/homeowner cooperation for the performance of a home.

Building America was instrumental in the development of the Engineered for Life program with industry partner Green Fiber; the Environments for Living program with industry partner Masco; and the "Energy Use and Comfort Guaranteed" program of home building partner Artistic Homes.

Future Challenges: Remaining Market and Technical Barriers

Each of the system research approaches described below has been critical to moving the Building America builder and their buyers beyond standard expectations for energy, comfort, health and safety, and durability to the high-performance standards.

The Cost Trade-off Approach

Historically, production builders have followed this motto:

> I have to figure out a place to save money to be able to devote resources to higher performance so that the first cost my homebuyer sees is ideally lower or just the same.

To satisfy this axiom, Building America developed the cost-trade off method, showing builders how things such as down-sized mechanical systems and advanced-framing savings could be used to support high-erformance windows, more insulation, and better HVAC equipment. The cost trade-off method proved very successful, not in overcoming the market barrier (i.e., the cost barrier with buyers), but the underlying design and construction barriers.

Going Beyond Cost Trade-offs to Value

The Building America teams have been successful in moving Building America builders beyond the issue of cost to that of delivered value. The message sent out by various divisions of Pulte Homes has resonated throughout the industry:

> Build and sell more homes at a slightly increased construction cost, but at a higher retail price with a higher profit margin. You can only do this if the buyer perceives higher delivered value. And again, the best vehicle for expressing that higher value to the buyer has been the energy bill and comfort guarantee programs such as Masco's Environments for Living and GreenFiber's Engineered for Life.

Value Back to the Builder: Reduced Call-backs

High-performance homes can deliver value back to the builder as well, in the form of reduced call-backs and associated builder expenditure. It's important to emphasize that the success of Building America has been a comprehensive approach to market barriers requiring the education and subsequent commitment of all elements of a production home builder's company—design, engineering, field construction, sales, and marketing.

Despite the overall success of Building America's system research strategies, there are high-performance concepts/strategies/systems that still are not ready for broad markets and remain difficult to sell to the builder, the buyer, or both.

The Low-Energy Home's Lack of Success

Despite the broad success Building America, production builders have had with the sales and marketing of homes with 30% to 35% energy savings in comparison to standard production homes, limited forays by the same builders into higher levels of energy efficiency have proved difficult. For example, the Pulte Tucson Low-Energy Home only sold after more than 9 months on the market and only after much, if not all, of the cost premium incurred by the builder had been parlayed into closing incentives on the home. (The nearly identical monitoring project home built to Building America standards was only on the market for a short period of time). Pulte felt sure that they could find homebuyers willing to shoulder the nearly $10,000 premium on the Low-Energy Home because of its performance value. But, according to the development's sales manager, other attributes of this particular home (three-car garage versus den, location dead-on to incoming development traffic, five adjacent homes) completely overshadowed the energy value of the home to prospective buyers.

The real market test for homes with greater than a 50% energy savings represented by a significant market premium will not come from single forays of challenging properties. It will come from the more significant commitment of a whole development of Low-Energy Homes—those with marketing, financing, energy bill guarantees, warranty, and even homeowner insurance premiums that truly reflect the greater value that these homes can deliver.

Financing Advantage – The EEM

For almost a decade, Fannie Mae and other leaders in the home mortgage industry have been developing energy-efficient mortgage (EEM) products that attempt to deliver real advantage to the buyer of high-performance homes. Their focus has been on the following:

- Adding the operational cost savings of high-performance homes to the income of the buyer
- Reducing down-payment requirements for qualifying buyers
- Capturing the added value of energy improvements in the home's appraisal
- Simplifying how each of the above is captured and managed by parties to the loan, including the lender, energy rater, appraiser, and private mortgage insurance (PMI) firm.

Working with BSC, RESNet, and builders such as BSC-uilders Artistic Homes and Pulte Homes, Fannie Mae has made progress on the above, particularly with two new mortgage products they are about to announce. Of particular importance, these new products have the following attributes:

- **Simpler for the lender** – there are now just two products
- **Simpler for the energy rater** – the manner in which the net present value of the energy improvements is calculated and documented for the loan have been vastly simplified
- **Simpler for the PMI** – the LTV ratio has been established to eliminate issues lenders had with private mortgage insurance firms on calculating their rates
- **Easier** – carried on Fannie Mae's Desktop Underwriting software.

Time is an important element in terms of Fannie Mae's efforts to move this item from "market barriers remaining" to "market barriers overcome." Lenders need a bit of time in the marketplace with these two new products to assess their real value to high-performance home builders and buyers. And perhaps just as important, Fannie Mae needs to build up some credit history on the performance of these two EEMs and then determine how they might increase power in the marketplace if the products come through with their expected superior performance for Fannie Mae.

The power of the EEM to reduce market barriers for high-performance homes is still in a bit of the chicken-and-egg stage. Builders need sharper mortgage products to help distinguish the value of their high-performance homes in the marketplace, and secondary lenders such as Fannie Mae need a deeper and broader base of actual EEMs in the marketplace to prove their superior performance to lenders.

One last element of EEMs that remains to be explored is the potential relationship between secondary lenders, such as Fannie Mae, and energy-bill guarantee programs, such as Masco's *Environments for Living* and GreenFiber's *Engineered for Life*. The issue of who absorbs the cost of the energy rating (ranging from $150 to $400) has been a stumbling block for EEMs and for all builders in the EFL programs. They readily absorb this cost because of the perceived marketing value of a third-party energy bill guarantee. Therefore, there should be a way for these two business entities to co-promote their products to the ultimate benefit of high-performance home builders and buyers. BSC is working on this issue in the last few months of the current cycle of Building America.

The Last Hurdle – Capturing the Durability Advantage

Durability has some distinct differences from energy efficiency. Durability is more difficult to define exactly, it is more difficult to measure and quantify, and it is more difficult to set standards for, particularly in terms of establishing a baseline. We just don't have a very good understanding or expression of how long houses or their components typically last or how environmental and other factors interact to affect overall building or individual material durability.

But here is what we do know:

- Durability stands squarely on the three-legged stool of quality—quality building design, quality materials, quality installation.
- Durability also stands squarely on homeowner maintenance, repair, and replacement. These are important operating costs to the homebuyer, and control or reduction of these costs could be translated into a real market advantage to the builder.
- Some builders are in their own way considering the concept of extended "product" responsibility, envisioning their business to be the supply of a continuous stream of services to a home over time, rather than just ending at or shortly after the home sale.

- Homeowners are concerned about the health risks and builders the liability associated with moisture and mold (both are facing exorbitant premiums or even unattainable insurance), a phenomenon directly associated with durability.

Building America began the exploration of capturing the market advantage of more durable homes with two builders: Artistic Homes and Pulte Homes. With Artistic Homes, this resulted in a detailed survey and analysis of building defects and homeowner maintenance and repair. With Pulte Homes it resulted in initial discussions of working with a major insurance firm on preferential home insurance premiums for high-performance homes. But, in neither case, did the initial work result in a real translation into market advantage for the builder or financial advantage to the high-performance homeowner. The market barrier of capturing the advantage of more durable homes remains and requires further exploration.

Mold – the Double-Edged Sword

Here is the bad news: mold in buildings is fueling fear, litigation, builder and homeowner insurance program withdrawals, and media hysteria. And energy efficiency is being linked to mold—and often rightly so.

Here is the good news: building science and systems thinking are being viewed by the building industry as the answer to the mold problem—and rightly so.

The Building America program is uniquely positioned to use this rather sudden and sweeping industry interest as a driver for promoting building science and systems thinking. The key is that mold management is risk management. That makes it more of a new market advantage, than a remaining market barrier—one that is likely to have a major impact on Building America's success in coming years. (For more information, see www.buildingscience.com/resources/mold/default.htm.)

Each of the research and development activities conducted within the Building America program resulted in specific lessons learned, as expressed in the first section of this report. But there are overarching lessons that have formed the Building America experience. These are organized below into three categories—building science, field, and general lessons learned.

Building Science Lessons

- Systems thinking in residential building requires the analysis of how air, heat, vapor, and liquid water move on and through building envelopes and HVAC systems. This cannot be reasonably accomplished without acknowledgment and incorporation of how hygro-thermal conditions drive this analysis.
- Each component of a building assembly should be assessed for its individual properties, particularly with respect to the movement of water, vapor, air, and energy. Product manufacturers need to supply and builders need to request (demand) detailed information on properties such as vapor permeability on all building products.
- Each component of a building assembly should be assessed for its contribution to the properties of the total assembly, particularly with respect to the movement of water, vapor, air, and energy. Again, product manufacturers and builders need to focus on how products perform in typical building assemblies, not just how the products perform individually.
- In high-performance homes in hot-humid climates, the latent-to-sensible load ratio is such that dehumidification must be a separate and yet integral element of the HVAC system.
- As we move from energy efficiency improvements of 30% to more than 50%, we have a lot to learn about hot water, appliances, lighting, and plug loads. This is particularly true with regard to how domestic hot water can be integrated with either space heating or cooling, and how we accurately model natural ventilation, day lighting, and solar-energy systems.

Lessons from the Field

- A systems approach and systems solutions almost always involve cooperation and communication among the trades. Particularly with HVAC contractors, the lack of this cooperation and communication is a real stumbling block in achieving high performance.
- Moving builders and framing contractors to advanced framing requires a progression of education and assistance—plan review and building redesign, Builder's Guide digestion, integration of HVAC, detailed drawings, and follow-up in the field. What is second-nature and

obvious to the "converted" is painful and difficult to the newly initiated.

- Builders operating in more than one of the six climate zones must pay careful attention to the transfer of high-performance techniques, systems, and components as they move these from one climate zone to another.
- The really top-notch Building America builders get buy-in on the importance and meaning of high performance from every level of their organization—company management, field management, design and engineering, trade contractors, and sales and marketing.
- Performance testing of every home at the beginning of the Building America experience provides critical feedback in "getting it right." Performance testing of every home after that provides critical feedback in "keeping it right."

General Lessons

- The best Building America partner companies—builders, manufacturers, etc.—are those large enough to have or create economies of scale, but also small enough or managed in such a way that the company can make decisions and, subsequently, changes in a straightforward and timely way. BSC's best builder relationships always included this characteristic.
- Energy bill guarantees are simply the most elegant and most effective vehicle for marketing the benefits of Building America high-performance homes.
- There are topics and times when the building science message must be translated for the homeowner as well as the builder.
- Manufacturers need to know, establish, and publicize all the performance properties of the products as a matter of course, not as a matter of inquiry.
- Moving builders from simply the "first cost" to the "value" criterion for making changes in the way they build is an important part of high-performance homebuilding.

Building America has been one of the most successful residential building technology development and transfer programs ever. The five teams have participation from every sector of the business and area of the country. Real changes have been instituted company-wide by real builders and real manufacturers to provide real benefits to homebuyers and the environment.

But there are, of course, ways in which the Building America teams could be even more effective, particularly by strengthening commitments from builder partners.

- **Builder financial commitment** – Builders need to make a deeper commitment in the form of actual financial resources rather than just in-kind contribution towards Building America work. This would separate out the really committed from the "window-shopping" builders, allowing the team leaders to focus on those builders who are really willing to deliver. In addition, a stronger builder commitment to long-term monitoring of Building America homes is required to ensure that we get the hard-core proof-of-concept data needed. Incidentally, this very approach was the one that BSC took with its builder and manufacturer partners in its Building America proposal for the next cycle of Building America work.
- **Depth of builder commitment** – It is surprising the number of builders who have truly valued and benefited from the building science/systems thinking of Building America without taking the step of developing the same expertise in-house. Perhaps the commitment required of Building America builders should be extended to some sort of mandatory formal training in building science by at least one member of the builder's company. Perhaps Building America and EEBA's Master Builder program could team up with the building science expertise of BSC to establish this requirement.
- **Breadth of builder commitment** – The lateral transfer (division to division) of the Building America program within regional and national production builders is an important phenomenon. It is a phenomenon that we need to studiously encourage, given how important comprehensive systems thinking is when the Building America approach is transferred from one hygro-thermal zone to another.

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