October 2002 • NREL/SR-550-31380

Subcontractor Report

Building America Field Project: Results for the Consortium for Advanced Residential Buildings (CARB)

January to October 2001

Steven Winter Associates, Inc.
Norwalk, Connecticut

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

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NREL Technical Monitor: Bob Hendron

Prepared under Subcontract No. KAR-8-18411-10

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Building America

The U.S. Department of Energy's Building America Program is reengineering the American home for energy efficiency and affordability. Building America works with the residential building industry to develop and implement innovative building processes and technologies – innovations that save builders and homeowners millions of dollars in construction and energy costs.

This Final Report is one of a series of reports that are products of the Building America program. The National Renewable Energy Laboratory maintains the contracts on Building America Teams, and the NREL Center for Buildings and Thermal Systems provides technical oversight for the program. Teams submit their Final Reports for publication by NREL. Technical Reports with further details on Building America projects can be obtained through the Building America Web site at www.buildingamerica.com in the Building America document database.

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Executive Summary

The Consortium for Advanced Residential Buildings (CARB) is one of five teams working under the U.S. Department of Energy Building America program, which is administered by the National Renewable Energy Laboratory. Led by Steven Winter Associates, Inc., building systems research architects and engineers, the consortium includes several leading manufacturers of building components, along with many homebuilders. The builders are located in nearly all major home-building regions of the country and range from small companies producing 200 homes a year to industry giants.

The first part of this report describes the various CARB projects that were active during the first 10 months of 2001, summarizing results, benefits, lessons learned, and future plans. The most important projects include the following:

- Beazer Homes in northern and southern California, including very energy efficient homes with photovoltaic solar systems
- Mercedes Homes in Melbourne, Florida, and Dallas, Texas, including highly energy efficient homes built with poured concrete walls that exceed the most stringent Florida wind standards
- Cambridge Homes in the Chicago area, including several subdivisions of attached and detached homes.

The second part of this report describes technical matters, summarizing innovative technologies, systems engineering and results, and industry team member contributions. Highlights include the following:

- poured-in-place concrete walls in the Melbourne homes by Mercedes
- precast concrete foundations
- photovoltaic solar systems
- the "CARB Package," in which better insulation and glazing is paid for by the resulting downsizing of the air-conditioning system
- the "CARB Plenum Truss" that brings all ductwork within the conditioned envelope
- a proprietary steel floor system for manufactured and modular homes.

Acknowledgments

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1. Introduction

1.1 Background on CARB

The Consortium for Advanced Residential Building (CARB) has worked under the U.S. Department of Energy (DOE) Building America program since 1995. Beginning with three of the nation's largest builders as team members — Beazer Homes, Del Webb Corporation, and NVR/Ryan Homes — CARB broadened its scope to include medium-sized and very small builders. While larger builders had greater potential impact, dealing with their unwieldy management made progress slow and frustrating. Smaller firms, by contrast, could "turn on a dime" and adopt radical new ways of building, as demonstrated when Mercedes Homes did extensive revamping of their construction practices with CARB's assistance. CARB builder team members range from some of the largest in the nation to those producing only 50 homes a year and cover nearly every important climatic region of the country. The number of homes constructed by CARB builders that meet Building America performance standards as a result of CARB efforts continues to grow dramatically and reached 1,200 by the end of 2001, with more than 2,000 starts planned for 2002.

In addition to CARB's builder team members, many companies have participated in the consortium. Larger companies that have participated in CARB from its beginnings include Owens Corning, Honeywell, Whirlpool, Andersen Windows, and Weyerhaueser. Along the way, Certainteed, U.S. Gypsum, and TJI MacMillen (now part of Weyerhaueser) have joined CARB's ranks, as have a large number of smaller firms. Also included as team members are important subcontractors working with CARB builders, such as Gale Insulation.

2. Project Results

CARB projects that were active during the first 10 months of 2001 are summarized in Table 1 and described in detail in subsequent paragraphs.

Table 1. Listing of CARB Projects in 2001

Builder	Project Name and Location	Details	Key Specifications	Percent Energy Savings[1]
Beazer Homes	Estates at Stevenson Ranch, Los Angeles, California	50 SF[2] homes, detached, 35 completed; specification upgrade	SEER-12[3] AC[4], vinyl window with Cardinal Low-E[5] glazing, mastic-sealed ductwork, optimized insulation	30%
Beazer Homes	The Fairways, Palmdale, California	Construction starts December, 2001 specification upgrade	Similar to Stevenson Ranch, plus cool roofs	30%
Beazer Homes	Country-Club Ridge, Palmdale, California	Construction starts January 2002, specification upgrade	Similar to Stevenson Ranch, plus cool roofs	30%
Beazer Homes	Product Line, Northern California Division	Affecting 1,200 homes per year, specification upgrade and PV[6] solar option	SEER-12 AC; EPS[7], exterior insulation; mastic-sealed ductwork; vinyl window with Cardinal Low-E[2] glazing	30%
Beazer Homes	Roseview, Sacramento, California	159 total one-story SF detached, specification upgrade PV solar option, Night-Time Economiser cooling option	R-38 attic insulation, SEER-14 AC, ducts buried under attic insulation, setback thermostats, PV option, all other upgrades in normal product line	46%
Beazer Homes	Piazza del Sol, Sacramento, California	133 planned SF detached, specification upgrade with PV solar option	Same as Roseview	46%
Beazer Homes	Highland Green, Sacramento, California	59 planned SF detached, specification upgrade with PV solar option	Same as Roseview	46%

[1] Percent Energy Savings is the average of the community and is relative to the Model Energy Code (MEC 1995)
[2] SF = single family
[3] SEER = seasonal energy efficiency ratio
[4] AC = air conditioner
[5] Low-E = low emissivity windows
[6] PV = photovoltaic
[7] EPS = expanded polystyrene

Table 1. Listing of CARB Projects in 2001 (continued)

Builder	Project Name and Location	Details	Key Specifications	Percent Energy Savings
Cambridge Homes	Carillon Lakes, Crest Hill, Illinois	Retirement community of 947 homes, 150 completed; two-story SF, one-story four-plexes, and one-story six-plexes; specification upgrade	R-38 attic, insulated base; ducts removed from attic; low-E, argon-filled windows; programmable thermostat	36% heating 28% cooling
Cambridge Homes	The Glen, Glenview, Illinois	244 homes, ~ ½ completed; two-story SF, rowhouses, duplexes, and two-flats; specification upgrade	R-38 attic, insulated base; ducts removed from attic; low-E, argon-filled windows; programmable thermostat	36% heating 28% cooling
Cambridge Homes	Forest Glen, Carol Stream, Illinois	60 townhomes, 6 completed; active adult community; new designs, all ENERGY STAR, new slab edge detail, primarily within the envelope ductwork	R-38 attic, insulated base; ducts removed from attic; low-E, argon-filled windows; programmable thermostat	36% heating 28% cooling
Cambridge Homes	The Maple	Best-selling large SF detached model, specification upgrade	Measures to improve glazing, insulation, mechanical systems, and framing have not been defined in detail	30+%
Crosswinds Communities	New Products for Detroit market	Price-point 1,200 to 1,600 ft^2 two-story SF detached; move-up 1,800 to 2,700 ft^2 two-story SF with downstairs MBR[8]; new CARB designs	Measures to improve glazing, insulation, mechanical systems, and framing have not been defined in detail	30%
Del Webb Corporation	Sun City Grand, Surprise, Arizona	Active adult community, specification option upgrade	SEER-12 AC, low-E windows, R-6 duct insulation, mastic duct seal	42% cooling, 10% heating
NYC Housing Partnership	Melrose Common II, Bronx, New York City, New York	30 three-unit, three-story townhouses on city block; specification upgrade	Sealed combustion boilers feeding indirect tank water heaters, low-E windows, programmable thermostats, ventilation system	33%
Mercedes Homes	Melbourne, Florida (Product Line)	One-story SF detached; expected 200 homes, 60 completed; specification upgrade and minor design changes	Poured concrete walls; Cardinal Low-E^2 windows; AHU[9] located inside conditioned space	30%

[8] MBR = master bedroom
[9] AHU = air handler unit

Table 1. Listing of CARB Projects in 2001 (continued)

Builder	Project Name and Location	Details	Key Specifications	Percent Energy Savings
Mercedes Homes	Oceanside Village, Melbourne, Florida	Two-story townhouses; specification upgrade, 36 two-story units	Poured concrete walls, Cardinal Low-E[2] windows, compact duct system, mechanical ventilation system	34%
Mercedes Homes	Dallas / Ft. Worth, Texas (Product Line)	One- and two-story SF, 700 homes/year and growing; specification upgrade	Duct sealing, low-E windows, SEER-12 Puron	26%
Mitchell Homes	Pensacola, Florida (Product Line)	One-story SF detached, design modifications and specification upgrade	Enhanced gap and duct sealing, low-E windows, cross-linked PEX[10] plumbing with manifold, Studor valves	30%
NV/Ryan Homes	Three Divisions in New York (Product Line)	Number affected not determined, specification upgrade to meet NYSERDA[11] program incentives	Explorations of opportunities are at an early stage and specific technologies have not yet been identified	Not determined
Palm Harbor Homes	HUD-Code Product Line	Number affected not determined, new floor system development for factory-built homes	New floor and chassis design using joists from Steel Floors, Inc.	Probably less than 10%
Tindall Homes	Southern New Jersey (Product Line)	Number affected not determined, new home designs, existing product uses high-efficiency mechanical equipment	Measures that will produce exceptionally high performance are being explored, including solar energy systems and HRVs.	40% proposed
Unibilt Industries	St. Mary's Neighborhood Housing, East Dayton, Ohio	Sixteen two-story SF detached in traditional neighborhood development; new CARB home designs	Compact duct system, electrical improvement, possible precast foundations, air-admittance valves	Less than 10%

[10] PEX = polyethylene
[11] NYSERDA = New York State Energy Research and Development Authority

2.1 Beazer Homes

Estates at Stevenson Ranch

Background

CARB initially worked with Beazer's Southern California division in the spring of 1999 on a project for the Partnership for Advanced Technology in Housing (PATH). This project was cosponsored by Southern California Edison and built in the Simi Valley, near Los Angeles. The result was an innovative, highly efficient, cost-effective home completed in the summer of 1999. The project was not replicated because the systems employed were too much of a departure for the builder; however, it established a good relationship between CARB and this division. Contact was maintained, and work began on another project in the spring of 2001.

CARB was asked to perform a specification upgrade involving a 50-home subdivision east of Los Angeles called Estates at Stevenson Ranch. Perceiving new market conditions after the California energy supply crisis in 2000, the division president requested that his staff develop specifications that would "set them apart from competition." Working with Beazer's production managers, purchasers, and mechanical subcontractors, CARB developed new specifications that included the following:

- SEER-12 air-conditioning (AC) equipment
- Cardinal Low-E[2][12] double glazing in vinyl sash and frame
- Mastic-sealed ducts
- Increased insulation.

The results were impressive. The homes exceeded the pre-June 2001 Title 24 cooling requirements by 50%.

Construction of the total buildout of 50 homes was completed in early spring 2002.

The Fairways, Country-Club Ridge

The successful work on Stevenson Ranch resulted in two new projects, both located in Palmdale, California, adjacent to Edwards Air Force Base. CARB is currently developing high-performance specifications similar to those used at Stevenson Ranch and is assisting Beazer in preparing a performance-based Title 24 compliance package using MicroPas software. A new feature, highly appropriate in this desert location, is the use of "cool roofs" light-colored concrete tiles to reduce the peak attic temperature, thereby reducing heat gain in the attic ductwork and through the ceiling.

The first of the two subdivisions, The Fairways, started construction in December 2001. The second, Country-Club Ridge, started in January 2002. Work on these two subdivisions is being viewed as a precursor to the Zero-Energy Home project, in which Steven Winter Associates, Inc., and Beazer are partnered. Beazer is implementing the CARB-developed performance specifications on all new communities as development proceeds.

Product Line, Northern California Division

For Beazer's Northern California division headquartered in Sacramento, CARB developed a revised package of energy-saving specifications that exceed Title 24 requirements and meet ENERGY STAR™ standards. These specifications are being used throughout the division and have been used in more than 700 homes to date, with a projected rate of 1,200 per year.

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[12] Low E^2 = low emissivity, low solar heat gain

The energy-saving package worked out by CARB and Beazer included SEER-12 AC equipment, R-30 blown-in attic insulation, vinyl-framed windows with Cardinal Low-E^2 glazing, mastic-sealed ductwork, and a layer of expanded polystyrene (EPS) exterior insulation over stud walls with R-13 fiberglass insulation.

Roseview

Beazer's Sacramento subdivision Roseview offers 1,000 to 1,500 ft^2 single-family homes for first-time homebuyers (Figure 2). These are all being built with enhancements to the specifications developed by CARB for Beazer's Northern California division. These enhancements (SEER-14 AC equipment and ductwork buried under a full layer of R-38 attic insulation) are now the new standard for this subdivision and all new subdivisions as they proceed.

At Roseview, Beazer for the first time is offering a PV solar rooftop electrical generation option, which consists of a roof-tile system generating 3.3 peak kilowatts and selling at a pass-through price of $11,200, subsidized by the Sacramento Municipal Utility District (SMUD). Because these are first-time buyers with limited resources, no buyers have yet accepted the option. It is projected that these homes will provide as much electric power as they use, making them net-zero electric energy homes.

Piazza del Sol

A second Sacramento-area subdivision with CARB involvement is Piazza del Sol, which features larger homes. The specification package is the same as Roseview and includes the same PV option. Presumably because the buyers are more upscale, several have ordered the PV option. Construction is just starting on this project. CARB investigated higher levels of energy savings (efficient lighting and appliance packages) in the homes that would allow a smaller, less expensive 2.2-kilowatt array to produce the same amount of electricity as the home used. Beazer, however, chose to stay with the previous specifications.

Highland Green

This is a third subdivision with the PV option, offering starter homes, but slightly larger ones than Roseview. The same specifications will be offered as in the other subdivisions.

Figure 1. Beazer's first community offering photovoltaic systems: Roseview near Sacramento, California

2.2 Cambridge Homes

CARB has so far worked on three projects for this company, which is Chicago's largest homebuilder and a division of D.R. Horton.

Carillon Lakes

This active adult community of about 1,000 units is the first Cambridge project to incorporate CARB improvements that bring the homes up to ENERGY STAR standards. The unit designs are a mixture of one-story and two-story single-family detached homes, one-story six-plexes, and one-story four-plexes. Energy-related improvements were primarily specification upgrades, but also included the addition of dropped ceilings to bring the return air ductwork out of the attic after modeling showed this to be a cost-effective way to achieve ENERGY STAR standards. The energy-saving upgrades included R-38 attic insulation, basement or crawl space wall insulation, vinyl-frame windows by Republic (a local manufacturer) with argon-filled Cardinal Low-E^2 glazing, ductwork removed from the attic, and setback thermostats. The "CARB package" concept was completed with the downsizing of the mechanical equipment. Now being built out at the rate of about 200 homes per year, more than 100 homes have been completed at Carillon Lakes to date.

Another part of CARB's efforts at Carillon Lakes is an investigation of slab-edge thermal losses and subslab ductwork (Figures 3, 4, 5, and 6). The details and computer printouts illustrate the results of extensive studies of thermal transmission through the slab edge, showing the need for a thermal break

The Glen

This development of more than 200 move-up homes at the Glenview Naval Air Station meets ENERGY STAR requirements with the same specifications as were used at Carillon Lakes. CARB performed all of the ductwork design for these two-story townhouses, two-story single-family homes, and two-story duplexes, along with a three-story over-and-under two-family home. Open-web floor trusses were used to allow ductwork to thread between floors instead of being placed in the unconditioned attics.

Forest Glen

CARB designed townhouses for this 60-unit age-restricted community, unusual because of its two-story and three-story configuration. All units are potentially compliant with Fair Housing Act (FHA) standards with minimal changes and include an elevator option that can be easily retrofitted. To more easily meet FHA requirements at the entries, the floor trusses used in the ground floor framing are top-chord bearing. Except for some subslab ducts, all ductwork is within the conditioned envelope. Like The Glen, open-web floor joists are used to allow ductwork to run between floors. All homes meet ENERGY STAR standards with the same specification package as at Carillon Lakes.

CARB investigated the use of aerated, autoclaved concrete (AAC) insulation masonry units outside the slab to prevent excessive heat loss; this idea was rejected because the AAC proved not to be weather-resistant. CARB developed a detail using pressure-treated wood.

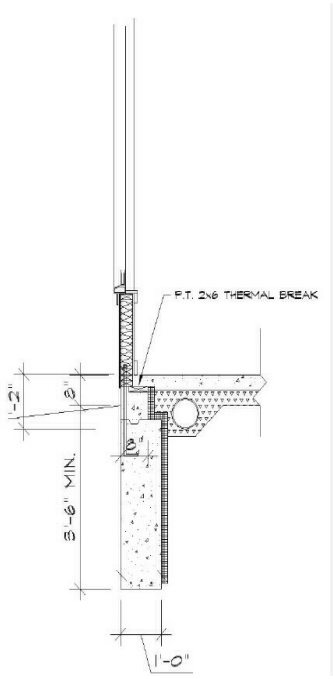


Figure 2. Slab-edge thermal losses near the subslab ductwork were a concern for Cambridge Homes

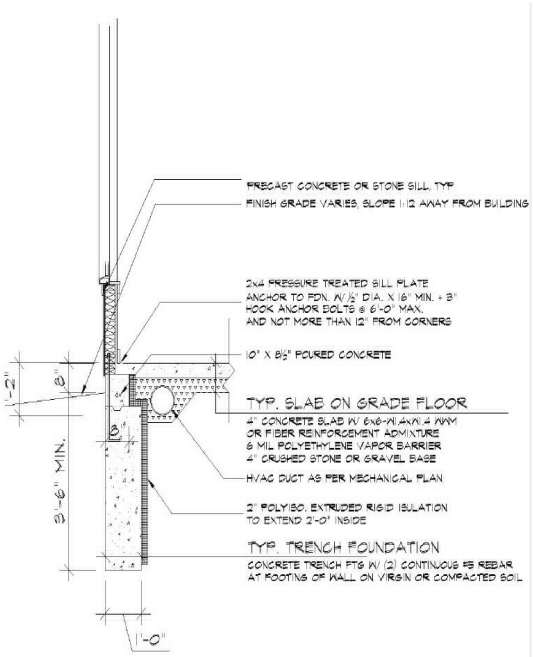
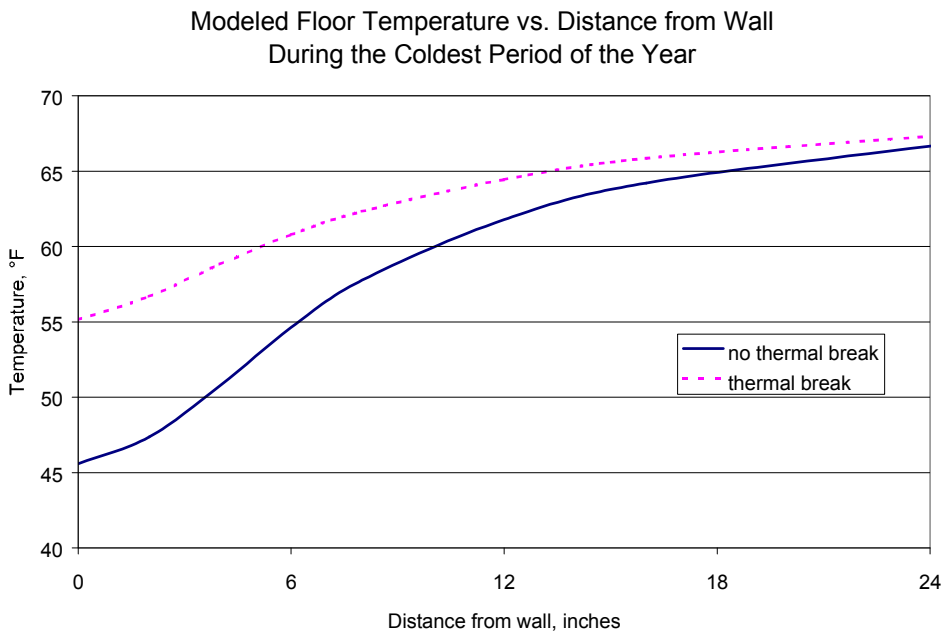


Figure 3. Proposed strategy for reducing heat losses at the slab edge



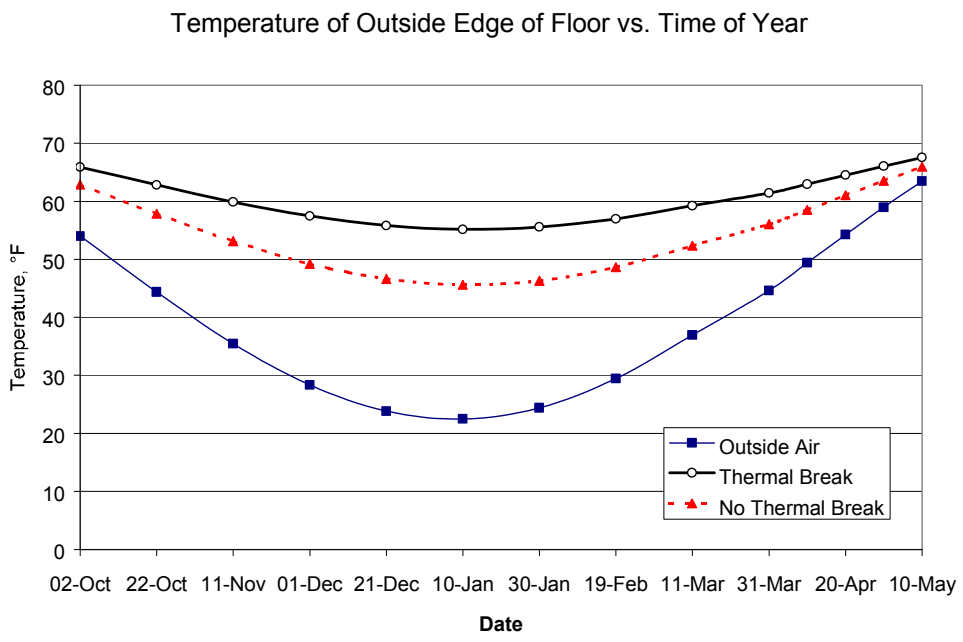
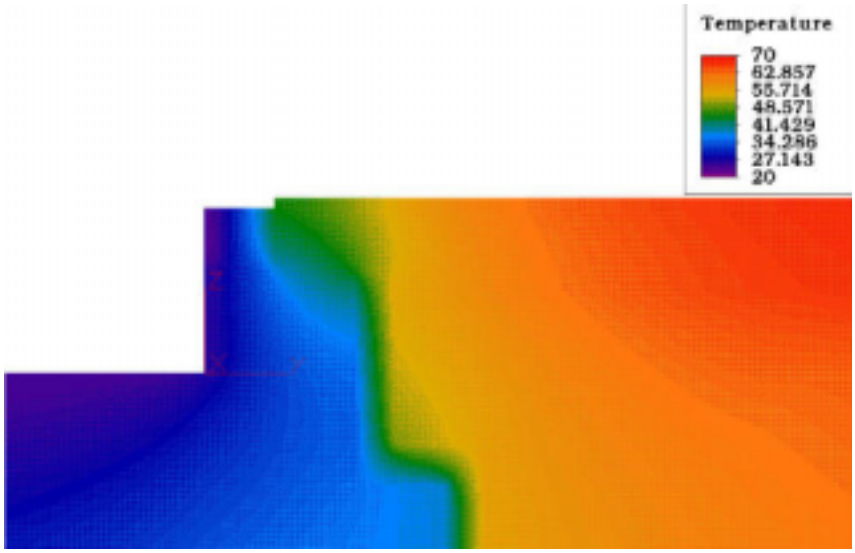


Figure 4. Computer simulations demonstrate the reduction in slab-edge heat loss possible by adding a thermal break

Floor Edge Surface Temperature
Without Thermal Break



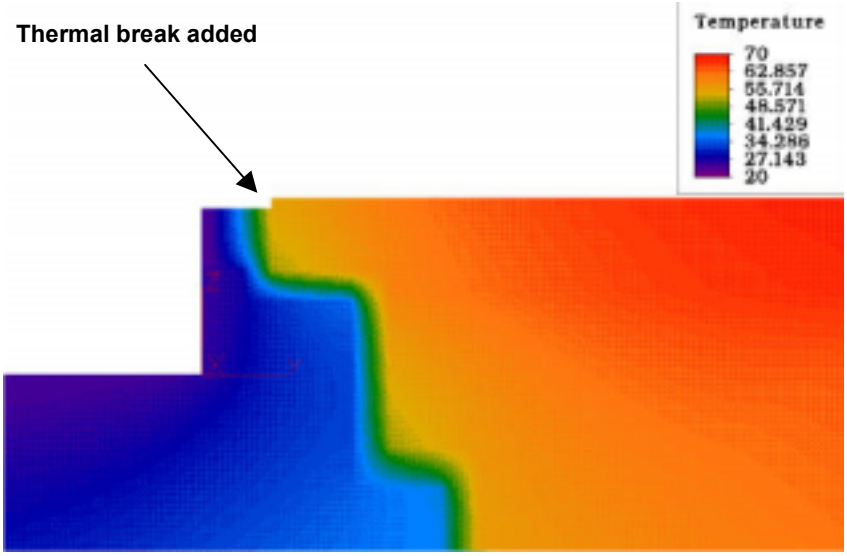


Figure 5. Temperature profiles illustrate benefits of adding a thermal break to the slab perimeter for Cambridge Homes

2.3 Mercedes Homes

Melbourne Single-Family Homes

Following two successful CARB prototypes, Mercedes worked with CARB to complete six pre-production home models for initial testing early in 2001. The first subdivision featuring these new designs was begun in June 2001. As of October, the company had sold out the first release of 40 lots, while a competing builder with conventional homes sold 6 houses in that same time frame in the same subdivision.

The following four major innovations were used on these homes:

1. Poured-in-place walls. Based on the success of the solid-pour concrete walls in the second prototype, Mercedes invested in prefabricated modular aluminum forms (fully described in section 3.2).

2. High-performance glazing. In an effort to gain some the energy performance advantage of low-E glass without some of the cost penalty, CARB suggested that Mercedes try the newly developed Pilkington product with a hard low-E coating. This product can be left exposed and, thus, does not have to be part of a double-glazed assembly. The coating faces inward and requires special techniques for cleaning, as it shows fingerprints easily. Mercedes began to use this glass in production, but soon found that the coating was softer and less durable than expected and that the fabricator too often reversed the glass so that the coating was on the outside. Rather than switch back to the glass used in the first prototypes, Mercedes chose a double-glazed unit using a high-performance Cardinal low-E^2 double-soft coating that far outperforms the glass used in the prototypes. This also provided the opportunity for additional downsizing of AC equipment in the larger models.

3. Plenum truss. This is fully described in section 3.2.

4. Mechanical equipment. Mercedes chose their standard TempStar SEER-11 mechanical equipment, placed in a closet located inside the conditioned envelope. CARB's tests show that the homes need a ton of cooling for every 83.6–87.3 m^2 (900–940 ft^2), not the 46.5–51 m^2 (500–550 ft^2) used by the subcontractor in his design. The mechanical subcontractor at first insisted on sizing the equipment according to his normal standards, resulting in a noticeable excess of indoor humidity and equipment short-cycling. CARB is currently working with the mechanical subcontractor to ensure that his Manual J design results in a correctly-sized system for the new specifications to control humidity and maintain comfort. This approach seems to be working. CARB met with the subcontractor, went over Manual J input, and changed wrong numbers. Spot-checking of actual results is just beginning.

The National Renewable Energy Laboratory (NREL) tested the homes and recommended some additional design improvements. The homes have all received ENERGY STAR ratings.

Melbourne Townhouses

A second product incorporating the new features is a new two-story townhouse development, the first townhouses Mercedes has built in the Melbourne market. In addition to poured concrete walls, which are also used between units, the project will use the Cardinal Low-E^2 glazing. CARB has designed the duct system for the project, replacing the two units used by the mechanical subcontractor in previous two-story designs with a single system. CARB placed the air handler on the second floor to serve both levels, allowing a compact duct design between floors. The mechanical system includes a mechanical ventilation system, which is a 15-cm (6-in.) insulated duct from outside to the return plenum, with a manual damper to set the flow rate. R-19 insulation is used in the attic. As this is a market where composition shingle roofs are standard, CARB made no serious effort to change the roof color in any of Mercedes' Melbourne products. Research by Lawrence Berkeley Laboratory and the Florida Solar Energy Center (not yet published as of March 2002) shows that white shingles provide only a marginal improvement over dark ones.

Dallas and Fort Worth Divisions

Based on the positive experience with CARB in Melbourne, Mercedes requested that we work with their divisions in Dallas and Fort Worth, Texas. In January 2001, CARB met with the Dallas product development and purchasing staff to find ways of improving their products through specification upgrades. Using computer simulations, site observations, and baseline testing of existing products, CARB came up with a package of specifications that would bring the buildings up to ENERGY STAR standards. Included on CARB's list of recommendations were weatherization improvements in flashing, mastic duct-sealing improvements, training in the installation of ductwork, relocation of central returns to improve comfort and indoor environmental quality, and new ductwork layouts to minimize duct runs. Ducts with R-6 insulation run in the attics in most of the Mercedes two-story homes.

During June 2001, based on their success with ENERGY STAR homes in Florida, Mercedes decided to offer ENERGY STAR homes as a promotion, selling the first houses in August 2001. The division builds in the town of Frisco, which had recently implemented the country's first ordinance requiring ENERGY STAR compliance in every new home, along with other building improvements (such as ventilation systems, limitations on ductboard, and other indoor environmental quality measures).

This gave the CARB initiative additional impetus and moved the program along much faster than would otherwise have occurred. As a result, both the Dallas and the Fort Worth divisions are switching their entire production to meet ENERGY STAR specifications. This currently involves 700 homes a year and a greater rate is anticipated in the future. A media event and grand opening is planned for early 2002 at the Frisco development.

2.4 Mitchell Homes

Pensacola Division

CARB's first prototype for Mitchell, completed during 1999, spawned the application of CARB-recommended improvements in 125 homes in nine developments in the area of Pensacola, Florida, during 2000. Mitchell's homes were already well-insulated, but greater efficiency was achieved by switching to conventional low-E glazing and adding more extensive gap sealing and duct sealing to curtail air leakage. Also included in the CARB designs were PEX (polyethylene) water supply tubing with manifold and Studor air-admittance valves. An integrated temperature control and home security system used on the first prototype was not applied to later homes.

Mobile (Alabama) Division

CARB and Mitchell unveiled their first Mobile Division ENERGY STAR prototype home on October 1, 2001, and are exploring the possibility of converting the rest of the division to the production of homes that are compliant with ENERGY STAR, using the same specification upgrade package worked out for the Pensacola Division. To provide a baseline for comparison, CARB tested existing homes produced by the division. CARB member Whirlpool featured their new popular ENERGY STAR washing machine in this house. Mobile has in the meantime switched to PEX water supply piping and Studor air-admittance valves at CARB's recommendation.

Mitchell Mobile and CARB also joined with Fannie Mae and Colonial Bank in applying Fannie Mae's new energy-efficient Home Performance Power Mortgage to a model home at Mitchell's Wakefield Place development in Mobile. The ENERGY STAR prototype was also featured in Mobile's Parade of Homes, resulting in 4,000 visitors who toured the home.

2.5 New York City Housing Partnership and the Seavey Organization

Melrose Common II

This project consists of a city block in the Bronx on which will be built 30 attached townhouses, each containing three units. Energy improvements proposed consist of sealed combustion boilers with indirect water heaters fed from the boiler (see section 3 for more details). Low-E glazing will be included (detailed specifications have not yet been decided) along with Honeywell programmable thermostats and possibly a mechanical ventilation system. This project may be eligible for the New York State Energy Research and Development Authority (NYSERDA) ENERGY STAR rebate program. The homes will also have ENERGY STAR refrigerators and compact fluorescent light fixtures.

2.6 Palm Harbor Homes

Innovative Floor System

CARB is working with Palm Harbor, a well-known producer of manufactured homes built to the National Housing and Urban Development (HUD) Code. Together they will develop a specific component—a steel floor system. After providing technical assistance and engineering during the development of an innovative system of steel joists for Steel Floors, Inc., in Greenwood Village, Colorado, CARB introduced Palm Harbor to the system. Palm Harbor immediately saw the joists as a practical way to reduce weight, more easily accommodate ductwork and plumbing in the floor system, potentially reduce cost, and, most important, eliminate the increasing callbacks resulting from bowing, twisting, or warping floor joists. Because a continuous layer of foam insulation was needed below the joists, the resulting floor was much better insulated than that of a typical HUD-Code home.

Working closely with the company and its engineer, CARB assisted in the development of the basic floor system, in one case using network design software to allow simultaneous work on the same drawing in both offices. CARB then introduced some never-before-used techniques for creating an economical undercarriage that meets the constraints of the HUD Code and of travel-induced loading. Production of this system is expected by early 2002. Because the joists span from side to side, the home can be placed on a conventional foundation. The radical new design should cost little or no more than a home with a traditional HUD-Code chassis. The design also results in an attractive continuous flat ceiling over the basement or crawl space.

2.7 Ryan Homes

We informed Ryan, our first CARB builder team member, about the new NYSERDA ENERGY STAR rebate program, which offers generous rebates to builders and home buyers for homes meeting ENERGY STAR requirements enhanced with other electricity-saving measures and mechanical ventilation. Ryan is enthusiastic about working with us, and there is the potential for major shifts in their New York products. Ryan is the largest builder in upper New York, building in three major markets. CARB is also making a presentation to Ryan's parent company, NVR, Inc., about doing a CARB demonstration home in the Washington, D.C., area with their company NV Homes, which builds upscale 223 to 613 m^2 (2,400 to 6,600 ft^2) homes. The proposal will be for a CARB specification upgrade coupled with a CARB redesign of the mechanical system using the "CARB package" cost-tradeoffs.

2.8 Tindall Homes

New Products

CARB began working with Tindall Homes in August 2001 by partially measuring the performance of a home under construction (it was not sufficiently completed to perform a blower door test). The company, which currently builds about 80 high-end homes annually in southern New Jersey, is working with the local utility, Public Service Electric and Gas (PSE&G), to satisfy their 5-star program requirements, which are similar to those of ENERGY STAR. Energy-saving measures already being used by Tindall include SEER-14 AC equipment, 92 AFUE[13] furnaces, and rigid foam insulation on the outside of 2 x 4 stud walls filled with R-13 insulation. CARB showed Tindall that 2 x 6 walls with R-19 would perform equivalently if properly built, but the firm will stay with the current system, partly because they value the extra air barrier provided by the foam.

CARB has been assigned the task of designing four modestly priced homes in the 185-m^2 (2,000-ft^2) range (considerably smaller than anything currently in Tindall's range of models) that will be highly energy efficient. As part of this effort, CARB will look at heat recovery ventilators and solar systems. This line of homes is a candidate for participation in the DOE Zero Energy Home program.

[13] AFUE = annual fuel utilization efficiency

2.9 Unibilt Industries

St. Mary's Neighborhood Housing, Dayton, Ohio

Unibilt is the largest modular-home builder in Ohio and became a CARB builder team member in March 2001. As a result of a long-standing interest in energy conservation, the company incorporates substantial energy-saving improvements in its product line, including R-19 wall insulation (with an option for 2.5-cm [1-in.] EPS foam), R-38 attic insulation, Andersen windows, extensive gap sealing, and careful installation of all ductwork installed at the factory.

CARB designed the site plan, along with three highly affordable two-story homes, for this 16-unit whole-block urban infill development in east Dayton. Unibilt will supply and construct not-for-profit homes. St. Mary will develop these projects on lots donated by the city. With narrow lots, front porches, detached garages served by an alley, and modest front setbacks, the development falls within the definition of a "traditional neighborhood development." CARB's design experience with modular housing resulted in homes that are compact and economical to build and are tailored to the dimensional and construction practices of this modular builder. The project is scheduled for completion in the spring of 2002.

CARB began work with Unibilt by field-testing three of their homes in Ohio. These field measurements uncovered duct leakage and duct installation concerns. These are being addressed by a joint CARB–Unibilt design effort. A training program for dealers and their subcontractors is being developed.

To help Unibilt meet ENERGY STAR standards with their homes, CARB will train their mechanical subcontractors in the proper installation of ducts and equipment and help them bridge the gap that may exist between the modular producer and their on-site contractors. In addition, CARB is examining the company's construction practices seeking value-engineering savings. Sources of savings already identified include PEX plumbing, a less expensive electrical layout with no four-way switches, and a smaller main panel. CARB is working with Studor and Unibilt to get Studor vents approved in Ohio.

3. Technical Innovations

3.1 The CARB Package

In nearly every CARB project, one of the first approaches to a cost-effective improvement in the energy performance of the product is a group of changes we have come to call the "CARB Package." Other Building America team members have discovered the importance of a similar package independently, as have other innovators outside the program. The term is not intended to imply that CARB is the sole, or even the earliest, user of the idea. The package typically works only when the home has central AC.

First, the package includes at least these two measures that add cost:

- better glazing, typically to high-performance low-E glazing
- better sealing and insulation of ductwork (where possible, by bringing the ductwork inside the envelope or covering it with full-depth attic insulation).

These measures reduce the peak cooling load in the home. This allows the AC equipment to be downsized without compromising comfort (indeed, these homes prove noticeably more comfortable than conventional designs).

The savings from downsizing the AC equipment, combined with minor savings achieved by reducing duct runs, reducing oversized windows, eliminating exterior plumbing vents, and reducing the amount of framing, pay for the better glazing and insulation. When one AC unit can be substituted for two, the savings can be even more dramatic. Finally, if the homeowner is purchasing electric power on a demand rate schedule, an added savings is possible with the CARB package because the AC unit is smaller and draws less power during peak load conditions.

At the positive extreme, applying the CARB package to a production home not only can cut the peak cooling load by almost 40% and annual energy consumption by about 30%, it can also save the builder $1,500 per home (the savings resulting from substituting one AC unit for two and reducing window size). At the other extreme, a builder who already uses bronze double-glazing and builds a tight home may find that the package would cost the consumer at least $1,000, causing the builder to reject the package.

CARB has consistently found that cooperation by the mechanical subcontractor is an essential element in making this package work. Because the package dramatically reduces the scope of the subcontractor's work in the home, it takes a very far-sighted contractor to see any advantage to the scheme. Most mechanical subcontractors refuse to downsize the equipment, supposedly out of fear of callbacks, despite assurance by the builder that the energy-saving measures will be applied. Builders are also afraid their competition will market against the smaller AC units on the mistaken philosophy that "bigger is better."

In hot and humid climates, oversized equipment compromises humidity control in the home and creates a strong potential for mold and mildew. The reduced loads resulting from better glazing and better duct leakage control must be accounted for, and downsizing must be included in the package.

CARB builders have tackled this problem in a variety of ways. Mercedes Homes had the leverage to insist that the subcontractor make the changes or lose the work. CARB then worked with the subcontractor to correct the subcontractor's assumptions in his Manual J heat-gain calculations.

Regarding specific components, the glass specified in most cases is some form of "high-performance" low-E glass, such as Cardinal's Low-E^2, or the new PPG high-performance SolarBan 55 and 60 glazings. However, simply changing to conventional low-E (which is cheaper) often makes a significant difference compared to clear glass, despite relatively high solar heat-gain coefficients (e.g., 0.6).

3.2 Product and System Innovations

CARB, in compliance with the Building America philosophy, explores a wide range of innovative products and systems. A few examples of these products and systems are discussed below.

Photovoltaic (PV) Solar Systems

Utility and state incentive programs (discussed elsewhere), coupled with the recent energy supply crisis in California, have made PV solar systems economically feasible on many production homes for the first time. Beazer Homes is offering a PV option in northern California (subsidized by SMUD), and other Beazer divisions are considering PV.

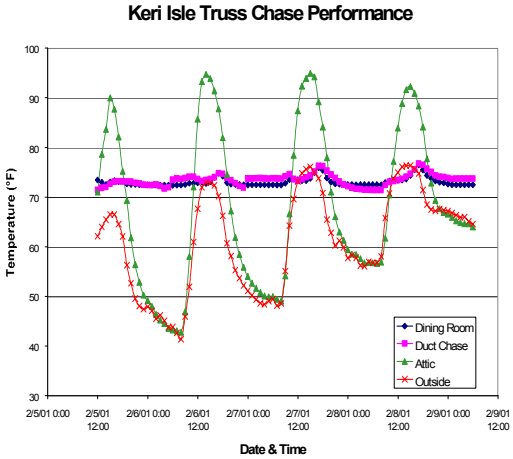
Builder reaction to the arrays is interesting. Given a choice between a lower-cost array mounted above the roof on standoffs or a higher-cost array producing the same power, but integrated into the roof – and most important, installed by the roofer – they unhesitatingly choose the latter. Currently, one company produces a handsome panel with cells adhered to a roofing tile, ready for plug-in attachment. The roofer attaches these tiles to a double grid of wood supports, which allows the wiring to run under the tiles. The roofer plugs them together according to manufacturer instructions. Builder objections to the standoff arrays include the need to coordinate another trade to install the roof, worries about how to fix the roof below, and appearance.

If one of an array of cells or panels is shaded, it will shut down all the cells wired in series with the shaded cell(s). For this reason, some care is needed to locate plumbing vents, chimneys, ventilators, and other roof projections so they do not shade the array during useful collection hours.

The CARB "Plenum Truss"

CARB targeted ductwork in the attic as a major source of thermal losses during work with Mercedes Homes in Melbourne, Florida. CARB first experimented with ductwork buried under attic insulation. This idea is almost uniformly rejected in humid climates on the theoretical assumption that ductwork will sweat excessively in humid attics if it is insulated outside of its vapor-tight cover. CARB testing, however, found that flex ductwork deeply buried under attic insulation did not sweat enough to be a problem and in that limited circumstance would consider applying the technology to smaller ducts fully buried in R-30 or deeper insulation. Whether less deeply buried ductwork, or large ducts wrapped with R-30 batts, would sweat unacceptably is a topic that justified further study. We know of one producer of manufactured homes and one builder who routine bury ductwork only partially under attic insulation in homes built for hot-humid climates. There are, however, anecdotal reports of damage from condensation at buried ductwork in hot-humid climates.

Taking advantage of the fact that Mercedes owns its own truss facility, CARB worked with the company on the design of a truss having a 40.6-cm-deep (16-in.) duct chase in the middle half of the attic, interrupting the bottom chord. The plenum is made wide enough to run over every room in the home, allowing all ductwork to be set into the recess. This "plenum truss" design was tried out on the six preproduction homes in Melbourne. The framers line the top and sides of the plenum with roll or sheet material (ThermoPly or Barricade housewrap) while framing and install a preassembled bottom chord with hangers, to continue the line of the ceiling (Figure 7). Ducts are then installed between the ceiling chords inside the plenum. Next, insulation is blown over the plenum. In NREL tests, the air in the duct chases was almost at the same temperature as that in the spaces below, showing that the plenum trusses were working as designed.



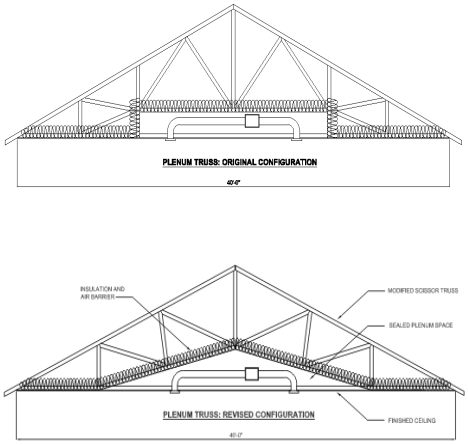


Figure 6. The CARB "plenum truss" is one innovative approach to moving ducts into conditioned space

After costing out the plenum trusses, Mercedes decided that approximately $400 (about 150 board-feet of truss lumber) needed to be saved in each home for the trusses to be cost-effective. CARB and Mercedes' truss group are working to refine an earlier scissors-truss design that promises to reduce the amount of lumber used. In the meantime, Mercedes is building its ENERGY STAR concrete homes without the plenums, placing well-sealed ductwork in the attic as usual.

Florida recently passed a regulation limiting the room-to-room pressure difference during mechanical system operation to a very low 2.5 pascals. As a result, the use of plenum trusses will probably increase in that state. A well-sealed plenum provides an effective way to move return air around the home, merely by inserting grilles into the plenum from each room.

PEX Water Supply Piping

The use of cross-linked PEX tubing in lieu of copper or chlorinated polyvinyl chloride (CPVC) for water supply piping is increasing steadily in the country, but the technology does not yet have a major share of the market. CARB has introduced many of its builders to the technology, which they adopt and learn to favor. In some cases, the piping is run to a central manifold near the water heater, where the homeowner can turn off individual fixtures anywhere in the home (each fixture is served by its own "home run" tubing). One advantage of this system is that almost all the joints in a manifolded system are out in the open. Another advantage is that no torches are used to make the fittings, eliminating a significant fire hazard. PEX manufacturers claim less heat is lost with PEX tubing than with metal piping.

"Studor" Air-Admittance Valves

Spring-loaded air-admittance valves were invented and popularized in Europe. They have been used for years in mobile homes (which, since 1976, have been properly called *manufactured homes* or *HUD-Code homes*). These devices allow air to enter the plumbing system, replacing venting through the roof. Unfortunately, the spring-loaded devices gained a reputation for early failure through rusting.

Studor air-admittance valves are made entirely of plastic and use a long-lasting plastic diaphragm to seal the valve when it is not admitting air. Because of its light weight, the diaphragm opens and closes by air suction and pressure, without the need for a spring. These valves effectively eliminate most of the vent piping in the home (although one vent needs to run through the roof somewhere in the home). State by state, Studor has fought opposition to the product's use and gained its acceptance. CARB recommends its use to all its builders, who typically accept the product and the resulting cost savings wherever its use is allowed.

Precast Concrete Foundations Systems

In several projects, CARB has specified one of two precast concrete foundation systems, the one made by Superior Wall or the one made by Kistner Products. These systems are similar in that they stiffen a relatively thin concrete wall with spaced vertical ribs and with ribs at the top and bottom. The trick is to insulate these panels effectively, as the structural integrity of the panel depends on some continuity between the ribs and the panel, and these connections become routes for the transmission of heat around the insulation. CARB is working with Kistner to develop alternative approaches to insulating the panels and several innovative manufacturing improvements. Beam support and off-size modules are areas of work. In the meantime, CARB builders are exploring cost savings, in particular those resulting from the ability to set basement walls during freezing weather without cold weather protection.

Poured-in-Place Concrete Walls

Again, working with innovation-minded Mercedes Homes in Melbourne, Florida, CARB has experimented with alternatives to conventional concrete masonry construction to increase speed of production, as well as hurricane and termite resistance. In an early experiment, CARB worked with a Mississippi precaster on a system where steel studs were embedded in thin concrete panels, which were preengineered and shipped to the job for erection. When these proved too expensive, Mercedes tried conventional poured concrete, but found that irregularities at the joints resulted in "telegraphing" through the spray-applied stucco, obviating the cost advantages of eliminating one of the substrates for the stucco. The advantages of using poured concrete, however, proved to be substantial (Figures 8 to 10).

Figure 7. Concrete-wall reinforcing cage

Figure 8. Modular aluminum wall forms

Mercedes then purchased a set of expensive aluminum forms (Figure 9) for its Melbourne division, which included the detailed formation of a "buck" at window and door openings. These forms have proved extremely successful, and Mercedes recently purchased another set of forms for its Orlando division. With only minor epoxy grouting at form-tie holes and a single sprayed-on undercoat, the final sprayed-on masonry coating is smooth and does not show form joints. The great advantage of a monolithic concrete home during hurricanes is a major selling feature.

To insulate the walls, CARB specified 19-mm (3/4-in.) foil-faced rigid polyisocyanurate foam insulation adhered to the concrete to avoid cavities outside the insulation that might encourage mildew growth. Interior finish is a layer of gypsum board mounted on furring strips. This design provides approximately double the thermal performance as their prior standard practice of 20.3-cm (8-in.) concrete masonry unit (CMU) walls with a radiant barrier applied between the gypsum board and supporting furring strips.

Wall forms are erected and the walls are poured in one day, and the wall forms are stripped on the next day (Figure 10). Originally, Mercedes thought they could eliminate two of the three stucco layers because of the smooth surface of the concrete, but at present are employing a modified two-coat process to prevent potential undesirable aesthetic effects. Only minimal surface preparation is required after the forms are stripped (i.e., a dab of epoxy at each form tie). A primer coat (stucco base) is then applied, over which traditional cementitious stucco is sprayed in a single coat. No joint telegraphing is noticeable. The average time to install form work and pour concrete for one house is down to 2 days, versus 5 to 6 days for a CMU wall.

Figure 9. Concrete is poured the morning of day 2, and forms are stripped the following morning

Lighting and Appliances

When possible, as with the higher-end homes produced by Tindall Homes in southern New Jersey, CARB attempts to promote the use of ENERGY STAR appliances. The appliances add cost and are not yet in high demand by consumers, so it is rare when they are added to the builder's product line as a standard, or even as an option. Options are typically oriented towards luxury, not energy savings.

Fluorescent lighting is gradually taking hold in the marketplace, overcoming long-standing customer resistance. New correct-color and instant-start fluorescent lamps help a great deal to sell the concept, but the slow ramping to full brightness and the unusual appearance of some lamps still restrain consumer acceptance. Using fluorescents requires judgment in choosing lamps that are likely to be lit enough of the time to justify their extra cost.

Heat Pump Water Heaters

CARB's builder member Mercedes Homes plans to include a heat pump water heater in one of its homes to help identify performance and installation issues as part of an 18-unit demonstration project organized by Oak Ridge National Laboratory (ORNL). A fully-instrumented WatterSaver unit, manufactured by ECR International, will be installed in a four-bedroom home likely sold to a family with children. This new product is designed as a fully integrated package that can be installed in place of a conventional electric-resistance water heater by a plumber with no extra training. The unit will be monitored for 12 months with equipment supplied by ORNL. The laboratory will also monitor the unit's installation.

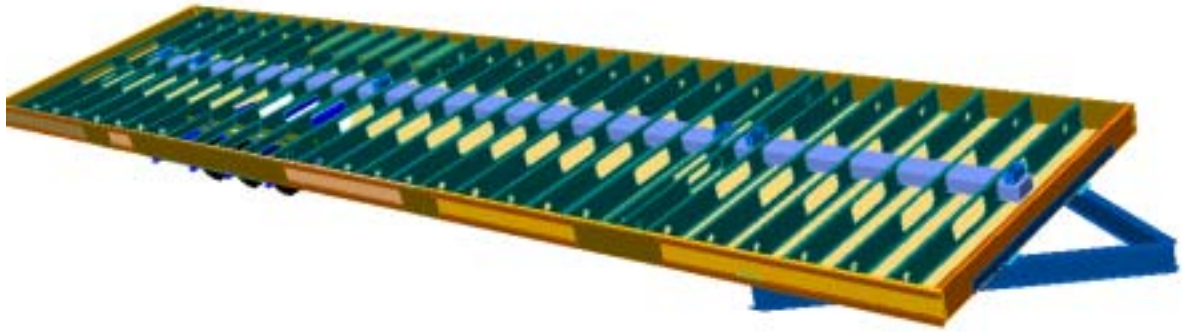
Steel Floor System for HUD-Code Home (Manufactured Home)

As described in Section 2, CARB is working with Palm Harbor Homes, a leading producer of HUD-Code (manufactured factory-built) homes, on an innovative floor system made with steel joists.

Conventional HUD-Code homes have a pair of longitudinal "chassis beams" for long home sections, at approximately the quarter points in width. These beams provide a convenient attachment place for the springs that support the wheels and axles that carry the home section to the site. They also provide longitudinal stiffness and carry the 2-x-6" or 2-x-8" floor joists that (compared with the 2-x-10" joists required for fully spanning joists) contribute to the economy of the homes. Ductwork runs between the chassis beams; batt insulation is trapped between the joists and beams, draping under the ductwork. Directly under the insulation is a black plastic "bottom board," which, because it exposes the beams and has an unsightly draping shape, provides an unattractive label that this is a HUD-Code home. Another negative feature of this system is the need to support the outside walls and chassis beams to prevent sagging floors and roofs.

The CARB/Palm Harbor floor system (Figure 10) replaces the longitudinal beams with laminated veneer lumber running under the sidewalls and intended to rest on a perimeter foundation or on piers. Between them run the steel floor joists, 35.5-cm-deep (14-in.) with 25.4-cm-deep (10-in.) oval holes for ductwork. A grid of steel beams forms a carriage that transmits the dead load and transportation stresses from the longitudinal side beams to the springs. This grid cannot be removed according to present law, but in the future may be removable.

Figure 10. The CARB/Palm Harbor Homes floor system for HUD-code manufactured homes



Except for the wheel recesses and the wheel-support carriage, the underside of the floor is a flat and uniform surface formed by a layer of foam insulation attached to the steel joists to suppress any cold bridges. Covered with a simple protective layer, this will form an attractive visible ceiling over the basement or crawl space.

CARB also contributed an innovative idea to the design of the carriage by welding the beams at an angle. This allows the use of lighter and stiffer 15.2-cm-deep (6-in.) beams and raises the outside end of the beams above the foundations.

3.3 Indoor Environmental Quality (IEQ)

CARB is using and evaluating a wide range of technologies that directly or indirectly influence IEQ. This work is gaining increased importance as buyers become more conscious of and litigious about mold and mildew.

Balanced Return Air

Many single-story homes are built with large owners' suites that can account for 40% of the home's living area and that are separated from the main living space by a single door, often closed. If, as is usual, the air distribution system has a single large return air (RA) grille within the main living space, a large part of the RA must find its way from the owners' suite to this central register under this closed door.

CARB has found, as have many other investigators, that when no special provisions are provided for this purpose, very large pressure imbalances can arise during operation of the air handler. We have measured pressure differences of 28 pascals (equivalent to about 1/8 in. water gauge), while at least one case of a 68-pascal difference (more than 1/4 in. water gauge) was reported to CARB anecdotally by another investigator. Under such conditions, the starved RA system draws air from outside, from the attic, and from the garage, bringing with it various pollutants and creating an artificial load on the system.

In addition to pollutants, the positive pressure created in the spaces lacking an adequate path for RA drives relatively humid air into the wall cavities in the heating season. This can create condensation or can raise the moisture content of the wood above safe levels. More serious is the effect of negative pressure in the living spaces during the cooling season in humid weather. Humid outside air is drawn into contact with the cool inside wall and ceiling finishes, resulting in mold and mildew buildup.

Some codes are beginning to regulate this problem, requiring that the maximum pressure difference induced in the home by air handling equipment be kept in the 2.5 to 3 pascal range (0.01 in. water gauge). CARB field measurements show that this result can be accomplished by the measures described below.

One common solution to this problem is to provide a separate system of RA ductwork from each room, typically run in the attic. Unless the ductwork is buried and carefully sealed, CARB recommends that other systems be substituted for this expensive approach. In the typical case, leakage in the attic RA ductwork draws in pollutants and unconditioned air. In one home tested by CARB, a section of the RA main was never connected, with the result that almost all the RA in the home was being drawn in from the attic. The moral of this example is that major errors often go undetected when they occur in the attic, which is hard to inspect, and can be very hot and uncomfortable to work in.

One approach recommended by CARB is to provide transfer grilles from large areas that are not part of the main living area. One simple transfer grille arrangement is to use a stud space that connects the two areas, placing a simple register at the top on one side of the stud space and at the bottom on the other. This effectively maintains visual privacy and in most cases provides adequate acoustic privacy and does not involve ductwork in the attic. Typically, for smaller bedrooms, there is no stud space in common between the room and the main living space. In many such cases, air transfer can be achieved through a

closet in the room that does have a common stud space, by placing two more grilles high on the wall between the closet and the bedroom. Because air must move through four grilles and down a stud cavity, the grilles need to be larger than normal.

More acoustic privacy can be achieved by installing a pair of grilles connected by a lined duct or by a length of flex long enough to dissipate sound. If this ductwork is in the attic, it should be well insulated and carefully sealed. The grilles and ducts need to be sized to allow the needed airflow at a pressure difference of 2 or 3 pascals (0.01 in. water gauge).

4. Summary and Recommendations

CARB has had dramatic success with one large builder, Beazer Homes. Unlike other larger builders with a centralized administration, Beazer operates as a consortium of highly independent divisions and so could be considered a collection of medium-sized builders. The other CARB "success stories" have involved medium-sized and small builders, where a key executive can act as a champion for change. Without such a champion, there is little hope to overturn the highly conservative attitudes of most large builders, who almost universally have an "if it isn't broke, don't fix it" attitude.

Market pull can be another powerful force for change, as evidenced by the dramatic improvement in the energy performance of recently built California homes. Market pull is also evident in the growing use of PV. Both these effects are a result of the 2000 energy shortage crisis in that state.

As the most important changes typically involve the AC system, having the AC sub-contractor on board as an enthusiastic, or at least accepting, partner is crucial for success. If the AC sub-contractor does not cooperate, pressure is needed from the builder to accomplish change. In the case of one large builder, the intense pressure they applied to the sub-contractor to reduce costs and profit margins produced resistance and suspicion that soured all attempts to make changes in the system.

The need for buy-in extends to other subs as well. It is not always easy to make tradeoffs where money is saved by one trade and a lesser amount added to another. Using innovative plumbing devices such as Studor vents, PEX or KITEC piping, and flexible gas piping requires forward-looking subcontractors. Systems that bridge the work of two trades, as in hydro-air heating coils fed by a water heater, can create headaches with regard to servicing and warranties. The development of the CARB Plenum Truss depended upon the truss fabricator being owned by the General Contractor. Window fabricators often are not willing to change the type of low-E glazing they use from older hard coat materials to newer soft coat products because of handling difficulties in the plant.

Insisting on quick results can be counter-productive when dealing with an industry as conservative as homebuilding. It is often essential to build trust with key management over a considerable time. CARB has found that builders will "test" the ability of the consortium to help them by assigning smaller tasks, the results of which can be evaluated before committing to a larger effort. This again takes time and sometimes seems to be tangent to the main thrust of the program. Helping the builder in the short run creates the confidence needed to accomplish the goals of the Building America program in the long run.

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13. ABSTRACT *(Maximum 200 words)* *This report describes the various projects by the Consortium for Advanced Residential Buildings (CARB) that were active during the first 10 months of 2001, summarizing results, benefits, lessons learned, and future plans. The second part of this report describes technical matters, summarizing innovative technologies, systems engineering and results, and industry team member contributions.*

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