Builder and Space-Conditioning System Challenges in Two Energy-Efficient Houses

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ABSTRACT

The builder challenges encountered in the design, construction, and commissioning of two Building America houses are reported. One house, located in Bordentown, New Jersey, was designed for 43 percent (48 percent including PV) source energy savings compared to the Building America benchmark. The other is located outside Chapel Hill, North Carolina, with predicted source energy savings of 49 percent (58 percent with PV). Both houses are two stories with three bedrooms.

These houses have to some degree been instrumented and monitored for evaluating comfort and energy performance. However, in the execution of these projects it has become apparent that for the predicted energy savings to be realized, fundamental changes in the process of designing and building houses must be embraced by the builder and their trade partners to ensure a successful project. This paper discusses the challenges faced by the builders in implementing a systems approach to higher performance housing.

INTRODUCTION

This effort documents a project team's support to two builders who have already embraced high quality, energy efficient houses toward achieving their goal of further increasing the energy efficiency, comfort, and durability of their products. The performance of two prototype houses built under the auspices of the Building America program is the subject of this work. Another objective was to document the builders' efforts at increasing the performance of the houses, including field execution and financial challenges. A snapshot of the builders' profiles may be found in Table 1. The project team worked with the builders to identify improvements to their processes as well as envelope, equipment, and renewable energy systems that would result in a higher performance house in a cost effective fashion. Automatic datalogging systems were installed to monitor performance of the houses.

Builder 1 in New Jersey

Builder 1 is a semi-custom homebuilder in western New Jersey and typically builds 20 to 25 houses a year. The homes are between 3,800 and 6,000 square feet (350-560 m^2) in floor area and feature two-stories, a full basement, and an attached two- or three-car garage. In recent years, all of their homes have met or exceeded Energy Star® energy efficiency requirements. They have indicated a willingness to continue making greater energy efficiency gains in their homes in all end-use areas.

Currently, this builder is achieving a minimum of 40 percent whole-house source energy savings when compared to the Building America (BA) benchmark (Hendron 2004) in a 39-unit community in suburban Trenton, New Jersey. Original plans included a solar electric system on every house in the community. However, the house orientations are not optimized for easy placement of roof-mounted solar electric arrays. This builder opted to take the unique approach of mounting the photovoltaic (PV) systems on garden sheds. This strategy optimizes the orientation of the panels and allows greater flexibility in site planning, house orientation, and aesthetics. Construction is continuing, and the project team is providing ongoing engineering and field training support to

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Table 1. Overview of the Builders Involved in This Study

	Builder 1	Builder 2
Location	Suburban Trenton, NJ	Chapel Hill, NC
Climate Region	Mixed humid	Mixed humid
Houses Per Year	20–25	10
Floor Area	3800–6000 ft^2 (350–560 m^2)	2500–4000 ft^2 (230–370 m^2)
Type	Semicustom	Custom and semicustom

the builder. Additionally, the project team is working with the builder to further develop process and cost effectiveness.

Builder 2 in North Carolina

The project team has also been working with Builder 2 in Chapel Hill, North Carolina. Builder 2 has worked with the project team to construct a prototype home that was used as a test bed for strategies to be applied in an energy efficient, community-scale project. The intent is to achieve at least 40 percent residential building source energy savings for all homes in the community.

Builder 2 is focused on using existing technologies to improve the thermal envelope and energy efficiency of the houses they build in a cost effective way. They use passive and active solar strategies to further reduce energy consumption and include PV to generate electricity. The project team, the builder, and their design team collaborated on integrated design, engineering, and construction processes in the prototype house so that lessons learned there could be applied to the larger community.

In order to achieve and sustain the advanced level of energy efficiency, several major construction practices had to be changed and improved. These changes went beyond simply improving the building specifications and extended to changing and educating all those involved in the construction process, inside and outside the builder's organization.

Monitoring Systems

The project team installed data acquisition systems in both houses. The goal of the instrumentation in the NJ house was primarily to capture comfort and HVAC system efficacy indicators. The NC house has a more detailed instrumentation scheme that will allow for a breakdown of the energy use of various systems in the house as well as general environmental variables needed for comfort studies. The locations of the temperature and relative humidity measurements are shown in the plan drawings of the houses in Figures 1 and 2. In this study, it is assumed that the efforts made by these builders to build better performing houses from an energy standpoint will be successful to some extent. The main results from the monitoring systems are used here to look at HVAC system efficacy at providing comfort.

STRATEGIES AND ARCHITECTURAL SPECIFICATIONS—BUILDER 1: NEW JERSEY

Builder 1 chose to make upgrades in multiple areas in a whole house systems approach, which allowed for a balanced performance gain and maximized utilization of the project team's experience. Builder standard and as-built architectural specifications are found in Table 2. The builder-supplied estimated upgrade costs, which include materials and labor, are listed in the table as well. Plans of the first and second floors are shown in Figure 1, including pertinent measurement locations.

Preinsulated, Precast Foundation

Builder 1 replaced its standard foundation with pre-insulated, pre-cast concrete walls. The concrete formulation and joint sealing methods are designed by the manufacturer for freeze/thaw and moisture protection without the need for further damp proofing. The wall system provides for a continuous layer of R-12.5 insulation in the foundation wall, offering good thermal performance with no added processes at the site. Being a modular, pre-cast system, the foundation can be installed in one to two days in all weather conditions, reducing cycle time.

Envelope Improvements

Builder 1's previous practice had been to install unfaced fiberglass batt insulation in conventional 2x4 (nominal) stud framing, 16 in. on center (38mm x 89mm @ 0.4 m OC). By using 2x6 (nominal) framing, 24 in. on center (38mm x 140mm @ 0.6 m OC), for the prototype house, the framing fraction and conductive heat loss through exterior walls were significantly decreased. Three inches (76 mm) of urethane foam within walls increased the insulation to R-18 and aided airtightness. For the ceiling insulation, the builder chose to use R-30 kraft-faced fiberglass batts with an added R-19 of blown-in cellulose insulation. The garage ceiling, which is below the master bedroom, was insulated with two inches of urethane foam and R-30 kraft-faced fiberglass insulation. The unconventional use of multiple insulating materials was a choice the builder made to protect himself. The main rationalization was that he had not worked with blown-in cellulose and had reservations about it providing adequate insulation in certain problem areas. He and his team already understood how to detail those difficult areas using fiberglass. Using fiberglass for the initial R-30 insulation levels made him confident in providing

Table 2. Builder 1—Standard and Prototype House Specifications and Upgrade Costs (Material and Labor) for the New Jersey House

	Standard Specifications	Prototype House	Estimated Upgrade Cost
Building Envelope			
Ceiling (Flat)	R-30 unfaced fiberglass (FG) batts	R-30 kraft-faced FG batts + R-19 cellulose	+$1050
Ceiling (Cathedral)	R-30 unfaced FG batts	R-30 kraft-faced FG batts	
Garage Ceiling	R-19 unfaced FG batts	2 in. (5 cm) urethane foam (R-12) + R-30 kraft-faced FG batts	+$550
Above Grade Walls	2 × 4 framing, 16 in. OC (38 × 89 mm @ 0.4 m OC), R-13 FG batts, R-3 exterior rigid sheathing	2 × 6 framing, 24 in. OC (38 × 140 mm @ 0.6 m OC), 3 in. (7.6 cm) urethane foam (R-18)	+$1000 for framing +$4000 for insulation
Basement Walls	Site-poured concrete basement walls with R-13 foil-faced FG batts	Precast, preinsulated concrete walls with exterior R-12.5 insulation	+$7000
Windows	Low-E, vinyl, argon-filled, U = 0.35, SHGC = 0.30	Low-E, vinyl, U = 0.36, SHGC = 0.33	+$0
Infiltration	Not tested	Tested at 3.2 ach_{50}	
Draftstopping	Main air barrier, interior drywall, often not continuous. Common troublesome airflow paths identified.	Draftstop sheathing behind tubs, showers, and fireplaces and the attic side of kneewalls	+$90
Airsealing	Housewrap with joints taped, sill sealer, caulk/ foam at interior of sill plates, foam around rough openings of windows and doors, penetrations in top plates	Same as standard practice	+$0
HVAC			
Heating	Two 92.1% efficient gas furnaces. Both @ 75,000 Btu/h (22 kW) input capacity. One furnace was located in vented attic space.	Two 92.1% efficient gas furnaces in conditioned basements. First floor, 75,000 Btu/h (22 kW) input; second floor 50,000 Btu/h (15 kW) input.	–$500
Cooling	Condensing units (2) are 14 SEER (nominal) with a 3-ton (10.6 kW) or 3.5-ton (12.3 kW) capacity	One 13 SEER, 2.5-ton (8.8 kW) unit and one 14 SEER, 3-ton (10.6 kW) unit	–$300
Ductwork	Sheet metal or flex duct. R-6 insulated flex duct used in unconditioned attic	Sheet metal or flex duct entirely in conditioned space. Attention paid to airsealing with mastic. Target duct leakage 6% of total airflow.	+$0
Ventilation	Ventilation air drawn into return plenum	Heat recovery ventilator	+$450
Structural Integration	Minimal. Use of TJI floor structure.	Improved with use of open web floor trusses	+$0
Water Heating	A power-vented 75-gallon (284 L) gas water heater with 76,000 Btu/h (22 kW) input and an energy factor of 0.59.	2-tankless water heaters with 15,000-180,000 Btu/h (4-53 kW) input and energy factor of 0.81.	+$1700
Lighting	100% Incandescent	95% fluorescent (strip and compact)/5% incandescent	+$500
Solar Electric Generation		2.64 kW grid-intertied PV system	+$12,000
		Total Without PV System	+$15,540
		Total Including PV System	+$27,540

at least that level of thermal resistance. Insulation levels were then augmented through the addition of blown-in cellulose. The decision-making process was similar in the case of the foam and fiberglass hybrid system in the garage ceiling.

Draftstopping on the unconditioned side of kneewalls as well as behind tubs, showers, and fireplaces was verified during construction.

Optimized Heating, Air Conditioning, and Ventilation

Because of the size and design of the floor layouts and structure, Builder 1's houses were typically conditioned by two heating, ventilating, and air conditioning (HVAC) systems: one located in the basement to serve the first floor, and the other based in the attic to serve the second floor. Locating the second floor HVAC system in the unconditioned attic leads to significantly increased energy use and greater potential for comfort issues. Working with the project team, Builder 1 elected to move the attic HVAC system to the conditioned basement. This change was facilitated by the use of open web floor trusses and an architecturally integrated duct layout. Open web floor trusses were especially important for the second floor, because they allowed ductwork to run through conditioned space, enabled both HVAC systems to be placed in the basement, and simplified installation of other mechanicals like plumbing and electrical. Two zones on each floor increase the flexibility and comfort of the systems.

The standard ventilation system was replaced with a heat recovery ventilator connected to the return plenums of both furnaces. This upgrade was done to provide adequate, balanced, and well-distributed ventilation while using the conditioned exhaust air to temper the incoming fresh air.

The project team's recommendations allowed the builder to decrease the size of the heating and cooling equipment. Smaller equipment reduced the cost to the builder. Bringing the HVAC system within conditioned space contributes to energy savings.

Plumbing, Domestic Hot Water, Appliances, and Lighting

A home-run plumbing strategy with manifolds for hot and cold water was used in the prototype house. The home-run plumbing scheme was chosen for its potential energy and water savings (NAHB Research Center 2002). Two tankless water heaters with an energy factor of 0.81 were installed in order to increase efficiency of the domestic hot water system. The tankless heaters have a much better energy factor and avoid the standby losses associated with the large tank-type water heaters the builder previously specified. The choice to install two tankless water heaters instead of one larger was made so that the system could efficiently handle both minimum and maximum estimated hot water flow rates. Installed lighting was 95 percent fluorescent (linear and compact) and 5 percent incandescent. Energy Star or equivalent appliances are recommended, but are not provided, by the builder to all homebuyers.

Solar Electricity Production

At the time of construction of the prototype house, New Jersey was offering an aggressive state rebate program for PV systems. A 2.64 kW grid-intertied PV system was installed at the prototype house. The PV system inverter powers the house electric panels and surplus electrical energy is sold to the grid via net metering. The state incentives have been reduced and now the builder offers PV as an option, but no longer installs the systems as a standard feature.

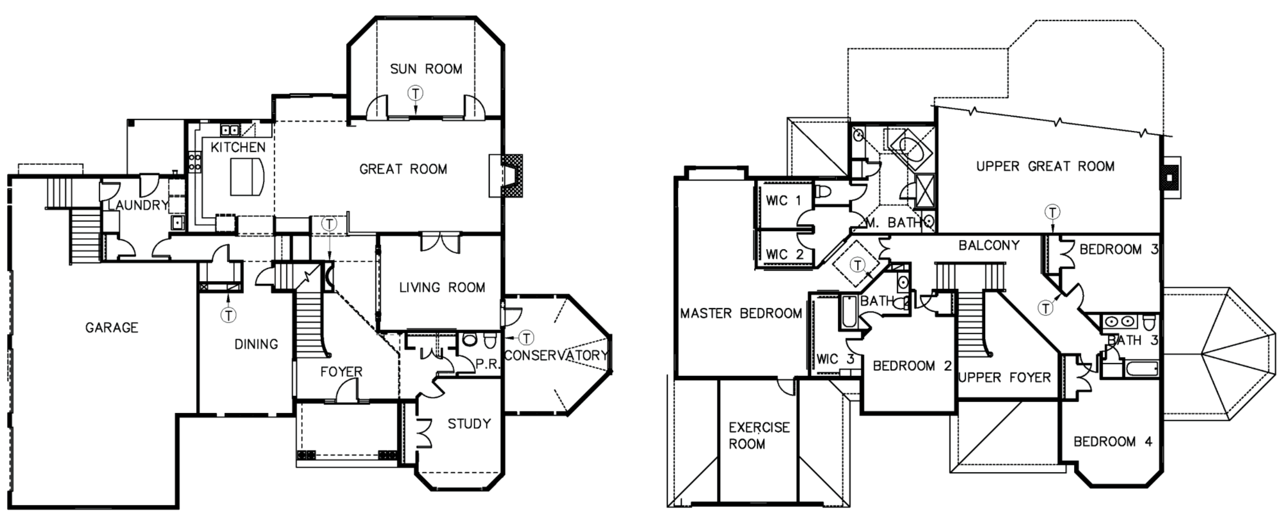

Figure 1 *New Jersey prototype house 1st floor plan (left) and 2nd floor plan (right). Temperature measurement locations are indicated.*

Building America Benchmarking

The project team performed energy analyses of the prototype, builder standard, and benchmark houses using a residential hourly energy simulation tool that uses DOE-2.1E. The applicable comparison at the time of analysis was the Building America Benchmark, which approximately describes the energy attributes of a house with similar architecture built to mid-1990s national U.S. model energy codes. The prototype house is estimated to use 43 percent less source energy annually than the benchmark due to the energy efficiency measures, of which the heating savings dominate the change. The addition of the PV system increases the savings to 48 percent. This package of measures equates to approximately 18 percent source energy savings compared to the builder's standard practice (excluding PV).

STRATEGIES AND ARCHITECTURAL SPECIFICATIONS—BUILDER 2: NORTH CAROLINA

A short list of specifications in the as-built North Carolina prototype house may be found in Table 3. The as-built house is a refinement of the builder's standard practice in multiple areas. As Builder 2 explored different strategies and processes, the standard practice varied from each custom-built home to the next prior to this prototype house. In light of this, the table describes the current prototype house specifications, and the standard practice is not listed. Floor plans may be found in Figure 2.

Sealed, Conditioned Crawlspace

On the prototype house, Builder 2 insulated the sealed crawl space foundation walls with R-10 interior insulation provided by 1½ in. (38 mm) thick polyisocyanurate rigid board insulation that meets flame spread and smoke developed code requirements for exposed applications. A polyethylene vapor retarder was used under the slab of the crawl space. The crawl space is indirectly conditioned by the HVAC system. The builder standard practice is to install at small dehumidifier in the crawlspace drained to the subslab drainage system as soon as the floor deck is installed, to eliminate construction-related moisture and prevent long-term moisture problems.

Improvements to the Building Envelope Thermal Performance

To reduce heating and cooling loads, Builder 2 utilizes passive solar design principles. The lots and houses were located within the community with solar orientation in mind. Solar gain through windows and doors in the southern orientation reduce heating loads in the winter. This strategy included installation of double glazed, clear fenestration with high solar heat gain values (SHGC of 0.81) in the southern orientation. On east, west, and north orientations, the use of low solar heat gain windows with a SHGC of 0.33 reduces cooling loads in rooms facing those directions. Overhangs on southern windows minimize overheating in the summer.

On the above-grade walls, ½ in. (13 mm) extruded polystyrene rigid board insulation sheathing was installed. Metal T-bracing was installed in lieu of oriented strand board (OSB) sheathing to provide lateral load resistance. In addition to its thermal properties, the ½ in. (13 mm) extruded polystyrene rigid board insulation sheathing was used as a drainage plane. Builder 2 tapes all joints in the sheathing. This helps to enhance

Table 3. As-Built North Carolina Prototype House Specifications

Crawlspace	Unvented, conditioned; foundation walls insulated on the interior (R-10) with rigid insulation
Above Grade Walls	Exterior R-3 insulating foam sheathing; R-19 fiberglass batts
Roof Rafter Cavities/Ceiling Areas	R-30 fiberglass batts
Windows	Low-e, SHGC = 0.33, U = 0.47 in north, east, and west; high solar gain, SHGC = 0.81, U = 0.47, south; more effective flashing practices at windows and doors
Airtightness	Continuous interior air barrier (drywall) and sealing of penetrations; air leakage target of 5.0 ach_{50}
HVAC	Single 90% AFUE dual fuel furnace located in conditioned space; SEER 10 condensing unit
Ductwork	Entire distribution system fully ducted, within conditioned space as much as possible; ductwork minimized through use of a central return; all ductwork is sealed to improve airtightness; system air leakage to outside must not be more than 3% of system cooling airflow at 25 Pa
Ventilation	A passive ventilation system connected to the return air plenum with mechanical damper and controller to regulate the airflow
Water Heating	Two closed-loop flat-plate collector panels; PV-driven pump; external heat exchanger; 80-gallon (303 L) storage tank with electric backup
Lighting	85% of bulbs are energy efficient (compact and linear fluorescent)
Appliances	Energy Star or equivalent appliances
Solar Electricity Generation	1.92 kW PV system, grid intertied and battery storage

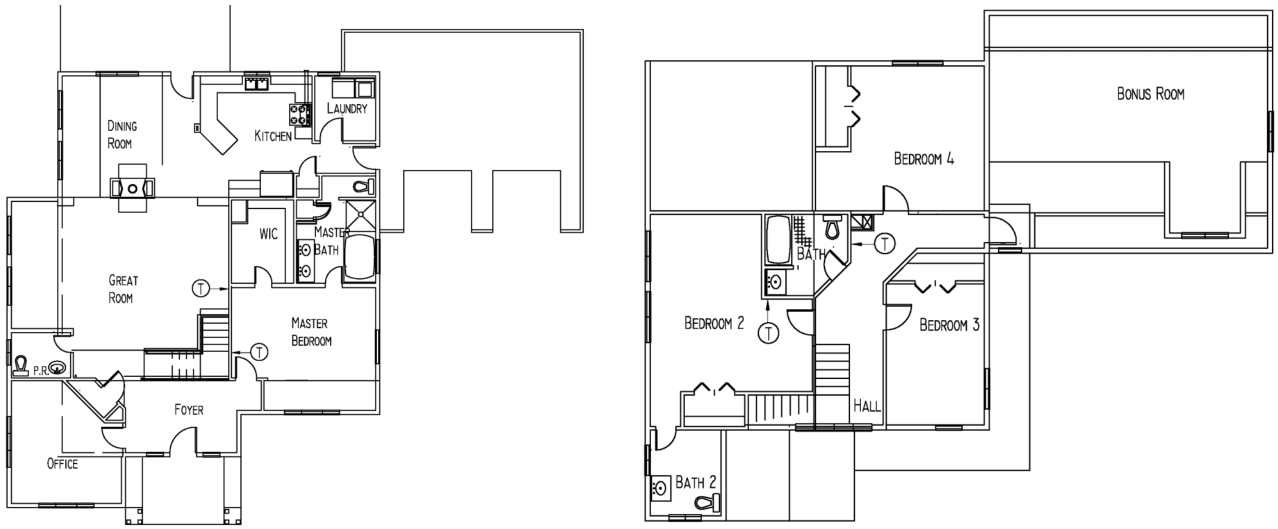

Figure 2 *North Carolina prototype house 1st floor plan (left) and 2nd floor plan (right). Temperature measurement locations are indicated.*

wall airtightness and makes use of the insulation as a drainage layer. Radiant-barrier roof sheathing reduces the temperature of the attic in the summer and reduces cooling loads.

Optimized Heating, Air Conditioning, and Ventilation

The builder's standard practice had been to install two systems, one in the conditioned crawlspace, and one in the unconditioned attic. The systems in total were oversized by approximately 12,000 Btuh (3.5 kW). On the project team's recommendations, a single, zoned system was chosen and located in the conditioned crawlspace. First floor ductwork was run in the conditioned crawlspace, and the second floor was serviced by insulated ducts run through the unconditioned attic.

High efficiency heating equipment was selected. The HVAC system consists of an electric air source heat pump with an HSPF of 8.0. A condensing propane furnace with 92 percent AFUE, rather than a traditional strip heat system, was installed as an independent cold weather back-up system. On the cooling side, the system is rated at an at-that-time code minimum of SEER 10. Although the builder is very proactive with the adoption of many energy efficiency improvements, he does not believe that higher efficiency air conditioning units are cost-effective within a short time frame in that climate. Energy analysis on the well-insulated, well air-sealed passive solar design indicates that installing a SEER 13 unit would amount to only $65 in annual energy cost savings, or less than $5 per month. At an incremental cost of $800, the simple payback for a SEER 13 unit would be 12.3 years. While from an annualized cash flow basis, the consumer would be roughly cost neutral with the higher SEER equipment, the builder has indicated that this first cost is tough to market to homeowners.

Solar Domestic Water Heating

Builder 2 uses two roof-mounted, closed loop flat plate collector panels with a PV-driven pump and an external heat exchanger attached to a modified 80-gallon (303 L) storage tank. The DHW storage tank is a high-efficiency electric tank-type water heater with only the upper heating element active.

Solar Electricity Production

An array of 12, 160W PV panels were installed on a south-facing roof of the prototype house. The PV system has battery storage capable of powering critical loads during grid power outages. The homeowners participate in the North Carolina GreenPower program, a dual metering arrangement that pays a premium for renewably generated electricity.

Building America Benchmarking

The project team performed energy analyses of the prototype, regional standard, and benchmark houses using a residential hourly energy simulation tool utilizing DOE-2.1E. The prototype house is estimated to use 49 percent less source energy annually than the benchmark due to energy efficiency measures. The addition of the PV system increases the savings to 58 percent. For comparison, the prototype house simulation shows a 39 percent reduction in source energy relative to a house built at the current regional standard.

RESULTS

New Jersey Prototype House Monitoring Data

Four months of data have been collected from the New Jersey prototype house. Measurements of whole house electrical usage, PV energy generation, and interior and exterior temperatures and relative humidities were made and collected. The system was initially installed in March 2006, but reliable data was not obtained consistently until the end of 2006. A series of technology failures as well as difficulties in coordination with the builder, trades, and homeowners resulted in the delay.

The main goal of the data collection is to assess the ability of the HVAC system to provide adequate temperature control throughout the house during all weather conditions. January through April data provide some insight into the cold- and swing-season performance of the system. Of particular interest is the temperature behavior of two high load rooms relative to the thermostat locations for each of their zones. The high-load rooms are the conservatory and the sunroom. The first floor is divided into two zones, each with its own thermostat. The front zone includes the dining room, foyer, study, and the conservatory. The front zone thermostat is in the dining room. The rear zone includes the kitchen, great room, and sunroom, and its thermostat is in the hall off the great room. The great room is a two-story, cathedralized space. Temperature measurement locations are shown in Figure 1. As shown in Figure 3, temperatures at the four first floor locations and the upper portion of the great room tracked each other. However, the conservatory and the sunroom are generally colder than the central areas of the house. Figure 4 shows the temperature differences between these rooms and their thermostats on two days with daytime temperatures in the low 30s F (~0C) and nighttime temperatures in the low to mid 20s F (~-6C). During this time, the upper part of the great room stayed within 1F (0.6C) of the first floor rear zone thermostat location temperature. The two thermostat locations for the first floor are measured to be within 2F (1C) of each other. The conservatory is consistently 4 to 6F (2 to 3C) colder than the front zone thermostat during this time period. The sunroom is 3 to 4F (1 to 2C) colder during the night relative to the rear zone thermostat, but has the advantage of the daytime solar gain to attain a more comfortable temperature during the day.

Figures 5 and 6 show the same rooms during the first week of May. The system was still in heating mode. Daytime highs are 65 to 75F (18 to 24C) and nighttime lows are 42 to 55F (5 to 13C). The only apparent time the HVAC system runs is a short period in the mornings when the system comes out of setback. During the latter part of the day, solar gain raises the temperatures in the sunroom and conservatory above those of the centrally-located thermostats. During the night, the space temperatures even out as these rooms cool faster than the core of the house. There is also a slightly higher level of stratification in the great room, as the upper portion is up to 3.6F (2C) warmer than the thermostat. The sudden drops in temperature difference for the spaces in the mornings are due to thermostat locations reacting to the heating system efforts more rapidly than the other spaces.

North Carolina House Monitoring Data

Two months of data have been collected in Builder 1's North Carolina prototype house. Measurements of whole house and subsystem electrical usage, PV energy generation, and interior and exterior temperatures and relative humidities were made and collected. The house is separated into three zones: two on the first floor and the second floor. The temperature measurement locations, as found in Figure 2, are at the thermostat locations on the first floor and in the hall on the second. Analysis shows that the space temperatures from room-to-room and floor-to-floor are consistently within 2F (1C) of each other This indicates the thermostat setpoints are probably the same for the three zones and the HVAC system is having no difficulty providing adequate conditioning during this time period.

DISCUSSION

Builder Innovation, Challenges, and Lessons Learned—Builder 1: New Jersey

The original design for the wall insulation called for 1 in. (25 mm) of spray urethane foam insulation on the interior surface of the sheathing, and then fiberglass R-15 batt insulation filling out the volume of the nominal 2x6 @ 16 in. OC (38 mm x 140 mm @ 0.6 m OC) stud bay. The local code official initially rejected the hybrid system. This was overcome by the use of the manufacturer's technical data sheets and national code approval certificate. However, in the end, Builder 1 chose to simplify the installation process by changing to the as-built 3 in. (76 mm) of spray urethane foam and no added fiberglass to fill out the remaining volume of the nominal 2x6 @ 16 in. OC (38 mm x 140 mm @ 0.6 m OC) stud bays.

In the beginning phases of this project, photovoltaic systems were a very desirable option for improving the residential energy landscape in New Jersey. At the time, builders were reimbursed for two-thirds of the investment under the state's rebate program. For Builder 1, this program provided more than $13,000 in savings on a $20,000 system. The builder analyzed the costs and benefits of possible systems, and then decided to offer photovoltaics as a standard feature on all 39 homes in this community. As the project progressed, however, state funding steadily declined, and program implementation became much stricter. The builder ended up installing solar electric systems on only 14 homes. While PV had the potential to offset another 5 ½ percent of the source energy use, it was no longer a cost-effective option.

Builder 1 has invested an additional $16,290 in first costs for its prototype house (not including the PV system) compared to standard specifications, as displayed in Table 2. Based on energy modeling, the homeowners are predicted to save approximately $1,500 a year in utility costs. The builder is dedicated to the project and feels the added first cost is worthwhile in terms of energy efficiency, durability, environmental impact, and customer satisfaction. A cash-flow analysis for the buyer was performed. Amortized costs were based on a 30-year mortgage at 7 percent interest. While the upgraded building practices required to achieve the 43 percent energy use reduction cost the buyer approximately $1,236

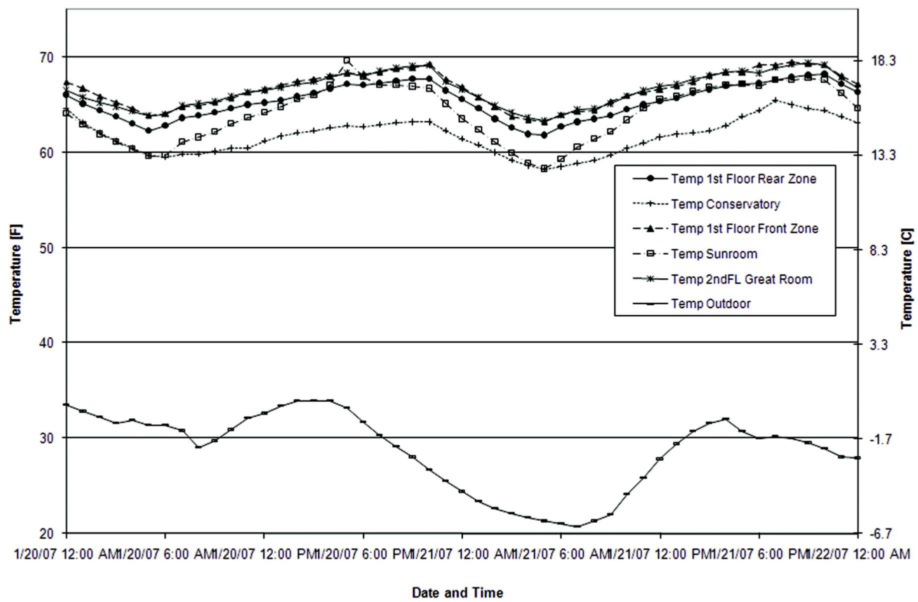

Figure 3 *New Jersey house relevant indoor and outdoor temperatures during two cold days.*

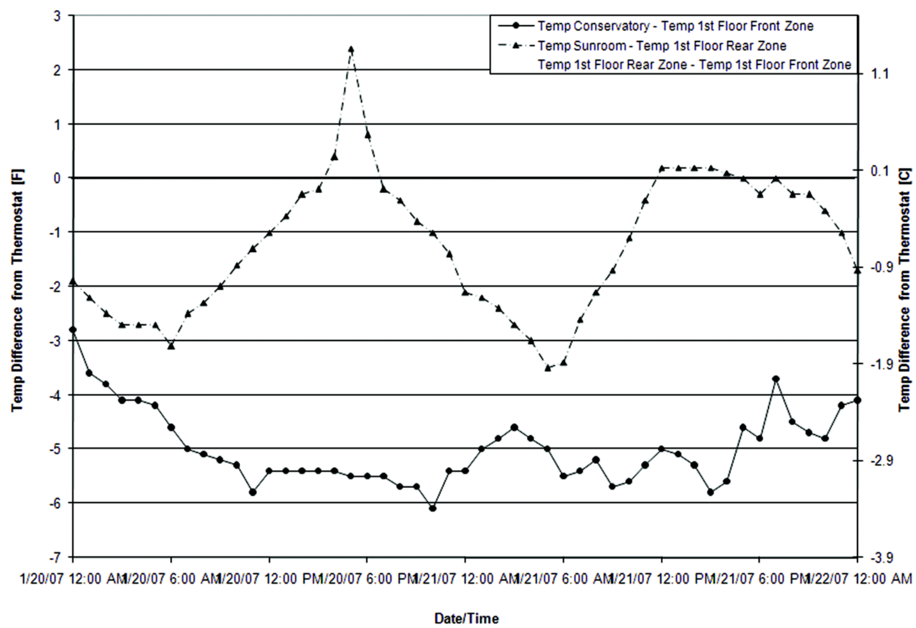

Figure 4 *New Jersey house temperature deviations from thermostats for two high load rooms during two cold days.*

annually, they offer $1,543 annual savings in energy costs. This translates to a net positive cash flow for the homeowner of $307 per year.

Numerous challenges resulted in the temperature uniformity issues shown in Figure 3. The conservatory is located on the northwest corner of the house. It abuts conditioned space only on two sides: one wall and its floor. The room also has a large ratio of window to wall surface area. In its zone, the conservatory is supplied by the longest duct runs. Because the conservatory is serviced by the longest duct run and the area near the thermostat by the shortest, the time for the conservatory to receive warm air is much greater than for the more central locations. The thermal loss is also greater in the longer run. On the installation and design side, the supply to the room also includes a significant detour in the flex duct to maneuver around a ceiling beam in the basement that was absent in the original design. Some significant deviations from the original design were also apparent during a pre-drywall inspection.

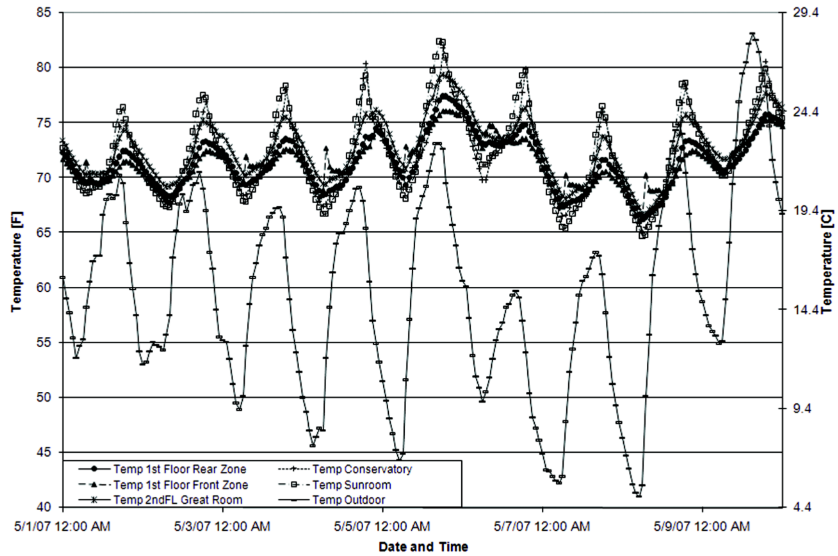

Figure 5 *New Jersey house indoor and outdoor temperatures during the swing season.*

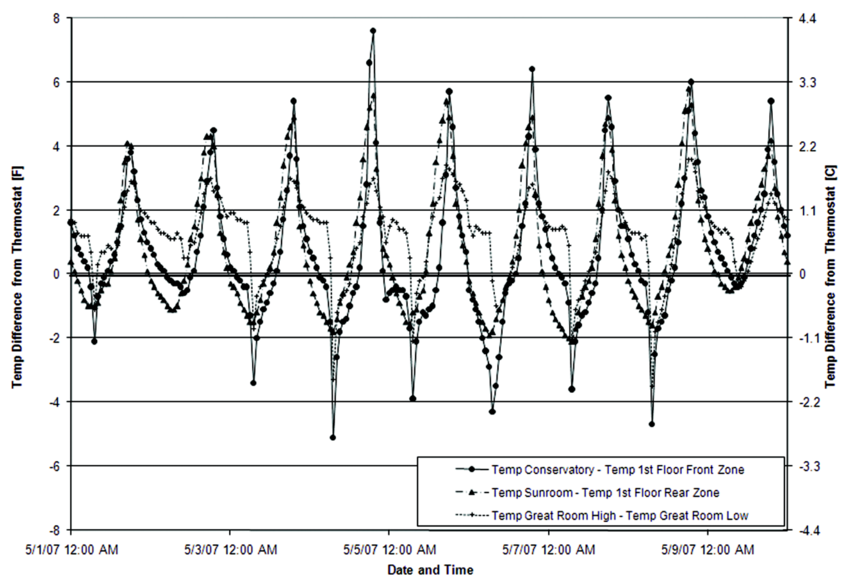

Figure 6 *Temperature deviations from thermostats for two high-load rooms and two-story great room during the swing season.*

These issues were remedied as much as possible by a second HVAC company brought in for the remainder of the work on the house. Preliminary airflow testing indicated that airflows throughout the house may be lower than called for in the original design. Complete system and airflow testing is being undertaken to help identify the system deficiencies. The design team and Builder 1 are currently pursuing courses of action to remedy the situation.

Swing season temperature profiles indicate the potential for the sunroom and conservatory to overheat due to the large window areas. Further study during the cooling season will show whether this becomes an issue or whether the system will provide adequate temperature uniformity in cooling mode.

Builder Innovation, Challenges, and Lessons Learned—Builder 2: North Carolina

Prior to working with the project team, Builder 2 had already taken several iterations to get from an unsealed crawlspace to the sealed, insulated crawlspace design used in the prototype house. Builder 2 was committed to this process, took the time to understand the problem, and chose to educate the contractor on the proper installation of the drain tile in a sealed crawl space. Due to the experience of dealing with water intrusion and mold mitigation in the past, the builder also decided to install a concrete slab over the polyethylene vapor retarder. This ensures the protection and continuity of the vapor retarder over time. In addition, the builder standard practice is to install at small dehumidifier in the crawlspace drained to the subslab drainage system to eliminate construction-related moisture and prevent long-term moisture problems.

The use of rigid insulation and T-bracing instead of OSB sheathing to provide the shear strength on the above grade walls was a relatively new process in the region. Builder 2 had to work with the local code officials to get this installation approved. Builder 2 and its engineer held meetings with the code officials to explain the installation. This work was vital to ensuring the installation of the insulation board without the OSB on the community scale and resulted in raising the regional understanding of this process at the code level. Another strategy that was challenged was the use of rigid foam insulated sheathing as a drainage plane. The manufacturer of the insulation board had to supply a letter to the siding manufacturer, certifying that its insulation product could be used as a drainage plane.

Builder 2 had historically relied on the HVAC contractor to size and install the equipment. While the contractor was experienced and better than most typical contractors in the area, regional standard practices were still used throughout the process. The contractor did perform load calculations, but would upsize the equipment by approximately 6,000 Btuh (1.8 kW) per system as a factor of safety. The contractor would typically install two units, one in the crawlspace and one in the unconditioned attic. Prior to using a sealed, conditioned crawlspace, this practice relegated the entire HVAC system to unconditioned space, increasing loads, and reducing system efficiency and comfort. To further compound this problem, the contractor used typical diffuser locations at the perimeter of the building, increasing duct runs, and the associated heating and cooling losses. Standard practices could not be employed to achieve the levels of energy efficiency targeted by Builder 2.

Fortunately, Builder 2 was aware of the importance of an integrated design process and wanted to undertake the learning process. One of the major areas of involvement for the project team with Builder 2 was on the design and engineering of the HVAC system. The team worked closely with the builder, their design team, and, to a lesser extent, the HVAC contractor to ensure an integrated design process. This iterative process took place during the design phase of the prototype house so that the lessons learned could be applied on the community scale. Instead of two systems, Builder 2 now typically uses one zoned system that serves the first and second floor. Builder 2 has all of their architectural design work done in-house, so this process has been integrated into their thinking for the community scale designs.

Interior space limitations led to careful planning of air handler and ductwork locations and routing. Keeping a majority of the air distribution system within conditioned space was a key design and construction parameter. The creation of an unvented, sealed, conditioned crawl space provided the space for the HVAC system rather than using the unconditioned attic. Because the second floor air handler and air distribution system were typically installed in the attic, there was no chase on the first floor for main duct risers to be run from the crawl space to any locations on the second floor. This was an area of learning for the builder and designer, and chases for the ductwork for the second floor zone from the air handler in the crawlspace are now part of their standard practice when designing new house plans.

Against the project team's recommendations, some of the duct system travels through unconditioned attic space following the traditional approach of servicing second floor rooms from ceiling diffuser locations. For these rooms the project team recommended ductwork routing through interior wall cavities to high wall diffuser locations. It is anticipated that the summer time heat gain experienced by the ducts in the attic will be lessened by the radiant barrier roof sheathing that is used.

This has served as both a learning experience for the builder and project team. Builder 2 now understands the integrated design and engineering process and implements the steps whenever designing a new plan. In addition, as mentioned above, Builder 2 now provides a duct chase on all of its new house plans. The project team may have been more effective were there more direct contact with the HVAC contractor earlier in the process. Understanding regional practices and materials is critical to the successful implementation of an integrated design. In addition to the stated changes, the as-built HVAC system has a few aspects that were done "70 percent in the spirit" of project team's design. On primary reason for deviation from the design was the difficulty the HVAC contractor had in cost effectively obtaining certain components for the air distribution system locally.

Solar water heating can be an efficient and affordable technology in the Mixed Humid climate to supplement hot water production and reduce overall energy consumption. For Builder 2, it was an easy decision to implement solar hot water on its houses. Given the tax credits offered by the State of North Carolina, the further reduction in electrical usage, and local access to a manufacturer and an experienced installing contractor, the builder knew this technology could successfully be implemented. Also, reducing overall annual site electricity consumption enabled a smaller photovoltaic system to be installed, helping to keep costs down. This technology is one of the system strategies that enable the house to achieve energy savings above the 40 percent level.

A local solar collector manufacturer produces the collectors that Builder 2 uses. The manufacturer capitalizes on their vast experience in the solar industry on the commercial sector to provide turnkey technology to the residential sector. Because of their involvement and experience at the commercial level, their residential products are trustworthy, scaled down versions. The system also utilizes a premanufactured heat exchanger and a high-quality, standard 80-gallon (303 L) storage tank to simplify the installation and maintenance of the system.

On the installation side, the project team has seen some builders struggle with integrating solar domestic water heating into their processes. Many regions do not have a installer base mature enough to support builders that actively install more than one or two systems at a time, especially mid-sized to production builders. Builder 2 was fortunate to be located near a solar installation company that has years of experience installing systems customized to specific applications. The installer was able to offer a full, custom installation for the prototype home project and was able to establish a long-term relationship with the builder and the homeowners. This allows them to be able to provide upkeep and maintenance to these systems, providing long-term durability and care.

The builder was part of the working group that developed the PV electricity buyback program, enabling builders throughout the state to add PV to houses and facilitating homeowners to use their PV system as a small business as an independent power producer. To ensure the proper installation and wiring of the PV system, Builder 2 approached their electrical contractor and worked out an agreement where the contactor would attend classes to understand this new technology. The electrical contractor also had a strong belief in PV technology and saw the benefit in becoming educated in its application. This reduced the learning curve on the installation and demonstrates how proactive thinking and training can reduce on-site learning time and ensure proper installations at the community level. In addition to the electrical contractor, Builder 2 worked with the local code office to ensure approval of the installation. According to Builder 2, the code office was open to the installation and interested in learning about the process.

CONCLUSIONS

The technical strategies associated with building energy efficient, high performance houses exist for builders in the United States. However, a builder must be willing to undertake a significant rethinking of the operational and construction processes associated with house design and construction. This includes undertaking an integrated design process, working closely with trade partners at all stages of the design and construction processes to develop solutions that can be readily built in the field. It also includes proactively and collaboratively working with code officials to overcome perceived code restrictions. It is also essential to commission systems to ensure that expected performance is actually attained in the finished product. These projects have also demonstrated that, as houses become more and more energy efficient, more attention must be paid to the design and installation of the HVAC system to minimize potential comfort problems. As houses are made more efficient and HVAC systems right sized, the air distribution system design becomes a critical factor for maintaining comfort. The design of the houses may also need to be altered to minimize dramatic differences in load densities from room to room. HVAC system design strategies should be reviewed in light of the differences in the length of runs between low-load and high-load density rooms. Further research is needed to develop minimal-risk solutions that can simultaneously assure energy efficiency, comfort for the occupant, and overall building durability.

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