Using Building America to Demonstrate "Less Is More"

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ABSTRACT

This paper discusses the performance results of a Building America prototype home constructed in Wisconsin and provides a perspective of market acceptance, ease of application and transferability of techniques and technologies promoted through the Building America initiative. The intent of this project was to demonstrate that a redesign of even the most basic home (two-story colonial) has systems engineering opportunities and value and that "less is more." The prototype home illustrates the value of systems engineering and resource efficiency methods as a counterpoint to trends that favor aesthetic architectural features that increase construction costs. The house used as the basis for the comparison is a 2,680 square foot two-story, with the redesigned version slightly smaller at 2,464 square feet. The two houses are of very basic design and share the same general outward appearance, but that is where the similarity ends. Within the building envelope, advanced framing techniques reduced cost, increased performance, and provided potential for cost shifting. The airtight drywall approach (ADA) was implemented as an advanced air sealing technique to determine performance advantages versus the cost of application. The home was re-designed with a simplified air distribution system to boost system performance while reducing installation labor and materials. Additional applications of systems engineering included the use of a central mechanical core for plumbing, and a simple and effective cost saving ventilation strategy. The advanced techniques and technologies implemented in this prototype produced a home that exceeded the high performance standards required for Wisconsin ENERGY STAR® Home certification (WFOE).

Background

The Wisconsin Building America Initiative builds upon the national Building America research by using a deployment model to reach a greater number of builders and to develop the expertise of individuals and organizations serving Wisconsin's trade professionals. In 2004, the Wisconsin Building America Initiative adopted a team approach to promote and implement systems engineering principles in the local building community. Four teams were assembled each consisting of the team leader, a builder, a designer/architect, and a HVAC contractor. The Wisconsin Building America prototype home that is the subject of this paper was designed and constructed by the Southeast team.

The Wisconsin Building America Initiative provides an additional toolbox of resources for Wisconsin ENERGY STAR® Home builder partners who are ready to take the next steps in advanced building techniques including high efficiency mechanical systems and renewable technologies. With the support of U.S. Department of Energy Building America national teams, the Wisconsin Building America Initiative works one-on-one with builder partners through the local Building America team leader. Each team uses a systems engineering approach to produce homes that incorporate energy, material and labor saving strategies from the start of the building process – the design.

The Kensington (Figure 1), used as the basis for the comparison, is a 2,680 square foot two-story located on a developed lot in an established real estate market in Cedarburg, Wisconsin. The 2005 Wisconsin Prototype (Figure 2) is located approximately 15 miles north on a fully improved lot in a new development in Random Lake, Wisconsin, and is slightly smaller at 2,464 square feet. The lot is relatively level like the Kensington's but with more deciduous shading on the south side of the home.

Figure 1. The Kensington

Figure 2. 2005 Wisconsin

Understanding that it is not necessary to make every possible improvement in the first prototype, the intent of this project was to demonstrate the potential of systems engineering when applied in the re-design of even the most basic two-story colonial home. Advanced framing techniques were proposed to reduce materials in the building envelope, increase the energy performance of the building, and provide cost shifting opportunities for reinvestment in other technologies. The airtight drywall approach (ADA) was planned as an advanced air sealing technique to determine the cost of implementation and the effect on the air-tightness of the building. The design included the use of a simplified air distribution system to provide an increased level of performance while reducing both labor and materials required for the installation. Other systems engineering design changes include a cost effective ventilation strategy, compact fluorescent lamps in light fixtures, and an efficient central plumbing design. The entire team developed and reviewed the selected design options. It was important that the designer, builder, and the HVAC contractor were all comfortable with the proposed strategies and all of the trades involved understood the importance of the location of components, of sequencing, and integration of tasks.

The 2005 Wisconsin Prototype performance package is similar to Building America homes constructed in cold climates to achieve 30 percent energy savings when compared to the same home built to meet the 1993 Model Energy Code. The 2005 Wisconsin Prototype compares to other Building America Case Study homes with home energy rating scores of 89. (Baechler et al. 2005)

House Description

Similar in curb appearance, the two homes are quite different when compared on the basis of design and performance. The goal with the prototype was to capture the attractive features of the Kensington while creating a more compact and efficient design.

Geometry

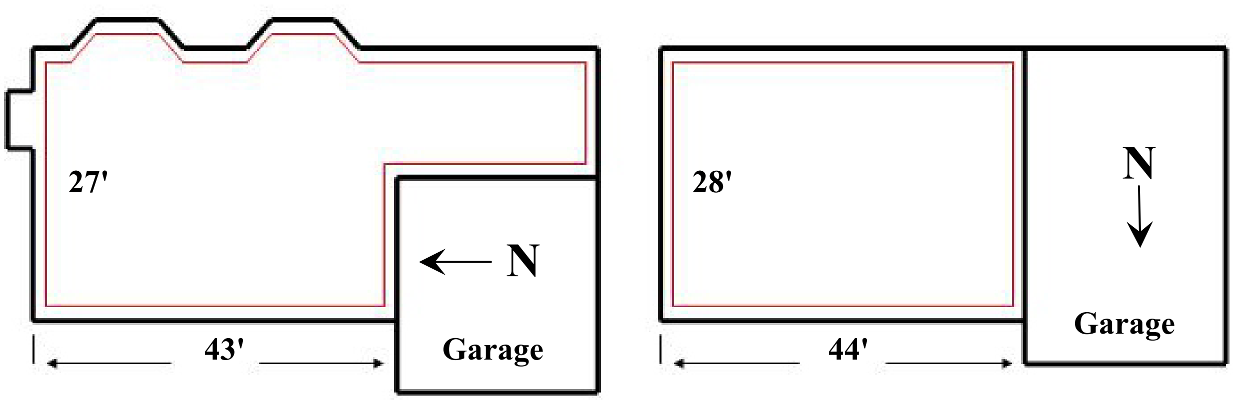
The plan review identified opportunities to increase the thermal performance of the home through general changes in geometry, such as reducing the number of corners in the exterior walls. The Kensington is a straightforward design with six 90˚ corners surrounding the living floor area. Two window bays and one fireplace chase add eight 45˚ corners and four 90˚ corners to the foundation and first floor. The prototype has just four corners on all three levels. Changes in dimension were made to bring the layout into alignment with a 24 inch grid. This step was taken to reduce waste and make more efficient use of sheet goods that are commonly sized at 4 by 8 feet. This basic footprint (Figure 3) was proposed to provide maximum square footage relative to the exterior wall exposure while reducing labor and materials costs. The living space floor area was reduced by only 216 square feet, but nearly 1,500 square feet of building envelope surface area was eliminated, reducing the heat loss/gain potential. The air volume of the conditioned space was reduced by over 4,000 cubic feet. A utility/storage trade-off of 281 square feet of basement floor area was made for 193 square feet of desirable garage space. The window bays and the fireplace chase on the exterior were eliminated (Table1).

Table 1. Building Geometry Comparison

The Kensington	2005 WI Prototype	Difference in square feet
• 6 Corners	• 4 corners from the basement through second floor	
• 2 first floor bays		
• 1 fireplace chase	• No bays or fireplace chase	
2,680 sq. ft. living floor area	2,464 sq. ft. living floor area	**(-216)**
1,519 sq. ft. basement	1,232 sq. ft. basement	**(-287)**
575 sq. ft. garage	768 sq. ft. garage	**(+193)**
7,746 sq. ft. envelope area	6,258 sq. ft. envelope area	**(-1488)**
33,850 cu. ft. volume	29,814 cu. ft. volume	**(-4036)**

Figure 3. Footprint Comparison

The Kensington **2005 WI Prototype**



Envelope

REM/Rate™ 11.0 software was used for the computer modeling because of its familiarity to consultants and builders participating with the Wisconsin ENERGY STAR® Homes program. The prototype includes energy improvements (Table 2) in insulation, windows and doors. The exterior wall cavity R-Value was slightly improved by using high density batt insulation. Batt insulation was used in the Kensington and the prototype in an effort to evaluate the impact of the air tightness performance results due to implementing the ADA. One inch of R-5 extruded polystyrene sheathing provides continuous insulation to reduce thermal bridging through the framing. One-half inch foil-faced polyisocyanurate rigid insulation over 1/2 inch oriented strand board was used for corner bracing assemblies. R-Values were slightly improved for the rim and band joists and attic insulation. The re-designed home has ENERGY STAR® windows (.35 U-factor or less for Wisconsin's climate zone). Exterior doors used in the prototype were R-7.5. The slab floor is seven feet below grade and is uninsulated. Computer modeling using R-10 under-slab insulation projected a $9.00 savings on annual heating costs, but it also projected a $5.00 increase in annual cooling costs because of the slab/ground connection being broken. The potential of $4.00 in net energy cost savings per year was not enough to justify the additional cost of under-slab insulation.

Table 2. Building Envelope Comparison

	Kensington	Prototype
Attic	R38 blown fiberglass	R50 blown cellulose
Above grade walls	2x6 16" O.C. R19 cavity / R5 continuous	2x6 24"O.C. R21 cavity / R5 continuous
Foundation walls	R5 exterior extruded polystyrene	R5 exterior extruded polystyrene
Slab floor	R0	R0
Rim and band joists	R19 batt	R21 spray foam
Windows	.48 U / .56 SHGC	.35 U / .30 SHGC (ENERGY STAR®)
Doors	R1.3 with storm	R7.5
Vapor retarder	Polyethylene	Vapor diffusion retarder paint
Air barrier	Polyethylene	Air tight drywall approach
Exterior cladding	Steel siding with painted cedar trim, fascia and soffit	Vinyl siding with vinyl trim, fascia and soffit (low maintenance)
Drainage plane	Extruded polystyrene with taped seams	Extruded polystyrene with taped seams

Maintenance

The exterior cladding on the Kensington is steel siding with painted cedar trim, fascia and soffits, all of which require regular painting and maintenance. Because the future costs of the home include more than just energy, a low maintenance exterior using vinyl siding, trim, fascia and soffit was selected for the prototype.

Drainage Plane

The insulated sheathing was taped and sealed at all joints to provide a continuous drainage plane from the top of the second floor down to the top of the footings. The garage walls are 2x4 24" O.C. with oriented strand board sheathing and a house wrap drainage plane.

Framing

The above grade wall system consists of 2x6 24” O.C. framing. Moving stud spacing from 16” O.C. to 24” O.C. saved lumber and offered increased cavity insulation area. Advanced framing recommendations would typically include single top plates and stack framing, however, the team decided on double top plates and a 16” O.C. floor system for the prototype. In the builder’s opinion from a dimensional stand point, standard building component dimensions would have to be altered in order to use single top plates. It was not believed that the material savings from single top plates would offset the additional cost of labor and increased degree of difficulty in assembling the wall system and material dimension adjustments (drywall, stud length). Even if stack framing were employed, double top plates would afford greater ease of assembly. A conventional 16” O.C. I-joist floor system was selected for the prototype due to the builder’s preference. The builder's concern over deflection rating outweighed the cost savings opportunity. The builder’s acceptance of techniques and materials is crucial. The builder must stand behind the finished product and will ultimately make the business decisions concerning the strategies to be implemented on an individual project.

Air Sealing

Figure 4. Attic gable wall detail

Rigid foam sheathing was used on the back of the attic gable walls to enclose the cavity insulation and provide increased thermal performance (Figure 4). All penetrations in the framing were caulked and/or foam sealed. Closed-cell polyurethane spray foam insulation was applied as insulation, vapor retarder and air seal at rim and band joists, the top of gable ends of vaulted ceiling on exterior walls and in exterior wall assemblies behind the tub enclosure and fireplace chase.

The ADA was chosen as the air barrier strategy. Wisconsin builders often use polyethylene as a vapor diffusion retarder and air barrier. Additional attention to detail, such as overlapping seams, the use of acoustical sealant, and taping is required to make the air barrier continuous and effective. No polyethylene was used in the prototype’s wall system. Instead, self-adhesive, closed-cell foam tape (Figure 5) was applied as a gasket at the framing perimeter and penetrations. This included gasketing the second floor interior partition wall top plates to seal off the attic connection. The foam tape used was 2” wide by 1/8” thick and available in 30 foot rolls. A more careful approach to drywall installation was important to avoid damaging the foam gaskets. The drywall contractor had no complaints about working around the gasket material.

Figure 5. Self-adhesive foam

The Wisconsin Uniform Dwelling Code requirement for a vapor retarder on the warm side of above grade exterior assemblies was satisfied with vapor diffusion retarder paint. Air tight electrical boxes and recessed can lights, along with the application of polyurethane spray foam in rim and band joist locations, were used to complete the building envelope airtightness strategy. Test data and energy use projections are provided in Table 3.

Table 3. Air Infiltration Test Data and Energy Usage Projections

	Kensington	Prototype
Tested Infiltration of the Building Envelope	1,812 cfm @ 50 PA	540 cfm @ 50 PA
Air Leakage Ratio: cfm @ 50 PA / envelope area	0.23	0.09
Estimated design infiltration rate: Winter Summer	 0.32 ACH (natural) 0.16 ACH (natural)	 0.06 ACH (natural) 0.03 ACH (natural)
Estimated cost of air leakage: Heating Cooling	 $118 per year $ 10 per year	 $ 35 per year $ 3 per year
Estimated average ACH (Natural)	0.20	0.04
Infiltration heat load:	7,200 Btu/hr	1,500 Btu/hr

Note: Diagnostic testing and analysis was completed using the Minneapolis Blower Door™ Model 3 and TECTITE™ 3.0 software.

Mechanical Systems

The advanced air sealing and enhanced thermal performance provided by these improvements provided an opportunity to implement right sizing of the heating and cooling equipment. Additional improvements to the mechanical systems include a power vented water heater and programmable thermostat. Table 4 gives a more detailed comparison of the two systems.

Table 4. Mechanical Systems Comparison

	Kensington	Prototype
Heating	80,000 Btu 92% AFUE with PSC blower motor	60,000 Btu 92% AFUE with PSC blower motor
Cooling	42,000 Btu 10 SEER with fixed refrigerant metering	24,000 Btu 10 SEER with fixed refrigerant metering
Controls	Single zone/non-programmable thermostat	Single zone with programmable thermostat
Filtration	1" pleated disposable filter	2" pleated disposable filter
Water Htg.	50 gallon atmospherically vented nat. gas	50 gallon power vented natural gas
Ventilation	3 Standard bath fans 3 fans - rated flows: 50 cfm tested flows: 35 cfm each sones: unknown	4 Quiet bath fans-1 with dehumidistat control 2 fans - rated flows: 90 cfm / sones: .7 tested flows: 74 cfm and 70 cfm 2 fans: rated flows: 50 cfm / sones: .3 tested flows: 46 cfm and 42 cfm Fresh air inlet with barometric control

Ventilation

Ventilation of the conditioned space is accomplished using low sone and energy efficient bath fans with insulated rigid ducts to the exterior to reduce external static pressure and maintain fan performance. One of the bath fans is wired to a centrally located dehumidistat control for whole house moisture control during winter months. This will allow for automatic control without relying on occupant interaction. The kitchen range hood is ducted to the exterior for spot ventilation of cooking odors and moisture. Make-up air is provided by a fresh air inlet and barometric control integrated with the heating and cooling air distribution system.

Air Distribution System

A simplified air distribution system was used in the prototype home because of the building's compact design and superior thermal performance and air tightness of the building envelope. A central return air chase was incorporated into the floor plan as an aesthetic design element during the plan review stage. A high sidewall grill draws air from the second floor and a low sidewall grill draws air from the first floor. The return air chase connects at the bottom to double panned floor joist cavities. The return air drop to the furnace was offset from the central return air chase to reduce blower noise transmission. No special acoustical material (duct liner) was required; but canvas flex connectors were used on trunk ducts to eliminate noise transmission through vibration. This is standard practice for the HVAC contractor. Transfer grills were used to provide a pathway for return air from areas isolated through door closure. Chases for supply ducts to the second floor were also designed into the building plan to ensure that all ducts are inside the envelope's thermal and pressure boundary. A fully ducted perimeter supply air strategy was incorporated using floor registers with improved throw. A central supply may have performed quite well in the very compact and open concept prototype.

The duct system is located entirely within the thermal and pressure boundary, reducing the potential for duct leakage to the outside because of the envelope air tightness. The modeled energy savings achievable by duct sealing were considered minimal. Comfort issues were a concern when taking this typical unsealed duct approach. It is the current practice of nearly all residential HVAC contractors in Wisconsin to leave ductwork unsealed when located in conditioned spaces. Comfort complaints due to poor duct design and significant duct leakage problems typically surface during the cooling season in this northern climate. It was considered that as air flow volumes were reduced by right-sizing equipment, the comfort impact of duct leakage may increase. Occupancy of the home will provide additional feedback on the comfort factors.

Lighting and Appliances

Additional operating efficiencies are provided by the ENERGY STAR® dishwasher and by the compact fluorescent lamps that reduce the lighting load by approximately 75 percent.

Mechanical System Test Documentation

As part of the Building America protocol, the following tests were performed on the house: Duct Blaster system total leakage and leakage to the outside, air flow at each supply and return, air handler system flow and Delta-pressure between room and main body with the air handler on. Performance testing results are noted in Table 5.

Table 5. Building America Testing Results for the Prototype

Airflow measure with duct-blaster (return blocked)	1,059 @ 28.2 PA
Duct leakage total	880 cfm @ 25 PA
Duct leakage to outside	0
System operating pressure (2' from plenum)	28.2 PA (high speed)
Designed air flow total	800 cfm
Measured air flow total at registers	716 cfm
Zone pressure testing (pressure difference between individual room and main body of the house with air handler on	All zones less than 3 PA Δ P
Building envelope air tightness	540 cfm @50 PA

Note: Diagnostic testing and analysis was completed using the Minneapolis Duct Blaster™

Cost Savings

A key element of the systems engineering approach is to identify cost savings opportunities and then to re-invest the savings into improvements that further increase the performance efficiencies of the home. Identified cost savings opportunities for this prototype were:

Geometry

Building the prototype using a more compact design offered the most significant labor and material savings. Framing labor cost comparisons per square foot provided by the builder are as follows:

- Average house - approximately $10 / sq. ft.
- More complex house – approximately $11 / sq. ft.
- Systems engineered house – approximately $9 / sq. ft.

The Kensington would be considered an average house for framing labor costs. In addition to reduced framing costs, the compact design of the prototype reduced costs in other areas, including concrete, roofing and siding.

Framing

The compact re-design of the house allowed advanced framing techniques to bring increased savings in material and labor costs. The prototype used 72 studs with 24" O.C. exterior wall framing instead of 108 studs that would have been required with 16" O.C. framing. The savings for studs was $176. Additional cost savings were realized by using rigid foam sheathing instead of OSB sheathing. In this case, there was an advantage in the comparative market price of sheathing material and in the enhanced thermal performance, which reduces the future cost of ownership. The advanced framing and air sealing techniques provided for a superior building envelope resulting in improved insulation opportunities and reduced air leakage.

Heating and Cooling

The increased performance of the building envelope allowed heating and cooling equipment to be reduced in size, resulting in a savings of $100 on 60,000 Btu furnace (instead of 80,000 Btu furnace) and $300 on 24,000 Btu CAC (instead of 36,000 CAC). A review of the prototype mechanical components, using REM/Rate 11.0 computer modeling software, indicated that installing a 10 Seasonal Energy Efficiency Ratio (SEER) air conditioner would have minimal energy usage and cost impact. The cooling load is very low and the savings in operating costs on a seasonal basis between a 10 SEER and a 12 SEER, which was the ENERGY STAR® level at the time of construction, is currently $11 annually. The energy savings does not justify the additional first cost increase of purchasing a 12 SEER unit.

Duct System

The HVAC contractor reported a $959 savings in material and labor by using the simplified air distribution system. This contributed to the heating and cooling system equipment cost savings of over $1,300.

Computer Modeling Results

Although the prototype does not have a utility history to compare to the Kensington, modeling projections were made (Table 6) and the comparisons are encouraging, especially with regard to cooling.

Table 6. Computer Modeling Data Comparison

	Kensington	Prototype
Annual heating cost	$746.00	$495.00
Annual cooling cost	$229.00	$60.00
Water heating cost	$276.00	$228.00
Heating energy intensity (Btu / sq. ft. shell area / DD)	1.39	1.15
Heating calculated peak load (kBtu/hr)	50.4	33.6
Infiltration	7.2	1.5
Envelope	43.2	32.1
Cooling calculated peak load (kBtu/hr)	30.9	13.0
Sensible	27.1	10.5
Latent	3.8	2.6
Annual consumption (MMBtu/yr)		
Heating	87.7	58.4
Cooling	8.8	2.6
Water heating	34.0	28.1
HERS Score	86	89
Surpasses WI Uniform Dwelling Code by Annual Energy Analysis Requirements	16%	30%

Note: Computer model comparisons used REM/Rate™ version 11.0 Wisconsin. Heating is based on natural gas at $0.811 per therm. Cooling is based on electricity at $0.089 per kWh. (2004 Wisconsin state averages)

Cost Re-Investment

The first costs savings recovered as a result of the systems engineering approach were reinvested into technologies that improve the performance and value of the home. Improvements in the building envelope and the integrity of the thermal boundary by using spray foam in traditionally difficult areas to achieve good performance and ENERGY STAR® windows, in moisture management strategy and equipment such as quiet fans and improved ductwork, in providing added quality of life features such as quiet exhaust fans and high quality interior wood products. The mechanical system was reduced in size but provides increased performance because of the thoughtful design. In addition to savings and reinvestment opportunities in construction costs (or first costs), reduced operating costs will benefit the homeowners well into the future.

The HVAC central return air strategy provided the heating and cooling contractor with a much easier application than is customary in this market. It is typical in Wisconsin to see a fully ducted return air system with pick-ups included through out the building and in each bedroom. A compact system, as in the prototype, that produces $959 less for the contractor may meet resistance in a profit driven market. The central return technology will also be difficult to bring into the mainstream market due to perceived comfort complaints and liability. The HVAC contractor that does not have previous experience with a central return system will not be comfortable with it and will avoid taking the risk. The irony is that it took decades to get HVAC contractors to fully duct returns and now we are attempting to reverse the trend by recommending central return systems.

The ease of application regarding the ADA method of air sealing was one of the primary areas of research in this prototype home. It was decided that the Wisconsin Building America regional team leader would provide and install the gasket material to get hands on experience with the system. The application process proved to be quite labor intensive; however, the gasket material selected was rather easy to install. Determining where to apply the gasket material may prove difficult for subcontractors lacking in air sealing knowledge and training. The lack of attention to detail during application will result in performance deficiencies that may hinder the transferability of ADA applications.

An opportunity arose during construction of the prototype to compare it to another home of similar square footage being built at the same time by the same building contractor. The comparison home used standard construction and framing methods, a standard duct system and contemporary architectural features such as complex and massive roof assemblies with multiple planes and an equally complex building envelope with many outside corners and difficult framing details. A comparison of the two homes is made in Table 7.

Table 7. Construction Comparison

	Prototype	Comparison House
Rough materials	$18,084	$32,064
Foundation	$ 6,403	$10,214
Framing hours	467	594
HVAC	$ 9,440	$11,451
Plumbing	$13,525 (2 1/2 baths)	$13,450 (2 baths)

Conclusions

The Southeast Wisconsin Building America team began planning and construction of the prototype home with a good understanding of the systems engineering approach and acceptance as a valuable process posed no problem for the team. The greatest barrier to overall building industry acceptance of the systems engineering process and the use of advanced techniques and technologies is a lack of exposure, lack of training and an unwillingness to change current decision making processes and construction practices. From an economic perspective, there are opposing views both from within the building industry and from the marketplace. One barrier is the perception common with builders that systems engineering is cutting cost by removing lumber thus reducing quality. At the same time, a highly competitive market drives builders to use almost any means to reduce costs and to make choices that may compromise the quality of a home even more than their perceived issues with systems engineering. Consumers usually perceive "quality" in visible finishes such as counter tops, whirlpools in master suites, elaborate interior woodwork, and complex geometry on the exterior with brick or stone finishes on the street side of the home. The irony here is that one of the best opportunities for a builder to provide popular features, and at the same time become more competitive through the advantages of systems engineering, is lost because of the myth that less lumber makes a home "cheaper."

During the construction of the prototype, application of advanced techniques and technologies met little resistance from the building and mechanical contractors and no difficulties were encountered in completing the work as specified. The use of advanced framing techniques required only slight extra attention to detail regarding additional blocking for attaching cabinets, railings, etc. The limited advanced framing techniques used in the prototype could be easily adopted as standard construction practices by the builder. The builder of the prototype typically builds large custom homes with all the complexities present in today's popular designs. The challenges encountered when attempting to implement advanced framing techniques in complex homes illustrates the need to promote the systems engineering process in the architectural design community. It is difficult to promote resource efficiency in a market that is going the other way as it builds to the sophisticated plans currently popular in the marketplace.

The perception that using the systems engineering approach will drive up cost because of changes in planning and construction practices contradicts the value our society places on education and the value of experience. If change is going to occur, it must be embraced by the production labor force. While a high percentage of builders want to reduce construction costs and improve building performance, a recent survey of Wisconsin and Minnesota builders indicates that, "convincing builders that they would be better off with a change is just one step in the process [and] builders will not adopt a change in design unless they are quite certain it will work for them the first time" (Nelson & O'Malley 2005, 2).

The results of the study also predict that "Building America strategies will be adopted in incremental steps as the benefits of each are gradually incorporated into the industry's way of doing things [because] the primary barriers to Building America wide scale deployment are related to the market in which builders participate, and not the technical details and designs of homes" (Nelson & O'Malley 2005, 2). This is warning us that less pressure as we begin to implement changes slowly is going to result in a more complete acceptance over time. Builders are risk adverse and "want to use tried and true practices and do not want to unwittingly participate in research for technologies or techniques that may be considered questionable" (Nelson & O'Malley 2005, 4). We need to offer strategies that make sense in the existing market before there will be general acceptance of building for resource efficiencies. It remains to be proven to the mainstream building community that building thoughtfully with less material can result in more value to both builders and homebuyers.

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