PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

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ADVANCED FRAMING:

An Examination of its Practical Use in Residential Construction

ACKNOWLEDGEMENTS

This project and analysis were made possible through funding from the Partnership for Advancing Technology in Housing (PATH), under the Department of Housing and Urban Development.

The authors, reviewers, and researchers who participated in this study include:

- Jay H. Crandell, P.E., ARES Consulting
- G. Robert Fuller, P.E., consultant
- Jeannie Leggett Sikora, consultant
- Margo Thompson, NAHB Research Center
- Joseph Wiehagen, NAHB Research Center

Special recognition is extended to the following individuals from the Lancaster County Career and Technology Center whose collective vision and cooperation helped to make this study a success:

- Doug Lyons, principal
- Kim Patrick, special projects coordinator
- Mike Dodson, building project supervisor
- Rich Burley, instructor
- Charlie Phillips, instructor

Prepared By:
NAHB Research Center
400 Prince George's Boulevard
Upper Marlboro, MD 20774

NAHB RESEARCH CENTER

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INTRODUCTION

Advanced framing, also known as Optimum Value Engineering (OVE), is not new to home building. It was featured in kit homes offered by the Sears & Roebuck Company in the early 1900s (HUD, 2001), researched extensively in the late 1960s and early 1970s, and featured in a landmark publication, *Manual of Lumber & Plywood Saving Techniques for Residential Light-Frame Construction* (NAHB Research Foundation, 1971). Again in 1994, OVE framing techniques were revisited, updated, and featured in *Cost-Effective Home Building* (NAHB, 1994). Currently, provisions for several key OVE framing practices are found in model U.S. building codes (ICC, 2006).

Despite the long-term experience and ample resources supporting its use, OVE framing has received limited market penetration. In part, this may be attributed to the industry which tends to adopt new practices at a very slow rate. However, there are more substantive reasons, including the need for additional planning and oversight; a market perception of OVE practices as inferior to conventional practices; alternate construction methods that diminish the benefits of OVE such as the use of exterior foam insulation which drastically reduces thermal bridging; and, quite importantly, practical constructability issues that raise questions regarding the value and viability of some OVE framing practices.

This report is a case study of the issues faced during the design, planning, and construction of a "first-time" (for the builder) home using OVE techniques. It evaluates the benefits of OVE, quantifies material savings, and identifies barriers to and opportunities for improved practices or alternatives. By evaluating lessons learned throughout the project, the report concludes with a set of recommendations that are practical to implement in view of competing interests, such as historical trade practice or code official familiarity.

PROJECT BACKGROUND

The case study home was built by the Lancaster County Career and Technology Center (LCCTC), a vocational high school in Lancaster County, Penn. In a typical year, the LCCTC Construction Technologies program builds or remodels one home or small commercial building to give students practical construction experience while they pursue a high school degree. In 2005, planning began for a four-home subdivision on LCCTC-owned land adjacent to the school's Mt. Joy campus. The idea to "go green" was the brainchild of LCCTC's special projects coordinator, Kimberly Patrick. Via internet research, Ms. Patrick found and approached the NAHB Research Center about a potential partnership on the project. Because the project represented an excellent opportunity to demonstrate advanced housing technologies while having a large outreach component, the NAHB Research Center eagerly joined the team.

The project evolved as not only a means to advance technology in housing but also as a way to demonstrate how NAHB's Model Green Home Building Guidelines (Guidelines) can be used to transform a conventional home into a more environmentally sustainable one. Starting with an ENERGY STAR®-rated home design, and using the Guidelines, a team—which included instructors and administrators of the LCCTC, local officials, and other interested parties—identified approaches that would improve the home's environmental footprint while continuing to prepare the students for the real world. Detailed specifications for the LCCTC green home can be found at www.toolbase.org/lcctc.

DESIGN PROCESS

In order to demonstrate that a green home can be mainstream, the LCCTC started with a conventional house plan from a local ENERGY STAR® builder, Norman L. Graham, Inc. Working groups—which included experts from the NAHB Research Center, the Lancaster Building Industry

Association, LCCTC staff, manufacturers, and community partners—were established to incorporate green practices into the site development, home design, and wastewater management.

For the home's structural system, a Building Envelope working group considered ICFs, steel framing, and OVE techniques. The NAHB Research Center presented technical information about advanced structural system options and guidance about available resources. Ultimately, the group elected to use OVE framing techniques because they would allow LCCTC to train students in practical and conventional framing skills while improving resource and energy efficiency.

During the design phase, the LCCTC team had a very positive attitude about using OVE techniques. The team was primarily concerned about how the new framing methods would be perceived by code officials and not terribly concerned about constructability issues. To facilitate acceptance by the local code official regarding one OVE technique—single member headers—engineering firm ARES Consulting created a single header span table to accompany the construction drawings.

The working group arrived at a final set of OVE practices for the case study home which represented a combination of conventional and OVE framing practices. Table 1 identifies the OVE framing practices that were used for the home, the conventional residential practice that was used for comparison[1], and the typical LCCTC 2x6 framing practice used prior to this project.

Table 1. Comparison of Framing Practices for the Case Study Home to Conventional and Typical LCCTC Framing Practice

Framing Assembly	Specified Framing for Case Study Home (As-Built)	Conventional Framing Practice	Typical LCCTC Framing Practice
Wall Framing			
First-story exterior walls	• 2x4 studs 16" o.c. • Two-stud exterior corners • Double top plate • Single 2x10 headers with header hangers (no jack studs) • Large openings with 2-2x10 headers and jack studs	• 2x4 studs 16" o.c. • Three-stud corners • Double top plate • Double 2x10 headers on all openings with jack studs	• 2x6 studs 24" o.c. • Three-stud corners • Double top plates • Double 2x8 headers on most openings with jack studs • Large openings with 2-2x10 headers and jack studs
First-story interior walls	• 2x4 studs at 16" o.c. • 2x6 studs at 16" o.c. (47 ln-ft) • 2x4 at 24" o.c. (two walls) • Double top plates • Double 2x4 door headers "flat" in non-load bearing walls	• 2x4 studs at 16" o.c. • 2x6 studs at 16" o.c. (47 ln-ft) • Double top plates • Double 2x10 headers on all openings with jack studs	• 2x4 studs at 16" o.c. • 2x6 studs at 16" o.c. (47 ln-ft) • Double top plates • Double 2x4 headers "flat" in non-load bearing walls
Second-story interior walls	• 2x4 studs at 24" o.c. • Single top plate • Double 2x4 headers "flat" over wall openings	• 2x4 studs at 16" o.c. • Double top plates • Double 2x10 headers on all openings with jack studs	• 2x4 studs at 24" o.c. • Double top plates • Double 2x4 headers flat over wall openings
Floor Framing			
First Floor	• TJI 230 x 11-7/8" I-joists at 16" o.c. and 24" o.c. • LSL 5/4"x11-7/8" rim/band • LVL 1-3/4x11-7/8 (2-ply) beams • 2x10 and 2x12 pressure treated sill plates	• All TJI 230 x 11-7/8" I-joists at 16"o.c. • LSL 5/4"x11-7/8" rim/band • LVL 1-3/4x11-7/8 (2-ply) beams • 2x10 and 2x12 pressure treated sill plates	• 2x10 Hem fir joists at 16" o.c. • 2x10 rim/band • LVL 1-3/4x11-7/8 (2-ply) • 2x8 pressure treated sill plates

[1] The conventional framing case represents a combination of IRC 2006 code requirements for 16" o.c. framing and simplifications commonly used such as a single header size and configuration for all openings.

Table 1 (continued)

Framing Assembly	Specified Framing for Case Study Home (As-Built)	Conventional Framing Practice	Typical LCCTC Framing Practice
Second Floor	• TJI 230 x 11-7/8" I-joists at 16" o.c. and 24" o.c. • LSL 5/4"x11-7/8" rim/band	• All TJI 230 x 11-7/8" I-joists at 16" o.c. • LSL 5/4"x11-7/8" rim/band	• 2x10 Hem fir joists at 16" o.c. • 2x10 rim/band
Roof Framing			
Trusses & Bracing	• Manufactured trusses at 24" o.c. with piggy-back (cap) trusses (9:12 pitch) • 2x bracing as indicated on truss shop drawings • Trusses of 2x4, 2x6, 2x8 LSL members	• No change	• No change
Overhangs	• Ladder rake overhang with 2x4 ladder framing and 2x6 fascia board • 12" eave overhang by trusses with 2x6 fascia board applied	• No rake overhangs • 12" eave overhangs by trusses with 2x6 fascia board applied	• No rake overhangs • 12" eave overhangs by trusses with 2x6 fascia board applied
Sheathing			
Wall Sheathing	• 7/16" continuous OSB sheathing • 1" XPS continuous insulating sheathing • Gable ends - 7/16" continuous OSB + 1" XPS[2]	• 7/16" continuous OSB sheathing • No foam sheathing	• 7/16" continuous OSB sheathing • No foam sheathing
Roof Sheathing			
	• 7/16" water-resistant OSB with taped joints (Advantech's "Zip System")	• Standard 7/16" OSB roof sheathing with separate roofing underlayment (15# felt paper)	• Standard 7/16" OSB roof sheathing with separate roofing underlayment (15# felt paper)
Floor Sheathing			
	• 23/32" water-resistant subfloor sheathing (Advantech)	• Standard 23/32" sub-floor sheathing	• Standard 23/32" sub-floor sheathing

CONSTRUCTION PHASE

During construction, there were several sessions with students regarding the rationale for OVE framing and its technical aspects, as well as close on-site project oversight by LCCTC instructors. LCCTC staff and instructors were on site to supervise construction at all times. Research Center engineers made several site visits, during the rough framing stage in particular.

Despite an initial lack of questions about OVE during the design phase, there were numerous on-site questions once construction began. Many of these questions could have been readily answered with a set of plans that included detailed framing drawings. For example, providing diagrams of framing details such as corners, wall intersections, and window framing on the architectural plans would provide pictorial guidance that framers could reference in the field. When using stacked framing, it is important to note where to start the layout for the floor, wall, and roof framing on the plans in order to maintain consistency and in-line framing.

[2] In order to achieve greater economic savings, the gable ends could be furred vertically with nominal 5/4-inch stock or other 1-inch material to achieve a uniform wall plane. Often, nominal 2-inch lumber is used to allow the gable to "stand proud" of the wall below.

METHODOLOGY—AS-BUILT ASSESSMENT

The survey and accounting of framing materials usage was conducted by the NAHB Research Center in September 2007. The status of construction at the time of this evaluation is shown in Figure 1 and plan views of each level are shown in Figures 2 through 4. The roof truss layout plan is shown in Figure 5. It should be noted that this study focuses on the main house structure only and does not include appurtenant structures such as the breezeway, garage, and porches.

Figure 1. Case Study Home at Rough Framing Stage

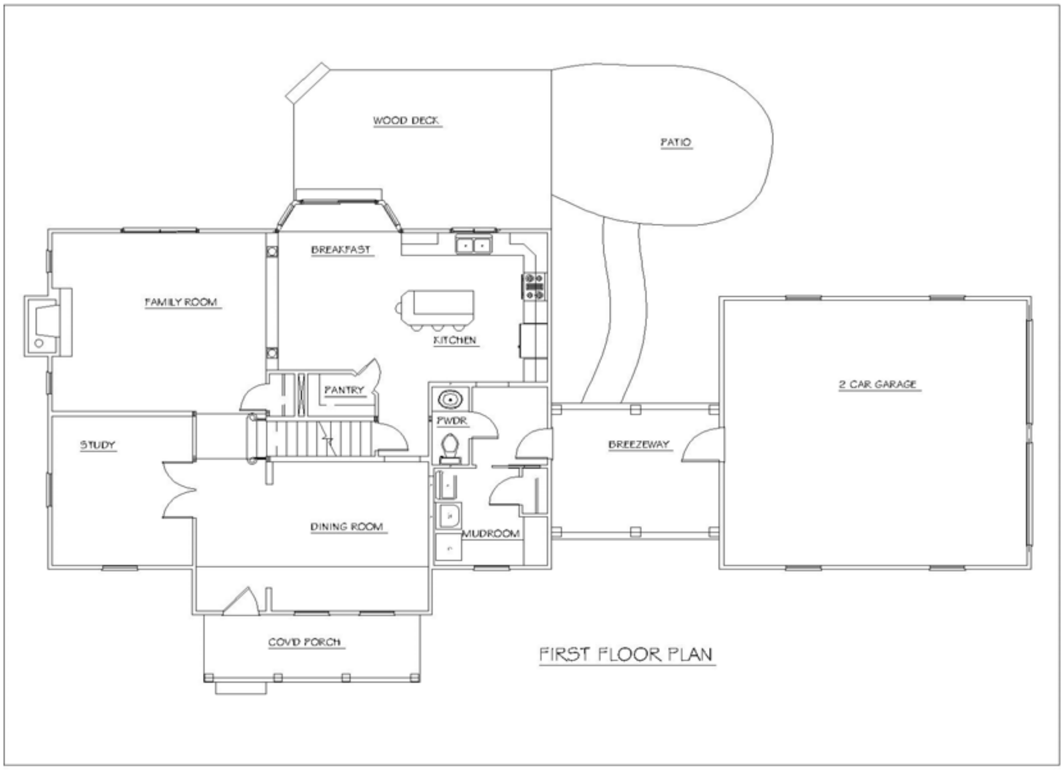

Figure 2. First Floor Plan

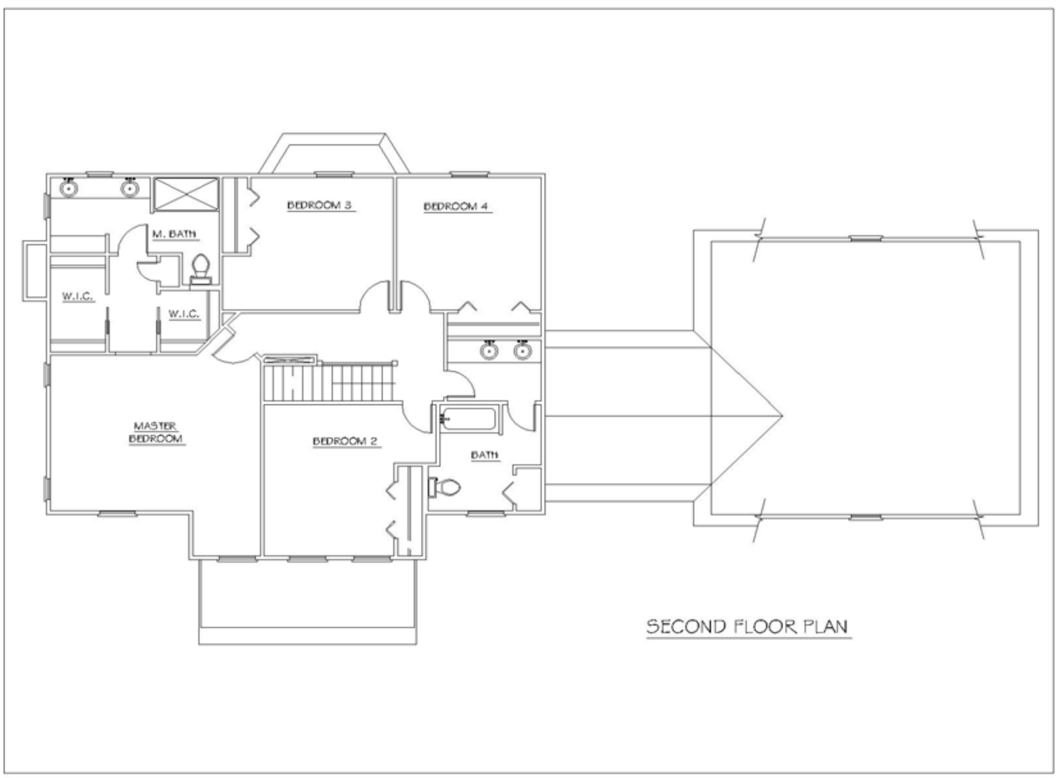

Figure 3. Second Floor Plan

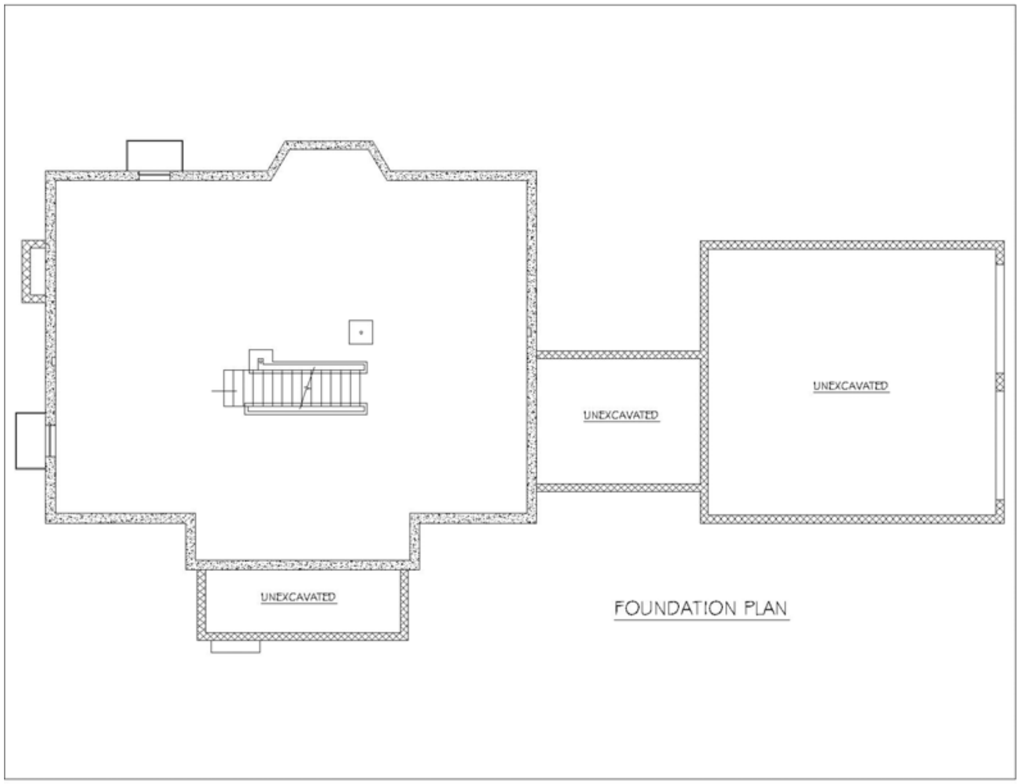

Figure 4. Basement Foundation Plan

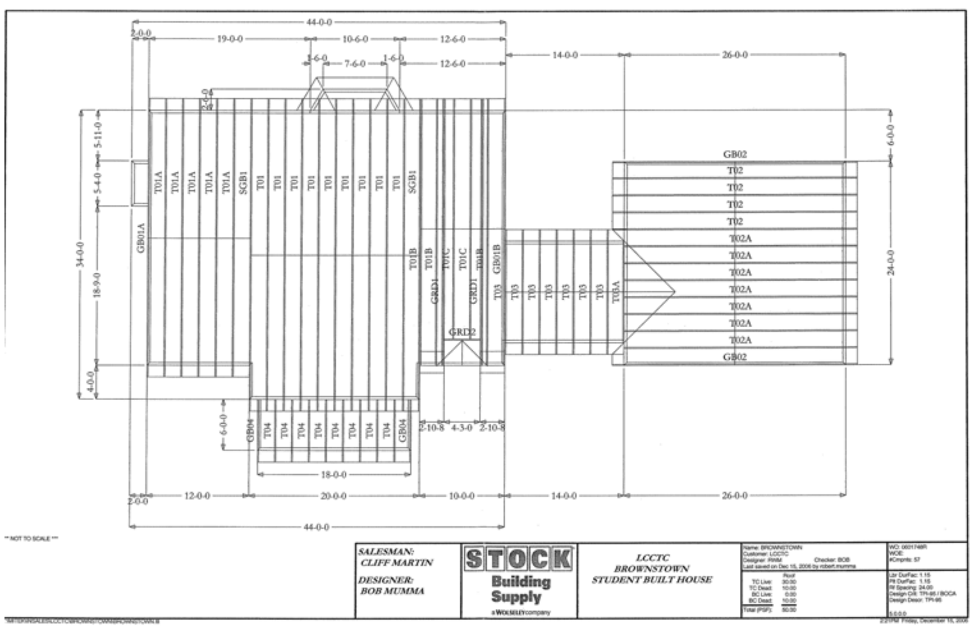

Figure 5. Roof Truss Layout

RESULTS

Table 2 summarizes framing material usage in the As-Built Home with comparison to a conventionally-framed 2x4 home and the typical 2x6 LCCTC framing practice described in Table 1.

Table 2. Comparison of Framing Material Usage: As-Built, Conventional, and LCCTC Typical

Framing Assembly	As-Built Framing Lumber (2x4 @ 16" and 24" o.c.)	Conventional Framing Lumber (2x4 @ 16" o.c.)	Material Savings As-Built over Conventional (%)	Typical LCCTC Framing Practice (2x6 @ 24" o.c.)	Material Savings As-Built over Typical LCCTC Practice (%)
Wall Framing					
1st Story Ext. Walls	847 bd-ft[3]	942 bd-ft	10.0%	1,136 bd-ft	25.4%
1st Story Int. Walls	705 bd-ft	715 bd-ft	1.3%	705 bd-ft	0.0%
2nd Story Ext. Walls	570 bd-ft	842 bd-ft	32.3%	958 bd-ft	40.5%
2nd Story Int. Walls	712 bd-ft	830 bd-ft	14.2%	801 bd-ft	11.1%
Basement Int. Walls	144 bd-ft	144 bd-ft	0.0%	144 bd-ft	0.0%
Total	**2,978 bd-ft**	**3,473 bd-ft**	**14.2%**	**3,744 bd-ft**	**20.4%**
Sill Plate					
Total	**246.1 bd-ft**	**199.5 bd-ft**	**0.0%**	**168.7 bd-ft**	**0.0%**
Floor Framing [4]					
Joists	1,584 ln-ft (11 7/8" I-Joists)	1,769 ln-ft (11 7/8" I-Joists)	10.5%	2,292 ln-ft (2x10) 2,651 bd-ft	-
Rim/band	287 ln-ft (LSL)	287 ln-ft (LSL)	0.0%	266 ln-ft (2x10) 307 bd-ft	-
Flush beams (LVL)	132 ln-ft	132 ln-ft	0.0%	132 ln-ft	0.0%
Total	**2,003 ln-ft (LVL)**	**2,188 ln-ft (LVL)**	**8.4%**	**2958 bd-ft (2x10) + 132 ln-ft (LVL)**	**-**
Lumber/blocking	300 bd-ft	300 bd-ft	0.0%	0.0	100%
Lumber/stairs	208 bd-ft	208 bd-ft	0.0%	208 bd-ft	0.0%
Total	**508 bd-ft**	**508 bd-ft**	**0.0%**	**208 bd-ft**	**(144%)**
Roof Framing					
Trusses/bracing	2,143 bd-ft	2,143 bd-ft	0.0%	2,143 bd-ft	0.0%
Overhangs	297 bd-ft	157 bd-ft	(89.2%)	157 bd-ft	(89.2%)
Total	**2,440 bd-ft**	**2,300 bd-ft**	**(6.1%)**	**2,300 bd-ft**	**(6.1%)**
Trusses (LSL chords)	165 ln-ft	165 ln-ft	0.0%	165 ln-ft	0.0%
Total	**165 ln-ft**	**165 ln-ft**	**0.0%**	**165 ln-ft**	**0.0%**
Sheathing					
Str. Wall Sheathing	3,137 s.f.	3,137 s.f.	0.0%	3,137 s.f.	0.0%
Insulating Sheathing	2,903 s.f.	0 s.f.		0 s.f.	
Str. Roof Sheathing	2,258 s.f.	1,936 s.f.	(16.6%)	1,936 s.f.	(16.6%)
Subfloor sheathing	2,901 s.f.	2,901 s.f.	0.0%	2,901 s.f.	0.0%
Total	**11,199 s.f.**	**7,974 s.f.**	**(3.0%)**	**7,974 s.f.**	**(3.0%)**

[3] Board feet were calculated on the basis of actual, rather than nominal, lumber dimensions.

[4] According to APA – The Engineered Wood Association, a conversion factor of 1 board-foot of lumber per 2 linear feet of I-Joist can be applied to compare I-joist and dimensional lumber wood use. However, since this is basically a "rule of thumb," such a conversion was not applied to this analysis.

Table 2 (continued)

Framing Assembly	As-Built Framing Lumber (2x4 @ 16" and 24" o.c.)	Conventional Framing Lumber (2x4 @ 16" o.c.)	Material Savings As-Built over Conventional (%)	Typical LCCTC Framing Practice (2x6 @ 24" o.c.)	Material Savings As-Built over Typical LCCTC Practice (%)
Quantities by Material Type					
Dimensional lumber (includes roof truss lumber)	5,925 bd-ft	6,281 bd-ft	356 bd-ft	9,643 bd-ft	3,718 bd-ft
I-Joist(TJI 230, 11-7/8")	1,584 ln-ft	1,769 ln-ft	185 ln-ft	0 ln-ft	(1584 ln-ft)
LSL (5/4" x 11-7/8"	287 ln-ft	287 ln-ft	0	0 ln-ft	(287 ln-ft)
LVL (1-3/4" x 11-7/8")	132 ln-ft	132 ln-ft	0	132 ln-ft	0
LSL (2x8 truss chord)	165 ln-ft	165 ln-ft	0	165 ln-ft	0
7/16"OSB sheathing	5,395 s.f.	5,073 s.f.	(322 s.f.)	5,073 s.f.	(322 s.f.)
23/32" OSB sheathing	2,901 s.f.	2,901 s.f.	0	2,901 s.f.	0
1" XPS foam sheathing	2,903 s.f.	0 s.f.	(2903 s.f.)	0 s.f.	(2903 s.f.)

Terminology and Units Used in This Report

bd-ft (board-foot, actual basis) = [(actual cross section area of member, in^2)/12] x Length (ft)
ln-ft (lineal foot) = length of a linear element or framing member in feet
I-joist = I-shaped joist with dimension lumber or laminated flanges and OSB web
LSL = laminated strand lumber
XPS = extruded polystyrene
1 bd-ft = 1/12th cubic foot of wood
LVL = laminated veneer lumber
OSB = oriented strand board
s.f. = square feet

Wall Framing

Lumber Usage

For wall framing, the As-Built Home used 14 percent less lumber than that estimated for conventional framing and 20 percent less than the LCCTC typical framing practice. Most of the lumber savings were attributed to the second story framing where the case study home used 23 percent less framing material than estimated for conventional framing and 27 percent less than LCCTC typical. In the As-Built Home, the second story achieved greater lumber savings than the first story due to increased stud spacing (24" o.c. on the second story versus 16" o.c. for the first[t] story) and reduced plate material (double top plate on first story, single top plate on second story).

Figure 6. Framing - 2x6, 24" o.c. Interior Basement Wall.
Wall could have been 2x4 since an LVL beam supported
first- and second-floor framing and roof trusses were clear-span.

Figure 7. Second-Story Wall Framing – 24" o.c. Window located to align with stud layout.

Figure 8. Two-Stud Corner. Drywall clips to be installed when gypsum panels installed.

Discussion

Wall framing savings in the As-Built Home, compared with conventional framing methods, are attributed to the use of 24" o.c. stud spacing and a single top plate on the second story, single member headers, two-stud corners, and the alignment of three gable-end windows that permitted wall studs to be used as king studs for windows. Interestingly, the As-Built Home achieved even greater wall framing savings when compared to the LCCTC typical practice of 2x6 wall framing. Even though LCCTC framed exterior walls and second-story interior walls on 24-inch centers, the use of double top plates and double 2x10 headers throughout, as well as three-stud corners, increased the amount of lumber on a board-foot basis. A comparison between amounts of first-story framing lumber used in the As-Built Home (2x4 16" o.c.) versus the LCCTC typical home (2x6 24" o.c.) indicates a 25 percent savings even with 16" o.c. spacing and double top plates. While much of the savings are attributed to the use of single headers in the As-Built Home, even consideration of studs, jacks, cripples, and plates alone reveals a 10 percent lumber savings with the 2x4 16" o.c. framing.

Not only did the As-Built Home use less lumber than the 2x6 construction, but the overall R-value of the As-Built wall system was greater as well.[5] By moving from an exterior framing system of 2x6 24" o.c. to 2x4 framing with a mix of 16- and 24-inch centers and exterior foam insulation, both material savings and thermal performance were increased.

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[5] Mainly due to the R-5 continuous exterior foam insulation—an analysis performed by the NAHB Research Center indicated that a 2x4 wall with R-5 exterior insulation and R-13 cavity insulation (nominal R-18) and with a 23% framing factor has about 2% to 3% better thermal performance than an R-19, 2x6 wall with a 20% framing factor. While exterior insulation is a benefit for either 4" or 6" framing systems, a 2x6 R-19 wall system is not necessarily "the next best step" from a 2x4 R-13 wall system. In addition, differences in overall wall thickness may be an important consideration.

Headers

Lumber Usage

Lumber usage was reduced by 176 bd-ft from the use of single headers in the As-Built Home as compared to the conventional and LCCTC typical methods of double 2x10 headers on all openings in load-bearing and non-load bearing walls alike. The use of metal header hangers in the As-Built Home in place of jack studs further reduced the framing lumber at openings by another 141 bd-ft.

Figure 9 shows several single header details – one illustrating the potential use of the rim joist as the header for the opening below. Note that, in all configurations, there is room for more insulation than if conventional double headers had been used.

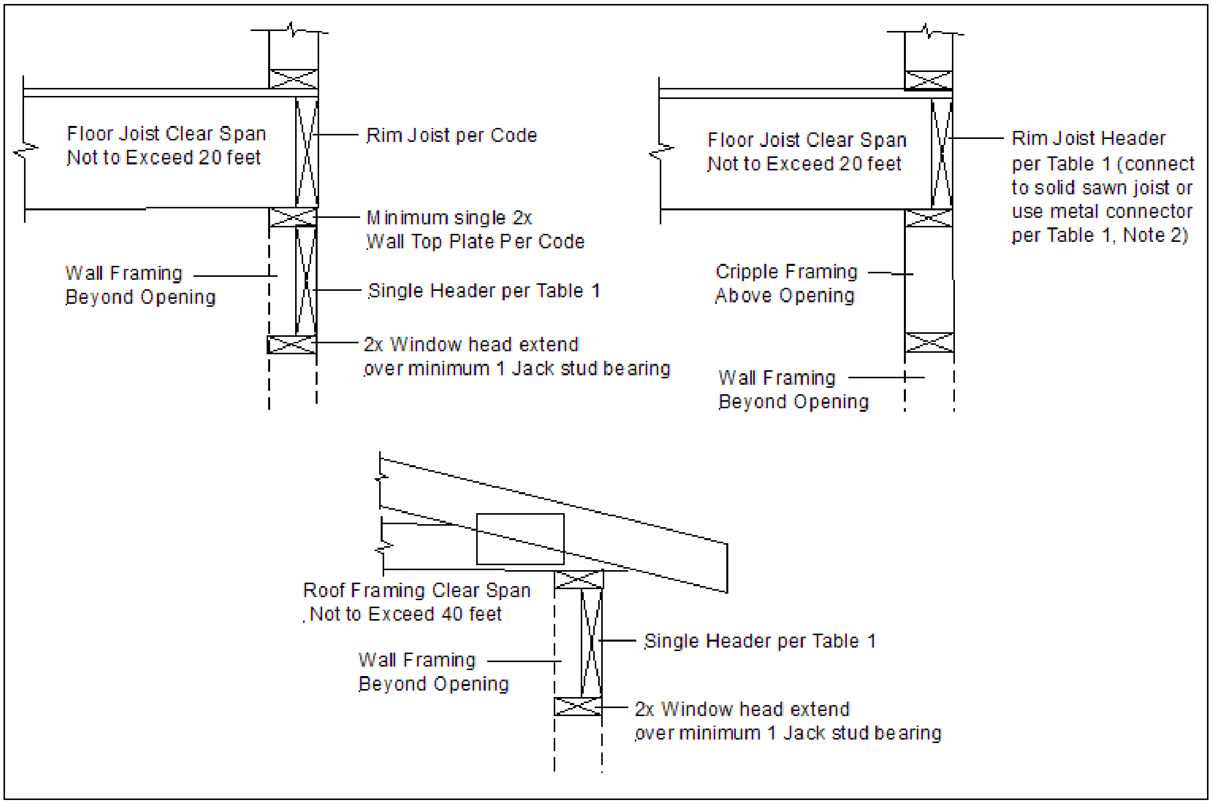

Figure 9. Single Header and Continuous Rim Joist Header Details

Discussion

In the engineered design for the As-Built Home, conventional double 2 x10 headers were replaced with single 2 x10 headers in all bearing wall openings that were less than 40-inches wide. Double 2x10 headers were to be used in bearing wall openings that were 40 inches or greater. Openings in non-load bearing walls were designed to be framed with two 2x4s installed flatwise. With this header design, 197 bd-ft of lumber would have been saved (the equivalent of about 21-2"x10"x8' boards).

However, due largely to a lack of communication between the multiple parties involved, the students framed <u>all</u> openings narrower than 40 inches—including those in non-bearing walls—with single 2x0 headers. This resulted in the unnecessary use of 23 bd-ft of lumber compared to the double 2x4 header detail originally intended for non-load bearing walls. As a result, header material savings were reduced to 176 bd-ft. This mistake highlights two issues that have been apparent in the industry as it has tried to implement OVE practices over many years:

1. The need to clearly specify OVE framing details on the architectural plans that are used in the field
2. The need for very close on-site supervision during construction until crews have become sufficiently familiar with the OVE details

The use of metal header hangers in place of single jack studs, as allowed by the IRC, reduced lumber usage at window openings by 141 bd-ft, or the equivalent of about 40 2"x4"x8' boards. It is important to note that when metal header hangers are used in exterior walls, it is particularly important to use a continuous exterior insulating sheathing to reduce thermal bridging across the metal. Additionally, metal header hangers can complicate interior and exterior trim attachment because nails cannot penetrate the metal hangers. Therefore, nailing patterns must be adjusted to avoid the metal hanger. While LCCTC carpenters were accustomed to nailing to the "far edge" of window trim (thereby avoiding the hanger), the single king stud precluded this practice in the As-Built Home. Single framing members around window and door openings (with or without metal hangers) presented problems for fastening both interior and exterior trim.

Although the single header design was relatively simple to construct, its widespread adoption is unlikely given the additional engineering cost required. For the project, a registered structural engineer (ARES Consulting) developed single header span tables as substantiating documentation. However, there is no single header span table that is recognized by any of the existing building codes. Therefore, a builder wishing to use the single header design in other homes would need to perform engineering calculations for each individual architectural plan. This is likely to add significant effort and expense to the design process. If single header design tables were available in the codes, adoption of the single header construction detail may be encouraged and economized.

Figure 10. 2x10 Header - Second-Story Non-Load Bearing Interior Partition. It was subsequently replaced with 2x4 header and cripples.

Design Recommendations

A more practical method for efficiently framing headers over openings in bearing walls (given the current building code status) is to properly size them according to widely available and recognized span tables rather than using a one-size-fits-all approach. In the *2006 International Residential Code for One- and Two-Family Dwellings,*[6] Tables R502.5(1) and R502.5(2) specify maximum spans and required number of jack studs for girders and headers in exterior and interior bearing walls. The code tables give the required dimensional lumber size for various spans based on local snow load, the width of the building, and loads supported by the header. Where only one jack stud is required to support each end of the header, these jack studs may also be replaced by an approved hanger.

[6] *International Residential Code for One- and Two- Family Dwellings 2006®*, published and copyrighted by the International Code Council, U.S.A., 2006

By properly sizing headers according to the code tables, most of the headers in the load-bearing walls could have been double 2x6—with the exception of one header over a 6-foot sliding glass door that would need to be double 2x12. While a double 2x6 header uses slightly more lumber on a board-foot basis than a single 2x10, using right-sized double 2x6 headers in load-bearing walls would have reduced lumber usage over conventional methods (double 2x10) by 17 bd-ft, even after accounting for cripples between the header and the top plate. It is important to also note that cripples are not required in non-load bearing walls for openings less than 8 feet if the distance between the header and top plate is less than 24 inches. This provision reduces the number of short cripples that need to be installed. When specifying "right-sized" headers, it is important to identify header size and configuration for every opening on the architectural plans in order to ensure that the design intent is carried out in the field.

A second issue that was encountered relative to the use of header hangers and the elimination of jack studs was inadequate solid nailing for siding and exterior and interior trim. Where single king studs and a single flat 2x4 head jamb were used for window and door framing, it was difficult to securely attach trim and siding. Not only did the metal hanger prevent nailing to the "inside" but lack of a 3-inch solid nailing surface prevented sufficient nailing to the "outside" as well. This situation highlights one of the constructability limitations that arises when recommendations for OVE practices are not thoroughly evaluated and implications for all construction phases considered. The intent of OVE is to reduce the use of unnecessary framing lumber—not to compromise other aspects of construction. If the quality of other systems within the home becomes compromised, the value of OVE can be rightly criticized. For these reasons, it is recommended that double framing members or cripples be used around all window and door openings on both exterior and interior walls. In the As-Built Home, this situation was rectified by adding nailers around the openings before the walls were closed in.

Single Top Plate

Material Usage

Using a single top plate on the second story saved 156 bd-ft of lumber over the conventional framing practice of using a double top plate. This is equivalent to approximately 22 2"x4"x16' boards.

Discussion

Although using a single top plate may save lumber in some cases, it presents several practical construction issues worth noting. In the case study home, using a single top plate on the second story with 92.5-inch pre-cut studs created a rough-framed ceiling height of only 95.5 inches. Therefore, the drywall for the second story had to be trimmed by approximately 1½ inches—certainly, not a task that a drywall crew would want to perform on a regular basis. In order to avoid this additional trimming, a builder could, 1) bulk order 94-inch pre-cut studs; 2) cut down 8-foot studs on site; or 3) use a double top plate. In the case study home, cutting 8-foot studs to size would have resulted in an additional 34 bd-ft of lumber waste plus additional labor time. For comparison, using a double top plate on the second-story walls of the As-Built Home would have increased the lumber usage by 156 bd-ft, as stated above.

If 94-inch pre-cut studs are available, this offers a more practical way to implement a single top plate on the second story. However, in the absence of 94-inch pre-cut studs, the use of a single top plate, on either story of the home[7], is not a very practical option in most cases. While LCCTC labor

[7] The use of a single top plate on the first story was not an option for the LCCTC case study home once the decision had been made to use 2x4 framing with 1" exterior rigid foam in order to gain the thermal benefits offered by that system. When a single top plate is used to support one floor, one roof, and one ceiling, the 2006 IRC requires that all structural members (including studs, joists, and rafters) must stack over one another within a tolerance of 1 inch. In order to realize the material savings achieved by 24" framing for some of the floor joists, second story wall framing, and conventional roof truss spacing, 2x6 dimensional wall framing would have been required for the first story.

is free, for most builders, any cost savings in materials will be offset by added labor. Additionally, an investment must be made in the materials and labor for installation of metal plates to secure adjoining wall sections.

Two-Stud Corners

Material Usage

Using two-stud instead of three-stud corners saved 16, 2"x4"x8' boards, for a total lumber savings of 56 bd-ft.

Discussion

LCCTC encountered several issues with regard to two-stud corners. The corners not only presented problems with siding and trim attachment, but also complicated the installation of cellulose insulation and drywall.

Exterior Cladding
With two-stud corners, the nailing surface for exterior cladding was inadequate. Fiber cement siding with plastic composite trim was used on the home. On one side of a corner, there was barely room to nail the corner trim through the flange securely into a solid stud; the lap siding could only be nailed into the 7/16-inch OSB sheathing at this end. Such a fastening schedule not only violates many manufacturers' recommended installation methods, but also prescriptive code requirements. For most types of horizontal lap-siding, the 2006 IRC requires fastener penetration of 1½ inches into solid wood. In some cases, the carpentry instructor added blocking to facilitate attachment.

Spray Cellulose
Initially, the use of two-stud corners concerned the spray-cellulose installer because of potential difficulty in smoothly "screeding off" excess insulation in the last wall cavity where there was no corner stud to serve as a guide. For the installation, 1-inch nailers were added along each corner to facilitate this process. Although this detail will compromise the R-value of the corner somewhat, it is preferable, in terms of energy efficiency, to a full three-corner stud.

Gypsum Wall Board Installation
Lastly, when using two-stud corners, the builder must coordinate with the gypsum wall board installer to ensure the use of drywall clips where there is no solid backing. Once the 1x4 nailers had been added to facilitate insulation installation, this was not an issue in the As-Built Home.

Discussion

It can be difficult to incorporate two-stud corners into routine framing practice, a finding that has been validated by this case study as well as numerous other "reports from the field." Many builders who have attempted or considered these particular details have noted the same issues described above.

Alternatives to two-stud corners are three-stud corners shown in Figures 11 and 12. The detail in Figure 11 provides adequate nailing for exterior cladding and access to insulate, but would still require the use of drywall clips. Figure 12 provides backers both inside and out, but necessitates the provision of insulating material on-site during the framing stage.[8]

[8] The detail in Figure 12 is particularly well-suited to factory-built panelized construction.

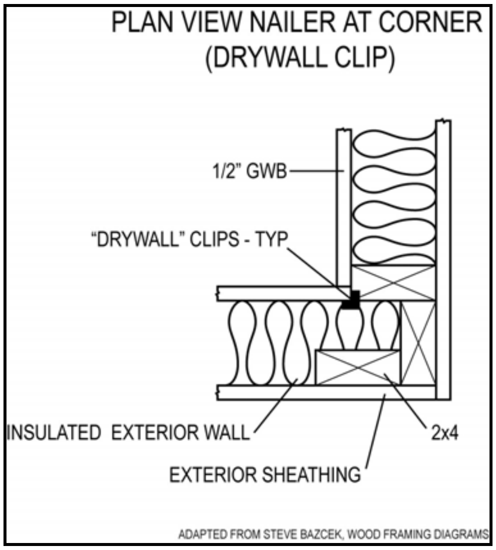

Figure 11. Three Stud Corner

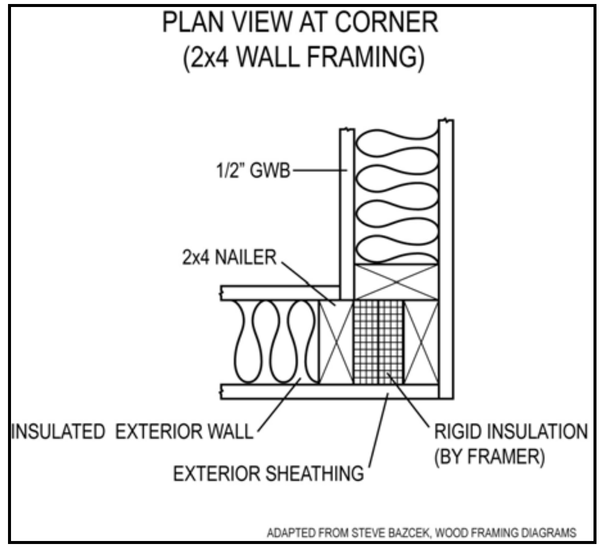

Figure 12. Alternate Three Stud Corner

Sill Plate

Material Usage

As one example of how perceptions about quality can affect lumber usage, 2x10 pressure-treated lumber was used for sill plate material when 2x8s would have sufficed. The LCCTC project manager believed that it was "preferable" to cover the majority of the top of the 12-inch ICF foundation wall in order to provide greater bearing width for the entire structure. The 2006 IRC makes no specific provision about the required width of the treated sill plate on top of the foundation. Indirectly, Section R502.6 requires that a wood joist, beam, or girder have at least 1½ inches bearing on a wood member beneath it or be supported with approved joist hangers. This then would permit a treated sill plate as narrow as a nominal treated 2x4 depending on the anchorage device used. Typically, 2x6 or 2x8 treated lumber is specified and used in most single-family homes with basement foundations. For ICF foundations, 2x8s are more commonly used due to the added thickness of the foam forms. With a total sill plate length of 186'-5", using 2x8s instead of 2x10s for the sill plates would have saved 47 bd-ft of lumber.

Floor Framing

Material Usage

Approximately half of the first- and second-story floors were framed with TJIs spaced 16" o.c. and half at 24" o.c.. Compared to a conventional 16" o.c. floor system, the As-Built Home used about 10 percent fewer joists (1,584 ln-ft TJIs compared to 1,764 ln-ft). If 24" o.c. floor joist spacing had been used throughout the home, about 30 percent fewer floor joists would have been needed, for a savings of 12 nominal 12-inch TJIs, totaling 337 ln-ft.

Discussion

Sixteen-inch on center joist framing was used in certain areas of the case study home instead of 24" o.c. throughout because, 1) the I-joist distributor was concerned with overall floor stiffness; and 2) the tile installer was concerned about stiffness of the subfloor for tile installation.

Figure 13. First Floor Framing (TJI 230, 11-7/8"). 24" o.c. (foreground) and 16" o.c.. (background).

However, both concerns were merely judgment calls. The L/360 deflection limit specified for the 24" o.c. joist framing is permissible by code, and the tile industry provides installation guidelines for any code-approved floor system. However, the design and construction industry commonly prefers the stiffer deflection limit of L/480 due to uncertainty about the future placement of and load created by furnishings. Furthermore, a bouncy floor is not easy to remedy, especially if finish flooring materials are damaged due to floor movement.

Finally, homeowners' perceptions and customer satisfaction are an important part of a builder's business and should not be ignored. As was the case in the LCCTC project, many builders and trade contractors are simply not willing to risk customer complaints and potential rework to achieve a relatively small amount of lumber or dollar savings.

However, it should be noted that floor stiffness depends on variables other than joist spacing—it is also a function of the joist size and design, type and thickness of sheathing material, blocking, and fastening method. A deflection limit of L/480 can be achieved using a stronger I-joist, thicker subflooring, additional blocking, or open web floor trusses while maintaining 24" o.c. spacing throughout. In reality, the TJI 230 joists used in the case study home were adequate to meet the L/480 deflection criteria for the longest floor joist span of 16'-3".[9] However, for a more conservative design, the slightly stronger TJI 360 could have been used which allows a span of 17'-10" and meets the L/480 deflection criteria. Using the TJI 360 would not have affected construction significantly, as the depth of the TJI 360 is the same as the TJI 230 and the cost premium is negligible. To use joists spaced 24" o.c., floor panels must be rated for 24" o.c. spacing and the subfloor should be glued and screwed, typical practice for both LCCTC students and most builders.

Therefore, cost-effective solutions could have addressed the multiple concerns of the various parties involved while still reducing lumber usage. Joist spacing at 24" o.c. could have been used to reduce the number of I-joists while more conservative design criteria could have been applied to ensure performance of finish materials, durability, and customer satisfaction. However, there continues to be a reluctance to use 24" o.c. floor joist spacing throughout the industry. Clarity in the codes, education for builders and floor installers, and manufacturers' testing of the stiffness of floor systems could help alleviate some of these concerns.

[9] Assumes a 40 psf live load and a conservative 20 psf dead load to make provision for the possibility of heavier tile or marble flooring.

Roof Framing

Material Usage

For the roof framing system, the case study home did not achieve any lumber savings over a conventionally framed home because the conventional method is identical to the As-Built method (engineered roof trusses spaced 24" o.c.). Further, the relatively straightforward rooflines of the home do not offer significant opportunity for savings since, in many ways, the simple design has already optimized material usage. The engineered roof trusses utilize smaller dimensional lumber to achieve greater span capability and hence, represent significant lumber savings when compared to dimensional lumber roof framing.

However, due to the desire to enhance durability, the As-Built Home had extended overhangs on the gable end walls as well as the eaves. This increased overhang size is helpful in protecting the wall from wetting, but it increased lumber usage by 140 bd-ft for the roof system. Usually, the amount of lumber used is not even a consideration for this detail because it is overshadowed by concerns regarding durability or aesthetics. An overhang provides some weather protection for portions of the exterior wall, reduces the potential for water penetration into wall systems caused by rainfall events, diverts water slightly further from the foundation (unless gutters are used and routinely maintained), may provide shading, and contributes to the aesthetic of some architectural styles. Modest material savings should not be considered an adequate tradeoff for a potential compromise to long-term durability of the structure or its cladding system.

Discussion

By slightly redesigning the dormer framing, three girder trusses could have been eliminated. Further lumber savings could have been achieved if the roof design were altered more dramatically. For instance, a shallower roof pitch would have reduced the size of the trusses and eliminated the need for "piggy-back" trusses. However, changing the roof design would have changed the aesthetics of the home. Because the intent of this study was to compare the As-Built Home to an identical, conventionally-framed home, such options were deemed beyond the scope of the research. Design changes are an option only very early in the project and often are outside the control of the builder, who frequently is not brought on board until the design is essentially complete. These kinds of changes also usually require that the owner place a priority on resource conservation which may compete with their other myriad considerations.

Sheathing

Material Usage

Sheathing material usage for the As-Built Home was identical to the conventional framing scenario (based on the common use of fully-sheathed construction in the region at the time of the LCCTC project). The As-Built walls were fully sheathed with 7/16-inch OSB and covered with 1-inch extruded polystyrene (XPS), providing a nominal R-18 wall with better predicted thermal performance than a nominal 2x6 wall with R-19 cavity insulation (see footnote 5). Material savings could have been achieved by eliminating housewrap because the XPS insulation, with properly taped joints and appropriate sealant and flashing details at windows and doors, could serve as the water-resistive barrier (WRB). However, the use of foam sheathing detailed as a WRB is not specifically called out in the 2006 IRC and, therefore, must be approved as an alternative means and method through a specific manufacturer's code evaluation report. Until resolved, this situation may cause some local code approval difficulties.[10]

[10] Currently, proposals to clarify the use of exterior rigid foam sheathing as an accepted WRB are before the ICC.

Discussion

OVE practitioners often recommend eliminating or reducing the amount of OSB sheathing by using other code-approved methods of wall bracing such as diagonal metal or 1x4 let-in bracing or intermittent sheathed wall panels (as specified in Section 602 of the 2006 IRC) when feasible. While such bracing methods could have reduced the amount of wall sheathing in this home by more than half (1,499 s.f. versus 3,137 s.f.), it may have been slightly more difficult to implement from a design and construction perspective. For example, the lower story front wall on this house would have still required continuous OSB sheathing to comply with current building code. This is due to the lack of space for conventional 4-foot-wide bracing panels at one end of the wall and inability to count narrower panels toward required bracing (something that is in the process of being remedied in the IRC). As discussed in an earlier report,[11] Section 602 of the 2006 IRC is sufficiently confusing to discourage an optimized bracing design that relies on multiple methods of compliance. In such cases, despite provisions in the IRC, a code official *may* require the method and location of braced panels to be clearly shown on stamped structural plans, something that may be required in the future for all plans designed in accordance with the IRC's wall bracing provisions.

Figure 14. All Exterior walls are fully sheathed With 7/16" OSB *and over-sheathed with 1"XPS foam sheathing.*

Fortunately, the IRC wall bracing provisions are in the process of being simplified and clarified by an ad-hoc committee created by the International Code Council. If successful, the wall bracing provisions should be easier to implement and more flexible from a design perspective. This should promote appropriate integration of wall bracing options with OVE sheathing design considerations. These improvements may also promote future OVE framing innovations in combination with wall bracing/sheathing options in the United States.[12]

Unless a complete wall bracing strategy is detailed on building plans, specific bracing requirements for any given method may be overlooked and create difficulties at the permitting or construction stages. While the services of a registered structural engineer were available to LCCTC at no extra cost for the case study project, this would not usually be the situation, nor is it an added expense that most builders are willing to incur. In addition, many structural engineers are not familiar with conventional wall bracing methods and they are lacking technical data in material design standards to support efficient design calculations. While future improvements to the IRC may require wall bracing strategies to be detailed on building plans, it is uncertain to what degree. Furthermore, it is unclear when bracing analysis data supporting the new IRC provisions will become available for use by building designers. Regardless, fully-sheathed OSB construction will likely remain the preferred conventional method of wall bracing.

For the reasons explained above, the method of sheathing the LCCTC house included two layers of sheathing—one for structural purposes (7/16" OSB wood structural panels) and another for

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[11] *Code Issues that Limit Innovative Systems*, Building America deliverable 4.D.1, NAHB Research Center, January 2008.

[12] In New Zealand most homes are typically braced with structurally fastened interior gypsum wall board products, including some that have fiber-reinforced cores for extra strength. With some modest additional detailing of interior finishes, a complete structural shell can be created by modifying the use of a wall component (interior finish) which is already required for aesthetic and fire-resistive reasons. Consequently, such innovations allow exterior wall surfaces to be cost-effectively detailed with a focus on building envelope performance (e.g., weather and thermal resistance).

thermal purposes (1” XPS foam sheathing). Other more material-efficient solutions involved trade-offs that were considered less favorable for the LCCTC project. For example, using intermittent wood structural panel braces would have required the use of two different thicknesses of foam sheathing—½-inch thickness when placed over brace panels, and 1-inch thickness elsewhere. While this would have economized the framing material usage, it would have created a more complex framing condition to manage in the field. In addition, it was desirable to maintain a uniform 1-inch thick layer of foam insulation on the exterior to enhance energy performance and reduce the potential for condensation within the wall cavity. A 1-inch thick foam sheathing layer could have been achieved without any exterior structural sheathing, but this would have required use of 1x4 let-in braces, which are no longer a common practice, or an engineered bracing method such as designed metal strap braces or interior gypsum wall board attachments. While several connector manufacturers provide metal brace equivalents to the traditional 1x4 let-in brace, many of these products are meant for temporary bracing and care must be taken to ensure that a proper product is specified as a true equivalent to code-required wall bracing.

In summary, a “dual sheathing” approach was selected for the LCCTC home for the following reasons:

1. Simplicity in meeting current IRC wall bracing provisions
2. Local familiarity and perceived market preference for fully-sheathed construction as a conventional practice
3. Maintaining a uniformly high R-value for the building envelope to maximize energy efficiency and avoid potential moisture (condensation) problems

CONCLUSION

OVE framing techniques, after a long period of research and outreach, are accepted by code. Yet, their acceptance by builders, framers, and consumers is limited, at best. From this case study, there is evidence that some OVE framing practices are impractical in today’s construction environment. Further, when exterior foam sheathing is used, the energy efficiency benefits of OVE diminish. From an economic standpoint, the lumber savings–although not inconsequential–are not likely to offset the soft additional labor and management costs required to successfully implement OVE.

Builders and designers considering OVE practices face unique design trade-offs and barriers for each project and company’s management practices. Thus, the outcome of any attempt to implement OVE framing practices varies. Unfortunately, most OVE framing resources focus on technical practices and do not adequately address the decision-making process for selecting best practices. A key aspect of appropriately selecting OVE framing techniques is to ensure that all factors are carefully considered, including trade-offs that may affect detailing and installation of non-structural components (such as flooring, trim, and siding). In some cases, lumber savings simply cannot justify the construction obstacles that may result.

Architectural features and building configuration can have a large impact on framing material usage. Thus, preliminary building design and planning decisions can affect the ability to implement OVE practices effectively (or offset the benefits achieved by using them). The inclusion of OVE framing details on construction plans is important for proper implementation.

Some OVE techniques are perceived by consumers, builders, and trades as inferior to typical practice. Consumer perceptions, although not always well founded or accurate, are a reality that builders face (and often perpetuate) in the marketplace. In most cases, even significant framing lumber savings do not offset the risk of losing a home sale due to a perception of inferiority.

As this case study illustrates, the successful implementation of OVE framing may increase “soft costs,” at least in the short term, for design and project oversight. Engineered headers and floor systems, additional architectural detailing, and closer on-site supervision during construction are all added costs that must be acknowledged. Framing contractors adopting typically recommended OVE practices in their entirety must shift their priority from job consistency to efficient material usage, which is a huge paradigm shift. These soft costs are often overlooked when considering OVE framing. Granted, soft costs will decline as practices become more familiar to crews, but a builder's concern regarding soft costs is a real barrier to the use of some OVE framing practices. In every case, a builder must not only weigh the pros and cons of a particular practice, but must also assess the level of effort required to successfully effect the change.

This case study not only demonstrates the complexity and uncertainties involved in the decision-making process for implementing OVE techniques, but also provides a detailed perspective on realistic lumber savings. Based on the experiences gained throughout this project, some recommendations can be made regarding the most practical and optimal OVE practices to encourage.

The OVE techniques that can be practical to implement (if visibly marked on the construction plans) and have noticeable material savings, thermal benefits, and contribute to the quality of the framing job include:

- Right sizing headers according to the IRC 2006
- Three-stud insulated corners
- Ladder-blocking for intersecting walls
- 24" o.c. floor joist framing (using L/480 deflection limits)

OVE techniques that require thorough consideration (and/or more thorough treatment in the code) before implementation include:

- Single top plate
- In-line framing
- 2x4 and/or 2x6 24" o.c. framing (provides thermal advantages primarily when continuous exterior insulation is not used; can cause detailing concern for attachment of some finishes)
- Two-stud corner
- Header hangers if exterior foam sheathing is not used
- Single member framing around window and door openings
- Single member headers

Furthermore, when foam sheathing is used on all stud walls, thermal bridging is reduced and the energy-saving benefits of OVE framing become lessened. Therefore, when using exterior foam sheathing, the benefits of some OVE practices, such as 24" o.c. wall framing, should be examined primarily from the perspective of material saving benefits and constructability trade-offs.

RECOMMENDATIONS

The following additional and alternate OVE practices are recommended for future LCCTC homes as well as for wider consideration in the building industry. Implementing some key recommended changes can significantly impact framing material and sheathing usage. Other recommendations do not necessarily result in material savings, but may provide more labor-efficient and practical solutions given current industry conditions.

Near-Term Efforts

- In load-bearing walls, "right-size" headers according to IRC Tables R502.5(1) and R502.5(2) and clearly label header size on the structural plan to reduce material use and cost and to increase insulating value compared to typically-oversized headers. This practice will require more design work due to the need to reference the building code case-by-case rather than to use a one-size-fits-all approach.
- Construct insulated three-stud corners, as depicted in Figures 11 and 12, which provide a nailing surface for exterior siding and trim. Although the third stud modestly increases material usage and requires the placement of rigid foam insulation during framing, it dramatically improves constructability of corners. When exterior foam insulation is used, the increased thermal bridging of three-stud insulated corners over two-stud corners will be minimal. The alternate three-stud corner requires additional construction planning in order to have insulation material on site at the framing stage.
- To increase a home's R-value when 2x4 construction with fibrous (batt or blown) cavity insulation is the standard, adding one inch of continuous insulating foam on the exterior of a 2x4 wall is more effective, and uses less lumber than going to a 2x6 wall at 24" o.c. with cavity insulation only. Use of exterior insulating sheathing in conjunction with good air sealing details will mitigate problems with condensation in the wall cavity. Foam thicknesses of one inch or higher are warranted in the northern sections of Zone 4 and colder climates.
- For homes with exterior foam insulation, use one jack stud plus a king stud or two king studs with header hangers for all window and door openings in exterior walls on both stories to provide a 3-inch wide nailing surface for attachment of siding, drywall, and interior and exterior trim. Although this creates a modest increase in material usage, it greatly improves constructability and, due to the continuous layer of insulation board, increased thermal bridging will be minimized. Thicknesses of exterior insulation exceeding one inch should be considered in at least climate zones 5 and colder.
- When implementing OVE framing techniques, *clearly specify OVE framing details on architectural plans*. Header size and configuration must be noted on the drawings *for every opening* if a successful transition from conventional framing practice is expected. Information about where to begin wall framing layout is very useful for successfully incorporating in-line framing.
- Unless pre-cut 94-inch studs are available, single top plates are impractical in most cases.
- For headers in non load-bearing walls, use two 2x4 studs oriented flatwise in both stories instead of larger dimensional lumber headers to reduce material usage, simplify window and door framing, and provide an adequate nailing base for drywall and trim. Header details must be clearly indicated on the architectural plans so that field personnel are not required to distinguish between bearing and non-load bearing walls.
- When designing a floor system, consider use of 24" o.c. floor joist spacing and ensure that adequate floor stiffness is achieved in accordance with the applicable building code. In some cases, a stiffer floor may be desirable to control floor vibration due to occupant activity or expectations. In addition, finish floor materials may have special requirements for floor stiffness that apply to floor joists as well as subfloor sheathing[13] criterion.
- For treated sill plate material on top of the foundation, as narrow as nominal 4-inch dimensional material beneath wood framed floor systems is permitted by code. Typically, 2x6 or 2x8 is used and provides for safer working conditions during the early stages of framing.

[13] Recent changes to floor deflection requirements in ANSI 108 and the Tile Council of America "TCA Handbook for Ceramic Tile Installations" have aligned tile industry requirements with provisions of the IRC and IBC building codes. This should serve to ensure proper specification of joists, subfloor, and tile installation practices for 16"oc, 19.2"oc, and 24"oc floor framing (provided the added dead load of tile flooring is properly addressed).

Longer-Term Efforts

- Future design and construction guidelines for OVE framing must address OVE decision-making factors and potential trade-offs with respect to serviceability considerations, energy-efficiency impacts, installation practices, and manufacturer requirements for various assemblies, components, and finishes. In addition, OVE guidance in the area of wall bracing would fill a needed void created by increased complexity of wall bracing provisions in modern building codes. Current guides tend to stress material savings without in-depth consideration of some of the cost and performance trade-offs involved. The goal should be to optimize, not maximize, the use of OVE framing in the context of all costs and objectives associated with a building project.
- Additional OVE framing practices, such as the use of single headers or band-joist headers, should be incorporated into prescriptive building codes to facilitate their use without incurring the added cost of professional engineering for each application.