Small-Scale High-Performance Sustainable Construction: Two Wisconsin Case Studies

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ABSTRACT

Conventional wood-frame construction for residential and light-commercial buildings has several common framing details that inhibit optimal energy performance in practice. This paper describes modified wood-framing practices that address these deficiencies. By slightly modifying conventional framing methods, higher envelope energy performance has been demonstrated in numerous residential and light-commercial projects built in the heating-intensive climate of central Wisconsin. Two case studies, one residential and one light-commercial, of the application of these techniques are discussed along with their thermal performance. All of the details discussed are relatively simple variations of conventional framing practices employed in the wood-frame building industry. The methods discussed involve slight shifts in the location of framing members, the insertion of air/vapor retarder film at critical points in the assembly, and providing interior and exterior strapping or furring to create a thermal break between the interior and exterior surfaces of the building envelope.

INTRODUCTION

There are several common framing details in conventional wood-frame construction practices that inhibit optimal energy performance in practice. Among these are:

- The percentage of solid wood present in the form of studs, plates, headers, etc. which create conductive heat transfer paths in the thermal envelope and compromise the overall insulating value of the assembly;
- The intersection of foundation and floor deck at the box sill or rim joist, complicating the continuity of air barrier and vapor retarder materials;
- The intersection of upper floor decks at outside walls, complicating continuity of air barrier and vapor retarder materials;
- The intersection of interior partitions at outside walls, complicating continuity of air barrier and vapor retarder materials; and
- The lack of sufficient depth in conventional stick-built framing in single-member wall and roof framing to accommodate sufficient insulation and cold-side ventilation in northern climates.

The modified framing details that address these deficiencies and that are described in this paper have been used successfully for several years in central Wisconsin. These construction techniques have typically been used only on custom residential projects where high-performance and energy-efficiency are the primary motivations. Such is the case with the Sullivan residence, the first case study presented. But these modified construction details have also been successfully adapted to several light-commercial buildings, including the Mead Wildlife Area DNR Headquarters and Education Center, which is the second case study presented.

While there are certainly incremental costs associated with incorporating these techniques into a project, such an economic analysis is not included in the scope of this paper. Rather, the intention is to describe the techniques used and report on actual energy performance for the two case study projects described. As with any high-performance construction project, a combination of measures, utilized in an integrated approach, are

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jointly responsible for the final outcome. This paper focuses on a family of construction details that contribute to the projects' energy and moisture performance by facilitating the continuity of air and vapor barriers in the framing.

MODIFICATIONS TO CONVENTIONAL WOOD-FRAME CONSTRUCTION

Five common framing details that inhibit optimal energy performance in practice are discussed below, with the suggested modifications described for each. These details were applied to the two case study projects described later in this paper.

Solid Conductive Heat Loss Path in Wood-Frame Walls

A typical wood-frame stud wall can have up to 25% solid content in the form of vertical studs, top and bottom plates, headers for openings, blocking, etc. For example, the solid content of an 8 ft. (2400 mm) tall by 25 ft. (7500 mm) long wall, as shown in the upper view in Figure 1, with 2x6 (38x140 mm) studs @ 16 in. (400 mm) on center and two 4 ft. x 5 ft. (1200x1500 mm) window openings, contains 16% of the total wall area as solid wood. This area of solid content has a conductive heat loss path from inside to outside with an insulating value of approximately R5 ft·°F·h/Btu (RSI 0.9 K·m/W), compared to the 5-1/2 in. (140 mm) cavity insulation between the studs, with an insulating value of approximately R20 (RSI 3.5). The net effect is to reduce the overall insulating value of the entire wall assembly due to the solid conductive path content.

One technique to reduce the area of solid conductive path is to provide a thermal break between the inside and outside surfaces of the wall assembly. This can be accomplished by adding a layer of interior horizontal furring members across the face of the studs, referred to in this paper as strapping. By adding this additional layer to the wall assembly, the conductive path is limited to where the wood members cross, to the perimeter members at the top and bottom plates, and to the perimeters of wall openings, such as windows and doors.

By using 2x2 (38x38 mm) horizontal strapping @ 16 in. (400 mm) on center, with a 2x4 (38x89 mm) at mid-wall to provide sufficient blocking for attaching horizontal gypsum board and a 2x4 (38x89 mm) at the base to provide sufficient blocking for attaching base trim, the solid conductive path of this example is reduced to 6.5% of wall area. The lower elevation view in Figure 1 illustrates the same wall with the strapping added.

There are two benefits to adding this layer of interior strapping. The first is to provide an additional 1-1/2 in. (38 mm) of insulation, an increase of 27.3%. The second is to create a thermal break to disconnect the conductive path between the inside and outside surfaces of the wall assembly. The darker intersections where the strapping crosses the face of the studs, along with the perimeters of the openings and the top and bottom plates, indicate areas with a solid conductive heat loss path through the wall assembly. In this case, a single 2x2 (38x38 mm) member is needed in areas of double top plates, doubled or tripled studs, and other areas of high solid content in conventional framing.

With the exception of these necessary areas of overlap, the strapping allows for the cavity insulation to extend over the interior face of the studs and headers, between the interior wall surface and the structural studs. The interior wall finish is

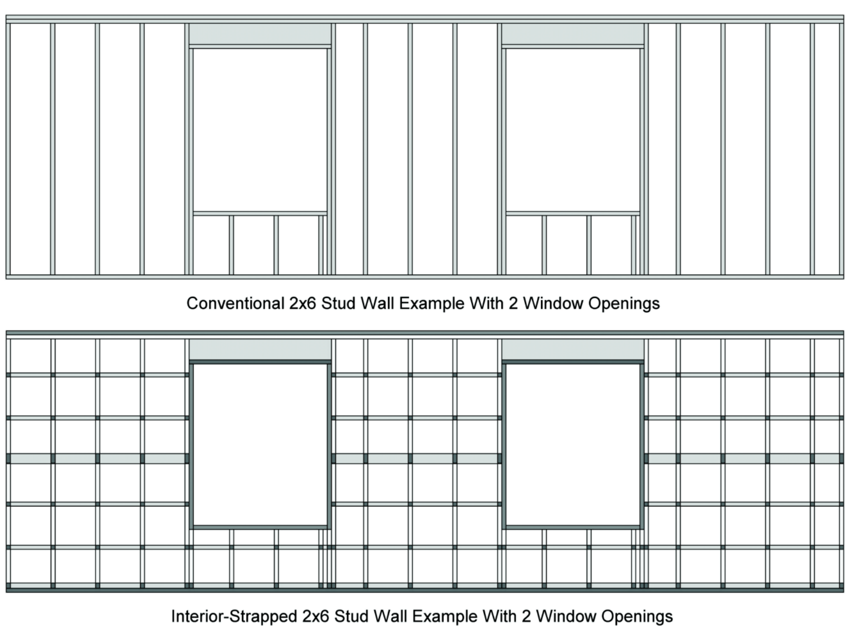

Figure 1 *Conventional vs. strapped wall elevation comparison view.*

attached to the horizontal strapping, while the exterior sheathing is attached to the structural studs.

Two-stud corners are used with a third stud on the overlapped-wall held back from the corner to allow for insulation behind the overlapping wall end stud. The interior strapping is cantilevered slightly to the interior corner and drywall clips are used at the interior corners.

These framing details are complemented with the inclusion of a continuous air/vapor retarder layer on the interior (warm) side of the insulation and an exterior air-barrier on the exterior (cold) side of the wall assembly. A blown or spray-applied loose-fill insulation in the wall cavity completes the configuration, without the typical gaps and material compression associated with batt insulation applications.

The additional wall thickness created by this strapping layer must be taken into account for window and door jamb widths and extensions. In addition, the thickness of the strapping layer needs to be taken into account when determining interior dimensions for adjacent spaces such as bathrooms, stairways, hallways, closets and similar spaces where minimum dimensions are determined by code or convention.

Figure 2 illustrates several variations on conventional wood framing details. These details have been modified to allow for the inclusion of continuous air and vapor barrier materials to achieve a higher level of airtightness than would normally be achievable with conventional framing practices. Discussion of several modified details follows.

Foundation/Floor Deck Intersection at Rim Joist

The rim joist area, where the floor deck rests on the top of the foundation wall in platform construction, has been a difficult area to achieve a high level of airtightness in conventional wood-frame construction. Typically, the vapor retarder is interrupted between the basement and upper levels in this location. Because the edge of the floor deck is usually flush with the exterior face of the foundation wall and wall studs, a continuous vapor retarder on the outside of the rim joist would be in a cold location and present problems with condensation and moisture damage. Labor-intensive solutions include cutting and inserting individual pieces of vapor retarder material or pieces of rigid insulation between the floor joists, or simply stuffing batt insulation in the box sill area without a vapor retarder.

One solution is to recess the floor deck the width of the structural stud wall to enable the studs to sit directly on the foundation sill plate, instead of on top of the floor deck. This allows the full thickness of the wall cavity insulation to be on the cold side of the vapor retarder, preventing condensation problems. This detail requires the use of taller wall studs to make up for the thickness of the floor deck assembly and possibly a wider foundation wall and sill plate to provide sufficient bearing for the floor joists.

A benefit of this modified framing detail is that it allows the installation of a continuous vapor retarder through the framing intersection. This is accomplished by laying a strip of vapor retarder material over the top of the foundation sill plate before adding the recessed floor deck. After the deck is in place, the vapor retarder strip is then wrapped up and over the face of the rim joist to lie on the subfloor deck. The taller structural stud wall can then be set in front of the vapor retarder and recessed rim joist. The rim joist vapor retarder strip can later be taped or sealed to the vapor retarder materials applied to the walls above and below the floor deck for continuity. Figure 2 contains several cross-section views illustrating this modified detail and Figure 8 is a construction case study photo.

During construction, care must be taken to avoid damage to the vapor retarder material. The use of a higher-strength material, such as cross-laminated polyethylene, is recommended. Since film materials can be slippery, care needs to be taken by the crew for safety with vapor retarder materials underfoot. Where insufficient bearing width is provided by the foundation, the detail described below for an upper wall/deck intersection can be substituted.

Exterior Wall/Upper Floor Deck Intersection at Rim Joist

Where there is insufficient width of the supporting wall to provide floor joist bearing for a fully-recessed floor deck and rim joist, such as in an upper floor/wall intersection or where a masonry veneer support ledge is required, a variation on the recessed rim joist detail noted above can be used. With 2x6 (38x140 mm) structural stud construction, the rim joist may still be recessed 2 in. (51 mm), without compromising required bearing length for the floor joists.

Construction is similar to the detail described above. A strip of vapor retarder material is laid over the top plate prior to setting the floor deck and then wrapped up and over the face of the rim joist to lie on the upper subfloor deck. The upper structural stud wall can then be set flush with the outside face of the lower structural wall studs, overhanging the recessed rim joist by 2 in. (51 mm). A piece of 2 in. (51 mm) R10 (RSI 1.8) rigid insulation the height of the floor deck is inserted in the gap between the upper and lower walls on the exterior (cold) side of the vapor retarder.

The rim joist vapor retarder strip can later be taped or sealed to the vapor retarder materials applied to the walls above and below the floor deck for continuity. Structural wall sheathing should extend across the face of the rim joist insulation to tie upper and lower wall assemblies together. While this detail allows for less insulation value than a fully-recessed rim joist, it does allow for continuity of the vapor retarder in a location where it is usually difficult to maintain barrier continuity. The typical application of a ceiling finish material in this location further isolates this framing intersection to maintain airtightness.

Exterior Wall/Interior Partition/ Roof-Ceiling Intersection

Another area that is typically thermally weak and usually creates a break in vapor retarder continuity is where an interior

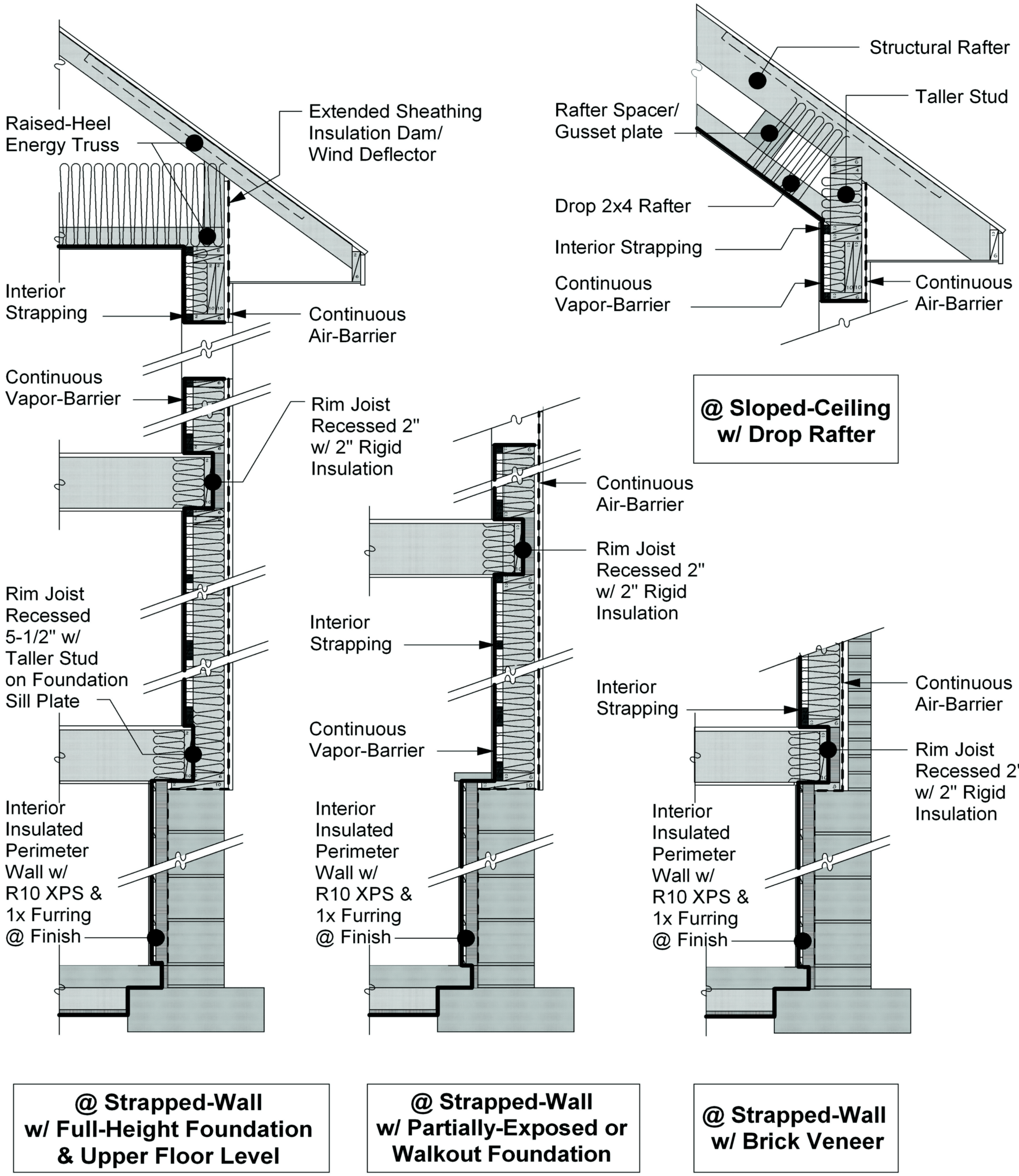

Figure 2 *Typical strapped wall section details.*

wall meets either an exterior wall or roof framing members, such as a roof truss or ceiling joists. Since rough framing is usually completed prior to attention to energy details, air/vapor retarder material in these areas is often missing or interrupted. This can be easily remedied by inserting strips of vapor retarder material in these locations during rough framing. By understanding and identifying where interior and exterior framing elements come together, normal framing practices can be followed with minimal interruption. Strips of vapor retarder material is simply attached to the backside or placed behind the end studs of interior partition walls that intersect exterior walls. In a similar fashion, strips of vapor retarder material are draped over the top plate of interior walls beneath ceiling or roof truss framing areas that will eventually be insulated. This can be done before the ceiling-roof framing is added or on the top of interior wall plates during erection. In some cases, the vapor retarder strip can be inserted between double top plates to prevent damage and to allow for safer footing. The rim vapor retarder strips can later be taped or sealed to the vapor retarder materials applied to the exterior walls and ceilings for continuity. Figure 9 is a construction case study photo illustrating this modified detail.

Exterior Wall and Roof Cavity Depth/ Cold-Side Venting

A typical 2x6 (38x140 mm) stud wall cavity is limited to an overall cavity insulating value of approximately R20 (RSI 3.5), without adding a layer of rigid insulation to the exterior or interior, which is often done in conventional construction. The deeper cavity thickness created by the layer of 2x (38 mm) interior strapping allows for R28 (RSI 4.9) insulation while at the same time creating the thermal break through the wall assembly.

A typical 2x10 (38x235 mm) ceiling joist or rafter is limited to an overall cavity insulating value of approximately R38 (RSI 6.7) or even less if pass-through venting is desired, and the additional depth is often not needed for structural purposes. A shallower structural rafter, such as a 2x8 (38x184 mm) can often be used, with a smaller 2x4 (38x89 mm) drop rafter added below to accommodate the desired insulation thickness.

A secondary thermal break can be provided on the exterior of the wall assembly by adding horizontal or vertical 1x3 (19x64 mm) furring strips between the exterior sheathing and finish siding material. Care should be taken to provide insect screening at the top, bottom and perimeter of the wall face. Such a spacer is also a critical best-practice for wood siding installation, where a drainage plane is desired behind the siding and creates a rain-screen cladding assembly with backside drying potential. The additional wall thickness created by this furring layer must be taken into account for window and door jamb widths and extensions.

Interior strapped-wall construction is similar to conventional 2x6 (38x140 mm) construction with a few differences, such as inserting vapor retarder strips in critical framing intersections to maintain a continuous insulated vapor retarder during rough framing. The interior-strapping is added after rough framing is completed. The resulting additional 1-1/2 in. (38 mm) wall thickness must be taken into account for window and door casings, as well as any dimension-dependent installations along the exterior walls. These might include stairs, plumbing fixtures, and/or other building elements. Some key features of this type of construction are listed below:

Foundation/Basement:

- sealed vapor retarder below slab, above or below rigid insulation
- rigid insulation below slab w/optional sand bed for protection
- optional sub-slab radon-mitigation gravel bed below vapor retarder
- interior 2x4 (38x89 mm) insulated perimeter stud wall, set in 1-1/2 in. (38 mm) from foundation wall, or PREFERRED:
- interior R-10 (RSI 1.8) rigid insulation, w/1x3 (19x64 mm) furring for interior drywall
- wall vapor retarder sealed to sub-slab and rim-joist vapor retarder
- electrical boxes mounted in plastic vapor retarder surrounds or gasketed

Floor Deck:

- vapor retarder strip laid over wider sill plate prior to setting joists
- rim-joist recessed 5-1/2 in. (140 mm) to allow insulated exterior walls to rest on sill plate, or
- rim-joist recessed 2 in. (51 mm) to allow for rigid insulation outside box sill
- vapor retarder strip folded up over subfloor to allow for continuity with wall vapor retarder

Walls:

- window and door unit frames wrapped with vapor retarder strip prior to installation
- wall vapor retarder sealed to rim joist and ceiling/upper floor vapor retarder
- wall vapor retarder sealed to window and door vapor retarder wrapping
- 2x2 (38x38 mm) horizontal strapping at interior face of studs to create thermal break/ 7 in. (178 mm) cavity
- 2x4 (38x89 mm) horizontal strapping at base and mid-height for base and drywall attachment
- vapor retarder strip inserted behind end stud of partitions intersecting outside wall
- electrical boxes mounted in plastic vapor retarder surrounds or gasketed
- 1x3 furring over housewrap at exterior for wood-siding rain-screen/drying cavity

Upper Floor Deck:

- vapor retarder strip laid over wall top plate prior to setting joists
- rim-joist recessed 2 in. (51 mm) to allow for rigid insulation outside box sill
- vapor retarder strip folded up over subfloor to allow for continuity with wall vapor retarder

Ceiling/Roof Truss:

- raised-heel energy trusses or raised-plate platform framing for flat ceilings
- raised-heel scissors-trusses, parallel-chord trusses, or false drop-rafters for sloped ceilings
- vapor retarder strip inserted at all roof/wall framing intersections
- vapor retarder sealed to wall vapor retarder

Figure 3 *Sullivan residence—exterior view.*

CASE STUDY: THE SULLIVAN RESIDENCE

The Sullivan residence is located in central Wisconsin. It is 1,936 sq. ft. (179.86 sq. m.) in area on the main level, including a small loft for passive-cooling and a breezeway airlock entry between the house and garage. A partially-finished lower level and a minimally-heated garage workshop bring the total heated area to 3,820 sq ft (354.89 sq. m.). The home floor plan layout is optimized for solar orientation, with an elongated east-west axis and main living spaces facing south. There is a high level of interior thermal mass, created by radiant-heated concrete slabs on both levels and thin-coat plaster over thicker gypsum board wall and ceiling finishes.

The home is all-electric and utilizes time-of-use electric rates for all energy usage. Heating is provided by a closed-loop ground-source geothermal heat pump coupled with hydronic-radiant heating in the floors. Heat-recovery ventilation and passive cooling is provided, along with a backup central masonry heater. There is no central or mechanical cooling. Figure 3 shows the southeast face of the home. Figure 4 shows the floor plan for the main level.

Figure 5 shows the recessed floor deck and rim joist wrapped with a taped and sealed vapor retarder, prior to the installation of the first floor structural walls, which will be set directly on the foundation wall sill plate in front of the floor deck and rim joist.

Figure 6 shows an interior view looking toward the kitchen. The interior strapping can be seen applied across the interior face of the wall studs. Note the wider strapping at mid-wall height and base for attaching horizontal sheets of gypsum board and baseboard trim. Strips of vapor retarder material are inserted in the modified framing at the intersection of the foundation wall and floor deck during construction. Secondary dropped 2x4 (38x89 mm) rafters, creating the insulation

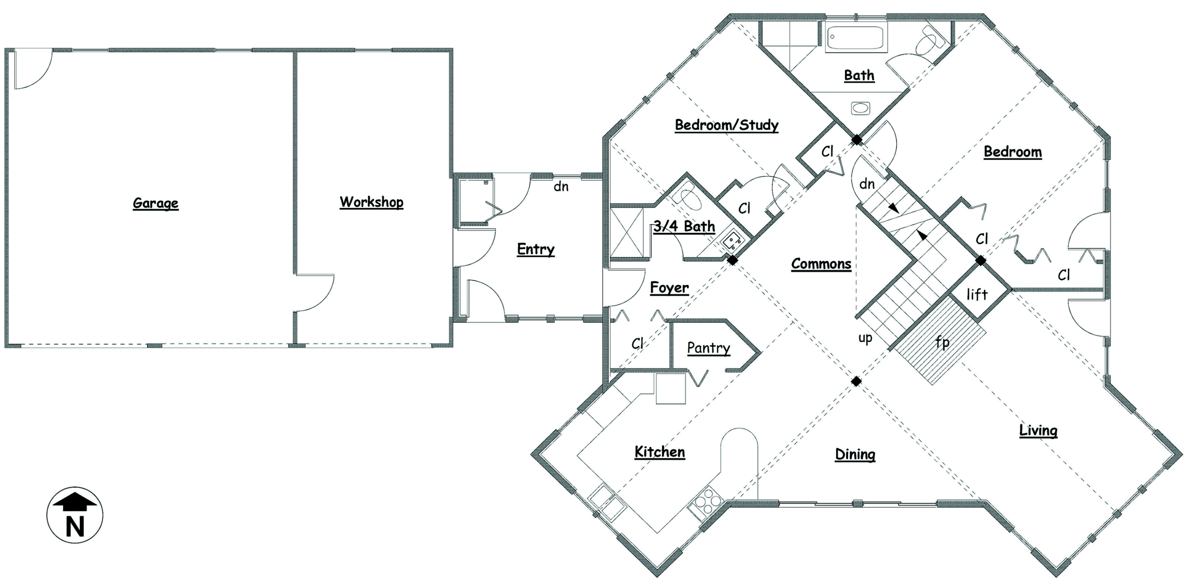

Figure 4 *Sullivan residence—plan view.*

Figure 5 *Sullivan residence—exterior view.*

Figure 6 *Sullivan residence—strapped-wall construction view (framing).*

Figure 7 *Sullivan residence—strapped wall construction view (insulation—vapor barrier).*

Figure 8 *Sullivan residence—strapped wall construction view (rafters—vapor barrier).*

cavity for the sloped ceiling, are visible below the 2x6 (38x140 mm) structural rafters.

Figure 7 shows the partially-finished and insulated lower level where it is exposed above grade to create a walkout. Blown fiberglass insulation has been applied in the stud cavity inside the foundation perimeter stud wall and in the conventionally-framed stud wall with interior horizontal strapping. Airtight electrical box enclosures are also visible, with the partially-installed vapor retarder material taped and sealed.

Figure 8 shows the upper loft area, with structural roof framing consisting of 2x6 (38x140 mm) rafters in the sloped ceiling of the living area below. Secondary 2x4 (38x89 mm) drop rafters are shown underneath the structural rafters to accommodate the insulating value of approximately R60 (RSI 10.6). Also visible are two airtight electrical box enclosures with wide flanges to facilitate sealing to the wall vapor retarder and the piece of vapor retarder inserted at the ceiling peak during rough framing. The window units have been individually wrapped with vapor retarder material that will be sealed to the wall vapor retarder.

In January 2000, the home received the First-place Gold Energy Value 2000 Award from the National Association of Homebuilders Research Center (NAHBRC). It was selected as the best Innovative/Advanced residence in a cold-climate region. It also received a 5-Star PLUS rating under the EPA Energy Star Homes program with a score of 93.9.

The home's energy usage was tracked and averaged over a four-year period, with time-of-day electric usage monitored for both on-peak and off-peak energy usage. Figure 9 shows a summary of the actual energy usage and costs, not including a $7.50-$8.00/month meter charge.

Total annual electrical energy consumed was 19,703 kWh. By subtracting the average summer usage from the winter usage, an approximation for heating usage for the six month winter period was calculated at 7,566 kWh at a cost of $212.67, not including the meter charge.

An Energy Use Index (EUI) was calculated by dividing total annual energy usage by the main heated floor area. This is a conservative number since it does not include the unfin-

4 year Average	Avg Total Energy	Winter Avg Total	Winter Avg Heating
1,936 sq.ft. (179.86 sq.m.)	Total April-April	Total October-April	Heating October-April
On-Peak kWh / $	2,094 / $238.55		
Off-Peak kWh / $	17,609 / $472.80		
Total kWh / $	19,703 / $711.35	13,630 / $465.61	7,566 / $212.67
MMBTU/yr / GJ/yr	67.25 / 70.92	46.52 / 49.08	25.82 / 27.24
EUI = kBTU/sq. ft./yr	34.74	-	-
MJ/sq. m./yr	394.96	-	-
HDD	7,344	6,406	5,990
EII = BTU/sq. ft./HDD	4.73	3.75	2.23
KJ/sq. m./HDD	53.72	42.60	25.29

Figure 9 *Sullivan residence—summary of actual energy usage (1998–2002).*

ished (but conditioned) basement area and a minimally-heated garage workshop area.

An Energy Intensity Index (EII) was calculated by dividing the total annual heating energy usage by the area of the house and the number of Heating Degree Days (HDD) recorded for the local climate. Utility records for the four-year period averaged 7,344 HDD annually, with a 5,990 HDD average in the six-month heating season.

Actual heating energy usage is 2.23 BTU/sq. ft./HDD (25.29 KJ/sq. m./HDD) of heated space and equates to a steady-state heat loss of 15,166 BTU/hour (16 MJ/hour) at -20 F (-29 C). The 1,936 sq. ft. (179.86 sq. m.) main floor area was used to calculate the indices, since this represents the fully-conditioned and regularly-occupied portion of the residence. The total conditioned area is 3,820 sq. ft. (354.89 sq. m.). Had the larger area been included in the calculations, the respective Index numbers would be reduced by approximately half.

CASE STUDY: MEAD WILDLIFE AREA DNR HEADQUARTERS AND EDUCATION CENTER

The Mead Wildlife Area DNR Headquarters and Education Center (completed 2006) is a 6,208 sq. ft. (576.74 sq. m.) facility showcasing renewable energy technologies. Figure 10 shows an exterior view of the building from the southwest. Figure 11 shows the building floor plan.

The one-story slab-on-grade building is targeted, but has not yet been submitted, for a Leadership in Energy and Environmental Design (LEED) Gold certification level. Modified wood-framing details described earlier in this paper were used in the construction of this building. Figure 12 shows an interior construction view. The interior horizontal strapping can be seen with spray cellulose insulation partially installed.

Among sustainable features and renewable energy systems incorporated into the design and construction of this project are:

- passive solar orientation and layout;
- high-performance exterior building envelope, employing modified wood-framing details;
- spray-applied cellulose insulation;
- cool daylighting;
- water-conserving fixtures and landscaping;

Figure 10 *Mead facility—exterior view.*

- environmentally-responsible materials and finishes;
- emphasis on the use of locally-sourced regional materials;
- panelized component construction for quality control and minimization of construction waste;
- eight geothermal closed-loop ground-source heating and cooling heat-pump units;
- grid-intertied 10kW wind energy turbine;
- grid-intertied 2.3kW tracking solar photovoltaic electricity array;
- ground-mounted solar hot water collector array; and
- biomass central masonry heater with hydronic loop.

Energy modeling, using Trace/DOE-2 software, projected a design-case energy load at 78% better than the ASHRAE 90.1 (2004) base case for this building. The reduced conductive-path aspects of the envelope were not specifically factored into the analysis.

Actual energy usage of 42,950 kWh (154.62 GJ) for 2006, the first year of occupancy, was entered into and compared with the EPA Energy Star Buildings Target Finder database (www.energystar.gov/index.cfm?c=new_bldg_design.bus_target_finder). The building scores in the top 10th percentile for buildings of similar type with an EPA Energy Performance Rating of 91, out of a possible 100, and an Energy Use Index

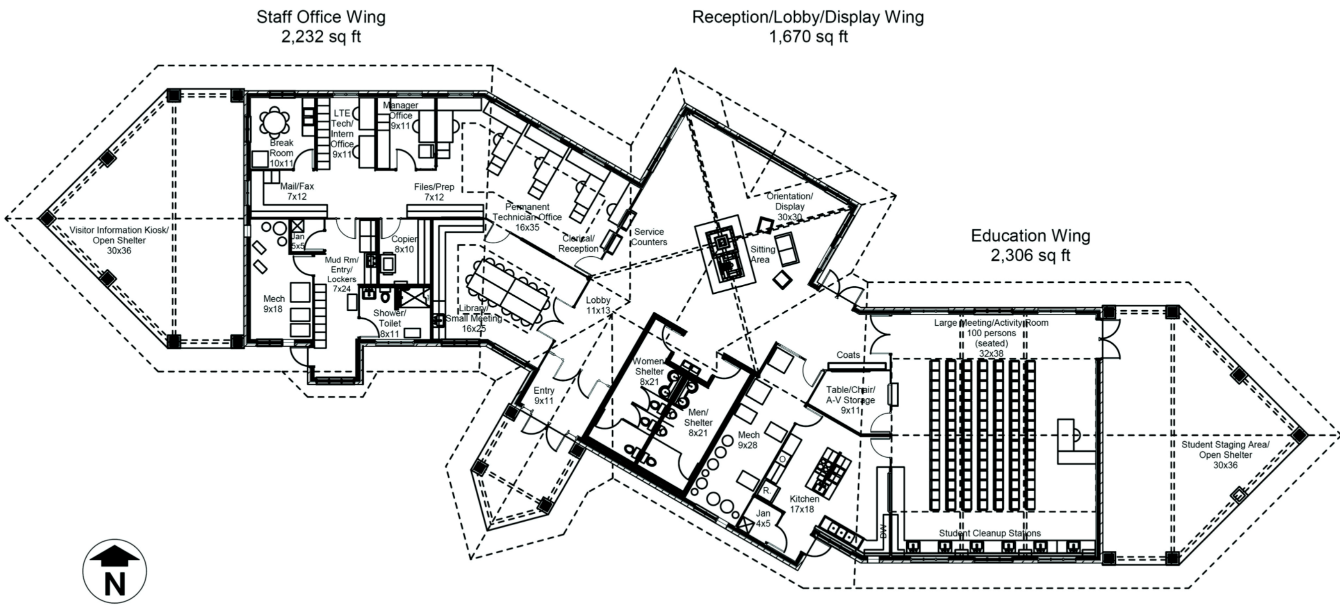

Figure 11 *Mead facility—plan view.*

(EUI) of 23.6 kBTU/sq. ft./year (268.1 MJ/sq. m./year). Renewable energy systems accounted for 10,390 kWh (36.4 GJ) or 24.19% of the building's energy.

CONCLUSIONS

The purpose of employing modified wood-framing details, such as those described in this paper, is to achieve a higher level of performance with conventional construction techniques. There are any number of construction systems and products available today for energy-efficient construction of smaller residential and light-commercial buildings. But many of these are proprietary in nature, which limit their applicability to a smaller number of projects, based on their cost or availability.

Each of the two case study buildings presented has performed at or above expectations. Some of these expectations have been tangible, in the form of reduced energy usage. Other expectations have been more intangible, such as the occupants' perceived level of comfort.

The Sullivan residence has performed consistently well, with the overall energy usage remaining fairly constant from heating season to heating season. Although the total energy cost has increased due to higher electricity prices, the electric energy usage has remained relatively constant, including the 90:10 ratio of off-peak to peak energy usage. Electricity rates are metered with different time-of-day rates. The high percentage of off-peak usage is attributable to several factors. There is a high level of thermal mass in the two-level radiant floor slab, thicker gypsum board walls with thin-coat plaster and the central masonry heater. This allows the geothermal heat pump operation to be shifted to off-peak periods much of the time. The owners also defer high-usage activities, such as laundry, to off-peak periods. The central masonry heater was intended as a back-up heat source during power outages but has been infrequently used.

Figure 12 *Mead facility—strapped wall construction view (insulation).*

The Mead Wildlife Area DNR Headquarters and Education Center is in its first full year of occupancy, and energy consumption is being monitored by an automated building control system, with energy usage compared with the energy model projections. Due to its recent construction, energy usage data is still being gathered for analysis.

Since most of this type and scale of building is locally procured from smaller construction firms, these modified framing techniques can be applied by most individuals with a small learning curve. They do not require specialized subcontractors or the use of proprietary construction systems to be effective. Rather than a radical new way of undertaking wood-frame construction, these techniques should be considered a refinement of and improvement to conventional construction methods to achieve a significantly improved level of airtightness and thermal performance. For builders unfamiliar with these techniques, most important is the contractor's openness to new ideas and willingness to change practices from conventional methods. To ensure a quality installation, contractors are typically pre-screened or provided with a personalized orientation and training on these techniques. In addition, architectural details and a step-by-step how-to narrative are included in the construction drawings.

There are certainly a number of variations on these framing details currently in practice in various regions of the country. One such system is often referred to as the Mooney Wall, a framing method developed by Mike Smith and Tom Mooney and described in an online forum hosted by Fine Homebuilding magazine (www.finehomebuilding.com) as early as 2003. The techniques described in this paper have been in use in central Wisconsin by this author since at least 1987. A variation of the interior-strapped wall detail by this author received an award from the New England Sustainable Energy Association in 1991 (Journal of Light Construction, August 1991, www.jlconline.com). In that configuration, a sheet of rigid foil-faced insulation was inserted between the studs and the strapping to form the vapor retarder, with wiring located in the un-insulated strapping cavity.

Although an economic or cost-benefit analysis of the incremental costs and potential return on investment is beyond the scope of this paper, these techniques have been used in dozens of buildings in central Wisconsin with similar results. Anecdotal cost information from contractors indicates an incremental cost premium in the range of 5% to incorporate the additional strapping, thicker blown insulation and give additional attention to air and vapor barrier detailing.

It should also be noted that these buildings were designed and built through an integrated design approach. Their energy performance can be attributed to a combination of factors including, but not necessarily limited to, solar orientation, high-performance building envelope, airtight construction, and interior thermal mass. The continuity of both the interior air/vapor retarder and the exterior air barrier combine to enhance the energy and moisture performance of the building envelope. Although the modified framing details discussed in this paper are only one part of this whole, as a system they stand out as one element that sets these buildings apart from others built in this region.