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The Role of the Structural Engineer in Zero Net Energy Construction

Karyn Beebe, P.E., LEED AP BD+C
APA
San Diego, CA

Abstract

Zero Net Energy design (ZNE) will be required by 2020 (residential construction) and 2030 (commercial construction) under provisions of the California Building Energy Efficiency Standards and the California Green Building Standards Code (CALGreen) set forth in Title 24 of the California Code of Regulations. This paper explores the role of structural engineers in the development of ZNE construction, summarizes the current Energy Code and applicable CALGreen requirements, and discusses new technologies that will allow Structural Engineers to take an active role in implementing and designing the new requirements, including a discussion of structural framing systems such as Advanced Framing, staggered stud and double-stud walls, structural insulated panels (SIPS), and hybrid systems, as well as case studies for residential (Habitat for Humanity ZNE residence) and commercial (Bullitt Center) construction.

Introduction

The State of California has set a goal of Zero Net Energy (ZNE) residential buildings by 2020 and commercial buildings by 2030 in accordance with Climate Change Scoping Plan, Building of the Framework, Pursuant to AB 32, The California Global Warming Act of 2006, May 2014, California Air Resources Board. On an annual basis, a ZNE building produces about as much energy as it uses. ZNE construction is primarily codified by the California Energy Code and partially by the California Green Building Standards Code (CALGreen), parts 6 and 11 of Title 24, and has just two more cycles to meet the state goal for residential construction. Building owners and architects are seeking cost-effective options that maintain strength and durability of the structural system while meeting energy-efficiency and other sustainability goals. ZNE design and construction uses structural detailing that is energy-superior to current construction techniques and identifies the impacts of energy producing technologies on the structural system. Structural Engineers need to become more familiar with how Title 24 impacts the design process.

ZNE Building Defined

The definition of a Zero Net Energy (ZNE) building varies widely worldwide. While the term ZNE has taken root in California, Net Zero Energy (NZE) and Zero-Energy Buildings (ZEB) are also commonly used to refer to the same energy design goal. Basically, this goal seeks to ensure that the amount of energy that is consumed on an annual basis is approximately equal to the energy produced by on-site renewables. Renewables are defined as energy systems that are based on natural resources such as the sun and wind.

Like the terminology itself, how ZNE is envisioned in the design, implemented in the construction drawings, and enforced by the building department varies as well.

The US National Renewable Energy Laboratory (NREL) authored *Zero Energy Buildings: A Critical Look at the Definition* and further discusses how the building's energy is produced (onsite: within or outside of the building's footprint; offsite: imported or renewable energy credits (RECs) purchased for renewable power produced elsewhere) and how the energy is measured.

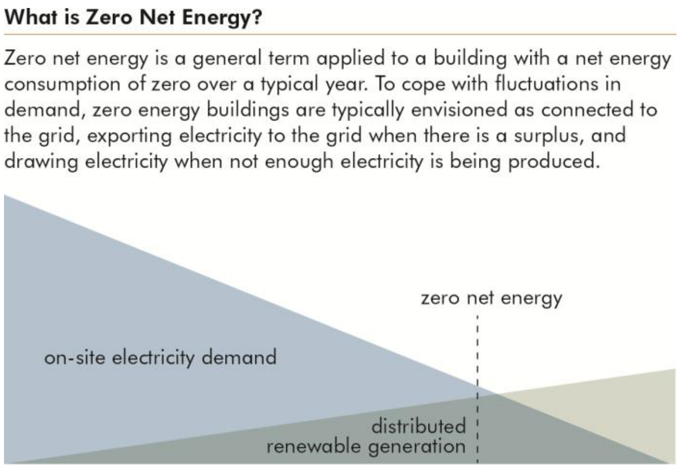

Figure 1—Zero Net Energy (CPUC, 2011)

Generally speaking, the goal is to produce energy onsite and only consider offsite when absolutely necessary. How the energy is measured can be assessed in several ways: by the energy usage at the site, the energy usage at the source, the energy cost to the purchaser, or by emissions associated with energy used and produced by the building.

The California Energy Commission measures the energy efficiency of the building using Time-Dependent Valuation (TDV). TDV uses the predicted building hourly energy usage multiplied by hourly factors representing the cost to the utility grid of providing energy (as well as some societal values), which creates an incentive to select systems that draw less power during peak times and more during off-peak times.

Benefits of ZNE

There are many benefits that may be gained through implementing ZNE. For example, the United States Environmental Protection Agency (EPA) (www.epa.gov/climatechange/wycd) lists 25 simple actions that everyone can implement to reduce emissions, such as reducing the amount of electricity to light and heat homes, in order to lessen adverse impacts to climate. As utility costs continue to increase, ZNE construction will benefit the building owner through lower operational costs (i.e., utility bills) and less reliance on fossil fuels. Local self reliance is another possible benefit, as building design moves toward “getting off the grid.” Building occupants also benefit from improved health and productivity with the increase in natural light and ventilation, a movement known as biophilia. Biophilia "promotes natural lighting and ventilation, the use of plants and natural materials, and in general, blurs the lines between buildings and landscape, is a design methodology that dovetails well with green building. While the latter has typically focused on resource and energy efficiency, biophilia supports the growing body of research in health, medicine and psychology indicating that patients recover more quickly, students learn better, retail sales are higher, and workplace productivity increases in spaces that offer an interaction and a connection with nature." (Vancouver Sun, Nov 2007)

Practically speaking, implementing ZNE now allows owners and designers to get ahead of the game and ahead of the learning curve. Early adopters will be more competitive, which can equal more project wins and greater profits.

How can the Structural Engineer Impact ZNE?

Many structures built today are like a leaky bucket. The energy needed to heat and cool a building is used inefficiently due to the use of “conventional” framing techniques. Before considering adding renewable energy sources to the building, we need to minimize the energy demand. The architect may consider many variables that can minimize the energy needed, including: size, building orientation, massing, air leakage, and enclosure design.

First, the smaller the building, the less energy that will be required. The long-term trend in the U.S. has been building ever-larger single-family homes. During recessions, new single-family home size typically falls slightly, but once the economy returns to expansion mode, new home size increases. In 2013, the average size of new single-family homes built in the U.S. was a record high of 2,592 square feet.

Multifamily structures are inherently more energy efficient, due to the shared surfaces that prevent heat loss through the enclosure, in contrast to that experienced by a detached single-family home. In addition, multifamily units are smaller in size than a detached single-family home.

Second, buildings should be oriented to capitalize on solar and wind energy through maximum daylighting and free air-conditioning. "Massing" defines how the building is shaped and distributed. Thermal mass can be utilized to passively warm a structure when the temperature cools off at night. The higher a material's thermal mass, the greater potential payoff.

Considering the building enclosure, the structural engineer can efficiently design the structure to maximize the airtightness and insulation, while minimizing the framing factor. (See framing factor definition below.) Heat transfer through the walls is measured in terms of thermal resistance (R) of a wall by the cumulative effects of the different components of the wall assembly. The U-factor is generally the inverse of the R-value and used to evaluate multiple heat flow paths within a single assembly, such as walls.

Heat transfer occurs through three parallel paths in the wall, as shown in Figure 2:

1. Through the cavity insulation. This path typically has the most heat resistance due to the absence of framing. Although wood is a good insulator, when compared to other structural building materials, heat transfers at a higher rate through wood than insulation.
2. Through the framing including: studs, top and bottom wall plates, and full-cavity width blocking.
3. Through the framing headers that carry structural loads above window and door openings. Important to note, often the structural headers can be designed to accommodate insulation by reducing the header thickness through the use of engineered lumber, or a single ply sawn lumber header by careful consideration of the load path.

Several ways to reduce the thermal conductance of the exterior walls are to increase the depth of the wall cavity, use higher performing wall cavity insulation (higher R-value per inch), reduce the framing factor, cover the outside of the building with continuous insulation, or use a combination of any of these strategies. Framing factor is defined as the percentage of the total solid exterior wall area occupied by framing members, including headers, assuming the balance is composed of insulation. According to a study performed for ASHRAE in 2001, there is very little regional variation in wall framing factors for attached, detached and multi-family dwellings, and the report recommends a residential wall framing factor of 25 percent for inclusion in the ASHRAE *Handbook of Fundamentals*. (APA P320, 2014)

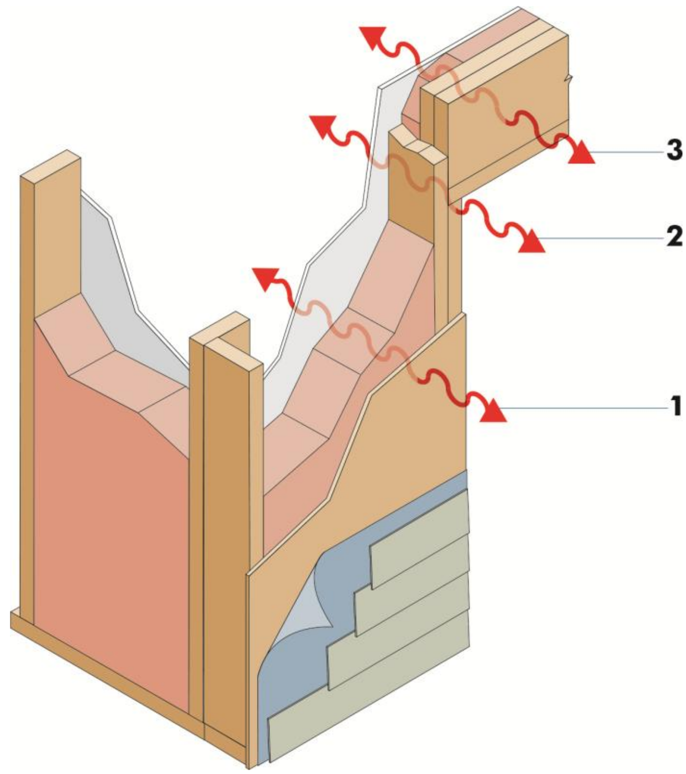

Figure 2—Heat Transfer Paths

Incorporating Advanced Framing techniques, as discussed in greater detail later, can bring the framing factor down to about 16 percent. Other envelope techniques include cool roofs and insulated foundations. Specific strategies will be discussed later in this paper.

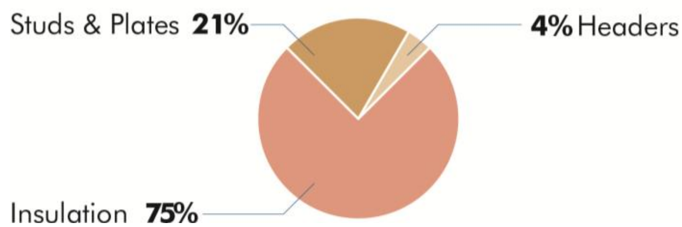

Figure 3—Framing Factor

California's Commitment to ZNE

The State of California mandated ZNE goals for new construction through the California Long Term Energy Efficiency Strategic Plan which established these "Big Bold Energy Efficiency Strategies":

1. All new residential construction will be ZNE by 2020.
2. All new commercial construction will be ZNE by 2030.
3. Heating, ventilation, and air conditioning will be changed to ensure optimal energy performance for the climate.
4. All eligible low-income customers will gain access to the low income energy efficiency program by 2020.

The strategies' broad goals are to: 1) bring the energy loads down, 2) use efficient systems, and 3) add renewables.

Deciphering Title 24

Title 24 of the California Code of Regulations (also known as the California Building Standards Code) is composed of 12 parts that address the regulations that govern the construction of buildings in California including the following:

- Part 2 – California Building Code (CBC)
- Part 2.5 – California Residential Code (CRC)
- Part 6 – California Building Energy Efficiency Standards (also known as Title 24)
- Part 11 – California Green Building Standards Code (CalGreen)

On January 1, 2014, the state adopted the 2013 Triennial Addition of Title 24, excepting Part 6 and energy related sections of Part 11. The CBC and CRC are based on the 2012 International Building Code (IBC) and International Residential Code (IRC), respectively. The Energy Code and CALGreen are not based on ICC model codes, but ICC has written the International Energy Conservation Code (IECC) and International Green Construction Code (IGCC) that have been adopted in other states. The energy regulations, covered in Part 6 and portions of Part 11, were adopted on July 1, 2014.

Although Title 24 represents all relevant construction codes, industry professionals frequently refer to Part 6, The Energy Code, as "Title 24," and so the balance of the paper will refer to the California Energy Code simply as Title 24.

The 2013 cycle of Title 24 has taken great strides toward making buildings more energy efficient: 25 percent more stringent for low-rise residential construction, 14 percent more stringent for multifamily residential, and 30 percent more stringent for nonresidential, in comparison to the 2008 standard.

Title 24 separates residential and nonresidential regulations. In light of the ZNE mandate for Residential construction happening first in 2020, we will focus most of our code research here. Within the code, there are two compliance paths: prescriptive and performance. According to the California Energy Commission, over 95 percent of new buildings take the performance path for Energy Code compliance. The prescriptive path establishes a baseline and is more commonly used for small remodels and additions. This is important to note, as the performance path gives the design team flexibility in detailing their building to best fit their design vision and budget.

Significant Changes to the Prescriptive Residential Requirements

If you have attended any energy code update seminars, you have likely noticed the focus on lighting and controls. One reason for this is that controls are relatively new and are easily adopted into a system to control how the building occupant uses energy.

Structurally speaking, the two most significant impacts to the 2013 Title 24 Residential requirements are U factors for wall insulation and solar ready roof requirements. There are 16 unique climate zones defined in California as shown in Figure 1-1 of the Residential Compliance Manual of Title 24. Table 150.1-A Component Package-A Standard Building Design sets the baseline for the Building Envelope construction. Interestingly, the 2013 version sets a uniform required U-factor for the wall assembly equal to 0.065 for all climate zones. Prescriptively speaking, the California Energy Commission equates this wall U-factor to an R 15 + 4 (3-1/2" high density fiberglass + 1" expanded polystyrene (EPS) or mineral fiber continuous insulation) or R 13 + 5 (3-1/2" regular density fiberglass, cellulose or low density spray foam + 1" extruded polystyrene (XPS), or equivalent continuous insulation). Both of these assemblies correspond to a 2x4 framed wall.

A common misconception is that all framed walls will require continuous insulation. Per Section 100.1 of the 2013 Title 24, continuous insulation is defined as:

> CONTINUOUS INSULATION (c.i.) is insulation that is continuous across all assemblies that separate conditioned from unconditioned space. It is installed on the exterior or interior or is integral to any opaque surface of the building envelope and has no thermal bridges other than fasteners and necessary service openings.

On the contrary, this table provides a framed U-factor baseline. The U-factor (0.065) allows the structural engineer to specify an alternate wall assembly such as a 2x6 wall with Advanced Framing, which will be discussed later. Furthermore, radiant barrier roof sheathing is required for all climate zones except for climate zones 1 and 16 when following the prescriptive path. (This will have more of a potential impact on the next code cycle when high performance attics are addressed.)

Why should the structural engineer care what the wall assembly is composed of? Currently, many builders clad 2x4 walls with 3-coat stucco without using continuous insulation. This will not prescriptively meet the required wall U-factor in the 2013 Title 24. The continuous insulation will need to be used in addition to the lateral resisting elements of the building, typically wood structural panels, or energy designers will need to consider alternative energy saving measures in order to meet the overall building performance guidelines. Providing both materials would likely increase the cost of construction over current practice, and eliminating all unnecessary sheathing in favor of the insulation may seem an attractive response to energy modelers. As a profession, we need to protect the structural integrity of the building. Two-by-six Advanced Framing allows the engineer to maintain the structural integrity of the load path while prescriptively providing the required insulation within the wall cavity.

Ultimately, cost is king, and the construction budget will not increase along with the Title 24 code changes unless that cost is transferred downstream to the building owner.

Section 110.10 – Mandatory Requirements for Solar Ready Roofs stipulates that the following occupancies design for solar ready: single family dwellings in developments of 10 or more, low rise multifamily (3 stories or less), hotels (stories </= 10), and nonresidential buildings 3 stories or less. The minimum area, orientation, and shading requirements are discussed in this section. Furthermore, Section 110.10, Item 4 states:

> Structural Design Loads on Construction Documents: For areas of the roof designated as solar zone, the structural design load for roof dead load and roof live load shall be clearly indicated on the construction documents.

Proposals for 2016 Title 24 – Residential

The 2016 Title 24 is currently under development. At the date of this paper's publication (September 2014), the language will be drafted and the California Energy Commission will be seeking comments and modifications from interested parties. The projected completion date is the end of the year, which allows for the year 2015 to be spent developing the compliance manuals, alternate calculation method, and building simulation software. The Building Standards Commission (BSC) will adopt the California Building Energy Efficiency Standards in the first quarter of 2016, and the code will go into effect on January 1, 2017. There will be only one additional code cycle to meet the ZNE goals for residential construction. In light of this, two proposed strategies for 2016 focus on high performance attics and the wall envelope.

High Performance Attics (HPA)

According to the Energy Commission, one of the least expensive places to make the largest impact on the building's energy efficiency is the attic. Most homes today house the HVAC system in unconditioned attic spaces. The extreme temperature swings in that space make these systems work much harder, so moving the mechanical equipment into the conditioned space of the home or increasing the conditioned space into the attic (in part or entirety) is being considered as a way to meet the high performance attic goals.

Depending on how the attic is insulated, this change does raise concerns. For example, some roofing products may experience weakened fire resistance if CI is used on top of the roof deck. If insulation is placed underneath wood structural panel roof sheathing, then the traditional drying path of the panels may be compromised. Section 1203.2 of the 2013 CBC states:

> …An airspace of not less than 1 inch (25 mm) shall be provided between the insulation and the roof sheathing…

APA's *Wood Moisture Content and the Importance of Drying in Wood Building Systems*, Form TT-111A, reinforces the need to provide a drying path for the wood products in a roof assembly. That being said, the Energy Commission claims to have no reported cases of moisture issues in CA-built, unvented attics (2-3 years of experience).

Furthermore, radiant barrier sheathing typically requires an air space to be effective. As noted earlier in the paper, all climate zones except for zones 1 and 16 currently require radiant barrier sheathing in the attic space. The purpose of radiant barrier sheathing is to block radiant heat in the roof from entering the attic, keeping the attic cooler, lowering energy costs, and making the home more comfortable.

In general, the Energy Commission seeks options that will have minimal cost increases for maximum energy benefits. Other measures under consideration are to increase duct insulation, decrease duct leakage, incorporate raised-heel trusses (for which there is a current performance credit in the 2013 Title 24), or increase attic ventilation to 1/300 from 1/150, which would create a savings in the summer (less so in the winter).

In summary, at the time this paper was written (July 2014,) the possible 2016 Title 24 HPA roof options under discussion include: an unvented attic with a roof deck of R-30 or R-38 (or U-factor equivalent), R6 on roof deck for a vented attic, and that roof and reflectance/radiant barrier could act as tradeoffs in the performance compliance path.

High Performance Walls

The other focus is the wall envelope. As mentioned earlier, the 2013 Title 24 sets a uniform wall U-factor of 0.065. This is expected to decrease further. As of July 2014, the Energy Commission stated a targeted wall U-factor of 0.045. This could be accomplished with the following wall assemblies: R21+6 (2x6 at 16" oc with 1-1/2" extruded polystyrene foam), or R13+10 (2x4 at 16" oc with 3-1/2" regular density fiberglass + 2" extruded polystyrene (XPS)). One challenge noted by a window manufacturer would be revising the best installation practices to meet thicker foam requirements, specifically cautioning that overly thick foam could cause bulk water intrusion challenges at openings in the wall. Other wall systems under consideration include: 2x6 walls with Advanced Framing, staggered stud walls, and double walls (2, 2x4 walls back to back). Ultimately, there will be a minimum U-factor established allowing designers to design a wall assembly of their preference such as structurally insulated panels (SIPs), I-joist stud walls (increasing the insulation area in the wall cavity), and insulated concrete forms (ICFs).

Per the 2016 Title 24 Code Change Advocacy authored *Request for Input: High Performance Walls Requirements for Residential Buildings*, the following five options were suggested:

1. 2x6 studs

2x6 studs for the entire exterior frame are not generally implemented in California residential construction. Currently, 2x6 studs are used in specific parts of walls where plumbing, wall height, or flue installation necessitates the increased wall size. Increasing stud size to 2x6 can allow for increasing stud spacing to 24" on center; this can reduce the number of studs in the exterior walls and offset the increased material costs from moving to larger studs. Additionally, if windows and doors are not strategically placed (i.e., within the 24" on center layout), the additional support lumber can offset the savings (both thermal and cost) of the increased spacing. This study will explore both 16" and 24" oc spacing.

2. Advanced Framing

Advanced Framing, as it is commonly referred to, is a suite of construction options. This approach is also commonly called Optimum Value Engineering (OVE) or Advanced Wall Systems (AWS). These techniques require fewer structural pieces and therefore reduce the framing factor and material costs. The main goal is to reduce the amount of lumber spanning from the exterior to the interior of a wall, thereby reducing thermal bridging. Structural engineers specializing in residential wood frame construction have successfully designed structures that significantly reduce the total amount of wood used in a dwelling. There are several variations and combinations of techniques that can be implemented to achieve Advanced Framing and reduce the framing factor. The 2013 Title 24 *Residential Compliance Manual* contains examples of construction practices that should be followed for Advanced Framing and can be used as a general guide for enforcement. More information about the benefits of Advanced Framing is available in the APA's *Advanced Framing Construction Guide,* Form M400, available online at: www.apawood.org.

3. Double Walls
Two 2x4 walls framed parallel are installed side by side. This allows for more insulation because the entire cavity can be filled. The parallel walls can be placed either on a single sill plate or on separate sill plates, and the walls can either be independently sealed on each side with an air gap between, or it can be sealed only to the interior and the exterior with cavity insulation filling the entirety.

4. Staggered Studs
A staggered stud wall can be at any depth, as long as the top and sill plates are wider than the studs (i.e., 2x6 sill plate with 2x4 studs). This creates a single wall that has studs alternately flush with the interior and exterior side of the wall to accommodate gypsum dry wall and exterior siding, stucco and other materials.

5. Structurally Insulated Panels (SIPs)
SIPs are prefabricated panels with an outside surface of sheet metal, or exterior-rated plywood or oriented strand board (OSB), and a rigid interior foam, typically expanded polystyrene, extruded polystyrene, or polyurethane. Structural Insulated Panels are allowed as compliance options in the 2013 Title 24 Standards. (More information on Structural Insulated Panels may be found on the Structural Insulated Panel Association's website at www.sips.org.)

According to the initial findings of the Energy Commission, 2x6 at 16" inches oc was generally more cost effective than 2x4 construction. Nationally, 2x6 studs make up 45 percent of residential single-family exterior wall framing. Thus far, there is favor for staggered wall system by some, as many builders commonly use it at the wall separating the garage and home for utility access. Overall, the proposed walls are cost effective for all climate zones in CA except 7 (sometimes 6 and 8), which is San Diego County and a very mild climate.

An excellent resource for learning more about Title 24 is *Energy Code Ace*, (www.energycodeace.com) which includes the following modules: Ace Form, Ace Installation, Ace Reference (2013 version including the Standards, Compliance Manuals and ACMs.), Ace Training, and Ace Resources. The program is funded by California utility customers under the auspices of the California public utilities commission and in support of the California Energy Commission.

Structural Systems that Enhance Energy Efficiency

One system that is currently under consideration as mentioned above is Advanced Framing. Advanced Framing is a suite of framing techniques that enhance the energy efficiency of the building, while bringing down the cost of construction, and maintaining structural integrity. As previously noted, APA published an *Advanced Framing Construction Guide,* Form M400, available online at: www.apawood.org, which provides the details as well as an implementation strategy as follows:

1. Switch to 2x6 studs to increase cavity insulation depth and meet R20 energy code requirements. (Especially important in colder climate zones.)

2. Where permitted by structural code requirements, change the wall framing module from 16 inches on center to 24 inches on center to reduce framing costs. Retain the use of double top plates to avoid in-line, or stack, framing alignment requirements.

3. Incorporate intersecting wall techniques and energy efficient corners, such as three-stud corners and ladder junctions, that allow for greater insulation volume.

Implement energy-efficient headers and limited framing around openings.

4. Eliminate double top plates. Because this step requires vertical framing alignment, including 24-inch on center floor and roof framing as well as non-industry standard stud lengths which may be difficult to source, it is often the last technique builders consider. For these reasons, many builders elect to retain double top plates.

As stated earlier, the building does not have to implement all Advanced Framing details in order to benefit from an energy efficiency or cost standpoint. That being said, the more holistic the approach, the more rewards that will be realized.

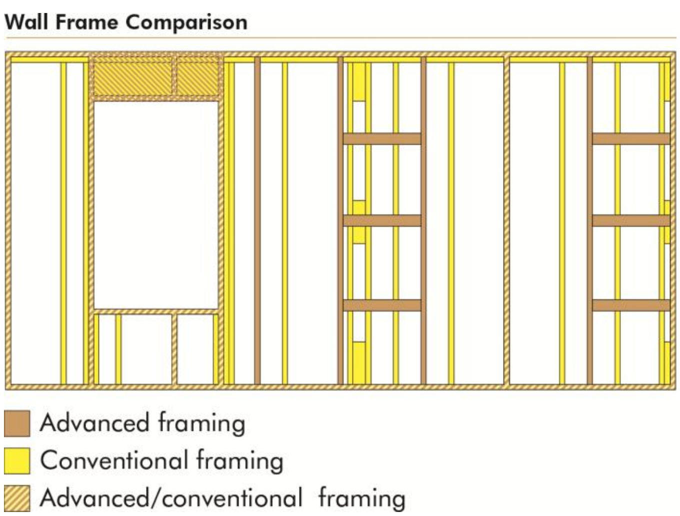

Figure 4—Wall Frame Comparison

As Figure 4 demonstrates, when implemented as a system, Advanced Framing removes a significant amount of framing. Since a deeper wall assembly is used, (6 inches instead of four) roughly the same volume of wood is necessary. However, there will be fewer pieces to frame, which will speed up the labor, and ease the installation of insulation, electrical and plumbing systems.

Structural Engineers may easily implement the third step of the strategy before the rest of the design team is ready to implement Advanced Framing. Most firms have standard header tables that get reused from job to job. Often the headers are sized to fill the cavity depth. With Advanced Framing, the goal is to leave space to insulate the header in addition to supporting the structural load.

In a 2x6 wall, the engineer might size a 4x nominal header or engineered wood beam (LVL or glulam, for example,) if the load necessitates it. In some cases, specification of engineered wood beams may allow for more space for header insulation.

There is also the possibility to design a wood structural panel box beam (single or double sided) header, depending on the load required. This is a great option to consider, particularly if the building is fully sheathed with wood structural panels to begin with. Engineered box header design is provided in *Nailed Structural-Use Panel and Lumber Beams*, Form Z416, on APA's website, www.apawood.org.

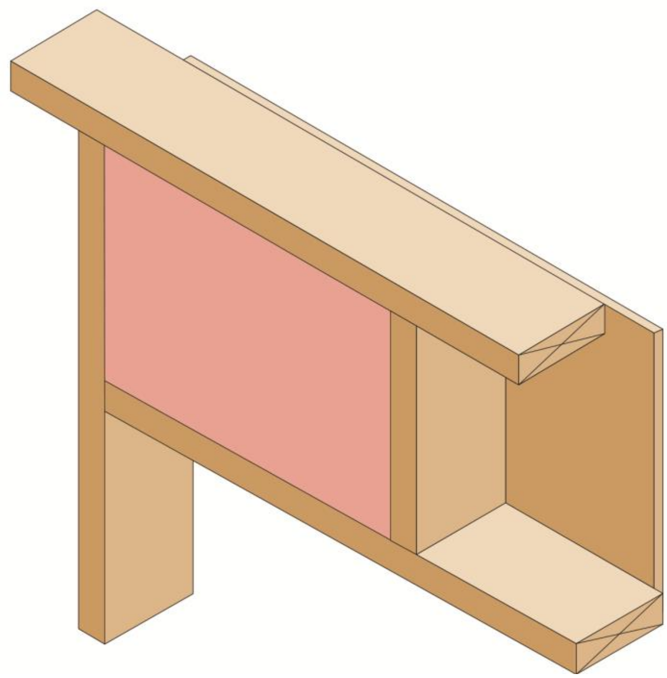

Figure 5—One-Sided Wood Structural Panel Box Header

Intersecting walls and corner details are another location where a simple detail in the plans can have a significant impact in the energy efficiency of the building envelope. Like the header, the first goal is to provide a deeper, more continuous cavity to insulate the wall more effectively.

Figure 6—Ladder Junction

Advanced Framing Challenges

First, as noted above, using single top plates takes a much greater level of precision. Furthermore, with our higher seismic loads in California, top plates function as the chords and drags in the lateral force resisting system. Therefore, the benefit received from eliminating one plate may not be worth the effort, unless splicing of the single top plate is carefully designed and executed.

Second, what is the impact on the shear wall when the studs are increased to 24" o.c.? If the panels are 3/8 or 7/16 Category (CAT), the required field nailing decreases to six inches on center instead of the normal twelve.

Third, you cannot take the shear capacity increase for 3/8 or 7/16 CAT panels unless the panels are installed with their strength axis across the supports or studs are spaced at 16” on center. This increase is utilized by some structural engineers as stipulated in Special Design Provisions for Wind and Seismic (SDPWS) Table 4.3A, Footnote 2:

> Shears are permitted to be increased to values shown for 15/32 inch sheathing with the same nailing provided (a) studs are spaced a maximum of 16 inches on center or (b) panels are applied with long dimension across studs.

Generally, the panels are manufactured with the strength axis oriented in the long direction of the panel, so this would require a horizontal installation. Horizontally installed panels would further require blocking of any unsupported edges. An alternative to horizontally installed panels would be to specify thicker panels or specify 3/8 or 7/16 CAT cross face panels. Cross face panels are manufactured with the strength axis oriented in the short (four foot) direction. Thicker panels and cross faced panels allow for vertically installed sheathing that provides increased stiffness, permits the use of the shear capacity increase, avoids the need for horizontal blocking in many cases, and provides a more rigid base for stucco. On the topic of stucco, APA has recommendations for wall sheathing thicknesses used in conjunction with stucco which increases for vertical installation as well as 24" o.c. stud spacing.

RECOMMENDED THICKNESS AND SPAN RATING FOR APA PANEL WALL SHEATHING FOR STUCCO EXTERIOR FINISH

Stud Spacing (in.)	Panel Orientation[a]	APA Rated Sheathing[b] Minimum Performance Category	APA Rated Sheathing[b] Minimum Span Rating
16	Horizontal[c]	3/8	24/0
	Vertical	7/16[d]	24/16
		15/32[e], 1/2[e]	32/16
24	Horizontal[c]	7/16	24/16
	Vertical	19/32[e], 5/8[e]	40/20

(a) Strength axis (typically the long panel dimension) perpendicular to studs for horizontal application; or parallel to studs for vertical application.

(b) Recommendations apply to all-veneer plywood or oriented strand board (OSB) except as noted.

(c) Blocking recommended between studs along horizontal panel joints.

(d) Structural I Rated Sheathing (OSB).

(e) OSB or 5-ply/5-layer plywood.

Figure 7—WSP Thickness Under Stucco (per APA's *Engineered Wood Construction Guide*, Form E30)

As mentioned earlier, Title 24 does allow Advanced Framing to be used in order to meet the U-factor. It is estimated that 2x6 studs at 24" o.c. yields a 0.066 U-factor. Incorporating a few more Advanced Framing details, such as insulated headers and two or three stud California corners, would allow the building to meet or exceed the minimum requirements. As suggested by California Energy Commission staff, the structural engineer would design the building to incorporate Advanced Framing details while maintaining the structural integrity of the building and then the energy modeler would model it accordingly. There are no specific requirements per the Energy Code as to which advanced framing techniques must be used.

Air Barriers

The topic of airtightness was mentioned under the heading, "How can the Structural Engineer Impact ZNE?" There is widespread agreement that air infiltration is one of the most significant sources of energy loss in buildings. The air barrier is the means to provide a barrier to air leakage through the building envelope. An efficient and cost-effective way to achieve an effective air barrier on walls is to incorporate a continuous, solid layer on the exterior of a building. The continuous solid material should be stiff enough to minimize the amount of deflection when pressure is applied to tape or sealants, which are applied to panel joints and around penetrations. Panel joints need to be properly sealed in order to complete an air barrier assembly. Continuous wood structural panel sheathing is one of the most common materials used in an air barrier system in exterior walls. The architect or energy rater typically details how all panel joints and other areas are to be sealed. This is most commonly done with a tape or sealant which is specifically recommended for use on plywood or OSB. Using continuous structural sheathing as part of the air barrier system provides a stiff support base for stucco, permits the option to incorporate box beam headers, and makes for more earthquake resistant buildings.

There are a couple of cautions to take note of when using continuous wood structural panels as the air barrier. Some designers have been known to recommend adhesion of wood structural panels to framing in order to achieve a tight air barrier. The engineer should caution against gluing the wall sheathing to framing as restricted from use in high Seismic Design Categories per SDPWS Section 4.3.6.1. A second caution that builders in particular need to be aware of related to air barriers is to make sure that any sealant or tape used does not impede the ability of the panels to expand due to increased humidity in the wall cavity or as a result of construction delay wetting. Anything that prevents panel expansion into the recommended 1/8 inch spacing between panels could result in buckling of the wall sheathing. And finally, a water-resistive barrier, such as housewrap, should always be installed over wood structural panel wall sheathing in order to direct any moisture that penetrates the cladding away from the sheathing and wall cavity.

Structural Considerations for Solar Panels

Once the energy load is minimized and the building is efficient, the introduction of renewable energy is addressed. SEAOC has worked closely with the California building regulations to provide guidance as to how a solar panel system can be safely attached to a structure. For example, what are the requirements for a ballasted solar PV roof system? As stipulated in CBC 1613.5.2, the panels should be dimensioned on the roof plans to show clearances between arrays and other permanent items such as HVAC equipment, skylights, vents, drains, and chimneys. The system should identify the loads of the system and supports, the connection of the ballast support assembly to the PV support systems, and the test results per ASTM G115 establishing a coefficient of friction between PV support system and roofing materials under wet conditions.

More limitations are addressed regarding roof slopes and array sizes depending on the occupancy of the building, Seismic Design Category, parapet geometry, and clearances which may require signed and stamped calculations.

Case Studies

Two ZNE projects, one residential and one commercial, showcase many of the concepts previously discussed. Norm Scheel has designed several energy efficient structures for Habitat for Humanity in Northern California. One recent project additionally achieved ZNE, LEED Platinum status, and was awarded the

SEAOC Excellence in Structural Engineering Award in the sustainable design category.

Scheel utilized the following energy efficient techniques in his structural design:

- Advanced Framing: 2x6 studs at 16" oc, 2 stud corners and energy efficient intersecting walls
- A continuous structural rim joist (eliminating all headers within the energy envelope)
- A raised-heel truss that ties into the structural rim, creating a 12" taller attic that provided the room needed to insulate and install high efficiency mechanical systems.

Figure 8 ZNE Residence (courtesy of Norm Scheel)

Further benefits of the continuous rim, according to Scheel, are the adaptability concept as described by many sustainable design philosophies where the rim is carrying the loads structurally, the door and window openings can be changed with little effort. For example, because the rim is replacing the headers, the builder could relocate the openings, or later could change them. The windows and doors in the energy envelope can be remodeled with very minor effort to install new finish materials. Lateral analysis using "top down" load path concepts can likely be accomplished with no hold downs at the foundation.

"The top down load path assumes that the bottom of the wall only carries shear and any overturning component is carried by the rim and the rest of the sheathing above," Scheel explained. "Shorter walls may need straps and edge nailing into studs. Longer walls likely will not need restraint." Even in new housing construction, this leaves open the possibilities of major changes well into the construction process with little costs.

In this particular home, with the modified scissor truss used to keep the mechanical platform and ducts in conditioned space, the future modification of most interior partition walls (non-plumbing) can be easily changed also. Finally, Scheel noted the engineer should be prepared for resistance in the field the first time they go to the site and explain to the framers they have to REMOVE studs, headers, cripples, trimmers, etc. The good news is, in his experience, this only happens once, and the remainder of the plans are followed to the letter.

"Meticulously Detailed Plans are Required."

Figure 9—ZNE Residence (Courtesy of Norm Scheel)

In contrast, the Bullitt Center is a commercial project designed by Miller Hull Partnership Architects in accordance with the Living Building Challenge (LBC). LBC dictates the building will create zero net energy, water, and waste among other sustainable goals. In an in-depth case study, available on the WoodWorks website, project architect Brian Court discusses how incorporating energy efficiency and structure revolve around daylighting.

In order to minimize the building's energy footprint, the Bullitt Center design required high ceilings and tall windows to let in as much natural daylight as possible. Miller Hull's unique use of 2x6 dimension lumber, set on edge and nailed in place to form the solid wood floor panels, provided an unusual design advantage in the quest to meet LBC criteria.

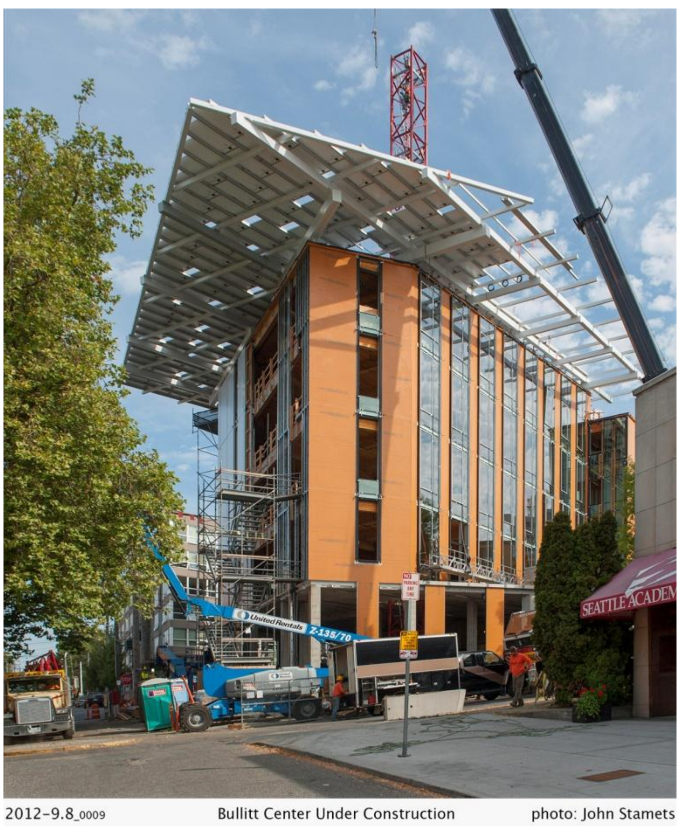

Figure 10—Bullitt Center

"Base zoning height for this site in Seattle is 65 feet, but the City directed a number of agencies to be flexible with existing codes," said Court. "The zoning office told us they would grant us an extra 10 feet of building height if we could show that doing so helped us achieve the goals of the LBC. In our case, we were able to show that by raising the standard 11-foot-6-inch floor-to-floor height to 14 feet, we could improve daylighting."

Court explained that the general rule of thumb is that, for every additional one foot of height on the perimeter of the building, daylight penetration increases by two feet. "So by getting an extra two feet in our floor-to-floor height, we got an extra four feet of daylight penetration," said Court. "And by having relatively shallow floors—achieved by using the solid 2x6 wood floor panels instead of deeper floor joists—it allowed us to increase the daylight penetration even further. Plus, the 2x6 deck easily spans the 10-foot-6 inch dimension, effectively eliminating the need for a perimeter beam. This allowed the windows to extend all the way to the bottom of the decking, improving daylighting even further."

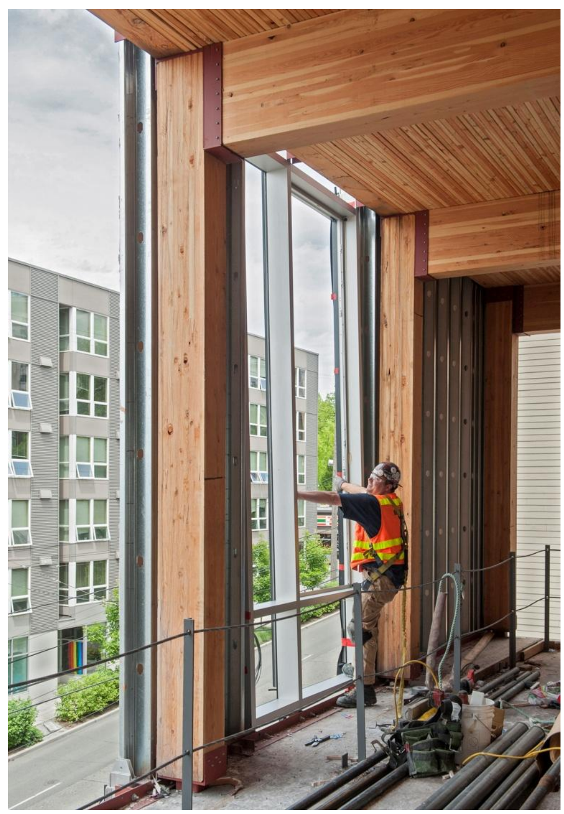

Figure 11—Daylighting Maximized (Bullitt Center)

He noted that the Bullitt Center is an investment in the future. "The Bullitt Center's initial construction costs are higher, but over its 250-year life, it's going to be a money maker," Court said. "This is a structure that essentially has prepaid utility bills for the life of the building."

Thanks to the trailblazers who are tackling ZNE construction today, the cost will reduce over time through lessons learned, technology advancements, and better access to knowledgeable construction professionals.

Conclusion

The time for Structural Engineers to take part in the energy design discussion has arrived. As the California Building Energy Efficiency Standards (also known as Title 24) proceed to mandate energy designs that approach Zero Net Energy, there is both an opportunity and a need for structural engineers to take a lead in ensuring these buildings are detailed for structural integrity as well as enhanced energy efficiency. Advanced Framing, Structural Insulated Panels, and double or staggered stud walls are among the recommended techniques that require the expertise of a structural engineer and yield an energy-superior structure.

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