Energy-Efficient Wood Buildings
Strategies for achieving energy objectives with wood-frame structures
Sponsored by reThink Wood

Wood’s favorable carbon footprint is one reason more North American architects are choosing wood-frame construction for mid-rise buildings up to six stories while closely following the rise of taller wood buildings made from mass timber and hybrid building systems. However, while it is fairly well known that wood products sequester carbon and typically require less energy to manufacture than other building materials, their performance related to operational energy efficiency is often overlooked.

From a thermal perspective, wood-frame building enclosures are inherently more efficient than steel-frame, concrete, or masonry construction—because of the insulating qualities of the wood structural elements, including studs, columns, beams, and floors, and because wood stud walls are easy to insulate. Options also exist for insulating wood-frame buildings that aren’t available for other construction types. For example, while requirements for lighting systems or mechanical systems do not change based on structural material, wood’s versatility related to building envelope configuration gives designers more insulation flexibility.

While wood-frame buildings have a history of cost-effectively achieving energy-efficiency objectives, new energy codes and standards have increased the minimum thermal requirements for building enclosure assemblies, and many of the new requirements exceed the cost-effective thermal insulation limits of traditional wood-frame construction. This has prompted the need for alternative assemblies—e.g., with insulation outside the framing spaces or deeper wall cavities—as well as more thermally efficient detailing.
With proper attention to detail and the application of building science in design, wood buildings can meet or exceed the requirements of new energy codes and standards, as well as conservation programs and labeling systems such as Passive House, net-zero energy, and the Architecture 2030 Challenge. With an emphasis on building envelope design for mid-rise buildings, this course will focus on design strategies for air and thermal control, and energy-efficient assemblies. It will discuss wood-frame construction in the context of the International Energy Conservation Code (IECC), and highlight expanding possibilities for the design of energy-efficient wood buildings using “mass timber” products.

A HISTORY OF HIGH PERFORMANCE

Wood framing has long been used to create energy-efficient buildings. For example, between 2004 and 2011, the Bethel School District (BSD) in Washington State reduced energy use by more than 7.6 million kilowatts and saved $4.3 million in utility costs—equivalent to the cost of electricity for 15 of the District’s elementary schools for one year. BSD reports an 81 percent ENERGY STAR rating overall, and several of their 17 elementary and six junior high schools have a rating of between 95 and 98 percent. While size, configuration, and age of the 23 facilities vary, one thing remains constant: each is wood-frame.

EMBODIED VS. OPERATIONAL ENERGY

As buildings become more energy efficient, embodied energy—that is, the energy used in the process of building material production, transportation, construction, maintenance, and demolition/re-use—assumes greater relative importance. Studies vary in their numbers, but a 2012 literature review noted that embodied energy for a conventional building may account for 2 to 38 percent of total life cycle energy, where embodied energy may account for up to 46 percent for a low-energy building. Another study found that embodied energy could account for up to 60 percent of a low-energy house compared to operational energy. Taken to its ultimate conclusion, embodied energy would account for 100 percent of life cycle energy use in a net zero energy building, and operational energy for 0 percent.

According to architect Wayne Lerch, “Steel and concrete need separation between the structure and exterior envelope. This separation is not required with wood because of its inherent thermal properties.” At the same time, the BSD strategy to over-insulate stud cavities with inexpensive batt insulation plays a significant role in meeting its energy objectives.

While this continuing education course focuses primarily on mid-rise buildings four-to-six stories, many of the principles hold true for other building types. Information on how to economically meet the residential requirements of the 2012 IECC for buildings under four stories can be found in the American Wood Council publication, DCA-7, Meeting Residential Energy Requirements with Wood-Frame Construction.

DESIGN CONSIDERATIONS FOR ENERGY-EFFICIENT BUILDING ENCLOSURES

As a general rule, the most significant sources of building envelope energy loss are windows, doors, and air infiltration (leakage). Therefore, use of high-efficiency windows and doors and proper sealing of joints can significantly reduce whole-building energy consumption. Recent changes to the energy codes have also been aimed at insulating the exterior building envelope with very high levels of insulation as another way to reduce energy consumption.

It must be noted that well-insulated assemblies also require effective moisture, water vapor, and air movement control strategies. While these are beyond the scope of this course, information on moisture in the context of air and thermal control can be found in the Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climates in North America (the Guide).

Following are several considerations for architects seeking to design an energy-efficient multi-story building. They are meant as examples as opposed to a comprehensive list, and are explained in greater detail in the Guide.

Heat Flow

Minimizing space heating or cooling energy use is a primary function of the building enclosure. While heat flow through the building enclosure cannot be prevented, it can be controlled in order to reduce the total energy consumption and improve comfort. This is achieved by constructing a thermally insulated and airtight building enclosure.

There are three principal mechanisms of heat transfer through the materials, components, and assemblies that make up the building enclosure: conduction, radiation, and convection. The control of all three is critical in thermally efficient building enclosure assemblies.

Conduction, or thermal conductivity, is a measure of the rate of heat flow through one unit thickness of a material subjected to a temperature gradient. The thermal
conductivity of common structural wood products is much less than the conductivity of metals, but is about two to four times that of common insulating material. For example, the conductivity of structural softwood lumber at 12 percent moisture content is in the range of 0.7 to 1.0 Btu×in/(h×ft²×°F) compared with 1,500 for aluminum, 310 for steel, 6 for concrete, 7 for glass, 5 for plaster, and 0.25 for mineral wool.

The thermal resistance, or effective insulating value, of building enclosure assemblies and components determines the magnitude of the conductive heat loss. All enclosure elements should be designed and detailed to maximize thermal resistance (within practical limits); detailing of often overlooked elements will reduce the amount of energy that is lost through conduction. For example, cladding supports, floors, balconies, fasteners, concrete slabs, and window frames can all be sources of energy loss. Energy standards and codes generally require thermal bridges to be accounted for in the code compliance of multi-unit residential buildings.

Radiation is the transfer of energy through a gas or vacuum in the form of electromagnetic waves. It is the process whereby a hot surface radiates heat to a colder surface and requires a clear line of sight between the surfaces involved. Both the temperature of the two surfaces and the emissivity of the materials affect the amount of heat loss.

Techniques for reducing heat loss due to radiation include employing low solar gain/low U-factor fenestration, cool roof technologies, and radiant barriers.

Convection is the transfer of energy by the movement of a fluid such as air. Convective heat transfer for building enclosures has two primary mechanisms: convective flow of air within assemblies or spaces, and convective flow through assemblies from interior to exterior or exterior to interior. The latter is referred to as air leakage.
THERMAL INSULATION STRATEGIES AND MATERIALS

Energy codes target greater thermal insulation levels in building enclosures as one of the key means for achieving energy efficiency. In order to achieve effective heat flow control, the continuity of thermal insulation should be maintained through assemblies. The use of thermal insulation must be considered, together with airtightness and the vapor permeability of materials in the assemblies, in order to achieve effective thermal efficiency.

One differentiating factor is the location of the insulation:

**Interior-insulated** – Insulating layer is located on the interior side of the water-resistant barrier. For walls, this typically means the insulation is located within the stud space. For roofs, the interior insulation may be located above the sheathing but under the roof membrane or, alternatively, below the sheathing within the roof framing. Both are considered “interior-insulated.”

**Exterior-insulated** – Insulating layer is located on the exterior of the water-resistant barrier—i.e., the likely wet zone. For walls, this means the insulation is located within the drained cavity space, while for roofs the insulation is located above the membrane (i.e., an inverted roof or protected membrane assembly). For mass timber systems (e.g., cross laminated timber walls), this is the preferred insulation strategy to protect the wood from moisture accumulation. Exterior insulation materials must be resistant to the effects of moisture.

**Split-insulated** – More than one insulating layer is provided, typically with one layer to the interior and one layer to the exterior of the water-resistant barrier.

In traditional wood-frame construction, heat flow has been controlled primarily by placing fiberglass batt insulation within stud cavities and attics. In some cases rigid and semi-rigid insulation boards are placed just to the exterior of the sheathing (exterior-insulated), or both are placed in the stud cavity and to the exterior of the sheathing (split insulation). Rigid insulation boards are also used below grade and in roofing applications. The use of spray-in-place polyurethane foams has also become more common in the past decade.

Continuous insulation (ci) is a term used in various energy codes and standards. It refers to the intended purpose of providing at least a minimum continuous layer of insulation that has an effective R-value equal to or very close to its nominal R-value (i.e., little to no thermal bridging). Continuous insulation is often specified as a stand-alone prescriptive requirement or, alternatively, in conjunction with nominal insulation (e.g., between wood studs) in order to achieve higher effective R-values. Common industry practice is to achieve the continuous insulation requirement with exterior rigid or semi-rigid insulation installed on the exterior of a framed assembly, but it may also be installed to the interior or within the middle of some assemblies, although it would be challenging to meet the requirement for continuity at floor levels in multi-story buildings.

Continuous insulation is necessary in structural systems using concrete and steel, which have high rates of thermal bridging, but is often avoidable in wood-frame envelopes. The selection of insulation type is based on a variety of factors including cost, availability, thermal performance, moisture retention and transmission performance, fire, and acoustics. Table 3.2.1 of the Guide lists the most common insulation types used in wood-frame construction, including a range of typical R-values along with vapor and air permeability. Products with low vapor permeability can be considered vapor barriers in typical thicknesses, and those with low air permeability can be considered suitable as an air-barrier material.

The control of air leakage is important to conserve space heat and reduce air-conditioning loads. In multi-story buildings, air leakage may account for up to half of the space-heat loss, depending on the air-leakage rate, building height and wind exposure, occupant behavior, mechanical penetrations, and several other factors including the effective enclosure thermal performance. Air leakage in multi-story buildings is typically higher than in smaller, single-family dwellings due to increased wind exposure, the stack effect, and mechanical systems, all of which contribute to higher and more sustained differential pressures across the building enclosure.

Air Barriers

The control of air flow through the use of air-barrier systems is important to, among other things, minimize the loss of conditioned air through the building enclosures. Air-barrier systems are required for all multi-unit residential buildings in all climate zones.

The air barrier is the means of preventing air leakage through the building envelope. A building’s air barrier should be continuous, integrating all the exterior envelope systems—e.g., the wall air barrier with the roof air barrier, etc. The air barrier can be installed on the interior or exterior of 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.
continuous solid material should be stiff enough to minimize the amount of deflection when pressure is applied to tape or sealants in order to create an effective seal when applied to panel joints and around wall penetrations. Panel joints need to be properly sealed to complete an air barrier assembly.

Continuous wood structural panel sheathing is commonly used as part of an air barrier system for exterior walls. The architect typically details how panel joints and openings are to be sealed—usually with tape or sealant specifically recommended for use on plywood or oriented strand board (OSB). Using continuous structural sheathing as part of the air barrier system also provides a solid support base for exterior cladding systems while increasing the structure’s earthquake and wind resistance.

When using continuous wood structural panels as the air barrier:

- Panels should not be glued directly to framing. This approach is restricted in high Seismic Design Categories per the American Wood Council’s Special Design Provisions for Wind and Seismic (SDPWS) Section 4.3.6.1. Gluing wall sheathing to framing also restricts wood panels from expanding as moisture is absorbed, which can contribute to out-of-plane buckling.
- Make sure that any sealant or tape used to complete the air barrier does not impede the ability of the panels to expand when exposed to increased humidity in the wall cavity or wetting due to construction delays. Anything that prevents panel expansion into the recommended 1/8-inch spacing between panels could result in buckling of the wall sheathing. Also, make sure the tape is rated to be used as part of an air barrier system.
- 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.

Unlike vapor barriers, there is little to no downside of redundancy in the air barrier provided the materials used do not negatively impact vapor flow. In fact, some designers incorporate more than one continuous air barrier—one on the building interior and one on the exterior.

ARCHITECTURAL FORM

Multi-story wood-frame architecture varies across the United States, with designs based on the architect’s response to the client brief, site conditions, and local environment. Consideration of orientation, building
form, and massing, as well as the ratios of enclosure area to volume, are essential factors in achieving energy-efficient designs. The use of building features to protect the enclosure is a fundamental architectural design principle. Roof overhangs, balconies, and other projections shelter walls, windows, and doors from driving rain, wind, snow, and ice, and provide solar shading.

Wood Construction and the IECC

While, historically, energy-efficiency strategies have tended to focus on HVAC systems, new energy codes such as the IECC have placed increasing emphasis on the thermal performance of building enclosures. When designing a building, architects have three main paths for obtaining compliance with the 2012 IECC:

- IECC prescriptive path
- IECC performance path
- ASHRAE 90.1 path

For either IECC path, certain sections of the code are mandatory. These include requirements specific to air leakage in the thermal envelope (Section C402.5), space conditioning and ventilation (Section C403.2), service water heating (Section C404), and electrical power and lighting systems (Section C405). Using the path outlined in the ASHRAE Standard 90.1-2010 (ASHRAE 90.1), developed jointly by the American National Standards Institute (ANSI), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and Illuminating Engineering Society of North America (IESNA), designers are not required to comply with the mandatory sections of the IECC; however, ASHRAE 90.1 has its own mandatory sections.

An above-code program, when deemed to meet or exceed code requirements by the code official, is a fourth compliance path. All mandatory sections of the IECC are still required to be met.

GOING BEYOND CODE

For designers seeking to “go beyond code,” Building Science Corporation’s Building America Special Research Project: High-R Walls Case Study Analysis takes an interesting look at the detailing of high-performance walls.

As a baseline, the report describes the construction and thermal performance of a standard 2”-by-4” stud wall. With only cavity insulation, this common construction gives a whole-wall R-value of 10 to 15. Placement of studs at 24 inches o.c. and spray foam insulation in the stud cavities brings the whole-wall R-value to between 16 and 19. However, the report goes further, analyzing the effects of additions such as double vs. single top plates, inclusion of a vapor control layer, exterior wood panel sheathing and housewrap, and a variety of insulation materials.

The assembly below, for example, was found to have a whole-wall R-value of 30+.

R-VALUE REQUIREMENTS FOR MULTI-UNIT RESIDENTIAL BUILDINGS

Minimum R-value requirements for above-grade wood-frame building enclosure assemblies in the 2012 IECC are provided for “commercial” buildings in IECC Table C402.2 (see page 7). They are broken down by climate zone, as defined in the U.S. Department of Energy’s climate zone map. Residential buildings have more stringent requirements based on climate zone.

CONTINUOUS INSULATION REQUIREMENTS

Under the prescriptive path of the IECC, walls, floors, and roofs have specific insulation requirements based on framing time and climate zone. For example, in IECC Table C402.1.3, above-grade metal-framed walls in Climate Zones 3 and 4 (except Marine) are required to have R-13 cavity insulation and R-7.5 continuous insulation (ci) applied to one face of the wall. The wood-framed walls at the same location are required to have R-13 cavity insulation and R-3.8 ci or have R-20 cavity insulation with no additional continuous insulation requirements. The option to forego continuous insulation requirements on wood-framed walls with R-20 cavity insulation is acknowledged that metal studs have a significantly higher thermal conductance than wood studs. The R-20 cavity insulation option allows wood wall frames with 6-inch-deep studs to meet the prescriptive wall requirements with no continuous insulation in Climate Zones 1 through 5 except Group R occupancies in Marine Climate Zone 4. The R-20 wood-framed wall is the only option available in the IECC prescriptive wall path using prescribed R-values that does not require continuous insulation for above-grade walls.

Like the IECC, the prescriptive path of ASHRAE 90.1 contains an option to reduce or forego continuous insulation in wood-frame walls with the use of 6-inch cavity walls.

AIR LEAKAGE REQUIREMENTS

The requirements in the 2012 IECC for air barrier assemblies and air-leakage control in residential buildings are different than those for commercial buildings. For commercial buildings (including most multi-family buildings), IECC Section C402.5.1 states that, “a continuous air barrier shall be provided throughout the building thermal envelope.” The air barrier can be installed inside, outside, or
within the building envelope, and must be continuous and sealed. In Climate Zones 2B, the installation of air barriers is not required for buildings following the commercial requirements of the IECC. Materials must be air impermeable (<0.004 cfm/ft² @75 Pa), and assemblies must have an average air leakage rate not exceeding 0.04 cfm/ft² @75 Pa. The completed building must be tested and the air leakage rate of the building envelope cannot exceed 0.40 cfm/ft² of enclosure area at 75 Pa when tested in accordance to ASTM E779 or equivalent (e.g., the U.S. Army Corps of Engineers [USACE] Standard).

**SIGNIFICANT CHANGES IN THE 2012 IECC**

The 2012 IECC commercial provisions have been found to have an Energy Use Intensity savings of 24.3 percent over the 2006 edition when plug and process loads are neglected. The 2015 IECC is a further reduction of 11.1 percent over the 2012 IECC. Of particular relevance to wood-frame construction, the opaque thermal envelope requirements, which dictate the thermal performance of walls, roofs, and floors when designing a building to the IECC prescriptive approach, have been tightened. Values in Table C402.1.3, if utilizing the prescriptive U-factor alternative, and Table C402.1.3, if utilizing the prescriptive R-value insulation and fenestration criteria, have been made more stringent. If a designer wants to minimize or eliminate the use of continuous insulation in wood-frame buildings, then 2×-by-6" construction may be required in the building envelope in order to accommodate R-20 cavity insulation (depending on the climate zone).

**New Opportunities with Mass Timber**

Mass timber construction uses large prefabricated wood members such as cross laminated timber (CLT) for wall, floor, and roof construction. Glulam can also be used in beam and column applications. These products, combined with a heightened awareness of wood’s carbon benefits, have focused attention on the possibility of “tall wood” buildings, either made entirely from wood products or a combination of wood and other materials.

From an energy-efficiency perspective, different materials and exposure conditions for taller buildings will dictate different—and likely more rigorous—approaches to heat, air, and moisture control than for buildings up to six stories. However, it is worth noting the unique characteristics of mass timber building systems that lend them to the design of energy-efficient structures.

Like all wood products, CLT panels have good thermal properties. However, their thickness provides both thermal insulation and thermal mass, which is recognized in the IECC. The thermal mass of the building-enclosure elements, as well as that of the interior floors and walls, can improve the energy efficiency of buildings by storing solar heat energy during the day and releasing it at night. This acts to reduce peak utility loads by shifting the time and intensity at which they occur.
reduce the building’s overall energy use, and improve occupant comfort. The actual benefits of thermal mass within a building will vary with climate and solar radiation, building type and internal heat gains, building geometry and orientation, and the actual amount and location of thermal mass used, but it is a common strategy in energy-efficient buildings. Thermal mass is typically associated with concrete or masonry buildings; however, heavy timber framing, with products such as CLT, has considerable thermal mass and the associated whole-building energy-efficiency benefits.

Although CLT panels may have some inherent level of airtightness, an additional air barrier membrane is recommended given the possibility that gaps between boards may develop as a result of drying-related shrinkage. The monolithic nature of CLT panels makes it possible to have a single membrane serve as both the water-resistant barrier and continuous air barrier.

CONCLUSION
While wood has low thermal conductivity, other factors—such as the use of high-efficiency windows and doors, high levels of insulation, and air sealing—have a greater influence on a building envelope’s energy efficiency than choice of structural material. In specifying wood, the more relevant point for many designers is that wood building systems lend themselves to structures that are energy efficient, with less impact on the environment in terms of embodied energy, air and water pollution, and carbon footprint than other major building materials.6

ADDITIONAL RESOURCES
This continuing education course draws from the FPInnovations Guide for Designing Energy-Efficient Building Enclosures for Wood-Frame Multi-Unit Residential Buildings in Marine to Cold Climates in North America. This area tends to have the greatest need for guidance in order to meet increasingly stringent energy code requirements. While much of the information is relevant in other climate zones, FPInnovations is developing similar guides for the hot-dry/hot-humid and arctic climates.

The following resources are also available to assist designers with the energy-efficient design of wood buildings:

2. Thermal Performance of Light-Frame Assemblies, Canadian Wood Council

Additional information on the design of mid-rise wood buildings is available from the U.S. WoodWorks program (www.woodworks.org) and American Wood Council (www.awc.org).

Endnotes
3. Ibid, Endnote 1
4. USDA Forest Products Lab Wood Handbook, Chapter 4

HEAVY TIMBER/HIGH PERFORMANCE
The Bullitt Center
Seattle, WA
Architect: The Miller Hull Partnership
Described as the greenest commercial building in the world, the Bullitt Center has surpassed its net-zero energy goals, sending a surplus back to the local power grid in its first year of operation. The six-story, 52,000-square-foot structure includes four stories of heavy timber construction over a two-story concrete podium and was designed to meet stringent requirements of the Living Building Challenge (LBC). While M/E/P engineer, PAS, predicted 16 kBtu per square foot—half the energy-use intensity of Seattle’s next best-performing office building—the building has already achieved a significantly lower 10 kBtu per square foot.

When Bullitt was conceived, the design team expected to use a reinforced concrete frame because they thought they needed it for thermal mass, but when they considered the embodied energy and carbon footprint of the concrete, timber turned out to be a better environmental solution. To let in as much natural light as possible, the design required high ceilings and tall windows. The architect chose 2”-by-6” lumber set on edge and nailed in place to create relatively shallow solid wood floor panels, which helped to increase daylight penetration.

Architect Brian Court attributed the building’s over-achievement to its occupants, whose plug loads have been considerably less than expected.

The reThink Wood initiative is a coalition of interests representing North America’s wood products industry and related stakeholders. The coalition shares a passion for wood products and the forests they come from. Innovative new technologies and building systems have enabled longer wood spans, taller walls and higher buildings, and continue to expand the possibilities for wood use in construction. www.ReThinkWood.com/CEU