Opportunities for Wood Use in Low Rise Commercial Buildings

September 12, 2023

Presented by
John O’Donald II, PE
WoodWorks
Course Description

This course is intended for designers who want to learn more about the use of wood-frame construction for low-rise retail, office and restaurant occupancies designed under the International Building Code. Topics covered include common framing systems and details, paths to code compliance and tall wall design.
Learning Objectives

1. Review permitted applications of wood-frame construction in the International Building Code in low-rise commercial buildings, with an emphasis on retail, office and restaurant occupancies.

2. Consider detailing options for the framing of common features in low-rise commercial buildings, such as flat roofs, parapets and open front floor plans.

3. Examine code requirements pertaining to multi-occupancy buildings and different paths to compliance.

4. Evaluate opportunities for tall wall framing with wood construction and understand the design requirements for code compliance.

Outline

» Introduction
» Framing System Design and Details
  » Structural Design Compliance
  » Wall Framing
  » Wall Bracing
  » Roof Framing
» Non-Structural Requirements and Design
  » Allowable Heights and Areas
  » Multi-Tenant and Multi-Occupancy Buildings
  » Fire Resistance and Detailing
» Large Retail Project Case Study
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Why Wood?
Using wood helps reduce environmental impact
Wood products play significant role in modern economy

- Wood Costs Less
- Wood is Versatile
- Wood Meets Code
- Wood is Durable
- Wood is Renewable

Photo courtesy OFRI
The Gibson, Hummel Architects, KPFF Consulting Engineers, photo Leo A. Geis
Carbon Benefits of Wood

- Less energy intensive to manufacture than steel or concrete
- Less fossil fuel consumed during manufacture
- Avoid process emissions
- Carbon storage in forests and promote forest health
- Extended carbon storage in products

Herrington Recovery Center – Roger’s Memorial Hospital
Oconomowoc, WI

- 3 stories; 21,000 square feet, 20 bed treatment facility
- Safe, confidential facility
- Institutional building with a residential feel
- Serene, spiritual environment; biophilic properties of wood
- LEED Silver
- Locally available wood products
Herrington Recovery Center – Roger’s Memorial Hospital
Oconomowoc, WI

Volume of wood used: 9,500 cubic feet of panel and engineered wood products
U.S. and Canadian forests grow this much wood in: 1 minute
Carbon stored in the wood: 230 metric tons of CO₂
Avoided greenhouse gas emissions: 480 metric tons of CO₂
TOTAL POTENTIAL CARBON BENEFIT: 710 metric tons of CO₂

Equivalent to:
- 135 cars off the road for a year
- Energy to operate a home for 60 years

Source: US EPA


Architect: TWP Architecture
Structural Engineer: Pujara Wirth Torke, Inc.

47% of energy goes to HVAC Systems

Source: US DOE Buildings Energy Data Book (2011 Data)
Thermal Performance of Walls

Thermal Conductivity of Materials

R-Value of Common Wall Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>R Value (hr-ft² F/ Btu) per Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td></td>
</tr>
<tr>
<td>Poured Concrete</td>
<td></td>
</tr>
<tr>
<td>Concrete Block (8&quot;)</td>
<td></td>
</tr>
<tr>
<td>Stucco</td>
<td></td>
</tr>
<tr>
<td>Common Brick</td>
<td></td>
</tr>
<tr>
<td>Gypsum Board</td>
<td>Low Thermal Resistance</td>
</tr>
<tr>
<td>Soft Wood Lumber</td>
<td>In-Between</td>
</tr>
<tr>
<td>Plywood</td>
<td>Insulation</td>
</tr>
<tr>
<td>Fiberglass (batt)</td>
<td></td>
</tr>
<tr>
<td>Mineral Wool (batt)*</td>
<td></td>
</tr>
<tr>
<td>Glass</td>
<td></td>
</tr>
<tr>
<td>Polystyrene (Molded)</td>
<td></td>
</tr>
<tr>
<td>Cellulose (blown)</td>
<td></td>
</tr>
<tr>
<td>Polystyrene (Extruded)</td>
<td></td>
</tr>
<tr>
<td>Polyurethane (Expanded)</td>
<td></td>
</tr>
<tr>
<td>Polyurethane (foam in place)</td>
<td></td>
</tr>
<tr>
<td>Polyisocyanurate</td>
<td></td>
</tr>
</tbody>
</table>

Wood vs Steel Framing

Given same amount of insulation, the wood framing walls perform better.

OR

It takes more insulation to get equivalent performance out of a steel stud wall.

Low-Rise Wood Construction

Storage Facilities
Offices
Medical Office Buildings
Schools
Wood Can Handle Common Features

- Flat Roofs and Parapets
- Large Openings
- Irregular Shapes

Wood Can Handle Common Features

- Brand Walls
- Tall Walls
Wood Can Handle Common Features

Open Floor Plans

IBC Occupancy Groups


» **Business**: Group B.

» **Educational**: Group E.

» **Factory and Industrial**: Groups F-1 and F-2.

» **High Hazard**: Groups H-1, H-2, H-3, H-4 and H-5.

» **Institutional**: Groups I-1, I-2, I-3 and I-4.

» **Mercantile**: Group M.

» **Residential**: Groups R-1, R-2, R-3 and R-4.

» **Storage**: Groups S-1 and S-2.

» **Utility and Miscellaneous**: Group U.
**IBC Occupancy Groups**

- **Assembly:** Groups A-2
  - Nightclubs, Restaurants, Taverns and bars
- **Business:** Group B
  - Banks, barber and beauty shops, dry cleaning and laundries, professional services, etc.
- **Mercantile:** Group M
  - Department stores
  - Drug stores
  - Markets
  - Motor fuel-dispensing facilities
  - Retail or wholesale stores
  - Sales rooms

---

**ICC Building Valuation Data**

<table>
<thead>
<tr>
<th>Occupancy Group</th>
<th>IA</th>
<th>IB</th>
<th>IIA</th>
<th>IIB</th>
<th>IIIA</th>
<th>IIIB</th>
<th>IV</th>
<th>VA</th>
<th>VB</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2 Assembly</td>
<td>233</td>
<td>226</td>
<td>220</td>
<td>212</td>
<td>199</td>
<td>194</td>
<td>204</td>
<td>181</td>
<td>174</td>
</tr>
<tr>
<td>B Business</td>
<td>241</td>
<td>232</td>
<td>224</td>
<td>213</td>
<td>195</td>
<td>187</td>
<td>205</td>
<td>172</td>
<td>164</td>
</tr>
<tr>
<td>M Mercantile</td>
<td>174</td>
<td>167</td>
<td>161</td>
<td>153</td>
<td>140</td>
<td>136</td>
<td>145</td>
<td>121</td>
<td>116</td>
</tr>
</tbody>
</table>

Published $ / Square Foot of Building Area

Source August 2021, ICC Published National Building Valuation Data
### ICC Building Valuation Data

#### Type IIA and IIIA Construction

<table>
<thead>
<tr>
<th>Occupancy Group</th>
<th>IIA</th>
<th>IIIA</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2 Assembly</td>
<td>220</td>
<td>199</td>
<td>$21/sf</td>
</tr>
<tr>
<td>B Business</td>
<td>224</td>
<td>195</td>
<td>$29/sf</td>
</tr>
<tr>
<td>M Mercantile</td>
<td>161</td>
<td>140</td>
<td>$21/sf</td>
</tr>
</tbody>
</table>

Published $ / Square Foot of Building Area

Type IIA and IIIA construction have very similar allowable heights and areas.

Is this enough to matter to you or your clients?

Source: August 2021, ICC Published National Building Valuation Data

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#### Type IIB and VA Construction

<table>
<thead>
<tr>
<th>Occupancy Group</th>
<th>IIB</th>
<th>VA</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-2 Assembly</td>
<td>212</td>
<td>181</td>
<td>$24/sf</td>
</tr>
<tr>
<td>B Business</td>
<td>213</td>
<td>172</td>
<td>$33/sf</td>
</tr>
<tr>
<td>M Mercantile</td>
<td>153</td>
<td>121</td>
<td>$24/sf</td>
</tr>
</tbody>
</table>

Published $ / Square Foot of Building Area

Type IIB and VA construction have very similar allowable heights and areas.

An even larger difference than IIA and IIIA.

Source: August 2021, ICC Published National Building Valuation Data
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Paths to Structural Compliance

» IBC Chapter 16 as starting point for most structural requirements
» IBC Chapter 23 for wood specific requirements and paths to compliance
» ASCE 7 Minimum Design Loads for Buildings and Other Structures referenced from IBC Chapter 16 for Wind and Earthquake Loading

<table>
<thead>
<tr>
<th>Path to Compliance</th>
<th>Reference</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Convention Construction</td>
<td>IBC 2308</td>
</tr>
<tr>
<td>2</td>
<td>AWC Wood Frame Construction Manual</td>
<td>IBC 2309</td>
</tr>
<tr>
<td>3</td>
<td>AWC National Design Specification for Wood Construction (NDS)</td>
<td>IBC 2305 IBC 2306 (ASD)</td>
</tr>
<tr>
<td></td>
<td>AWC Special Design Provisions for Wind and Seismic (SPDWS)</td>
<td>IBC 2307 (LRFD)</td>
</tr>
</tbody>
</table>
Prescriptive Methods

Both Limited to 40 psf Live loads.
Possibly useful for 1 story Commercial Buildings

Engineered Design via AWC NDS and SDPWS

General Engineered Approach:
Not limited in scope as Conventional Construction and WFCM
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Wall Framing Options

Solid Sawn Lumber Sizes
  » 2x4 to 2x14
  » 4x, 6x and greater thickness available

Different Species Groups Available
  » “Southern Pine” is not a single species but a group of related species which are graded together
  » Other common species groups include: Doug-Fir Larch, Hem-Fir, Spruce-Pine-Fir

Different Grades
  » Visually Graded: #1, #2, etc
    » Most Common
  » Machine Graded:
    » Machine Stress Rated (MSR)
    » Mechanical Evaluated Lumber (MEL)
Wall Framing Options

Finger-Jointed Dimensional Lumber:
» Structural end-gluing of shorter members
» Technically called “End-Jointed”
» Can be used interchangeably with solid sawn lumber of same species and grade, where approved.
  » See IBC 2303.1.1
» Look for grading and grade stamp by

Variations of Finger Jointed Lumber
» HRA (Heat Resistant Adhesive)
  » Only use HRA FJ Lumber in fire rated assemblies
» Non-HRA (or no HRA in stamp)
» Vertical Use Only or Stud Use Only
  » Bending or tension stresses only from short term loading

Wall Framing Options

Engineered Lumber Products
» Laminated Strand Lumber (LSL)
» Laminated Veneer Lumber (LVL)
» Parallel Strand Lumber (PSL)
» Glue Laminated Lumber (Glulam)
Tall Walls in Low Rise

Structure Parameters
- Design height - $h$
- Stud spacing
- Wall thickness – $t$

Loading Parameters
- Dead Load - $DL$
- Live and Snow Load – $LL/SL$
- Wind Loads (C&C and MWFRS) – $W_w$
- Any eccentricity

Deflection Criteria based on Finishes
Exterior Wall Design Checks

» Strength Check 1:
  Gravity + Main Lateral Force Loads

» Strength Check 2:
  Full Components and Cladding Wind Loads

» Deflection Check:
  Reduced Components and Cladding Wind Loads

Strength Check 1 for Stud Design

**Strength Check as a Vertical Load Supporting element:**

» Apply Vertical Dead, Live, Roof and/or Snow Loads

» Apply out-of-plane lateral loads
  » MWFRS wind loads (ASCE 7-15 Chapter 27 or 28)
  » Seismic wall forces (ASCE 7-15 12.11.1)

» Apply vertical MWFRS wind or Seismic force (if any)
  » For example: a hold-down post.

» Combined Bending & Axial Load Check per AWC NDS

» Use standard load combinations
  » IBC Section 1605 or
  » ASCE 7 Chapter 2

*Design Tip: Bottom plate crushing may govern over Stud and Post Capacities*
Wall Sheathing Provides Weak Axis Bracing

NDS Commentary:
“Experience has shown that any code allowed thickness of gypsum board, hardwood plywood, or other interior finish adequately fastened directly to studs will provide adequate lateral support of the stud across its thickness irrespective of the type or thickness of exterior sheathing and/or finish used.”

Design Considerations

Slenderness Limits (NDS 2018 3.7.1.4)
Max Effective Unbraced Length = 50d, d = depth in inches
Max of 75d during construction

- 1½” depth
  - 6'-3" max unbraced length.
  - 9'-4" during construction.

- 3½” (2x4) Max Height: 14'-7"
- 5½” (2x6) Max Height: 22'-11"
- 7¼” (2x8) Max Height: 30'-2"

Stud or column can be braced against buckling in this direction by sheathing.

Stud or column is not braced against buckling in this direction by sheathing.
Intermediate Wall Stud Blocking

Strength Checks on Stud Design 2

Strength Check for Components & Cladding Winds

» No axial loading
» **C&C transverse Wind loads only**
» Check stud for bending and shear

*Design Tip: Be aware of ASCE 7 Definition of Effective Wind Area to decrease the required C&C wind load*

**EFFECTIVE WIND AREA, A**: The area used to determine (G_{C}^A). For component and cladding elements, the effective wind area in Figs. 30.4-1 through 30.4-7, 30.5-1, 30.6-1, and 30.8-1 through 30.8-3 is the span length multiplied by an effective width that need not be less than one-third the span length. For cladding fasteners, the effective wind area shall not be greater than the area that is tributary to an individual fastener.
Effective Wind Area Example

Tributary Area = (22)(1.33) = 29 ft$^2$

Effective Wind Area = 22*22/3 = 161 ft$^2$

Strength Checks on Stud Design 2

Strength Check for Components & Cladding Winds

- No axial loading
- C&C transverse Wind loads only
- Check stud bending and shear.

Design Tip: For bending stress check, be aware of Repetitive Use factor $C_r$ of NDS and Wall Stud Repetitive Member Factor of SDPWS 3.1.1
Deflection Checks on Stud Design

**Deflection Check for Components and Cladding Winds**

» No Axial Loading
» C&C transverse Wind load only.
» Check out-of-plane deflection to IBC Table 1604.3 or other more stringent requirements.

*Note: This check often governs tall walls*

*Design Tip: ASCE 7 Definition of Effective Wind Area to decrease the required C&C wind load applies here.*

---

**Deflection Checks on Stud Design**

**Deflection Check for Components and Cladding Winds**

» No Axial Loading
» C&C transverse Wind load only.
» Check out-of-plane deflection to IBC Table 1604.3 or other more stringent requirements.

<table>
<thead>
<tr>
<th>TABLE 1604.3 DEFLECTION LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTRUCTION</td>
</tr>
<tr>
<td>Exterior walls:</td>
</tr>
<tr>
<td>With plaster or stucco finishes</td>
</tr>
<tr>
<td>With other brittle finishes</td>
</tr>
<tr>
<td>With flexible finishes</td>
</tr>
</tbody>
</table>
Deflection Checks on Stud Design

Deflection Check for Components and Cladding Winds

» No Axial Loading
» C&C transverse Wind load only.
» Check out-of-plane deflection to IBC Table 1604.3 or other more stringent requirements.

Design Tip: Change in SDPWS 2015 referenced from IBC 2015 allows application of Wall Stud Repetitive Factor to Stud STIFFNESS. See SDPWS 3.1.1

Can this Exterior Wall Pass Deflection Check?

“Hinge Point” creates a structural weakness in the wall

Gable End with sloped ceiling

2 Story Exterior Wall
Can this Exterior Wall Pass Deflection Check?

Solution = Continuous Studs

Tall Walls in Office

Atlanta, GA
2-Story, 12,000 sf office bldg.
≈20ft tall
2x6 SYP #2 at high entry
Tall Walls in Restaurant

Emeryville, CA
24’+ tall
2x8 Doug Fir

Tall Walls in Retail

Large Diamond Retailer
Murfreesboro, TN
22’ tall 2x8 Pre-Fabricated
Small Retail Building – Northern CA

Flat Roof with:
» WSP Sheathing
» 2x Sub-Purlins
» Glulam Purlins
» Glulam Beams

20 ft 2x6 DF walls
» Interior
» Exterior
Small Retail Building – Northern CA

Glulam headers

Many Windows
Little Wall

Small Retail Building – Northern CA
Retail Building – Berlin Vermont

4,500 sf

Retail Building – Berlin Vermont

Roof Construction:
» Metal Plate Connected Monoslope Wood Roof Trusses
» 6’ Deep at Front, 4.5’ at Back, 50’ Span, 24” o.c.
» Wood Structural Panels
» 2x6 @ 16” o.c. Bearing Walls & Shear Walls– 13’ Tall
» Structural Steel Open Front Frame
Retail Building – Berlin Vermont

Front Canopy and Façade

Retail Building – Berlin Vermont
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Anatomy of Wood Sheathed Shear Walls
Lateral Load Capacity


AWC SDPWS
Provides details and capacities of these types of nailed wood shear walls

Shear Wall Requirements in AWC SDPWS

Table 4.3.4 Maximum Shear Wall Aspect Ratios

<table>
<thead>
<tr>
<th>Shear Wall Sheathing Type</th>
<th>Maximum h/b, Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood structural panels, unblocked</td>
<td>2:1</td>
</tr>
<tr>
<td>Wood structural panels, blocked</td>
<td>3.5:1</td>
</tr>
<tr>
<td>Plywood, block</td>
<td>2:1</td>
</tr>
<tr>
<td>Diagonal sheathing, conventional</td>
<td>2:1</td>
</tr>
<tr>
<td>Gypsum wallboard</td>
<td>2:1</td>
</tr>
<tr>
<td>Portland cement plaster</td>
<td>2:1</td>
</tr>
<tr>
<td>Structural fiberboard</td>
<td>3.5:1</td>
</tr>
</tbody>
</table>

3:5:1 max aspect ratio for blocked Wood Structural Panel Shear Wall. Reduction in Capacity when greater than 2:1
Shear Wall Requirements in AWC SDPWS

Capacities in SDPWS are **Nominal** values. Not ASD

**SDPWS 2021**  
*Single Nominal Value*  
Divide Nominal Values by 2.0 for ASD Wind and by 2.8 for ASD Seismic  
Multiply Nominal Values by 0.8 for LRFD Wind and 0.5 for ASD Seismic

### Table 4.3A Nominal Unit Shear Capacities for Sheathed Wood-Frame Shear Walls

<table>
<thead>
<tr>
<th>Sheathing Material</th>
<th>Minimum Nominal Panel Thickness (in.)</th>
<th>Minimum Nailing Length (in.) or Bracing, ( f_b ) (in.)</th>
<th>Nail Type &amp; Size</th>
<th>Panel Edge Nail Spacing (in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wood-based Panels</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wood Structural</td>
<td>5/16</td>
<td>1-1/4</td>
<td>6d common nail</td>
<td>OSB PLY OSB PLY OSB PLY</td>
</tr>
<tr>
<td>Panels – Sheathed</td>
<td>(5/16 x 0.13 x 0.2595)</td>
<td></td>
<td>(2 x 0.15 x 0.2595)</td>
<td>960 13 10 960 16 10 960 16 10</td>
</tr>
<tr>
<td></td>
<td>7/16</td>
<td>1-3/8</td>
<td>6d common nail</td>
<td>OSB PLY OSB PLY OSB PLY</td>
</tr>
<tr>
<td></td>
<td>(2 x 0.15 x 0.2595)</td>
<td></td>
<td>(2 x 0.15 x 0.2595)</td>
<td>945 19 14 965 24 14 929 16 20</td>
</tr>
<tr>
<td></td>
<td>9/16</td>
<td>1-1/2</td>
<td>15d common nail</td>
<td>OSB PLY OSB PLY OSB PLY</td>
</tr>
<tr>
<td></td>
<td>(2 x 0.15 x 0.2595)</td>
<td></td>
<td>(2 x 0.15 x 0.2595)</td>
<td>950 22 16 1400 20 20 1800 20 20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(2 x 0.15 x 0.2595)</td>
<td>950 22 16 1400 20 20 1800 20 20</td>
</tr>
</tbody>
</table>

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### Engineered Shear Wall Types

- **Solid or Segmented Walls**
- **Perforated Walls**
- **Force Transfer Around Openings Walls**
Why Use Force Transfer Around Openings?

Full height wall piers do not meet max 3.5:1 Ratio

Why Use Force Transfer Around Openings?

Shorter Constrained piers do meet 3.5:1 max aspect ratio
Open Front & Narrow Walls

Prefabricated Shear Wall Options

Proprietary Products with Evaluation Reports
Different Material Options

The primary benefit is to have lateral force resistance where a 3:5 to 1 aspect ratio shear wall does not fit.
Using Prefabricated Shear Walls

**Considerations:**

- Drift compatibility with other walls sharing load
- Large hold-down forces
- Foundation Anchorage Coordination
- Sizes range from 12”->24” wide to 6.5’->20’ tall

*Tip:* Cast-in-place anchorage to concrete needed. Don’t expect post-installed concrete anchors to work.

Small Retail Building – Northern CA
Open Front Structures

2015 SDPWS unifies Cantilever Diaphragms and Open Front Structures
2015 SDPWS Figure 4A

SDPWS allow Open Front Structures... provide certain important requirements are met.

Possible 1-Story Open-Front Structure in SDPWS 2015 & 2021
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Common Roof Framing Options

- Glulam
- Trusses
- I-Joists
Metal Plated Wood Truss

Metal Plated Wood Truss
Truss Configurations

- Monopitch
- Double Fink
- Hip
- Stub
- Double Howe
- Scissors
- Monopitch
- Sloping Flat
- Flat

Exposed Timber Trusses

T&G Deck over Timber Trusses

Berlin Shopping Mall, Berlin VT
Exposed Timber Trusses

90ft Span Concealed Connector Timber Truss

Exposed Timber Trusses

67’ Span Glulam Trusses

Whole Foods Market, Atlanta, GA
Metal Plated Trusses over Exposed Timber Trusses

Shenandoah Social Center

Photo courtesy D. Remy & Co.

I-Joist Roof Framing

» Flat or Sloped Roofs
» Vaulted Ceiling Possibilities

Havens Elementary, Photo courtesy RedBuilt

Strip Mall Building
Large Flat Roof Systems

Creating Open Floor Space

Grid dimensions in low rise commercial buildings are often a deciding factor when determining structural systems. Accommodation of large, open floor plans with a minimal number of columns is required.

Common Grid Dimensions: 25’x30’ to 45’x50’ and larger
Anatomy of a Large Flat Roof

- Sheathing
- Purlins
- Sub-purlins
- Girders
- Column
### Different Flat Roof Framing Systems

<table>
<thead>
<tr>
<th>Girder</th>
<th>Purlin</th>
<th>Sub-Purlin</th>
<th>Sheathing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glulam</td>
<td>Glulam @ 8’ to 10’ o.c.</td>
<td>2x</td>
<td>WSP</td>
</tr>
<tr>
<td>Glulam</td>
<td>Trusses @ 4’ to 10’ o.c.</td>
<td>2x</td>
<td>WSP</td>
</tr>
<tr>
<td>Glulam</td>
<td>Trusses @ 16” to 48” o.c.</td>
<td>None</td>
<td>WSP</td>
</tr>
<tr>
<td>Glulam</td>
<td>I-Joists @ 16” to 48” o.c.</td>
<td>None</td>
<td>WSP</td>
</tr>
<tr>
<td>Glulam</td>
<td>Glulam @ 4’ to 10’ o.c.</td>
<td>None</td>
<td>T&amp;G Decking</td>
</tr>
<tr>
<td>Glulam</td>
<td>Glulam @ 8’+ o.c.</td>
<td>None</td>
<td>Mass Timber Panels: Cross-Laminated Timber Nail-Laminated Timber Etc.</td>
</tr>
</tbody>
</table>

**Architectural Grade Exposed Wood Options**

### Material Connection to Nature (visual)

**Biophilic Pattern**

- Wood is a natural material – timber is sourced from trees in our forests.
- Exposing natural materials provides a connection to nature in this biophilic pattern
Material Connection to Nature (non-visual)

Biophilic Pattern

Other sensory connections to nature:
- Soft feel of wood – might this contribute to this biophilic pattern?
- Smell of wood in offices – might this contribute to this biophilic pattern?
- Smell of wood has surprised some designers who didn’t consider it in design

Biophilic Design Patterns
Nature in the Space

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Stress Reduction</th>
<th>Cognitive Performance</th>
<th>Emotion, Mood &amp; Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Connection w/ Nature</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Non-Visual Connection w/ Nature</td>
<td>✓</td>
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<td>✓</td>
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<tr>
<td>(smell, touch)</td>
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<td>Non-Rhythmic Sensory Stimuli</td>
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<td>Thermal &amp; Airflow Variability</td>
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<td>✓</td>
<td></td>
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<tr>
<td>Presence of Water</td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Dynamic &amp; Diffuse Light</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Connection w/ Natural Systems</td>
<td></td>
<td></td>
<td></td>
</tr>
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</table>

Source: Terrapin Bright Green: 14 Patterns of Biophilic Design, 2014
Example Roof Framing System

15 psf Roof DL
20 psf Roof Live Load

Example Roof Framing System

15 psf Roof DL
20 psf Roof Live Load

6-3/4”x31-1/2” Glulam Girders
5-1/8”x21” Glulam Purlins @ 8’-9” o.c.
2x8 @ 24” o.c. Sub-Purlins, 15/32” Wood Structural Panels
Example Roof Framing System

- 15 psf Roof DL
- 20 psf Roof Live Load
- 6-3/4”x31-1/2” Glulam Girders
- 3’-0” Deep Prefabricated Metal Plate
- Connected Wood Trusses @ 24” o.c.
- 15/32” Wood Structural Panels
Example Roof Framing System

15 psf Roof DL
20 psf Roof Live Load

6-3/4”x31-1/2” Glulam Girders
5-1/8”x21” Glulam Purlins @ 8’-9” o.c.
HT/Mass Timber Decking Options: NLT, CLT, GLT, 3x T&G

Parapet Framing Options

Tall Stud Parapet Style
**Parapet Wall Example**

- Sporting Good Retailer
- Dinuba, CA
- 17’ to top of roof
- 22’ to top of parapet
- 2x6 DF
- Used with hybrid panelized roof

![Parapet Wall Example Image](image)

**Parapet Framing Options**

- 2x parapet studs
- 2x diagonal bracing
- Boundary nailing
- Shear clip
- Cont. 2x plate
- 2x blocking below
- Edge nailing
- Trusses or Joists

- Top Flange Hanger Style

- 2x parapet studs
- 2x diagonal bracing
- Boundary nailing
- Shear clips as req’d
- Cont. 2x plate
- 2x blocking below
- Edge nailing
- Uplift clip
- Shear clip
- Trusses or Joists

- Platform Framing Style

**Built-Up Parapet Style**
Parapet Framing Options

Parapet in Truss Style

Parapet Flush with Wall

Cantilevered Truss

Flexible Detailing for Roof Openings

www.woodworks.org/cad-revit/
for example details
Layton Petro Mart, Greenfield, WI

Photos by Arquitectura

Commercial Wood Design Award 2009
Arquitectura Inc. – Milwaukee, WI

Layton Petro Mart, Greenfield, WI

Photo: Arquitectura, Inc.
Fast Food Restaurant

» 2x6 wall studs
» 10’ tall walls + 3’ Parapet
» Brick and Stone Cladding

Roof Construction:
» Metal Plate Connected Wood Roof Trusses
» 36” Deep, 34’ Spans, 32” o.c.
Wood in Retail Design

Restaurant
» Murfreesboro, TN
» Completed July, 2015

Restaurant – Brewery Chain

Roof Construction
» Wood Structural Panels Sheathing
» Composite Wood-Steel Open Web Trusses
» Glulam Beams
» 2x6 Bearing Walls
Wood in Retail Design

Restaurant – Brewery Chain

Blocked Roof Diaphragm for Higher Capacity
Retail Store: Gravity Framing System
Glulam Roof Beam Connection Details

Roof Framing Detail

BLOCKING AT ROOF SHEATHING PANEL EDGES
BLOCKING BTWN TRUSSES
ROOF SHEATHING
ROOF TRUSSES
GLULAM BEAM
Wood in Retail Design

Fast Food Restaurant in Provo, UT

Fast Food Restaurant

Building Construction
» Wood Structural Panels & T&G Decking Sheathing
» Composite Wood-Steel Open Web Roof Trusses & Solid Sawn Rafters
» Glulam Beams
» PSL & Built-Up Solid Sawn Columns
» 2x6 Bearing Walls & Shear Walls
Outline

» Introduction
» Framing System Design and Details
  » Structural Design Compliance
  » Wall Framing
  » Wall Bracing
  » Roof Framing
» Non-Structural Requirements and Design
  » Allowable Heights and Areas
  » Multi-Tenant and Multi-Occupancy Buildings
  » Fire Resistance and Detailing
» Large Retail Project Case Study

Height and Areas Code Analysis

Question:

For the building program, including occupancies and size, what Construction Types are allowed by the Building Code?

Answer:

Determined by Heights and Areas Code analysis
Heights and Areas – IBC 2018 Table 503

<table>
<thead>
<tr>
<th>GROUP</th>
<th>TYPE OF CONSTRUCTION</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
<th>TYPE V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HEIGHT (feet)</td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>A</td>
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<tr>
<td>M</td>
<td>UL</td>
<td>160</td>
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<td>4</td>
<td>11</td>
<td>2</td>
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<td></td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>R-1</td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
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<td></td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>R-2</td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
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<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
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<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>R-4</td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>S-1</td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
<tr>
<td>S-2c</td>
<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
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<td>UL</td>
<td>65</td>
<td>15</td>
<td>4</td>
<td>11</td>
<td>2</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>STORIES(S) AREA (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
</tr>
<tr>
<td>R-1</td>
</tr>
<tr>
<td>R-2</td>
</tr>
<tr>
<td>R-3</td>
</tr>
<tr>
<td>R-4</td>
</tr>
<tr>
<td>S-1</td>
</tr>
<tr>
<td>S-2c</td>
</tr>
<tr>
<td>U</td>
</tr>
</tbody>
</table>

Normal Calculated Allowable Heights and Area
One route to an answer.
Don’t overlook Unlimited Area Route

Unlimited Area Buildings

IBC Section 507 gives Unlimited Area Building routes for Type III, IV and/or V Construction for the following occupancies:

- Assembly
- Education
- Business
- Factory
- Mercantile
- Storage
Unlimited Area Buildings

Provisions for unlimited area buildings rely on open space surrounding building (IBC 507)

A reduction to 40 feet open space of up to 75% of perimeter is allowed provided the exterior wall and openings at reduced frontage have 3-hour ratings
Unlimited Area Building Route 1

B F M and S Occupancies can have unlimited area for any construction type provided:

» Two stories or less above grade plane
» Equipped with automatic sprinklers
» See IBC 507.4

Unlimited Area Buildings

Can these buildings meet the open space provision to qualify for Unlimited Area?
Unlimited Area Building(s)?

IBC 507.2 Commentary: Two unlimited area buildings on the same lot must be separated by 60 feet [or 40 feet if Section 507.2.1 is used] unless they are treated as a single building under the provisions of Section 503.1.2

Construction Types

Allowable Building Area

IBC 2018 Table 506.2
Floor Area Increase
Buildings equipped throughout with an NFPA 13 sprinkler system can be increased
300% (single story buildings) or
200% (multi-story buildings) over nonsprinklered conditions

Allowable Story Area
IBC 2018 Table 506.2

Provides base (non-sprinklered) & increased areas

<table>
<thead>
<tr>
<th>OCCUPANCY CLASSIFICATION</th>
<th>SEE FOOTNOTES</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
<th>TYPE V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A</td>
<td>B</td>
<td>A</td>
<td>B</td>
<td>HT</td>
</tr>
<tr>
<td>R-1</td>
<td>NS&lt;sup&gt;a&lt;/sup&gt;</td>
<td>UL</td>
<td>UL</td>
<td>24,000</td>
<td>16,000</td>
<td>24,000</td>
</tr>
<tr>
<td></td>
<td>S13R</td>
<td>UL</td>
<td>UL</td>
<td>96,000</td>
<td>64,000</td>
<td>96,000</td>
</tr>
<tr>
<td></td>
<td>S1</td>
<td>UL</td>
<td>UL</td>
<td>96,000</td>
<td>64,000</td>
<td>96,000</td>
</tr>
<tr>
<td></td>
<td>SM</td>
<td>UL</td>
<td>UL</td>
<td>72,000</td>
<td>48,000</td>
<td>72,000</td>
</tr>
</tbody>
</table>

**Can still increase these areas by the Frontage Factor of Section 506.3

NS = Buildings not equipped throughout with an automatic sprinkler system
S1 = Buildings a maximum of one story above grade plane equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1 (NFPA 13)
SM = Buildings two or more stories above grade plane equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1 (NFPA 13)
S13R = Buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.2 (NFPA 13R)
Fire Department Access

IBC 506

**Frontage**
Frontage provides access to the structure by fire service personnel, a temporary refuge area for occupants as they leave the building in a fire emergency and a reduced exposure to and from adjacent structures. Larger building area possible with certain amount of frontage.

**AWC Code Conforming Wood Design**
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Multi-Tenant Buildings

Lead to mixed occupancy buildings
Code Sections Related to Multiple Occupancies

» Incidental Uses (509)
» Accessory occupancies (508.2)
» Non-Separated occupancies (508.3)
» Separated Occupancies (508.4)
» Separate Buildings (503.1)
» Covered and Open Malls (402)

Outside scope of presentation

Incidental Uses (IBC 509)

» Ancillary function associated with an Occupancy
» Pose GREATER risk than the Occupancy
» Examples:
  » Laundry room over 100 square feet.
  » Refrigerant machinery room
  » Incinerator room
  » Furnace room
  » Boiler room
Incidental Uses (IBC 509)

- Not more than 10% of area of story
- Have fire separation, smoke separation and/or sprinkler systems per Table 509 and Section 509.4
- NOT classified as a different occupancy.
- Allowable Building Area and Height per main Occupancy

![Incidental Use](https://example.com/incidental_use_image.jpg)

Accessory Occupancies (508.2)

- Ancillary to the main Occupancy
- Accessory Area not greater than:
  - 10% of the main Occupancy on same floor
  - IBC 506 “NS” Allowable Area limit of Accessory Occupancy
- No separation between occupancies required*
- Allowable Building Area and Height per main Occupancy

![Accessory Occupancy](https://example.com/accessory_occupancy_image.jpg)

*Hazardous occupancies require separation
*Residential separations per Section 420 still apply
Non-Separated Occupancies (508.3)

» Most restrictive requirements of all occupancies apply for:
  » Fire Protection Systems (Chapter 9)
  » Allowable Height and Area
» Other requirements for each portion based upon occupancy of that portion
» No separation between occupancies required*

*Hazardous occupancies require separation.
*Residential separations per Section 420 still apply

Non-Separated Occupancies (508.3)

Acceptable Height & Area?

Acceptable Height & Area?

No Separation Required*
Non-Separated Occupancies (508.3)

» Requirements of code for each portion based upon occupancy of that portion
» Allowable Height of each occupancy based upon construction type and occupancy
» Allowable Area of each story
  » Sum of actual area over allowable area of each occupancy ≤ 1.0

Separated Occupancies (508.4)
Separated Occupancies (508.4)

Separation Per Table 508.4

\[
\frac{A_1}{\text{Allowable Area for Occupancy 1}} + \frac{A_2}{\text{Allowable Area for Occupancy 2}} \leq 1.0
\]

Check performed for each story.
Separation by Fire Barriers and Horizontal Assemblies

Separated Occupancies (508)

Separation by *Fire Barriers and Horizontal Assemblies* required per Table 508.4

<table>
<thead>
<tr>
<th>OCCUPANCY</th>
<th>A, E</th>
<th>H1, H1-1, H4</th>
<th>H2</th>
<th>R²</th>
<th>F-2, S-2, U</th>
<th>B⁺, F-1, M, S-1</th>
<th>H-1</th>
<th>H-2</th>
<th>H-3, H-4</th>
<th>H-5</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>S</td>
<td>NS</td>
<td>S</td>
<td>NS</td>
<td>S</td>
<td>S</td>
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<td>S</td>
</tr>
<tr>
<td>A, E</td>
<td>N</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>NP</td>
<td>1</td>
<td>2</td>
<td>N</td>
<td>1</td>
</tr>
<tr>
<td>L⁺, L-1, L-4</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td>L-2</td>
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<td>—</td>
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<td>R³</td>
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</tr>
<tr>
<td>F-2, S-2, U</td>
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<td></td>
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</tr>
<tr>
<td>B⁺, F-1, M, S-1</td>
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<td>H-1</td>
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<td>H-5</td>
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<td>—</td>
<td>—</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*NP = Not Permitted,  N = No Separation Required*
Separate Buildings

Each portion of a building separated by one or more fire walls shall be considered to be a separate building.

Heights and Areas Calculator

IBC H&A Calculator available from App Stores for Windows, iOS and Android.
Outline

» Introduction
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» Large Retail Project Case Study

Fire Resistance Ratings – IBC Table 601

<table>
<thead>
<tr>
<th>Building Element</th>
<th>Type III</th>
<th>Type IV</th>
<th>Type V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>HT</td>
</tr>
<tr>
<td>Primary Structural Frame</td>
<td>1</td>
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<td>HT</td>
</tr>
<tr>
<td>Exterior Bearing Walls*</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Interior Bearing Walls</td>
<td>1</td>
<td>0</td>
<td>1/HT</td>
</tr>
<tr>
<td>Exterior Nonbearing walls*</td>
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<td></td>
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<tr>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Interiors Nonbearing walls</td>
<td>0</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Floors</td>
<td>1</td>
<td>0</td>
<td>HT</td>
</tr>
<tr>
<td>Roofs</td>
<td>1</td>
<td>0</td>
<td>HT</td>
</tr>
</tbody>
</table>

* See IBC Table 602 for Exterior wall Fire Resistance Rating modifications due to Fire Separation Distance
Fire Resistance Rating – IBC Table 601

**TABLE 601**

<table>
<thead>
<tr>
<th>BUILDING ELEMENT</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
<th>TYPE V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>A^a</td>
<td>A^a</td>
<td>HT</td>
</tr>
<tr>
<td>Roof construction and secondary members (see Section 206)</td>
<td>1(\frac{1}{2})</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

b. Except in Group F-1, H, M, and S-1 occupancies, fire protection of structural members shall not be required, including protection of roof framing and decking where every part of the roof construction is 20 feet or more above any floor immediately below. Fire-retardant-treated wood members shall be allowed to be used for such unprotected members.

c. In all occupancies, heavy timber shall be allowed where a 1-hour or less fire-resistance rating is required.

**Table 601 Footnotes – “b”**

Fire protection of structural members shall not be required, where every part of the roof construction is 20 feet or more above any floor immediately below.

» FRT wood allowed in Roofs of Such Type I and II buildings

Except in group F-1, H, M, and S-1 occupancies
AC0  Footnotes should be updated for most current IBC provisions.
Ashley Cagle, 2023-08-18T16:42:31.280

AC0  Footnotes should be updated for most current IBC provisions.
Ashley Cagle, 2023-08-18T16:42:50.387
Table 601 Footnotes – “c”

Heavy Timber roof can be used where fire rating is 1hr or less

» Applies to any type of construction except Type IA

<table>
<thead>
<tr>
<th>BUILDING ELEMENT</th>
<th>TYPE I</th>
<th>TYPE II</th>
<th>TYPE III</th>
<th>TYPE IV</th>
<th>TYPE V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof construction and secondary members (see Section 202)</td>
<td>Δ</td>
<td>R</td>
<td>Δ</td>
<td>R</td>
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</tr>
</tbody>
</table>

Sources of Fire Rated Assemblies and Components

Commonly Approved Sources:

» American Wood Council’s DCA3: Fire-Rated Wood-Frame Wall and Floor/Ceiling Assemblies
» SBCA’s Metal Plate Connected Wood Truss Handbook – Section 17 Fire Performance of Trusses
» Underwriters Laboratory Fire Rated Listing

An “UL Assembly” listed by the Underwriters Laboratory is only ONE of MANY routes to compliance with fire ratings.
Outline

» Introduction
» Framing System Design and Details
  » Structural Design Compliance
  » Wall Framing
  » Wall Bracing
  » Roof Framing
» Non-Structural Requirements and Design
  » Allowable Heights and Areas
  » Multi-Tenant and Multi-Occupancy Buildings
  » Fire Resistance and Detailing
» Large Retail Project Case Study

Retail Store Design

» 55,000 sf chain grocery store in northern CA
» Originally designed and built with steel and masonry
» WoodWorks commissioned structural re-design with wood framing
» Comparing original to wood re-design, WoodWorks commissioned cost estimate & LCA studies
Big Cost Savings for Retail Store

» Original Steel & Masonry Building: $4.49 M
» Wood Building: $3.5 M
» Nearly $1 M Savings – 22% Savings - $18/sf Savings

Retail Store: Gravity Framing System

Partial Roof Framing Plan

47'-4"

45'-0"

32'-0"
Cost Savings Factor: Structure

<table>
<thead>
<tr>
<th>Description</th>
<th>Insulation Type</th>
<th>Cost (in $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original Steel &amp; Masonry Building</td>
<td>4.5” Extruded Polystyrene (XPS) Rigid Insulation on Top of Steel Roof Deck, R-22</td>
<td>$783,000</td>
</tr>
<tr>
<td>Wood Building</td>
<td>5.5” Fiberglass Batts Between Roof Trusses, R-22</td>
<td>$383,000</td>
</tr>
<tr>
<td>Roof Insulation Savings</td>
<td></td>
<td>$400,000</td>
</tr>
</tbody>
</table>

Source: Owens Corning, Networx

Cost Savings Factor: Roof Insulation

- Original Steel & Masonry Building: 4.5” Extruded Polystyrene (XPS) Rigid Insulation on Top of Steel Roof Deck. R-22. Cost = $783,000
- Wood Building: 5.5” Fiberglass Batts Between Roof Trusses. R-22. Cost = $383,000
- Roof Insulation Savings of **$400,000**

Source: Owens Corning, Networx
Cost Savings Factor: Structure

Total Structure Cost Savings for Wood Building = $425,000

Source: Canadian Wood Council

Source: APA

Source: LP Building Products
Retail Store: Gravity Framing System

- 15/32” Roof Sheathing
- Roof Trusses @ 2'-0” o.c. (24” to 54” Deep)
- 2x10 @ 16” o.c. Exterior Bearing Wall
- Solid Sawn Columns (10”x12” – 14”x14”)
- Interior Glulam Beams (8-3/4” wide; 24” – 36” deep)

Cost Savings Factor: Structure

<table>
<thead>
<tr>
<th>Category</th>
<th>Steel Bldg Element</th>
<th>Wood Bldg Element</th>
<th>Wood Bldg Cost Savings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof Beams</td>
<td>Open web steel joist girders</td>
<td>Glulam Beams</td>
<td>$164k</td>
</tr>
<tr>
<td>Roof Decking</td>
<td>1-1/2” Steel Deck</td>
<td>15/32” Sheathing</td>
<td>$114k</td>
</tr>
<tr>
<td>Columns</td>
<td>HSS Columns</td>
<td>Solid Sawn Columns</td>
<td>$107k</td>
</tr>
<tr>
<td>Primary Roof Framing</td>
<td>Open web steel joists</td>
<td>prefab Trusses</td>
<td>$66k</td>
</tr>
<tr>
<td>Wall Framing</td>
<td>6” metal studs &amp; 8” masonry</td>
<td>2x10 @ 16” o.c.</td>
<td>$54k</td>
</tr>
<tr>
<td>Ceiling</td>
<td>N.A.</td>
<td>5/8” gyp &amp; RC</td>
<td>$80k Extra</td>
</tr>
<tr>
<td>Total Wood Structure Cost Savings</td>
<td></td>
<td></td>
<td>$425k</td>
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</tbody>
</table>
Life Cycle Assessment

» Measures the environmental impacts of materials, assemblies or buildings over their entire lives—from extraction or harvest of raw materials through manufacturing, transportation, installation, use, maintenance and disposal or recycling.

» Allows design professionals to compare different building designs based on their environmental impacts and make informed choices about the materials they use.
Life Cycle Assessment (LCA)

Retail Store: LCA Comparison

Reference Building = Original Steel & Masonry Building
Proposed Building = Wood Building

Retail Store: LCA Comparison

LCA Results Comparison – Raw Materials through Demolition/Disposal

Reference Building = Original Steel & Masonry Building
Proposed Building = Wood Building


Additional Resources

American Wood Council Publications: www.awc.org
- National Design Specification (NDS) for Wood Construction
- Special Design Provisions for Wind and Seismic (SDPWS)
- Wood Frame Construction Manual (WFCM)
- Code Conforming Wood Design Series

Force Transfer Around Openings Paper by APA

Metal Plated Wood Trusses:
Structural Building Components Association. www.SBCIndustry.com

Big Box Retail Design Case Study:
Questions? Ask us anything.

John O’Donald II, PE
Regional Director | VA, DC, DE, MD, WV
(814) 880-5636
john.odonald@woodworks.org

903 East Sixth, Thoughtbarn-Delineate Studios, Leap! Structures, photo Casey Dunn

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