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Athena Impact Estimator Case Studies

Prepared for

The Metal Building Manufacturers Association

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Introduction

The Metal Building Manufacturers Association (MBMA) engaged Walter P. Moore and Associates, Inc. to conduct a Whole Building Life Cycle Assessment (WBLCA) comparing the environmental impacts of a metal building system against other forms of construction based on the results of the Athena Institute Impact Estimator software. The purpose of the study was to compare the environmental impacts for the building envelope of ten case study buildings that included metal building systems and other forms of construction located in three different climate regions in the United States. As a result, thirty total building case studies were evaluated in this study. The purpose of this study is to determine how metal buildings compare to other construction types in a Whole Building Life Cycle Assessment (WBLCA), with a focus on building types that use wood, masonry, concrete tilt up and conventional steel construction as part of the building envelope. Since metal building systems are commonly used for small offices, medium sized warehouses, and large industrial buildings, these building types were selected for the basis of this study, along with typical building layout with limited to no interior framing supports. MBMA developed the initial scope of the case study project for Walter P Moore to refine, with the goal in mind of having their structural engineers design the non-metal building examples to meet the intended design criteria based on site specific designs, along with generating the bill of materials common to typical construction practices in various regions of the country.

Scope

Figure 1 summarizes the dimensions, building types, uses and site locations used for this case study project. Each site represents either high seismic, high wind, or high snow loads. The building examples were chosen as comparable structural systems to the metal buildings for the different uses, footprints and elevations.
In line with WBLCA practice, the case study buildings were designed for a general comparison of metal buildings versus other construction types and design assumptions were made accordingly. It is understood that this study was not intended to cover all individual variations in building types and design assumptions. This study was based on functionally equivalent prototype buildings to understand the general relationships between the different structure and enclosure systems.

The smallest metal building was compared to the same size wood framed building, and the two larger metal buildings were compared to the following building types: load bearing masonry walls with joist and metal deck roof, concrete tilt up with joist and metal deck roof, and wide flange steel members with joists and metal deck roof. These building types were chosen as common alternative structural systems for metal buildings in each case study in terms of their functionality and size. Each building scheme was designed for loads in three different sites: California, Florida, and Minnesota.

The structure and enclosure components of the thirty case study buildings were designed for each of the three locations mentioned above based on the appropriate codes and standards referenced in this report. Walter P Moore designed the non-metal buildings based on common design practices to determine the appropriate bills of materials, while the MBMA provided the designs and bills of materials for the metal building examples based on common industry practices. To provide a representative MBMA industry average, two separate metal building manufacturing companies provided complete designs and bills of materials, which were consolidated. The plan views and building sections for all the building types are shown in Appendix A.

After the designs were completed, a bill of materials was created for each building to be input into the Athena Impact Estimator for a whole building life cycle assessment (WBLCA) comparison. The six environmental impact measures studied were global warming potential, stratospheric ozone depletion, acidification, depletion of nonrenewable energy resources, eutrophication, and tropospheric ozone depletion. These are the WBLCA metrics used in nationally recognized high performance green building codes, standards and rating systems (e.g. International Green Construction Code, ASHRAE 189.1 and LEED v4).

Design Criteria

The general design criteria outlined in this study was prepared by MBMA and refined by Walter P Moore to provide an unbiased comparison of metal buildings against other forms of construction based on the site-specific structural designs.

Case Study Buildings

There are 30 total buildings in the case study matrix (See Figure 1). All buildings were considered fully conditioned, and each building type had the same bay and column layouts. Case studies A and B have no interior columns and case study C has two rows of interior columns. See Appendix A for layouts of each building.

The study was comprised of three building sizes (see Table 1), with each building size comparing a metal building with comparable non-metal building structural types for each of the three project locations (see Table 2). Case study A compared a metal building with a wood framed building for a small office, while case studies B and C compared a metal building with a load bearing masonry, concrete tilt up and conventional steel buildings for a medium storage facility and a large industrial building.

CASE STUDY MATRIX		
A	**B**	**C**
40'W x 75'L x 16'Ht	**120'W x 125'L x 24'Ht**	**210'W x 240'L x 20'Ht**
Office Building	**Equipment Storage Facility**	**Industrial Packaging Facility**
FL | CA | MN	FL | CA | MN	FL | CA | MN
Building Type: 1A **Metal Building System** Primary Frame "Bay" Spacing: 25'-0" Interior Columns = 0 Roof Slope: 3:12 Roof Secondary Framing: Zee Purlins Roof Covering: Standing Seam Wall Secondary Framing: Zee Girts Wall Covering: Metal Cladding	**Building Type: 1B** **Metal Building System** Primary Frame "Bay" Spacing: 25'-0" Interior Columns = 0 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Zee Purlins Roof Covering: Standing Seam Wall Secondary Framing: Zee Girts Wall Covering: Metal Cladding	**Building Type: 1C** **Metal Building System** Primary Frame "Bay" Spacing: 30'-0" Interior Columns = 2 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Zee Purlins Roof Covering: Standing Seam Wall Secondary Framing: Zee Girts Wall Covering: Metal Cladding
FL | CA | MN	FL | CA | MN	FL | CA | MN
Building Type: 2A **Wood Framed Building** Primary Frame "Bay" Spacing: n/a Interior Columns: n/a Roof Slope: 3:12 Roof Secondary Framing: Gable Truss Roof Covering: Plywood/Shingles Wall Secondary Framing: Studs & Plywood Shear Wall Covering: Brick Wainscot/Wood Siding	**Building Type: 3B** **Load Bearing Masonry Building** Primary Frame "Bay" Spacing: n/a Option 1: Interior Columns = 0 Option 2: Interior Columns = 1 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Bar Joists Roof Covering: Built Up Roof Wall Secondary Framing: None Wall Covering: Masonry	**Building Type: 3C** **Load Bearing Masonry Building** Primary Frame "Bay" Spacing: n/a Interior Columns = 2 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Bar Joists & Joist Girders Roof Covering: Built Up Roof Wall Secondary Framing: None Walls Covering: Masonry
	FL | CA | MN	FL | CA | MN
	Building Type: 4B **Concrete Tilt Up** Primary Frame "Bay" Spacing: n/a Option 1: Interior Columns = 0 Option 2: Interior Columns = 1 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Bar Joists Roof Covering: Built Up Roof Wall Secondary Framing: None Wall Covering: Concrete Tilt Up	**Building Type: 4C** **Concrete Tilt Up** Primary Frame "Bay" Spacing: n/a Interior Columns = 2 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Bar Joists & Joist Girders Roof Covering: Built Up Roof Wall Secondary Framing: None Wall Covering: Concrete Tilt Up
	FL | CA | MN	FL | CA | MN
	Building Type: 5B **Conventional Steel** Primary Frame "Bay" Spacing: 25'-0" Option 1: Interior Columns = 0 Option 2: Interior Columns = 1 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Bar Joists Roof Covering: Built Up Roof Wall Secondary Framing: Zee Girts Wall Covering: Metal Cladding	**Building Type: 5C** **Conventional Steel** Primary Frame "Bay" Spacing: 30'-0" Interior Columns = 2 Roof Slope: $^{1}/_{4}$:12 Roof Secondary Framing: Bar Joists & Joist Girders Roof Covering: Built Up Roof Wall Secondary Framing: Zee Girts Wall Covering: Metal Cladding

Figure 1. Case Study Matrix

Table 1. Case Study Building Sizes and Uses

Case Study Label	Building Dimensions	Square Footage	IBC Occupancy Category	Use
A	40’x75’x16’	3,000 sq. ft.	(B) Business Group	Business
B	120’x125’x24’	15,000 sq. ft.	(S-2) Low- Hazard Storage	Equipment Storage
C	210’x240’x20’	52,500 sq. ft.	(F-2) Low Hazard Factory Industrial	Beverages (finish, packaging, processing)

Table 2. Case Study Structural Types

Building Label	Building Type	Case Study
1	Metal Building	A,B,C
2	Wood Framed Building	A
3	Load Bearing Masonry	B,C
4	Concrete Tilt Up	B,C
5	Conventional Steel	B,C

Codes and Standards

The designs were based on the following Building Codes and Standards for the site-specific locations to determine the appropriate design loads (i.e. seismic, wind, snow) and bill of materials. However, the intent of the study is to compare the overall WBLCA of building types in the various climate regions based on common codes and standards. Therefore, the ICC codes were used for design criteria in lieu of state specific building codes.

International Building Code 2024 .... IBC 2024
International Energy Conservation Code 2024 .... IECC 2024
Minimum Design Loads for Buildings and Other Structures .... ASCE 7-22
AISC Specification for Structural Steel Buildings .... AISC 360-22
Building Code Requirements for Structural Concrete .... ACI 318-19
AISC Serviceability Design Considerations for Low-Rise Steel Buildings .... Design Guide 3

Site Specific Design Requirements

Project Location #1 - Florida

Address: .... 2911 E Robinson Street
City, State, Zip .... Orlando, FL 32803
Lat./Long. .... 28.546, -81.346
Climate Zone .... Climate Zone 2A
County .... Orange County
Snow .... 3 psf
Wind .... 137 mph (Risk Category 2)
Exposure .... Exposure Category B. Developed Suburban Location
Seismic
Site Soil Class .... D
Risk Category II
Ss (0.2 second spectral response acceleration) .... 0.085 g
S1 (1.0 second spectral response acceleration) .... 0.036 g
TL (Long-period transition period) .... 8 seconds
Soil Bearing .... 3,500 psf
Foundation Type .... Shallow Foundation (spread footings)

Project Location #2 – California

Address: .... 1500 W. Rialto Avenue
City, State, Zip .... San Bernardino, CA 92410
Lat./Long. .... 34.101, -117.319
Climate Zone .... Climate Zone 3B
County .... San Bernardino County
Snow .... 6 psf
Wind .... 96 mph (Risk Category 2)
Exposure .... Exposure Category B. Developed Suburban Location
Seismic
Site Soil Class .... D
Risk Category II
Ss (0.2 second spectral response acceleration) .... 2.75 g
S1 (1.0 second spectral response acceleration) .... 1.04 g
TL (Long-period transition period .... 8 seconds
Soil Bearing .... 3000 psf
Foundation Type .... Shallow Foundation (Spread Footings)

Project Location #3 – Minnesota

Address: .... 1433 NE Stinson Blvd
City, State, Zip .... Minneapolis, MN 55413
Lat./Long. .... 45.002, -93.221
Climate Zone .... Climate Zone 6A
Climatological Data
County .... Hennepin County
Snow .... 57 psf
Wind .... 109 mph (Risk Category 2)
Exposure .... Exposure Category B. Developed Suburban Location.
Seismic
Ss (0.2 second spectral response acceleration) .... 0.053 g
S1 (1.0 second spectral response acceleration) .... 0.034 g
TL (Long-period transition period) .... 12 seconds
Frost Depth .... 5'-0" deep per WPM
Soil Bearing .... 3000 psf
Foundation Type .... Shallow Foundation (Spread Footings)

LCA Software and Metrics

All life cycle analyses were performed using Athena Impact Estimator Version 5.4.0103. Metal Building Systems are included in the Athena software for comparison with other building types in a WBLCA. For this study, the bills of materials for each case study were input as Extra Basic Materials, instead of using areas and volumes with the predefined structural systems. This allowed for input of actual material quantities based on design, rather than general material quantities based on average area and volumes. A total of 30 separate Impact Estimator .AT4 software files were compared.

The Athena Impact Estimator life cycle analysis tool accounts for material manufacturing, including resource extraction and recycled content, on-site construction, transportation, building type and assumed lifespan, maintenance and replacement effects, and demolition and disposal. The Athena software also allows an option to include operational energy use in order to include the impacts associated with production of the operational energy used over the life cycle of the building. However, the intent of this study was to compare the embodied impacts of various structural systems. To ensure functional equivalence across the study, all case study buildings use the applicable prescriptive energy code provisions described in this report. Consequently, no building operational energy measures were entered into the Athena software.

This study evaluates the overall building lifespan using a common 60-year life cycle, which is aligned with the life cycle used for WBLCA for the LEED rating system. All material replacement schedules were per the Athena defaults.

The phases included in the overall WBLCA for the building lifespan include the following:

- Product manufacturing
- Product transport
- Construction
- Construction transport
- Use replacement
- Use replacement transport
- End of life deconstruction
- End of life transport

The environmental metrics used in this study are as follows.

- Global Warming Potential
- Stratospheric Ozone Depletion
- Acidification of Land and Water
- Depletion of Non-Renewable Energy Resources
- Eutrophication
- Tropospheric Ozone Formation

Building Design

The scope of this study includes the primary and secondary structural framing, wall and roof materials, including insulation, and foundations. It does not include items that are common to all case study buildings, including interior finishes, sprinklers, fenestration and doors, gutters, downspouts, and slab-on-grade since these elements would be repeatable with no value in the overall WBLCA comparisons.

To determine the insulation bill of materials for this study, all buildings followed the prescriptive insulation provisions of the 2024 IECC Table C402.1.3 as described in the Envelope Design section of this report.

Metal Building Structural Design

The design included the analysis for gravity, wind, snow, and seismic loads of the following elements:

- Primary Rigid Framing (built-up tapered steel columns and beams, and interior steel wide flange columns where applicable)
- Cold-Formed Steel Secondary Framing (zee shaped roof purlins and wall girts)
- Metal Cladding (24 ga standing seam roof and 26 ga through fastened wall panels)
- Structural bolts, clips and fasteners
- Longitudinal building bracing, flange bracing and purlin bracing
- Foundations (3000 psi, normalweight concrete)

The metal building foundations were designed and checked by Walter P Moore, using typical metal building foundation design assumptions and site-specific foundation reactions, including using the soil and structure above the footing to resist uplift and allowing for the shear force at the base of the columns to be transferred to the slab-on-grade.

Non-Metal Building Structural Design

The design included the analysis and design for gravity, wind, snow, and seismic loads of the following structural elements:

- Roof framing (joists, steel girders and roof deck)
- Steel columns or load bearing exterior walls
- Lateral load resisting system (bracing or exterior shear walls)
- Foundations

The design did not include detailing of embeds, connections, bearing plates, or similar items. Allowances based on typical conditions were used instead when calculating material weights for the bill of materials.

Material Design Assumptions

Reinforcing Steel .... ASTM A615, Grade 60
Concrete: Foundation Elements .... 3,000 psi, Normalweight
Concrete: Tilt Up .... 5,000 psi, Normalweight
Concrete Masonry Units .... 1,900 psi
Structural Steel: Wide flange shapes .... ASTM A992 Grade 50
Structural Steel: HSS .... ASTM A500 Grade B
Structural Steel: Angles A36
Steel Roof Deck: 1 ½” deep .... 20 - 22 ga (Fy = 33 ksi)

These materials are common and generally correlate with the Athena inputs.

Common Structural Design Attributes

Concrete Mix Designs

One of the variables of WBLCA is the amount of cement replacement used in concrete mix designs. Portland cement is the largest contributor to the environmental impact of concrete, and the amount of cement replacement in a concrete mix can have a significant impact on the results. Cement replacement for a typical building will vary by type, location, and concrete provider.

To determine the amount of cement replacement for each case study, concrete mixes for each location were taken from the *A Cradle-to-Gate Life Cycle Assessment of Ready-Mixed Concrete Manufactured by NRMCA*

Members – Version 3.2, prepared for the National Ready Mixed Concrete Association (NRMCA) in July of 2022 for use by Athena users. The report gives average mix designs for nine regions in the United States based on mix designs submitted by the member companies for various compressive strengths. The South Eastern, Pacific Southwest, and North Central region mix designs were used in this study for Florida, California, and Minnesota, respectively.

Gravity Design

The building envelopes of the case study buildings were designed for combined wind, dead, live and snow loads where appropriate per the Site Specific Design Requirements section above. The 20 psf roof live load was reduced as allowed by code. For Building A, the roof framing consisted of the following:

- The metal building system consisted of a standing seam roof supported by cold-formed steel zee shaped purlins supported by primary rigid frame steel rafters and columns.
- The wood framed building consisted of plywood supported by prefabricated roof truss joists further supported by load bearing wood stud walls.

For Buildings B and C, the roof framing consisted of the following:

- The metal building system included the same structural members as described in Building A.
- The load bearing masonry, concrete tilt up and conventional steel buildings consisted of a galvanized roof deck supported by open web long span steel joists bearing on either the CMU, concrete tilt up bearing walls or steel wide flange beams and columns, respectively.

The roof member sizes were typically the same for the Florida and California buildings and heavier for the Minnesota building due to the greater snow loads. Roof deflection limits were followed per IBC. The roof member sizes can be found in Appendix A.

For case study C buildings, the metal buildings used standard W-shapes for interior columns and the non-metal buildings included HSS interior columns and sized appropriately for the site specific conditions. For example, the HSS columns were the same size for Florida and California and larger for Minnesota, similar to the roof framing members.

Lateral Design

Wind and seismic forces were calculated per the Site Specific Design Requirements section above. Wind governed the design for the Minnesota and Florida buildings, and seismic governed the California buildings design. The metal building primary framing members provide lateral resistance to the transverse lateral forces while the braced frames (x-configurations) in the plane of the walls provide resistance to the longitudinal forces. The metal building primary and secondary framing members were designed based on lateral design requirements and include braced frames (x-configuration) and secondary bracing to provide lateral resistance where needed. The CMU and concrete tilt up walls were designed as shear walls and plywood shear walls were used in the wood framed building. Due to reduced lateral loads, the tilt up panel thickness for the Minnesota case study was 2” thinner than the California and Florida case studies. HSS exterior braced frames (x-configuration) provided lateral resistance for the conventional steel framed building. See Appendix A for additional information.

Foundation Design

Bearing pressures used in design are shown in the Site Specific Design Requirements section above. The shallow foundations of the metal buildings and non-metal buildings were designed for the worse case of gravity and uplift from lateral loads. Uplift was resisted by the weight of the footing and the soil above the footing, and the lateral load was taken into the slab on grade.

The bill of materials used for the envelope can be found in Table 3, which corresponds with the available material options in the Athena software.

Envelope Design

The structural framing of the building envelope also included insulating materials to comply with the 2024 International Energy Conservation Code. Consideration for building envelope covering were per local building practices as it relates to building type and function. The energy code includes various levels of insulation requirements based project location as determined by the IECC Figure C301.1 Climate Zone Map. The insulating materials were derived from the IECC Table C402.1.3 as it applies to climate zone location and building type utilizing the insulation prescriptive R-value method. The Site Specific Design Requirements section of this report calls out which climate zone applies to which project location. Where continuous insulation is called out in the energy code, extruded polystyrene or poly-iso insulation was the specific material type chosen with varying thicknesses to meet the intended R-value listing.

For case study A (small office building):

- The walls for the wood framed building in climate zone 2 (FL) and 3 (CA) were insulated with R-20 fiber glass blanket insulation in between the wood studs. R-3.8 continuous insulation was added to meet the prescriptive R- value for the climate zone 6 (MN) building. Blown insulation was used for the roof insulation for all three locations to be equivalent to R-38, with a thicker insulation used for Minnesota to reach R-49. Asphalt shingles and underlayment on plywood deck provided the weather proofing.
- The walls of the metal building systems in climates zone 2 (FL) and 3 (CA) included 8 inch cold-formed steel zee shaped girts. These walls included R-13 metal building fiber glass blanket insulation with R-6.5 continuous insulation between the girts and the metal wall panels. The metal building wall insulation was increased in climate zone 6 (MN) to include R-13 metal building fiber glass blanket insulation with R-14 continuous insulation. The metal building roofs in climate zones 2 (FL) and 3 (CA) included 8 inch cold-formed steel zee shaped. These roofs included a fiber glass insulation liner system as described in the IECC consisting of a continuous membrane installed below the purlins and uninterrupted by framing members. Uncompressed, unfaced insulation rests on top of the membrane between the purlins and with the second layer of insulation draped over the purlins then compressed when the standing seam roof is attached. The metal building roof liner systems consisted of two layers of unfaced fiber glass blanket insulation of R-19 and R-11 in climate zones 2 (FL) and 3 (CA), and R-25 and R-11 in climate zone

6 (MN). The purlin depth for the climate zone 6 building was increased to 10 inches to accommodate the added insulation thickness.

For case studies B (warehouse facility) and C (industrial facility):

- The CMU walls were insulated with a gypsum wallboard along with continuous insulation equivalent to R-5.7, R-7.6, and R-13.3 on the interior for climate zones 2, 3, and 6, respectively. A latex paint was used on the outside for aesthetic reasons. These roofs were comprised of a single ply membrane roof with continuous insulation for the climate zone 2 and 3, and for climate zone 6 modified bitumen asphalt roof with ballast was used appropriate to that region.
- The concrete tilt up walls were insulated with an air gap and the same insulation R-values as that of the CMU buildings. No additional paint or finish was applied to the concrete tilt up walls. The roof covering is also the same as that noted in the CMU example above.
- The metal building roofs and walls for case studies B and C included framing members, insulation and cladding the same as defined for the case study A buildings above.
- The conventional steel framed building walls included similar framing members and wall cladding as the metal building walls. The insulation levels were slightly less with R-13 plus R-5 continuous insulation for climate zones 2 and 3, and R-13 plus R-13 continuous insulation for climate zone 6. The roofs for the conventional steel framed buildings fell under the insulation entirely above deck category of the IECC with R-20 continuous insulation used for climate zones 2 and 3, and R-30 continuous insulation for climate zone 6. The roof covering is the same as that noted in the CMU example above.

The materials used for the envelope can be found in the bill of materials in Table 4, which corresponds with the available materials and naming categories listed in the Athena Impact Estimator software. For example, R-20 poly-iso continuous roof insulation would fall under the category of extruded polystyrene since poly-iso is not an option. Another example would be the double layer liner systems R-19 + R11 would fall under the category of FG Batt R30, with FG representing fiber glass.

Bill of Materials

The scope of this study includes the primary and secondary structural framing, wall and roof materials including insulation, and foundations. It does not include items that are common to all the case study buildings, including interior finishes, sprinklers, fenestration and doors, gutters, downspouts, and slab on grade. The focus of this study was to compare the elements that differ between metal buildings and alternate construction types to get a representation of how metal building fared against alternates with their special materials and loads. See Tables 3 and 4 for a list of materials used in the bill of materials in each case study, along with the input for the units.

Construction waste is accounted for in Athena calculations and was not added in the initial material quantities.

Metal Buildings

The bill of materials for metal buildings were combined into the Athena material categories as follows:

- MBS Metal Roof Cladding (includes 24 ga Standing Seam Roof, 26 ga Trim, bolts, fasteners, clips)
- MBS Metal Wall Cladding (includes 26 ga Through Fastened Metal panels, 26 ga Trim, bolts, fasteners)
- MBS Secondary Components (includes purlins, girts, purlin/ girt clips, flange bracing, and purlin bridging)
- MBS Primary Frames (includes Rigid frames tapered columns/rafters, end wall columns, interior columns, bolts, longitudinal building bracing, purlin and girt bracing)
- Metal building Insulation was broken down into the following software categories:
  - Polyiso Foam Board (to account for continuous insulation board)
  - Polypropylene Scrim Kraft Vapour Retarder (to account for laminated vapour retarder adhered to fiber glass insulation blankets where applicable or where the vapour retarder is installed separately as in the liner system application.
  - FG Batt R11-15 (to account for the R-13 fiber glass blanket insulation that falls in the software range of R11-R15)
  - FG Batt R30 (to account for the fiber glass blanket insulation that uses R19 plus R11 and R25 plus R11, which is close to the designated software category of R30)

In addition, regional concrete mix designs and rebar for the concrete foundations were also included, along with standard brick and mortar used for the case study A buildings with brick wainscot. For the complete summary of materials used from the Athena Impact Estimator software, please refer to Table 3 and Table 4 below.

Non-Metal Buildings

The bill of materials for each non-metal buildings was created from the design and analysis of the structural systems and selection of the envelope materials by Walter P Moore. These bills of materials were then entered into the Athena software to compare the case studies using the quantities and material listed in the program.

Fifteen percent of the total steel tonnages were added to the calculated member tonnages for bolts, fasteners, gussets, edge angles, base plates and anchor rods for the non-metal building examples. The Athena Impact Estimator software accounted for these items within the software for the metal building examples.

Table 3. Bill of Structural Materials

Material	Units	Case Study Buildings
MBS Primary Frames	Tons	1A,B,C
MBS Secondary Components (purlins, girts, bracing)	Tons	1A,B,C; 5B,C
Softwood Plywood	msf- thousand square feet based on 3/8”	2A
Nails	Tons	2A
Screws, Nuts & Bolts	Tons	2A
Small dimensions Softwood Lumber, kiln-dried	thousand board-feet	2A
10” Concrete Block	total number of blocks based on total surface area	3B,3C
Steel plate	Tons	3-5B, 3-5C
Bolts, Fasteners Clips	Tons	3-5B, 3-5C
Galvanized Decking	total tons based on total area of deck	3-5B; 3-5C
Grout	total volume based on percentage of CMU surface area	3B,3C
Mortar	total volume based on percentage of CMU surface area	3B,3C
Open Web Joists	total tons of joist weight multiplied by total joists lengths including bridging	3-5B; 3-5C
Wide Flange Sections	Tons	5B; 3-5C
Hollow Structural Steel	Tons	5B; 3-5C
Rebar	Total tonnage of rebar including bends and laps for both foundations and walls as appropriate	All
Coarse Aggregate Natural	Tons	All
Fine Aggregate Natural	Tons	All
Fly Ash	Tons	All
Portland Cement	Tons	All
Slag Cement	Tons	All
Water	Tons	All

Table 4. Bill of Building Envelope Materials

Material	Units	Case Study Buildings
Organic Felt shingles 30 yr	square feet based on roof area	2A
#15 Organic Felt	square feet based on roof area	2A
FG Open Blow R31-40	square feet of attic area based on 1" thickness	2A
FG Batt R20	square feet of attic area based on 1" thickness	2A
Oriented Strand Board	msf- thousand square feet based on 3/8" thickness	2A
Ontario (Standard) Brick	square feet based on 4' tall around perimeter	1A; 2A
Polyiso Foam Board (unfaced)	square feet based on 1" thickness	1A,B,C; 5B,C
PVC Membrane 48 mil	Lbs	3B,C; 4B,C
MBS Metal Roof Cladding- Commercial (24 Ga)	Tons	1A,B,C; 5B;5C
MBS Metal Wall Cladding- Steel Building (26 Ga)	Tons	3,4,5B; 3,4,5C
Water based latex paint	gallons based on square feet of CMU painted	3B,C
FG Batt R11-15	square feet based on 1" thickness	1A,B,C; 5B,C
FG Batt R30	square feet based on 1" thickness	1A,B,C
Polypropylene Scrim Kraft Vapour Retarded Cloth	square feet	1A,B,C; 5B,C
Extruded Polystyrene	square feet based on 1" thickness	2A; 3B,C; 4B,C; 5B,C
½" moisture resistant gypsum board	square feet	3B,C

Results and Discussion

When comparing environmental impact of different building materials for a building with comparable function and performance, it is important to evaluate the whole system, as the selection of the building system will affect the type of insulation. It is also important to keep the buildings equivalent as possible in terms of their function and performance.

Whole building life cycle assessment shows a general comparison between building systems. The results shown in the figures below summarize metal buildings as the base line for comparison against other building types in all three project locations. For example, Figure 2 compares a metal building and a wood building designed for the California design criteria, similarly the same graph compares the buildings located in Florida and Minnesota.

This study did not include elements common to all buildings such as interior finishes, sprinklers, fenestration and doors, gutters, downspouts, and slab-on-grade. As a result, the study focused on the primary material differences in the case studies. It should be noted that in LCA comparisons used by the high performance green building codes, standards and rating systems, all of the envelope and structural materials such as fenestration and slab on grade need to be included and therefore these items would need to be included in project specific WBLCAs to meet the LCA provisions. For the purposes of this study, the bill of materials for the common building elements would have cancelled each other out. For that reason, they were excluded from this comparative study.

This study also highlighted the sensitivities in the Athena software to individual material effects. As shown in the results, the eutrophication potential and ozone depletion are very high when PVC Membrane 48 mil material was selected. The eutrophication potential values extend beyond the scale used in the tables below where a PVC membrane was used (case studies B and C for California and Florida).

Structural materials typically have the greatest impact for global warming potential, acidification potential, tropospheric ozone formation, ozone depletion potential. Insulation has a greater impact on the eutrophication and non-renewable energy categories.

Case Study A: Small Office Building

For the small office building case study, a metal building was compared to a wood framed building, as summarized in Figure 2. Overall, the wood frame building materials showed less embodied impact than the metal building in the categories of global warming, ozone depletion, acidification potential and non-renewable energy for all project locations. It showed more impact for eutrophication potential.

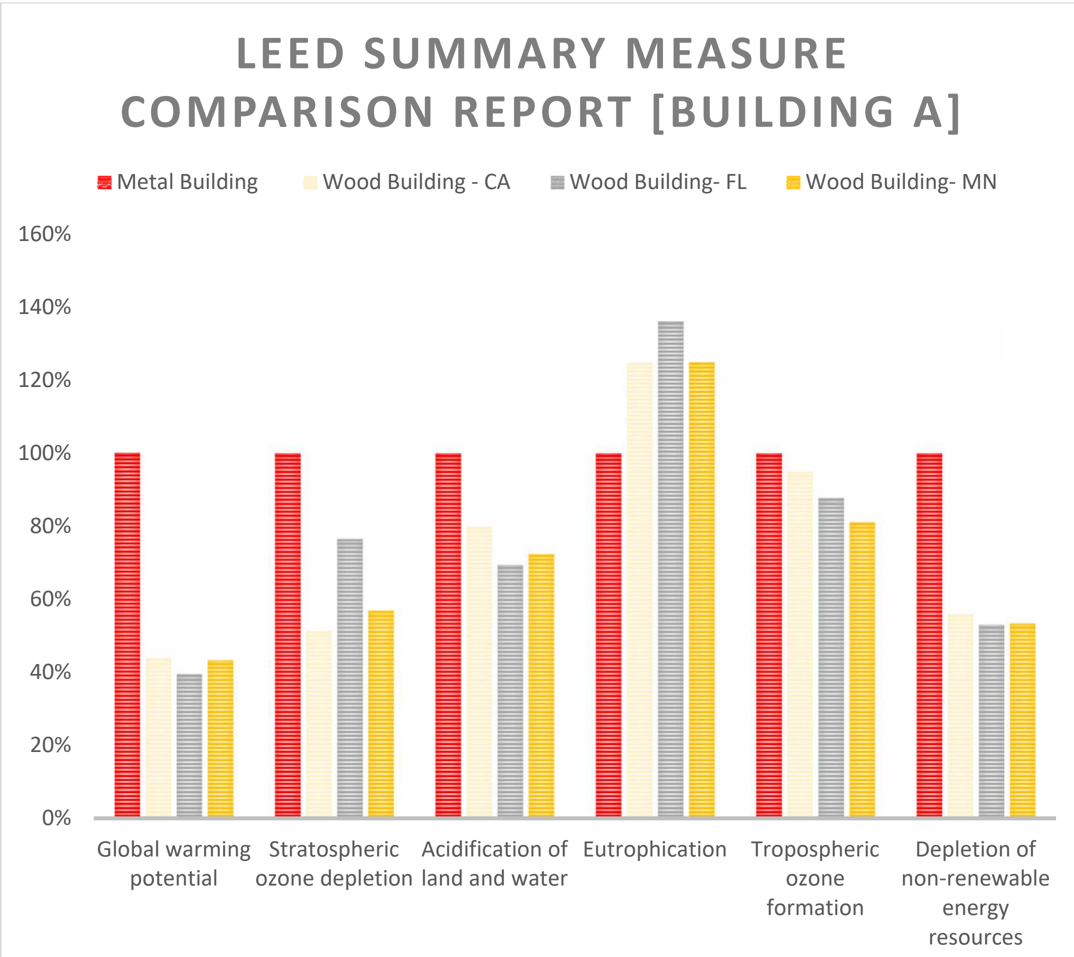
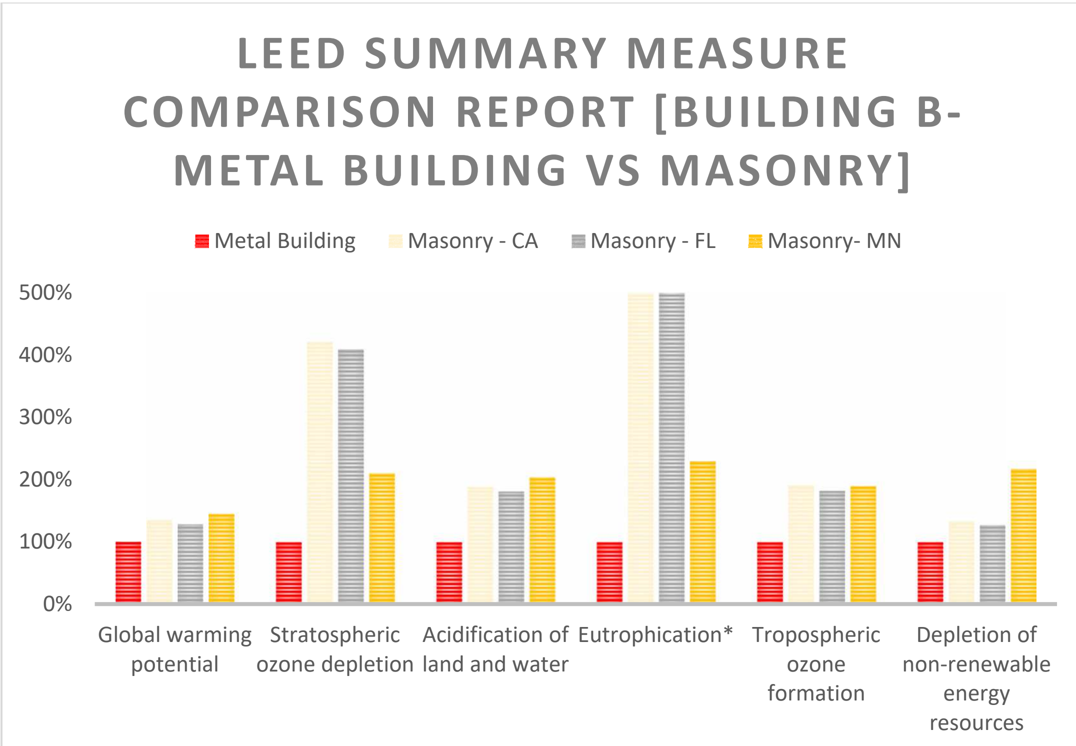


Figure 2. Case Study A: Metal Building vs. Wood

A case study was also done considering the use of wood paneling instead of metal wall cladding for the building A metal building type. This swap resulted in a decrease across all impact categories and narrowed the margins between metal and wood building types in global warming potential by approximately 10-12%. So, while the wood building still outperformed the metal building in most categories, the difference between the two decreased by switching from metal cladding to wood siding.

Case Study B: Medium Sized Storage

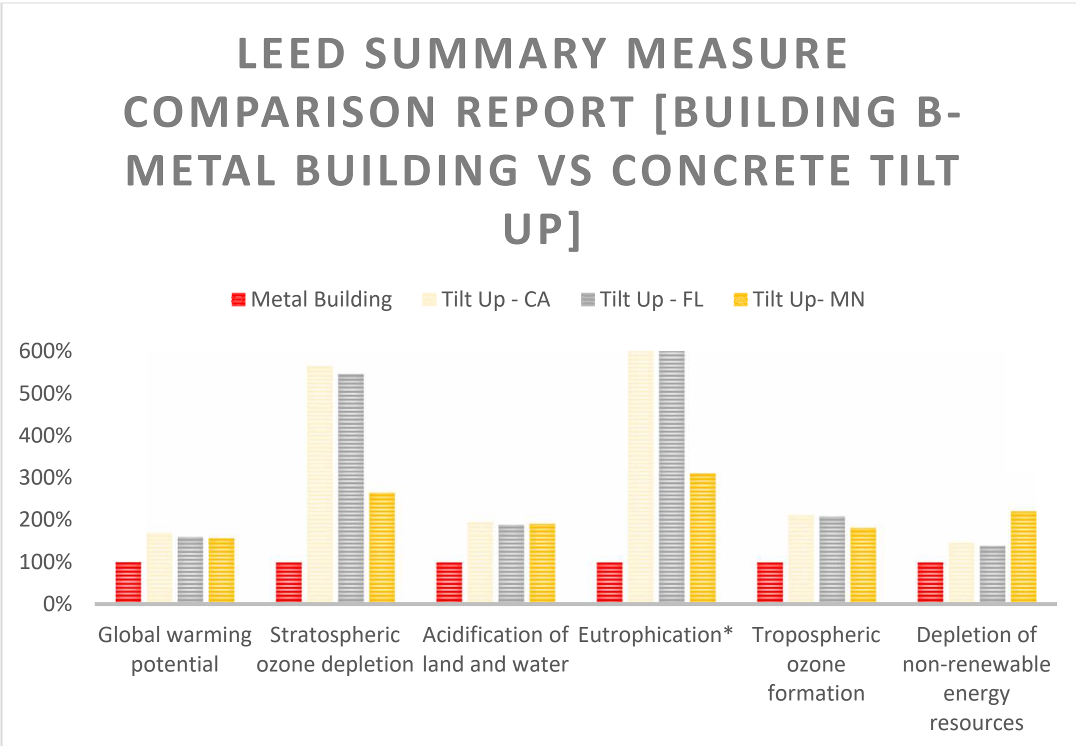
The medium size storage case study building compared the metal building to a load bearing masonry, concrete tilt up, and conventional steel framed building for each of the three locations. Overall, the metal building had less environmental impacts than all three other building systems in all six categories, with the largest difference between metal buildings and concrete tilt up. The results are closest between the metal buildings and conventional steel buildings. The non-metal buildings case study buildings had the same structural roof members for CA and FL, and a higher roof tonnage for the MN buildings due to snow load.



**The Eutrophication Potential values are greater than 1000% for CA and FL.*

Figure 3. Case Study B: Metal Building vs. Masonry

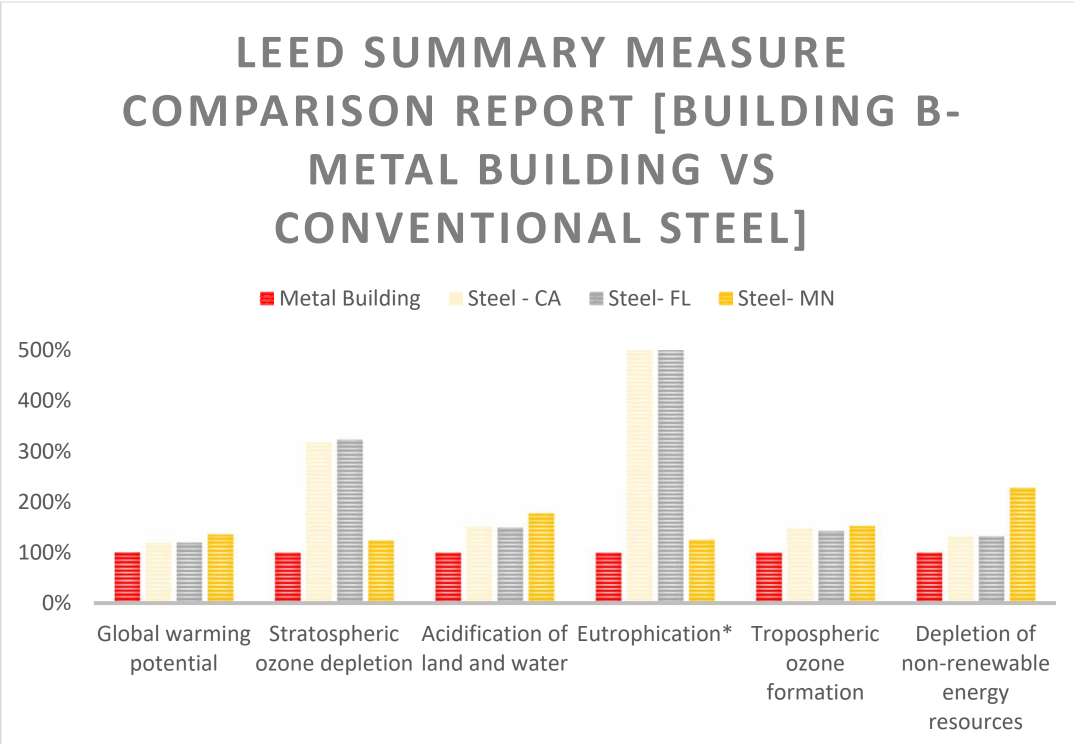
Figure 3 shows the comparison of the metal building to the load bearing masonry building for case study B. Metal buildings showed less environmental impacts in each category. The narrowest margin was in the global warming potential category where metal buildings showed approximately 25-50% less impact than the masonry building. The greatest margin was in the Minnesota building example, which showed the masonry building had over 200% greater impact in the eutrophication potential category than the metal building. As noted previously, the effects of the PVC membrane material in Athena caused off the chart results for the Florida and California case studies with a single ply membrane roof, where the comparison of the Minnesota building with a modified bitumen asphalt roof makes a clearer comparison.



**The Eutrophication Potential values are greater than 1300% for CA and FL.*

Figure 4. Case Study B: Metal Building vs Concrete Tilt Up

Figure 4 shows the comparison of the concrete tilt up building to the metal building, with metal buildings showing less environmental impacts in each category. The comparison results were similar to the CMU to metal building comparisons although the impact difference margins were greater with concrete tilt up due to the higher volume of concrete used. The narrowest margin was in the global warming category and the highest margin was in the eutrophication category, even with the modified bitumen asphalt roof. The Minnesota tilt up case study had the smallest amount of concrete due to the smaller lateral loads; therefore, it fared closest to the metal building in almost all categories. Conversely, the California case study has the largest concrete foundations due to the higher seismic loads from the heavier building type.



**The Eutrophication Potential values are greater than 1000% for CA and FL.*

Figure 5. Case Study B: Metal Building vs Conventional Steel

Figure 5 shows the comparison of the metal building to the conventional steel building. The wall cladding was the same for both the metal building and conventional steel, while the roofing of the conventional steel building was similar to the load bearing masonry and tilt up buildings. The impact results for each category for the steel building were within 250% of the metal buildings (closer than the load bearing walls case study comparisons), except for the eutrophication potential and ozone depletion categories for the buildings with a PVC roof membrane.)

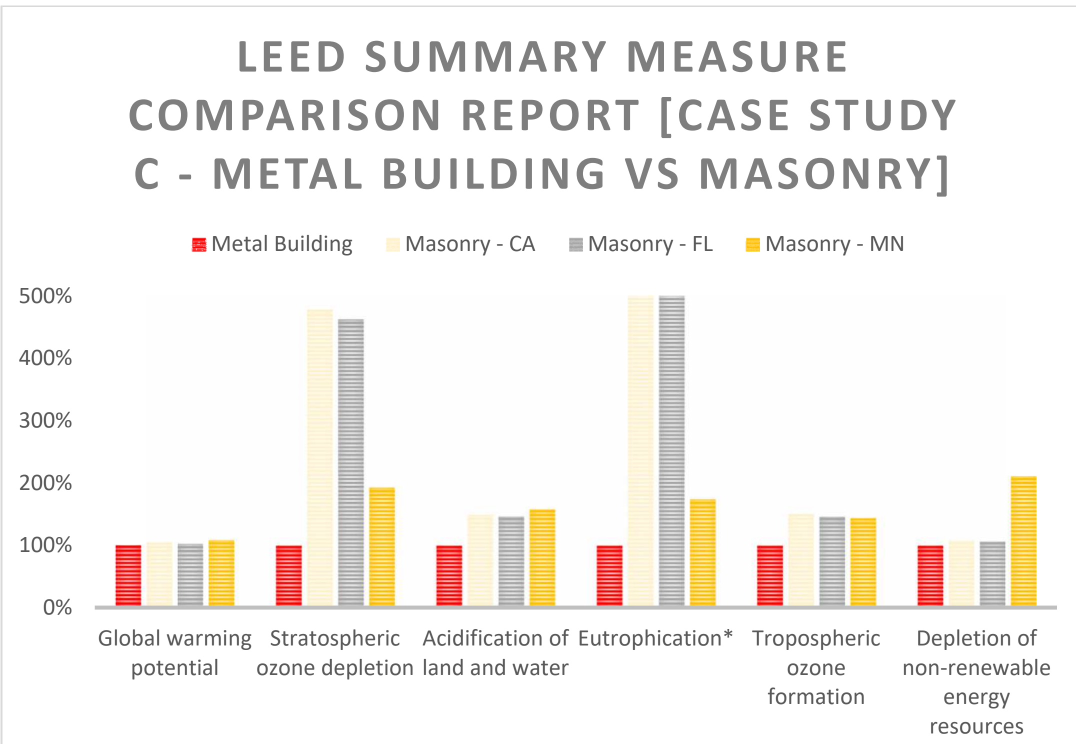
There is less variation between each location due to the overall lighter structural system and an increase in steel brace sizes has less impact than an increase in the wall thickness or reinforcing for the load bearing wall case studies.

Supported Span Option in Case Study B

The purpose of this case study B was to compare buildings that span 120'-0" wide without interior columns, which is most common to metal building construction. However, if the span was supported by interior columns, there would be a reduction in the roof tonnage for the various building types. For the non-metal building construction, the roof tonnage can be reduced by approximately half (including columns and girders) when adding interior columns and girder to divide the span into two. The roof tonnage for a metal building also reduces by approximately 20% when adding interior column supports. While the joist tonnage reduces, it would not reduce the amount of roof deck, insulation, wall thicknesses, or other structural materials. It would have some impact on the amount of concrete in the foundations. These reductions would have the largest impact in the Global Warming Potential category but are not expected to alter the overall results by more than 10%.

Case Study C: Large Sized Industrial

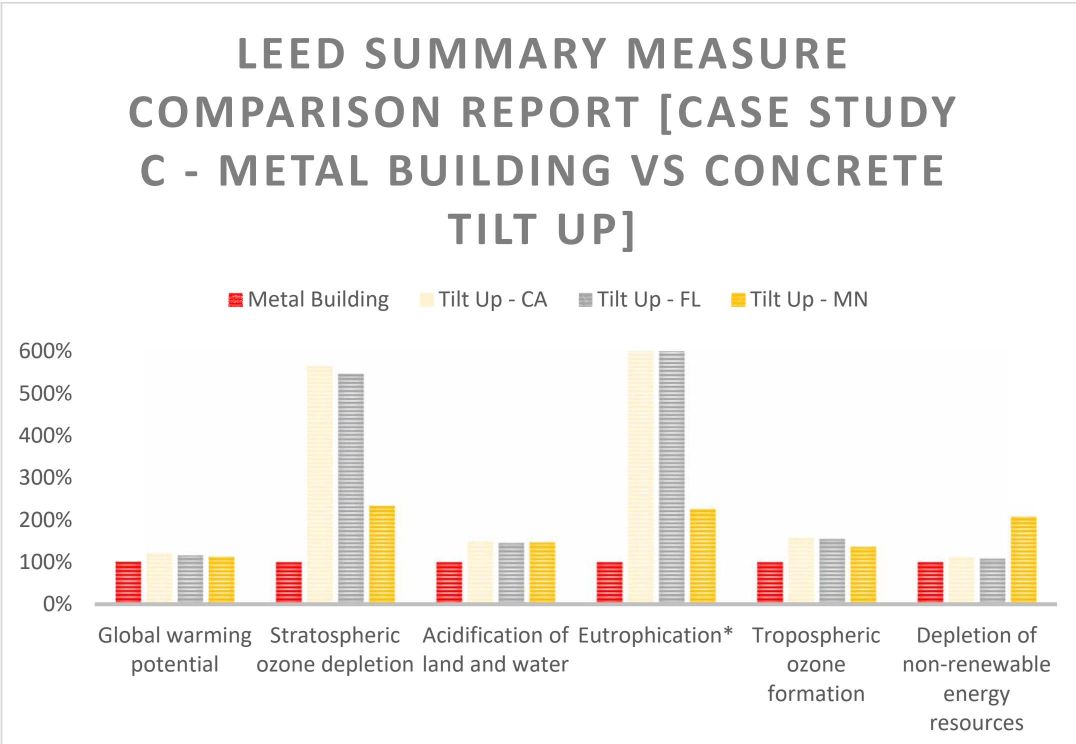
The large sized industrial building case study compared the metal building to a load bearing masonry, concrete tilt up, and conventional steel framed building for each of the three locations. Similar to case study B, the metal building showed less impact than all three other building systems in all six categories, with concrete tilt up scoring the worst among the non-metal buildings. The environmental impact differences between the metal building and the other results were closer for case study C compared to case study B.



**The Eutrophication Potential values are greater than 1400% for CA and FL.*

Figure 6. Case Study C: Metal Building vs Masonry

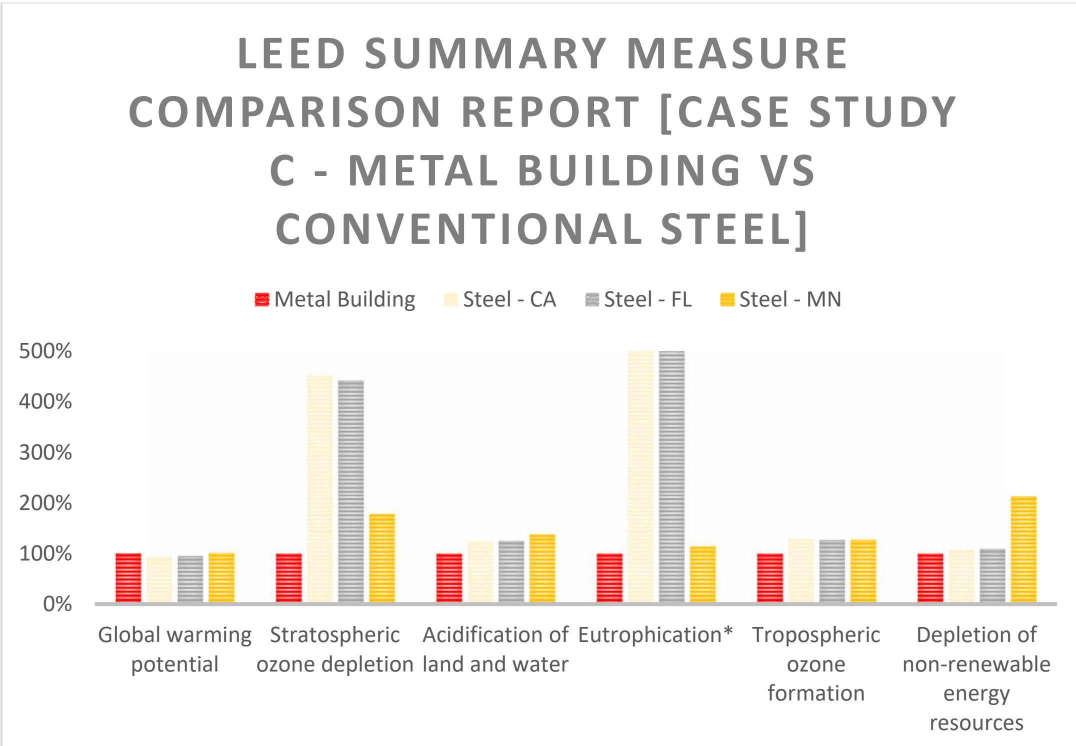
Figure 6 shows the comparison of the case study C metal building to the load bearing masonry building. Metal buildings showed less environmental impact for most categories. The narrowest margin was in the global warming potential category where the two building types were within 8% of each other. The greatest margin was in the eutrophication potential category where the California and Florida buildings showed over 300% more impact than the metal building, if ignoring the spikes for the PVC membranes.



**The Eutrophication Potential values are greater than 1500% for CA and FL.*

Figure 7. Case Study C: Metal Building vs Concrete Tilt Up

Figure 7 shows the comparison of the case study C metal building to the concrete tilt up building. As with case study B, this building type comparison has the largest variation in results between building locations. The categories with the smallest margins were global warming potential where the concrete tilt up buildings showed more impact than metal buildings by between 10 and 25%, depending on project location. The comparison of eutrophication potential category showed a difference of 200 - 1600% between the concrete tilt up and the metal building.



**The Eutrophication Potential values are greater than 1300% for CA and FL.*

Figure 8. Case Study C: Metal Building vs Conventional Steel

Figure 8 shows the comparison for case study C metal building versus the conventional steel building, with similar trends as shown in case study B. The global warming potential values were within 5% between the two building types. The greatest difference between the building types was in the Minnesota non-renewable energy category, which was over 200% greater in impact than the metal building baseline building.

Eutrophication and ozone depletion potential impacts continue to have the largest impacts compared to metal buildings for this case study C.

Conclusion

This study compared whole building life cycle assessments (WBLCA) between metal buildings and alternate construction types for three different building uses and footprints using Athena Impact Estimator software. The WBLCA is not intended to give exact calculations of environmental metrics but instead gives a picture of how the buildings compare in various categories. This study focused on the following environmental metrics:

- Global warming potential
- Stratospheric ozone depletion
- Acidification of land and water
- Depletion of non-renewable energy resources
- Eutrophication
- Tropospheric ozone formation

Metal buildings showed higher environmental impacts than wood construction for the small office case study in the global warming, ozone depletion, acidification and non-renewable energy categories but less impact for eutrophication potential. Overall, wood construction had less of an environmental impact for the small building case study than metal buildings.

Metal buildings showed lower environmental impacts in all six metrics when comparing structural and envelope materials to load bearing masonry walls, concrete, tilt up, and steel framed construction of the same building footprint and functional equivalence for Building B. Therefore, metal buildings performed better than similar concrete, masonry, and steel construction types for long span building footprints in the WBLCA for these case studies. The steel framed buildings in this case study typically had the second smallest environmental impacts compared to metal buildings, while concrete tilt up buildings had the largest impact.

For Building C case studies, the impacts between metal buildings and other building types were more similar. Metal buildings still had lower impacts in all six categories when compared to tilt up and masonry buildings. When comparing metal buildings and conventional steel buildings for the larger building layout, the global warming potential values were almost identical. However, the impacts of the conventional steel building were still higher than the metal building in the other five metrics.

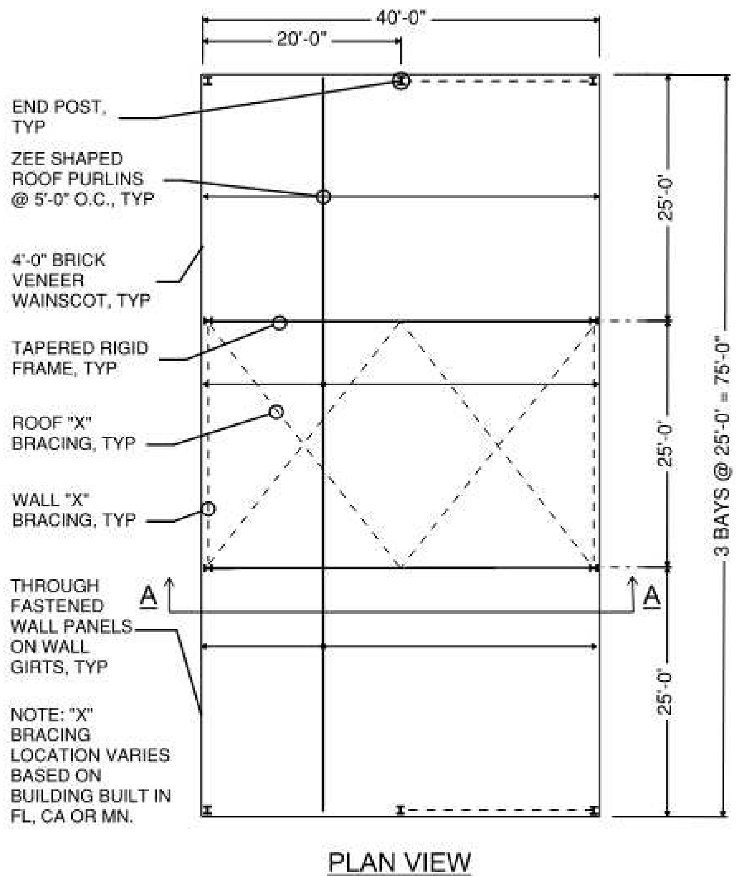
In conclusion, the study results show that for the types of building where metal buildings are typically most economical, they typically also perform better in life cycle assessments and have the least embodied building material impact.

Areas of future research could include the inclusion of fenestration, different types of roof and cladding material, different bay and building configurations. In addition, a similar analysis would be of interest using a different LCA tool. Lastly, the individual material sensitivities could also be investigated more in depth in the Athena software or when using another LCA software tool.

Appendix

Building Layouts

Figure 1a: Building Type 1a (Metal Building System)



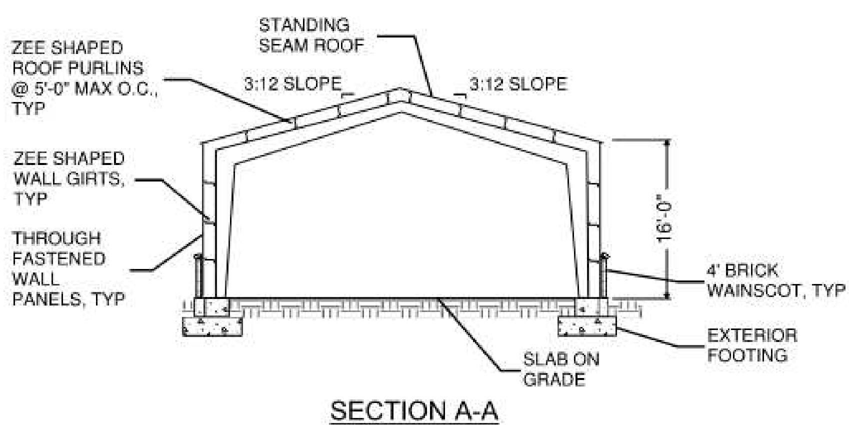


Figure 1b: Building Type 1b (Metal Building System)

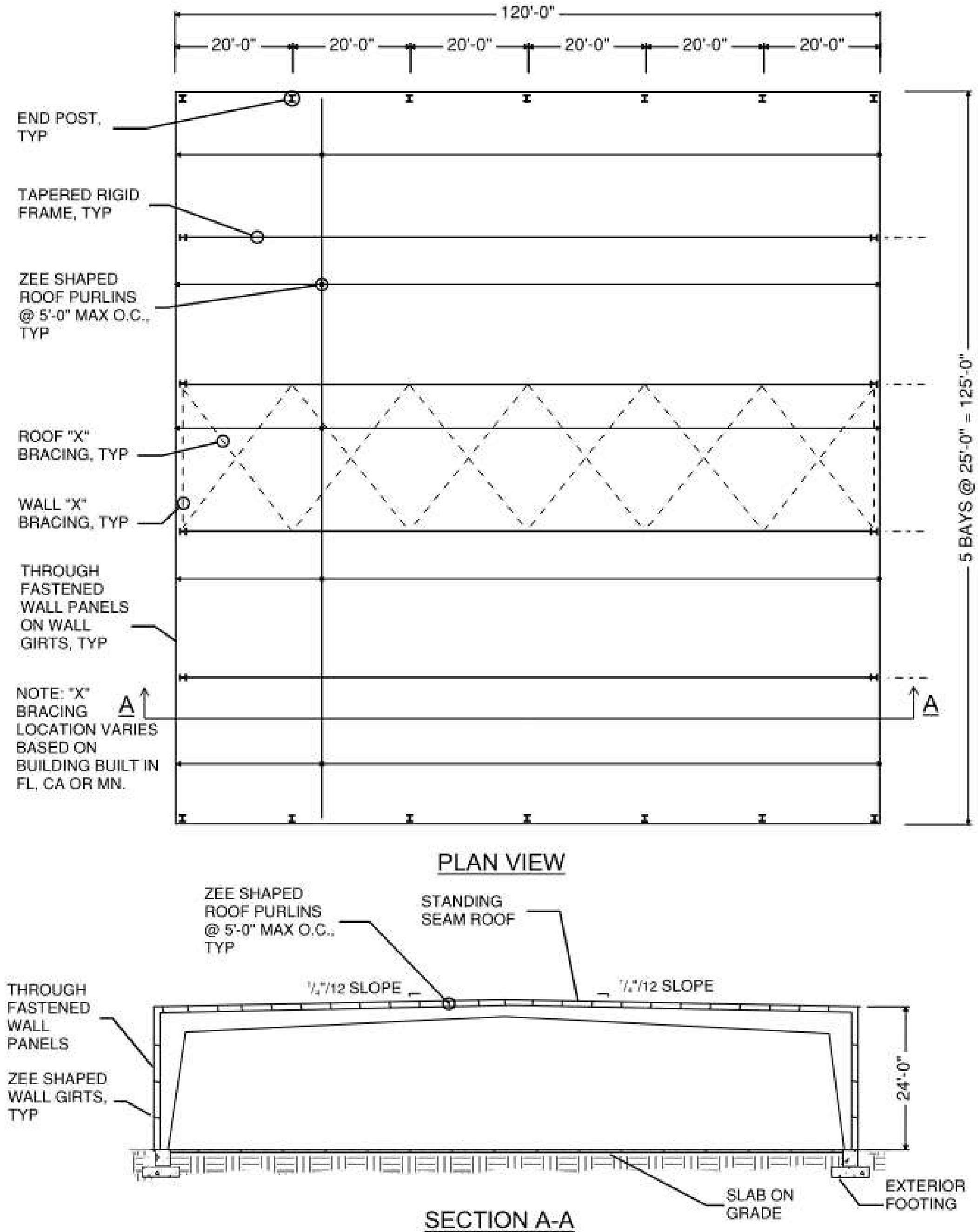


Figure 1c: Building Type 1c (Metal Building System)

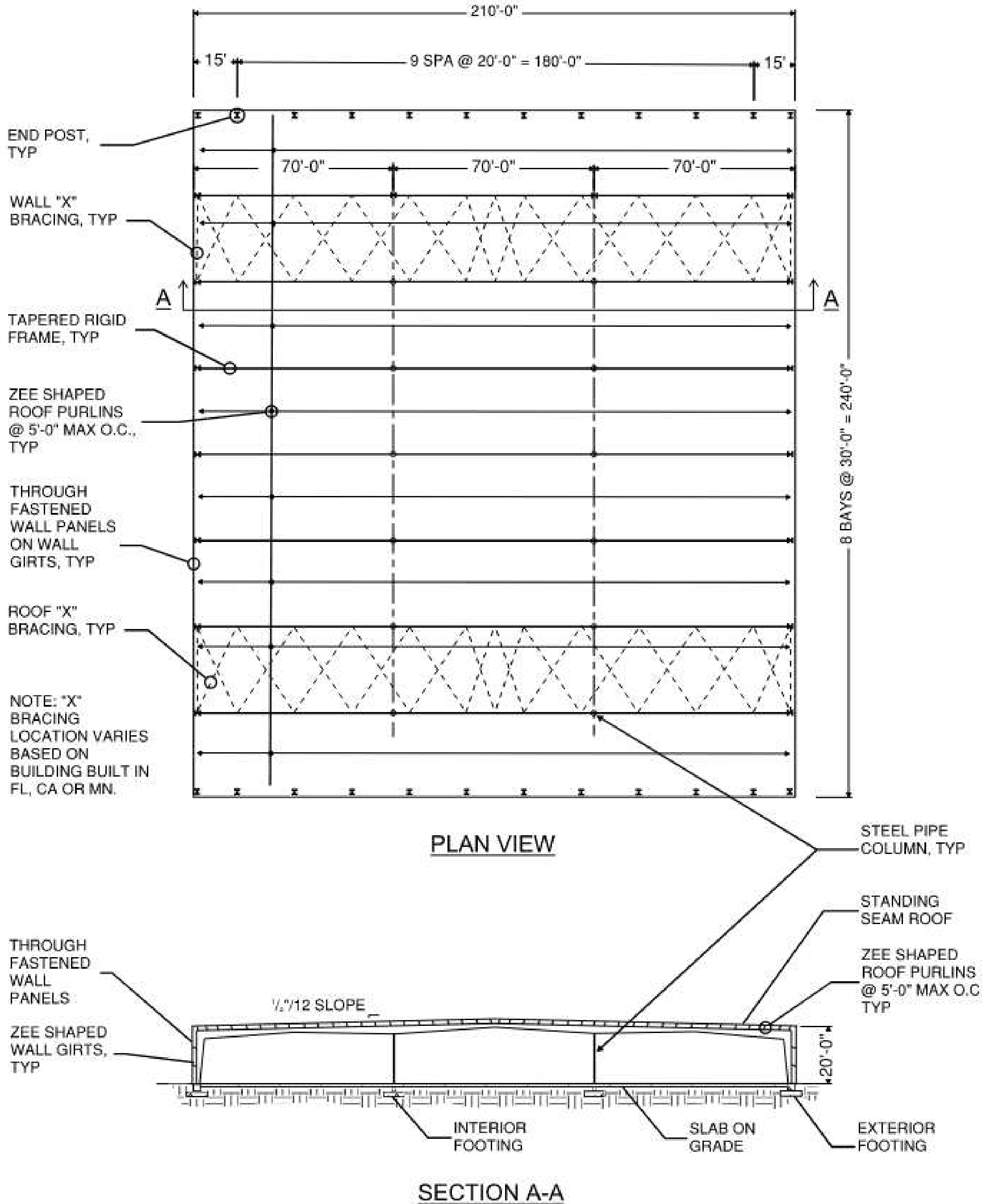
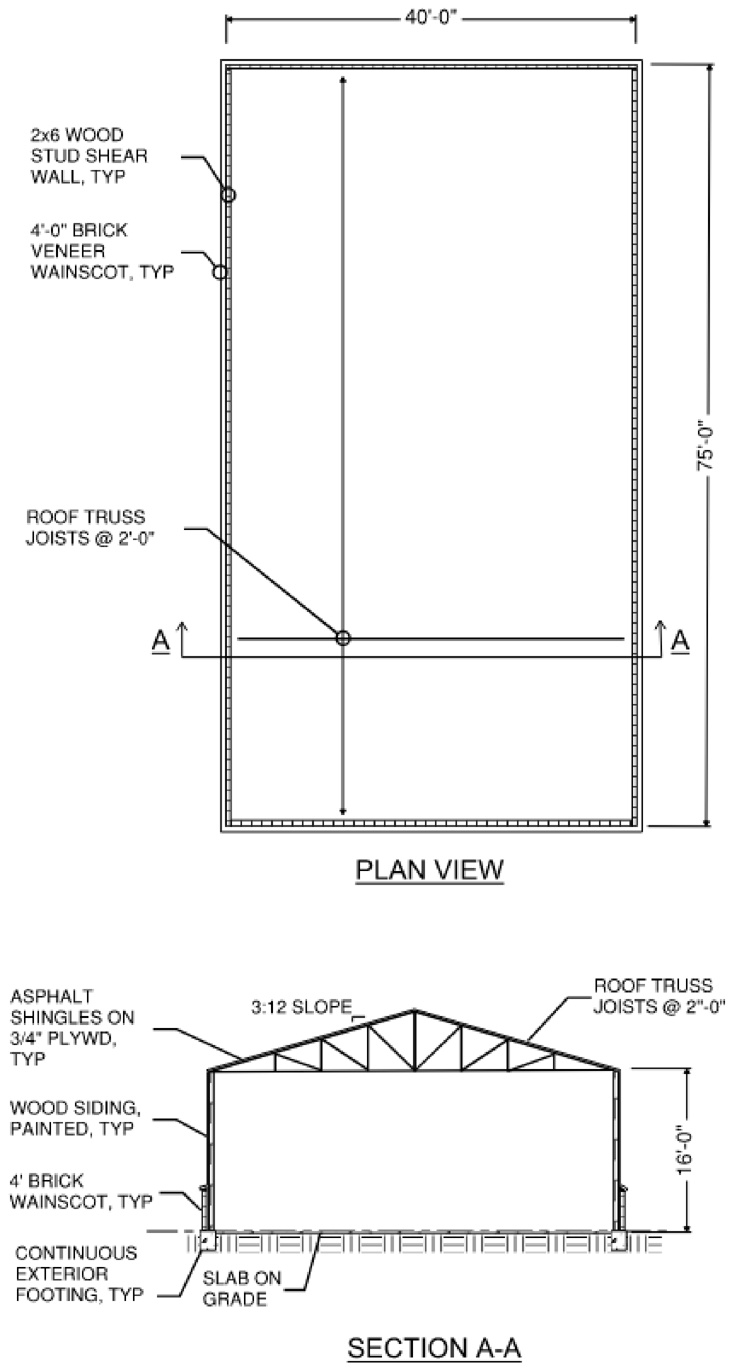


Figure 2a: Building Type 2a (Wood Framed)



NOTE:
SEE TABLES FOR MEMBER SIZES FOR EACH LOCATION.

Figure 3b: Building Type 3b (Masonry Wall)

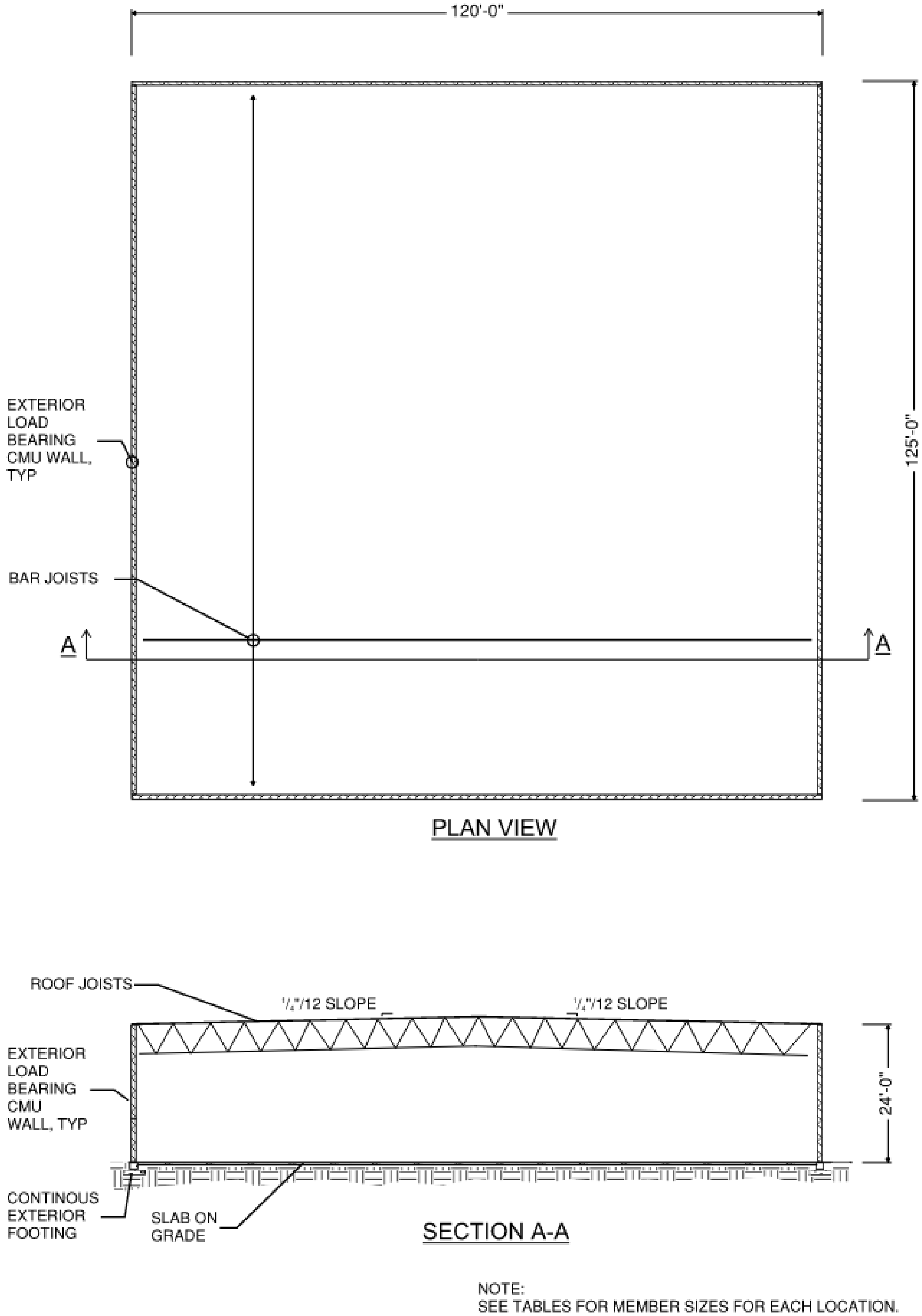
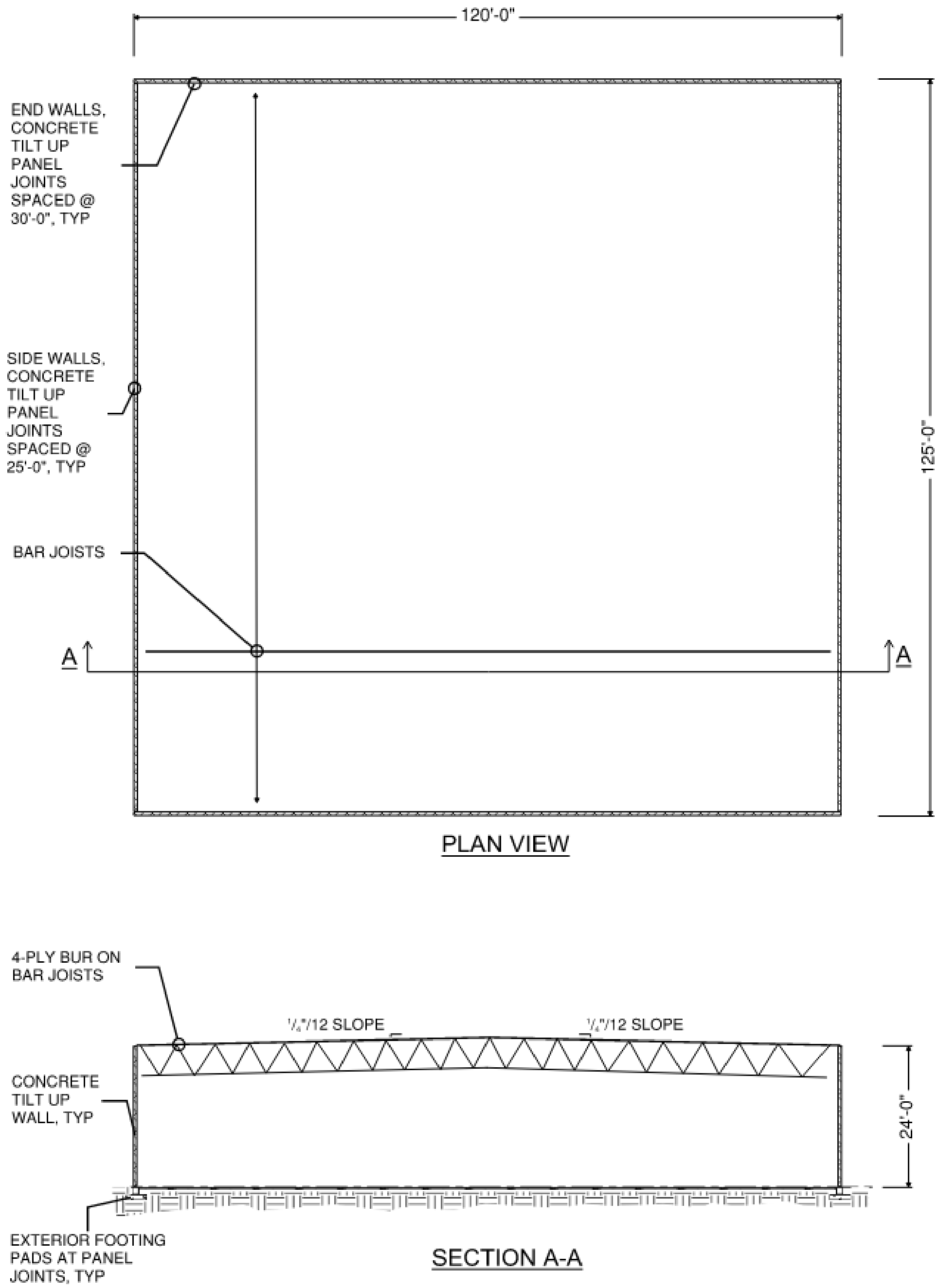


Figure 4b: Building Type 4b (Concrete Tilt Up)



NOTE:
SEE TABLES FOR MEMBER SIZES FOR EACH LOCATION.

Figure 5b: Building Type 5b (Conventional Steel)

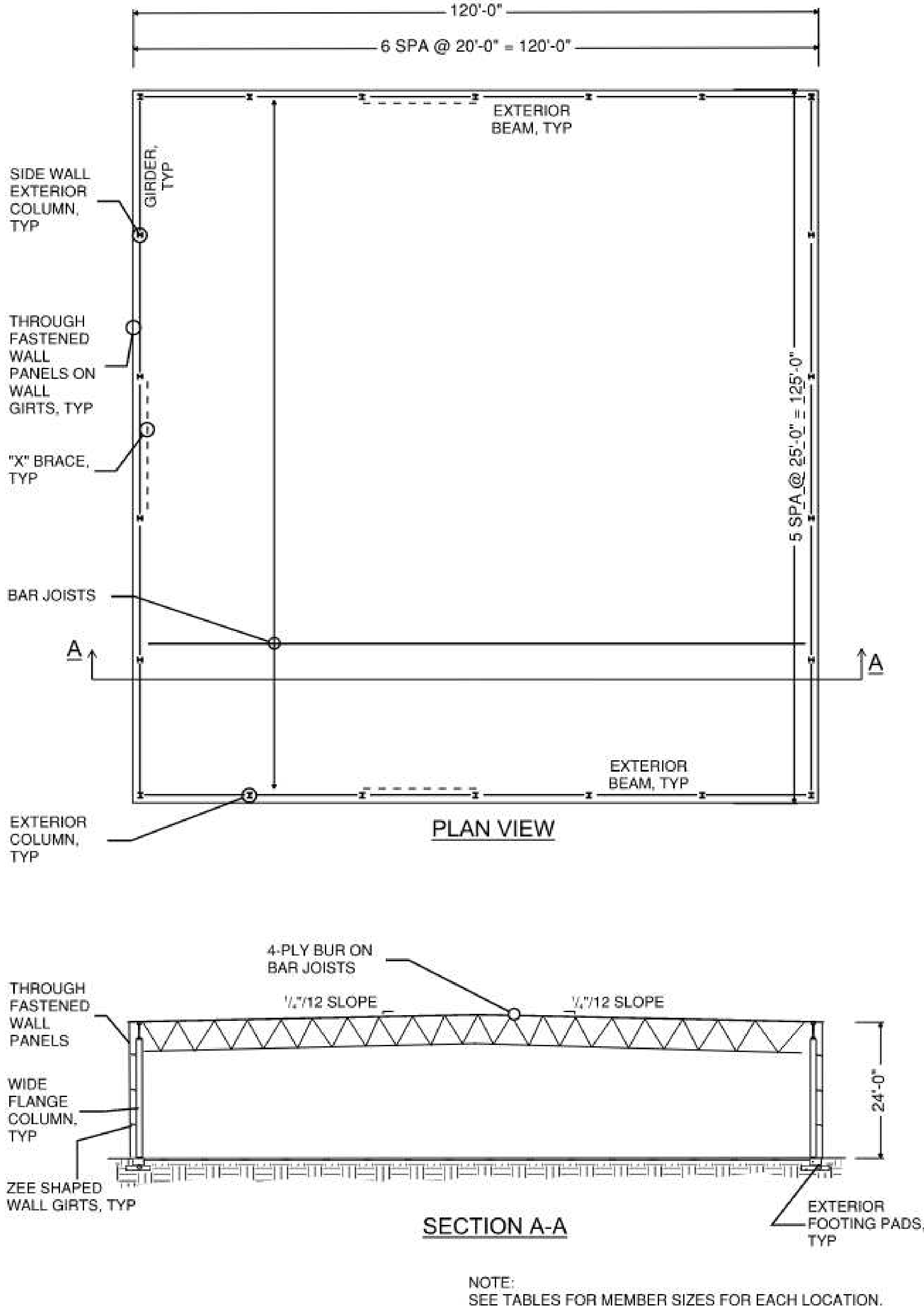
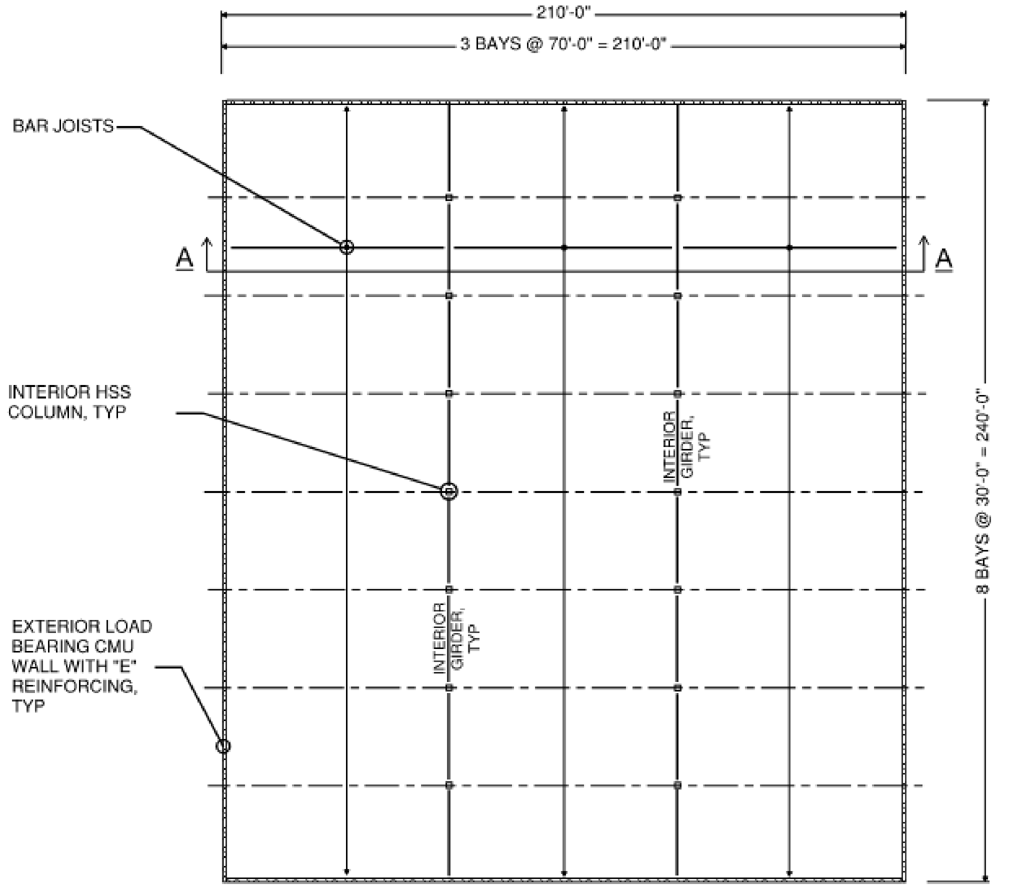
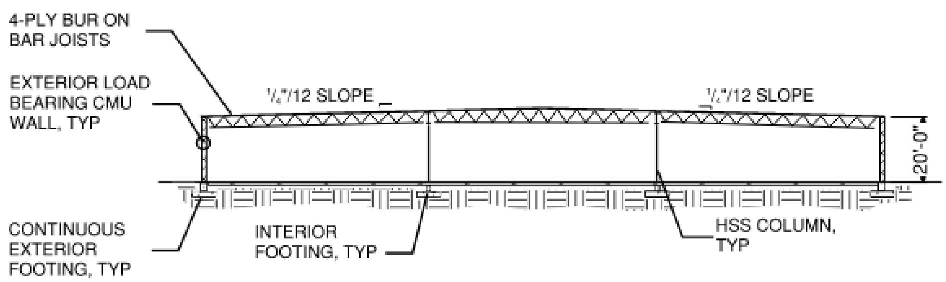


Figure 3c: Building Type 3c (Masonry Wall)



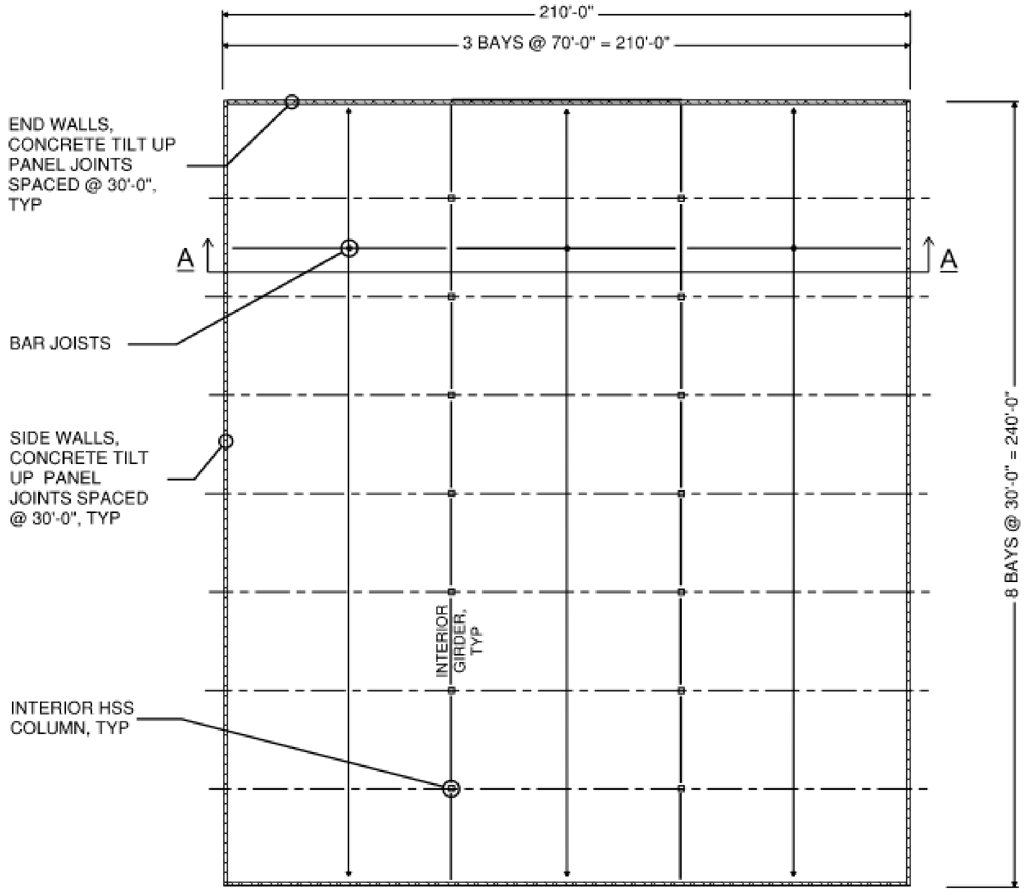
PLAN VIEW



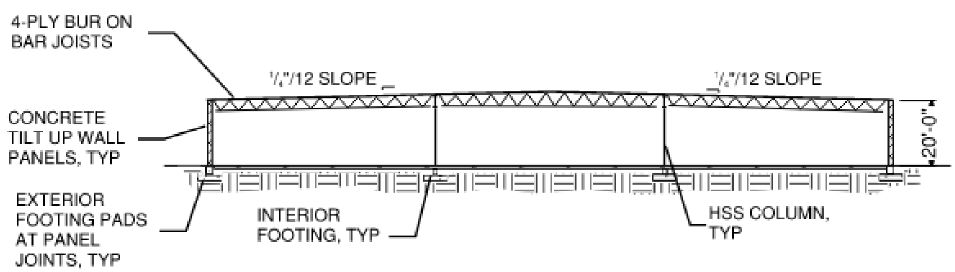
SECTION A-A

NOTE:
SEE TABLES FOR MEMBER SIZES FOR EACH LOCATION.

Figure 4c: Building Type 4c (Concrete Tilt Up)



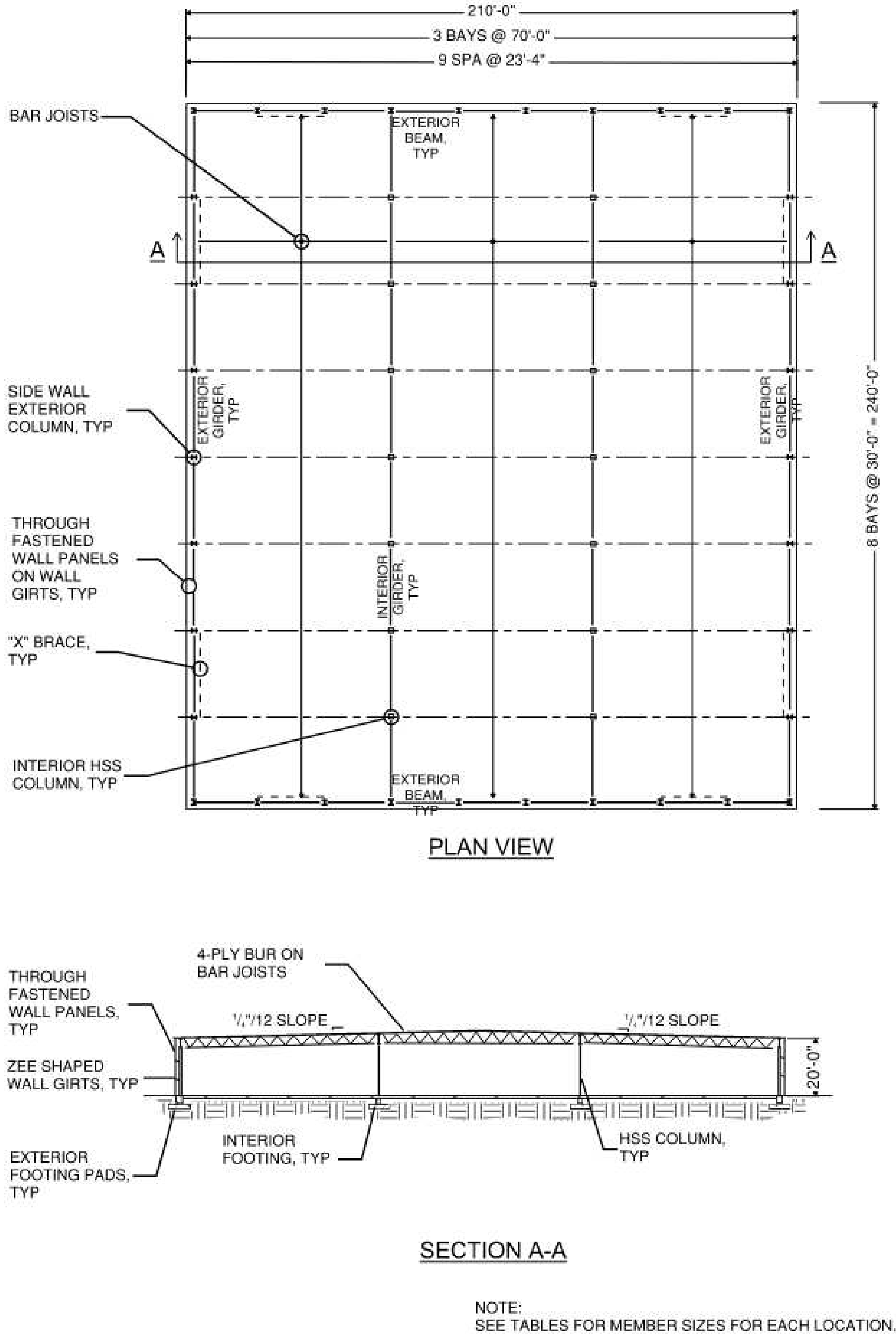
PLAN VIEW



SECTION A-A

NOTE:
SEE TABLES FOR MEMBER SIZES FOR EACH LOCATION.

Figure 5c: Building Type 5c (Conventional Steel)



Case Study A Tables of Structural Building Member Sizes

Table 5. Structural Materials for Building Type 1a

Metal Building System							
Location	Primary Framing		Column	Secondary Framing with X-Bracing		Metal Cladding	
	Size	Spacing	Interior	Roof	Wall	Roof	Wall
FL	Tapered Members	25’-0”	None	8" Purlins @ 5'-0" o.c. avg.	8" Girts @ 5'-4" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels
MN	Tapered Members	25’-0”	None	10" Purlins @ 5'-0" o.c. avg.	8" Girts @ 5'-4" o.c. avg..	24 ga Standing Seam Roof	26 ga Through Fastened Panels
CA	Tapered Members	25’-0”	None	8" Purlins @ 5'-0" o.c. avg.	8" Girts @ 5'-4" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels

Table 6. Structural Materials for Building Type 2a

Wood Framed Building			
Location	Roof Framing		Exterior walls
	Size	Spacing	
FL	Prefabricated Southern Pine Trusses	2’-0”	2x6 stud walls
MN	Prefabricated Southern Pine Trusses	2’-0”	2x6 stud walls
CA	Prefabricated Southern Pine Trusses	2’-0”	2x6 stud walls

Case Study B Tables of Structural Building Member Sizes

Table 7. Structural Materials for Building Type 1b

Metal Building System							
Location	Primary Framing		Column	Secondary Framing with X-Bracing		Metal Cladding	
	Size	Spacing	Interior	Roof	Wall	Roof	Wall
FL	Tapered Members	25’-0”	None	8" Purlins @ 5'-0" o.c. avg.	8" Girts @ 5'-4" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels
MN	Tapered Members	25’-0”	None	10" Purlins @ 5'-0" o.c. avg.	8" Girts @ 5'-4" o.c. avg..	24 ga Standing Seam Roof	26 ga Through Fastened Panels
CA	Tapered Members	25’-0”	None	8" Purlins @ 5'-0" o.c. avg.	8" Girts @ 5'-4" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels

Table 8. Structural Materials for Building Type 3b

Load Bearing Masonry Building				
Location	Joists		CMU	
	Size	Spacing	Thickness	Reinforcing
FL	60DLH13	8’-4”	10”	#4@16 EF
MN	64DLH18	6’-3”	10”	#4@24 EF
CA	60DLH13	8’-4”	10”	#5@16 EF

Table 9. Structural Materials for Building Type 4b

Concrete Tilt Up Building				
Location	Joists		Tilt Up Panel	
	Size	Spacing	Thickness	Reinforcing
FL	60DLH12	8’-4”	9 ¼”	#4@12 EF Vert / #4@12 Horz
MN	64DLH18	6’-3”	7 ¼”	#5@12 Vert / #4@12 Horz
CA	60DLH13	8’-4”	9 ¼”	#4@12 EF Vert / #4@12 Horz

Table 10. Structural Materials for Building Type 5b

Conventional Steel Building							
Location	Joists		Exterior Column		Framing		
	Size	Spacing	Side Frames	End Frames	Beam	Girder	X Brace
FL	60DLH12	6’-8”	W12x40	W10x33	W12x30	W16x36	HSS4x4x1/4 (1 Per Side)
MN	60DLH17	5’-0”	W12x40	W10x33	W12x30	W21x48	HSS4x4x1/4 (1 Per Side)
CA	60DLH12	6’-8”	W12x40	W10x33	W12x30	W16x36	HSS5.500x3/8 (2 Per Side)

Structural Material Glossary:
EF: Each Face. Vert: Vertical. Horiz: Horizontal. DHL: Deep Longspan Steel. W: Wide Flange. HSS: Hollow Structural Section.

Case Study C Tables of Structural Building Member Sizes

Table 11. Structural Materials for Building Type 1c

Metal Building System							
Location	Primary Framing		Column	Secondary Framing with X-Bracing		Metal Cladding	
	Size	Spacing	Interior	Roof	Wall	Roof	Wall
FL	Tapered Members	30’-0”	W10x45	8" Purlins @ 5'-0" o.c. avg.	8" Girts @ 6'-0" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels
MN	Tapered Members	30’-0”	W10x45	10" Purlins @ 5'-0" o.c. avg.	8" Girts @ 6'-0" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels
CA	Tapered Members	30’-0”	W10x45	8" Purlins @ 5'-0" o.c. avg.	8" Girts @ 6'-0" o.c. avg.	24 ga Standing Seam Roof	26 ga Through Fastened Panels

Table 12. Structural Materials for Building Type 3c

Load Bearing Masonry Building						
Location	Joists		CMU		Column	Framing
	Size	Spacing	Thickness	Reinforcing	Interior	Interior Girder
FL	36LH09	7'-6"	10"	#4@16 EF	HSS6x6x1/4	W18x50
MN	40LH15	7'-6"	10"	#4@24 EF	HSS6x6x1/2	W24x68
CA	36HL09	7'-6"	10"	#5@16 EF	HSS6x6x1/4	W18x50

Table 13. Structural Materials for Building Type 4c

Concrete Tilt Up Building						
Location	Joists		Tilt Up Panel		Column	Framing
	Size	Spacing	Thickness	Reinforcing	Interior	Interior Girder
FL	36LH09	7'-6"	9 ¼"	#4@12 EF Vert / #4@12 Horz	HSS6x6x1/4	W18x50
MN	40LH15	7'-6"	7 ¼"	#5@12 Vert / #4@12 Horz	HSS6x6x1/2	W24x68
CA	36LH09	7'-6"	9 ¼"	#4@12 EF Vert / #4@12 Horz	HSS6x6x1/4	W18x50

Table 14. Structural Materials for Building Type 5c

Conventional Steel Building								
Location	Joists		Column		Framing			
	Size	Spacing	Interior	Exterior	Interior Girder	Exterior Beam	Exterior Girder	X Brace
FL	36LH09	7'-6"	HSS6x6x1/4	W10x33	W18x50	W12x30	W16x36	HSS4x4x1/4 (2 Per Side)
MN	40LH15	7'-6"	HSS6x6x1/2	W10x33	W24x68	W12x30	W21x48	HSS4x4x1/4 (2 Per Side)
CA	36LH09	7'-6"	HSS6x6x1/4	W10x33	W18x50	W12x30	W16x36	HSS5.500x3/8 (4 Long Side/ 3 Short Side)

Structural Material Glossary:
EF: Each Face. Vert: Vertical. Horiz: Horizontal. DHL: Deep Longspan Steel. W: Wide Flange. HSS: Hollow Structural Section.