Design of an Educational Center for the Aldrich Astronomical Society

Major Qualifying Project

Submitted to the Faculty of

Worcester Polytechnic Institute

in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Congshan Li

Lain Zembek

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Wood Truss Design
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Advised by:

Professor Kenneth Elovitz

Abstract

This project presents the design of a STEM educational center for Aldrich Astronomical Society (AAS) at Treasure valley, Oakham, MA. The group designed a structural system, evaluated appropriate mechanical systems, and developed architectural drawings for the proposed structure. The group created the design based on specified building codes and the needs of AAS. The group focused on establishing a net zero building by assessing effective insulation, ventilation, lighting, and abate the building’s energy consumption.

Capstone Design Statement

The Capstone Design Requirement for the Architectural Engineering department at Worcester Polytechnic Institute requires that all students participate in a culminating project that brings together the knowledge learned from courses during their time with the university. To meet the capstone requirement with this project, a proposed plan for a new education center was designed for the Aldrich Astronomical Society (AAS). This design involves the assessments to achieve net zero energy production. This plan was developed through evaluating the needs of AAS while considering the efficiency and cost savings for the organization. This plan includes recommendations for a unique architectural floor plan, a durable structural system, an energy efficient insulation method, and a high-performance HVAC system arrangement. This project considered many restraints and addresses architectural, structural, mechanical, and net zero issues as follows:

Architectural: The layout of the building prevents light pollution to the star gazing field. The architectural arrangement fulfills the desires of the AAS while also addressing the International Building Code (IBC) requirements for handicap accessibility and egress.

Structural: The proposed structural system is based on the International Building Code (IBC) and American Society of Civil Engineers (ASCE) code requirements. This code guided our methods throughout the project.

Mechanical: The proposed mechanical system is based on the requirements of the International Building Code (IBC), the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), and the required values of being a net zero project.

Net Zero: With guidance from the *New Net Zero*, this project fulfills multiple requirements to be considered a net zero energy building (9)

Acknowledgements

We would first like to express our gratitude to the entire Aldrich Astronomical Society and their committee for the amazing opportunity to make an impact on such an outstanding organization. Next, we would like to thank our advisor, Professor Kenneth Elovitz, for the guidance through the project. His knowledge was instrumental in the success of this design. Finally, the successful completion of this project would not be possible without the support of Worcester Polytechnic Institute. We are grateful for the opportunity to develop our engineering skills.

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1. Introduction

The Aldrich Astronomical Society (AAS) is a club that promotes understanding of the night sky to people of all ages. The club hosts sky viewing sessions at its locations in Paxton and Oakham, Massachusetts in addition to having outreach programs for local schools and libraries. The current location in Oakham has a roll off roof observatory, outdoor pads, and several maintenance sheds. The AAS desires a space for its volunteers to participate in amateur telescope making as well as a space to host lectures.

The goal of this project is to design a state-of-art STEM (science, technology, engineering and mathematics) educational center with a parking lot and outdoor pad. The following set of objectives were developed

1. To conduct a detailed floor plan based on requirements from AAS.
2. To provide engineering system designs (structural/mechanical/architectural).
3. To achieve net zero energy.

By evaluating the site, we designed a structure to suit the club's needs. After assessing the site, we also identified energy efficient and durable systems for the club's educational center.

2. Background

2.1. Current site

The Aldrich Astronomical Society currently has an observatory in Oakham, Massachusetts. This observatory has the appearance of a shed and has a roll off roof. It sits in a four-acre field about fourteen miles outside of Worcester, Massachusetts. The reason for the location is to get away from the light pollution produced in the large city of Worcester. The observatory is currently used by members of the club, students, scouts, and the public. In addition to the observatory, the club hosts board meetings and public observing nights at Anna Maria College in Paxton, Massachusetts.

(Figure 1. Current Location of the Observatory)

2.2 Site Assessments

2.2.1. Soil Evaluation

Based on the soil report given to our group from the AAS committee, we were able to determine the soil texture in the area to be silty loam (SL). The soil was evaluated on October 14th, 2017 and measured at depths of up to ninety inches. Four measurements were taken, all at approximately 100-foot elevation. Each test consisted of three trials: zero inches to four inches deep, four inches to twenty-four inches deep, and twenty-four inches to ninety inches deep.

DH-1 OBSERVATION HOLE RESULTS ELEVATION=100.33					
DEPTH FROM SURFACE (INCHES)	SOIL HORIZON	SOIL TEXTURE (USDA)	SOIL COLOR (MUNSELL)	SOIL MOTTLING	OTHER (STRUCTURES, STONES, BOULDERS, CONSISTENCY, & % GRAVEL
0-4"	A	SL	10YR 3/4	MOTT @60"	FRIABLE
4-24"	B	SL	10YR 5/6		FRIABLE
24-80"	C	SL	2.5Y 5/4	10YR6/1 7.5Y5/4	FRIABLE

DH-1A OBSERVATION HOLE RESULTS ELEVATION=100.37					
DEPTH FROM SURFACE (INCHES)	SOIL HORIZON	SOIL TEXTURE (USDA)	SOIL COLOR (MUNSELL)	SOIL MOTTLING	OTHER (STRUCTURES, STONES, BOULDERS, CONSISTENCY, & % GRAVEL
0-4"	A	SL	10YR 3/4	MOTT @60"	FRIABLE
4-24"	B	SL	10YR 5/6		FRIABLE
24-80"	C	SL	2.5Y 5/4	10YR6/1 7.5Y5/4	FRIABLE

DH-2 OBSERVATION HOLE RESULTS ELEVATION=100.43					
DEPTH FROM SURFACE (INCHES)	SOIL HORIZON	SOIL TEXTURE (USDA)	SOIL COLOR (MUNSELL)	SOIL MOTTLING	OTHER (STRUCTURES, STONES, BOULDERS, CONSISTENCY, & % GRAVEL
0-4"	A	SL	10YR 3/4	MOTT @60"	FRIABLE
4-24"	B	SL	10YR 5/6		FRIABLE
24-90"	C	SL	2.5Y 5/4	10YR6/1 7.5Y5/4	FRIABLE

DH-2A OBSERVATION HOLE RESULTS ELEVATION=100.52					
DEPTH FROM SURFACE (INCHES)	SOIL HORIZON	SOIL TEXTURE (USDA)	SOIL COLOR (MUNSELL)	SOIL MOTTLING	OTHER (STRUCTURES, STONES, BOULDERS, CONSISTENCY, & % GRAVEL
0-4"	A	SL	10YR 3/4	MOTT @60"	FRIABLE
4-24"	B	SL	10YR 5/6		FRIABLE
24-90"	C	SL	2.5Y 5/4	10YR6/1 7.5Y5/4	FRIABLE

PARENT MATERIAL: GLACIAL TILL
DEPTH TO BEDROCK: >90"

STANDING WATER IN HOLE: NONE
WEEPING FROM PIT FACE: NONE

ESTIMATED SEASONAL HIGH
GROUNDWATER ELEVATION: 60" BELOW SURFACE

(Table 1. Soil Depth Measurements)

With this information we found through the United States Department of Agriculture that the soil density of silty loam is usually between 1.5 and 1.6 grams per cubic centimeter, which is 94 to 100 pounds per cubic foot (10). Assuming the lower value of 1.5 grams per cubic centimeter, we converted the value down to 90 pounds per cubic foot which was needed in calculations for the wall footing design. This will be further explained later in the report.

2.2.2. Landscape

In addition to a soil report, our group was given a topographic site plan of the area for the proposed design. The plan consisted of a North arrow, elevation lines, a proposed septic location, a septic system profile, and additional notes. For our design proposal, the main concerns were the elevation lines and where the most effective and efficient location for the building would be. As seen in the elevation plan in Appendix G, the site where the building is to be constructed is mostly sloped from West to East. There are existing concrete slabs and buildings at the top of the Western sloped hill, and a wetland buffer to the North end of the plan.

3. Methodology and Results

3.1 Introduction: Building Design

The AAS committee, and an architect working with them, proposed a two-story building design for the site. With a two-story design, the basement would consist of a storage room, a workshop for children, and a small garage for storing tools and utilities. However, a lift to provide handicap access to and from the basement and first floor of the building was not feasible, and an accessibility ramp indoors or outdoors would not be appropriate due to slope and distance complications.

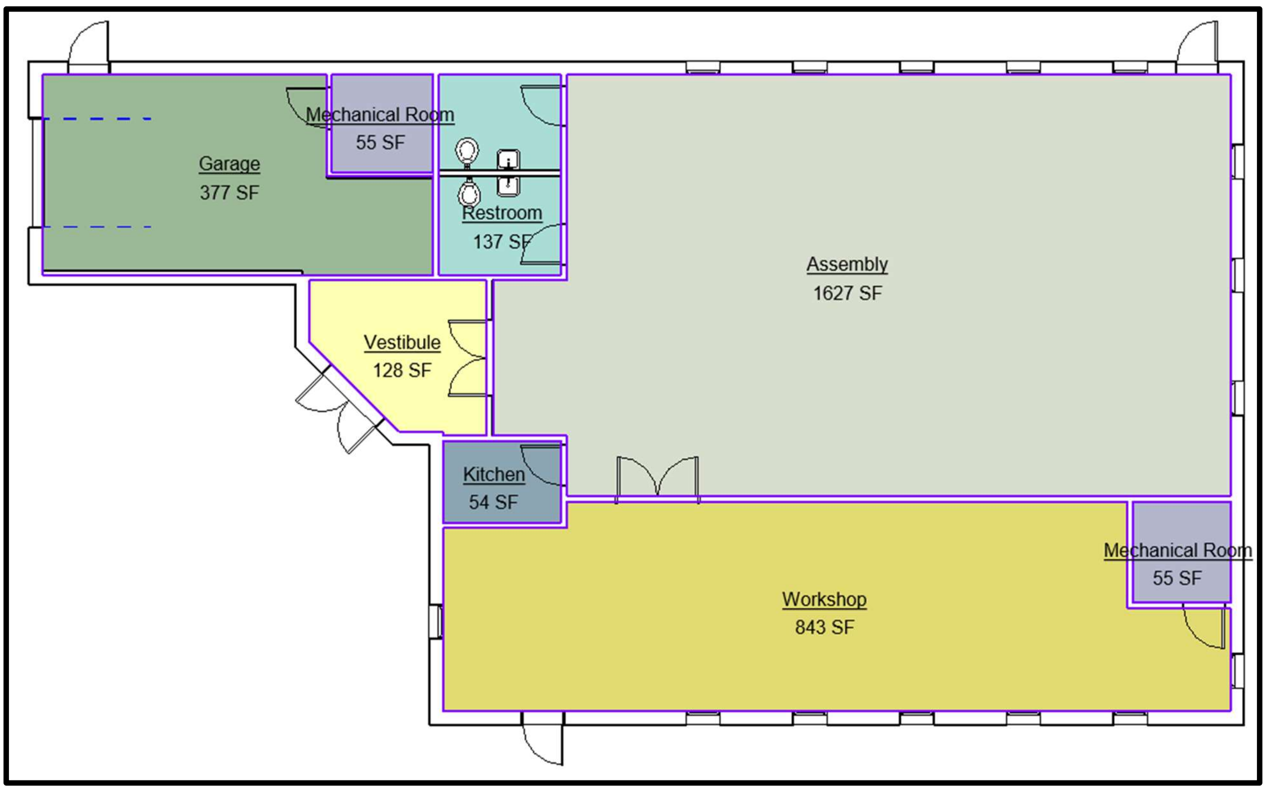
Although a one-story design would have a larger footprint than the two-story design, a one-story design meets the organization's needs for a workshop, assembly space, garage, restrooms, kitchen, and storage space. The larger footprint, however, is minimal in comparison to the four-acre site. The proposed one-story design, including the parking lot, is approximately 10,000 square feet and four acres is equal to 174,240 square feet, so in comparison the design would take up a small portion of the land. A building at the bottom of the hill at a 101-foot grade level would be away from the stargazing land and nearby wetlands. This location does present a risk of runoff water draining toward the building, however, the design would include French drains on the sides of the building to collect that water and steer it away from the building. Figure 2 shows the proposed building location on the site plan.

(Figure 2. Proposed Building Location)

3.2 Architectural Design

3.2.1 Considerations

As previously mentioned, AAS needs a workshop, assembly space, garage, restrooms, kitchen, and storage space included in the design. Our proposal, taking these considerations into account, fulfills the needs of the organization and will allow their building to operate at a high level of efficiency. In figure 3, each space is labeled with its square footage. The proposed assembly location is the main space in the building. The main entrance accesses the assembly space directly, and from that area, the restrooms, kitchen, and workshop can be accessed. The garage/storage space is accessed from either the garage door or a door on the back side of the building. AAS also requested the building to block light from incoming traffic so that it does not interfere with stargazing activity. The proposed plan includes a parking lot that will be blocked by the building and prevent light pollution to the stargazing sessions. Our design proposal also took into consideration accessibility needs for those visiting the building and provides ready to each space as well as to the back of the building where the stargazing sessions occur.



(Figure 3. Proposed Architectural Layout)

3.2.2. Layout

As previously mentioned, our group determined a one-story design to be more practical for the landscape. As discussed with AAS, the building must include an assembly space, storage space, a workshop, restrooms, a kitchenette, and a garage. In figure 3, the proposed layout to include those areas effectively is drawn. Figure 2 shows the lot on the Southeast side of the building with an approximate 6,000 square foot area, twenty parking spaces of approximately 300 square feet each, that would be for parking. The area for the parking lot slopes from the 101-foot grade level to a 99-foot level on the South end of the lot. This slope would be taken advantage of by inserting a catch basin at the South end of the lot with a one-eighth inch per foot sloped pavement from the sidewalk of the building to the catch basin making it a total drop near one foot. The garage is at the West end of the lot with a garage door that faces South away from the Northwest stargazing field. This will block light interference with stargazing. The main entrance is at an angle tucked between the garage and the workshop extension of the building. When walking through the main entrance the two restrooms will be on the left and the small kitchenette on the right. The main space of the building is an assembly area for the teaching sessions hosted by the AAS. After walking in the main entrance, on the right will be a door to enter the workshop area. This layout of the workshop and restrooms allows easy access for those in need.

3.2.3. Lighting

3.2.3.1. Exterior Lighting

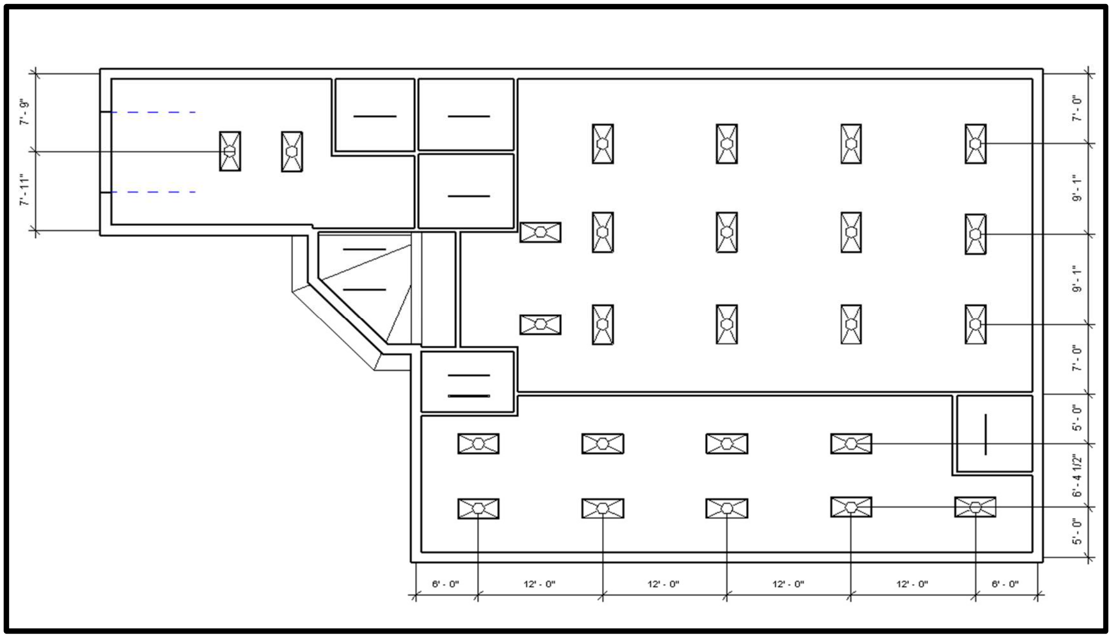
The intention with our proposed design is to use the property year-round and at any time of the day. Our goal is to make this a net zero building, and to produce no light pollution, especially any light interference to the stargazing field. Based on these considerations, we defined our choices for lighting. Starting with the parking lot, visitors are going to need to see where to park and be able to get to and from their vehicles safely. A recommended quantity of lights for this parking lot would be two poles spaced twenty feet apart at sixteen feet high each producing at least 20,000 lumens (7). The light that best suits these recommended numbers is a LED Way Series Outdoor Street Light, which can be seen as Fixture C in Appendix A. The building is approximately twenty feet high, so the lights would be blocked if viewing from the stargazing field. To confirm that the lights will not affect the field, the lights can be directed Southeast, or they can have a glare shield attached to avoid visual interference. When entering the building through the main entrance, the two adjacent walls could include LED wall mounted lights to produce a safe, lit entrance for visitors. The LED wall mounted fixtures produce an average of 1,000 lumens. After providing a safely lit path to the entrance, the next important step is to continue the energy efficient lighting throughout the interior.

3.2.3.2. Interior Lighting

In our proposed design we used two different types of lighting fixtures for the interior, as well designing for the effective use of daylight. The design consists of an open ceiling with exposed ductwork, and with an open ceiling, there is a larger amount of space for natural light to travel. Our roof insulation design is concluded with a reflective material that will allow for infiltrating daylight to reach every corner of the space. Even with a design based purely on daylight, the building still needs artificial light for the anticipated occupied hours when daylight is not available.

The lighting fixtures that we chose are all surface mounted LED lights. LED lights are more energy efficient, won't be affected by rapid cycling, and have a long lifespan that would result in low maintenance fees (15). They also produce less heat than fluorescent lights, which will decrease the cooling load in the summer.

In the lighting plan below, the fixture proposed for the restrooms, mechanical rooms, and vestibule has a value of 3,000 lumens per fixture, and the fixture proposed for the assembly space, the workshop and the garage has a value of 4,800 lumens per fixture. See spec sheets in Appendix A for further explanation.



(Figure 4. Lighting plan)

Based on the light level requirement for each room shown in table 1 below, we were able to calculate how many fixtures are needed in each room. In order to calculate the number of fixtures needed in each room, we used the equation below where A is the total room area in square feet, E is the designed foot-candles, L is the initial luminous flux, CU is the coefficient of utilization, and LLF is the lighting loss factor.

$$Number\ of\ fixtures = \frac{A * E}{L * CU * LLF}$$

The initial luminous flux can be found from the spec sheet of the lighting in Appendix A. The coefficient of utilization depends on the space to be illuminated, but in this case equals 80%. The light loss factor is also 80% in this case.

	Garage	Vestibule	assembly	work shop	Restroom	Kitchen	Mechanical room
Floor Area (sf)	374	128	1627	841	137	54	128
Lighting - Design footcandle	15	30	25	30	25	40	15
Light Loss Factor	0.8	0.8	0.8	0.8	0.8	0.8	0.8
CU	0.8	0.8	0.8	0.8	0.8	0.8	0.8
lumens needed	8765.63	6000.00	63554.69	39421.88	5351.56	3375.00	3000.00
fixture lumen	4800.00	3000.00	4800.00	4800.00	3000	3000	3000
# fixture needed	**2**	**2**	**14**	**9**	**2**	**2**	**1**
fixture watts	45	27	45	45	27	27	27
BTUHs	282.6	169.56	1978.2	1271.7	169.56	169.56	84.78

(Table 2. Number of Light Fixtures)

3.3 Structural Design

3.3.1. Roof

3.3.1.1. Roof Material

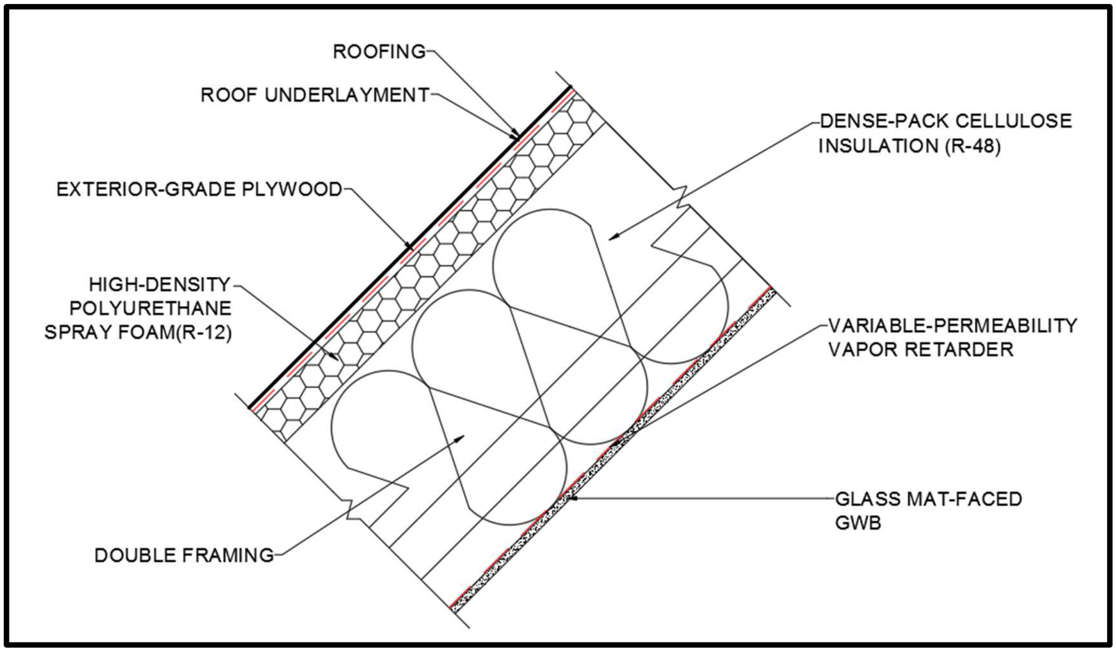
When searching for an effective, high performance design for the roof, materials were the first step. Our choice of material focused primarily on life expectancy and first cost. The materials that were analyzed were asphalt shingles, a common material used on homes, and aluminum standing seam metal roofing, a slightly more expensive alternative.

Asphalt shingles appeared to be a lower cost material, with reasonable wearability, and they typically have a thirty-year warranty. They also have fire retarding properties and are available in different styles, sizes, and colors which is helpful for consumer preferences. Shingles are also easy to install, however, they do have some drawbacks. Asphalt shingles tend to lose surface material and will eventually wear out. Using shingles can also allow for leaks and damage to the roof insulation (12). Although shingles are effective against weather, issues can occur which will cause damage to the inner layers of the structure.

Aluminum standing seam roofing is a cost-effective material with durable properties. Standing seam metal roofing has the advantage of fewer seams, as opposed to aluminum shingles and the grandetile method, which is usually where moisture issues occur in roofing, and the seams are raised above the level of the roofing panel eliminating water getting into the seam. Another advantage of this type of roofing is the durability. The tough, durable properties allow for the roofing system to have a lifetime between thirty to fifty years (13). Even though the metal roofing is more expensive, it is the more cost-effective option.

3.3.1.2. Roof Insulation

Following the metal roofing cover is the layering of insulation. The focus of the roof insulation was to achieve a net zero R-value of 60 while keeping any moisture from affecting the layers. Below the metal roofing are sheets of zip-system plywood, followed by a layer of closed cell spray foam. The closed-cell spray foam will prevent any vapor or water leakage coming through the roof from reaching the interior cellulose layer. Since cellulose is not a vapor barrier and absorbs water, it must be protected. The choice of using cellulose is based on its cheap cost and insulating ability. Following the cellulose is a vapor retarder to prevent rising moisture inside the building from affecting the insulation. Finally, the last section of the roof insulation is glass mat wallboard. This material provides an attractive cover and support for the insulation.

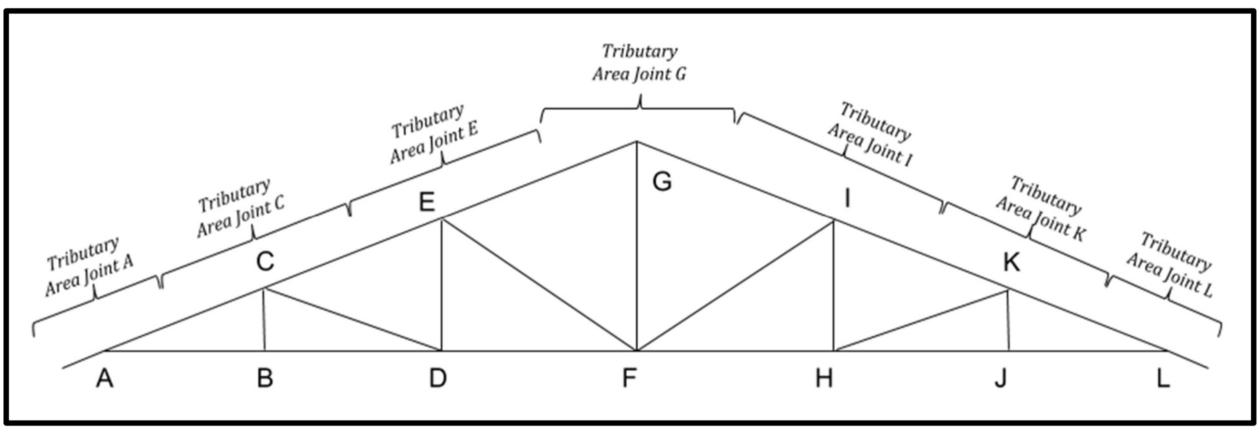


(Figure 5. Roof Section View)

3.3.1.3. Truss Analysis

The roof truss will carry the loads on the building and divert those loads to the exterior walls, creating column-free internal space and reduce the construction cost time because trusses can be prefabricated and delivered to the site. Based on the layout of the walls in our architectural drawings, the span of the roof must cover fifty-one feet in order to have a one-foot overhang on each side. The width of the truss, however, is forty-nine feet because the overhang on each side is on the eave of the roof. With the goal of achieving column-free space, our group did some research on which type of truss could span this width and still perform the stability needed. The howe truss is used mostly in construction for longer spans of up to 60 feet rather than regular king post truss, so this was the viable option for our design. By having a truss that can span a long distance, we achieved our goal of column-free space. Eliminating column supports saves on additional spending, as well as creating a more open space for the organization and allowing for obstacle-free sight lines for presentations and flexibility with the furniture layout.

A wall separating the assembly area from the workshop provides an optional point to add stability to the truss. Even though the wall provides additional stability, the group designed the truss based on a forty-nine-foot span because calculations showed that the load bearing wall would not add much additional support. Refer to Appendix B for further explanation. To determine the loading on the roof, our group first evaluated the tributary area on each joint of the roof face. The tributary area is a distance halfway to each joint surrounding it, or in the case of an end joint it would be halfway to the next joint. The distance between A and C, and the other corresponding joint spans at an angle are 9.13 feet, but the one-foot overhang on the eave must be considered for the tributary area for the end joints. The distance between A and B, as well as the other five spans on the bottom of the truss, is 8.17 feet. In figure 6, the additional support wall is located between joint F and H at a distance 32.42 feet from A and 16.58 feet from L. Since the truss is symmetrical, the tributary area for point A and L are equal, the tributary area for point C and K are equal, and the tributary area for point E and I are equal.



(Figure 6. Tributary Area for Truss Nodes)

3.3.1.3.1. Dead Load

The dead load acting on the roof is calculated by adding the weight of the metal roof and the weight of the plywood that connects the truss to the metal roof. The average weight of plywood and metal roofing is 2 pounds per square foot and 0.67 pounds per square foot, thus we determined the dead load to be 2.67 psf.

3.3.1.3.2. Live Load

Based on the International Building Code, we determined the live load acting on the roof to be 100 pounds per square foot (IBC 2015, Table 1607.1).

3.3.1.3.3. Snow Load

In order to calculate snow load for a sloped roof p_s , we needed to use the following equations and chapter 7 of the ASCE to define the following factors.

Flat roof snow load $p_f = 0.7 * C_e * C_t * I * p_g$

Sloped roof snow load $p_s = C_s * p_f$

Factors	Meaning	ASCE	Value
C_e	exposure factor	Chapter 7: Table 7-2	1
C_t	thermal factor	Chapter 7: Table 7-3	1
p_g	ground snow load	Chapter 7: 7.2	50 psf
I	Importance factor	Chapter 7: 7.3.3	1
C_s	snow load factor	Chapter 7: Figure 7.2-a	0.4

(Table 3. Snow Load Factors)

$$p_f = 0.7 * 1 * 1 * 50 * 1 = 35\, psf$$

$$p_s = 0.4 * 35 = 14\, psf$$

3.3.1.3.4. Wind Load

In order to calculate the design wind pressure p, we needed to use the following equations and chapter 7 of the ASCE to define the following factors:

Velocity pressure coefficient $q_z = 0.00265 * k_z * k_{zt} * k_d * V^2 * I$

Design pressure $p = q_z * G * C_p$

Factors	Meaning	ASCE	Value
G	Gust effect factor	Chapter 6.5.8.1	0.85
V	Wind speed	Chapter 6.5.11	90 mph
k_z	Velocity pressure exposure coefficient	Chapter 6.5.6: Table 6-3	0.85
k_{zt}	Topographic factor	Chapter 6.5.7.2	1
k_d	Wind direction factor	Chapter 6.5.4.4	0.85
I	Category I	Chapter 6.5.11.2.1	1
C_p	windward	Chapter 7.6.17	0.2
	leeward	Chapter 7.6.17	0.4

(Table 4. Wind Load Factors)

$$q_z = 0.00265 \; * \; 0.85 \; * \; 1 \; * \; 0.85 \; * 90^2 * 1 = 14.9 psf$$

$$p = 14.9 psf \; * 0.85 \; * \; 0.2 \; = \mathbf{2.5}\, \boldsymbol{psf\ windward\ side}\ (\boldsymbol{West})$$

$$p = 14.9 psf \; * x 0.85 \; * \; 0.4 \; = \mathbf{5.1}\, \boldsymbol{psf\ leeward\ side}\ (\boldsymbol{East})$$

3.3.1.4. Load Calculation

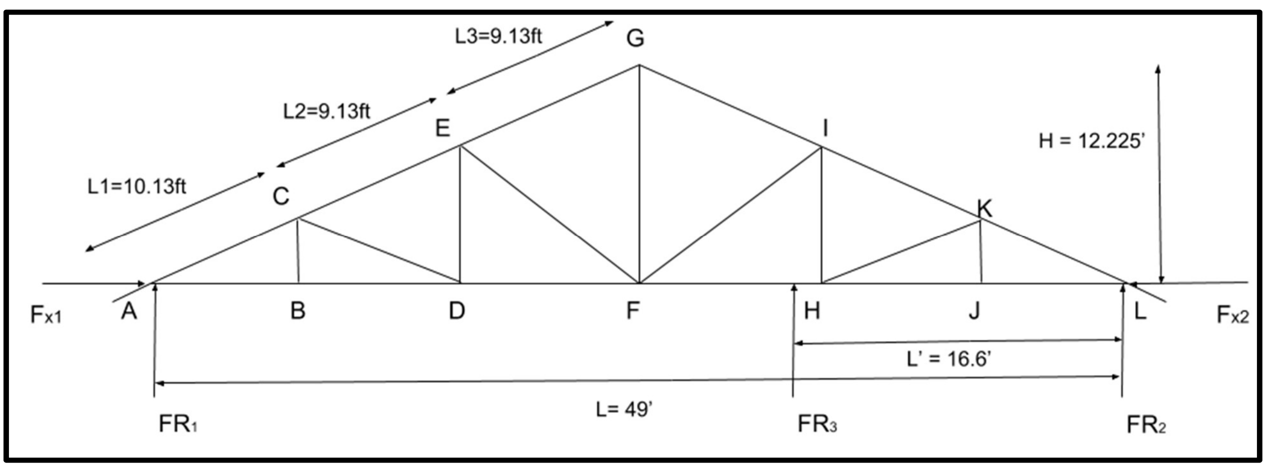
Type of Load	
Dead Load	2.67 psf
Live Load	100 psf
Snow Load	14.9 psf
Wind load	2.5 psf from the West side 5.1 psf from the East side (Assume a wind load of 6 psf)

(Table 5. Resultant Loads)

We calculated the resultant load force R_F by adding all the loads above.

$$R_F = Dead\ Load\ +\ Live\ Load\ +\ Snow\ Load\ +\ Wind\ load\ = 2.67 + 100 + 14.9 + 6 = \mathbf{123.57\ psf}$$

Then, we calculated the force acting on each point of the truss. Since the truss is symmetrical, the force acting on points A and L are equal, the force acting on points C and K are equal, and the force acting on points E and I are equal. The force is calculated by the following equation where A_T is the tributary area: $F = R_F * A_T$



(Figure 7. Dimensions of Truss)

Point	Tributary Area
A and L	$\frac{L1}{2} * distance\ between\ trusses$=5.065*6=**30.39 ft^2**
C and K	$(\frac{L1}{2}+\frac{L2}{2}) * distance\ between\ trusses$= 9.63*6= **57.78ft^2**
E and I	$(\frac{L2}{2}+\frac{L3}{2}) * distance\ between\ trusses$= 9.13*6= **54.78ft^2**
G	$(\frac{L3}{2}+\frac{L3}{2}) * distance\ between\ trusses$= 9.13*6= **54.78ft^2**

(Table 6. Tributary Area)

Point	Force on Each Point
F_A=F_L	$R_F * A_T$= 122.67*30.39**=3727.94 lb**
F_C=F_K	$R_F * A_T$= 122.67*57.78=**7087.87 lb**
F_E=F_I	$R_F * A_T$= 122.67*54.78=**6719.86 lb**
F_G	$R_F * A_T$= 122.67*54.78=**6719.86 lb**

(Table 7. Force on Each Point)

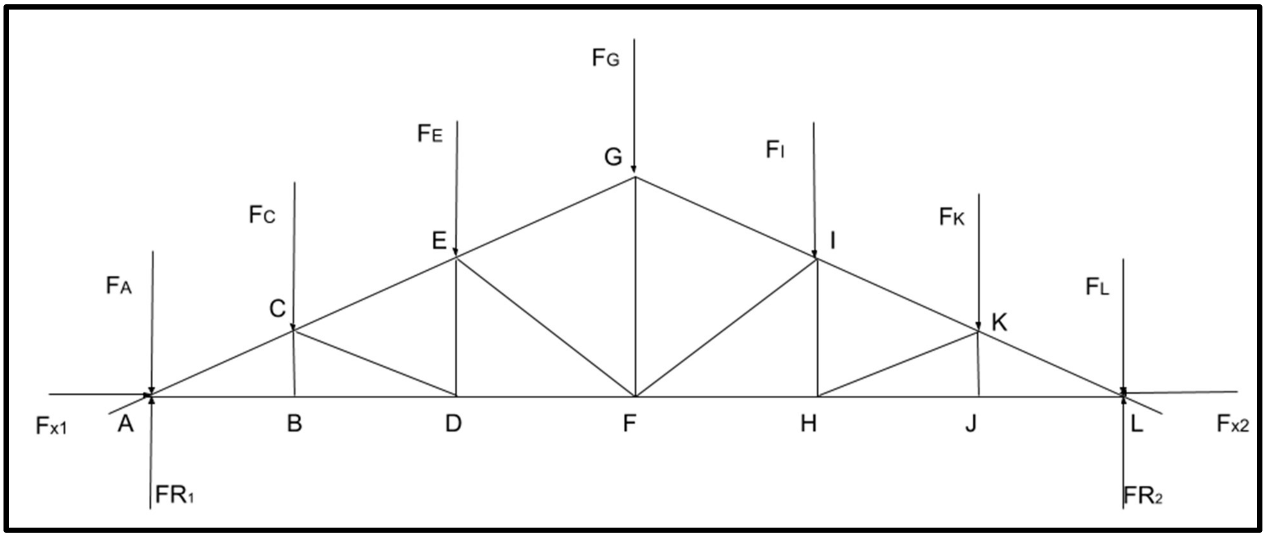
We then calculated the resultant force FR . Originally, there were three resultant forces since our interior wall could be considered a load bearing wall, however, the answer from the calculation shows that the load FR_3carried is so insignificant compared to FR_1 and FR_2, and the exterior load bearing walls would provide enough support, so we made the interior wall no longer load bearing. This can be seen in figure 8.

$\sum F_y = 0$, refer to Appendix B for explanation of calculations.

$$FR_1 = FR_2 = ½ \sum F_y = ½ (F_A + F_C + F_E + F_G + F_I + F_K + F_L) = \mathbf{20895.6\ lb}$$

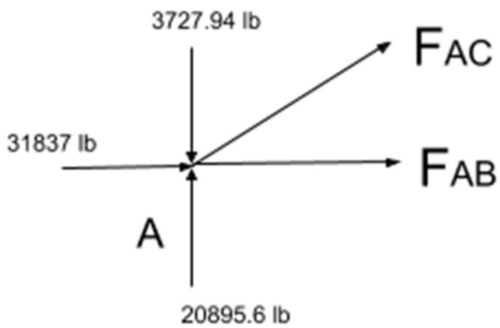
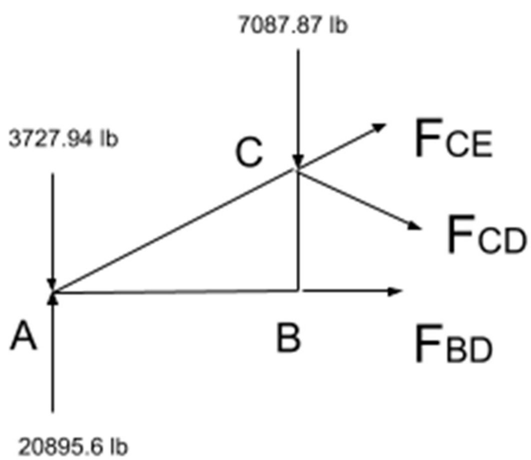
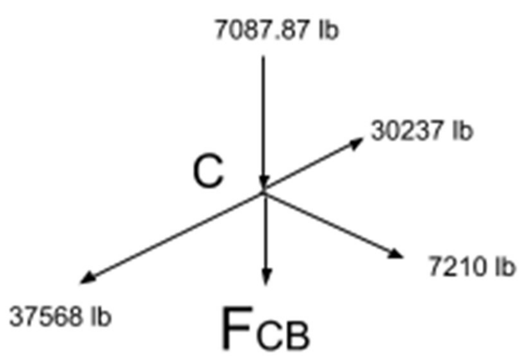
$\sum M_E = 0$ and $\sum M_C = 0$, refer to Appendix B for explanation of calculations.

$$Fx_1 = Fx_2 = \mathbf{31837\ lb}$$



(Figure 8. Force on Each Point)

3.3.1.5. Forces on the Truss Members

<table>
<tr><th>Section</th><th>Member</th><th>Force
(T) Tension
(C) Compression</th></tr>
<tr><td rowspan="2">
</td><td>F_{AC}</td><td>37568 lb (C)</td></tr>
<tr><td>F_{AB}</td><td>2122 lb (T)</td></tr>
<tr><td rowspan="3">
</td><td>F_{CD}</td><td>7210 lb (C)</td></tr>
<tr><td>F_{BD}</td><td>2180 lb (T)</td></tr>
<tr><td>F_{CE}</td><td>30237 lb (C)</td></tr>
<tr><td>
</td><td>F_{CB}</td><td>376 lb (C)</td></tr>
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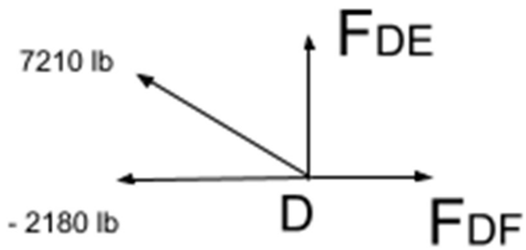
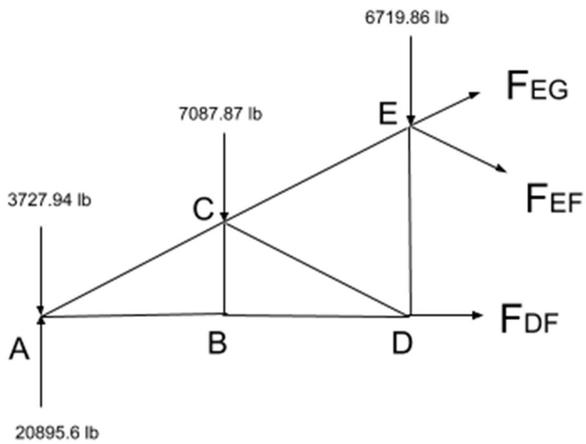
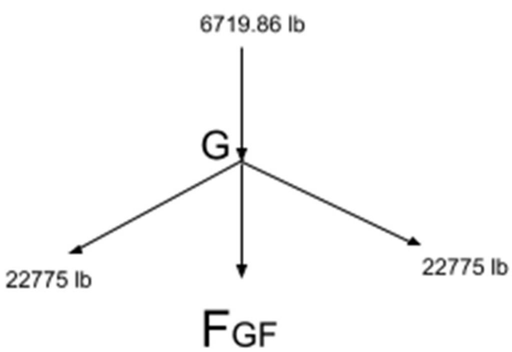
<tr><td rowspan="2">
</td><td>F_{DE}</td><td>3116 lb (T)</td></tr>
<tr><td>F_{DF}</td><td>4308 (C)</td></tr>
<tr><td rowspan="3">
</td><td>F_{EG}</td><td>22775 lb (C)</td></tr>
<tr><td>F_{EF}</td><td>9265 lb (C)</td></tr>
<tr><td>F_{DF}</td><td>4308 l (C)</td></tr>
<tr><td>
</td><td>F_{GF}</td><td>13319 (T)</td></tr>
</table>

(Table 8. Forces of Each Member)

3.3.1.6. Member Stress

To calculate the stress, we used the stress formula $\sigma = F/A$, where F is the member force and A is the area of the member.

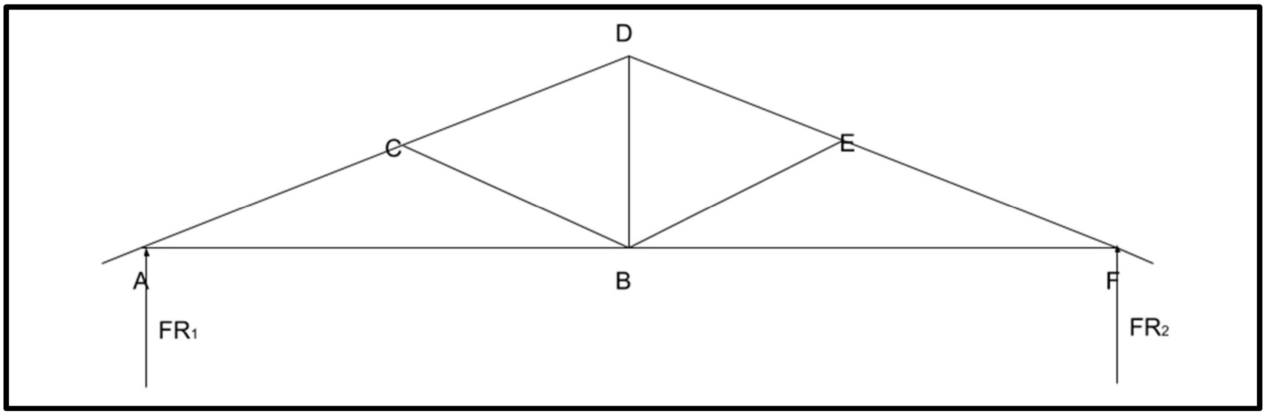
Member	Member Force	Force: (T) Tension (C) Compression	Base (in)	Height (in)	Area (in^2)	**Stress (psi)**
FAC	37568	C	4	12	48	**782.67**
FAB	2122	T	4	12	48	**44.21**
FCD	7210	C	4	12	48	**150.21**
FBD	2180	T	4	12	48	**45.42**
FCE	30237	C	4	12	48	**629.94**
FCB	376	C	2	6	12	**31.33**
FDE	3116	T	2	6	12	**259.67**
FDF	4308	C	4	12	48	**89.75**
FEG	22775	C	4	12	48	**474.48**
FEF	9265	C	4	12	48	**193.02**
FDF	4308	C	4	12	48	**89.75**
FGF	13319	T	4	12	48	**277.48**

(Table 9. Member Stress)

We assumed the use of douglas fir, and according to the National Design Specification, the strength in tension parallel to grain F_T is 1750 psi, and the strength in compression parallel to grain F_C is 2725 psi. Our stress value is below the allowable stress, so our design is safe.

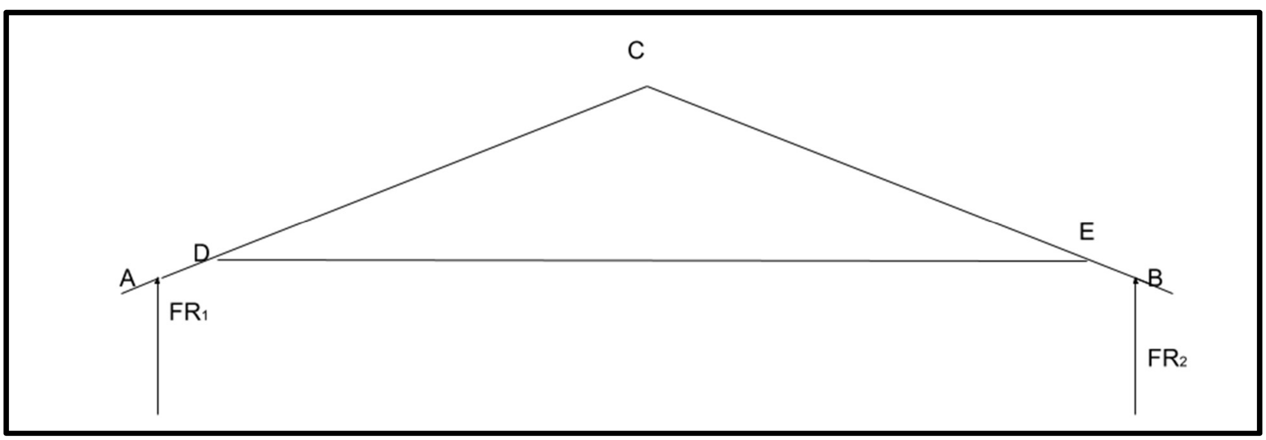
3.3.1.7. Truss for Garage

After analysis of the truss for the main building, we did some research in order to find the best option for our garage roof. One option was to do a queen post truss shown in figure 9. A queen post truss has two supporting posts and can support a span up to 20 feet. Since the span is much shorter, the simple and less expensive queen post truss is sufficient.



(Figure 9. Queen Post Truss)

Another option was to do a rafter tie support instead of a truss, which is shown in figure 10. A rafter tie is a tension tie, and usually installed in the lower third of the opposing gable rafters (2), which helps resist the exterior wall from spreading due to the weight on the roof.



(Figure 10. Rafter Tie)

We repeated the calculation above to find out if the rafter tie would provide enough support. See Appendix C for calculations. After the calculation, we decided to use rafter tie support for our garage, because it eliminates the need for more lumber, offers a sufficient amount of support, and offers a cost-effective solution.

3.3.2. Wall System

3.3.2.1. Wall Design

The proposed wall design is a double stud system using staggered 2x4 wood studs on a twelve-inch plate. The entire framing system of the wall is composed of 2x4 lumber with additional ties and fasteners for extra support. The reason for the decision to use double stud was based on the goal of achieving net zero. In order to achieve net zero, our wall design needed an R-value of at least 40. By using a double stud system, there is an increased amount of space for additional insulation. The more insulation, the greater the thermal performance of the wall, which then allows the R-value to reach the value of at least 40. With the double stud design, we had the option of using conventional stud or alternating stud. The reason we chose the alternating stud method is because of the soundproof advantage as well as the elimination of any infiltration through simultaneous studs if it were conventional. Our design proposes a twelve-inch gap between each set of studs with sixteen inch spacing on center between studs along each wall. The twelve-inch gap allows for a larger layer and higher performance from the insulation. Of course, this is all based on the type of insulation selected for the wall.

3.3.2.2. Insulation

When determining the most effective type of insulation, we needed to focus on the R-value, but also consider the prevention of any wind, air, or vapor penetration. In table 9 below is a list of the types of insulation considered for this design. We first evaluated the types of insulation and the properties of each, which are shown. In addition to the comparison laid out in the table, we used some guidance from the *New Net Zero* by William Maclay. In the book, specifically the design of the education center, we were able to visualize an example of what layout is most efficient and qualifies to be net zero.

Type of Insulation	R-Value (per inch)	Air Barrier	Vapor Retarder	Absorbs Water	Price per square foot
Cellulose	3.5-4.0	N	N	Y	$0.50
Spray Foam: Closed Cell	6.0-6.5	Y	Y	N	$1.50
Spray Foam: Open Cell	3.5	Y	Y	N	$1.20
Rockwool	3	N	N	N	$0.62
Fiberglass	3.5	N	N	Y	$1.20
XPS Foam Board	5	Y	Y	N	$1.10

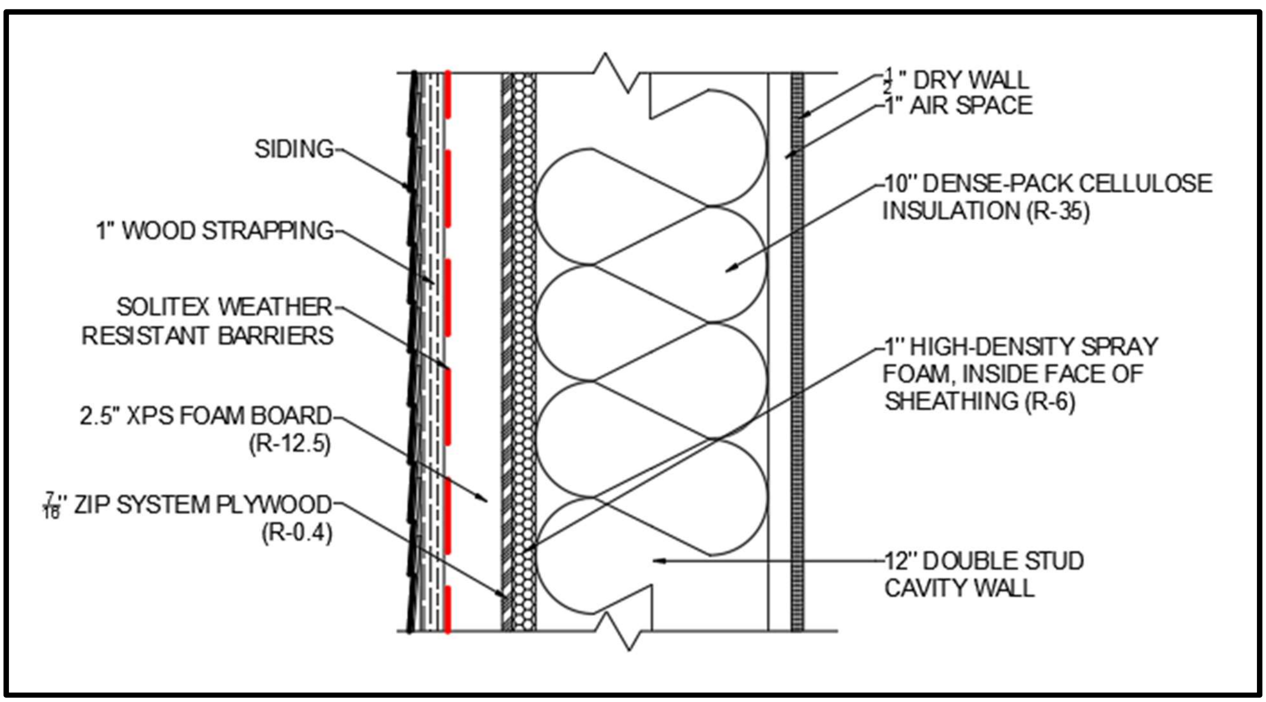
(Table 10. Insulation Matrix)

In the book, Maclay uses cellulose as his thickest layer of insulation which inspired our decision to choose cellulose, despite its lack of barrier properties and the fact it absorbs water. The benefits of using cellulose are its very affordable pricing, high R-value, and ability to reach small corners and other hard-to-reach places. In addition to the inspirations of the book, we analyzed section views from double stud walls and saw the use of XPS foam board with a solitex barrier on the exterior side of the wall. The foam board is a high R-value product with air and vapor resistive properties. By including the solitex barrier over the foam board, this confirms no penetration of water vapor and acts as an airtight barrier. In addition to solitex and the foam board, spray foam was another choice of insulation to include in the design. The reason for the selection of spray foam is also because of its air and vapor retardant properties. Spray foam applied to the interior side of the wall keeps any moisture on the outside of the wall from affecting the materials on the inside. Spray foam is also a type of insulation that can be effectively applied to small spaces, like that of cellulose.

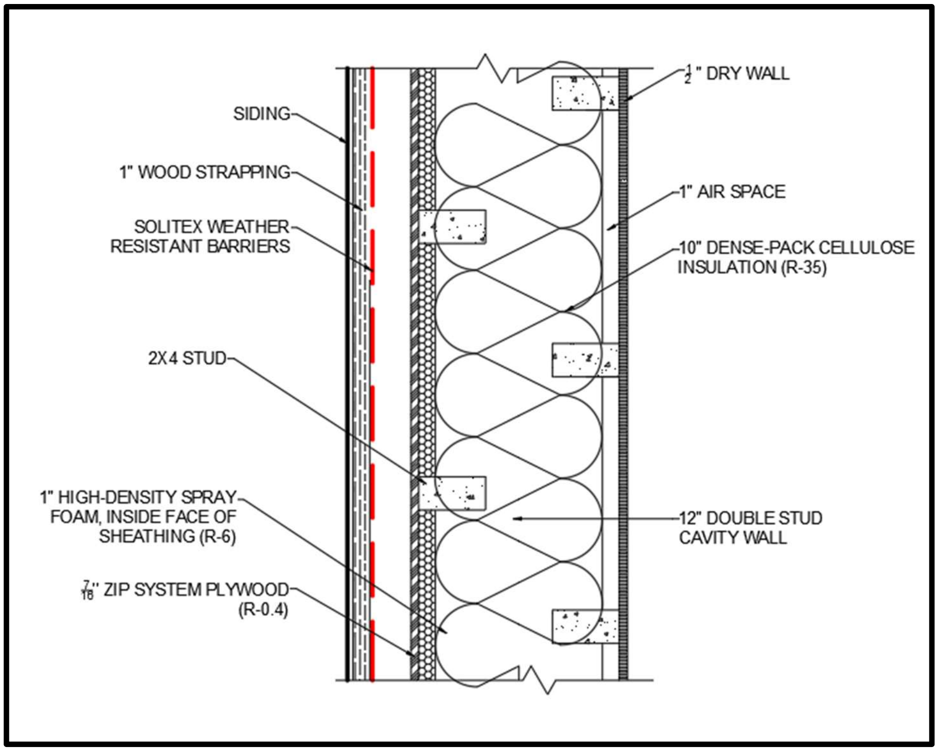
The total R-value of the wall is 40.5. It appears as though the wall should have a higher insulation performance because of the ten inch section of cellulose with an R value of 35, the coating of spray foam at R-6, and then the R-12.5 of XPS foam board, however, due to the arrangement of insulation being in both series and parallel with the alternating double studs, the average R-value of the twelve inch gap is 28. Since the R-value is expressed in units of $\frac{F^{o} ft^{2} hr}{BTU}$ and the studs are spaced sixteen inches apart, the value of each section of insulation is averaged out and then divided by sixteen inches to get an R-value of 28 per foot of insulation, which is the thickness of the double stud wall. With the average value of 28 and the R-value of 12.5 for the exterior XPS foam board, the total value for the wall is 40.5. See appendix E for further explanation.

3.3.2.3. Wall Arrangement

With the various types of insulation previously discussed, it was important to organize them in the most efficient order possible. Using the information from the New Net Zero, we organized our insulation choices in the following order seen in figure 11 and 12. Starting from the inside we have drywall with a one-inch air gap. The reason for the air gap is to allow for any electric wiring to be installed. After the air gap, the ten inches of dense pack cellulose starts. The reason for the cellulose being at this location is due to the distance away from the exterior vapor threat. Following the cellulose is a layer of closed-cell spray foam. It is following the cellulose so it can secure the cellulose layer from any water penetration. The spray foam is the last section before the layer of plywood, which is then succeeded by the exterior arrangement of the envelope. The zip system plywood was chosen because of its built-in vapor permeable water-resistive barrier. This eliminates the hassles of house wrap and felt. It was designed with optimal permeability to allow water vapor to pass through and promote drying of the material. The arrangement of exterior layers first includes a section of XPS foam board insulation, this is due to the New Net Zero recommendation of having roughly one third of the insulation on the exterior of the wall. The XPS foam board offers weather resistance, but more importantly has a very high R-value. To seal the XPS foam board and affirm the wall is airtight, the insulation layers are concluded with a roll of solitex weather barrier. Over top of the solitex barrier is a coating of wood strapping, which is necessary for the succeeding arrangement of siding to be secured to the building.



(Figure 11. Wall Section View)



(Figure 12. Wall Top View)

3.3.3. Slab

The proposed slab is a six-inch, slab on-grade design. The six inches of concrete, succeeded by six inches of stone, is for both the garage region and the main assembly and workshop portion. Included in the concrete slab is a layer of wire mesh for additional support within the concrete and to help prevent cracking. The reason for the selection of a slab on-grade design, as opposed to a design with a crawlspace, is to prevent any growth of mold or moisture build-up that could affect the slab and cause cracking. By using the slab on-grade method, we are preventing instability within the floor space (T. Donovan, personal communication, February 5, 2019). With our proposed design, however, came the addressing of energy efficiency. To make the slab design energy efficient, we incorporated rigid insulation between the foundation wall and the slab, as well as a layer outside the foundation wall, to block heat gain during the summer months and prevent heat escape during the winter months. By keeping the slab at the relatively same temperature year-round, this will avert cracking in the slab that can occur from constant temperature change. Refer to figure 13 for a visual perception of the proposed design.

(Figure 13. Insulated Frost Wall Design (6))

3.3.4. Foundation

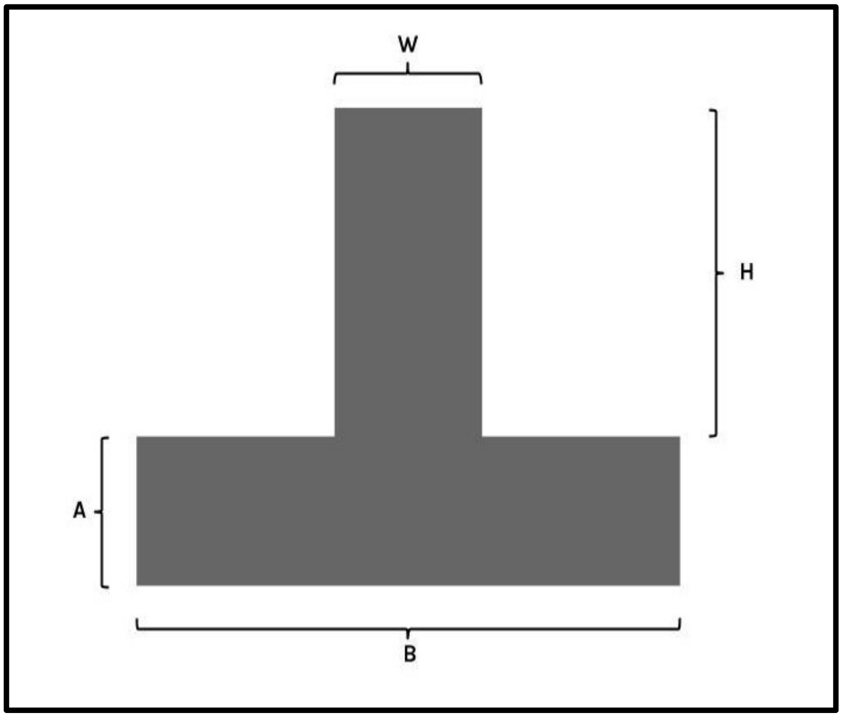
To design the foundation, the soil must first be evaluated, and the loads of the overall building must be known. When calculating our specific design, we first evaluated the soil report given to us and determined the soil of the proposed location for the building is a silty loam soil which has a soil density of 90 pounds per cubic foot and an allowable bearing pressure of 3 kips per square foot. For the calculation we assumed a compressive strength of concrete of 4,000 pounds per square inch, a yield strength of steel of 60,000 pounds per square inch, and the weight of concrete to be 150 pounds per cubic foot. With the soil density, allowable bearing pressure, and density of concrete, we determined the soil bearing strength using the equation below where q_e is the effective allowable bearing pressure, q_n is the allowable bearing pressure of the soil, q_{soil} is the pressure generated by the soil, and q_{self} is the pressure generated by the concrete.

$$q_e = q_n + q_{soil} + q_{self}$$

With an overall dead load of the building being about 1 kip per foot and a design live load of 2.8 kips per foot, the two values are summed together and divided by the soil bearing strength to find a value for the minimum width of the base of the footing design. The equation used is shown below where $b_{required}$ is the required length of the base of the footing, D is the dead load, and L is the live load.

$$b_{required} = \frac{D + L}{q_e}$$

In our calculations we received an approximate value of 1.5 feet, or 18 inches for $b_{required}$. To make the footing stronger, we rounded the base width value, *B* as shown in figure 14, up to 20 inches, or 1.67 feet. Using the loads and the value for B, we then found the ultimate soil bearing strength which is needed to find the nominal flexural strength. The nominal flexural strength allowed us to find the required amount of steel support needed in our design, which is one number two rebar laid horizontally in the base and one number two rebar vertically in the footing wall, both spaced 18 inches around the perimeter of the building. The International Building Code requires a footing wall width, *W,* of 12 inches and thickness of footing, *A,* to be six inches (IBC 2015, Table R403.1(1)). The value *H* is referring to the distance below the surface, which in our case must be at least four feet due to the frost line. Refer to figure 14 or Appendix D for clarification in the design process.



(Figure 14. Wall Footing Layout)

3.4 Mechanical Design

3.4.1 Heat loss

The maximum heat loss is used to determine the size of the heating system. The total heat loss is the combination of heat loss through building components and infiltration. Heat loss through building components is calculated by the infiltration from walls, doors, windows, roof and floor using the equation $Q = U * A * \triangle T$, where U equals the heat transfer coefficient, A equals the surface area, and delta T is the change in temperature. Refer to Appendix F.

		Garage	Vestibule	Assembly	Workshop	Restroom	Kitchen	Mechanical room
Exterior Wall	Area (sf)	672.0	156.2	1136.2	1185.0	110.0	154.6	262.0
U=0.025	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	**1176.0**	**273.4**	**1988.4**	**2073.7**	**192.5**	**270.6**	**458.5**
Windows	Area (sf)	0.0	0.0	76.8	67.2	0.0	0.0	0.0
U=0.37	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	**0.0**	**0.0**	**1989.1**	**1740.5**	**0.0**	**0.0**	**0.0**
Glass door	Area (sf)	0.0	82.0	0.0	0.0	0.0	0.0	0.0
U=0.37	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	**0.0**	**2123.8**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
Solid door	Area (sf)	56.0	0.0	21.0	21.0	0.0	0.0	0.0
U=0.5	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	**1960.0**	**0.0**	**735.0**	**735.0**	**0.0**	**0.0**	**0.0**
Floor	Area (sf)	374.0	128.0	1627.0	841.0	137.0	54.0	128.0
U=0.033	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	**863.9**	**295.7**	**3758.4**	**1942.7**	**316.5**	**124.7**	**295.7**
Roof	Area (sf)	907.2	147.6	1876.4	976.8	158.0	62.3	227.6
U=0.017	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	**1079.5**	**175.7**	**2232.9**	**1162.4**	**188.0**	**74.1**	**270.8**
Infiltration	ACHs	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	CFM/room	31.2	10.7	135.6	70.1	11.4	4.5	10.7
	Design temp difference(F)	70.0	70.0	70.0	70.0	70.0	70.0	70.0
	Heating load (BTUH)	2399.8	821.3	10439.9	5396.4	879.1	346.5	821.3
	Total load (BTUH)	**7479.3**	**3689.9**	**21143.7**	**13050.7**	**1576.1**	**816.0**	**1846.3**

(Table 11. Heating Load)

3.4.2 Heat gain

In order to determine the best size and type of system for this project, we needed to calculate the peak cooling and heating loads. The envelope heat gain is the sum of transmission heat gain and solar heat gain. Transmission heat gain can be calculated for the wall, roof and glass using the Cooling Load Temperature Difference (CLTD). CLTD is the rate at which heat enters a space through a building's materials. CLTD will vary depending on the building material of the envelope, thicknesses of the building materials, location of the site, and the orientation of the wall surface. U is the heat transfer coefficient, A is the surface area, and CLTD is the cooling load temperature difference. Refer to Appendix E.

$$Qtotal = Qsolar + Qtransmission$$

$$Q = U * A * CLTD$$

		Garage	Vestibule	Assembly	Workshop	Restroom	Kitchen	Mechanical room
Exterior Wall	Area (sf)	672.00	156.24	1136.22	1104.95	110.00	154.64	262.00
U=0.025	Design temp difference(F)	18.60	18.60	18.60	18.60	18.60	18.60	18.60
	Cooling load (BTUH)	**312.48**	**72.65**	**528.34**	**513.80**	**51.15**	**71.91**	**121.83**
Windows	Area (sf)	0.00	0.00	76.80	67.20	0.00	0.00	0.00
	CLF: NE&NW	40.00	40.00	40.00	40.00	40.00	40.00	40.00
	CLF: SE&SW	48.00	48.00	48.00	48.00	48.00	48.00	48.00
	Cooling load (BTUH)	**0.00**	**0.00**	**3072.00**	**3148.80**	**0.00**	**0.00**	**0.00**
Glass door	Area (sf)	0.00	82.00	0.00	0.00	0.00	0.00	0.00
	CLF: NE&NW	40.00	40.00	40.00	40.00	40.00	40.00	40.00
	CLF: SE&SW	48.00	48.00	48.00	48.00	48.00	48.00	48.00
	Cooling load (BTUH)	**0.00**	**3936.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Solid door	Area (sf)	56.00	0.00	21.00	21.00	0.00	0.00	0.00
U=0.50	Design temp difference(F)	18.60	18.60	18.60	18.60	18.60	18.60	18.60
	Cooling load (BTUH)	**520.80**	**0.00**	**195.30**	**195.30**	**0.00**	**0.00**	**0.00**
Roof	Area (sf)	907.18	147.62	1876.39	976.82	158.00	62.28	227.55
U=0.02	Design temp difference(F) -dark	39.00	39.00	39.00	39.00	39.00	39.00	39.00
	Cooling load (BTUH)	**601.46**	**97.87**	**1244.05**	**647.63**	**104.75**	**41.29**	**150.87**
Infiltration	ACHs	0.50	0.50	0.50	0.50	0.50	0.50	0.50
	CFM/room	31.17	10.67	135.58	70.08	11.42	4.50	10.67
	Design temp difference(F)	15.00	15.00	15.00	15.00	15.00	15.00	15.00
	Cooling load (BTUH)	**514.25**	**176.00**	**2237.13**	**1156.38**	**188.38**	**74.25**	**176.00**
Internal	People (BTUH)	0.00	0.00	11025.00	6750.00	0.00	0.00	0.00
	Lighting -Designed footcandle	20.00	25.00	40.00	50.00	20.00	60.00	20.00
	Lighting (BTUH)	296.42	180.24	2074.91	1333.87	90.12	180.24	90.12
	Other (BTUH)	0.00	0.00	0.00	0.00	0.00	1200.00	0.00
	Cooling load (BTUH)	**296.42**	**180.24**	**13099.91**	**8083.87**	**90.12**	**1380.24**	**90.12**
	Total load (BTUH)	**2245.41**	**4462.76**	**20376.73**	**13745.78**	**434.40**	**1567.69**	**538.81**

(Table 12. Cooling Load)

3.4.3 HVAC System

When comparing various types of mechanical systems with the estimated use and location of the building, our group narrowed the type of system to three choices: a fan coil unit, a geothermal heat pump, and an air source heat pump. First, we evaluated the cost of each and compared them with one another. The fan coil unit ranges from $2,000 to $4,000 including installation (8). This unit is simple to operate and easy to maintain, however, the operating costs are high, and the unit is poorly suited for open plan spaces (5).

The geothermal heat pump unit, nonetheless, is approximately $30,000 including install and has 70% lower utility bills than fan coil units and air source heat pumps (14). The geothermal unit has multiple benefits such as being environmentally friendly, quiet operation, and no visual disturbance like that of a fan coil unit or air source heat pump (3). The only major issue is the high upfront cost, which compared to the cost of other units and the amount of time the units will be operated is not the appropriate choice.

The last unit, the air source heat pump (ASHP), costs approximately $5,500 including install (11). The benefit of an air source heat pump is that it replaces both a furnace and an air conditioning unit. Despite having leakage issues with ductwork, an air source heat pump can be serviced to prevent the leaks and also to adjust the system, so it is efficient for the building (1). Based on the three systems evaluated, our group decided to choose a ducted, split system air source heat pump for the proposed building design.

In addition to the ASHP selection, our proposed design includes a heat recovery ventilator (HRV) above the two restrooms that will relieve the spaces of its contaminated air and rely on the clean air from the assembly space to infiltrate through the doorway.

The HRV intake from the restrooms will then exhaust through a small space on the front side of the assembly roof. The HRV also requires intake from outside and exhaust to the mechanical room.

3.4.4 HVAC Supply

With the selection of the air source heat pump system, we then had to calculate the amount of air supply into each room of the building. In order to calculate the amount of supply for each room, our group followed certain guidelines to produce the greatest efficiency. First, we found the amount of cubic feet per minute (CFM) of supply air for each room with an approximation of one CFM per one square foot. The two main rooms that need supply air are the assembly area and the workshop. To make the arrangement of ductwork simple, we chose to have two different ASHP units. The required unit for the assembly area is a 4-ton split system, open ductwork ASHP. This will supply 1,600 CFM for the approximately 1,630 square foot assembly area. The second unit is also split system, open ductwork but is only a 2-ton ASHP to supply 800 CFM for the approximately 850 square foot area. The 4-ton unit will be located in a secured, sealed room in the garage area. The 2-ton unit will be located in a separate but secured, sealed room in the workshop area. This is to prevent any dangerous gases or materials getting into the intake and supply air.

When determining the size of the ductwork to supply each room, we used the Friction Chart for Round Duct from the 2017 ASHRAE® Handbook - Fundamentals (I-P Edition). The assumed friction loss was based on a guideline of 0.1 inches of water per 100 feet. The guideline was from the equal friction method which creates an "initial guess" for duct sizing by establishing a constant pressure loss per unit of duct length.

This length is selected for the "critical path," which is the longest branch in an air distribution system. It is predicted that the longest span will have the highest total pressure loss. However, the longest span is not necessarily the run with the greatest friction loss because shorter spans may have more elbows, fittings, and other flow restrictions (4). The figure used to determine the duct size is shown below.

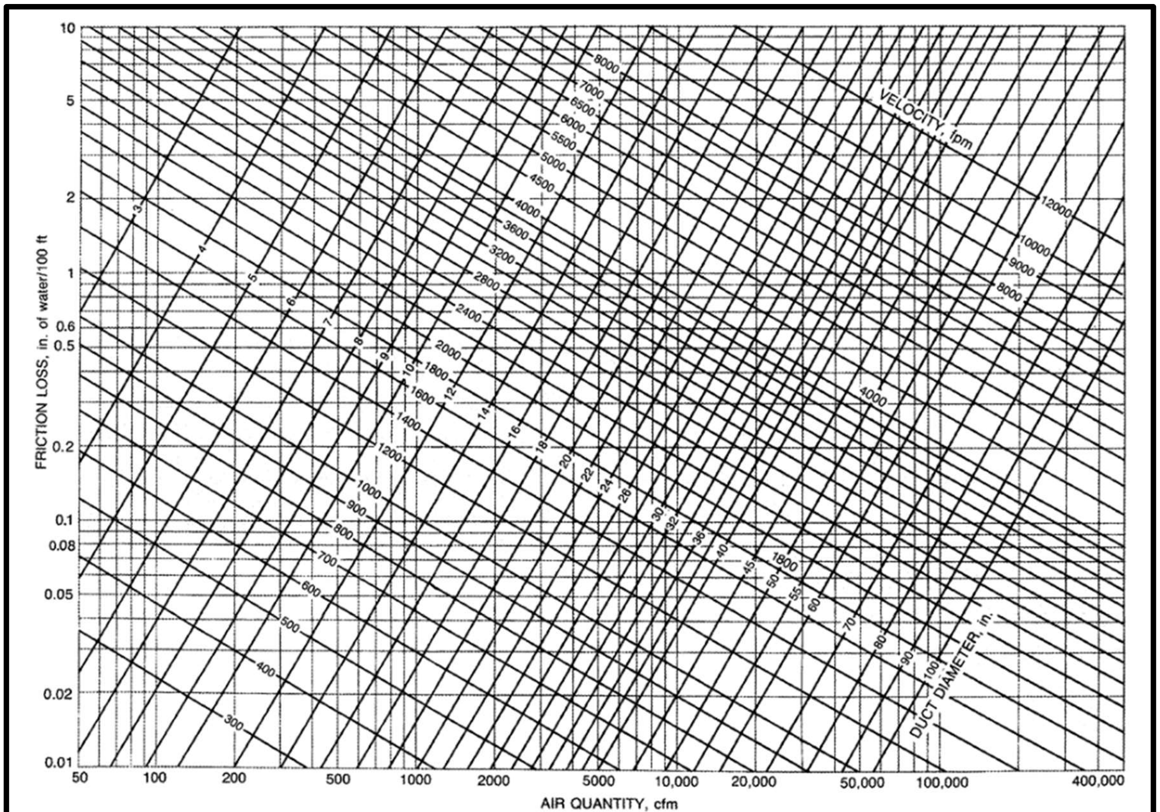


Fig. 10 Friction Chart for Round Duct ($\rho = 0.075\ lb_m/ft^3$ and $\varepsilon = 0.0003$ ft)

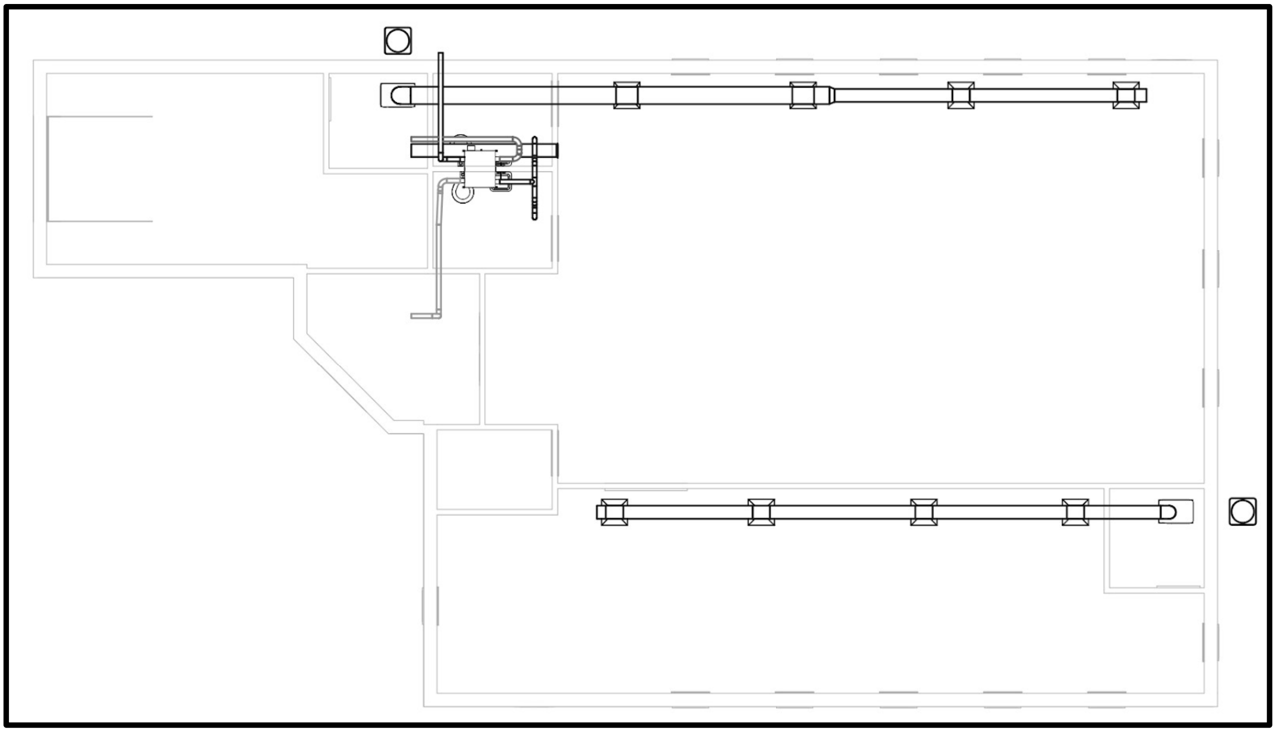
(Figure 15. Friction Chart)

The assembly area requires 1,600 CFM which translates to a 16-inch duct diameter. The initial 30 feet of supply air ductwork consists of two supply ducts which would dispense 1,600 CFM and then 1,200 CFM. We chose to continue with 16-inch duct through to the 1,200 CFM supply duct to make less size transitions in the ductwork. After the 1,200 CFM vent, the ductwork decreasing in size to 12-inch diameter. The remaining 20 feet of ductwork also has two supply ducts with one being at the very end of the ductwork. The first supply duct of the 12-inch diameter ductwork would dispense 800 CFM and the final supply duct a CFM of 400.

For heat supply to the other smaller spaces like the restrooms, kitchen, and vestibule, our design plans to include electric baseboard heaters that can regulate the amount of heat needed for those spaces. By including the baseboard heaters, we are eliminating the need for additional ductwork. The smaller spaces may not need additional heat because of the infiltrating air from the assembly space, so by having manually controlled baseboard heaters and no additional ductwork, we are relieving extra costs for the building.

3.4.5. HVAC Layout

As previously discussed, the proposed design calls for two separate units to supply air to two different areas. The two mechanical rooms are located at the desired locations based on visual appeal of the main entrance to building. The two heat pumps require both an interior and exterior unit, so by having the mechanical rooms at their proposed spots, the exterior units will be away from the parking lot making it a more attractive entrance way. Below is figure 16 showing the HVAC layout including the HRV above the restrooms.



(Figure 16. HVAC Systems Layout)

3.5 Egress

Effective egress is essential to building safety, so it is a vital part of the building design. For designing means of egress, the first step is to determine the occupancy load. AAS is a Group B occupancy, with occupancy load less than 50 (IBC 2015, 1004.1).

3.5.1. Number of Exits

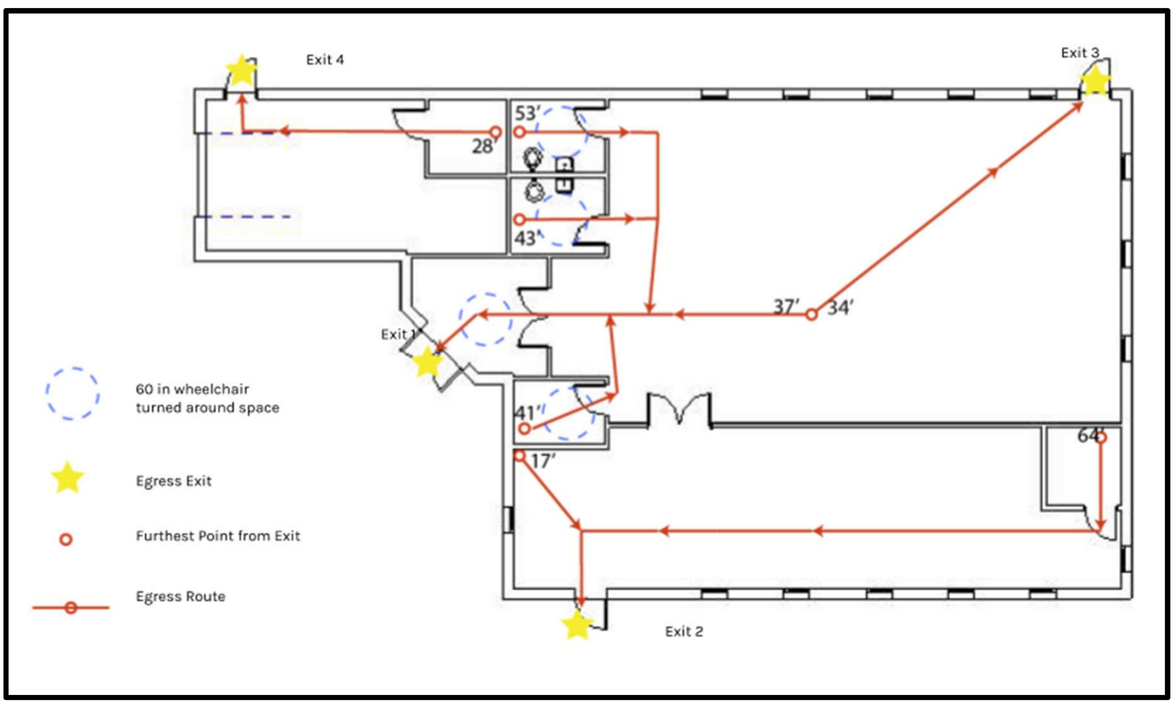
For group B occupancy, only one exit is required if the maximum common path of egress travel distance is less than 100 feet with a sprinkler system.

Story	Occupancy	Max occupant load per story	Maximum common path of egress travel distance (feet)
First story above or below grad plane	B	49	100

(Table 13. Number of Stories)

3.5.2. Dimensions

The preliminary building design had two exits in the assembly area, one main exit and one in the shop area. This design gave us a maximum travel distance of 72 feet from the upper right corner to the main exit. However, 72 feet is close to the maximum of 100 feet, so another exit was added. Three exits decreased the maximum travel distance to 64 feet. The new floor plan with exit access travel distance is shown below in figure 17.



(Figure 17. Max travel Distance)

4.0. Conclusion

The overall goal of this project was to produce an energy efficient design for an education center for the Aldrich Astronomical Society. Through the analysis of architectural, structural, and mechanical systems, various codes were explored in order to achieve suitability. The proposed design fulfills the requirements set by the AAS and stresses the goal of achieving net zero energy. We hope our design inspires the organization and aids in the construction of their future building.

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Appendix A: Lighting Spec Sheet

Lighting Fixture A

PHILIPS
Lighting

FastSet, Surface Mounted

SM150C LED48S/840 PSU TW3 PI5 L1160

840 neutral white - Power supply unit - Connection unit 5-pole

Upgrading to LED is a key trend in office applications. Recognizing the need for an easy to use luminaire that can work as the perfect 1:1 replacement of conventional office lighting, we developed FastSet. This luminaire is an ideal choice to quickly achieve the benefits of LED lighting since being the perfect 1:1 replacement, no additional lighting calculation is needed prior to the LED lighting installation. The luminaire simply fits into all different indoor applications. Moreover, it is available in both standalone and through-wiring versions, which makes the luminaires ready-to-connect at a later stage.

Product data

General Information	
Beam angle of light source	116 °
Light source color	840 neutral white
Light source replaceable	No
Number of gear units	1 unit
Driver/power unit/transformer	Power supply unit
Driver included	Yes
Optic type	Wide beam
Luminaire light beam spread	100°
Connection	Connection unit 5-pole
Cable	-
Protection class IEC	Safety class I
Glow-wire test	Temperature 850 °C, duration 30 s

Flammability mark	For mounting on normally flammable surfaces
CE mark	CE mark
ENEC mark	-
Warranty period	5 years
Remarks	*-Per Lighting Europe guidance paper "Evaluating performance of LED based luminaires - January 2018": statistically there is no relevant difference in lumen maintenance between B50 and for example B10. Therefore the median useful life (B50) value also represents the B10 value.
Constant light output	No
Number of products on MCB of 16 A type B	24

Datasheet, 2019, February 12

data subject to change

FastSet, Surface Mounted

RoHS mark	RoHS mark
Unified glare rating CEN	25

Operating and Electrical

Input Voltage	220-240 V
Input Frequency	50 to 60 Hz
Inrush current	8 A
Inrush time	0.06 ms
Power Factor (Min)	0.9

Controls and Dimming

Dimmable	No

Mechanical and Housing

Housing Material	Metal
Reflector material	-
Optic material	Polycarbonate
Optical cover/lens material	Polycarbonate
Fixation material	Steel
Optical cover/lens finish	Opal
Overall length	1160 mm
Overall width	160 mm
Overall height	61 mm

Approval and Application

Ingress protection code	IP44 [Wire-protected, splash-proof]
Mech. impact protection code	IK03 [0.3 J]

Initial Performance (IEC Compliant)

Initial luminous flux (system flux)	4800 lm
Luminous flux tolerance	+/-10%
Initial LED luminaire efficacy	107 lm/W
Init. Corr. Color Temperature	4000 K
Init. Color Rendering Index	≥80
Initial chromaticity	(0.3828, 0.3803) SSDCM
Initial input power	45 W
Power consumption tolerance	+/-10%

Over Time Performance (IEC Compliant)

Control gear failure rate at median useful life 50000 h	5 %
Lumen maintenance at median useful life* 50000 h	L80

Application Conditions

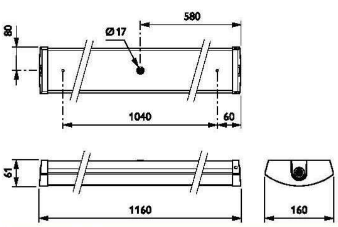
Ambient temperature range	0 to +35 °C
Performance ambient temperature Tq	25 °C
Suitable for random switching	Not applicable

Product Data

Full product code	871869938125799
Order product name	SM150C LED48S/840 PSU TW3 PI5 L1160
EAN/UPC - Product	8718699381257
Order code	912401483057
Numerator - Quantity Per Pack	1
Numerator - Packs per outer box	4
Material Nr. (12NC)	912401483057
Net Weight (Piece)	2.410 kg

IP44 IK03

Dimensional drawing



FastSet SM150C

Lighting Fixture B

SmartBalance, surface mounted

SM480C LED30S/840 POE ACC-MLO ACL

SmartBalance Surface Mounted - LED Module, system flux 3000 lm - 840 neutral white - Luminaire controller with power over Ethernet - Acrylate micro-lens optic clear - ActiLume

Although in many cases the functional lighting performance is key, customers are also keen to apply luminaires that are attractive and/or unobtrusive. Especially in applications where luminaires need to be surface-mounted or suspended, it can be difficult to satisfy both these requirements. SmartBalance is clearly the next step in surface-mounted and suspended luminaires for the specification market. It not only offers increased energy efficiency, but is also visually appealing without being intrusive. And its design helps to minimize clutter on the ceiling and meets all relevant office norms. SmartBalance is also available in recessed and free floor-standing versions., With Power-over-Ethernet (PoE) technology, building owners and facility managers can create a complete, integrated network of intelligent luminaires – a sort of 'digital ceiling' – simply by connecting a single standard Ethernet cable for both power and data. The SmartBalance PoE surface mounted lighting system gives office users personal control over their preferred light settings via their smartphone. It also enables building occupants and/or facility managers to gather data on building usage as smart luminaire sensors track, for example, energy consumption, humidity, CO2, temperature and presence. This can help them optimize facility utilization, enhance the end-user experience, and improve asset management. For example, the facility manager may see that on a given afternoon a particular floor or area is not used, and adjust the temperature, lighting and cleaning roster accordingly. SmartBalance PoE surface mounted offers high-quality, energy-efficient illumination and is a smart, connected device for the 'Internet of Things' in lighting.

Product data

SmartBalance, surface mounted

General Information	
Number of light sources	1 pc
Lamp family code	LED30S [LED Module, system flux 3000 lm]
Beam angle of light source	40 °
Light source color	840 neutral white
Cap-Base	- [-]
Light source replaceable	No
Number of gear units	1 unit
Gear	-
Driver/power unit/transformer	Luminaire controller with power over Ethernet
Driver included	Yes
Optic type	-
Optical cover/lens type	Acrylate micro-lens optic clear
Luminaire light beam spread	100°
Emergency lighting	-
Embedded control	ActiLume
Control interface	Power over Ethernet
Connection	RJ45 connector
Cable	-
Protection class IEC	Safety class III
Mounting	Surface
Glow-wire test	Temperature 650 °C, duration 5 s
Flammability mark	For mounting on normally flammable surfaces
CE mark	CE mark
ENEC mark	ENEC plus mark
UL mark	-
Warranty period	5 years
Remarks	*-Per Lighting Europe guidance paper "Evaluating performance of LED based luminaires - January 2018": statistically there is no relevant difference in lumen maintenance between B50 and for example B10. Therefore the median useful life (B50) value also represents the B10 value.
Constant light output	No
Number of products on MCB of 16 A type B	20
RoHS mark	RoHS mark
Accessory PFC	N/A
Product family code	SM480C [SmartBalance Surface Mounted]
Unified glare rating CEN	19

Operating and Electrical	
Input Voltage	51 to 54 V
Input Frequency	- Hz
Control signal voltage	42.5 to 57 V DC POE+
Inrush current	5 A
Inrush time	1 ms
Power Factor (Min)	-

Controls and Dimming	
Dimmable	Yes

Mechanical and Housing	
Geometry	Width 0.24 m, length 1.34 m
Housing Material	Polycarbonate
Reflector material	-
Optic material	-
Optical cover/lens material	Acrylate
Gear tray material	Steel
Fixation material	-
Optical cover/lens finish	Textured
Overall length	1340 mm
Overall width	240 mm
Overall height	52 mm

Approval and Application	
Ingress protection code	IP40 [Wire-protected]
Mech. impact protection code	IK02 [0.2 J standard]

Initial Performance (IEC Compliant)	
Initial luminous flux (system flux)	3000 lm
Luminous flux tolerance	+/-10%
Initial LED luminaire efficacy	111 lm/W
Init. Corr. Color Temperature	4000 K
Init. Color Rendering Index	>80
Initial chromaticity	(0.38, 0.38) SDCM <3
Initial input power	27 W
Power consumption tolerance	+/-10%

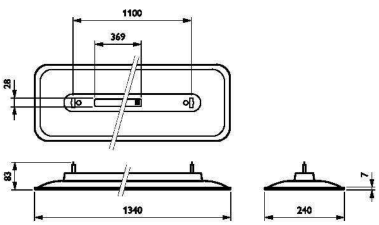
Over Time Performance (IEC Compliant)	
Control gear failure rate at median useful life 50000 h	5 %
Lumen maintenance at median useful life* 50000 h	L85

Application Conditions	
Ambient temperature range	+10 to +40 °C
Performance ambient temperature Tq	25 °C
Maximum dim level	1%
Suitable for random switching	Yes (relates to presence/ movement detection and daylight harvesting)

Product Data	
Full product code	871869906404400
Order product name	SM480C LED30S/840 POE ACC-MLO ACL
EAN/UPC - Product	8718699064044
Order code	910504108603
Numerator - Quantity Per Pack	1
Numerator - Packs per outer box	1
Material Nr. (12NC)	910504108603
Net Weight (Piece)	4.700 kg

SmartBalance, surface mounted

Dimensional drawing



SmartBalance SM480C

www.lighting.philips.com
2019, February 12 - data subject to change

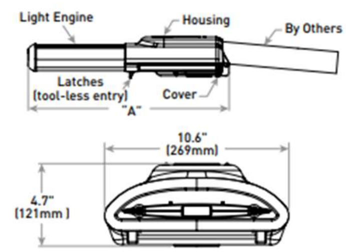
Lighting Fixture C

LEDway® Series

LEDway® LED Street Light

Product Description

Luminaire housing is all aluminum construction. Standard luminaire utilizes terminal block for power input suitable for #2-#14 AWG wire. Luminaire is designed to mount on a 2" (51mm) IP, 2.375" (60mm) O.D. horizontal tenon and/or a 1.25" (32mm) IP, 1.66" (42mm) O.D. horizontal tenon (minimum 8" [203mm] in length) and is adjustable +/- 5° to allow for luminaire leveling (two axis T-level included).
Applications: Roadway, parking lots, walkways and general area spaces



Performance Summary

Patented NanoOptic® Product Technology
Made in the U.S.A. of U.S. and imported parts
CRI: Minimum 70 CRI
CCT: 4000K (+/- 300K), 5700K (+/- 500K) standard
Limited Warranty*: 10 years on luminaire/10 years on Colorfast DeltaGuard® finish

*See http://lighting.cree.com/warranty for warranty terms

LED Count (x10)	Dim. "A"	Weight
02	17.5" (443mm)	13.0 lbs. (5.9kg)
03	17.5" (443mm)	13.5 lbs. (6.1kg)
04	22.0" (559mm)	16.5 lbs. (7.5kg)
05	22.0" (559mm)	17.0 lbs. (7.7kg)
06	22.0" (559mm)	17.5 lbs. (7.9kg)
07	26.8" (681mm)	22.0 lbs. (10.0kg)
08	26.8" (681mm)	22.5 lbs. (10.2kg)
09	26.8" (681mm)	22.5 lbs. (10.2kg)
10	33.1" (842mm)	27.5 lbs. (12.5kg)
11	33.1" (842mm)	28.0 lbs. (12.7kg)
12	33.1" (842mm)	28.0 lbs. (12.7kg)

Accessories

Field-Installed		
Bird Spikes for Light Engine XA-BRDSPK30 - 20-30 LED XA-BRDSPK60 - 40-60 LED XA-BRDSPK90 - 70-90 LED XA-BRDSPK120 - 100-120 LED	**Bird Spikes for Housing** XA-BRDSPKHSG	**External Backlight Shield** XA-XSLBLS30 - 20-30 LED XA-XSLBLS60 - 40-60 LED XA-XSLBLS90 - 70-90 LED XA-XSLBLS120 - 100-120 LED

Ordering Information

Example: STR-LWY-2M-HT-02-E-UL-SV-700

STR-LWY		HT		E				
Product	**Optic**	**Mounting**	**LED Count (x10)**	**Series**	**Voltage**	**Color Options***	**Drive Current**	**Options**
STR-LWY	**2M** Type II Medium **2S** Type II Short **3M** Type III Medium **4M** Type IV Medium **5M** Type V Medium	**HT** Horizontal Tenon	**02** **03** **04** **05** **06** **07** **08** **09** **10** **11** **12**	**E**	**UL** Universal 120-277V **UH** Universal 347-480V	**BK** Black **BZ** Bronze **SV** Silver	**525** 525mA **700** 700mA	**DIM 0-10V Dimming** - Control by others - Refer to Dimming spec sheet for details - Can't exceed specified drive current **R NEMA® Photocell Receptacle** - 3-pin receptacle per ANSI C136.10 - Intended for downlight applications with maximum 45° tilt - Photocell and shorting cap by others **UTL Utility** - Includes exterior wattage label that reflects watts for the drive current selected. The ability to exceed selected drive current will be disabled **40K 4000K Color Temperature** - Minimum 70 CRI - Color temperature per luminaire

* Light engine portion of extrusion is not painted and will remain natural aluminum regardless of color selection

c UL us

Rev. Date: V4 10/04/2018

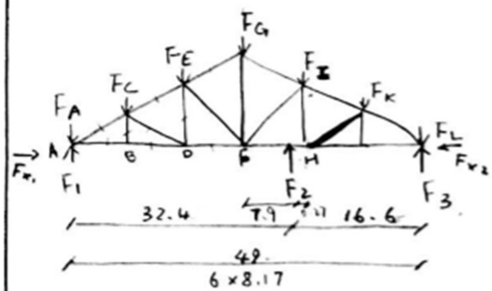
CREE

US: lighting.cree.com T (800) 236-6800 F (262) 504-5415

Canada: www.cree.com/canada T (800) 473-1234 F (800) 890-7507

Appendix B: Roof Truss Calculation

truss	Calculation of R_F & F_R	Assembly



$\Sigma F_y = 0$

$F_1 + F_2 + F_3 = F_A + F_C + F_E + F_G + F_I + F_K + F_L$

$= 41791.22$ Eq 1

$\Sigma M_G = 0$

$F_2(7.9) + F_3(24.5) = F_1(24.5)$

$F_2 = 3.1(F_1 - F_3)$ Eq 2

$\Sigma M_H = 0$

$F_K \cdot 8.17 + F_L \cdot (8.17 \times 2) + F_2(0.27) + F_1(4 \times 8.17)$

$- F_A \cdot (4 \times 8.17) - F_C \cdot (3 \times 8.17) - F_E(2 \times 8.17)$

$- F_G \cdot 8.17 - F_3 \cdot (2 \times 8.17) = 0$

$0.27 F_2 + 32.68 F_1 - 16.34 F_3 = 341434.104$ Eq 3.

$$\begin{cases} F_1 + F_2 + F_3 = 41791.22 \\ 3.1 F_1 - F_2 - 3.1 F_3 = 0 \\ 32.68 F_1 + 0.27 F_2 - 16.34 F_3 = 341434.104 \end{cases}$$

$$\begin{cases} F_1 = 20895.6 \text{ lb} \\ F_2 = -2.65 \text{ lb} \\ F_3 = 20895.6 \text{ lb} \end{cases} \Rightarrow \begin{cases} F_1 = 20895.6 \\ F_3 = 20895.6 \end{cases}$$

Calculation for R_F.

1. Snow Load $P_s = 14$ psf: $P_f = 0.7 \cdot C_e \cdot C_t \cdot I = 35$; $P_s = C_s \cdot P_f = 14$ psf
2. Live Load: $LL = 100$ psf
3. Wind Load. $WL = 6$ psf
4. Dead Load: $DL = 2.67$ psf

$R_F = (\Sigma \text{Load})(\text{distance between trusses})$

$= (14 + 100 + 6 + 2.67) \times (6)$

$= 736.02$ lb/ft

Force on each point.

$F = A_{tr} \times R_F$

	Tributary Area (ft)	Force on each point (lb)
A	5.065	3727.94
C	9.630	7087.87
E	9.130	6719.86
G	9.130	6719.86
I	9.130	6719.86
K	9.630	7087.87
L	5.065	3727.94

$\Sigma M_E = 0$

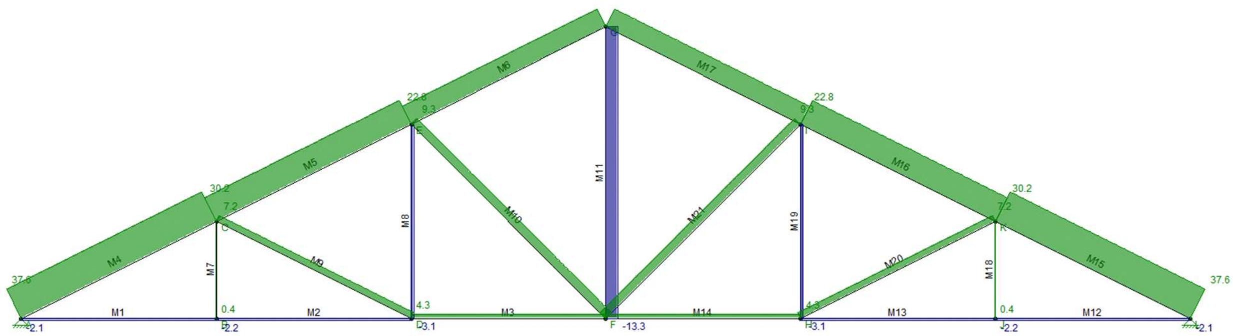
solve for F_{x_1} & F_{x_2}

$$\begin{cases} F_{x_1} = 31837 \\ F_{x_2} = -31837 \end{cases}$$

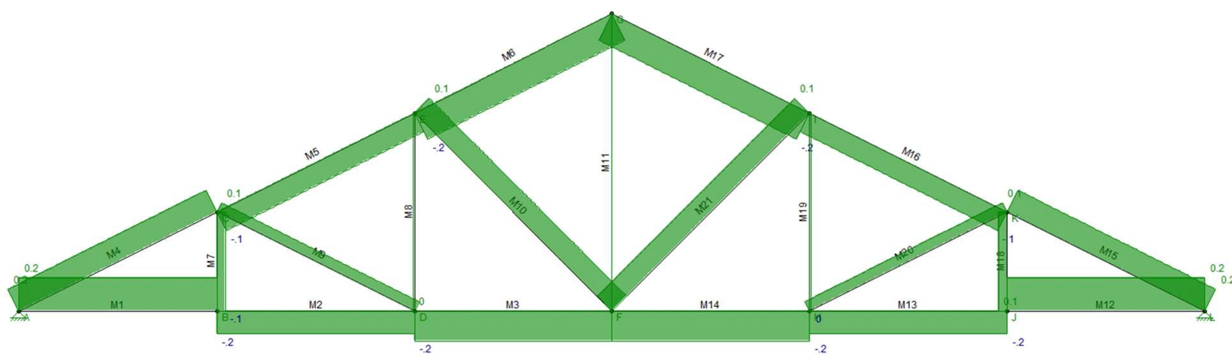
Appendix C: Roof Truss Risa Model Result

Main Building Roof Truss (Not Include the Garage Roof)

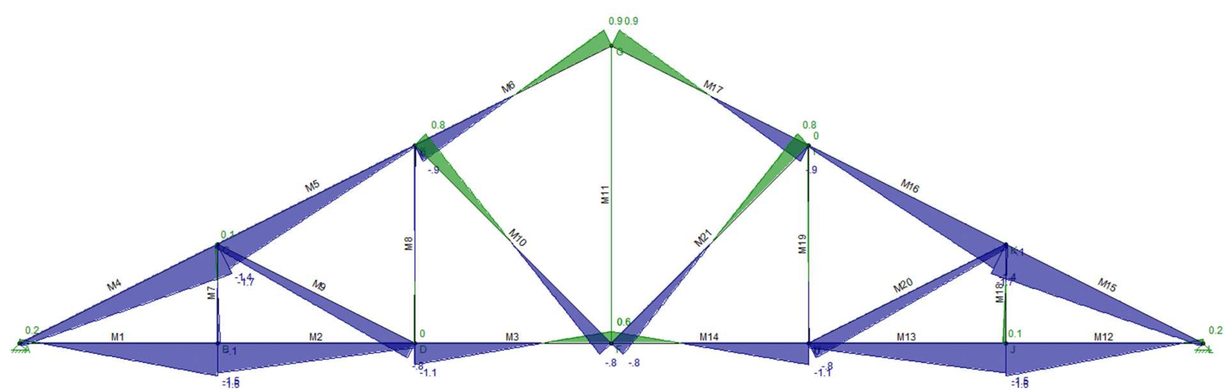
Axial Force



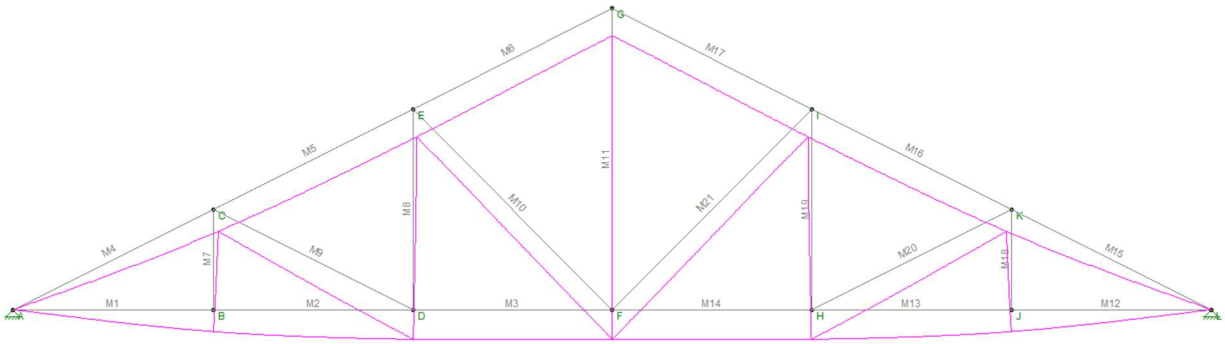
Shear



Moment



Deflection



Joint Deflections (By Combination)

	L...	Joint Label	X [in]	Y [in]	Z [in]	X Rotat...	Y Rotat...	Z Rotat...
1	1	A	0	0	0	0	0	-3.087e-03
2	1	B	.003	-.269	0	0	0	-1.867e-03
3	1	C	.066	-.27	0	0	0	-1.384e-03
4	1	D	.006	-.363	0	0	0	-4.275e-04
5	1	E	.047	-.341	0	0	0	-3.347e-05
6	1	F	0	-.361	0	0	0	0
7	1	G	0	-.332	0	0	0	0
8	1	H	-.006	-.363	0	0	0	4.275e-04
9	1	I	-.047	-.341	0	0	0	3.347e-05
10	1	J	-.003	-.269	0	0	0	1.867e-03
11	1	K	-.066	-.27	0	0	0	1.384e-03
12	1	L	0	0	0	0	0	3.087e-03

Member Section Forces (By Combination)

Sections | Maximums | End Reactions

	L...	Member Label	Sec	Axial[k]	y Shea...	z Shea...	Torque[k-ft]	y-y Moment[k-ft]	z-z Moment[k-ft]
1	1	M1	1	-2.122	.222	0	0	0	.176
2			2	-2.122	.222	0	0	0	-.278
3			3	-2.122	.222	0	0	0	-.732
4			4	-2.122	.222	0	0	0	-1.186
5			5	-2.122	.222	0	0	0	-1.64
6	1	M2	1	-2.18	-.154	0	0	0	-1.493
7			2	-2.18	-.154	0	0	0	-1.179
8			3	-2.18	-.154	0	0	0	-.864
9			4	-2.18	-.154	0	0	0	-.549
10			5	-2.18	-.154	0	0	0	-.234
11	1	M3	1	4.308	-.202	0	0	0	-1.081
12			2	4.308	-.202	0	0	0	-.669
13			3	4.308	-.202	0	0	0	-.257
14			4	4.308	-.202	0	0	0	.155
15			5	4.308	-.202	0	0	0	.567
16	1	M4	1	37.568	.162	0	0	0	-.176
17			2	37.568	.162	0	0	0	-.545
18			3	37.568	.162	0	0	0	-.914
19			4	37.568	.162	0	0	0	-1.284
20			5	37.568	.162	0	0	0	-1.653
21	1	M5	1	30.237	-.14	0	0	0	-1.363
22			2	30.237	-.14	0	0	0	-1.044
23			3	30.237	-.14	0	0	0	-.725
24			4	30.237	-.14	0	0	0	-.406
25			5	30.237	-.14	0	0	0	-.086
26	1	M6	1	22.775	-.197	0	0	0	-.916
27			2	22.775	-.197	0	0	0	-.467
28			3	22.775	-.197	0	0	0	-.018
29			4	22.775	-.197	0	0	0	.431
30			5	22.775	-.197	0	0	0	.88
31	1	M7	1	.376	-.058	0	0	0	-.147
32			2	.376	-.058	0	0	0	-.088
33			3	.376	-.058	0	0	0	-.029
34			4	.376	-.058	0	0	0	.03
35			5	.376	-.058	0	0	0	.089
36	1	M8	1	-3.116	.008	0	0	0	.02
37			2	-3.116	.008	0	0	0	.004
38			3	-3.116	.008	0	0	0	-.012
39			4	-3.116	.008	0	0	0	-.028
40			5	-3.116	.008	0	0	0	-.044
41	1	M9	1	7.21	.068	0	0	0	-.201
42			2	7.21	.068	0	0	0	-.357
43			3	7.21	.068	0	0	0	-.513
44			4	7.21	.068	0	0	0	-.67
45			5	7.21	.068	0	0	0	-.826
46	1	M10	1	9.265	.139	0	0	0	.785
47			2	9.265	.139	0	0	0	.386
48			3	9.265	.139	0	0	0	-.014
49			4	9.265	.139	0	0	0	-.414
50			5	9.265	.139	0	0	0	-.814
51	1	M11	1	-13.319	0	0	0	0	0
52			2	-13.319	0	0	0	0	0
53			3	-13.319	0	0	0	0	0
54			4	-13.319	0	0	0	0	0
55			5	-13.319	0	0	0	0	0
56	1	M12	1	-2.122	.222	0	0	0	.176
57			2	-2.122	.222	0	0	0	-.278
58			3	-2.122	.222	0	0	0	-.732
59			4	-2.122	.222	0	0	0	-1.186
60			5	-2.122	.222	0	0	0	-1.64

61	1	M13	1	-2.18	-.154	0	0	0	-1.493
62			2	-2.18	-.154	0	0	0	-1.179
63			3	-2.18	-.154	0	0	0	-.864
64			4	-2.18	-.154	0	0	0	-.549
65			5	-2.18	-.154	0	0	0	-.234
66	1	M14	1	4.308	-.202	0	0	0	-1.081
67			2	4.308	-.202	0	0	0	-.669
68			3	4.308	-.202	0	0	0	-.257
69			4	4.308	-.202	0	0	0	.155
70			5	4.308	-.202	0	0	0	.567
71	1	M15	1	37.568	.162	0	0	0	-.176
72			2	37.568	.162	0	0	0	-.545
73			3	37.568	.162	0	0	0	-.914
74			4	37.568	.162	0	0	0	-1.284
75			5	37.568	.162	0	0	0	-1.653
76	1	M16	1	30.237	-.14	0	0	0	-1.363
77			2	30.237	-.14	0	0	0	-1.044
78			3	30.237	-.14	0	0	0	-.725
79			4	30.237	-.14	0	0	0	-.406
80			5	30.237	-.14	0	0	0	-.086
81	1	M17	1	22.775	-.197	0	0	0	-.916
82			2	22.775	-.197	0	0	0	-.467
83			3	22.775	-.197	0	0	0	-.018
84			4	22.775	-.197	0	0	0	.431
85			5	22.775	-.197	0	0	0	.88
86	1	M18	1	.376	.058	0	0	0	.147
87			2	.376	.058	0	0	0	.088
88			3	.376	.058	0	0	0	.029
89			4	.376	.058	0	0	0	-.03
90			5	.376	.058	0	0	0	-.089
91	1	M19	1	-3.116	-.008	0	0	0	-.02
92			2	-3.116	-.008	0	0	0	-.004
93			3	-3.116	-.008	0	0	0	.012
94			4	-3.116	-.008	0	0	0	.028
95			5	-3.116	-.008	0	0	0	.044
96	1	M20	1	7.21	.068	0	0	0	-.201
97			2	7.21	.068	0	0	0	-.357
98			3	7.21	.068	0	0	0	-.513
99			4	7.21	.068	0	0	0	-.67
100			5	7.21	.068	0	0	0	-.826
101	1	M21	1	9.265	.139	0	0	0	.785
102			2	9.265	.139	0	0	0	.386
103			3	9.265	.139	0	0	0	-.014
104			4	9.265	.139	0	0	0	-.414
105			5	9.265	.139	0	0	0	-.814

Member Stress Analysis

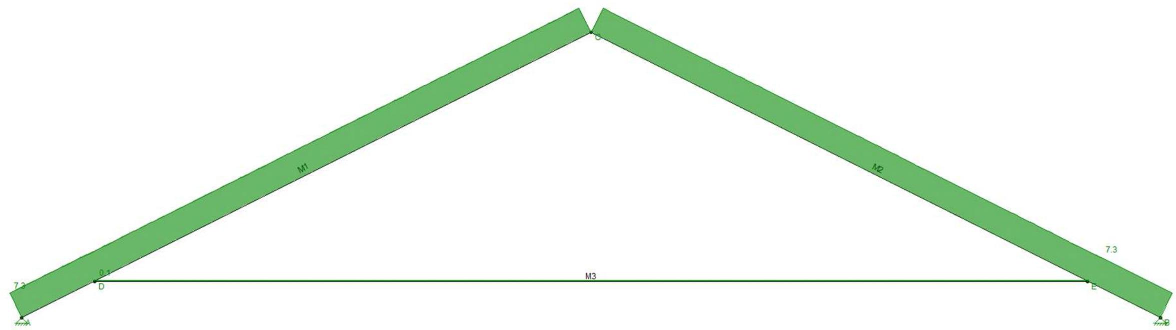
Member Section Stresses (By Combination)

	L...	Member Label	Sec	Axial[ksi]	y Shea...	z Shea...	y top Be...	y bot B...	z top B...	z bot B...
1	1	M1	1	-.054	.008	0	-.029	.029	0	0
2			2	-.054	.008	0	.045	-.045	0	0
3			3	-.054	.008	0	.119	-.119	0	0
4			4	-.054	.008	0	.193	-.193	0	0
5			5	-.054	.008	0	.267	-.267	0	0
6	1	M2	1	-.055	-.006	0	.243	-.243	0	0
7			2	-.055	-.006	0	.192	-.192	0	0
8			3	-.055	-.006	0	.14	-.14	0	0
9			4	-.055	-.006	0	.089	-.089	0	0
10			5	-.055	-.006	0	.038	-.038	0	0
11	1	M3	1	.109	-.008	0	.176	-.176	0	0
12			2	.109	-.008	0	.109	-.109	0	0
13			3	.109	-.008	0	.042	-.042	0	0
14			4	.109	-.008	0	-.025	.025	0	0
15			5	.109	-.008	0	-.092	.092	0	0
16	1	M4	1	.954	.006	0	.029	-.029	0	0
17			2	.954	.006	0	.089	-.089	0	0
18			3	.954	.006	0	.149	-.149	0	0
19			4	.954	.006	0	.209	-.209	0	0
20			5	.954	.006	0	.269	-.269	0	0
21	1	M5	1	.768	-.005	0	.222	-.222	0	0
22			2	.768	-.005	0	.17	-.17	0	0
23			3	.768	-.005	0	.118	-.118	0	0
24			4	.768	-.005	0	.066	-.066	0	0
25			5	.768	-.005	0	.014	-.014	0	0
26	1	M6	1	.578	-.007	0	.149	-.149	0	0
27			2	.578	-.007	0	.076	-.076	0	0
28			3	.578	-.007	0	.003	-.003	0	0
29			4	.578	-.007	0	-.07	.07	0	0
30			5	.578	-.007	0	-.143	.143	0	0
31	1	M7	1	.046	-.01	0	.233	-.233	0	0
32			2	.046	-.01	0	.139	-.139	0	0
33			3	.046	-.01	0	.046	-.046	0	0
34			4	.046	-.01	0	-.047	.047	0	0
35			5	.046	-.01	0	-.141	.141	0	0
36	1	M8	1	-.378	.001	0	-.032	.032	0	0
37			2	-.378	.001	0	-.007	.007	0	0
38			3	-.378	.001	0	.019	-.019	0	0
39			4	-.378	.001	0	.044	-.044	0	0
40			5	-.378	.001	0	.07	-.07	0	0
41	1	M9	1	.183	.003	0	.033	-.033	0	0
42			2	.183	.003	0	.058	-.058	0	0
43			3	.183	.003	0	.083	-.083	0	0
44			4	.183	.003	0	.109	-.109	0	0
45			5	.183	.003	0	.134	-.134	0	0
46	1	M10	1	.235	.005	0	-.128	.128	0	0
47			2	.235	.005	0	-.063	.063	0	0
48			3	.235	.005	0	.002	-.002	0	0
49			4	.235	.005	0	.067	-.067	0	0
50			5	.235	.005	0	.132	-.132	0	0
51	1	M11	1	-.338	0	0	0	0	0	0
52			2	-.338	0	0	0	0	0	0
53			3	-.338	0	0	0	0	0	0
54			4	-.338	0	0	0	0	0	0
55			5	-.338	0	0	0	0	0	0
56	1	M12	1	-.054	.008	0	-.029	.029	0	0
57			2	-.054	.008	0	.045	-.045	0	0
58			3	-.054	.008	0	.119	-.119	0	0
59			4	-.054	.008	0	.193	-.193	0	0
60			5	-.054	.008	0	.267	-.267	0	0

61	1	M13	1	-.055	-.006	0	.243	-.243	0	0
62			2	-.055	-.006	0	.192	-.192	0	0
63			3	-.055	-.006	0	.14	-.14	0	0
64			4	-.055	-.006	0	.089	-.089	0	0
65			5	-.055	-.006	0	.038	-.038	0	0
66	1	M14	1	.109	-.008	0	.176	-.176	0	0
67			2	.109	-.008	0	.109	-.109	0	0
68			3	.109	-.008	0	.042	-.042	0	0
69			4	.109	-.008	0	-.025	.025	0	0
70			5	.109	-.008	0	-.092	.092	0	0
71	1	M15	1	.954	.006	0	.029	-.029	0	0
72			2	.954	.006	0	.089	-.089	0	0
73			3	.954	.006	0	.149	-.149	0	0
74			4	.954	.006	0	.209	-.209	0	0
75			5	.954	.006	0	.269	-.269	0	0
76	1	M16	1	.768	-.005	0	.222	-.222	0	0
77			2	.768	-.005	0	.17	-.17	0	0
78			3	.768	-.005	0	.118	-.118	0	0
79			4	.768	-.005	0	.066	-.066	0	0
80			5	.768	-.005	0	.014	-.014	0	0
81	1	M17	1	.578	-.007	0	.149	-.149	0	0
82			2	.578	-.007	0	.076	-.076	0	0
83			3	.578	-.007	0	.003	-.003	0	0
84			4	.578	-.007	0	-.07	.07	0	0
85			5	.578	-.007	0	-.143	.143	0	0
86	1	M18	1	.046	.01	0	-.233	.233	0	0
87			2	.046	.01	0	-.139	.139	0	0
88			3	.046	.01	0	-.046	.046	0	0
89			4	.046	.01	0	.047	-.047	0	0
90			5	.046	.01	0	.141	-.141	0	0
91	1	M19	1	-.378	-.001	0	.032	-.032	0	0
92			2	-.378	-.001	0	.007	-.007	0	0
93			3	-.378	-.001	0	-.019	.019	0	0
94			4	-.378	-.001	0	-.044	.044	0	0
95			5	-.378	-.001	0	-.07	.07	0	0
96	1	M20	1	.183	.003	0	.033	-.033	0	0
97			2	.183	.003	0	.058	-.058	0	0
98			3	.183	.003	0	.083	-.083	0	0
99			4	.183	.003	0	.109	-.109	0	0
100			5	.183	.003	0	.134	-.134	0	0
101	1	M21	1	.235	.005	0	-.128	.128	0	0
102			2	.235	.005	0	-.063	.063	0	0
103			3	.235	.005	0	.002	-.002	0	0
104			4	.235	.005	0	.067	-.067	0	0
105			5	.235	.005	0	.132	-.132	0	0

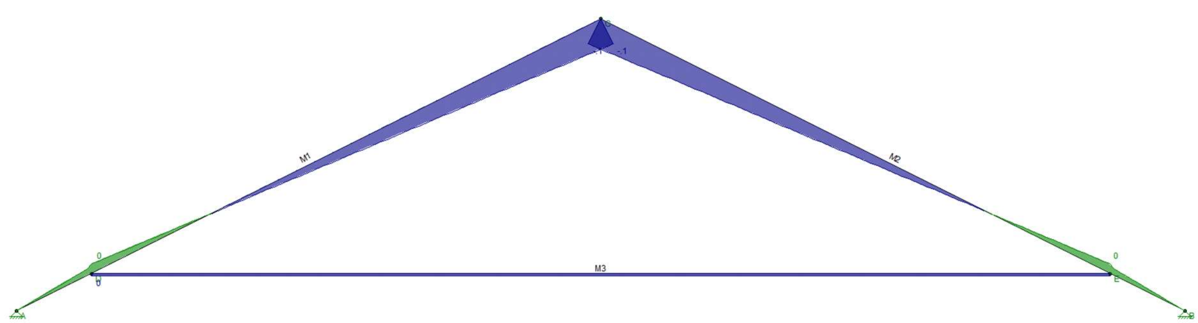
Garage Roof Truss

Axial Force

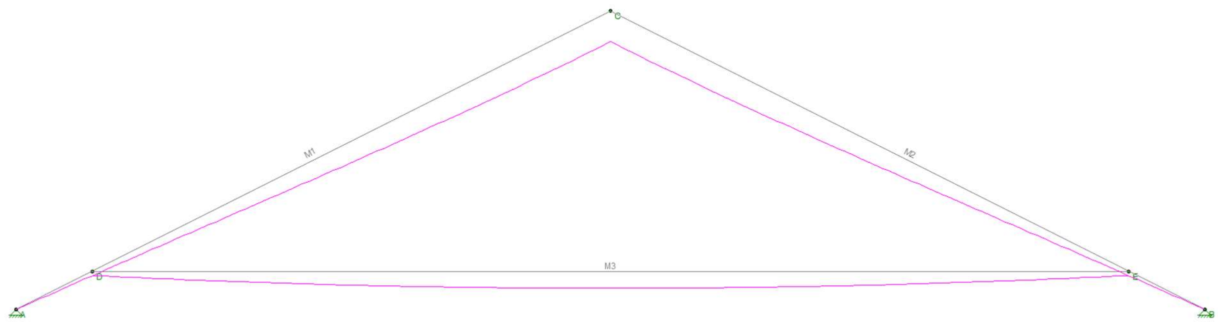


Shear

Moment



Deflection



Joint Deflections (By Combination)

	L...	Joint Label	X [in]	Y [in]	Z [in]	X Rotat...	Y Rotat...	Z Rotat...
1	1	A	0	0	0	0	0	-1.162e-03
2	1	B	0	0	0	0	0	1.162e-03
3	1	C	0	-.12	0	0	0	0
4	1	D	0	-.017	0	0	0	-1.218e-03
5	1	E	0	-.017	0	0	0	1.218e-03

Member Force Analysis

Member Section Forces (By Combination)

Sections | Maximums | End Reactions

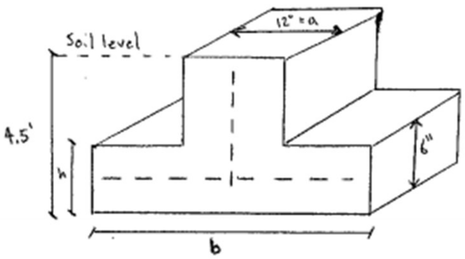
	L...	Member Label	Sec	Axial[k]	y Shea...	z Shea...	Torque[k-ft]	y-y Moment[k-ft]	z-z Moment[k-ft]
1	1	M1	1	7.252	-.022	0	0	0	0
2			2	7.169	.02	0	0	0	.015
3			3	7.169	.02	0	0	0	-.028
4			4	7.169	.02	0	0	0	-.071
5			5	7.169	.02	0	0	0	-.114
6	1	M2	1	7.169	-.02	0	0	0	-.114
7			2	7.169	-.02	0	0	0	-.071
8			3	7.169	-.02	0	0	0	-.028
9			4	7.169	-.02	0	0	0	.015
10			5	7.252	.022	0	0	0	0
11	1	M3	1	.093	0	0	0	0	-.011
12			2	.093	0	0	0	0	-.011
13			3	.093	0	0	0	0	-.011
14			4	.093	0	0	0	0	-.011
15			5	.093	0	0	0	0	-.011

Member Stress Analysis

Member Section Stresses (By Combination)

	L...	Member Label	Sec	Axial[ksi]	y Shea...	z Shea...	y top Be...	y bot B...	z top B...	z bot B...
1	1	M1	1	.879	-.004	0	0	0	0	0
2			2	.869	.004	0	-.023	.023	0	0
3			3	.869	.004	0	.045	-.045	0	0
4			4	.869	.004	0	.113	-.113	0	0
5			5	.869	.004	0	.181	-.181	0	0
6	1	M2	1	.869	-.004	0	.181	-.181	0	0
7			2	.869	-.004	0	.113	-.113	0	0
8			3	.869	-.004	0	.045	-.045	0	0
9			4	.869	-.004	0	-.023	.023	0	0
10			5	.879	.004	0	0	0	0	0
11	1	M3	1	.018	0	0	.044	-.044	0	0
12			2	.018	0	0	.044	-.044	0	0
13			3	.018	0	0	.044	-.044	0	0
14			4	.018	0	0	.044	-.044	0	0
15			5	.018	0	0	.044	-.044	0	0

Appendix D: Foundation Calculation



Soil Density = 90 pcf

Allowable bearing pressure $[q_n]$ = $3.0\, k/ft^2$

Compressive Strength $[f'_c]$ = 4 ksi

Stress $[f_y]$ = 60 ksi

Weight of Concrete = 150 pcf

Dead Load [D] = 50 k / 270 ft = 0.2 k/ft ↑ 1.0 k/ft

Live Load [L] = 756 k / 270 ft = 2.8 k/ft

Wall Footing Design

(1) $q_e = q_n - q_{soil} - q_{self}$

$q_e = [3.0\, k/ft^2] - [(4.5\,ft - 0.5\,ft)(0.09\, k/ft^3)] - [(0.5\,ft)(0.15\, k/ft^3)]$

$q_e = [3.0\, k/ft^2] - [0.36\, k/ft^2] - [0.075\, k/ft^2]$

$q_e = 2.565\, k/ft^2$

(2) $b_{required} = \dfrac{D + L}{q_e}$ * design for b = 20" *

$b_{req} = \dfrac{1.0\, k/ft + 2.8\, k/ft}{2.565\, k/ft^2}$

$b_{req} = 1.5\, ft = 18" = b$

(3) $q_u = \dfrac{1.2(D) + 1.6(L)}{b}$

$q_u = \dfrac{1.2(1.0\, k/ft) + 1.6(2.8\, k/ft)}{(20")\left(\frac{1 ft}{12"}\right)}$

$q_u = 3.4\, k/ft^2$

(4) $M_u = \frac{1}{2} q_u \left(\frac{b-a}{2}\right)^2$

$M_u = \frac{1}{8}(3.4\, k/ft^2)(1.67' - 1')^2$

$M_u = 0.19\, k$

(5) $d = h - 3"$ $d = 6" - 3" = 3"$

$V_u = q_u\left(\frac{b-a}{2} - d\right) = (3.4\, k/ft^2)\left(\frac{1.67' - 1'}{2} - 0.25'\right)$

$V_u = 0.29$

$\phi V = \phi 2 \sqrt{f'_c}\, b\, d = (0.75)(2)\frac{\sqrt{4000\, lb}}{1000}(12")\, d$

$d \geq 0.21' = 2.5"$ [ACI clear cover = 3"]

$d = 3"$

(6) A_s [area of steel] for 1 ft width, assume a = 3"

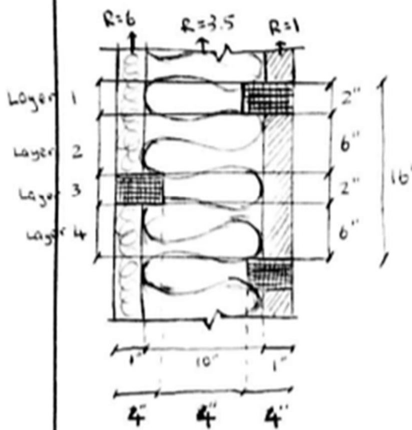
$A_s = \dfrac{M_u}{\phi f_y (d - \frac{a}{2})} = \dfrac{0.19\, k}{(0.75)(60\, ksi)(3 - \frac{3}{2})}$

$A_s = 0.003$

one #2 reinforcement : No. 2 rebar with diameter of 0.25 inches

Appendix E: Written Wall Insulation Calculation

Wall Insulation



$$R_{L1} = 6 + 7'' \times 3.5 + 4.75 = 35.23$$

$$R_{L2} = 6 + 10'' \times 3.5 + 1 = 42$$

$$R_{L3} = 4.75 + 7'' \times 3.5 + 1 = 30.25$$

$$R_{L4} = R_{L2} = 42$$

$$U_{L1} = \frac{1}{R_{L1}} = 0.028$$

$$U_{L2} = U_{L4} = \frac{1}{R_{L2}} = \frac{1}{R_{L4}} = 0.024$$

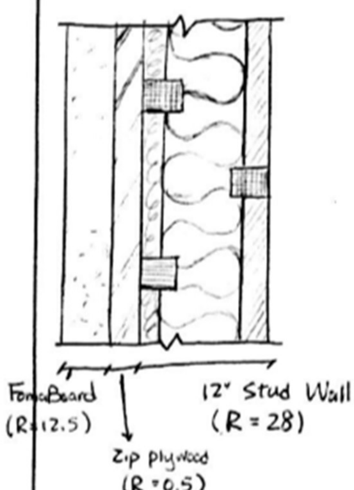
$$U_{L3} = \frac{1}{R_{L3}} = 0.033$$

$$U_{total} = U_{L1} \times \left(\frac{2''}{16''}\right) + U_{L2} \times \left(\frac{6''}{16''}\right) + U_{L3} \times \left(\frac{2''}{16''}\right) + U_{L4} \times \left(\frac{6''}{16''}\right)$$

$$= 0.026$$

$$R_{total} = \frac{1}{U_{total}} = 37.9 \quad \text{(per 16")}$$

$$R_{(pre\ 12")} = 28$$



$$R_{total} = 12.5 + 0.5 + 28 = 40$$

Double Stud R-40 Wall

Appendix F: Heating and Cooling Load Calculation Manual

Table 7.2 Summary of Procedures for Residential Heating and Cooling Load Calculations

q = Sensible heating or sensible cooling load except for q_{total}, Btu/hr
Δt = Design temperature difference between inside and outside air except as noted otherwise, deg F
A = Area in square ft. of the applicable load source
U = U-values for the appropriate construction, Btu/(hr · ft^2 F)

Load Source	Heating	Cooling
Glass and window areas	$q = U_G \times \Delta t \times$ Area q = (HLF) × A where HLF = $U_G \times \Delta t$ Solar effects are neglected for heating load considerations.	q = CLF × Area Glass Cooling Load Factors, CLF, are found in Table 7.6 according to window orientation, type of glass, type of interior shading, and outdoor design temperature. See Table 7 7 for the effect of shading due to overhangs. The CLF includes effects of both transmission and solar radiations.
Doors	$q = U_D \times \Delta t \times$ Area q = (HLF) × A where HLF = $U_D \times \Delta t$ Note: Glass in the doors should be treated as window area and the net door area used for this calculation.	q = (CLF) × Area Table 7.8 for Δt CLF = $U_D \times \Delta t$ Note: Glass in the doors should be treated as window area and the net door area used for this calculation.
Above-grade exterior walls	$q = U_W \times \Delta t \times$ Area q = (HLF) × A where HLF = $U_W \times \Delta t$ Table 7.4 for U_w	q = (CLF) × Area Tables 7.4 and 7.8 CLF = $U_w \times \Delta t$
Partitions to unconditioned space	$q = U_p \times A \times \Delta t$ where Δt is the temperature difference across the partition	$q = U_p \times A \times \Delta t$ where Δt is the temperature difference across the partition
Below-grade portions of exterior walls (with basement floor level more than 3 ft below grade)	$q = U_{bg} \times A \times \Delta t_{bg}$ Δt_{bg} : Below-grade temperature difference. The ground temperature (t_{bg}) is found by the equation $t_{bg} = t_A - A$ Temperature fluctuation amplitude for the region (Fig. 7.2) Average winter air temperature for the location (Table 7.1) Δt_{bg} is then given by $\Delta t_{bg} = t_{basement} - t_g$ A: Below-grade wall area U_{bg} : Average U-value for a below-grade insulated wall, (Table 7.10A) For an uninsulated wall use U = 0.60. However, this may not meet energy conservation standards.	Not applicable (In fact, some cooling is usually provided by the below-grade wall area)
Ceilings and roofs	$q = U_R \times \Delta t \times$ Area q = (HLF) × A where HLF = $U_R \times \Delta t$ Table 7.4 for U_R	q = (CLF) × Area Tables 7.4 and 7.8 CLF = $U_R \times \Delta t$
Exposed floors	$q = U_F = \Delta t \times$ Area q = (HLF) × A where HLF = $U_R \times \Delta t$	$q = U_F \times \Delta t \times$ Area = (CLF) × Area Table 7.8 for Δt
Basement floors (more than 3 ft below grade)	$q = \text{HL} \times \Delta t_{bg} \times$ Area Below-grade temperature difference. See "Below grade exterior walls" Section. Heat Loss rate from Table 7.10B	Not applicable
Slab floors (less than 3 ft below grade)	q = (HLF) × ft Feet of exposed perimeter Heat Load Factor given in Table 7.9A or Table 7.9B	Not applicable
Infiltration	$q = 1.10 \times (\text{cfm}_H) \times \Delta t$ or q = HLF × Floor Area where Δt is the design indoor-outdoor temperature difference for heating. Tables 7.11A, 7.11B and 7.12	$q = 1.10\ (\text{cfm}_C) \times \Delta t$ or q = CLF × Floor Area where Δt is the summer design indoor-outdoor temperature difference. Tables 7.11A, 7.11 C and 7.12
Internal loads - people, appliances and lights	Not applicable	225 Btu/hr per person, divided evenly among the rooms not used as bedrooms. If the number of occupants is not known, assume 2 people per bedroom. 1200 Btu/hr is usually added to the kitchen load for appliances.
Total loads	q_{total} = sum of the individual sensible heating loads	q_{total} = (1.3 or 1.2) × (sum of individual sensible cooling loads) For arid climates, use 1.2. For all other applications use a value of 1.3. This factor allows for the latent cooling loads as a fraction of the sensible cooling load.

Table 7.3 Design Conditions

Item	Heating	Cooling
Outdoor Design Temperatures[2]	Table 2.1 97 1/2% values	Table 2.1 2 1/2% values
Design Wind Speeds	15 mph	7 1/2 mph
Indoor Design Conditions	72 F dry bulb. If humidification is provided, it shall be designed to a maximum relative humidity of 30%	75 F dry bulb with a temperature swing of 3 deg F
Design Temperature Difference	[Indoor Design Temp.] − [Outdoor Design Temp.]	[Outdoor Design Temp.] − [Indoor Design Temp.]
Mean Daily Range Classifications		Table 2.1 Represents the difference between the average daily maximum and average daily minimum temperatures for each station Low (L) - Less than 15 deg F daily range Medium (M) - 15 deg F to 25 deg F daily range High (H) - More than 25 deg F daily range
Average Winter Air Temperature	Table 7.1	Not Applicable
Degree Days	Base 65 F, Table 7.1	

[1]ASHRAE Standard 90-75 and HUD/MPS Revision 5a; May, 1977.
[2]Adjustments may be made to reflect local climates which differ from the tabulated data, and local weather data may be used for locations not listed.

Table 7.4 Adjusted U-Value for Some Insulated Walls and Roofs with Wood Framing Members (Winter Conditions)

Construction	Wood Members, Nominal Sizes	U-Value At Wood Section	% Wood Framing For Surface	Air Space	Between Studs or Joists or Furring R 7	R 11	R 19	R 30	R 38
Roof/Ceiling, Combined Asphalt shingles, felt membrane, plywood sheathing, gypsum wallboard, with foil backing	2-in. × 4-in., 16-in. o.c.	0.145	*	0.213	0.086	0.074			
			9.4	0.207	0.092	0.081			
			15	0.203	0.095	0.085			
	2-in. × 6-in. 16-in. o.c.	0.106	*	0.213	0.086	0.064	0.046		
			9.4	0.203	0.088	0.068	0.052		
			15	0.197	0.089	0.070	0.055		
Ceiling Metal lath & plaster, joists, no floor above	Joists 2-in. × 8-in., 16-in. o.c.	0.093	*	0.592	0.115	0.079	0.048	0.032	0.025
			9.4	0.545	0.113	0.080	0.052	0.038	0.029
			15	0.517	0.112	0.081	0.055	0.041	0.031
Frame Wall Wood siding, sheathing, framing, gypsum wall board or plaster (approximately the same values can be used for brick veneer and for metal siding with insulated frame walls)	2-in. × 4-in. 16-in. o.c.	0.128	*	0.225	0.087	0.069			
			9.4	0.216	0.091	0.074			
			15	0.210	0.093	0.078			
			20	0.206	0.095	0.081			
	2-in. × 4-in. 16-in. o.c. with insulated sheathing of $R = 5$	0.087	*	0.123	0.066	0.055			
			9.4	0.120	0.068	0.058			
			15	0.118	0.069	0.060			
			20	0.116	0.070	0.061			
	2-in. × 6-in. 24-in. o.c.	0.097	*	0.225	0.087	0.069	0.045		
			6.3	0.217	0.088	0.071	0.048		
			10	0.212	0.088	0.072	0.050		
			15	0.206	0.089	0.073	0.053		
Masonry Wall 8-in. concrete block, furring, dry wall with foil backing	2-in. × 1-in., 16-in. o.c. (Flat)	0.240	*	0.167	0.098				
			9.4	0.174	0.111				
	2-in. × 2-in., 16-in. o.c.	0.196	*	0.176	0.098	0.070			
			9.4	0.178	0.107	0.082			

*U-Values for the section between wood members.

Table 7.5 Approximate Thickness of Insulation for Thermal Resistances, in.

Thermal Resistance of Insulation	Batts or Blankets		Loose Fill			Boards and Slabs	
	Glass Fiber	Rock Wool	Glass Fiber	Rock Wool	Cellulosic	Polyurethane	Cellular Glass
R-7	2 1/4 to 2 3/4	2	3 to 4	2 to 3	2	1	2 5/8
R-11	3 1/2 to 4	3	5	4	3	1 3/4	4 1/4
R-13	3 5/8	3 1/2	6	4 to 5	4	2	5
R-19	6 to 6 1/2	5 1/4	8 to 9	6 to 7	5	3	7 1/4
R-22	6 1/2	6	10	7 to 8	6	3 1/2	8 3/8
R-30	9 1/2 to 10 1/2	9	13 to 14	10 to 11	8	4 3/4	11 3/8
R-38	12 to 13	10 1/2	17 to 18	13 to 14	10 to 11	6	14 1/2

Table 7.6 Design Cooling Load Factors Through Glass

Outdoor	Regular Single Glass						Regular Double Glass						Heat Absorbing Double Glass						Clear Triple Glass		
Design Temp	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95	100	105	110	85	90	95
No Awnings or inside Shading																					
North	23	27	31	35	39	44	19	21	24	26	28	30	12	14	17	19	21	23	17	19	20
NE and NW	56	60	64	68	72	77	46	48	51	53	55	57	27	29	32	34	36	38	42	43	44
East and West	81	85	89	93	97	102	68	70	73	75	77	79	42	44	47	49	51	53	62	63	64
SE and SW	70	74	78	82	86	91	59	61	64	66	68	70	35	37	40	42	44	46	53	55	56
South	40	44	48	52	56	61	33	35	38	40	42	44	19	21	24	26	28	30	30	31	33
Horiz. Skylight	160	164	168	172	176	181	139	141	144	146	148	150	89	91	94	96	98	100	126	127	129
Draperies or Venetian Blinds																					
North	15	19	23	27	31	36	12	14	17	19	21	23	9	11	14	16	18	20	11	12	14
NE and NW	32	36	40	44	48	53	27	29	32	34	36	38	20	22	25	27	29	31	24	26	27
East and West	48	52	56	60	64	69	42	44	47	49	51	53	30	32	35	37	39	41	38	39	41
SE and SW	40	44	48	52	56	61	35	37	40	42	44	46	24	26	29	31	33	35	32	33	34
South	23	27	31	35	39	44	20	22	25	27	29	31	15	17	20	22	24	26	18	19	21
Roller Shades Half-Drawn																					
North	18	22	26	30	34	39	15	17	20	22	24	26	10	12	15	17	19	21	13	14	15
NE and NW	40	44	48	52	56	61	38	40	43	45	47	49	24	26	29	31	33	35	34	35	35
East and West	61	65	69	73	77	82	54	56	59	61	63	65	35	37	40	42	44	46	49	49	50
SE and SW	52	56	60	64	68	73	46	48	51	53	55	57	30	32	35	37	39	41	41	42	43
South	29	33	37	41	45	50	27	29	32	34	36	38	18	20	23	25	27	29	25	26	26
Awnings																					
North	20	24	28	32	36	41	13	15	18	20	22	24	10	12	15	17	19	21	11	12	13
NE and NW	21	25	29	33	37	42	14	16	19	21	23	25	11	13	16	18	20	22	12	13	14
East and West	22	26	30	34	38	43	14	16	19	21	23	25	12	14	17	19	21	23	12	13	14
SE and SW	21	25	29	33	37	42	14	16	19	21	23	25	11	13	16	18	20	22	12	13	14
South	21	24	28	32	36	41	13	15	18	20	22	24	11	13	16	18	20	22	11	12	13

Table 7.7 Shade Line Factors

Direction	N Latitude, Deg						
Window Faces	25	30	35	40	45	50	55
E/W	0.8	0.8	0.8	0.8	0.8	0.8	0.8
SE/SW	1.9	1.6	1.4	1.3	1.1	1.0	0.9
S	10.1	5.4	3.6	2.6	2.0	1.7	1.4

Note: Distance shadow line falls below the edge of the overhang equals shade line factor multiplied by width of overhang. Values are averages for 5 hr of greatest solar intensity on August 1.

Table 7.8 Design Equivalent Temperature Differences

Design Temperature, deg F	85		90			95			100		105	110
Daily Temperature Range [a]	L	M	L	M	H	L	M	H	M	H	H	H
WALLS AND DOORS												
1. Frame and veneer-on-frame	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
2. Masonry walls, 8-in. block or brick	10.3	6.3	15.3	11.3	6.3	20.3	16.3	11.3	21.3	16.3	21.3	26.3
3. Partitions, frame	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
masonry	2.5	0	7.5	3.5	0	12.5	8.5	3.5	13.5	8.5	13.5	18.5
4. Wood doors	17.6	13.6	22.6	18.6	13.6	27.6	23.6	18.6	28.6	23.6	28.6	33.6
CEILINGS AND ROOFS [b]												
1. Ceilings under naturally vented attic or vented flat roof—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
2. Built-up roof, no ceiling—dark	38.0	34.0	43.0	39.0	34.0	48.0	44.0	39.0	49.0	44.0	49.0	54.0
—light	30.0	26.0	35.0	31.0	26.0	40.0	36.0	31.0	41.0	36.0	41.0	46.0
3. Ceilings under unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
FLOORS												
1. Over unconditioned rooms	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0
2. Over basement, enclosed crawl space or concrete slab on ground	0	0	0	0	0	0	0	0	0	0	0	0
3. Over open crawl space	9.0	5.0	14.0	10.0	5.0	19.0	15.0	10.0	20.0	15.0	20.0	25.0

[a] Daily Temperature Range
L (Low) Calculation Value: 12 deg F. Applicable Range: Less than 15 deg F.
M (Medium) Calculation Value: 20 deg F. Applicable Range: 15 to 25 deg F.
H (High) Calculation Value: 30 deg F. Applicable Range: More than 25 deg F.

[b] Ceiling and Roofs: For roofs in shade, 18-hr average = 11 deg temperature differential. At 90 deg F design and medium daily range, equivalent temperature differential for light-colored roof equals $11 + (0.71)(39 - 11) = 31$ deg F.

Table 7.9A Heat Loss of Concrete Floors at or Near Grade Level per Foot of Exposed Edge (less than 3 ft Below Grade)

Outdoor Design Temperature, F	Heat Loss per Foot of Exposed Edge, Btu/(hr·ft) R = 5.0 Edge Insulation	R = 2.5 Edge Insulation	No Edge Insulation [a]
−20 to −30	50	60	75
−10 to −20	45	55	65
0 to −10	40	50	60
+10 to 0	35	45	55
+20 to +10	30	40	50

[a] This construction not recommended; shown for comparison only.

Table 7.9B Floor Heat Loss to be Used When Warm Air Perimeter Heating Ducts Are Embedded in Slabs[a] [Btu/hr per (linear foot of heated edge)]

Outdoor Design Temperature, F	Edge Insulation		
	R = 2.5 Vertical Extending Down 18 in. Below Floor Surface	R = 2.5 L-Type Extending at Least 12 in. Deep and 12 in. Under	R = 5 L-Type Extending at Least 12 in. Down and 12 in. Under
−20	105	100	85
−10	95	90	75
0	85	80	65
10	75	70	55
20	62	57	45

[a] Factors include loss downward through inner area of slab.

Table 7.10A Heat Loss for Below-Grade Walls with Insulation on Inside Surface — (For walls extending more than 3 ft below grade) Average Btu/(hr·ft²·F)

Distance Wall Extends Below-Grade,* ft	Insulation Over Full Surface			Wall Insulated to a Depth of Two Feet Below Grade		
	R-4	R-8	R-13	R-4	R-8	R-13
4	0.110	0.075	0.057	0.136	0.102	0.090
5	0.102	0.071	0.054	0.128	0.100	0.091
6	0.095	0.067	0.052	0.120	0.097	0.089
7	0.089	0.064	0.050	0.112	0.093	0.086

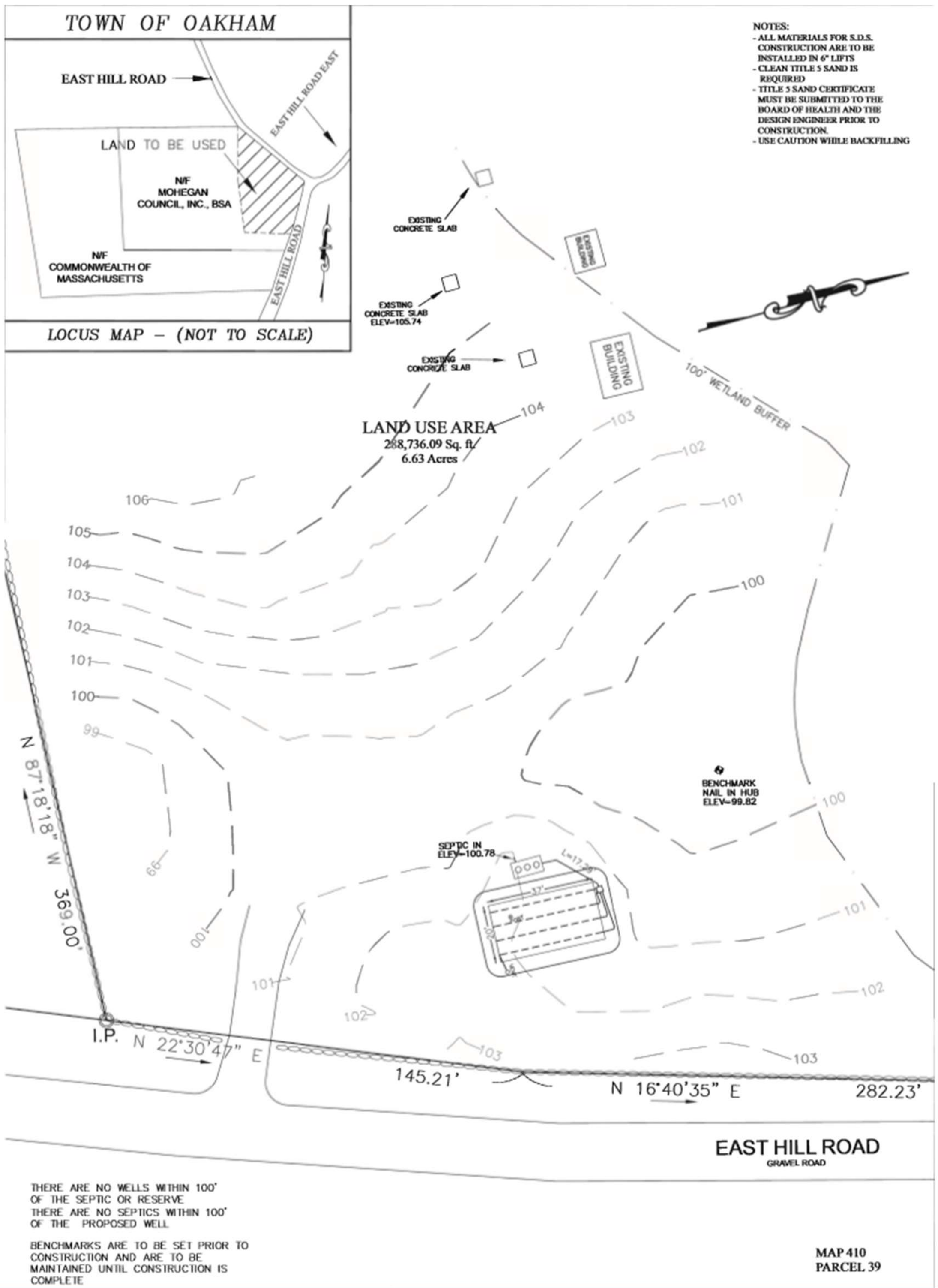
* For a depth below-grade of 3 feet or less, treat as a slab on grade.

Table 7.10B Heat Loss Through Basement Floors (For Floors more than 3 ft below grade) Btu/(hr·ft²·F)

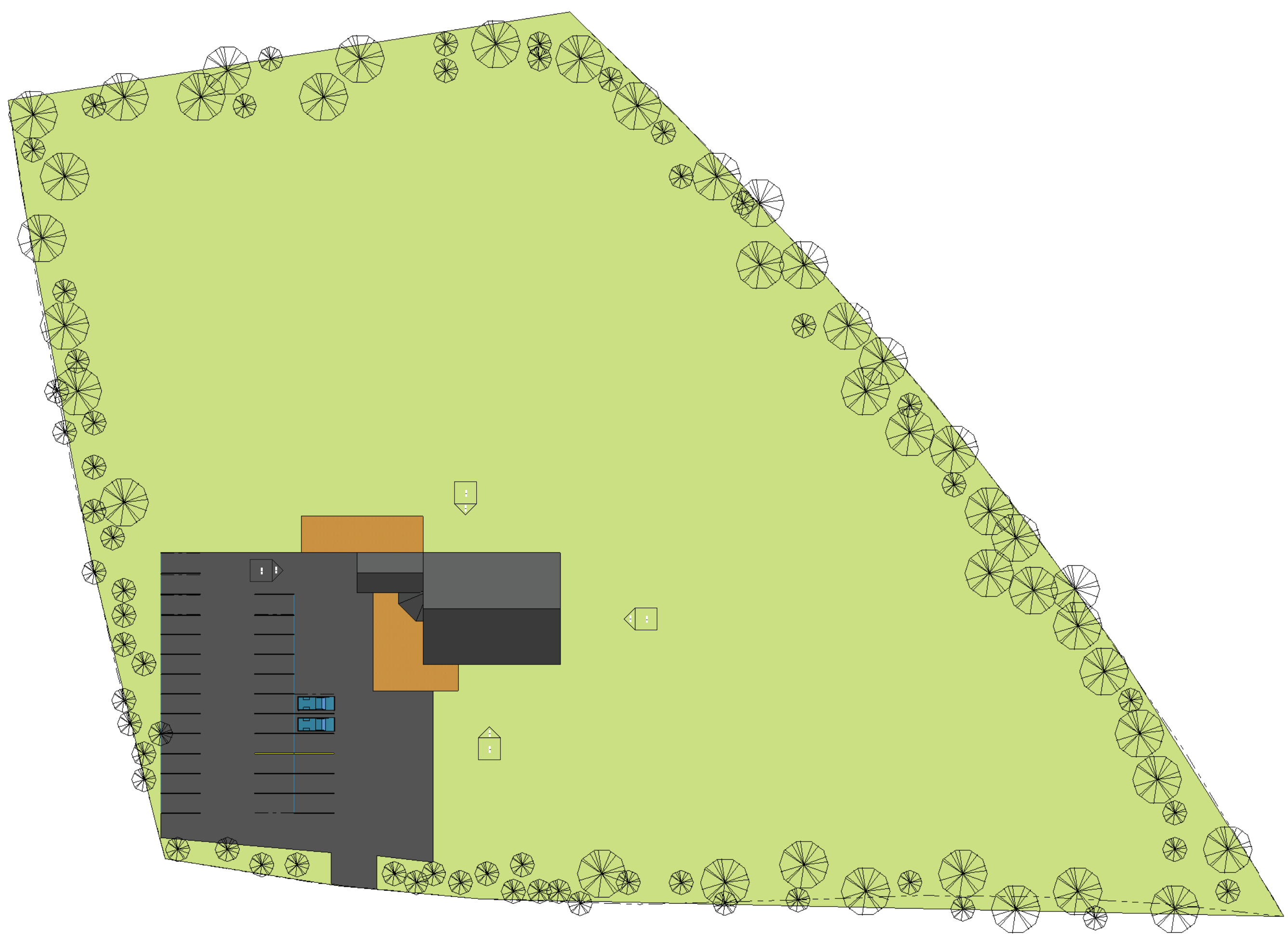
Depth of Foundation Wall Below Grade,* ft	Width of House, ft 20	24	28	32
4	0.035	0.032	0.027	0.024
5	0.032	0.029	0.026	0.023
6	0.030	0.027	0.025	0.022
7	0.029	0.026	0.023	0.021

*For a depth below-grade of 3 feet or less, treat as a slab on grade.

<u>Appendix G: Site</u>



<u>Appendix H: Full Drawing Set</u>



① Site
1" = 20'-0"

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Site Plan

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Scale 1" = 20'-0"

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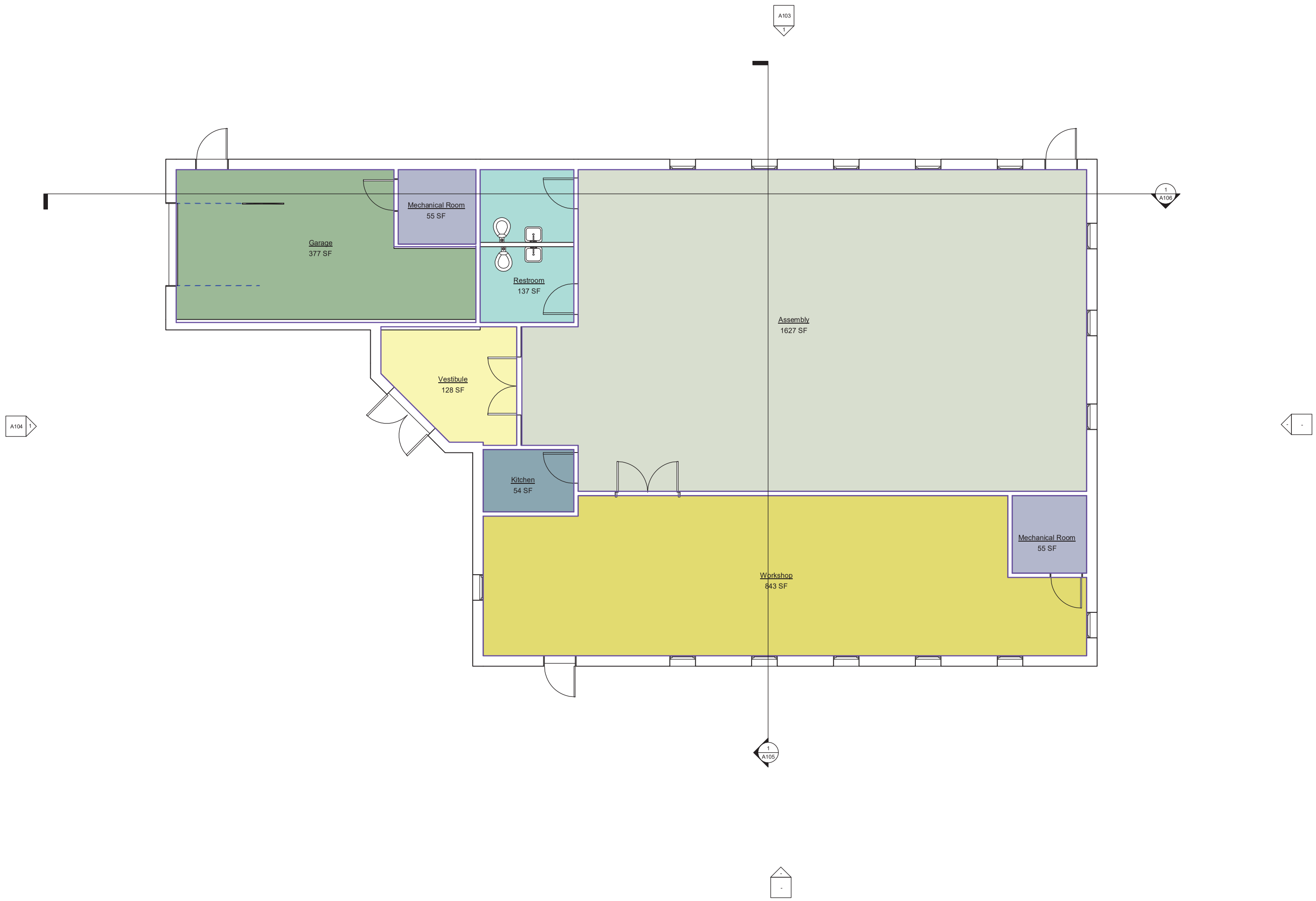

Level 1
1/4" = 1'-0"

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Floor plan

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Scale 1/4" = 1'-0"

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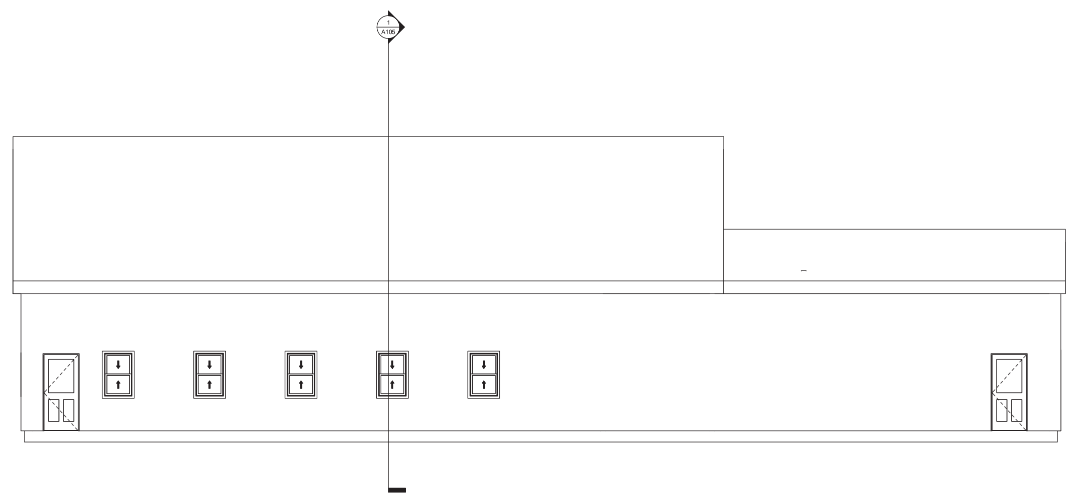

1 North
1/4" = 1'-0"

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Elvation- North

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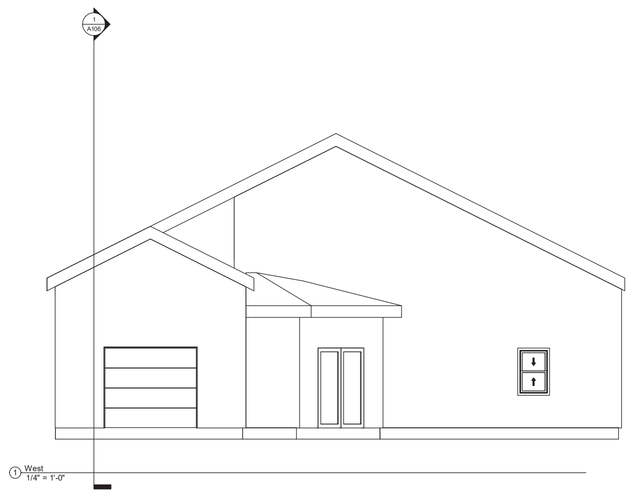

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Scale 1/4" = 1'-0"

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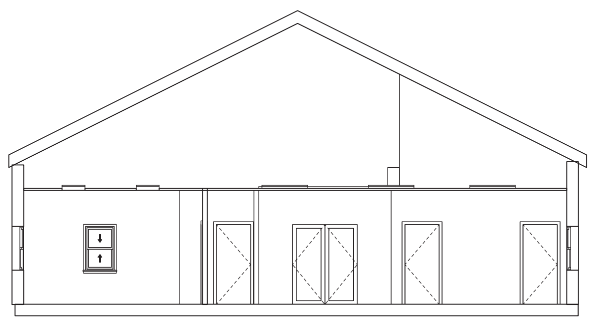

Section 1
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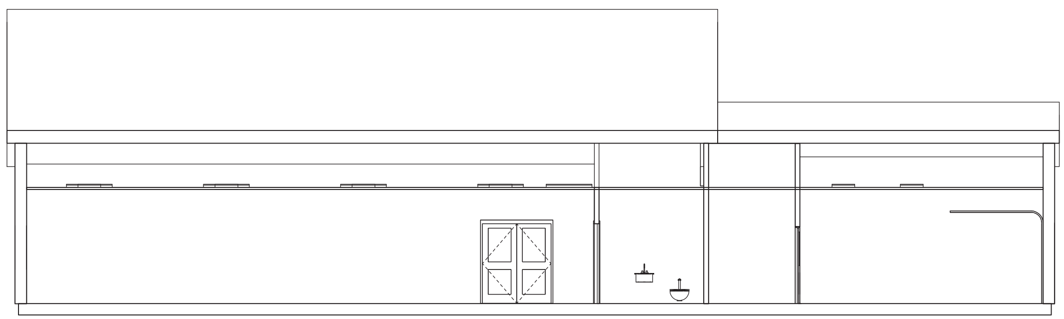

① Section 2
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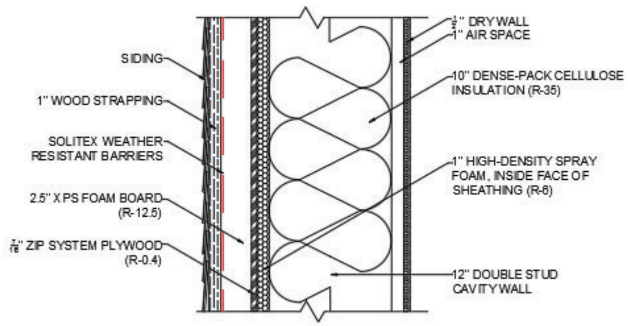
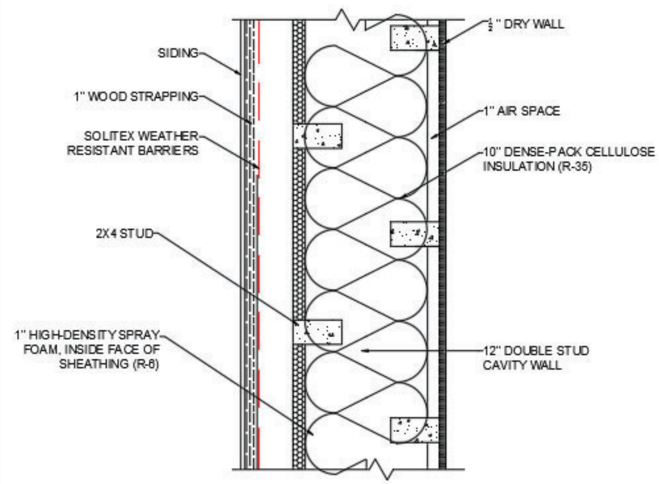


Side Section View



Top Section View

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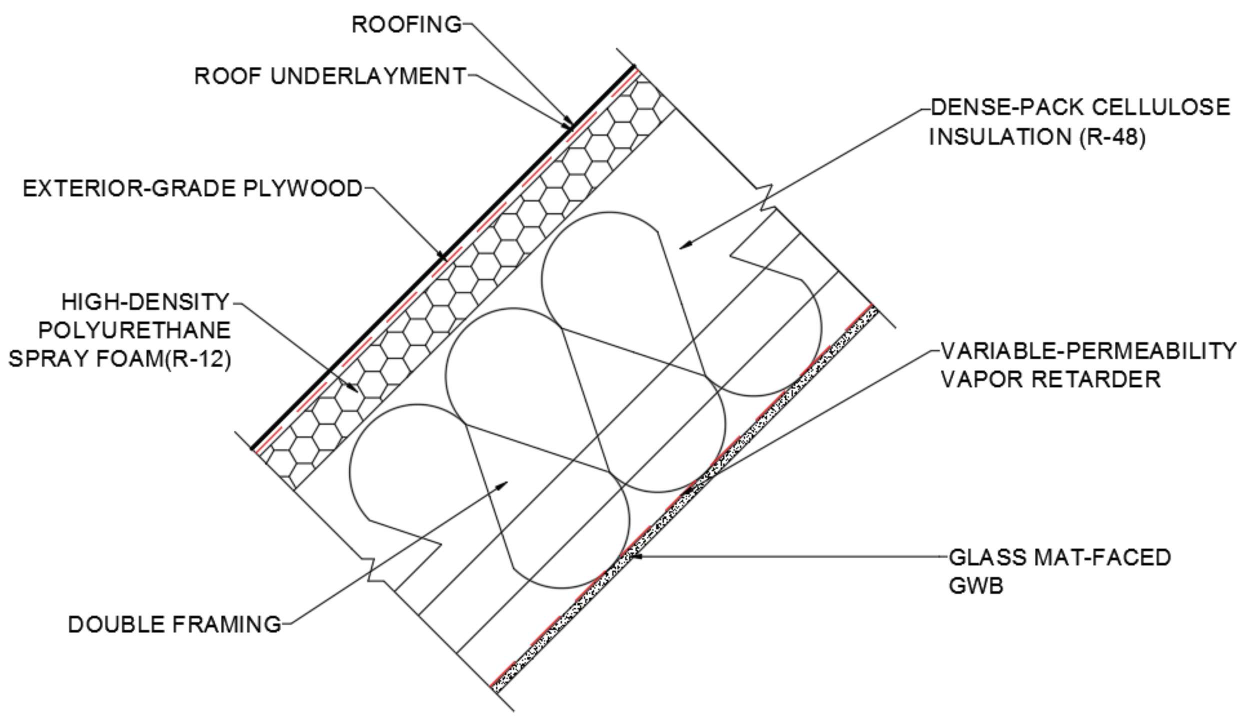

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