Designing a Tiny House on Wheels for Wildfire and Indoor Air Quality Research and Teaching

Final Report Submitted to:
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Abstract

As the effects of climate change become more prevalent, along with rising temperatures and droughts, the risk of wildfires has also increased. While there is ongoing research in labs that replicate the wildfire atmosphere, it is impossible to account for every variation that could affect research. Additionally, conducting a field study in occupied residential homes would pose significant challenges in terms of timely organization and setup of experimental equipment. Therefore, our goal was to design a portable research space that could be transported to locations around the US that are impacted by wildfires, perform live research, and produce accurate results. In the future, this research could help come up with solutions to completely eliminate harmful exposure to wildfire smoke.

Executive Summary

As climate change becomes more prevalent, with it comes an increase in natural disasters such as droughts and wildfires. These wildfires have been predicted to be larger in size and last longer than those in the past, burning down more acreages and negatively affecting the surrounding air quality. With poor air quality comes negative health effects and costs to society, such as hospital visits or even deaths from respiratory issues. One of the biggest problems with wildfire smoke is that it is easily carried by the wind and can infiltrate surrounding areas within a radius of three thousand miles. Therefore, researching the direct impacts of wildfire smoke on indoor air quality is important. While there is ongoing research in labs that replicate the wildfire atmosphere, it is impossible to account for every variation that could affect research. Our goal is to design a portable research space that can be transported to locations that are impacted by wildfires, perform viable research, and produce relevant results. In the future, this research could help come up with solutions to completely eliminate harmful exposure to wildfire smoke.

Studies have shown that outdoor pollutants can enter indoor spaces via mechanical ventilation (heating and/or cooling systems), natural ventilation (open windows or doors), or infiltration through a building's leaks and/or cracks. Just within the past year, nearly 1/7 of Americans have been exposed to dangerous air quality caused by wildfire smoke. Many schools in the United States have air quality labs that research air quality, pollution, and sustainability; however, this research is limited due to the immobility of the labs. While there are a couple of live-in labs that research air quality, their scope does not include the effects of wildfires.

A tiny home is defined as a house that is less than 400 square feet (not including the loft area) and it has become an increasingly popular movement because it can alleviate financial difficulties and homelessness. Tiny living is less expensive than owning a modern-sized house and can either be built on a permanent foundation or portable foundation via trailers for those who prefer traveling. While tiny homes on wheels offer a lot more freedom, there are two major restrictions to be aware of. The first is those who want to go tiny must research laws and regulations in their respective state (as it differs state-to-state) to ensure their tiny home is within code. The second consideration is that in addition to the 400 square feet restriction, trailers must not exceed 40 ft long or 8.5 ft wide, and the tiny home can't be taller than 13.4 ft in order to fit under the average bridge.

The trailer of a tiny home on wheels is extremely important because, in addition to meeting size restrictions, it must be strong enough to carry the weight of the tiny home (from framing and insulation to appliances and amenities). It must also be durable enough to withstand wind loads and vibrations from transportation. When choosing trailers, each trailer's load capacity, gross vehicle weight rating (GVWR), axle connection, and dimensions were compared to maximize strength. In the end, one of the most popular tiny home trailers, Iron Eagle's PAD20k30 trailer, was chosen as it was designed specifically as a tiny home foundation.

This project was broken down into three goals. The first was to design a versatile tiny home/research lab to study indoor air quality from wildfire smoke. This would allow researchers to travel between states and study the effects of wildfire smoke in different areas. To ensure the design is safe during transport, structural calculations were done. The second goal was to design an exterior structure that represents the modern construction of residential homes in a community at risk of wildfires. Because the western region is the most susceptible area to a wildfire outbreak, the tiny home design resembles a modern Californian residence that is up to the International Residence Code (IRC). The last goal is for the tiny home to be a comfortable living space. Since the space is small, and aimed to house one to two researchers, it is important to design for both functionality and comfort. The plan is to conduct research for about one month per location, and either park the tiny home in a trailer park, where there are water and electricity hook-ups, or ask for permission to stay on a resident's property.

After the initial design process, the final design embodied all the goals of this project. The construction of the tiny home was to replicate a typical Californian residence fit with fiber-cement siding and a standing seam metal roof. The construction details drawn took several iterations to understand the system and its ability to perform adequately. The 255 square-foot design includes space for research, a typical kitchen and bathroom, a lofted bedroom, and finally a mechanical closet to house various equipment.

A structural analysis was performed to ensure that the wood frame was strong enough to withhold the stress and strain of the tiny home while driving and stationary. An analysis was also performed on the trailer to confirm that it could hold the weight of the tiny home while stationary and mobile. The structural analysis concluded that the trailer and framing are stable enough to hold the load of the home while stationary and mobile.

The air leakage area was also calculated based on three changing variables: 1) location, where average temperature and wind speeds would change, 2) shelter class, affecting how much shielding the tiny home might experience, and 3) air change rate, taking into consideration different home ventilation rates. These calculations can be used during research to determine different types of home ventilation.

An HVAC and MEP system analysis was also done to determine battery size. Appliances were chosen based on reviews from within the tiny home communities, and the total energy and voltage consumption was found using an estimated appliance usage timeline. Two 74V-2.1kWh batteries and an inverter were included. To test them, two, 9-day periods, with varying sun absorption through a 3.4kW solar power system, were graphed. It was concluded that the battery and amenities would run well together and the batteries would never get completely depleted. In addition, to maximize comfort, a 40-gallon freshwater tank and a 30-gallon gray water tank were included in the final design. To get rid of the need for a black water tank, the typical household toilet is replaced with a composting toilet. Lastly, to maintain a comfortable interior temperature, a ductless mini-split would be the best decision as it could be run as both an air conditioner and a heater, depending on what is needed for wherever the tiny home is parked.

A space was designed that could function both as a tiny home and a research facility, to learn more about the connection between wildfire smoke and indoor air quality. Structural calculations were performed to ensure the safety and durability of the tiny home, and a Revit model visually shows the interior and exterior layout of the tiny home. Heating and cooling loads were calculated to determine proper insulation, and energy calculations were done to see how much energy the tiny home consumes. Lastly, HVAC systems and amenities were chosen to provide maximum comfort and meet basic necessities.

In the next step of this project, there are a few recommendations. The first is to look into the specific research equipment that will be used to see how it would affect the battery. Additionally, it is recommended to furnish the interior with a variety of different types of fabrics to replicate the abundance of materials found in homes and how they might absorb smoke pollutants differently. Lastly, it is acknowledged that there are situations that will arise during the construction phase that could not be predicted during the design phase

Acknowledgements

We would like to thank all the people who have helped us throughout the entirety of this project. First, we would like to thank our advisors, Professor Shichao Liu, Professor Steven Van Dessel, and Professor Nima Rahbar for their guidance, support, and feedback throughout this project. We would also like to thank Professor Leonard Albano and Professor Tahar El-Korchi for their assistance in structural calculations. Their recommendations and contributions to this project were essential to the success of this project.

Authorship

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Design Statement

According to ABET Criterion 5, “the four basic architectural engineering curriculum areas are building structures, building mechanical systems, building electrical systems, and construction/ construction management. Graduates are expected to reach the synthesis (design) level in one of these areas, the application level in a second area, and the comprehension level in the remaining two areas” (ABET Criterion 5). For this MQP, the students have achieved design levels in both structural systems and mechanical systems with a focus on construction and construction management. A breakdown of each student’s accomplishments can be seen below.

Architectural Design:

Hannah Rodenbush was the Architectural Engineering (AREN) student and began our design phase by creating conceptual 3D modeling using the software Revit. This preliminary model helped us in visualizing the shape and size to create our final design. The team determined the final wall and roof assemblies based on modern Californian housing and standard code which was implemented into our model. Architectural details were also drawn to represent a theoretical construction set. Conditioning load calculations were also performed and were used to size HVAC equipment.

Mechanical Design:

Nathalie Martin-Nucatola was the Mechanical Engineering (ME) student and focused on implementing cost and weight-conscious mechanical components such as an HVAC system, solar power panels, water tanks, and basic home amenities. Solar panels on the roof and a battery unit were researched and included to aid in powering amenities such as lights, a stove, and a water heater. Additionally, a 40-gallon freshwater tank and a 6-gallon water heater were included to provide comfort to the researchers when infrequently off-grid. The ME student also calculated the difference in air leakage rates to represent smoke infiltration from wildfires. To numerically represent this, the air leakage area was calculated, respective to changing location, shelter class, and air change rate.

Civil Design:

Hannah Frank was the Civil Engineering (CE) student and performed a structural analysis of the Iron Eagle Trailer to confirm its ability to withstand various loads and forces. Structural calculations of simple wooden framed walls and roofs were made to support the structure of our tiny home in coordination with the steel beams of the trailer. The CE student also ensured that the weight of the structural and mechanical systems on the trailer were dispersed evenly and were proven to be under the limit of trailer laws and regulations.

Criterion 5 also states “the design level must be in a context that:

(a) Considers the systems or processes from other architectural engineering curricular areas,
(b) Works within the overall architectural design,
(c) Includes communication and collaboration with other design or construction team members,
(d) Includes computer-based technology and considers applicable codes and standards, and
(e) Considers fundamental attributes of building performance and sustainability” (*Criteria for Accrediting Engineering Programs*).

It is important to acknowledge that each student worked together in reaching the synthesis of each design level, and the coordination of design could not be completed without the collaboration of each team member’s role within this project. This project was also possible with the use of several computer-based programs to simulate our iterative design process.

Professional Licensure Statement

Professional licensure is referred to as “the demonstration of ability or knowledge required by law before being allowed to perform a task or job” (Licensure). According to the National Council of Examiners for Engineering and Surveying, or NCEES, gaining professional licensure allows individuals to achieve credibility in their degree of engineering and ensure competency. Licensure ensures individuals “practice in a manner that protects the health, safety, and welfare of the public by satisfying minimum qualifications in education, work experience, and exams” (Engineering Licensure, 2021).

Professionally licensed engineers (such as architectural or civil engineering) are able to add their stamp of approval to a set of drawings, calculations, and professional documentation alike. A stamp of approval is required for the permitting and legal aspects of any design.

In order to attain professional licensure in most states, the individual first must obtain a bachelor’s degree from an EAC or ABET-accredited program. At the same time, the individual also must pass the NCEES Fundamentals of Engineering (FE) exam during or after their senior or final year of undergraduate education. After passing the FE exam, the individual must obtain at least four years of “acceptable, progressive, and verifiable work experience” under a professional engineer (Engineering Licensure, 2021). This work experience is followed by passing the Practice of Engineering (PE) exam. Passing this exam is the final step to obtaining licensure. It is important to note that each state has different rules and processes for obtaining professional licensure, but the most common are described above.

Professional licensure is an important aspect to “demonstrate competency, qualification, and expertise in professional practice” (Licensure). It also shows commitment to “understanding professional, ethical and societal responsibilities” and emphasizes “the protection of the public health, safety, and welfare within society” (Licensure). This licensure defines specific standards that a professional engineer has to follow in order to create a safe and reputable design to serve the public.

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Introduction

Across the United States, wildfires have become more prevalent due to climate change and the increase in human population across the Wildland-Urban Interface (WUI). Recent trends of increased temperatures and frequency of droughts suggest that fires will "start more easily and burn hotter. These trends of longer wildfire seasons and larger wildfire size are predicted to continue more frequently and for longer periods of time" (Environmental Protection Agency). As seen in Figure 1 below, the amount of acres burned in the United States is increasing each year, reaching over 10 million acres in the year 2020.

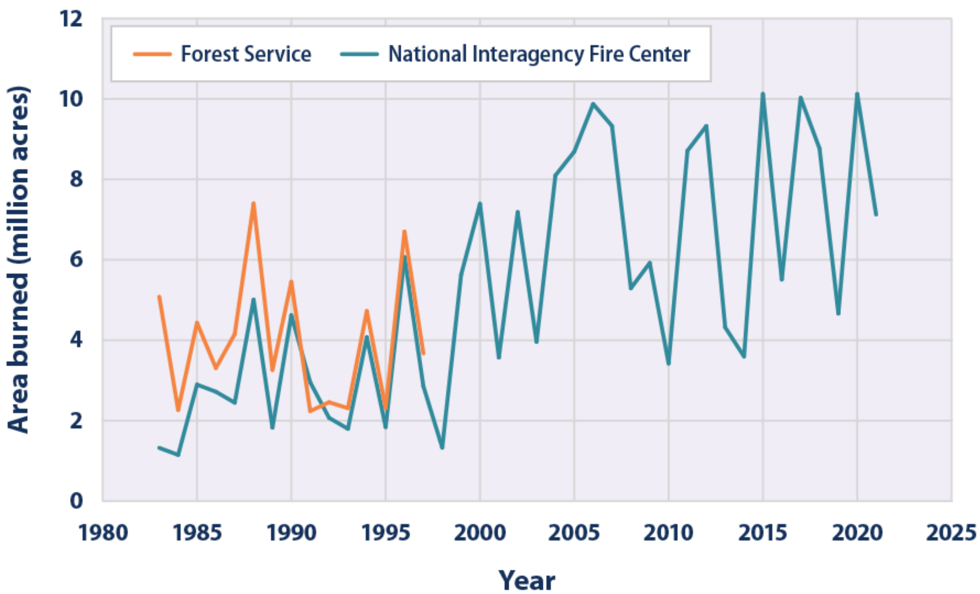

Figure 1 - "Annual wildfire-burned area (in millions of acres) from 1983 to 2021" (Environmental Protection Agency)

According to the United States Environmental Protection Agency (US EPA), "wildfire smoke has been directly linked to poor air quality that can lead to significant health effects and costs to society (emergency department visits, hospital admissions, and deaths, often due to respiratory ailments)" (Environmental Protection Agency). Smoke from wildfires lingers in the atmosphere for weeks, travels thousands of miles, and penetrates an indoor space through infiltration and ventilation. Understanding smoke transmission within buildings and their systems will shed light on the effects inhalation of wildfire smoke has on human health. There are ongoing studies of the effect of wildfire smoke on indoor air quality, however many aspects cannot be replicated within a lab such as effects from weather, human ware, or changing temperature. Replication in a representable atmosphere is necessary to achieve results that resemble as close to real-life scenarios as possible.

Studying indoor air quality (IAQ) allows for "understanding and controlling common pollutants indoors [that] can help reduce your risk of indoor health concerns. Health effects from indoor air pollutants may be experienced soon after exposure or, possibly, years later" (Environmental Protection Agency). Studying the source and cause of the pollutant, allows the possibility to decrease or eliminate harmful exposure to the individual involved.

Our goal for this project is to design a tiny house on wheels that can be towed to various locations exposed to wildfire smoke. Within our design, we want to implement an interior space where key research can be made on wildfire smoke fate and transport to gain a better understanding of the effects it may have on modern living spaces and their mechanical systems. Fate and transport "describes where a chemical goes when it gets out into the environment and how it might be chemically transformed in the process" (Freeman).

Literature Review and Background

This chapter will provide background information and literature texts that will provide context for the development and design of a tiny home that can be used to research indoor air quality from wildfires.

Studying Indoor Air Quality

Studies have shown that pollutants that are found outside have also been found inside homes and other buildings. There are three main ways that this takes place; mechanical ventilation, natural ventilation, and infiltration. Mechanical ventilation occurs through heating and/or cooling systems, which draw in outdoor air to heat or cool the home/building. Natural ventilation takes place when a window or door is opened and outside air that contains pollutants is drawn inside. Even without ventilation outside air can infiltrate the building through cracks or leaks in the building envelope due to pore sealing (Leung).

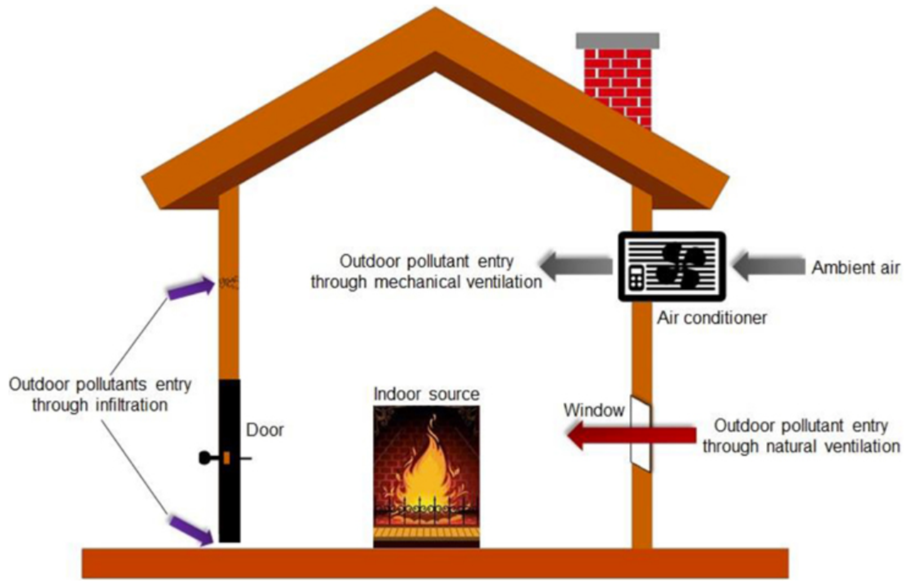

Figure 2 - Ventilation and Infiltration (Leung)

About one out of every seven Americans experience dangerous air quality due to wildfire smoke in just this past year. Smoke can linger and trigger air quality alerts 3,000 miles away. Pollutants from wildfires are far more dangerous than other pollutants from smoke, such as car exhaust, and have a negative impact on public health. They can cause shortness of breath, headaches and can trigger more severe respiratory or cardiac events. Experts believe that the only way to reduce pollutants from lingering in buildings and entering our airways and bloodstream is by using air filters, however these can cost a lot of money. An air purification system for a standard home can cost hundreds of dollars, and HVAC systems in schools cost thousands of dollars. Some people don't have the financials to afford protection against pollutants (Rott).

Live-in Lab

Currently there are no mobile labs studying indoor air quality effects from wildfires. Many schools in the United States have air quality labs that are conducting various types of research. Purdue University in West Lafayette, Indiana has an air quality facility. Research is focused on air pollution. Major pollutants consist of ozone, nitrogen oxides, carbon monoxide, PM_{10}, $PM_{2.5}$, and UFPs (Purdue). Some of these elements like carbon monoxide PM_{10}, $PM_{2.5}$, and UFPs can be found in wildfire smoke (EPA, 2022). The test chamber can be configured to simulate different types of occupancy. The lab allows for the implementation of control strategies such as filtration and ventilation to reduce the exposure of pollutants to the occupants.

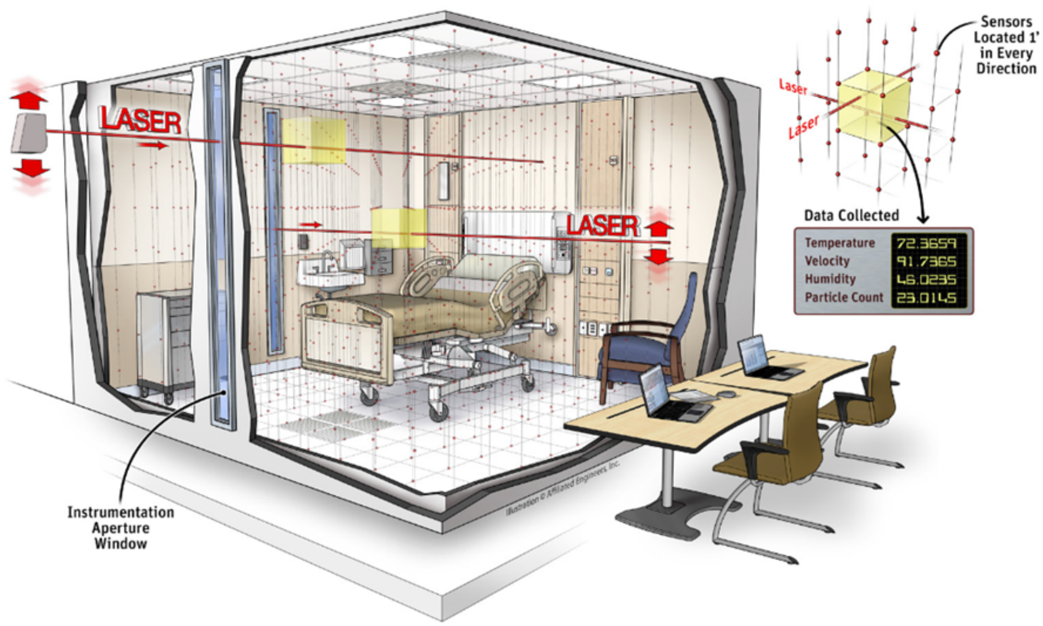

Figure 3 – Purdue Indoor Air Quality Test Chamber

University of Texas (UT Austin) in Austin, Texas also has an air quality lab that specializes in indoor and outdoor air quality, sustainability, and energy systems. UT Austin has one of the world's largest Air Resources Engineering programs. Since humans spend about 90% of their time indoors, it is important to understand how compound indoors interact throughout our daily lives. Tests are performed on the indoor air quality from cooking, cleaning, and the effects of hosting large gatherings. Research is aimed to help develop strategies to prevent airborne diseases and improve health (CEER).

The University of Pennsylvania State University in Centre County, Pennsylvania also contains an air quality lab. Penn State focuses on how air quality affects plants, farms, gardens, forests, and fields. Research is done to show the presence of pollutants and how they can affect plant species (Air Quality Research). University of Surrey in the United Kingdom has 45+ lab machines worth more than half a million pounds. University of Surrey focuses on air pollution and sustainability (Air Quality Lab). All these universities have done extensive research on air quality, pollution, and sustainability. Unfortunately, the scope of these research facilities is limited because these labs are stationary.

Today very few live-in labs exist and the ones that do research air quality don't focus on the effects of wildfires. The Louisiana Department of Environmental Quality (LDEQ) has three mobile vans. One van was bought in 2006, and then in 2019 two more vans were bought. These vans are known as Mobile Air Monitoring Labs (MAML). The vans perform routine air monitoring, emergency response and support, investigate past and current complaints or concerns, investigate the cause of poor air quality, and other issues ordered by the LDEQ. Unfortunately, these vans only investigate the air quality in Louisiana (MAML).

Figure 4 – The LDEQ Mobile Air Monitoring Labs

Louisiana is not the only state with a mobile lab, the University of Pittsburgh also has a mobile air quality lab. The lab can measure nitrogen concentrates and PM_{10} and $PM_{2.5}$ particles. Unlike Louisiana, the lab is on a trailer. The trailer is powered by an electrical hookup or a low-emission generator (Department of Geology and Environmental Sciences). Similar to the air quality labs, the live-in labs that exist today do not study the effects that wildfire has on our air quality. These live-in labs are also confined by state boundaries that can restrict research.

What is a Tiny Home?

"The Tiny House Movement is an architectural and social movement that encourages living a simpler life in a smaller space" (Tiny House Builders). While tiny homes have always been around, this movement has become an increasingly trending idea within the last decade. The ability to live a freeing and minimalistic lifestyle is now very popular in a range of communities, especially among young people as well as retired couples.

While many tiny homes can be built on permanent foundations, some can be designed to reside on trailers and are referred to as Tiny Homes on Wheels (THOW). THOWs are a favorable design method due to portability and lack of local governing residential codes. Like an RV, THOW's can be towed, making them a popular choice for those who enjoy traveling or those who simply do not wish to be tied down to one area. Currently, many people fret modern sized housing because of the responsibility of tending to a large home with increasing costs to become a homeowner. With the smaller size of a tiny home often comes a lower price tag, making these houses a more affordable alternative for those in need of shelter due to homelessness, financial difficulties, disaster, etc.

Going "tiny" has gained a large following today, which is increasing and promoting the benefits of doing so. Many follow the trend because of its intriguing minimalist designs typically built by DIYers (Do It Yourself) sharing their journeys online. Others enjoy the views of traveling to new places and the great outdoors while also waking up to a new backyard every morning. Either way, social media plays a great deal in the popularity of tiny living.

Although often portrayed as the perfect lifestyle to some, tiny homes do come with their downsides. One of the biggest issues faced by tiny livers is where to park their THOWs. Unfortunately, codes and laws to park a tiny home vary from city to city all across the United States, making it a great challenge to find ways around specific regulations. Local laws must be researched by the homeowner before making any great commitments.

The size of our tiny house has to abide by United States law restrictions. For it to be considered a tiny home, it has to be less than 400 square feet, not including the loft area (IRC, 2018). For the safety of other drivers on the road, the trailer is not allowed to be more than 40 feet long and 8.5 feet wide, and because most bridges are about 13.5-14 feet high, the height from the ground up should not exceed about 13.4 feet (Wood, 2022). The style of our tiny home is constructed to closely resemble that of a real Californian home, but sized down to fit the constraints of a portable trailer.

The Tiny Home Competition

Impact, a platform for architectural design, held a competition in 2021 to design a tiny house. The challenge was to create a space for two people, and "the house should respond to the ever-changing needs of its users and the site context it sits in" (Impact Competition, 2021). The judging criterion had four main aspects to judge the creativity of the design. 1) Innovation and originality in the design with respect to the client selected by the participants, 2) Justification of the selected site for the design proposal, 3) Overall functionality and spatial design, and lastly 4) Responsiveness of the design with respect to the physical and emotional needs of the client (Impact Competition, 2021).

The first-place winner designed a space called Myco-Shelter (Figure 5), that was "self-sufficient and uses locally sourced materials, including agricultural byproducts bound together with mycelium, a thread-like structure, to form a material and biodegradable insulator" (Torres, Martínez, 2021). The second-place winner designed a tiny home that was also self-sufficient and adapted to the weather (Figure 6). In the winter, it preserved interior heat and used a "wood stove, solar panels, a rainwater collection system, and two gas bottles if the light does not allow to generate enough electricity". In the spring and summer, the walls of the house could fold down to provide more space, and "these spaces are covered by a waterproof tent, protecting us from rain, sun and mosquitoes" (Vignes, Ilievski, Disille, 2021).

Our design took inspiration from these winners because they uniquely upheld the judges criteria which resembled closely to this project's goals. This helped visualize unconventional ideas of tiny homes that could also provide a comfortable living space.

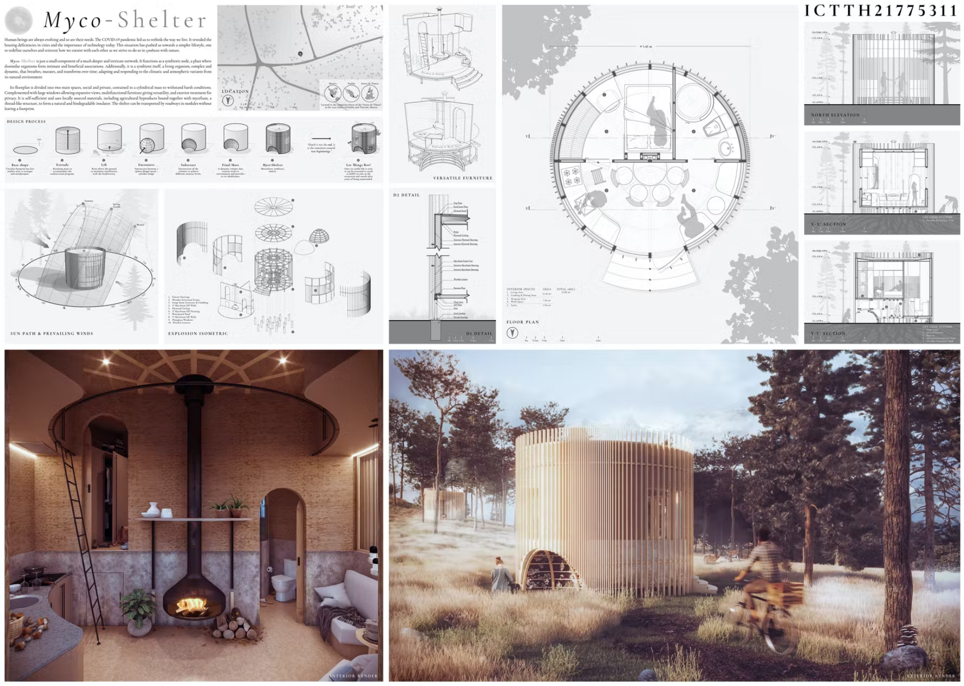

Figure 5 - First Place Winner of the Tiny House Competition 2021

Figure 6 - Second Place Winner of the Tiny House Competition 2021

Trailer Foundations

The trailer foundation of the tiny home is one of the most important features to research because it must carry the entire weight of the tiny home, from framing and insulation to appliances and amenities, in addition to wind loads and vibrations from transportation. When research was conducted on potential trailer foundations, a handful of trailers were investigated to determine what was the best option for a research facility. A comparison was performed on each trailer's respective load capacity, gross vehicle weight rating (GVWR), axle connection, and dimensions (Table 1). The trailer weight and the GVWR were analyzed to ensure that the trailer could hold the weight of the tiny home and its inhabitants, in addition to being able to be pulled by a pickup truck or a similar vehicle. Axle types were also explored because of the different ways that they absorb shock and distribute weight. While the torsion axle is good for shock absorption, the tandem axle is best because it can carry heavy weights and maintain stability at high speeds (Quadratec). Lastly, the dimensions of the trailer were important to maximize the space of the tiny home, while still being within U.S. regulations.

Trailer	Trailer Weight	GVWR	Axles	Dimensions
PJ Trailers: 8” Channel Super-Wide (B8)	4,980 lb	19,000 lb	Tandem (2) 7k [spring]	30 ft x 8.5 ft
Diamond C: Low Profile Extreme Duty Equipment Trailer (LPX)		20,000 lb	Torsion (2) 7k [drop]	30 ft x 6.8 ft
Kaufman Trailers: Heavy Equipment Flatbed Trailer	11,440 lb	62,000 lb	(3) 22.5k [spring]	30 ft x 8.5 ft
Iron Eagle Trailer: PAD20k30	2,680 lb	21,000 lb	Tadem (3) 7k	30 ft x 8.5 ft
Big Tex Trailers: 10CH Pro Series Tandem Axle Car Hauler	2,280 lb	9,990 lb	Tandem (2) 5.2k [cambered]	20 ft x 7 ft

Table 1: Trailer Comparison

In the end, the Iron Eagle PAD20k30 trailer was chosen. One of the main reasons why the Iron Eagle Trailer was chosen is because it is designed specifically for tiny homes. The other trailers that were researched weren't specifically designed for tiny houses but rather for hauling cars or large equipment. The dimensions of these trailers were good, but they were heavier than the Iron Eagle Trailer which meant that there was a larger limit on how heavy the tiny house could be. Additionally, the structure of the trailer is designed to distribute uneven loads throughout the trailer, and most of the weight is on the outside of the trailer which allows more support for the walls and roof (Iron Eagle).

Figure 7 - Iron Eagle Trailer

Methods

As previously stated, the goal of this project is to design a tiny house on wheels that can be towed to safe locations exposed to wildfire smoke. The space will be used for key research conducted on smoke behavior and fate to gain a better understanding of the effects it may have on modern buildings and their mechanical systems. Our goals and approach to this project are broken down below.

Goals

1. **Design a tiny house on wheels as a research facility to study indoor air quality from wildfire smoke.**

The tiny home will be designed so that it can be transported from one location to another. This allows the researcher to travel between states and study the effects that wildfires have in different areas. The house must be able to endure the travel from state to state. Structural calculations will prove the strength of our design and the ability to be pulled by a truck to the researchers' desired locations.

2. **Design an exterior system that represents modern construction of residential homes in a community at risk to wildfires.**

For our design, we are aiming to closely resemble a modern Californian residence. This will allow the data that is collected to be relevant to homes that are exposed to wildfire smoke. Our design will be up to International Residence Code (IRC) within the western region, where wildfires occur most frequently (Global Wildfires). This will include a designed building envelope that will be protected from all elements.

3. **Design a tiny home that closely resembles a typical living space.**

The third objective of our project is to create a space large enough for one to two researchers to live in comfortably. Because the home is only 255 square feet (30 ft in length and 8.5 ft in width), designing a functional space to include all necessary amenities and research equipment is important.

The most common spot to stay is at an RV park. RV parks have the benefit of ready-to-use utilities such as water and electricity which would eliminate the worry of running out of power and using up the water tank. There are also Tiny House Communities that provide communal spaces. Another potential location to park the tiny house is on someone's property with their consent. This is probably the best location as it would accurately represent how wildfire smoke affects the community.

Approach

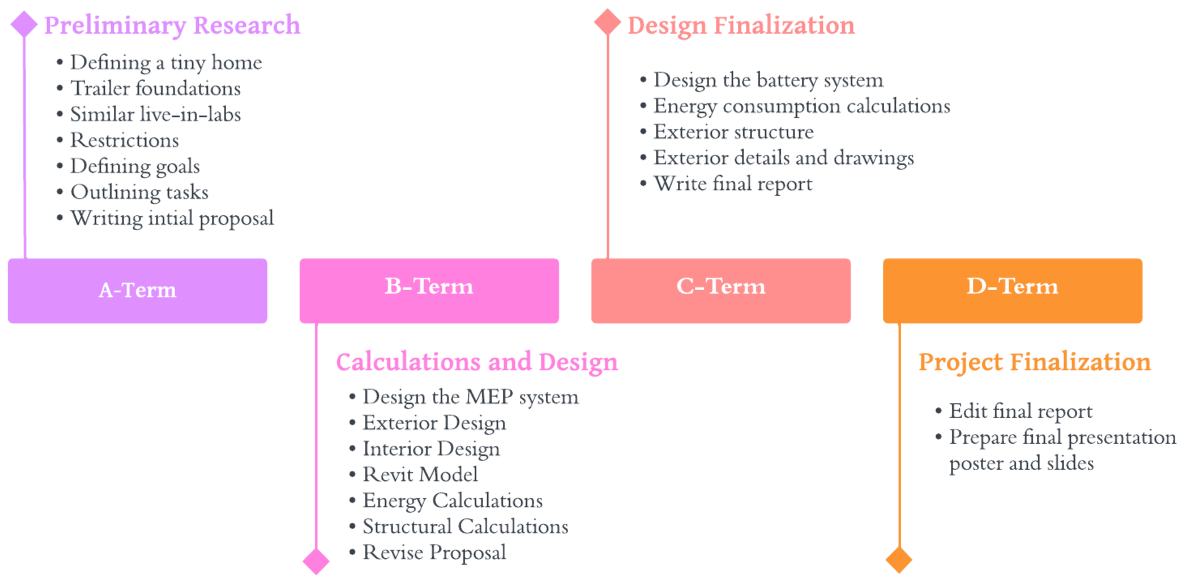

Figure 8 - Approach to our Design Process

Results

After months of researching and iterative design processes, we were able to produce a final design given the goals and scope of our project. Designing a tiny home on wheels has come with several challenges that were unexpected, but allowed our team to continuously learn and enhance our personal skills to produce the results given below.

Exterior and Interior Design

The following section shows renders of our design, including both exterior and interior views. Our design is implemented on a trailer that is 30 feet long and 8.5 feet wide, creating 255 square feet of interior space (not including the extra lofted bedroom space). See the end of the report for a more detailed construction bid set.

1. 3D Model and FloorPlan

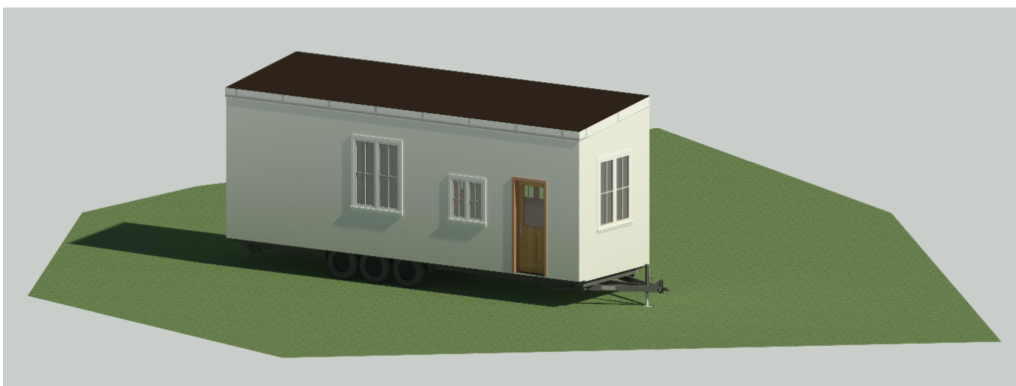

Figure 9 - 3D Rendering

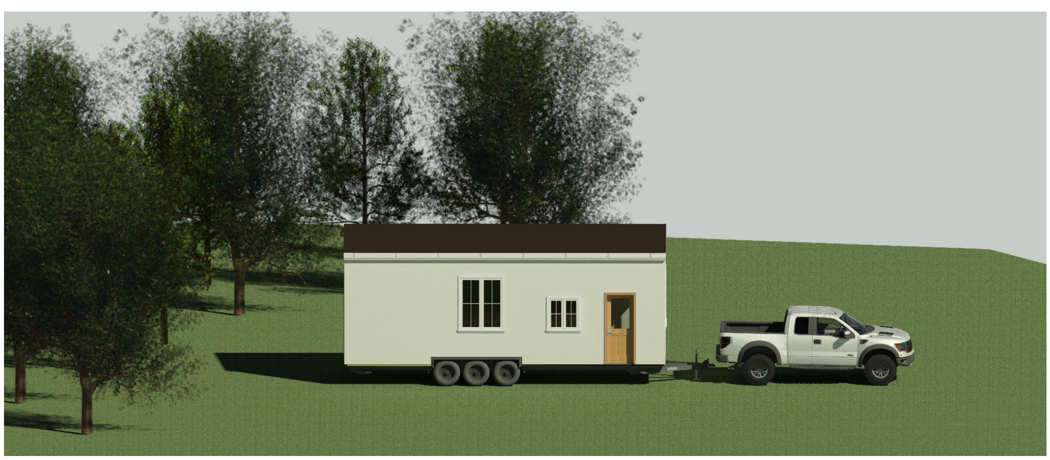

Figure 10 - 3D Elevation Rendering Including Truck for Towing

Figure 11 - 3D Rendering Including Truck for Towing

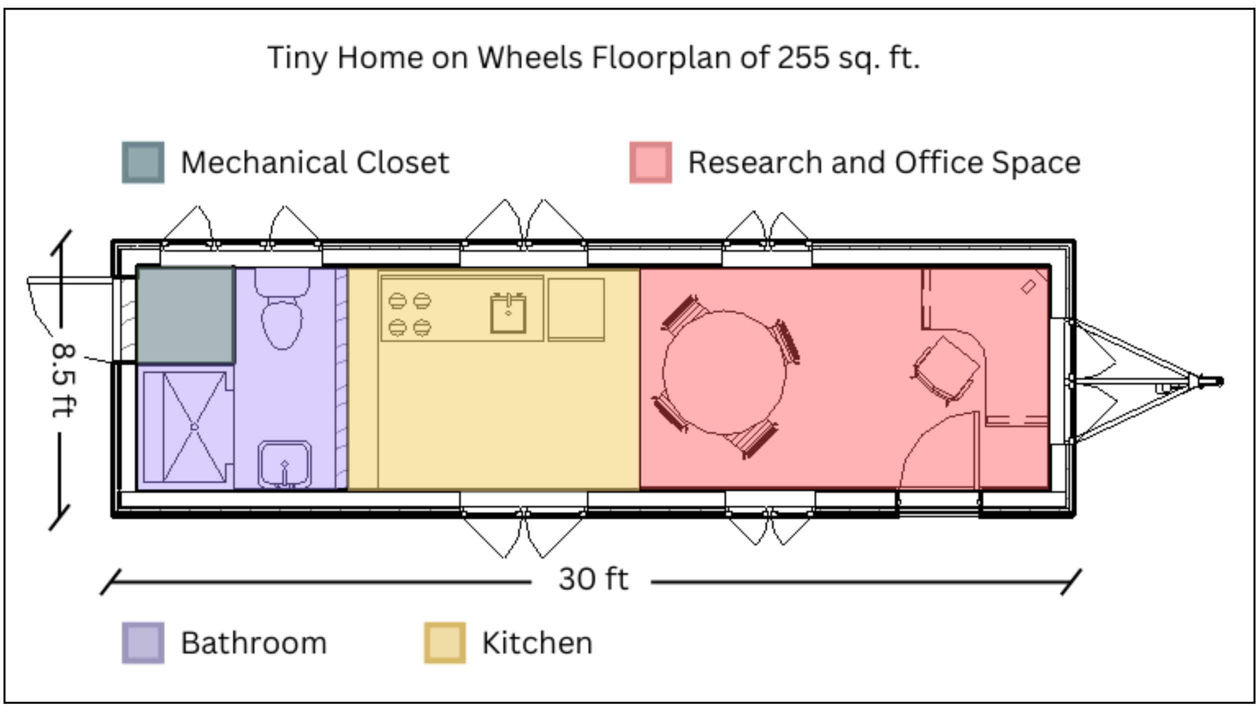

Figure 12 - Theoretical Floorplan to House 1-2 Researchers (Loft not included)

Figure 13 - Theoretical Interior Design

2. Construction Details

There were many considerations kept in mind while designing our tiny home to ensure it resembles the details of a modern home built in California, or an area typically surrounded by wildfires. In order to create an effective design, we had to choose materials that would not only relate to these homes, but also look at their compatibility with a tiny home on wheels.

2.1 Wall Assembly

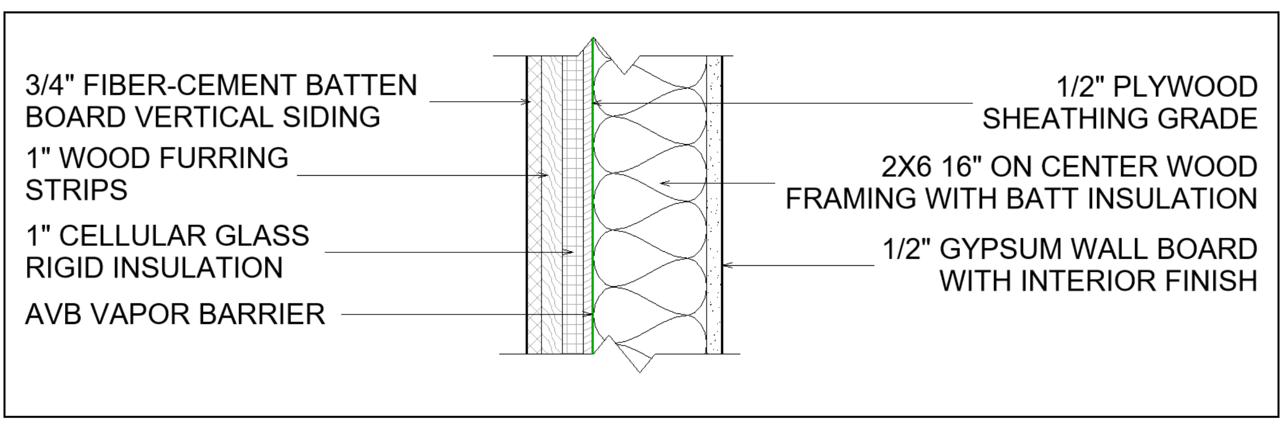

Figure 14 - Wall Assembly Detailing

One of the most important aspects of our design was the wall assembly. The wall to our tiny home has to not only perform adequately structurally, but it also needs to provide thermal and moisture barriers to ensure comfortability and shelter for our researchers. The construction of our walls are made up of 2x6 in. wood studs spaced 16 in. on center with typical batt insulation. Almost all homes in California are made of wood framing due to its weight and availability that make it easy to build with. The exterior sheathing is ½ in. plywood wrapped with an AVB membrane that withstands moisture and air.

Siding is more than just the appearance of a structure because of its properties to protect from the elements. When choosing a product to act as the shell to our design, we researched that many homes in California use a material called fiber-cement. Fiber-cement is a composite material of cement mixed with cellulose fibers. One of the most important properties to fiber-cement is its resistance to heat and moisture. It has a Class A fire-rating and is non-combustible, making it hold against flames and ignition. Although completely fire-proofing our design is outside the scope of our project, it's an important feature that many homes are turning to as the number of wildfires increases. The product we chose was the Hardie® Panel Vertical Siding that can be further inspected in Figure 15 and Appendix G (JamesHardie).

Figure 15 - James Hardie Panel Vertical Siding real world application

The Hardie® panels are attached onto 1-inch furring strips that create a rainscreen in our design. A rainscreen is a detail in our design that allows the siding to stand off from the AVB (air and vapor barrier) membrane that is applied to our exterior sheathing, which creates an air cavity between the siding and the rest of the wall. This cavity allows any moisture that passes the exterior cladding to drain away from the structure.

To ensure a tight building envelope, our design also utilizes exterior continuous insulation made up of 1-inch cellular glass rigid insulation. This increases the R-Value of our wall and gets rid of thermal breaks that may occur. This insulation sits in between the exterior sheathing and the cladding. According to the International Energy Conservation Code (IECC), Table C402.1.3 “Opaque Thermal Envelope Insulation Component Minimum Requirements, R-Value Method” (Shown in Appendix H), the minimum R-value for wooden framed walls for a home based in Los Angeles is R-13 + R-3.8 continuous insulation or R-20. The higher the R-value means a more insulated system that each material provides. The breakdown of the R-values can be seen below in Table 2.

Material Type	Thickness (in)	R-Value Rated for Thickness Listed ($\frac{Ft^2{}^\circ F}{Btu/hr}$)
Outdoor Air Film	-	0.7
Fiber Cement Hardie® Panel Vertical Siding	0.75	0.15
Wooden Furring Strips Rain Screen Cavity	1.00	0.9
Cellular Glass Insulation	1.00	3.0
Plywood Sheathing	0.50	0.6
2x6 Stud Cavity with Batt Insulation	5.50	16.5
Gypsum Wall Board	0.50	0.5
Total	9.25	22.35

Table 2: R-Values for Wall Assembly system with coordination from Table J in Lechner, Norbert. Heating, Cooling, Lighting.

2.2 Roof Assembly

One of the most effective roof types in California are metal roofs. Metal roofs are known for their durability and can last up to 70 years if properly installed and taken care of. With low maintenance, they provide high fire-resistance and are not able to catch fire. Although not immune to the damage of fire, the odds of salvaging your structure with a metal roof are much greater. According to the Metal Roofing Alliance (MRA), “Because quality metal roofing lasts for decades, carries the highest Class A rating for fire protection and is strong enough to stand up to hurricane winds, hail and heavy snow, it is increasingly popular in regions where better protection against Mother Nature’s unpredictability is essential” (Meihoff).

Our design utilizes a standing-seam metal roof pitched at an angle. The product implemented into our design comes from MBCI®, one of the “industry-leading manufacturers of metal roofing and wall panels” (MBCI). The Superlok® product “is a mechanically field-seamed, vertical leg standing seam roof system that combines a 2-inch tall slim rib with exceptional uplift resistance” (MBCI). An example of the Superlok® product in real world application can be seen below in Figure 16.

Figure 16 - MBCI Superlok® utilized on an assisted living building.

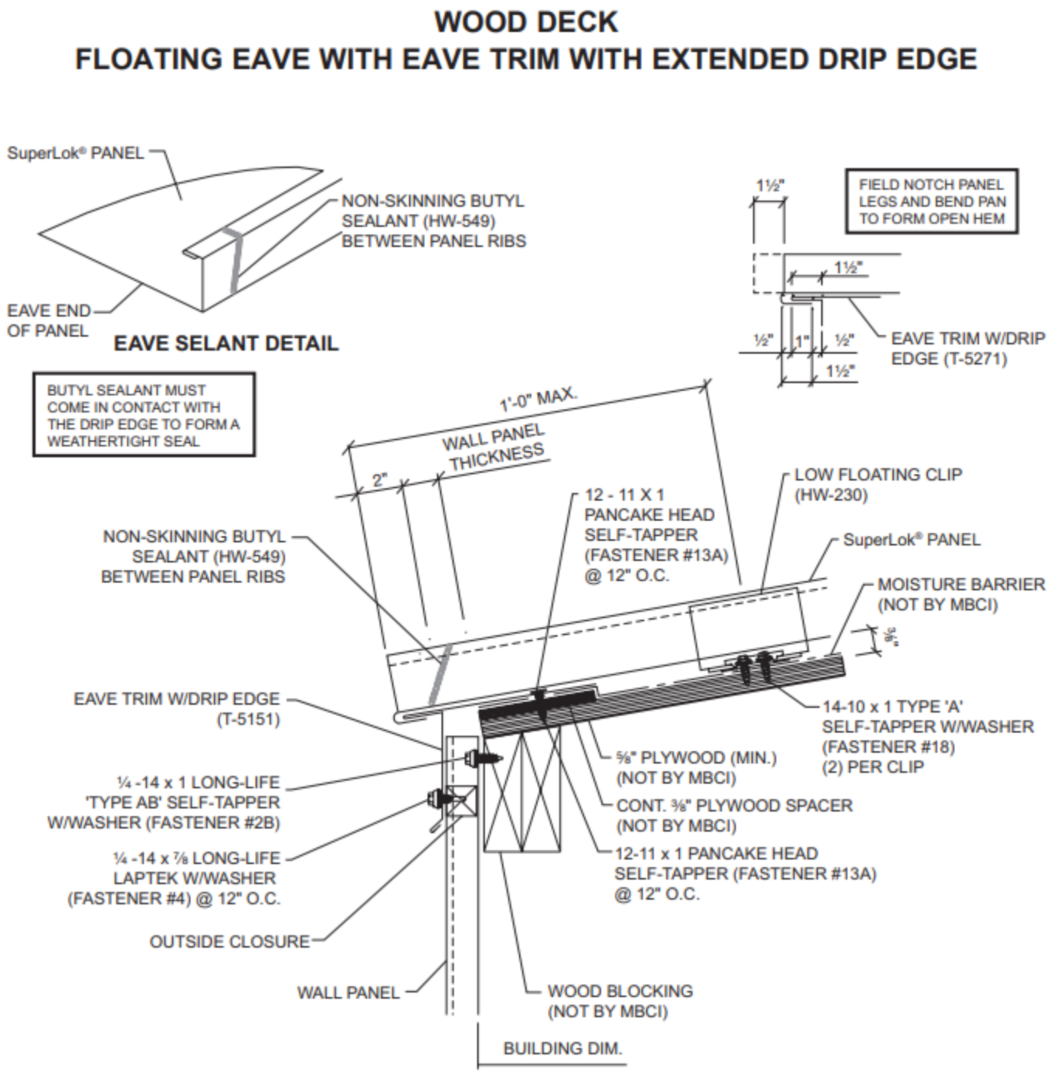

Figure 17 - MBCI Superlok® Installation (MBCI Superlok Manual).

The detail above showcases the installation of the standing seam metal roof from MBCI's standards, with further consideration in Appendix I.

2.3 Floor Assembly and Foundation

The foundation of our tiny home is the Iron Eagle trailer. Connecting to the trailer was one of the biggest components of our design to ensure the building envelope would be complete without any gaps or thermal bridging. The full connection detail can be seen below in Figure 18.

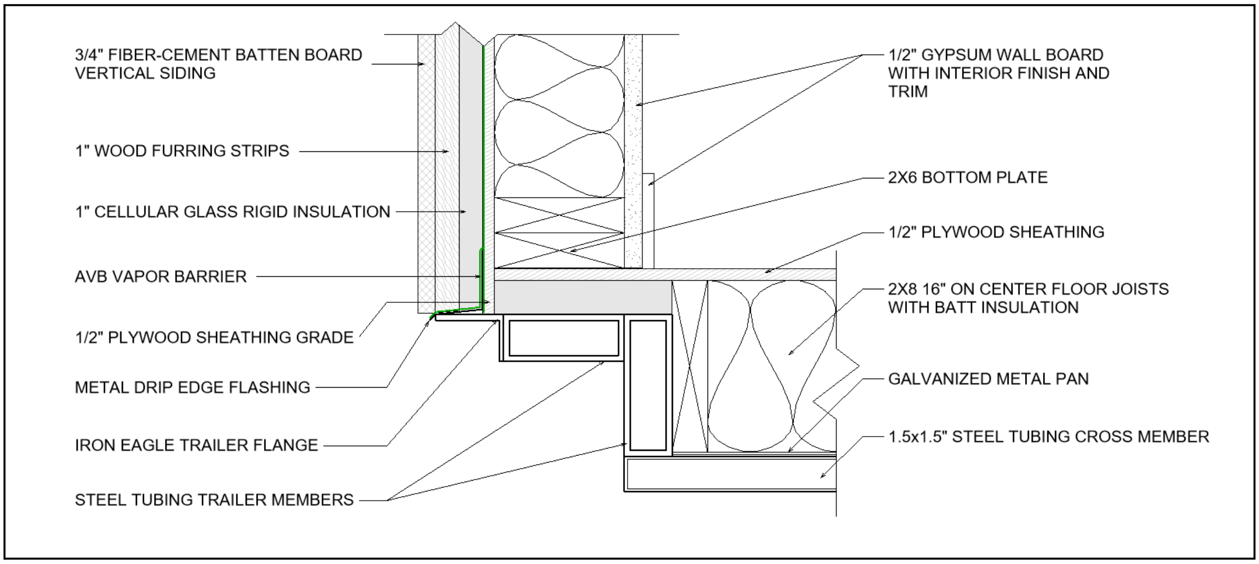

Figure 18 - Wall to Trailer Foundation Connecting Detail

This detail focuses on how the wall assembly previously described in Figure 14 meets with the Iron Eagle Trailer steel members. The most important factors to design for were moisture mitigation and thermal bridging to make sure the building envelope was as tight as possible. Shown in green, the AVB membrane continues down the rain screen cavity and connects to a metal drip edge flashing to ensure any moisture exits accordingly. The exterior cellular glass rigid insulation is also continuous and wraps underneath our structural framing to mitigate thermal bridging. “Thermal bridging is the movement of heat across an object that is more conductive than the materials around it. The conductive material creates a path of least resistance for heat. Thermal bridging can be a major source of energy loss in homes and buildings, leading to higher utility bills” (What is Thermal Bridging). Continuous insulation is the key component to combat the problem of thermal bridging that occurs at the studs.

Structural Analysis

In order to determine the required strength of the wood frame, the total load was calculated. The weight of the mechanical systems were displaced evenly and were proven to be under the limit of trailer laws and regulations. Table 3 shows the total load on the roof, frame, and floor.

Type	Dead Load(lbs)	Span (ft)	Load (lbs/ft)
Roof	476.42	30.000	15.881
Frame	1462.9	30.000	48.767
Floor	431.79	29.167	14.804

Table 3: Loading

The loads were then used to determine the required load each member can hold. The allowable load of each member is then determined based on the member size, type, and wood species; these values are represented in Table 3 (NDS, 1997). Southern pine was chosen as the wood material because of its strength and durability. Southern pine is also a lightweight material while being inexpensive. The studs were placed 16 inches apart on center in order for the insulation to fit and allow maximum strength. A stud size of 1.5 inches by 5.5 inches was chosen to fit insulation (Figure 19).

Figure 19 - Revit Framing

Calculations were done based on whether compression was applied parallel or perpendicular to the grain. The load on the roof is displaced onto the roof beams, perpendicular to the grain. Because the roof has an angle of about 7 degrees, calculations were done to determine the force acting on the beam (Appendix A). The load of the roof was then applied to the double top plate beam supporting the studs. The strength of the studs were then determined based on their displacement (Table 4).

	Required	Allowable	
Roof Bending	255.84	1233.8	psi
Roof Shear	12.004	78.570	psi
Beam Bending	776.51	1413.2	psi
Beam Shear	44.490	78.570	psi
Beam Compression ⊥	40.783	321.60	psi
Stud Compression	296.63	889.89	psi
Wall Sheathing	250.00	280.00	plf
Roof Sheathing	68.750	128.80	plf

Table 4: Required and Allowable Loads

Since the frame is bolted to the trailer, calculations were performed to determine the strength of the steel bars to ensure the trailer could support the load of the home. An analysis was performed to determine the shear, moment, and stress forces acting on the trailing while it is stationary and being driven (Table 5). The strength of the vertical member was determined because it is the strongest member of the frame (Appendix B).

	Moment (lbf*ft)	Shear (lbf*ft)	Stress (psi)
Stationary	7200.0	2400.0	17049
Moving	10080	3360.0	23869

Table 5: Stress

The ASTM A500 (Square/Rectangle) grade steel has a minimum yield point/strength of 39 ksi so the trailer is strong enough to support the load while the tiny home is stationary or driving.

Thermal and Energy Calculations

The following sections provide various equipment sizing for the tiny home to ensure proper comfort levels and the adequate amount of power required.

1. Heating and Cooling

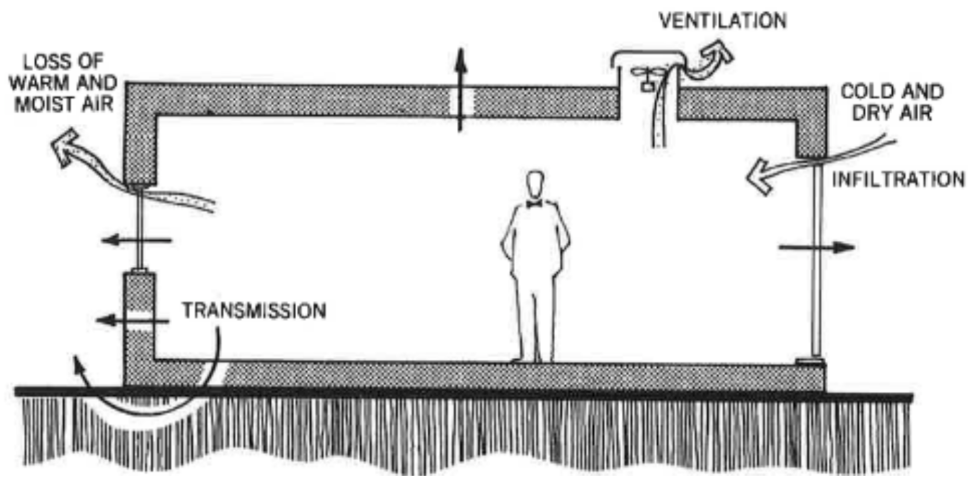

Figure 20 - Heat Loss Through a Building (Lechner)

In order to size the HVAC equipment for our tiny home, heating and cooling load calculations were performed based on several factors. Figure 20 encompasses the different variables when considering heat loss in a building, such as transmission, infiltration, exfiltration, and ventilation. Transmission is heat loss through surfaces such as walls, roofs and glazing. Infiltration and exfiltration is heat loss due to cold air through joints in building construction, around window and door assemblies, and at penetration details. Ventilation is a controlled and purposeful form that coordinates with HVAC design strategies. These factors were considered when performing calculations to size equipment. The area of each surface divided by the total thermal resistance of the assembly determined the total heat loss for our assembly for a location such as Los Angeles, California.

With calculations performed in a spreadsheet shown in Appendix J, the total heat loss by transmission through our walls, roof, windows, and doors equates to a total of 7,343 Btu/hr. The value calculated for total heat lost must be supplied from the heating system in order to maintain an interior temperature of 68 ℉ during winter months.

The next step was to calculate the cooling load for the space for an average summer day in Los Angeles California. These calculations, shown in Appendix K take the area of each surface and multiply it by its cooling load factor (CLF). The CLF is determined by the U-value of each assembly, which is the reciprocal of the R-value. The total cooling load calculated equates to 8768 Btu/hr. The value calculated for total cooling loads must be supplied from the cooling system in order to maintain an interior temperature of 68 ℉ during summer months.

2. Air Leakage Area

To determine the different types of ventilation of houses, the air leakage area, based on three changing conditions, was calculated. The first condition was the location of the tiny home. Whether the tiny home was in Los Angeles, California; Austin, Texas; or Portland, Oregon, their respective average temperature and wind speed would be different. The second condition was the shelter class. Depending on where the tiny house was parked, the amount of shelter surrounding the tiny home would be different (Table 6).

Shelter Class	**Description**
1	No obstructions or local shielding
2	Typical shelter for an isolated rural house
3	Typical shelter caused by other buildings across the street from building under study
4	Typical shelter for urban buildings on larger lots where sheltering obstacles are more than one building height away
5	Typical shelter produced by buildings or other structures immediately adjacent (closer than one house height: neighboring houses on same side of street, trees, bushes, etc)

Table 6: Local Shelter Classes, from 2017 ASHRAE- Fundamentals

The last condition that was analyzed was the air change rate, which took into consideration the different ventilation rates that homes could have. The air change rate of 0.1 ach, 0.5 ach, 1 ach, and 2 ach was examined. The different variations that could occur from changing the conditions were then calculated. The equation for the airflow rate from infiltration is $Q = A_L\sqrt{C_s|\Delta T| + C_w U^2}$ and the definition of each variable and the breakdown the calculations are shown in Appendix C. In the end, using the airflow rate from the infiltration equation, and considering the different locations, shelter classes, and air change rates, the respective Effective Air Leakage Area (A_L) was calculated, which can be found in Appendix C. These calculations can be used during air quality research to mimic different home ventilation units and determine how they affect the air quality of the house.

3. HVAC and MEP

In order to size the battery of the tiny home so that it would be able to power all amenities, specific amenities were chosen to determine the amount of voltage and energy the battery must provide. The most basic amenities were researched and selected based on what has worked well for tiny home communities in the past. Appendix D lists the amenities, and there were many design choices to consider.

All-electric amenities were chosen since it would be better for the environment, and while tankless water heaters are environmentally friendly, they require too much energy. In the end, a 6-gallon electric water heater was decided upon. Water is pumped from a 40-gallon fresh water tank and later stored in a 30-gallon gray water tank. Additionally, while it's not common in a lot of homes, the tiny home is equipped with a composting toilet because it is environmentally friendly and removes the necessity of a black water tank. To minimize equipment, a ductless mini-split is installed to both heat and cool the tiny home. Because the tiny house is portable, it is important to prepare for comfort in any type of weather. In the end, a *Pioneer® 9,000 BTU 20.5 SEER 115V Ductless Mini-Split Inverter & Air Conditioner Heat Pump System* was chosen because of its high SEER value and compliance to heating and cooling load calculations. SEER stands for Seasonal Energy Efficient Ratio, and the "higher the ratio, the more energy efficient the air conditioner is", and the SEER value of the ductless mini split is 20.5 which means it is very efficient (Purushothama, 2009). Figure 21 is a heat map that shows the estimated timeline of all of the appliances being used in hourly periods. The darker the block, the more energy it consumes.

Row Labels	Sum of Fridge (W)	Sum of LED Lights	Sum of Toilet (W)	Sum of TV (W)	Sum of Cell Phone (W)	Sum of Computer (W)
12:00 AM	209.3	0	15	0	36	1200
1:00 AM	209.3	0	15	0	0	0
2:00 AM	209.3	0	15	0	0	0
3:00 AM	209.3	0	15	0	0	0
4:00 AM	209.3	0	15	0	0	0
5:00 AM	209.3	0	15	0	0	0
6:00 AM	313.95	200	17.5	0	0	0
7:00 AM	209.3	1000	15	0	0	0
8:00 AM	209.3	0	15	0	0	0
9:00 AM	209.3	0	15	0	0	0
10:00 AM	209.3	0	15	0	0	0
11:00 AM	209.3	0	15	0	0	0
12:00 PM	209.3	0	15	0	0	0
1:00 PM	209.3	0	15	0	0	0
2:00 PM	209.3	0	15	0	0	0
3:00 PM	209.3	0	15	0	0	0
4:00 PM	209.3	0	15	0	0	0
5:00 PM	209.3	200	15	0	0	0
6:00 PM	209.3	1200	15	0	0	0
7:00 PM	209.3	1200	15	150	0	0
8:00 PM	209.3	1200	15	900	0	0
9:00 PM	209.3	1200	15	900	0	0
10:00 PM	209.3	1000	15	750	6	200
11:00 PM	104.65	0	12.5	0	30	1000

Row Labels	Sum of Microwave power (W)	Sum of Stove only one burner (W)	Sum of Water Heater (W)	Sum of Heat pump power (W)
12:00 AM	0	0	0	0
1:00 AM	0	0	0	0
2:00 AM	0	0	0	0
3:00 AM	0	0	0	0
4:00 AM	0	0	0	0
5:00 AM	0	0	0	0
6:00 AM	1000	0	0	5040
7:00 AM	0	0	1440	4320
8:00 AM	0	0	8640	4320
9:00 AM	0	0	5760	4320
10:00 AM	0	0	0	4320
11:00 AM	0	0	0	4320
12:00 PM	0	0	0	4320
1:00 PM	1000	0	0	4320
2:00 PM	0	0	0	4320
3:00 PM	0	0	0	4320
4:00 PM	0	0	0	4320
5:00 PM	0	0	0	4320
6:00 PM	1000	900	0	3600
7:00 PM	0	1800	1440	0
8:00 PM	0	0	8640	0
9:00 PM	0	0	5760	0
10:00 PM	0	0	0	0
11:00 PM	0	0	0	0

Figure 21 - Heat map of each appliance and their usage every hour

A timeline of energy consumption in 10-min intervals can be seen in Figure 22. They help better visualize power consumption since appliances may not be in use for an entire hour. For example, the fridge is predicted to run on a 10-min on, 20-min off cycle all day to maintain a constant temperature. Figure 23 shows the breakdown of each appliance's energy consumption in 10-min intervals.

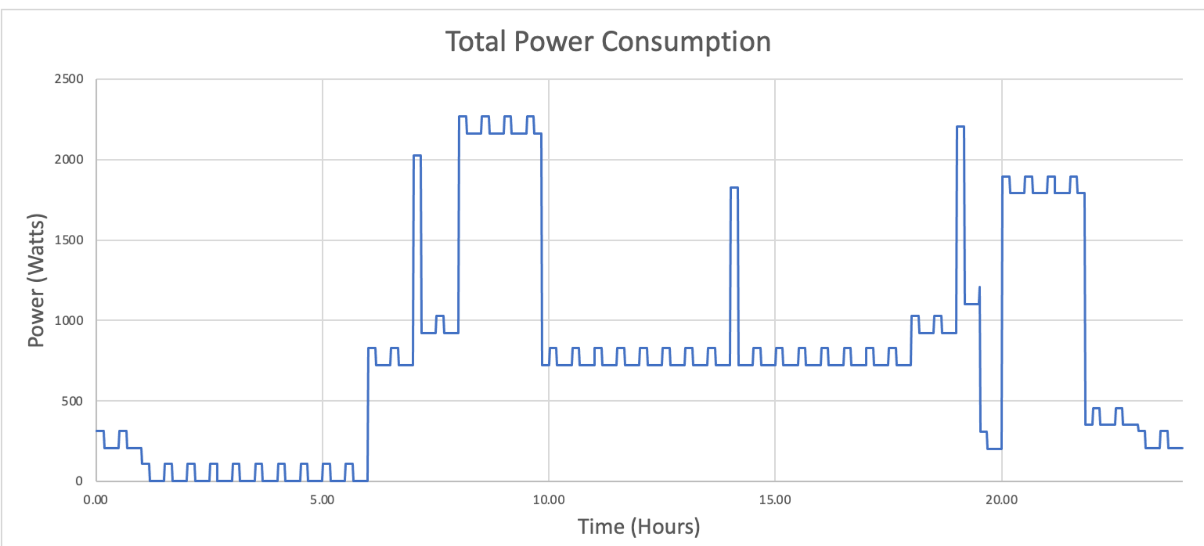

Figure 22 - Total power required of all appliances every hour

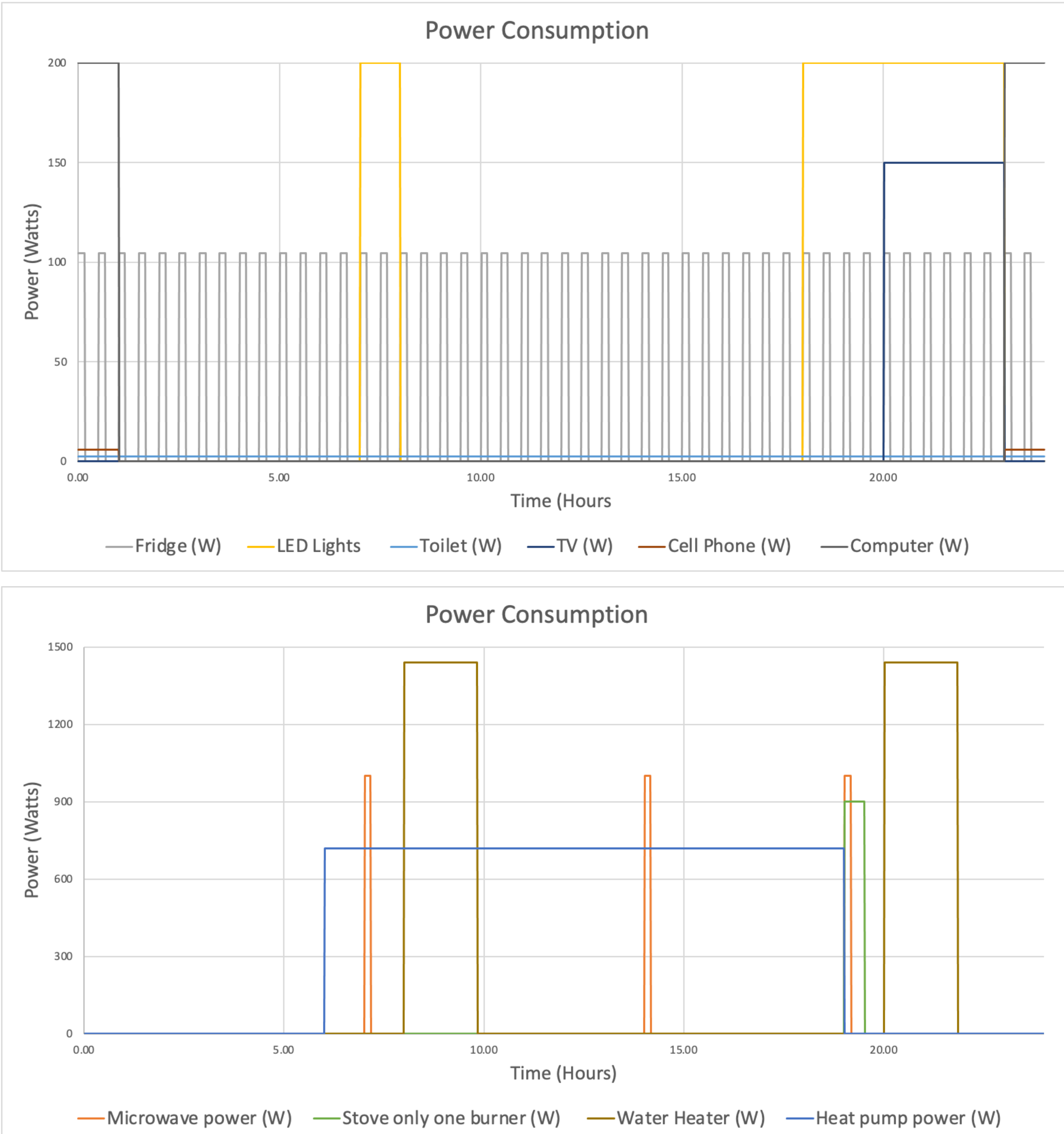

Figure 23 - Breakdown of individual appliance's timeline

Once the appliances and how much power they consume were determined, the size of the battery could be estimated. There were six main considerations to determine the most efficient battery: it could not be too heavy, had to provide enough power, energy, and voltage to the appliances, would ideally last an hour, and couldn't be too expensive. The breakdown for Big Battery's *72V FALCON - LiFePO4 - 28Ah - 2.1kWh* battery can be seen in Table 7.

	Requirements	Big Battery
Weight [lb]		63
Power [W]	2267.15	6000
Energy [kWh]	0.0378	2.1
Voltage [V]	120	72
Time [hrs]	~1	~0.93
Price [$]	< $10,000	$1,750 SALE: $1,090

Table 7: Battery Requirements and Specifications of the chosen battery

Other than not meeting the voltage requirement which can be remedied by having two systems, the rest of the criteria is met. However, to support the 120V required for the fridge and the stove, a DC/AC inverter is needed. The *2kW Pure Sine Wave Inverter* from Ideal Plusing would be sufficient. To help the battery remain charged, solar panels with a system size of 3.4kW will be added to the roof of the tiny home (Appendix E).

To test the battery and solar panels against real-life situations, two, nine-day periods were plotted. These included a summer in LA, California (7/17/22 to 7/25/22), where the sun would be the strongest, and a winter in Portland, Oregon (2/13/22 to 2/21/22), where there would be less sun. There were three important factors for the graphs. The first was the DC Array Output (watts) taken from the National Renewable Energy Laboratory's (NREL) PVwatts calculator. The second factor was the cloud cover percentage of that day, taken from Visual Crossing. Cloud cover was used to mimic different solar energy inputs that might be affected by cloud coverage. However, it is important to note that there isn't a 1:1 ratio between the cloud coverage percentage and the amount of energy absorbed by the solar panels. The comparison was made solely as a representation of how cloud coverage could affect the energy in the battery. Figure 24 is an example of the total solar energy on 7/25/22 in LA, California based on the two factors stated above, and Figure 25 is an example of the total solar energy on 2/20/22 in Portland, Oregon.

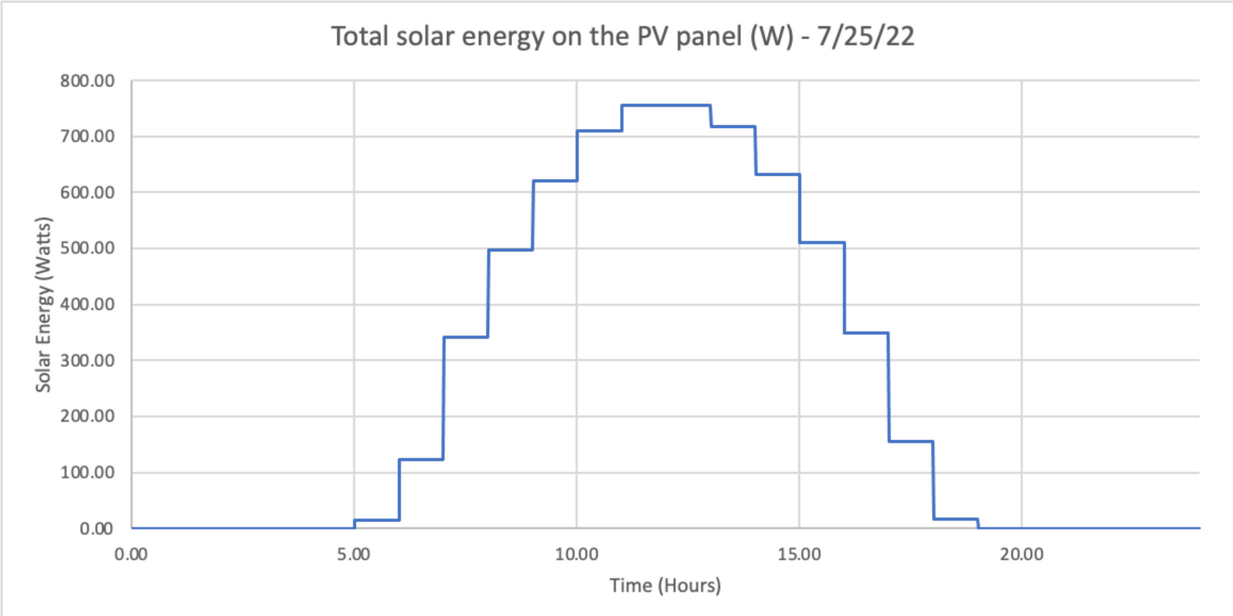

Figure 24 - Total solar energy on 7/25/22 in LA, California

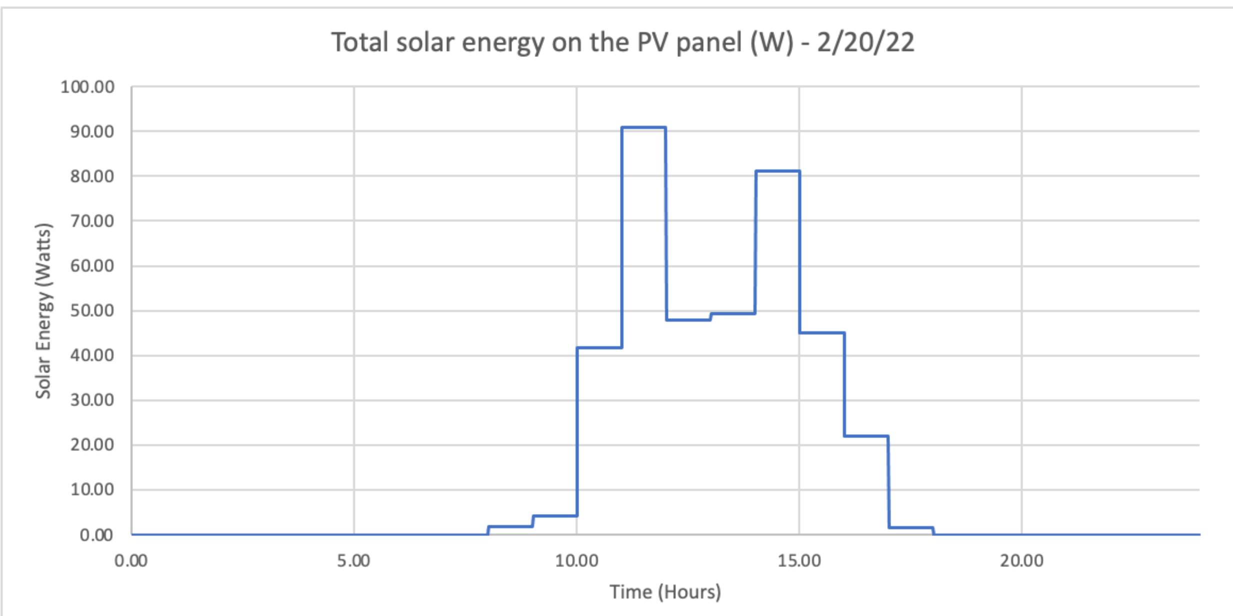

Figure 25 - Total solar energy on 2/20/22 in Portland, Oregon

The last factor was how much energy the battery started the day with, which was the previous day's ending wattage. Appendix F breaks down each step in making these graphs. Figure 26 represents 7/21/22 in LA, California, in which there was a 12.2% cloud cover, and had an initial battery energy of 11386.10 [Wh] from the day before. Figure 27 represents 2/16/22 in Portland, Oregon, in which there was 99.1% cloud coverage and an initial battery wattage of 11,389.58 Wh from the day before.

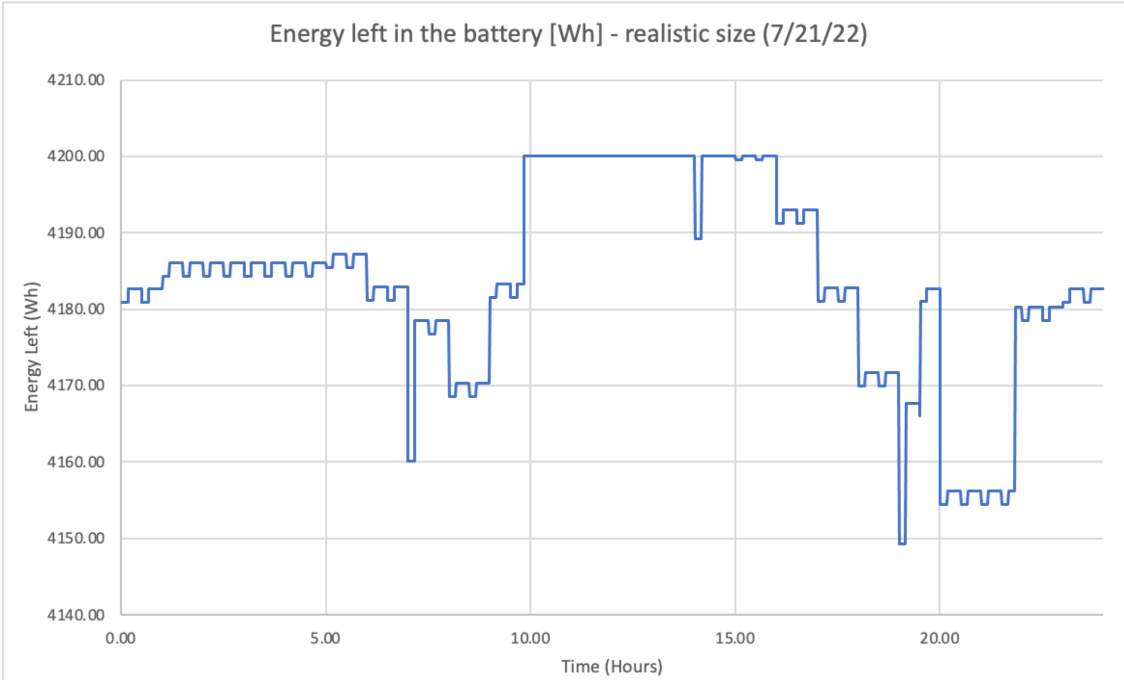

Figure 26 - Energy Left in the Battery on 7/21/22 in LA, California

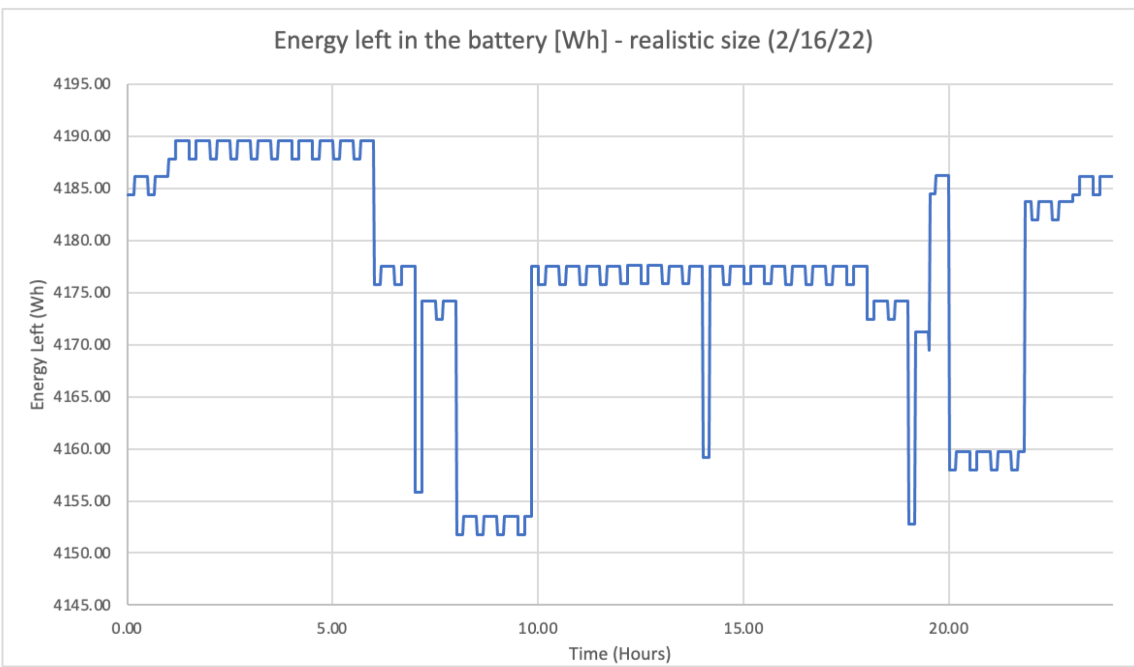

Figure 27 - Energy Left in the Battery on 2/16/22 in Portland, Oregon

From these eighteen days of varying solar input, it can be determined that the two batteries are sufficient to run the appliances, regardless of how much solar energy is absorbed by the 3.2kW solar system.

Recommendations and Conclusion

A tiny home was designed that could be used as a research facility to learn more about the effects of wildfire smoke infiltration on homes. To achieve this goal, design calculations and a Revit model were constructed to determine the interior and exterior layout. Structural calculations were also performed to ensure the strength and durability of the tiny home was safe to live in. Heating and cooling loads were calculated so that the trailer would be equipped with the proper insulation and HVAC systems. Fire protection/suppression systems within the exterior design were not included, to mimic the exterior of California homes as closely as possible in order to not disrupt any future research.

In the future, the team would recommend researching the specific smoke monitoring equipment to see how it would affect battery consumption. Choosing interior furniture that includes as many types of fabrics and materials so that the research is inclusive of the abundant types of materials found in homes. This is important because different materials can absorb pollutants and smoke differently. Since the team was unable to physically build the design, factors that would arise only during construction could not be considered during the design phase.

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Appendix

Appendix A - Framing Structural Analysis

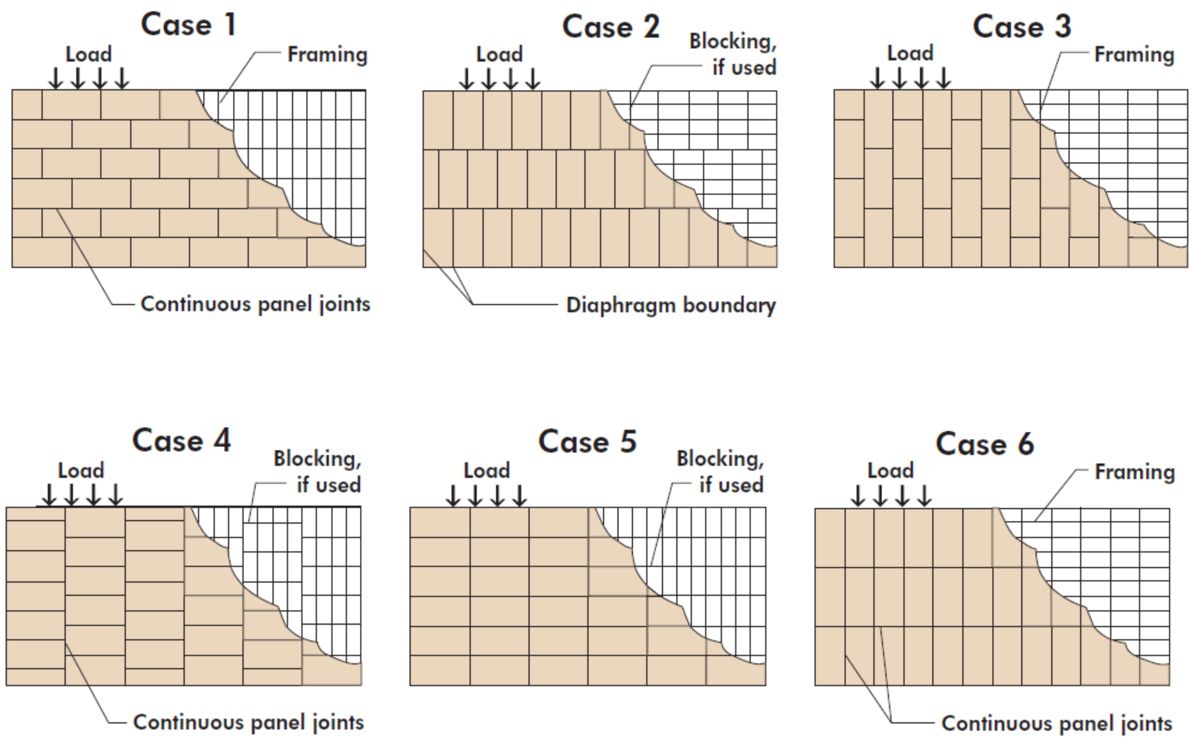


TABLE 1

ALLOWABLE SHEAR (POUNDS PER FOOT) FOR APA PANEL SHEAR WALLS WITH FRAMING OF DOUGLAS-FIR, LARCH, OR SOUTHERN PINE[a] FOR WIND OR SEISMIC LOADING[b,h,i,j,k] (See also IBC Table 2306.4.1)

Panel Grade	Minimum Nominal Panel Thickness (in.)	Minimum Nail Penetration in Framing (in.)	Panels Applied Direct to Framing: Nail Size (common or galvanized box)[k]	Nail Spacing at Panel Edges (in.): 6	4	3	2[e]	Panels Applied Over 1/2" or 5/8" Gypsum Sheathing: Nail Size (common or galvanized box)	Nail Spacing at Panel Edges (in.): 6	4	3	2[e]
APA STRUCTURAL I grades	5/16	1-1/4	6d (0.113" dia.)	200	300	390	510	8d (0.131" dia.)	200	300	390	510
	3/8	1-3/8	8d (0.131" dia.)	230[d]	360[d]	460[d]	610[d]	10d (0.148" dia.)	280	430	550[f]	730
	7/16			255[d]	395[d]	505[d]	670[d]					
	15/32			280	430	550	730					
	15/32	1-1/2	10d (0.148" dia.)	340	510	665[f]	870		—	—	—	—
APA RATED SHEATHING; APA RATED SIDING[g] and other APA grades except Species Group 5	5/16 or 1/4[c]	1-1/4	6d (0.113" dia.)	180	270	350	450	8d (0.131 dia.)	180	270	350	450
	3/8			200	300	390	510		200	300	390	510
	3/8	1-3/8	8d (0.131" dia.)	220[d]	320[d]	410[d]	530[d]	10d (0.148" dia.)	260	380	490[f]	640
	7/16			240[d]	350[d]	450[d]	585[d]					
	15/32			260	380	490	640					
	15/32	1-1/2	10d (0.148" dia.)	310	460	600[f]	770	—	—	—	—	—
	19/32			340	510	665[f]	870	—	—	—	—	—
APA RATED SIDING[g] and other APA grades except Species Group 5			**Nail Size (galvanized casing)**					**Nail Size (galvanized casing)**				
	5/16[c]	1-1/4	6d (0.113" dia.)	140	210	275	360	8d (0.131" dia.)	140	210	275	360
	3/8	1-3/8	8d (0.131" dia.)	160	240	310	410	10d (0.148" dia.)	160	240	310[f]	410

TABLE 2

ALLOWABLE SHEAR (POUNDS PER FOOT) FOR HORIZONTAL APA PANEL DIAPHRAGMS WITH FRAMING OF DOUGLAS-FIR, LARCH OR SOUTHERN PINE[a] FOR WIND OR SEISMIC LOADING[g] (See also IBC Table 2306.3.1)

Panel Grade	Common Nail Size[f]	Minimum Nail Penetration in Framing (in.)	Minimum Nominal Panel Thickness (in.)	Minimum Nominal Width of Framing Member at Adjoining Panel Edges and Boundaries (in.)	Blocked Diaphragms: Nail Spacing (in.) at diaphragm boundaries (all cases), at continuous panel edges parallel to load (Cases 3 & 4), and at all panel edges (Cases 5 & 6)[b]				Unblocked Diaphragms: Nails Spaced 6" max. at Supported Edges[b]	
					6	4	2-1/2[c]	2[c]	Case 1 (No unblocked edges or continuous joints parallel to load)	All other configurations (Cases 2, 3, 4, 5 & 6)
					Nail Spacing (in.) at other panel edges (Cases 1, 2, 3 & 4)[b]					
					6	6	4	3		
APA STRUCTURAL I grades	6d[e] (0.113" dia.)	1-1/4	5/16	2	185	250	375	420	165	125
				3	210	280	420	475	185	140
	8d (0.131" dia.)	1-3/8	3/8	2	270	360	530	600	240	180
				3	300	400	600	675	265	200
	10d[d] (0.148" dia.)	1-1/2	15/32	2	320	425	640	730	285	215
				3	360	480	720	820	320	240
APA RATED SHEATHING; APA RATED STURD-I-FLOOR and other APA grades except Species Group 5	6d[e] (0.113" dia.)	1-1/4	5/16	2	170	225	335	380	150	110
				3	190	250	380	430	170	125
			3/8	2	185	250	375	420	165	125
				3	210	280	420	475	185	140
	8d (0.131" dia.)	1-3/8	3/8	2	240	320	480	545	215	160
				3	270	360	540	610	240	180
			7/16	2	255	340	505	575	230	170
				3	285	380	570	645	255	190
			15/32	2	270	360	530	600	240	180
				3	300	400	600	675	265	200
	10d[d] (0.148" dia.)	1-1/2	15/32	2	290	385	575	655	255	190
				3	325	430	650	735	290	215
			19/32	2	320	425	640	730	285	215
				3	360	480	720	820	320	240

Loading

Type	Dead Load(lbs)	Span (ft)	Load (lbs/ft)
Roof	476.4184027	30	15.88061342
Frame	1462.999316	30	48.76664387
Floor	431.7878394	29.16666667	14.8041545
			79.45141178

Roof

Dimesions			
Size	2x6		
b (thick)	1.5	in	1B
d (wide)	5.5	in	1B
L	8	ft	
Sx	7.563	in3	1B
Ix	20.8	in4	1B
DL	20	lb/ft	
LL	0	lb/ft	
V	80.62257478	lb	
M	1934.941795	inlb	

Table M4.3-1 Applicability of Adjustment Factors for Sawn Lumber

Allowable Stress Design	Load and Resistance Factor Design
$F_b' = F_b C_D C_M C_t C_L C_F C_{fu} C_i C_r$	$F_b' = F_b C_M C_t C_L C_F C_{fu} C_i C_r (2.54)(0.85) \lambda$
$F_t' = F_t C_D C_M C_t C_F C_i$	$F_t' = F_t C_M C_t C_F C_i (2.70)(0.80) \lambda$
$F_v' = F_v C_D C_M C_t C_i$	$F_v' = F_v C_M C_t C_i (2.88)(0.75) \lambda$
$F_{c\perp}' = F_{c\perp} C_M C_t C_i C_b$	$F_{c\perp}' = F_{c\perp} C_M C_t C_i C_b (1.67)(0.90)$
$F_c' = F_c C_D C_M C_t C_F C_i C_P$	$F_c' = F_c C_M C_t C_F C_i C_P (2.40)(0.90) \lambda$
$E' = E C_M C_t C_i$	$E' = E C_M C_t C_i$
$E_{min}' = E_{min} C_M C_t C_i C_T$	$E_{min}' = E_{min} C_M C_t C_i C_T (1.76)(0.85)$

Cos(7.125)	=	Load/x	
x	=		20.15564369

Bending Fb							
Sign	Value	units	table				
Fb	1500	lb/in2	4B				
Cd	0.9		2.3.2				
Cm	0.85		4B	1650	<	1150	*Cm = 1
CF	1.1		4B				
Ct	1		2.3.4				
CL	1		3.3.3	5.5	>	1.5	
Cfu	1		4B				
Ci	0.85		2.3.11				
Cr	1.15		4B				
Fb'	1233.849375	lb/in					
Check							
fb	255.8431568	<	Fb'	1233.849375			
Actual Shear fv	14.65864996	psi					

Shear Fv				
Fv	90	psi	4B	
CD	0.9		2.3.2	
CM	0.97		4B	
Ct	1		2.3.4	
Ci	1		2.3.11	
Fv'	78.57	psi		
Check				
Vr'	12.00375	<	78.57	
dn	4	in		notch depth

Beam

Dimesions			
Size	2x6		
b (thick)	5.5	in	1B
d (wide)	1.5	in	1B
L	8	ft	
Sx	7.563	in3	1B
Ix	20.8	in4	1B
DL	21.17415123	lb/ft	
LL	40	lb/ft	
V	244.6966049	lb	
M	5872.718518	inlb	

Table M4.3-1 Applicability of Adjustment Factors for Sawn Lumber

Allowable Stress Design	Load and Resistance Factor Design
$F_b' = F_b C_D C_M C_t C_L C_F C_{fu} C_i C_r$	$F_b' = F_b C_M C_t C_L C_F C_{fu} C_i C_r (2.54)(0.85)\lambda$
$F_t' = F_t C_D C_M C_t C_F C_i$	$F_t' = F_t C_M C_t C_F C_i (2.70)(0.80)\lambda$
$F_v' = F_v C_D C_M C_t C_i$	$F_v' = F_v C_M C_t C_i (2.88)(0.75)\lambda$
$F_{c\perp}' = F_{c\perp} C_M C_t C_i C_b$	$F_{c\perp}' = F_{c\perp} C_M C_t C_i C_b (1.67)(0.90)$
$F_c' = F_c C_D C_M C_t C_F C_i C_P$	$F_c' = F_c C_M C_t C_F C_i C_P (2.40)(0.90)\lambda$
$E' = E C_M C_t C_i$	$E' = E C_M C_t C_i$
$E_{min}' = E_{min} C_M C_t C_i C_T$	$E_{min}' = E_{min} C_M C_t C_i C_T (1.76)(0.85)$

Bending Fb							
Sign	Value	units	table				
Fb	1500	lb/in2	4B				
Cd	0.9		2.3.2				
Cm	0.85		4B	1889.881575	<	1150	*Cm = 1
CF	1.25992105		4B				
Ct	1		2.3.4				
CL	1		3.3.3	1.5	>	5.5	
Cfu	1		4B				
Ci	0.85		2.3.11				
Cr	1.15		4B				
Fb'	1413.229818	lb/in					
Check							
fb	776.5064813	<	Fb'	1413.229818			
Actual Shear fv	44.4902918	psi					

Shear Fv			
Fv	90	psi	4B
CD	0.9		2.3.2
CM	0.97		4B
Ct	1		2.3.4
Ci	1		2.3.11
Fv'	78.57	psi	
Check			
Vr'	44.4902918	<	78.57

Fc(perpendicular)			
Sign	Value	units	table
W	5.097845936	lb/in	
96By	23490.87407		
By	244.6966049	lb	
Ay	244.6966049	lb	
M@L/2	938.0036522		
V@0	244.6966049		
V@L/2	0		
Fc(perpendicular)	480	psi	4B
CM	0.67		4B
Ct	1		2.3.4
Ci	1		2.3.11
Cb	1		2.3.10
Fc(perpendicular)'	321.6	psi	
P	61.17415123		
Abearins	1.5		
fc(perpendicular)	40.78276749		
Check			
Fc(perpendicular)'	321.6	>	40.7827

Stud

Dimesions			
Size	2x6		
b (thick)	1.5	in	1B
d (wide)	5.5	in	1B
L	8	ft	
Sx	7.563	in3	1B
Ix	20.8	in4	1B
DL	50	lb/ft	
LL	40	lb/ft	
V	360	lb	
M	8640	inlb	

Table M4.3-1 Applicability of Adjustment Factors for Sawn Lumber

Allowable Stress Design	Load and Resistance Factor Design
$F_b' = F_b C_D C_M C_t C_L C_F C_{fu} C_i C_r$	$F_b' = F_b C_M C_t C_L C_F C_{fu} C_i C_r (2.54)(0.85) \lambda$
$F_t' = F_t C_D C_M C_t C_F C_i$	$F_t' = F_t C_M C_t C_F C_i (2.70)(0.80) \lambda$
$F_v' = F_v C_D C_M C_t C_i$	$F_v' = F_v C_M C_t C_i (2.88)(0.75) \lambda$
$F_{c\perp}' = F_{c\perp} C_M C_t C_i C_b$	$F_{c\perp}' = F_{c\perp} C_M C_t C_i C_b (1.67)(0.90)$
$F_c' = F_c C_D C_M C_t C_F C_i C_P$	$F_c' = F_c C_M C_t C_F C_i C_P (2.40)(0.90) \lambda$
$E' = E C_M C_t C_i$	$E' = E C_M C_t C_i$
$E_{min}' = E_{min} C_M C_t C_i C_T$	$E_{min}' = E_{min} C_M C_t C_i C_T (1.76)(0.85)$

Fc				
Sign	Value	units	table	
Ke	1		3.7.1	
L	96	in	3.7.1	
Le	96	in	3.7.1	
le/d	64	in	<	50
Fce	321.09375	psi	3.7.1	
E	1600000	psi	4B	
Fc	1600	psi	4B	
CM	0.8		4B	
Ct	1		2.3.4	
Ci	0.85		2.3.11	
CF	1.090552321		4B	
Fc'	1186.520925	psi		
Cp	0.25			
c	0.8			
Fc'	296.6302312			
P	2447.199408	lbs		
Check				
fc	296.6302312	<	1186.52	
.75Fc'	889.8906937	>	296.630	

Sheathing

Wall			
Sheathing thickness	5/8	in	
Nail Size	10d		
Required Capacity	250	plf	
Edge Nail Spacing	6	in	
Innner Nail Spacing	12	in	
Sheathing Capacity	200	plf	4.2
Wind Ratio	1.4		2309.4.1
Capacity	280	>	250

Roof			
Sheathing thickness	5/8	in	
Nail Size	10d		
Wind	25		
Edge Nail Spacing	6	in	
Innner Nail Spacing	12	in	
Length	30	ft	
Width	8	ft	
Wall height	9	ft	
Roof height	10	ft	
Wn-s	137.5		
We-w	125		
Vn-s	68.75		
Ve-w	16.66666667		
SGAF	0.92		
Sheathing Capacity (case 5)	140	plf	
Sheathing Capacity (case 6)	140	plf	
Capacity (case 5)	128.8	>	68.75
Capacity (case 6)	128.8	>	16.66666667
Tn-s	1546.875		
Te-w	33.33333333		

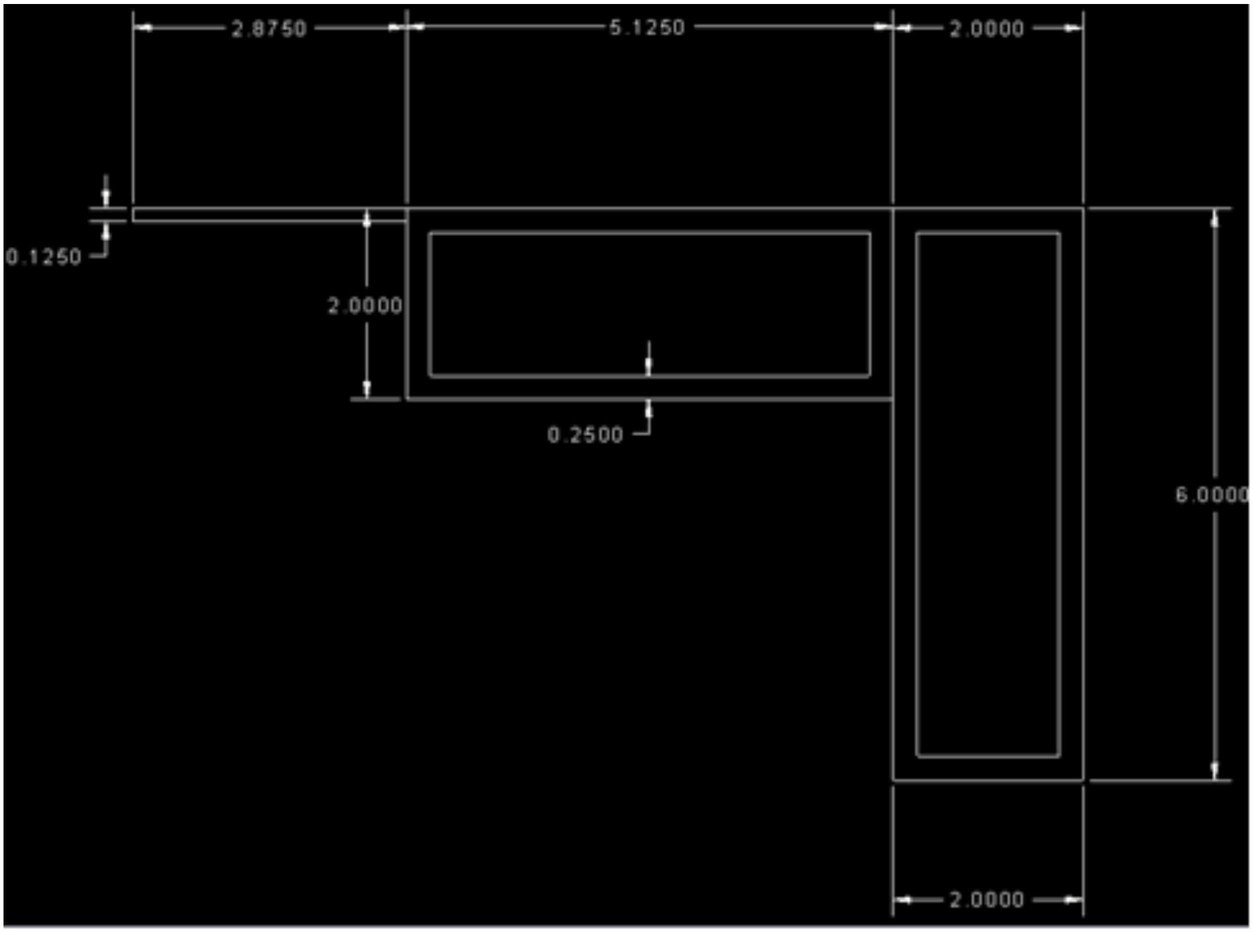
Appendix B - Steel Trailer

Table 5.3
Approved Base Metals for Prequalified WPSs (see 5.3)

GROUP	Steel Specification Requirements		Minimum Yield Point/Strength ksi	Minimum Yield Point/Strength MPa	Tensile Range ksi	Tensile Range MPa
		Steel Specification	ksi	MPa	ksi	MPa
	ASTM A36	≤ 3/4 in [20 mm]	36	250	58–80	400–550
	ASTM A53	Grade B	35	240	60 min.	415 min.
	ASTM A106	Grade B	35	240	60 min.	415 min.
	ASTM A131	Grades A, B, D, E	34	235	58–75	400–520
	ASTM A139	Grade B	35	240	60 min.	415 min.
	ASTM A381	Grade Y35	35	240	60 min.	415 min.
	ASTM A500 (Square/ Rectangular)	Grade A	39	270	45 min.	310 min.
		Grade B	46	315	58 min.	400 min.
		Grade C	50	345	62 min.	425 min.
	ASTM A500 (Round)	Grade A	33	230	45 min.	310 min.
		Grade B	42	290	58 min.	400 min.
		Grade C	46	315	62 min.	425 min.

Table 5.4
Filler Metals for Matching Strength for Table 5.3, Groups I, II, III, and IV Metals—SMAW and SAW (see 5.6)

Base Metal Group	AWS Electrode Specification	SMAW: A5.1, Carbon Steel	SMAW: A5.5[a], Low-Alloy Steel	SAW: A5.17, Carbon Steel	SAW: A5.23[c], Low-Alloy Steel
I	AWS Electrode Classification	E60XX E70XX	E70XX-X	F6XX-EXXX F6XX-ECXXX F7XX-EXXX F7XX-ECXXX	F7XX-EXXX-XX F7XX-ECXXX-XX
II	AWS Electrode Classification	E7015 E7016 E7018 E7028	E7015-X E7016-X E7018-X	F7XX-EXXX F7XX-ECXXX	F7XX-EXXX-XX F7XX-ECXXX-XX
III	AWS Electrode Classification	N/A	E8015-X E8016-X E8018-X	N/A	F8XX-EXXX-XX F8XX-ECXXX-XX
IV	AWS Electrode Classification	N/A	E9015-X E9016-X E9018-X E9018M	N/A	F9XX-EXXX-XX F9XX-ECXXX-XX


2.8750
5.1250
2.0000
0.1250
2.0000
0.2500
6.0000
2.0000

Appendix C - Air Leakage Area Calculations

Airflow rate from infiltration equation: from 2017 ASHRAE- Fundamentals

$$Q = A_L\sqrt{C_s|\Delta T| + C_w U^2}$$

Where: Q = airflow rate [cfm]

A_L= effective air leakage area [in^2]

C_s= stack coefficient [$\frac{cfm^2}{in^4 ºF}$]

ΔT= average indoor-outdoor temperature difference for time interval of calculations [ºF]

C_w= wind coefficent [$\frac{cfm^2}{in^4 \cdot mph^2}$]

U = average wind speed measured at local weather station for time interval of calculator [mph]

The Volume of our tiny home is 2868.75 ft^3 and the stack coefficient for a one-story house is 0.015 $\frac{cfm^2}{in^4 ºF}$

	ΔT [ºF]	U [mph]
LA, California	4	6
Austin, Texas	1	8
Portland, Oregon	14	4.5

*The temperature difference for each location was assuming that the average indoor temperature is 68ºF and the outdoor temperature value was taken from Climate Consultant

**The average wind speed values were taken from Climate Consultant

Shelter Class	C_w [$\frac{cfm^2}{in^4 \cdot mph^2}$]
1	0.0119

2	0.0092
3	0.0065
4	0.0039
5	0.0012

*Values taken from the 2017 ASHRAE- Fundamentals book

Air Change Rate [ach]	Airflow rate [cfm]
0.1	286.875
0.5	1434.375
1	2868.750
2	5737.500

*Airflow rate values calculated from the equation $I = \frac{Q}{V}$ where I = air change rate [ach], Q = airflow rate [cfm] , and V = volume [ft^3]

Finally, using the airflow rate from infiltration equation, and considering the different locations (LA, Austin, Portland), Shelter Classes (1, 2, 3, 4, 5), and Air Change Rates (0.1, 0.5, 1, 2) we can calculate the respective Effective Air Leakage Area (A_L)

LA, California			$A_L = in^2$			
Shelter class	$c_s \Delta T + c_w U^2$	$\sqrt{c_s \Delta T + c_w U^2}$	I = 0.1	I = 0.5	I = 1	I = 2
1	0.4884	0.6989	6.8415	34.2077	68.4154	136.8307
2	0.3912	0.6255	7.6444	38.2219	76.4438	152.8875
3	0.2940	0.5422	8.8180	44.0898	88.1795	176.3591
4	0.2004	0.4477	10.6805	53.4026	106.8052	213.6105
5	0.1032	0.3212	14.8834	74.4169	148.8338	297.6676

Austin, Texas			$A_L = in^2$			
Shelter class	$c_s\Delta T + c_w U^2$	$\sqrt{c_s\Delta T + c_w U^2}$	I = 0.1	I = 0.5	I = 1	I = 2
1	0.7766	0.8812	5.4255	27.1277	54.2554	108.5107
2	0.6038	0.7770	6.1531	30.7656	61.5311	123.0623
3	0.4310	0.6565	7.2829	36.4144	72.8287	145.6575
4	0.2646	0.5144	9.2949	46.4747	92.9494	185.8988
5	0.0918	0.3030	15.7805	78.9024	157.8048	315.6095

Portland, Oregon			$A_L = in^2$			
Shelter class	$c_s\Delta T + c_w U^2$	$\sqrt{c_s\Delta T + c_w U^2}$	I = 0.1	I = 0.5	I = 1	I = 2
1	0.4510	0.6715	7.1198	35.5988	71.1976	142.3952
2	0.3963	0.6295	7.5950	37.9751	75.9503	151.9006
3	0.3416	0.5845	8.1803	40.9013	81.8025	163.6050
4	0.2890	0.5376	8.8943	44.4715	88.9429	177.8858
5	0.2343	0.4840	9.8777	49.3884	98.7769	197.5538

Air Leakage Area Values for LA, Austin, and Portland, with varying air change rates and shelter levels.

Appendix D - Appliances

Appliance	Power (watts)	Voltage (V)	Description
Microwave Oven	1000	120	Toshiba EC042A5C-SS Countertop Microwave Oven With Convection
Fridge	104.65	115	Insignia™ - 10.5 Cu. Ft. Top-Freezer Refrigerator
Water Heater	1440	120	Camplux ME60 Mini Tank Electric Water Heater 6-Gallon with Cord Plug,1.44kW at 120 Volts
Mini Split	720 (cooling) 1000 (heating)	115	Pioneer® 9,000 BTU 20.5 SEER 115V Ductless Mini-Split Inverter + Air Conditioner Heat Pump System Full Set
Stove	1800	120 (AC)	Cuisinart Double Burner Induction Cooktop
Composting Toilet	2.5	12	Separett Villa 9215 AC/DC Urine Diverting Toilet
LED Lights	200		
TV	150		
Cell Phone	6		
Computer	200		

*The last four energy values were taken from *Consumer Guide to Home Energy Savings* by Alex Wilson and John Morrill

** The Power of the Fridge was calculated by multiplying the amperage (0.91 amps) by the voltage (115 volts) of the fridge

Appendix E - Size of Solar Systems

$$Size\ (kW)\ =\ Array\ Area\ (m^2)\ *\ 1\ (\frac{kW}{m^2})\ *\ Module\ Efficiency\ (\%)$$

where: Array Area = 8.5 ft * 30 ft = 255 ft^2 = 23 m^2 (leaving some space on the edges)

Module efficiency = 15%

*Equation from National Renewable Energy Laboratory's (NREL) PVwatts calculator

Appendix F - Breakdown of Battery Consumption Timeline Graphs

The basic template for each graph broke each day into one-min increments. For every one-min row, there were 18 columns, each varying in input.

Column #	Column Description
1	Solar energy per m^2 on the PV panel, 100% (W/m2)
2	Solar energy per m^2 on the PV panel reduced to __% (W/m2)
3	Total solar energy on the PV panel (W)
4	Heat pump power (W)
5	Microwave power (W)
6	Fridge (W)
7	LED Lights (W)
8	Toilet (W)
9	Stove only one burner (W)
10	TV (W)
11	Cell Phone (W)
12	Computer (W)
13	Water Heater (W)
14	Total consumption [W}

15	Total energy consumption [Wh]
16	Total energy generated [Wh]
17	Energy left in the battery [Wh] - unlimited size
18	Energy left in the battery [Wh] - realistic size

Column 1 was the solar energy per m^2 on the PV panel, 100% (W/m2), in which the data was taken from an hourly dataset downloaded from NREL PVwatts Calculator, with the inputs below.

Column 2 was the Solar energy per m^2 on the PV panel reduced to __% (W/m2). This column was a percentage reduction of the first column. The reduction percentage was based on the cloud coverage, obtained from Visual Crossing. If the cloud coverage percentage was **100% - cloud coverage percent**. However, it must be noted that there is not a 1:1 ratio between cloud coverage percentage and the amount of solar energy on the PV panel. This comparison was done solely to test different solar energy reductions and how it would affect the energy left in the battery.

Column 3 was the Total solar energy on the PV panel (W). This column was **column 2 * 23**, as our tiny home has 23 square meters of solar panels, and columns 1 and 2 were only the solar energy input of one meter of solar panel.

Column 4 to Column 13:

The next ten columns were the minute breakdown of the appliance consumption. The timeline can be seen below.

Appliance:	Hourly Peak Power [W]	Time Appliance runs
Heat pump power- cooling (W)	720	6:00 – 18:00 (summer time)
Heat pump power- heating (W)	1000	6:00 – 18:00 (winter time)
Microwave power (W)	1000	7:00 – 7:10 , 14:00 – 14:10 , 19:00 – 19:10
Fridge (W)	104.65	10-min ON, 20-min OFF (all day)
LED Lights (W)	200	7:00 – 8:00 , 18:00 – 23:00
Toilet (W)	2.5	All day
Stove only one burner (W)	900	19:00 – 19:30
TV (W)	150	20:00 – 23:00
Cell Phone (W)	6	23:00 – 2:00

Computer (W)	200	23:00 – 2:00
Water Heater (W)	1440	8:00 – 8:50 (warm the tank) 8:50 – 9:00 (shower) 9:00 – 9:50 (warm the tank) 20:00 – 20:50 (warm the tank) 20:50 – 21:00 (dishes) 21:00 – 21:50 (warm the tank)

The length of time it takes for the water heater to warm up the entire tank was calculated using the equation $time = \frac{c\rho(V)(\Delta T)}{Q'}$ which resulted in about 48-min to heat up the water tank.

Where

c = specific heat capacity of water

ρ = density

$c\rho = 4.18\ x\ 10^3\ \frac{J}{kg^{o}C}$

V = volume $[m^3]$: 0.6 GPM = (3.7854 x $10^3\ \frac{m^3}{s}$) x 600 sec = 0.02271 m^3

ΔT = change in temperature [ºC]: 48.9ºC - 4.4ºC = 44ºC

Q' = Power [W]: 1440 W

Column 14 was the Total consumption [W] in which adds up column 4 to column 13 for every minute.

Column 15 was the Total energy consumption [Wh] which is calculated by: **column 14 divided by 60**.

Column 16 was the Total energy generated [Wh], which is calculated by: **column 3 (Total solar energy on the PV panel (W)) divided by 60**.

Column 17 was the Energy left in the battery [Wh] - unlimited size. This is calculated by: **the initial energy of the battery per unit * number of units + column 16 - column 15**.

Lastly, **Column 18** was the Energy left in the battery [Wh] - realistic size. This is calculated using an IF-statement. Column 16 does not take into consideration that the battery can only hold a maximum of 11400 Wh for every unit, and sometimes column 16 says that there is more energy left in the battery than the battery can actually hold. Therefore, the IF-statement corrects this assumption and says: **IF(column 16 is less than 11400 * the number of units, then the value is the same as column 16. If not, then put 11400 * the number of units)**

Appendix G - HardiePanel Vertical Siding Installation (JamesHardie).

HardiePanel® Vertical Siding

MULTIFAMILY / COMMERCIAL INSTALLATION REQUIREMENTS

EFFECTIVE JANUARY 2020

IMPORTANT: FAILURE TO FOLLOW JAMES HARDIE WRITTEN INSTALLATION INSTRUCTIONS AND COMPLY WITH APPLICABLE BUILDING CODES MAY VIOLATE LOCAL LAWS, AFFECT BUILDING ENVELOPE PERFORMANCE AND MAY AFFECT WARRANTY COVERAGE. FAILURE TO COMPLY WITH ALL HEALTH AND SAFETY REGULATIONS WHEN CUTTING AND INSTALLING THIS PRODUCT MAY RESULT IN PERSONAL INJURY. BEFORE INSTALLATION, CONFIRM YOU ARE USING THE CORRECT HARDIEZONE® PRODUCT INSTRUCTIONS BY VISITING HARDIEZONE.COM OR CALL 1-866-942-7343 (866-9-HARDIE).

STORAGE & HANDLING:

Store flat and keep dry and covered prior to installation. Installing siding wet or saturated may result in shrinkage at butt joints. Carry planks on edge. Protect edges and corners from breakage. James Hardie is not responsible for damage caused by improper storage and handling of the product.

⚠ CUTTING INSTRUCTIONS

OUTDOORS

1. Position cutting station so that airflow blows dust away from the user and others near the cutting area.
2. Cut using one of the following methods:
   - a. Best: Circular saw equipped with a HardieBlade® saw blade and attached vacuum dust collection system. Shears (manual, pneumatic or electric) may also be used, not recommended for products thicker than 7/16 in.
   - b. Better: Circular saw equipped with a dust collection feature (e.g. Roan® saw) and a HardieBlade saw blade.
   - c. Good: Circular saw equipped with a HardieBlade saw blade.

INDOORS

DO NOT grind or cut with a power saw indoors. Cut using shears (manual, pneumatic or electric) or the score and snap method, not recommended for products thicker than 7/16 in.

- DO NOT dry sweep dust; use wet dust suppression or vacuum to collect dust.
- For maximum dust reduction, James Hardie recommends using the "Best" cutting practices. Always follow the equipment manufacturer's instructions for proper operation.
- For best performance when cutting with a circular saw, James Hardie recommends using HardieBlade® saw blades.
- Go to jameshardiepros.com for additional cutting and dust control recommendations.

IMPORTANT: The Occupational Safety and Health Administration (OSHA) regulates workplace exposure to silica dust. For construction sites, OSHA has deemed that cutting fiber cement with a circular saw having a blade diameter less than 8 inches and connected to a commercially available dust collection system per manufacturer's instructions results in exposures below the OSHA Permissible Exposure Limit (PEL) for respirable crystalline silica, without the need for additional respiratory protection.

If you are unsure about how to comply with OSHA silica dust regulations, consult a qualified industrial hygienist or safety professional, or contact your James Hardie technical sales representative for assistance. James Hardie makes no representation or warranty that adopting a particular cutting practice will assure your compliance with OSHA rules or other applicable laws and safety requirements.

GENERAL REQUIREMENTS:

- Refer to table 1 for multifamily/commercial drainage requirements for James Hardie® vertical siding.
- References to the 2005 National Building Code (NBC) of Canada are made throughout this document. Local building code requirements may supersede the NBC in some locations.
- HardiePanel® siding can be installed over furring strips (in accordance with local building code requirements). HardiePanel vertical siding can be installed over braced wood or steel studs, 20 gauge (0.836 mm) minimum to 16 gauge (1.367 mm) maximum, spaced a maximum of 610mm (24 in) o.c.
- Where local building code requires a capillary break (Rainscreens, Furring, Etc.), fastener specifications per the CCMC can still be used as long as the required fastener penetration is achieved into an approved nailable substrate.
- A water-resistive barrier is required in accordance with local building code requirements. The water-resistive barrier must be appropriately installed with penetration and junction flashing in accordance with local building code requirements. The manufacturer will assume no responsibility for water infiltration. James Hardie does market HardieWrap® Weather Barrier, a non-woven non-perforated housewrap, complies with building code requirements.
- Information on installing James Hardie products over non-nailable substrates (ex: gypsum, foam,etc.) can be located in JH Tech Bulletin 19 at www.jamehardie.com
- Do not install James Hardie products such that they may remain in contact with standing water.
- HardiePanel® vertical siding may be installed on vertical wall applications only.
- DO NOT use HardiePanel vertical siding in Fascia or Trim applications.
- The designer and/or architect shall take into consideration the coefficient of thermal expansion and moisture movement of the product in their design. These values can be found in the Technical Bulletin #8 "Expansion Characteristics of James Hardie® Siding Products" at www.jameshardiecommercial.com.
- James Hardie Building Products may be installed on buildings with a maximum mean roof height of 25.9 m (85 feet).
- Minimum standard panel design size is 12" x 16". Note:Panels may be notched and cut to size to fit between windows, doors, corners, etc.

Table 1: HardiePanel® Vertical Siding – Wall Drainage Requirements

<table>
<tr><th rowspan="3"></th><th rowspan="3">Building Height (Stories)</th><th colspan="4">Exterior Wall Drainage Requirements</th></tr>
<tr><th colspan="2">With a Minimum 12-inch Eave Overhang</th><th colspan="2">Without a Minimum 12-inch Eave Overhang</th></tr>
<tr><th>Vertical Joints formed by: Board and Batten; Moderate Contact; Caulk</th><th>Vertical Joints formed by Expressed Seam Joints</th><th>Vertical Joints formed by: Board and Batten; Moderate Contact; Caulk</th><th>Vertical Joints formed by Expressed Seam Joints</th></tr>
<tr><td rowspan="7">James Hardie Panel Products > 30% of Building's Total Exterior Wall Covering</td><td>7 story building</td><td colspan="4" rowspan="6">Rainscreen (min. 3/8 in. air gap)[3]</td></tr>
<tr><td>6 story building</td></tr>
<tr><td>5 story building</td></tr>
<tr><td>4 story building</td></tr>
<tr><td>3 story building</td></tr>
<tr><td>2 story building</td></tr>
<tr><td>1 story building</td><td>WRB[1]</td><td colspan="3">Rainscreen (min. 3/8 in. air gap)[3]</td></tr>
<tr><td rowspan="7">James Hardie Panel Products ≤ 30% of Building's Total Exterior Wall Covering</td><td>7 story building</td><td colspan="4" rowspan="3">Rainscreen (min. 3/8 in. air gap)[3]</td></tr>
<tr><td>6 story building</td></tr>
<tr><td>5 story building</td></tr>
<tr><td>4 story building</td><td colspan="2" rowspan="2">Drainage Plane (e.g. drainable WRB) with 90% drainage efficiency[2]</td><td colspan="2" rowspan="4">Rainscreen (min. 3/8 in. air gap)[3]</td></tr>
<tr><td>3 story building</td></tr>
<tr><td>2 story building</td><td rowspan="2">WRB[1]</td><td rowspan="2">Drainage Plane (e.g. drainable WRB) with 90% drainage efficiency[2]</td></tr>
<tr><td>1 story building</td></tr>
</table>

[1] Water-resistive Barrier and drainage requirements as defined by building code.[2] Water-resistive Barrier as defined by local building code that is manufactured in a manner to enhance drainage; must meet minimum 90% drainage efficiency when tested in accordance with ASTM E2273 or other recognized national standards.[3] Water-resistive Barrier (WRB) as defined by building code and a minimum 3/8 in (10mm) air space between the WRB and the panel siding (formed by minimum 3/8 in. furring).

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Visit jameshardiepros.com for the most recent version.

COM1301 P1/5 01/20

INSTALLATION:

Fastener

Position fasteners 3/8 in from panel edges and no closer than 2 in away from corners. Do not nail into corners.

- HardiePanel vertical siding must be joined on stud.
- Double stud may be required to maintain minimum edge nailing distances.
- When screws are used to attach panels to steel studs/furring, the screws shall have wing tips. If screws do not have wing tips, then pre-drilling is required. (Not applicable when using pins) Follow chart below for pre-drilling:

SCREW	PRE-DRILL	HEAD DIAMETER
No. 8	7/32 in	Min 0.323 in
No. 10	1/4 in	Min 0.323 in

Refer to Table 1 for correct installation condition

Joint Treatment

- Vertical Joints - Install panels in moderate contact (fig. 1), alternatively joints may also be covered with battens, PVC or metal jointers or caulked (Not applicable to ColorPlus® Finish) (fig. 2).
- Horizontal Joints - Provide Z-flashing at all horizontal joints (fig. 3).

A: Water Resistive Barrier Condition

Figure 1

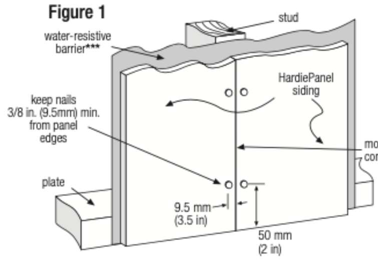
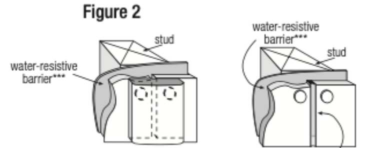


Figure 2



Batten Joint

Caulk Joint
(Not applicable to ColorPlus® Finish)

Figure 3

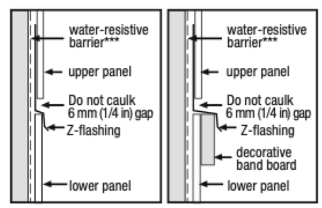
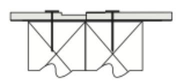


Figure 4



Recommendation: When installing Sierra 8 panel, provide a double stud at panel joints to avoid nailing through grooves.

B: Drainage Plane/Wrap Condition

Figure 1

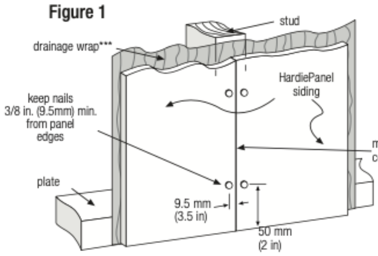
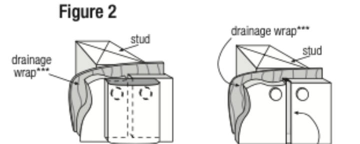


Figure 2



Batten Joint

Caulk Joint
(Not applicable to ColorPlus® Finish)

Figure 3

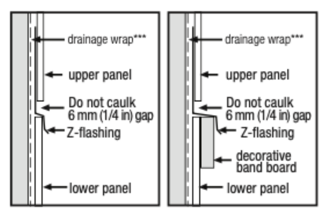
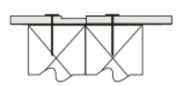


Figure 4



Recommendation: When installing Sierra 8 panel, provide a double stud at panel joints to avoid nailing through grooves.

C: Furring/Rainscreen Condition

Figure 1

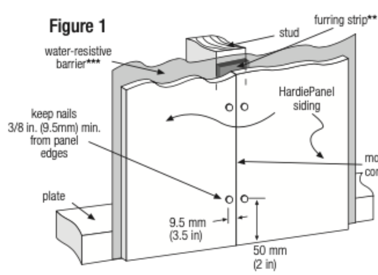
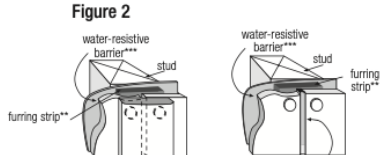


Figure 2



Batten Joint

Caulk Joint
(Not applicable to ColorPlus® Finish)

Figure 3

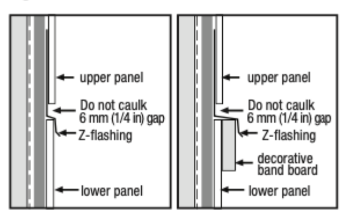
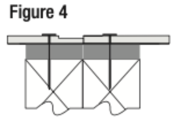


Figure 4



Recommendation: When installing Sierra 8 panel, provide a double stud at panel joints to avoid nailing through grooves.

* Apply caulk in accordance with caulk manufacturer's written application instructions.
** Furring as prescribed in Table 1.
*** WRB or Drainage Plane as prescribed in Table 1.

CLEARANCE AND FLASHING REQUIREMENTS

Install siding and trim products in compliance of Part 9.27.2.4 of the NBC which requires a minimum 200mm (8 in) for clearance between the bottom edge of the siding and the adjacent finished grade.

Figure 3
Roof to Wall

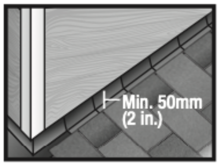


Figure 4
Horizontal Flashing

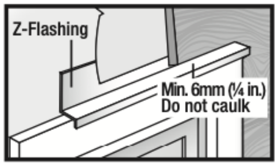


Figure 5
Kickout Flashing

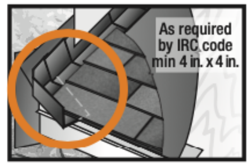


Figure 6
Slabs, Path, Steps to Siding

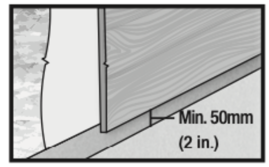


Figure 7
Deck to Wall

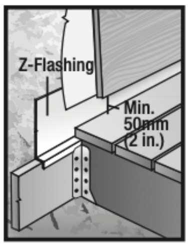


Figure 8
Ground to Siding

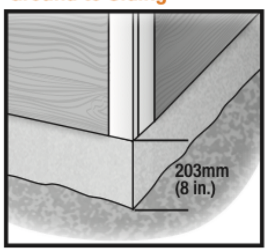


Figure 9
Gutter to Siding

Figure 10
Sheltered Areas

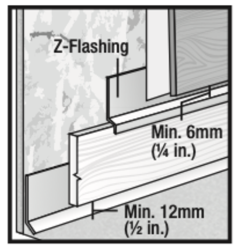


Figure 11
Mortar/Masonry

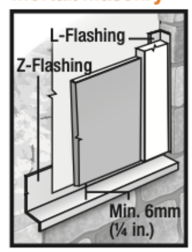


Figure 12
Drip Edge

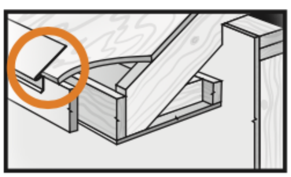


Figure 13
Block Penetration

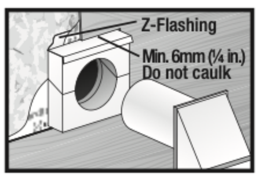
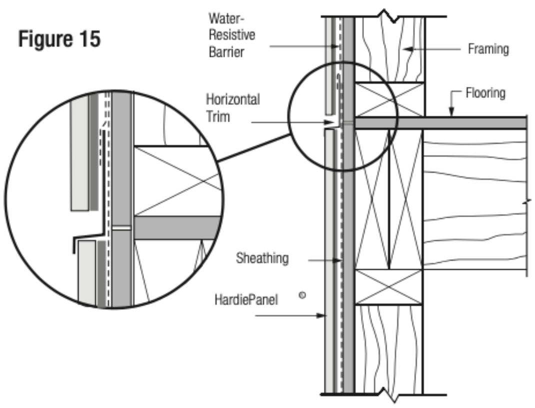


Figure 14
Valley/Shingle Extension

At the juncture of the roof and vertical surfaces, flashing and counterflashing shall be installed per the roofing manufacturer's instructions. Part 9.27.2.4 requires a minimum 50mm (2 in) clearance between the roofing and the bottom edge of the siding and trim. (fig. 3)

Do not bridge floors with HardiePanel siding. Horizontal joints should always be created between floors (fig. 10).

Figure 15



Note: Furring shown is as a best practice or as prescribed per Table 1.

HardiePanel® vertical siding complies with ASTM Specification C1186 (Grade II, Type A) and ISO Standard 8336 (Category 3, Type A).

When tested in accordance with CAN/ULC-S102, the product is recognized to have the following properties: Flame Spread Rating: 0, Smoke Developed Classification: 0.

When tested in accordance with CAN/ULC-S114, the product is recognized as noncombustible.

RECOGNITION:

HardiePanel vertical siding is recognized as an exterior wall cladding in CCMC Evaluation Report 12678-R. This document should also be consulted for additional information concerning the suitability of this product for specific applications. For technical assistance, call 1-800-9-HARDIE.

FIRE-RESISTIVE CONSTRUCTION:

HardiePanel vertical siding is recognized as a component in 1-hour & 2-hour fire-related wall construction when tested in accordance with CAN/ULC-S101. Details of the listed assemblies may be found at: https://bpdirectory.intertek.com

ALLOWABLE LOADS FOR STRUCTURAL EXTERIOR HARDIEPANEL® VERTICAL SIDING

FRAME TYPES	STUD SPACING	VERTICAL FASTENER SPACING	FASTENERS	RATING (kPa)	
				Non-Post-Disaster Building (Height < 12 m)	Non-Post-Disaster Building (Height < 20 m)
2x4 SPF wood	610 mm (24 in)	305 mm (12 in)	6d common nail (2.87mm x 6.75 mm x 50.8 mm)	Q50<0.55	Q50<0.45
2x4 SPF wood	610 mm (24 in)	203 mm (8 in)	6d siding nail (2.34 mm x 5.64 mm x 50.8 mm)	Q50<0.55	Q50<0.45
2x4 SPF wood	610 mm (24 in)	152 mm (6 in)	6d common nail (2.87mm x 6.75 mm x 50.8 mm)	Q50<0.75	Q50<0.65
2x4 SPF wood	610 mm (24 in)	152 mm (6 in)	4d ring shank siding nail (2.41 mm x 5.56 mm x 38 mm)	Q50<0.55	Q50<0.45
20-ga. steel	610 mm (24 in)	305 mm (12 in)	#8 bugle head screw (8.2 mm x 31.8 mm)	Q50<0.45	N/A
20-ga. steel	610 mm (24 in)	203 mm (8 in)	1.5 in ET&F fastener (2.54 mm x 6.35 mm x 38 mm)	Q50<0.55	Q50<0.45
20-ga. steel	406 mm (16 in)	152 mm (6 in)	1.5 in ET&F fastener (2.54 mm x 6.35 mm x 38 mm)	Q50<0.75	Q50<0.65

METRIC TO IMPERIAL CONVERSION TABLE

The following table provides a conversion of the nominal metric measurements presented in these installation instructions to nominal Imperial fraction measurement values

mm	inches	mm	inches	mm	inches	mm	inches
2.3	3/32	6.7	17/64	25	1	150	6
2.5	3/32	7.5	5/16	38	1-1/2	203	8
2.8	7/64	8.2	21/64	50	2	305	12
5.7	7/32	9	23/64	92	3-5/8	406	16
6.2	1/4	12	15/32	102	4	610	24

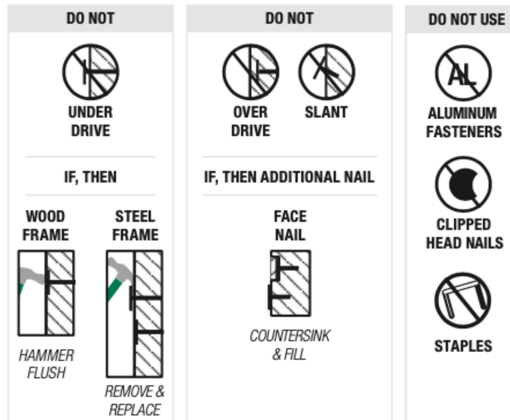
GENERAL FASTENING REQUIREMENTS

Fasteners must be corrosion resistant, galvanized, or stainless steel. Electro-galvanized are acceptable but may exhibit premature corrosion. James Hardie recommends the use of quality, hot-dipped galvanized nails. James Hardie is not responsible for the corrosion resistance of fasteners. Stainless steel fasteners are recommended when installing James Hardie® products near the ocean, large bodies of water, or in very humid climates.

Manufacturers of ACQ and CA preservative-treated wood recommend spacer materials or other physical barriers to prevent direct contact of ACQ or CA preservative-treated wood and aluminum products. Fasteners used to attach HardieTrim Tabs to preservative-treated wood shall be of hot dipped zinc-coated galvanized steel or stainless steel and in accordance to 2009 IRC R317.3 or 2009 IBC 2304.9.5

• Consult applicable product evaluation or listing for correct fasteners type and placement to achieve specified design wind loads.
• NOTE: Published wind loads may not be applicable to all areas where Local Building Codes have specific jurisdiction. Consult James Hardie Technical Services if you are unsure of applicable compliance documentation.
• Drive fasteners perpendicular to siding and framing.
• Fastener heads should fit snug against siding (no air space).
• NOTE: Whenever a structural member is present, HardiePlank should be fastened with even spacing to the structural member. The tables allowing direct to OSB or plywood should only be used when traditional framing is not available.

James Hardie products can be hand nailed or fastened with a pneumatic tool. Pneumatic fastening is highly recommended. Set air pressure so that the fastener is driven snug with the surface of the siding. A flush mount attachment on the pneumatic tool is recommended. This will help control the depth the nail is driven. If setting the nail depth proves difficult, choose a setting that under drives the nail. (Drive under driven nails snug with a smooth faced hammer - Does not apply for installation to steel framing).



PAINTING

• Care should be taken when handling and cutting James Hardie® ColorPlus® products. During installation use a wet soft cloth or soft brush to gently wipe off any residue or construction dust left on the product, then rinse with a garden hose.
• Touch up nicks, scrapes and nail heads using the ColorPlus® Technology touch-up applicator. Touch-up should be used sparingly. If large areas require touch-up, replace the damaged area with new HardiePlank® lap siding with ColorPlus® Technology.
• Laminate sheet must be removed immediately after installation of each course.
• Terminate non-factory cut edges into trim where possible, and caulk. Color matched caulks are available from your ColorPlus® product dealer.
• Treat all other non-factory cut edges using the ColorPlus Technology edge coaters, available from your ColorPlus product dealer.
Note: James Hardie does not warrant the usage of third party touch-up or paints used as touch-up on James Hardie ColorPlus products.

Problems with appearance or performance arising from use of third party touch-up paints or paints used as touch-up that are not James Hardie touch-up will not be covered under the James Hardie ColorPlus Limited Finish Warranty.

BLOCKED PENETRATIONS

Penetrations such as hose bibs and holes 1 ½" or larger such as dryer vents shall have a block of trim around point of penetration.

CAULKING

For best results use an Elastomeric Joint Sealant complying with ASTM C920 Grade NS, Class 25 or higher or a Latex Joint Sealant complying with ASTM C834. Caulking/Sealant must be applied in accordance with the caulking/sealant manufacturer's written instructions. **Note: some caulking manufacturers do not allow "tooling".**

CUT EDGE TREATMENT

Caulk, paint or prime all field cut edges. James Hardie touch-up kits are required to touch-up ColorPlus products.

COLORPLUS® TECHNOLOGY CAULKING, TOUCH-UP & LAMINATE

DO NOT use stain, oil/alkyd base paint, or powder coating on James Hardie® Products. Factory-primed James Hardie products must be painted within 180 days of installation. 100% acrylic topcoats are recommended. Do not paint when wet. For application rates refer to paint manufacturers specifications. Back-rolling is recommended if the siding is sprayed.

PAINTING JAMES HARDIE® SIDING AND TRIM PRODUCTS WITH COLORPLUS® TECHNOLOGY

When repainting ColorPlus products, James Hardie recommends the following regarding surface preparation and topcoat application:
• Ensure the surface is clean, dry, and free of any dust, dirt, or mildew
• Repriming is normally not necessary
• 100% acrylic topcoats are recommended
• DO NOT use stain, oil/alkyd base paint, or powder coating on James Hardie® Products.
• Apply finish coat in accordance with paint manufacturers written instructions regarding coverage, application methods, and application temperature
• DO NOT caulk nail heads when using ColorPlus products, refer to the ColorPlus touch-up section

COM1301 P5/5 01/20

SILICA WARNING

DANGER: May cause cancer if dust from product is inhaled. Causes damage to lungs and respiratory system through prolonged or repeated inhalation of dust from product. Refer to the current product Safety Data Sheet before use. The hazard associated with fiber cement arises from crystalline silica present in the dust generated by activities such as cutting, machining, drilling, routing, sawing, crushing, or otherwise abrading fiber cement, and when cleaning up, disposing of or moving the dust. When doing any of these activities in a manner that generates dust you must (1) comply with the OSHA standard for silica dust and/or other applicable law, (2) follow James Hardie cutting instructions to reduce or limit the release of dust; (3) warn others in the area to avoid breathing the dust; (4) when using mechanical saw or high speed cutting tools, work outdoors and use dust collection equipment; and (5) if no other dust controls are available, wear a dust mask or respirator that meets NIOSH requirements (e.g. N-95 dust mask). During clean-up, use a well maintained vacuum and filter appropriate for capturing fine (respirable) dust or use wet clean-up methods - never dry sweep.

⚠ **WARNING:** This product can expose you to chemicals including respirable crystalline silica, which is known to the State of California to cause cancer. For more information go to P65Warnings.ca.gov.

Product warranties, safety information and additional installation information are available at jameshardiepros.com

JamesHardie™

Appendix H - IECC Table C402.1.3 (IECC 2018)

TABLE C402.1.3 OPAQUE THERMAL ENVELOPE INSULATION COMPONENT MINIMUM REQUIREMENTS, R-VALUE METHOD[a, i]

CLIMATE ZONE	1		2		3		4 EXCEPT MARINE		5 AND MARINE 4		6		7		8	
	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R	All other	Group R
Roofs																
Insulation entirely above roof deck	R-20ci	R-25ci	R-25ci	R-25ci	R-25ci	R-25ci	R-30ci	R-30ci	R-30ci	R-30ci	R-30ci	R-30ci	R-35ci	R-35ci	R-35ci	R-35ci
Metal buildings[b]	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-19 + R-11 LS	R-25 + R-11 LS	R-25 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS	R-30 + R-11 LS
Attic and other	R-38	R-38	R-38	R-38	R-38	R-38	R-38	R-38	R-38	R-49	R-49	R-49	R-49	R-49	R-49	R-49
Walls, above grade																
Mass[g]	R-5.7ci[c]	R-5.7ci[c]	R-5.7ci[c]	R-7.6ci	R-7.6ci	R-9.5ci	R-9.5ci	R-11.4ci	R-11.4ci	R-13.3ci	R-13.3ci	R-15.2ci	R-15.2ci	R-15.2ci	R-25ci	R-25ci
Metal building	R-13+ R-6.5ci	R-13 + R-6.5ci	R13 + R-6.5ci	R-13 + R-13ci	R-13 + R-6.5ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-13ci	R-13 + R-13ci	R-13+ R-19.5ci	R-13 + R-13ci	R-13+ R-19.5ci
Metal framed	R-13 + R-5ci	R-13 + R-5ci	R-13 + R-5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-7.5ci	R-13 + R-15.6ci	R-13 + R-7.5ci	R-13+ R17.5ci
Wood framed and other	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-3.8ci or R-20	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R-13 + R-7.5ci or R-20 + R-3.8ci	R13 + R-15.6ci or R-20 + R-10ci	R13 + R-15.6ci or R-20 + R-10ci
Walls, below grade																
Below-grade wall[d]	NR	NR	NR	NR	NR	NR	R-7.5ci	R-7.5ci	R-7.5ci	R-7.5ci	R-7.5ci	R-7.5ci	R-10ci	R-10ci	R-10ci	R-12.5ci
Floors																
Mass[e]	NR	NR	R-6.3ci	R-8.3ci	R-10ci	R-10ci	R-10ci	R-10.4ci	R-10ci	R-12.5ci	R-12.5ci	R-12.5ci	R-15ci	R-16.7ci	R-15ci	R-16.7ci
Joist/framing	NR	NR	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-30	R-30[f]	R-30[f]	R-30[f]	R-30[f]	R-30[f]
Slab-on-grade floors																
Unheated slabs	NR	NR	NR	NR	NR	NR	R-10 for 24" below	R-10 for 24" below	R-10 for 24" below	R-10 for 24" below	R-10 for 24" below	R-15 for 24" below	R-15 for 24" below	R-15 for 24" below	R-15 for 24" below	R-20 for 24" below
Heated slabs[h]	R-7.5 for 12" below + R-5 full slab	R-7.5 for 12" below + R-5 full slab	R-7.5 for 12" below + R-5 full slab	R-7.5 for 12" below + R-5 full slab	R-10 for 24" below + R-5 full slab	R-10 for 24" below + R-5 full slab	R-15 for 24" below + R-5 full slab	R-15 for 24" below + R-5 full slab	R-15 for 36" below + R-5 full slab	R-15 for 36" below + R-5 full slab	R-15 for 36" below + R-5 full slab	R-20 for 48" below + R-5 full slab	R-20 for 48" below + R-5 full slab	R-20 for 48" below + R-5 full slab	R-20 for 48" below + R-5 full slab	R-20 for 48" below + R-5 full slab
Opaque doors																
Nonswinging	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75	R-4.75

Appendix I - MBCI Superlok Standing Seam Metal Roof (MBCI Superlok Manual)

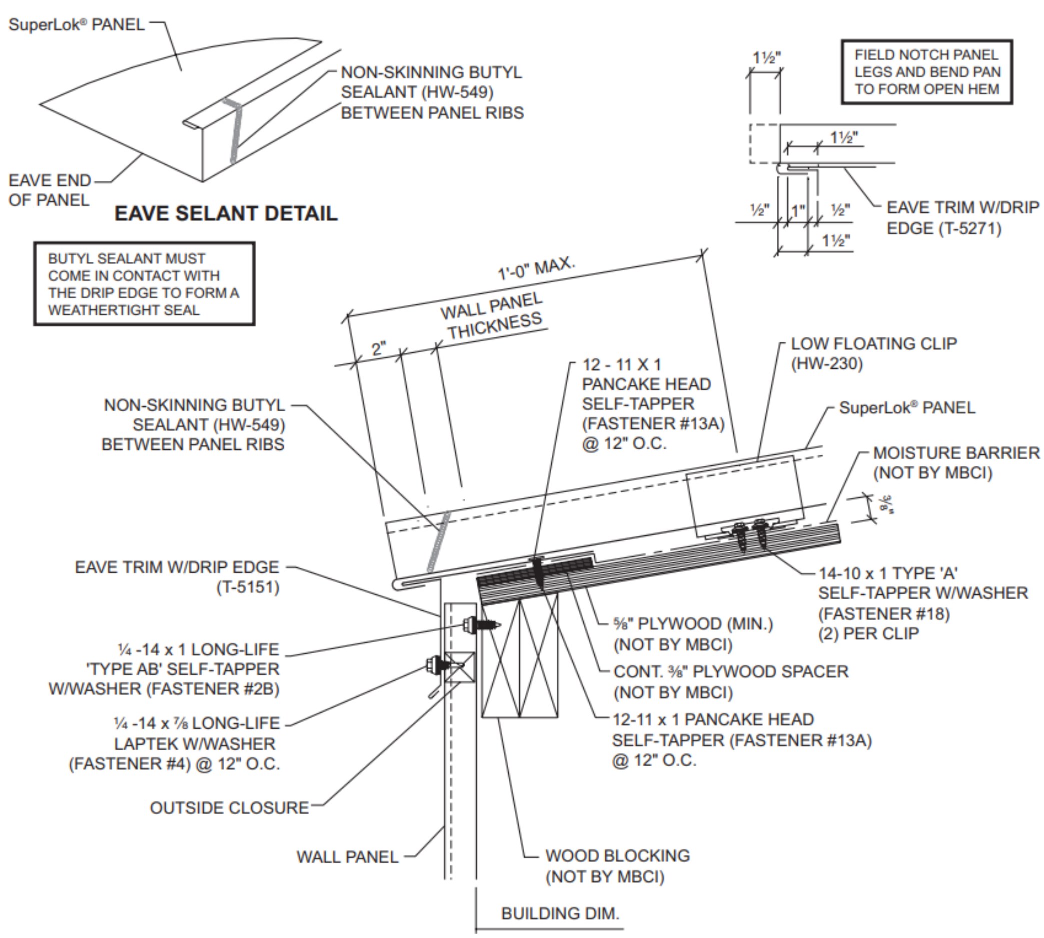
ARCHITECT/ENGINEER INFORMATION

1. **SuperLok®** is a mechanically seamed roof system. **SuperLok®** panels are available in 12" and 16" widths. Factory applied mastic inside of female leg of panel is standard.
2. **SuperLok®** is a structural roofing panel. This panel can be installed directly over purlins or bar joists. It does not require a solid substructure for support. The **SuperLok®** roof system has several different UL 90 construction numbers.
3. **SuperLok®** is recommended for roof slopes of ½:12 or greater.
4. Weathertight and aesthetically pleasing endlaps may be accomplished through the use of swaged and prepunched panels. **12" wide panels are not prepunched for endlaps**. The manufacturer provides a prepunched back-up plate at the endlap for weathertightness. Swaged endlaps require the roof erection to proceed from right to left as viewed from the eave looking toward the ridge. Roofs with no endlaps and less than 6:12 may be erected from either direction.
5. Heavier gauges, striations and embossing minimize oil canning. Industry standard is a minimum 24 gauge material. Striations are standard to reduce oil canning. Oil canning is not a cause for rejection.
6. Substructure must be on an even plane from eave to ridge to avoid panel distortion (¼" in 20', ⅜" in 40' tolerance).
7. All panels require end sealant at eave and valley conditions; however, for illustration purposes, this sealant is not shown on all drawings.
8. For proper fastener application, see Product Checklist.
9. All perimeter trim dimensions in this manual are based on a wall panel thickness of 1¼" ("PBR" Panel). Any variation from this wall panel thickness may affect the perimeter trim dimensions.
10. The information in this manual is believed to be correct and accurate.
11. Drawings in this manual utilize the low floating clip. Clips are available in low or high fixed, low or high floating and utility.
12. **Avoid restricting the thermal expansion and contraction of the SuperLok® panels. (ie: Do not attach panel to the substructure at both the eave and ridge.) However, panels must be attached to the substructure at one end to prevent their sliding downslope.**
13. **SuperLok® panels are not designed to be work platforms.** Avoid any unnecessary foot traffic on **SuperLok®** panels. If foot traffic is required, protect the roof panels by using soft soled shoes and some type of roof pad, temporary deck, or walkway.
14. **WARNING: Light transmitting panels are not designed or intended to bear the weight of any person walking, stepping, standing or resting on them. THE MANUFACTURER DISCLAIMS ANY WARRANTY OR REPRESENTATION, EXPRESS OR IMPLIED, that any person can safely walk, step, stand or rest on or near these light transmitting panels or that they comply with any OSHA regulation.**
15. A vapor retarder may be necessary to protect roofing components when high interior humidity is a factor. The need for a vapor retarder, as well as the type, placement and location should be determined by an architect or engineer. The following are examples of conditions that may require a vapor retarder: (A) Projects where outside winter temperatures below 40°F are anticipated and where average winter interior relative humidity of 45% or greater is expected. (B) Building usages with high humidity interiors, such as indoor swimming pools, textile manufacturing operations, food, paper or other wet-process industrial plants. (C) Construction elements that may release moisture after the roof is installed, such as interior concrete and masonry, plaster finishes and fuel burning heaters.
16. Field cutting of the panels should be avoided where possible. If field cutting is required, the panels must be cut with nibblers, snips, or shears to prevent edge rusting. **Do not cut the panels with abrasive saw blades, grinders, or torches.**

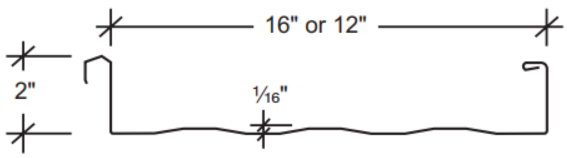
CAUTION

Application and design details are for illustration purposes only, and may not be appropriate for all environmental conditions or building designs. Projects should be engineered to conform to applicable building codes, regulations, and accepted industry practices.

WOOD DECK
FLOATING EAVE WITH EAVE TRIM WITH EXTENDED DRIP EDGE



GENERAL DESCRIPTION



Coverage Width - 16" or 12"

Minimum Slope - 1/2:12

Panel Attachment - Low, High (Fixed or Floating)

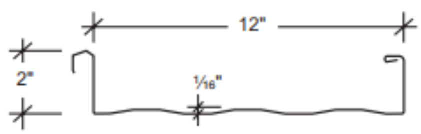
Panel Substrate - Galvalume® (standard)

Gauge - Standard: 24 ; Optional: 22

Finishes - Smooth Striated (standard)* or Embossed Striated

Coatings - Signature® 200, Signature® 300, Signature® 300 Metallic

SuperLok® Panel



SECTION PROPERTIES								
			NEGATIVE BENDING			POSITIVE BENDING		
PANEL	Fy	WEIGHT	Ixe	Sxe	Maxo	Ixe	Sxe	Maxo
GAUGE	(KSI)	(PSF)	(IN.4/FT.)	(IN.3/FT.)	(KIP-IN.)	(IN.4/FT.)	(IN.3/FT.)	(KIP-IN.)
24	50	1.47	0.0756	0.0711	2.1307	0.1667	0.1025	3.0693
22	50	1.83	0.1053	0.1027	3.0751	0.2231	0.1387	4.1551

NOTES:

1. All calculations for the properties of SuperLok panels are calculated in accordance with the 2012 edition of the North American Specification For Design Of Cold-Formed Steel Structural Members.
2. Ixe is for deflection determination.
3. Sxe is for bending.
4. Maxo is allowable bending moment.
5. All values are for one foot of panel width.

Appendix J - Heat Loss through Transmission Supporting Calculations

Heat Loss				
Location	LA, California			
	Winter Conditions			
Temperature (i) F	68			
Temperature (o) F	35			
Delta T	33			

Area	ft^2
Floor Area	250
Wall 1	67.31
Wall 2	262.38
Wall 3	69.34
Wall 4	289.5
Windows	60
	17
	10.58
Doors	424
Roof	250

R-Value	(ft^2)(F) / Btu/h	U- Value (1/R)
Walls	22.35	0.04474
Roof	38	0.0263
Windows		0.5
Doors	3	0.3333

Heat Loss by Transmission (HL) Btu/h	Area (Temperature Difference) / Total Thermal Resistance	
Wall 1	99	Btu/h
Wall 2	387	Btu/h
Wall 3	102	Btu/h
Wall 4	427	Btu/h
Roof	217	Btu/h
Windows	1445	Btu/h
Doors	4664	Btu/h
Total Btu/h Lost by Transmission	7343	Btu/h

Appendix K - Cooling Load Calculations

Cooling Loads			
Location	LA, California		
	Summer Conditions		
Temperature (i) F	68		
Temperature (o) F	95		
Delta T	27		
Area	ft^2		
Floor Area	250		
Wall 1	67.31		
Wall 2	262.38		
Wall 3	69.34		
Wall 4	289.5		
Windows	60		
	17		
	10.58		
Doors	424		
Roof	250		
R-Value	(ft^2)(F) / Btu/h	U- Value (1/R)	
Walls	22.35	0.0447	
Roof	38	0.0263	
Floor	30	0.0333	
Doors	3	0.3333	
Windows		0.5	
Glass and Window Areas			
q= CLF x Area			
	CLF (Uwin x delta T)	Area	q (Btu/hr)
	13.5	87.58333333	1182.375
Doors			
q= CLF x Area			
	CLF (Ud x delta T)	Area	q (Btu/hr)
	9	424	3816
Exterior Walls	CLF (Uw x delta T)	Area	q (Btu/hr)
	1.208053691	688.53	831.781
Roof	CLF (Ur x delta T)	Area	q (Btu/hr)
	0.7105263158	250	177.632

Floor of Trailer	CLF (Uf x delta T)	Area	q (Btu/hr)
	0.9	250	225
Infiltration			
q= 1.10 (cfm) x delta T	1.10 x cfm (Tables 7.11C, 7.12)	delta T	q (Btu/hr)
	0.055	27	1.485
Internal Loads			
People	Seated Light work	# people	q (Btu/hr)
	255	2	510
Total Loads			
qtotal = (1.3 x sum of individual sensible cooling loads)		sum of sensible cooling loads	q (Btu/hr)
	1.3	6744.273	8767.555

Designing a Tiny House on Wheels for Wildfire and Indoor Air Quality Research and Teaching

BID SET APRIL 2023

NOT APPROVED FOR CONSTRUCTION

WORCESTER POLYTECHNIC INSTITUTE

MQP

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DESIGN TEAM:

Hannah Frank
Civil Engineering

Nathalie Martin-Nucatola
Mechanical Engineering

Hannah Rodenbush
Architectural Engineering

No.	Description	Date

Tiny Home on Wheels

Cover Sheet

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

A000

Scale

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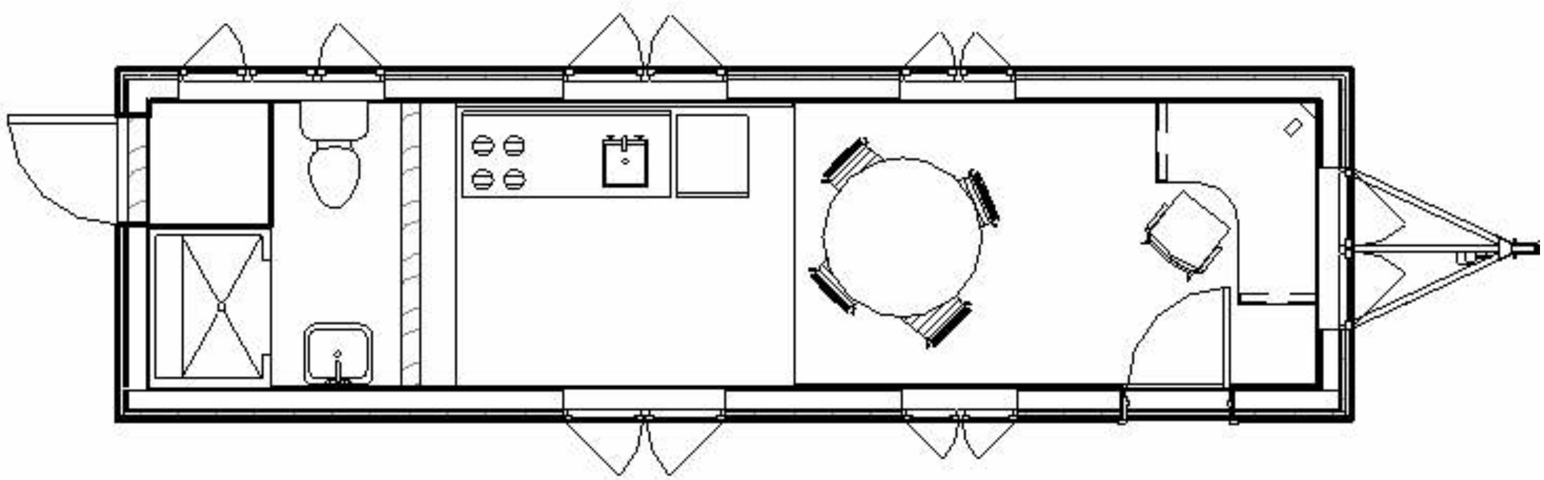

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No.	Description	Date

Tiny Home on Wheels

Site Plans and Floor Plans

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

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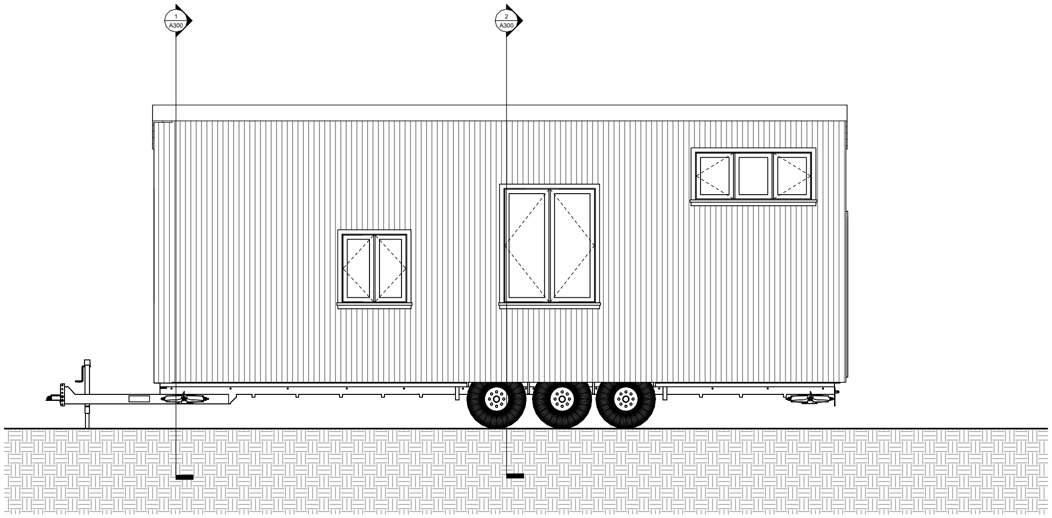
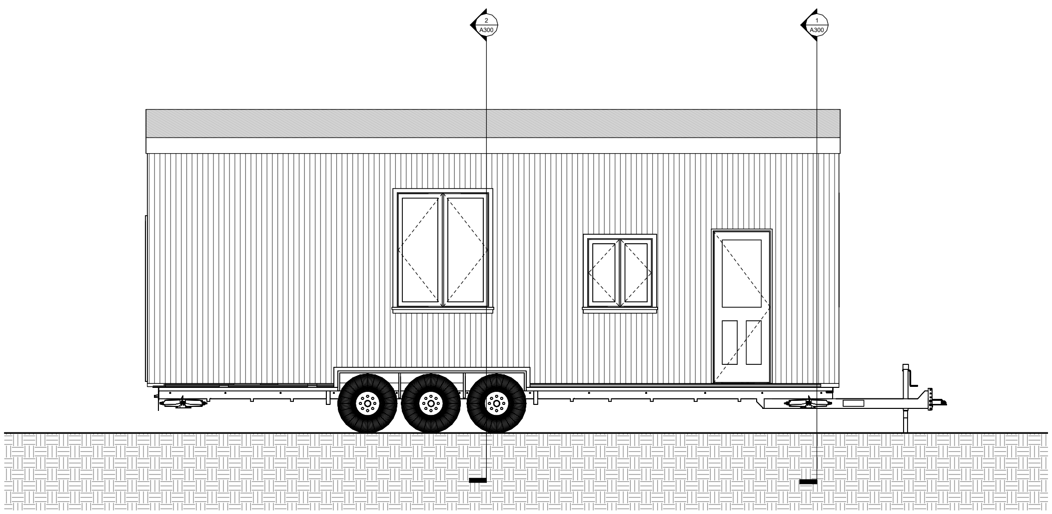


1 BackSide of Trailer
1/2" = 1'-0"



2 FrontSide of Trailer
1/2" = 1'-0"

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No.	Description	Date

Tiny Home on Wheels

Elevations

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

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Scale 1/2" = 1'-0"

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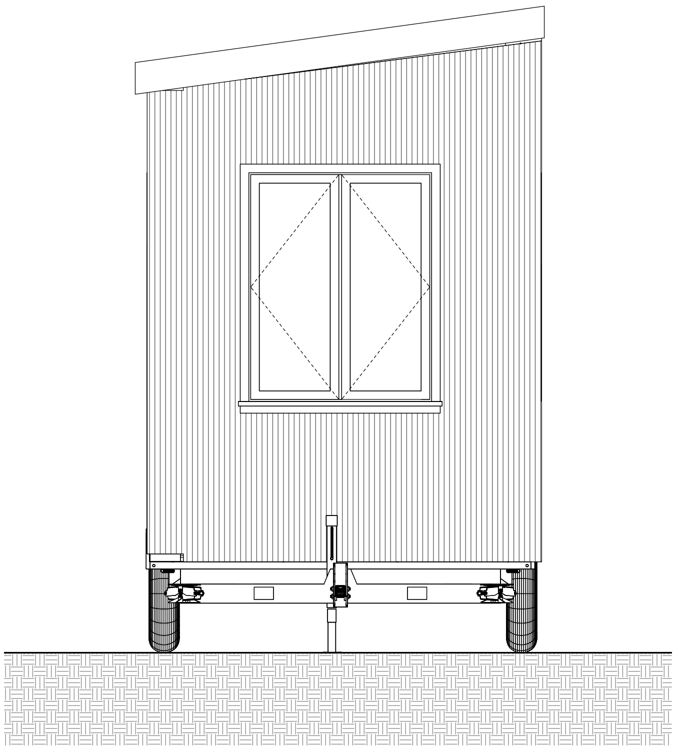
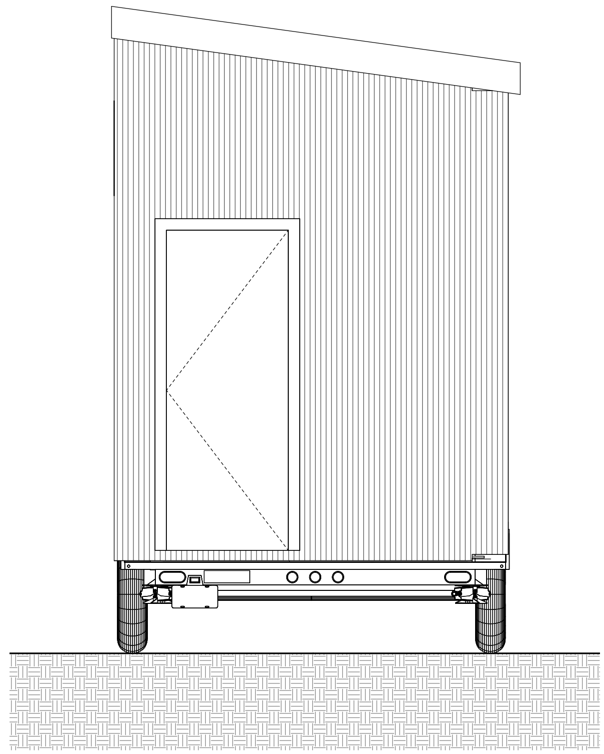


1 Front of Trailer
1" = 1'-0"



2 Back of Trailer
1" = 1'-0"

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MQP

NOT APPROVED FOR CONSTRUCTION

No.	Description	Date

Tiny Home on Wheels

Elevations

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

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Scale	1" = 1'-0"

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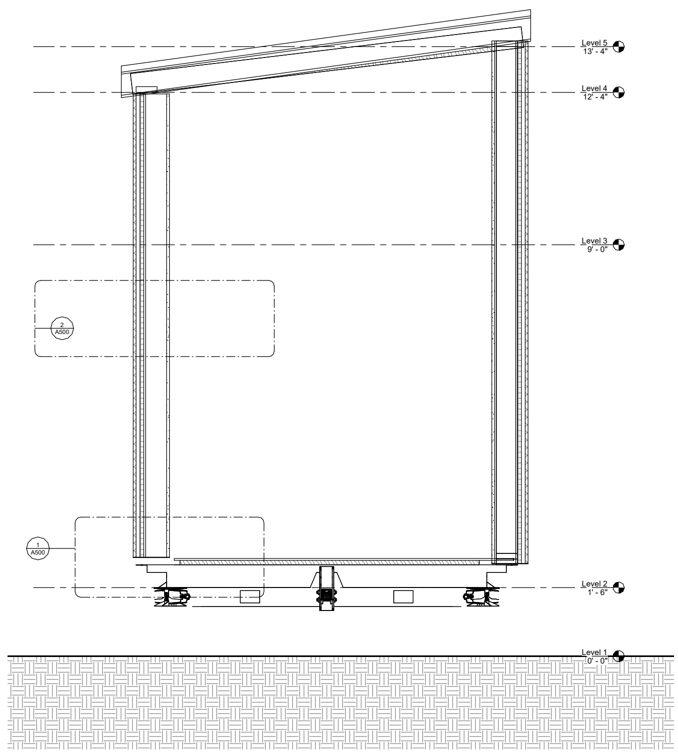
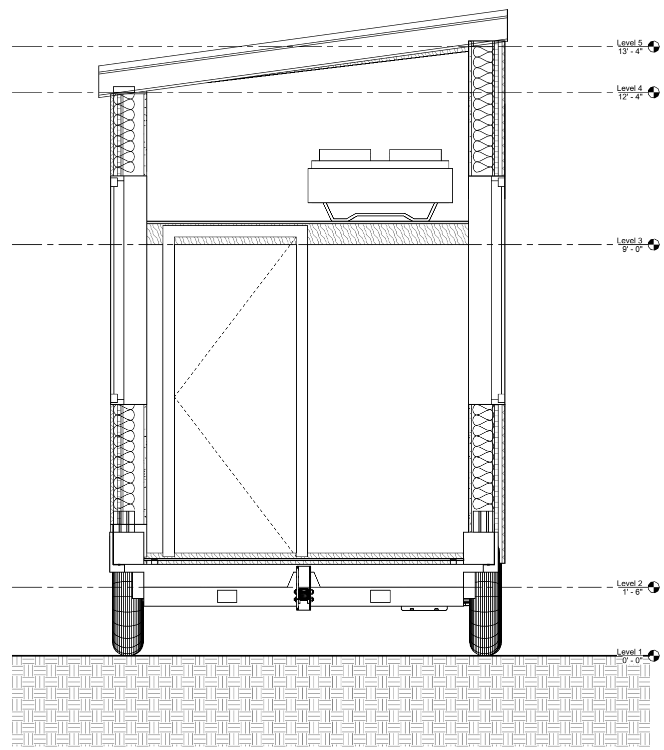


① Section 1 - Front of Trailer
1" = 1'-0"



② Section 2 - Middle of Trailer
1" = 1'-0"

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MQP

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No.	Description	Date

Tiny Home on Wheels

Wall Sections

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

A300

Scale 1" = 1'-0"

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No.	Description	Date

Tiny Home on Wheels

Large Scale Views Exterior

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

A400

Scale

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MQP

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No.	Description	Date

Tiny Home on Wheels

Large Scale Views Interior

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

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Scale

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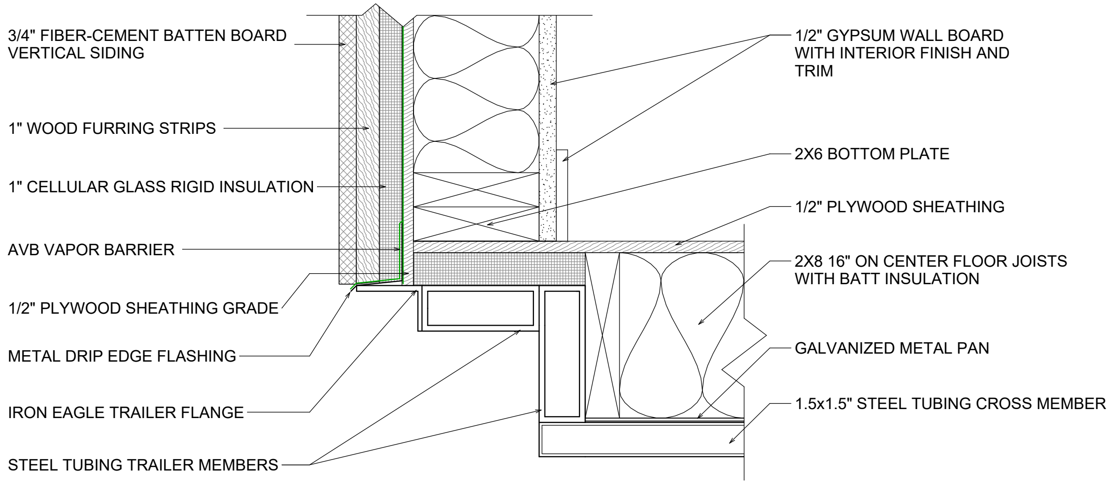
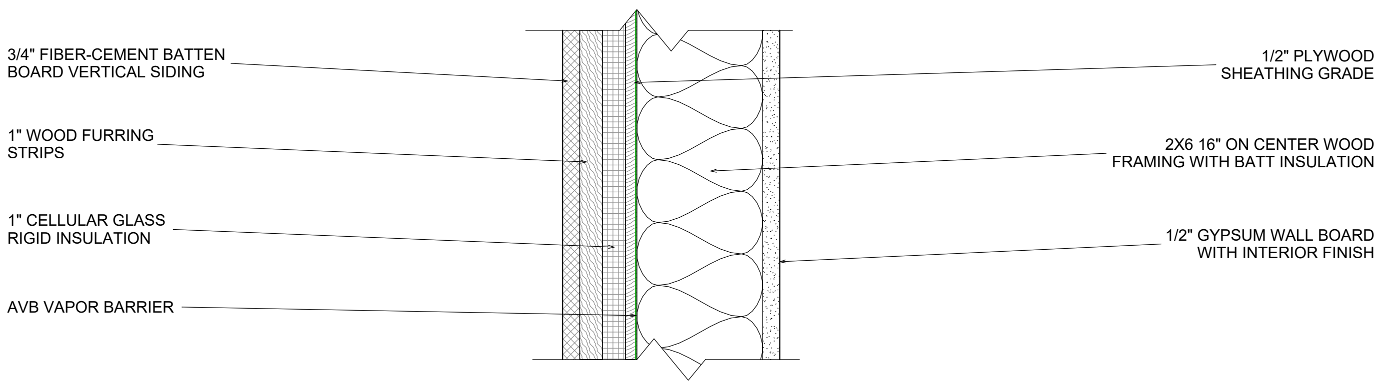


1 Wall to Bottom of Trailer
6" = 1'-0"



2 wall assembly
6" = 1'-0"

WORCESTER POLYTECHNIC INSTITUTE

MQP

NOT APPROVED FOR CONSTRUCTION

No.	Description	Date

Tiny Home on Wheels

Details

Project Number	Project Number
Date	Issue Date
Drawn By	Author
Checked By	Checker

A500

Scale 6" = 1'-0"

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