Environmentally Responsible Nomads:
A guideline for the renovation of a recreational vehicle using sustainable principles

by

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Abstract

There are people who would like to renovate an old recreational vehicle to create a personalized travelling or living experience. Although the restoration of recreational vehicles can be done in many ways, there are not many guidelines or design books to direct the renovation using sustainable principles. The general public usually does not know appropriate considerations, processes, systems, and methods for the sustainable redesign of a recreational vehicle. The goal of this thesis is to provide a set of design guidelines to direct the renovation process of a recreational vehicle in a way that the vehicle is in harmony with its ephemeral environment. The guidelines include material suggestions, insulation properties, passive solar techniques, heating and cooling, electronic appliances and devices, water and waste management, and photovoltaic energy options. They also provide design principles, used in interior design, that deal with issues of space management and multi-use of furniture. The guidelines developed and described in this thesis are demonstrated by using an existing recreational vehicle shell and conceptually renovating its interior and exterior. The demonstration uses hypothetical appliances and equipment due to budget constraints.

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List of Terms

Biodegradable- A substance or object capable of being decomposed by bacteria or other organisms.

Biodiesel- A fuel comprised of fatty acids derived from vegetable oil and mixed with petroleum based diesel fuel.

Demountable buildings- Buildings that are transported in a number of parts for assembly on site. They are much more flexible in size and layout and can be usually transported in a relatively compact space.

Dwelling- A building or place of shelter to live in; place of residence.

Ephemeral- Lasting for only a short time; transitory; short-lived.

Insulation- The action of separating a conductor from conducting bodies by means of non-conductors to prevent transfer of electricity, heat, or sound.

Nomad- A member of a tribe that has no permanent residence, but moves about from place to place, usually seasonally and often following a traditional route of circuit according to the state of the pasturage or food supply.

Organic- Of relating to, or derived from living matter.

Portable buildings- Buildings transported as a whole and intact. Sometimes they include the method for transport within their own structure (wheels, hull) and can be towed or carried – a few can be described as self-powered. However, the dividing line between building and vehicle then becomes blurred.

Recreational Vehicle- A van or utility vehicle used for recreational purposes, as camping, and often equipped with living facilities.

Relocatable buildings- Buildings transported in parts but are assembled at the site almost instantly into usable built form. These are almost always carried but in a few limited cases may have part of their transportation incorporated into their structure. The main advantage of this type is that it can provide space almost as quickly as the portable building without restriction in size imposed by transportation.

Renovation- To reinvigorate; refresh; revive.

Restoration- Return of something to a former, original, normal, or unimpaired condition.

Sustainability- The quality of not being harmful to the environment or depleting natural resources, and thereby supporting long-term ecological balance.

Transesterification- A process that separates glycerin from the animal fat or vegetable oil.

Upcycle- To process used goods or waste material to produce something better than the original.

Vintage- Of lasting interest and importance; venerable; classic.

Volatile organic compounds- Any compound of carbon which participates in atmospheric photochemical reactions.

Chapter 1: INTRODUCTION

1.1 Problem Statement

According to the Recreational Vehicle Industry Association (RVIA, 2015), there are approximately 400,000 modern nomads that classify their primary residence as a recreational vehicle. Within the next decade, the RVIA estimates that the number of RV owners will increase from 9 million to 10.4 million. The increasing number of RV owners will produce a larger nomadic living culture than is seen today. This growth will create sustainability structural design issues. It is known that recreational vehicles have low fuel efficiency due to the heavy bulk they carry. Although manufacturers have produced lightweight vehicles, their structure is usually designed with poor insulation because one of the primary goals of the manufacturers is to reduce the weight of the vehicle (RVIA, 2015). The imbalance of insulation and lightweight structures requires readjustment to count for changes in energy and fuel costs and to be able to advertise lower miles per gallon to the consumer. The low impact lifestyle of those who participate in RV travel, is usually much more sustainable than most forms of travel usually offsetting the carbon footprint of fuel usage. Still, there are sustainability and design issues such as waste, water conservation, fuel emissions, energy use, materials, interior design, notion of space, and more that need to be addressed.

Renovated models of RVs appear often as old unused vehicles that are left behind because of leaking roofs, inefficiency, broken parts, or any other deficiencies. However, practically any old recreational vehicle can be renewed and remodeled in a custom way. Many people in the USA take old RVs and renovate them to create a personal travelling experience. Unfortunately, there

are few guidelines or design books that help with the process of renovating and repurposing old travel trailers. The thesis project intends to fix the missing links among sustainability, recreational vehicles, and portable architecture by providing a set of guidelines for renovating recreational vehicles while using sustainable practices. This thesis project defines a new conceptual nomadic dwelling for the 21st century that can be completely off the grid and self-sustained.

1.2 Need for Thesis Project

The main goal of this thesis project is to provide a set of guidelines to people interested in renovating a recreational vehicle using sustainable practices. The first objective is to cover basic interior and exterior material selections including fenestration, insulation, finishes, lighting, and furniture. A second objective is to analyze the existing energy, water, and waste systems and compile a sustainable alternative to each of the systems. The third objective is to create a cost analysis comparing a standard working RV trailer to a comparably sized sustainable RV trailer to confirm the efficiency of the renovated RV. Finally, the fourth objective is to demonstrate the use of the guidelines established in this thesis by creating a conceptual solution to an existing RV shell.

1.3 Assumptions

This thesis project includes the following assumptions: a) there are people that are interested in sustainably renovating recreational vehicles for any purpose; b) the person who wants to renovate a recreational vehicle is physically and mentally able to complete such a task; c) people that are taking on this task will have a basic understanding of design and construction in general,

and if not, will be willing to learn; d) the published literature and referenced material are accurate; e) after going through the procedures and guidelines for the sustainable renovation of recreational vehicles, people will try to encourage others to create and maintain sustainable living conditions.

1.4 Scope

The scope of this thesis project, in terms of its geographic area, is limited to the United States. It covers materials to be used internally and externally of the RV, waste management systems, water collection and water recycling systems, solar power technology, interior design for small spaces, and multi-use furniture. Furthermore, there are many different designs of recreational vehicles both in and out of production. As best as possible, the guidelines described in this document are written not specific to a particular RV so they can be used in many different vehicles.

1.5 Methodology

The goal of this study is to develop a set of guidelines for the sustainable renovation and restoration of unused recreational vehicles. It ensures that people who are interested in renovating a vintage recreational vehicle can do so in a sustainable manner. The methodology used in the development of this thesis project was as follows:

- Investigated Internet sources and books on the history of recreational vehicles.
- Identified and evaluated current recreational vehicle statistics.
- Studied materials and methods for interior and exterior renovations.
- Investigated efficient and sustainable products available in the market.
- Investigated the application of concepts of mobility, lightweight, and materiality from the vehicle industry towards portable dwellings.

- Identified the minimization of space division within a dwelling.
- Integrated manufacturing processes and architecture to centralize process, design, materials, and tools.
- Studied the difference between portable, re-locatable, and demountable buildings.
- Developed the application of multiuse furniture design.
- Developed a self-sustained system using reclaimed materials.

1.6 Contribution

The major contribution of this thesis project is a set of guidelines for the sustainable renovation and restoration of a used recreational vehicle. The guidelines cover subjects such as which sustainable materials can be used to a bio-diesel conversion (if applicable). In addition, the guidelines cover interior design considerations such as multi-use furniture and types of appliances to purchase. Both waste management and water usage, which are big issues concerning RV travel, are considered on the guidelines as well. Because several options are available for waste management and water usage, the guidelines outline some of the most viable and affordable options. Another issue considered for the renovation process regarding RV travel is power consumption when parked overnight. For an overnight stay, the guidelines describe the kind of self-power options available in the market for specific and broad uses. The thesis project includes a demonstration of how to use the guidelines by taking an existing RV shell and conceptually renovating its interior and exterior. The demonstration uses hypothetical appliances and equipment due to budget constraints. It is expected that the set of guidelines completed in this thesis project will encourage people to use existing vehicle shells as the starting point to a customized transportable dwelling that can be called a home.

Chapter 2: Literature Review

Early humans were nomadic people, moving for various reasons: following food sources, adjusting to changing climate, locating communal protection, and exchanging goods. Due to their constant movement, early humans created dwellings made of wood and animal skins to protect themselves from the weather. The first highly developed humans originated in Africa around 200,000 years ago, where the weather was constantly tropical and protection from the conditions was not needed besides the occasional cave for cover from the rain. During the last ice age, beginning roughly 110,000 years ago, early humans had to adapt to protect themselves from the cold weather. This event encouraged man to use his intelligence as a way to survive the cold. Clothing and shelter became a pivotal part of survival (Kronenburg, 2002).

Temporary architecture was, without a doubt, early human's first form of building. However, most architectural history revolved around the permanent structures that have been left from previous generations. History does not focus on the ephemeral architecture that was created by the nomad peoples during the last ice age. It focuses on the large monuments left by a large civilizations around the world. According to Kronenburg (2002), ephemeral architecture from prehistoric times has not interested architectural historians because it was functional to a single individual or small groups rather than for cultural ambition. There have been numerous discoveries by anthropologists on the subject of ephemeral dwellings and the essential role they played in the survival of early human as a species. There is valuable research available to investigate the technology and systems used in a travelling group of our early ancestors that people have not tapped into. In addition, the technology developed by early humans is filled

with ingenuity and basic knowledge of the environment to create long-lasting portable dwellings with regards to limited and local resources. Kronenburg (2021, p. 17) states that the forms created by early humans provide a lesson to those who are searching for a solution to environmental and construction problems that society is experiencing today.

Although early humans had relocated around the world and did not have an efficient system for communication, they mostly shared coinciding natural threats that forced them to provide shelters that were easily transportable through use of lightweight, flexible, and durable materials (Siegal 2002). Only a few examples of portable architecture are currently part of the realm of traditional architecture. One of the limiting factors towards a movable architecture is the use of materials. There is a size and weight restriction to materials that can be easily carried by a human or a draft animal. Nevertheless, there are some cultures that have incorporated a portability factor into their buildings that allows for them to be moved to a different location. Usually, it was survival that pushed the nomadic existence, however; in the modern age, reasons to move around have changed and the distance is quite shorter.

It is common in North America for retired people to sell their homes, buy a trailer home, and travel the United States to visit their children and other relatives. They follow the clement weather from north to south, moving in a migratory pattern similar to the early humans that inhabited this land thousands of years ago (Siegal, 2002, p. 13). The covered Conestoga wagon was America's precedent for the traditional mobile dwelling that we associate with this pattern today. Settlers during the nineteenth century used the Conestoga wagon as their home during

Figure 1: Covered Wagon

the journey to the west. The wagon was originally used to transport goods, but it was quickly converted to become a portable dwelling for the pioneer family (Siegal, 2002, p. 20). In more than a century since, the applications for portable architecture have become more flexible since these buildings have no borders (Siegal, 2002, p. 16).

There are several types of movable buildings that have been manufactured specifically for mobility. The issue is to incorporate sustainable practice into the manufacture and use of these portable buildings. According to Kronenburg (2002), most movable buildings are designed without the input of professional designers, resulting in a subpar object that is of poor quality and degrades the status of portable architecture. Kronenburg states that portable architecture needs to be designed with the mindset that they are temporary in location, but not temporary in use. Precisely, it is this characteristic that makes portable architecture non-disposable (p.11). The aspect of a building able to be transported and reused means that specific care must be taken with the choice of materials and resources finishing with a product for a specific need and not a specific location.

The purpose of traditional architecture has remained constant since its conception: to provide shelter from the natural elements and contribute to a sense of place to a community. Kronenburg (2002) believes people who build and use portable dwellings have a sophisticated natural comprehension of the essential individuality of a sense of place and the significance of the home as an abstract idea. To comprehend the meaning of place, the user must give emotional meaning to the location they inhabit. Some places have stronger meaning than others, such as given names or definitions by society as a whole. Urban planners, architects, anthropologists have all studied the particular details that give meaning to a location to make it a place. To some, a sense of place is the environment in which they are most familiar, basically any location

that exists within the person's perceptions and experiences, although the place is dependent on the interactions of the person. For some people, a sense of stability and strength is what they need to constitute a place, but there are others who have an understanding that the home can be any place they wish it to be. Heingartnerm (2001, p. 62) proposes that portable architecture be defined as function of a specific living environment at a specific time and location.

The characterization of a portable building is not a simple task. The portable building is inherently tied to architecture because like all inhabitable buildings, it must perform the same objectives that traditional dwellings achieve. There is a misconception that architecture must be in the permanent solid form of a building, often associated with works of art and cultural symbols. Kronenburg (2002, p.10) states that as long as portable buildings express the essence and value in the appearance and function of a physical construct, then what was built must be called architecture. The Webster dictionary defines architecture as the action of designing and building form, space, and ambience, especially habitable structures that follow functional and aesthetic considerations. It also requires the designer to be comfortable with the manipulation of light, shadow, and material. Another concept the user must the familiar with is the usable space within an RV. Smaller spaces may give the impression of feeling cramped; therefore, one must rely on the qualitative use of interior space as well as the surrounding space. Researching other cultures where small living spaces is the norm can provide more interesting solutions to space management and improve the experience of the surrounding space (Freeman, 2004, p.6). These are concepts that can, and have been, easily incorporated into transportable dwellings. Unfortunately, the current social perception of portable dwellings are that of a convenient tool rather than architecture due to the fact that they are designed as so. As previously stated, most

portable buildings are not developed with the consultation of professional designers; therefore, they are not designed to respond to a set of complex issues (Kronenburg, 2002, p. 10).

From early civilization house layouts, the common home usually includes front gardens, foyers, courtyards, and hallways that lead to more private areas such as bedrooms and bathrooms. When designing a small space, the user or designer should take into account that many public spaces commonly included in a home cannot be incorporated into an RV. In order to optimize the space that is available, it is necessary to first establish basic functions within the RV. Once basic functions are established, the user can decide on the components that will be included. More often than not, multiuse furniture and components will be used to improve the usable space. The focus should stay on the qualitative use of space rather than the overall size, the solution of which results in highly precise and efficient components. Designing the RV using simple shapes and avoiding interior walls can optimize usable space, making the space to look larger (Bahamón, 2002).

One issue that is not taken as seriously as it could be into account in the design of recreational vehicles is 'sustainability'. There is already an intuitive sense of sustainability when traveling in an RV because the users know that they are in a cramped space and supplies are to be rationed. However, there is more that can be accomplished. Recently, there has been a sustainable realization around the world where people have begun to pay more attention to the damage the human species is causing to the environment. Construction of buildings is a major contributor to environmental degradation, both in material and building use. It is important to minimize the damage to the environment by parts and processes used in the construction of buildings (Carpenter, 2009, p. 16). To accomplish this goal, a few fundamental considerations

must be taken into account. They are location, orientation, insulation, exterior/interior materials, doors/windows, and systems incorporation.

a) **Location.** According to Building America, a program initiated by the US Department of Energy, the United States is divided into five climate zones: Cold, hot-humid, hot-dry/mixed-dry, mixed-humid, and marine. It is important to understand the different climates that are located within the United States to know what techniques and practices work best. Recreational vehicles are in constant movement and the design should accommodate a number of construction considerations in order to maintain homeostasis.

b) **Orientation.** The orientation of the RV is important to take advantage of passive solar techniques such as day-lighting, heating, and cooling. When approaching a location to set camp, the user should take note of the orientation to place the RV. Orienting large uncovered windows to the south during winter months will provide direct heat from the sun. It is also important to inspect the microclimate that surrounds the location, such as trees and other shading elements. Orientation is also important for the use of photovoltaic power because the panels need to be unobstructed from direct sunlight.

c) **Insulation.** It is important to have a well-insulated structure for energy efficiency. According to William Carpenter (2009), home contractors are moving away from using fiberglass insulation and instead turning to spray foam insulation, which has higher R-values and has the ability to seal air leaks of the structure.

d) **Exterior/interior materials.** Protection from the natural elements is the main task that a home should accomplish. A recreational vehicle is in perpetual motion, sometimes reaching speeds of up 85 miles per hour on the interstate. The exterior materials need to be able to protect from wind, water, snow, and any other natural event that can cause damage. In

addition, the selection for interior materials is a major consideration for sustainable construction. There are several aspects of sustainability that should be taken into consideration such as recycled content, source location, reclaimed, recyclable, energy efficiency, and durability.

e) **Doors/windows.** For the purpose of this study, placement of windows and doors currently on a recreational vehicle cannot be changed. The user can, however, protect and properly seal the doors and windows. Proper sealant is important because no matter how well the structure is insulated, if the shell is leaking, efficiency will suffer.

f) **Incorporating systems.** It is important for technologies and systems work well together within the structure. If the user is to install photovoltaic power, care must be taken with the location of the batteries and wiring harness. The same care must be taken with the waste management and water systems. The use of appliances is also a systems problem because of its connectivity to power and location within the portable dwelling.

Since the literature on this topic is rather limited, literature on sustainability efforts that have been implemented in other fields such as the housing and automotive industries was reviewed. Stewart (2008) mentions a Canadian company that incorporates solar panels, a wind turbine, and propane within the mobile housing they manufacture. They also incorporate mobility through the centralization of materials, process, and tools in one location to provide quicker transportation of a sustainable mobile home to a site. Furthermore, techniques and material advances in the automotive industry can be utilized with the creation of portable buildings. The concept of mobility and place should be incorporated in the design, materials, and process of pre-manufactured buildings. Incorporating sustainable systems similar to those found in what is

traditionally perceived as architecture, an off-the-grid nomadic dwelling could be created that would be able to be in any place at any time.

In summary, the literature shows that there is a missing link between sustainability, recreational vehicles, and portable architecture. Nomadic cultures from the past knew that portability, materials, and durability were key concepts in the execution of a portable dwelling. We should take cues from older generations and combine them with present technology to provide a way to create an efficient dwelling that can provide a feeling of place no matter where the user is located. The guidelines developed in this thesis project become an important contribution to the limited existing literature in this area. They provide the necessary process for repurposing an existing shell to become a completely off-the-grid dwelling, lightweight in nature, and be able to cope with the stress of mobility.

Chapter 3: Research and Design Guidelines

For research purposes, this thesis analyzes three different scenarios for what the airstream will be used for. **Scenario #1** assumes a full-time living, large budget, and off-the-grid design. This scenario could be for someone who has a large budget to purchase top of the line sustainable equipment and materials and intents to live full-time in the RV. **Scenario #2** corresponds to a full-time living situation with a partial budget. A partial budget means that the user will be able to afford some off-the-grid equipment, but will still need to appear in an RV park periodically for water, energy, or waste management. **Scenario #3** assumes a part-time, limited budget, and limited off-the-grid equipment.

The use of materials and systems within a recreational vehicle indicates a level of sustainability that the occupant achieves. The following chapter outlines suggested materials and systems for the sustainable renovation and provides design considerations for each of the three scenarios. Materials were selected following a specific life-cycle assessment chart provided by the Ecodesign section of the IDSA's, Industrial Design Society of America, Okala guide (Okala, 2013). The chart describes several categories and instructions to consider a material or product sustainable. Systems such as electrical, waste, and water were selected through a process of reading through public off-the-grid, RV, marine, and outdoor living forums along with product data sheets.

3.1 Recreational Vehicles

The initial step is to find an RV that is suitable for renovation. Some people may have one that was passed down through family or friends. Other people would have to find a used recreational vehicle. There are several sources online to find one within a close distance from a

localized location. The first decision is to determine the type of RV that is appropriate for the needs of the person renovating it.

3.1.1 Types of Recreational Vehicles

There are two categories and several classes of recreational vehicles, motorized RVs and towable RVs. They are classified as follows:

Figure 2: Motorhome

Class A – Motorhome: A Class A motorhome will usually have the same shape as a large bus and is the most spacious of motorhomes. They are luxurious and will generally have sections that slide out for extra space and comfort. These motorhomes are expensive because of their luxurious nature. Most will be fully equipped with a kitchen, sleeping quarters, bathrooms, entertainment systems, and centrally controlled heating and cooling. Class A RVs will have either a gas or diesel engine on a specially designed motorhome chassis for support.

Figure 3: Mini Motorhome

Class C – Mini Motorhome: A Class C motorhome is slightly smaller than the Class A bodies with a distinctive overhang bunk over the driver compartment. The Class C RV is usually designed on a commercial van chassis and with careful planning, can include as many amenities as a Class A motorhome. There are slightly less expensive due to size, but come with slide out areas to maximize interior space.

Figure 4: Van Camper

Class B – Van Camper: A Class B camper is a smaller motorhome that resembles a large van with a higher roof. They are easier to drive and can fit in most parking spaces. They can come with fully equipped bathrooms, kitchens, and can sleep up to four people comfortably.

Figure 5: Conventional Trailer

Conventional Travel Trailer: The conventional travel trailer is one of the most common RVs that can be towed by any vehicle with a hitch. These come with endless features and prices due to the amount of different sizes and manufacturers that offer them. One of the most recognized brands of travel trailers is Airstream, with its timeless streamlined aluminum designs.

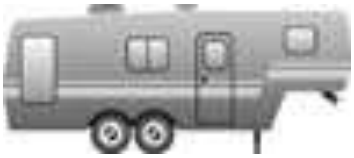


Figure 6: Fifth Wheel

Fifth Wheel Travel Trailer: This style of travel trailer needs to be towed by a pick-up truck with a special fifth wheel hitch in the bed of the truck. Fifth wheel trailers are generally the easiest to handle and can come with several slide out areas to maximize space. They are inexpensive and can be larger than a conventional travel trailer.

Figure 7: Pop-up

Pop-up trailer: Pop-up trailers are a smaller version of the conventional travel trailer. They are designed to be lightweight and easy to transport. The small size makes it easy to tow with a small car. A pop-up trailer is essentially an expandable tent built on a trailer base. These trailers can come with a rigid roof and a lift system to make set-up quickly and easy. Pop-up trailers can

come with many amenities and because of their collapsible nature, they take up very little space when not in use.

Figure 8: Truck Camper

Truck camper: This style of camper is fully sustained by the pickup truck used to transport it. It does not feature an extra axle so size is limited to the pickup truck bed. Truck campers are popular for short trips and weekend campers because of the ease of installation and transport. The limited size will affect the amount of amenities offered, but for short trips, the consumer will usually have what they need.

- Types of RVs, 2014

If possible, a customer should try out a few RVs before fully committing to a purchase. A good way to fulfill this task is to simply rent one for the weekend and try out the outdoor life for a few days. This way, the person will be able to choose the right RV. Each style of RVs has advantages and disadvantages. The choice depends on the amount of space needed, the length of trips that will be taken, and if someone will want a self-driven or a tow-behind trailer. A few other things to consider are tasks that are usually done when acquiring a vehicle of any size like registration, insurance, storage, maintenance, and repairs.

3.1.2 Design Considerations in Choosing an RV

No matter how the RV is obtained, it needs to be inspected and checked through the entire body to find what needs to be fixed and if the fixes can be afforded. Buying an RV is similar to buying a car or a house. Consider that an average person can inspect simple cosmetic

problems, but a qualified technician can look at mechanized items, such as brakes, engines, axle, and the condition of gas and water pipes.

3.2 Materials

There is an extensive amount of literature available for consumers to choose the best material for an application. Unfortunately, sometimes this information becomes flooded with facts and figures that can easily be misunderstood. There are many third party certifications for sustainable products that one cannot trust solely on their claims of being "green." Some of the time, these eco-labels apply to certain aspects of the product, such as the material or manufacturing process. It is important to research multiple options when sourcing a sustainable material. In-depth research must be done before a material can be considered sustainable. This is usually done through an environmental life-cycle assessment chart. According to the IDSA's Okala guide (2013), the sustainable design goals include:

- To make ecological design easy to teach and understand
- To increase the understanding of the significance of design in the global ecological crisis
- To impart a thorough understanding of ecological impacts and methods to evaluate the ecological performance of any product
- To prepare designers with an ability to integrate ecological design strategies with strategic business and market planning
- To inspire design professionals to use this inclusive design process

In addition, Lacey Muszynski from Facilitiesnet (2008) lists some factors that should be investigated in an environmental life assessment:

a) **Materials**- The raw materials that make up a product should be renewable or sustainably harvested. Recycled content is ideal, preferably from post-consumer sources.

b) **Manufacturing**- At least some aspects of most manufacturing processes cause harm to the environment. The goal is to find a product with the least impact on the environment.

c) **Location**- The proximity of the product's raw materials origin and production is important. A product that is produced 100 miles away will take less energy to get to its destination than a product produced 1,000 miles away.

d) **Installation**- Even a product that is made from 100 percent recycled material will be harmful in a space if it needs to be installed with VOC-laden adhesives. Look for products and contractors that focus on occupant health during installation.

e) **Maintenance**- A product that must be cleaned or repaired frequently with harmful chemicals or energy-intensive practices will defeat the sustainable goals of an organization.

f) **End of life**- At the end of a product's useful life, it can either be reused, upcycled, downcycled, recycled or dumped in a landfill. Reusing the material is the option with the least environmental impact (Muszynski, 2008).

Materials for flooring, interior finishes, lighting, insulation, doors, windows, furniture, and appliances are suggested by following the environmental life-cycle assessment chart by the Industrial Design Society of America.

3.2.1 Flooring

Flooring is an essential element for comfortable and safe living situations in most dwellings. Careful consideration must be paid when choosing a floor material. The floor material that is chosen needs to meet certain criteria put forth by the user according to sustainable, health, and comfort standards. Typically, flooring is made from hardwoods to provide a stiff base for people and equipment to stand on. Unfortunately, most of this wood comes from outside the country where wood farming is not as carefully monitored and can result in deforestation. The following floor materials are some of the better choices when replacing the floor of an RV.

3.2.1.1 Bamboo

As a quickly renewable resource, bamboo is a popular choice among sustainable materials. Although sometimes considered a wood, possibly due to its replacement of timber in construction applications, it is actually a fast growing grass. Bamboo grows at a phenomenal rate, sometimes even growing six inches in one day and reaches maturity in just three to five years. Bamboo is naturally resistant to insects and pests and does not need irrigation, fertilizers, or pesticides when grown in its natural environment. It is a naturally durable material and the manufacturing process it goes through only increases its strength.

After harvesting the bamboo, it is then boiled at a manufacturing plant to remove natural starches and moisture within the stalk to prevent termites. The skin of the bamboo is removed and the stalk is cut into small strips for flooring. The strips are boiled again to make them harder. The strips are later adhered together, and depending on the manufacturing plant, using low volatile organic compounds (VOC) adhesives, although most American manufacturers use urea-formaldehyde, which is a toxic substance. There are many finish options once the bamboo is ready for flooring, from natural unfinished to a nearly black finish, which is more toxic.

Most of the bamboo available in North America is harvested in southern China. Many American importers market the idea of sustainable products although they do not have much information about the manufacturing process used by the Chinese exporters. Certain manufacturers use highly toxic adhesives and finishes, and use equipment that pollutes the environment. It is imperative to find manufacturers that are registered under organizations for quality and environmental control, even though the organizations are sometimes not strict or set high standards. The environmental consequences of transportation of bamboo from China are another concern. However, the environmental downside of ocean transportation industry is relatively comparable to the trucks used in the United States due to the amount of cargo transported at a time. The amount of embedded energy used in transporting bamboo from China may be comparable to the energy used in domestic hardwood transportation. Although bamboo comes from a rapidly renewable source, the amount of toxic adhesives and finishes used in manufacturing and its source location offset its life cycle (Piepkorn, 2008).

Figure 9: Bamboo

3.2.1.2 Cork

Cork comes from the outer bark of an oak tree that grows primarily in Portugal, Algeria, Spain, and Morocco. The bark is harvested in large slabs from the cork oak trees in a sustainable manner every nine to ten years. The trees survive the debarking process, although they are left vulnerable without their protective coating until it is regenerated. Cork is a durable, insulated, cushioning, waterproof, and sustainable material. According to buildinggreen.com, cork gets its properties from microscopic multi-sided cells that are exceptionally strong and flexible. They are also waterproof and airtight, creating a durable surface that is easy to clean. (Wilson, 1996). The cells are arranged in a honeycomb pattern, which gives the material strength and insulation properties, while at the same time giving it lightweight and compressible properties.

According to Alex Wilson (1996), cork forests are carefully regulated on how frequently the cork trees can be harvested to minimize the damage done to the trees. The first Portuguese regulations on the protection of cork date back to 1320 when King Dinis commanded there would be penalties on anyone caught damaging the cork trees belonging to the throne. In the early 20th century, it became illegal to cut down cork oak trees other than for essential purposes.

Figure 10: Cork Floor

Once harvested, the sections of bark are boiled and cleaned. The primary use of cork is for bottle stoppers and the remaining scrap is ground and mixed with an adhesive to produce an accumulated cork product. There are several types of adhesives used when combining the ground pieces of cork. The manufacturing process

included the use of urea formaldehyde in the past, but natural protein based binders replaced the formaldehyde in the 1980s. The production of most cork tiles for flooring includes slicing sheets normally 12”x12”x3/16” nominal. The tiles are thin, so they need to be adhered to a backer piece to be used in a flooring application. Alex Wilson, from Environmental Building News, recommends the use of DriTac Flooring Adhesive for installation of cork flooring because it is a water based, low-VOC, latex adhesive (1996). After installation, the cork should be treated with water-based, low-VOC polyurethane or a wax treatment to better protect from moisture and foot traffic (Wilson, 1996).

3.2.1.3 Linoleum

Linoleum is an all-natural material made from renewable resources that is used as an alternative to polyvinyl chloride (PVC) flooring. The primary raw materials used in making linoleum are linseed oil, pine rosin, wood flour, cork flour, limestone, and jute as a backing material (Wilson, 1998). Linseed oil is extracted from the seeds of the flax plant, which is mainly grown in North America and Argentina. Pine rosin is the bonding agent that is used in linoleum and is harvested from pine trees. A cut is made in the bark of the tree and the sap that is collected is distilled into rosin and when combined with linseed oil, the rosin gives the linoleum strength and flexibility. Wood flour, or sawdust, is a byproduct of timber production and can be obtained from several locations locally in the United States. The use of sawdust is used to keep a smooth surface and bind the pigments and ensure that the color of linoleum retains its original hue without fading. As mentioned before, cork is a highly renewable material and the powdered cork used in linoleum is a byproduct of the manufacturing process. Limestone is a material that is readily found all around the world. In linoleum, powdered limestone is used

as filler. The backing material used for linoleum is made from jute, which is a plant grown in India and Bangladesh (Wilson, 1998).

The manufacturing process for producing linoleum is forthright. First, linseed oil is mixed with rosin and is then pumped with oxygen to oxidize and polymerize the oil. This mixture is left to cure for several weeks and is blended with the remaining raw materials forming linoleum granules. These granules are then pressed into jute backing to make linoleum sheets. The sheets are left to hang in rooms where they cure and gain the required flexibility and resilience (Attributes That Make Linoleum Floors "Green", 2012).

During the initial oxidation of linseed oil and rosin, a significant amount of VOCs is generated. The majority of the VOCs are captured and burned for use during the drying process. Alex Wilson from buildinggreen.com states that there are VOC emissions that are released into the atmosphere during the drying process. These emissions amount to 4.6 grams per square meter of linoleum produced, according to a 1995 report by Åsa Jönsoon, Anne-Marie Tillman, and Torbjörn Swenson, "Life-Cycle Assessment of Flooring Materials," published by the Swedish Council for Building Research in Stockholm. Solvents, chiefly toluene, butanol, and ethyl acetate are also released during manufacture, according to the report, although where they come from is not clear (Wilson, 1998).

Linoleum can be easily recycled through many different options. When linoleum is burned in an energy-recycling plant, the product can produce heat that is comparable to coal and the amount of CO2 produced during incineration is offset by the flax plants, trees, and jute plants that are used as raw materials. Linoleum is fully biodegradable and can also decompose naturally, returning the original materials back to the Earth. Other types of flooring cannot be

easily recycled because of the high levels of energy needed, ending with negative implications on a life cycle assessment (Attributes That Make Linoleum Floors “Green”, 2012).

3.2.1.4 Reclaimed Wood

Reclaimed wood is usually timber and lumber rescued from old structures that have been deconstructed or demolished. Wood has been a primary building material in the United States for centuries due to its abundance and strength. Factories built during the industrial revolution used types of wood that were of a size and quality that is difficult, and sometimes impossible, to get from forests today. Reclaimed wood from these older structures is sought after because although they have aged, they still have not suffered from decay, are naturally mold and insect resistant, and are more stable than new wood. Reclaimed wood is also popular because of its unique appearance and its contribution to sustainable building. There are several companies that offer reclaimed wood flooring with characteristic nail holes and signs of wear. Reclaimed wood can sometimes come from underwater as well. This might involve harvesting trees that have been drowned in reservoirs or finding sunken logs from the bottom of rivers and lakes (EBN, December 2011).

Figure 11: Reclaimed Wood

Due to new waste management issues, increases in disposal fees, environmental awareness, and recycling, the reclaimed wood industry has become somewhat of a lucrative market. The higher demand for reclaimed wood has exponentially increased the price of the product and has also made it difficult to source. It is also difficult to tell the species of older

wood unless it is closely inspected. Reclaimed wood could also be a source of VOCs associated with finishes, treatments, and paints that may have been used on the wood in the past. Sometimes, this wood will also have miscellaneous pieces of metal in it that has to be removed from the material (Geller, 1998).

3.2.1.5 Sustainable Carpet

Ray Anderson founded Interface INC. to produce and sell carpet to large-scale corporate buildings. It was a profitable business, making about 800 million dollars in 1995 and continuing to grow. But Ray Anderson had an analysis completed showing that for the 800 million dollars to be made, the company had taken and processes 1.224 billion pounds of raw materials from the Earth (Anderson, 1998 p.4). This is why he believes himself to be a "legal thief" of nature. People see him as an entrepreneurial giant, but he sees himself as a plunderer of the earth. Thus began the reconstruction of Interface to become a sustainable worldwide corporation through the management of waste and resource development. A new management team brought new ideas and came up with a series of schematics to facilitate the progression of wasteful tycoon to sustainability leader. According to Interface (2012), the seven ambitious fronts are as follow:

Figure 12: Interface

a) **Zero Waste**: Eliminate and reduce all waste from every area of business. Waste is defined as anything that is spent or consumed without any return. Interface also believes that not doing something right the first time is considered waste. They began by identifying 70 million dollars in waste based on their 1994 operations

and in 1995 began the process of cutting that number in half by the end of 1997. Through the redesign of products to use less material, ease of repair, adaptability, and modularity, the company has drastically reduced its waste.

b) **Benign Emissions**: Reduce and eventually eliminate all emissions from the company, products, and vehicles that may have negative effects on the environment. In the beginning, they had 192 smokestacks from the manufacturing facilities and grew to 250. By instituting the world's strictest regulatory standards, they have reduced that number to 205 smokestacks and reduced the number of flowing waste pipes from 18 to 15. It is important to reduce emissions coming from commercial raw materials because whatever toxic emissions come into the cycle must be dealt with somehow.

c) **Renewable Energy**: Eventually harnessing renewable energy such as solar, hydrogen, gas, or wind. Harnessing renewable energy will eventually allow for a closed loop system and reduce the need for fossil fuels. All fossil fuel energy has been declared as waste by Interface and should be eliminated. The first steps taken to collect renewable energy were to install photovoltaic panels to produce the first Solar-made™ carpet.

d) **Closing the Loop**: The step introduces two cycles; an organic cycle and a technical cycle. The natural cycle emphasizes the use of natural materials and compostable products to be returned back into the earth. The technical cycle emphasizes the re-use and recycling of materials back into the factories to create new carpets. The latter is more difficult to accomplish because the technology is

still under development. Once it is fully developed, factories will never have to use fossil fuels or deplete natural resources again.

e) **Resource Efficient Transportation**: Nearly all businesses rely on transportation of goods, people, and resources from one place to another by using vehicles that burn fossil fuels, thus creating excess carbon dioxide. Interface is trying to minimize the amount of travel by locating factories near large markets and raw material sources, using fuel-efficient vehicles, and video conferencing to avoid unnecessary trips. They also offset carbon dioxide emissions by planting a tree for every 4,000 miles of air and ground employee travel.

f) **Sensitivity Hookup**: This step ensures that the public, organizations, and stakeholders are informed about sustainability and the achievements being accomplished at the company. Informing the stakeholders and the people responsible for materials about the importance of leading sustainable lives to help the future generations is important. Bringing awareness to the community about sustainability will also push everyday people to do the right thing and inch towards sustainability.

g) **Redesign of Commerce**: The final front to be completed is the redesign of commerce itself. In order to do this, a new understanding and acceptance of economics must be set in place. People have to understand that prices will increase if companies are to go fully sustainable. Interface sees this step as not selling products, but shifting that emphasis to providing a service to finally create a full cradle-to-cradle relationship with customers and suppliers. They innovated the concept of carpet tiles that can be installed and uninstalled quickly, reducing

the waste and installation time of replacing old carpet. This modular carpet can easily be recycled and reused.

3.2.2 Interior Finishes

As with flooring, interior finishes are also essential elements for comfortable living. Harmful interior air quality, caused by toxic chemicals, can produce severe health problems from long-term exposure. There are companies that offer products that are marketed towards the removal of harsh chemical compounds in products and using organic and raw materials. The interior finishing materials need to meet a certain criteria in regard to sustainable, health, and comfort standards. The following interior finishes are a few good choices when painting, decorating, and furnishing an RV.

3.2.2.1 Non-toxic paint and finishes

According to the EPA, one of the top hazards to human health is the current indoor air quality caused by paints and finishes, which can be multiplied in small living spaces with minimal ventilation. Paints and finishes slowly release toxic emissions into the air, even after several years after they have been applied. These toxins are a variety of volatile organic compounds, or VOCs, as mentioned before. These compounds have been essential to the application and performance of paint and finishes, until fairly recently. New environmental regulations have led to the development of paint and finishes with low and zero VOC emissions (Eartheasy, 2003). Unfortunately for this achievement, some paints and finishes with low or zero VOCs contain other chemicals that are dangerous to human health and are not classified as VOCs. According to Joel Hirshberg (2004) from *greenbuildingsupply.com*, fungicides and

biocides are some toxic chemicals that are added to prevent the growth of mildew and to make the paint last longer on retail shelves. The chemicals added continue to off-gas for years after they have been applied. Another issue that manufacturers need to deal with is the fact that only reducing the amount of VOCs in their products does not stop the problem. Even small amounts of dangerous emissions into the atmosphere can have negative effects on the Earth.

The best kinds of paints and finishes to use are made from natural raw ingredients. Water-based paints are almost odorless, and oil-based natural paints give off a pleasant smell. Hundreds of natural ingredients and minerals such as plant oils, clay, talcum, resins, wax, and earth can be made into paints and finishes. There are several manufacturers of natural paints and finishes; unfortunately, they will charge a significant amount more for the product. When a product contains EPA, OSHA, and DOT registrations, it means that there is some toxic chemical that needs to be monitored. It is important to pay attention to the labels that come on finishing products and check for VOC levels and if the product is natural (Eartheasy, 2003).

One example of a company that produces sustainable paints and finishes, American Clay (2014), is a company that focuses on using earth plaster for finishing interior walls. They offer consumers the choice of five types of plaster choices for interior walls along with choices of color and texture. Manufactured locally in Albuquerque, New Mexico, American Clay brings environmental

Figure 13: American Clay

awareness to interior finishes by offering a product that is natural and non-toxic. Zero-VOC primers are also available through the company for an unparalleled service offering quality products and awareness through educational hands-on workshops for the community (American Clay, 2014).

3.2.2.2 Upholstery

Sustainable upholstery is composed of several types of textiles composed of organic fibers, natural fibers, synthetic fibers, and recycled fibers. The best types of textiles to use in a sustainable fashion are those made with organic renewable materials grown without pesticides, manufactured in a safe and sustainable manner, and processed or dyed without the use of harsh chemicals. Organic fibers are produced in a system that promotes a healthy agricultural practice of biodiversity, soil rotation, and biological cycles. This is done by only using cultural, biological, natural, and mechanical processes to accomplish specific tasks needed for crop production. "An organic production system is designed to a) enhance biological diversity within the whole system; b) increase soil biological activity; c) maintain long-term soil fertility; d) recycle wastes of plant and animal origin in order to return nutrients to the land, thus minimizing the use of nonrenewable resources; e) rely on the renewable resources in locally organized agricultural systems; f) promote the healthy use of soil, water, and air, as well as minimize all forms of pollution thereto that may result from agricultural practices" (Textile Exchange, 2012). One has to be careful with the acquisition of sustainable textiles, because there are some countries that do not have strict manufacturing rules and the chemicals used to process textiles can be harmful to the environment.

3.2.2.2.1 Organic Cotton

Organic cotton began to be farmed as a social response to production practices, farmer debt, and misuse of pesticides. It has since become an ethical choice for textile manufacturers and designers because of its organic production and certification according to organic agriculture standards. For cotton to be sold as organic, it must be certified by an independent, accredited certification agency. Beside the cotton, six other food crops, on average, are grown to promote soil diversity. Currently, there is a little over one percent of the cotton produced in the world that is certified organic.

Stated by TextileExchange (2010), conventional cotton relies on chemical fertilizers to grow, causing the death of soil organisms that are responsible for decomposition and soil formation. The soil will gradually lose its organic matter, slowly break down, and lose its ability to hold water and nutrients. The inability of the soil to hold water forces the use of irrigation. The amount of chemicals in the fertilizers and pesticides causes degradation of nearby land, waterways, and kills aquatic life.

Organic cotton uses organic fertilizers, causing an improvement to the soil over time and results in higher yields. Farmers will also participate in crop rotation to provide the soil with needed nutrients to avoid soil degradation. Approximately eighty percent of organic cotton is rain fed and farmers use watersheds to collect and hold water. Due to their natural composition, organic soils without harsh chemicals have the ability to hold water better than non-organic soils, lessening the dependence on water (TextileExchange, 2010).

3.2.2.2.2 Organic Wool

Similar to organic cotton, organic wool must be certified as organic in accordance to certain standards for organic production. For organic wool to be certified organic, feed provided to the livestock must be certified organic, livestock cannot be given synthetic hormones or be genetically engineered, synthetic pesticides cannot be used on pasture or around animals, and the producers must show healthy livestock through good cultural and management habits. Organic wool can replace conventional wool in almost any application. Wool is naturally flame retardant and antibacterial, making it safe to use at home. Organic wool can also be used as a replacement for polyurethane foam in bedding. Organic wool is washed and formed in the United States and the manufacturing is ensured to be organic, with no harmful chemicals or soaps that would usually harm the user and the environment (OTA, 2005).

3.2.2.2.3 Hemp

Hemp is a common name for a low strain of the plant Cannabis sativa used mainly for fiber and oilseed purposes. Hemp is a strong and durable all-natural material that can be used for several applications including paper, fabric, food, rope, insulation, carpeting, and many more. The hemp industry is one of the oldest in history, dating back to over 10,000 years ago. Hemp produces fibers that are similar to the flax plant, both coming from the bark of the plant. The strands within the hemp plant have naturally evolved to be longer and have a greater surface area presenting a stronger thread

Figure 14: Hemp Fabric

when made into rope (Hemp Traders, 2012). As a crop, hemp is an environmentally friendly plant because it requires few pesticides and no herbicides and is a one of the faster growing biologically renewable resources. Used as a fabric, hemp provides insulation, better color retention, flexibility, softness, and superior durability not usually found in other materials (thehia.org, 2009).

Hemp is harvested for fiber after reaching maturity in approximately 120 days. The harvesting time is important as to gain the highest quality fiber. The bark of the stalk is peeled away and the fibers are separated from one another. The fibers are then spun into hemp yarns using modified spinning equipment originally made for flax plants. Unfortunately, due to legal reasons, the United States does not allow for large quantities of hemp to be grown. Most hemp used in the United States is imported from China and Europe (thehia.org, 2009).

3.2.2.2.4 Enviro-Fiber Foam

Enviro-Fiber Foam is the first ecologically friendly material alternative to polyurethane foam. Polyurethane foam is used in several everyday products such as mattresses, furniture, shoes, helmets, insulation, carpets, and many more. Gord Kerr from livestrong.com (2011) states that long exposure to petroleum-based chemicals found in materials such as urethane foam may seriously affect the nervous and immune system, causing grave health problems including respiratory illness, cancer, immunity weakness, and many others. The

Figure 15: EnviroFiber Foam

raw material for polyurethane foam is petroleum and it often contains dangerous chemicals such as formaldehyde, benzene, toluene, and other dangerous toxins. There is concern for children, as they spend most of their early life on a baby mattress, that they may contract respiratory and mental illness as the baby mattress slowly releases these dangerous chemicals. Polyurethane is used as insulation in houses and when polyurethane burns, it releases harmful toxic gases into the air, making it difficult to evacuate a building and put out the flames. To minimize the flammable hazard of polyurethane foam, certain flame retardant chemicals, which are toxic, are added to the mixtures. One of the common chemicals used as a fire-retardant is pentaBDE, a toxic chemical known to cause behavior and mental problems (Kerr, 2011). Enviro-Fiber Foam addresses these problems by only using natural and renewable raw materials. It is a mixture of coconut fiber and natural latex. The coconut tree has a fifteen-year growing cycle to produce fruit, and once it has produced fruit, the tree bears fruit twice a year. Enviro-Fiber Foam is a byproduct of coconut oil and coconut meat production, using the husk as the main raw material. The applications of Enviro-Fiber Foam include any common polyurethane foam use such as soundproofing, carpet pad, mattresses, furniture padding, insulation, and many others. The production of Enviro-Fiber Foam has no bleaching agents, no dyes, and promotes a clean and safe work environment. The agricultural production of Enviro-Fiber Foam is done in Mexican coconut plantations using no fertilizers, no pesticides, and no irrigation. EnviroTextiles, the company that offers Enviro-Fiber Foam, strictly follows the requirements provided by the Sustainable Biodegradable Products (EnviroTextiles, 2012).

3.2.3 Lighting

Traditional incandescent lighting is a large consumer of power in the typical American home. Typically, about ninety percent of the energy used for incandescent lights is given off as heat. Currently, there are new technologies emerging on the lighting market that are more efficient, longer lasting, and cost-effective versions of incandescent bulbs. It is important to carefully choose lighting equipment that can satisfy both efficiency and aesthetics. Lamp selection is based on several considerations, but primarily on amount of light produced, color temperature, endurance, and cost (Nelson, 2010). Some of the most common choices for efficient lighting are energy saving incandescent bulbs, compact fluorescent lights, and LEDs.

3.2.3.1 Energy Saving Incandescent Bulbs

There are incandescent lamps that have a capsule inside the bulb that holds gas around the filament to increase the efficiency of the bulb. These types of bulbs are similar to regular incandescent bulbs in that they have instant power on and can be used with a dimmer. They are about twenty-five percent more efficient and last about three years longer than normal incandescent bulbs.

3.2.3.2 CFL Bulbs

Compact fluorescent lamps (CFLs) are a miniaturized version of the long tube fluorescent lights that are commonly used in kitchens, garages, and retail spaces. The CFLs have been designed to replace incandescent lamps and can fit directly into a typical home light fixture. The lamp uses a tube that has been folded or twisted to fit within the area of a conventional incandescent bulb. A CFL lamp that has been “Energy Star” qualified lasts longer and uses

about one-fourth the energy of an incandescent lamp outputting the same amount of light (Energy Savers, 2012). Energy star ratings are awarded to products that meet strict qualifications including efficiency, lifetime, quality, and power use. Currently, CFL lights are available in different color ranges, including warm tones that were not available when they were first introduced to the market (How a Product Earns the Label, 2014). Unfortunately, CFLs contain the element mercury, but can be properly recycled at the end of the life span at participating retailers for free.

3.2.3.3 LED Lamps

Light emitting diodes, or LEDs, are solid-state lamps that are exceptionally energy efficient. When they were first developed, LEDs were used for small electronic applications such as instrument panels, penlights, small electronics, and Christmas lights. Manufacturers have been able to produce LED bulbs by clustering the small bulbs inside a diffuser, which spreads the light in a wider beam. LED modules use less energy and last much longer than traditional incandescent lamps (Energy Savers, 2012). A feature to note about LEDs is that the light is directional, in comparison to incandescent bulbs that radiate light in all directions. According to David Nelson, AIA, LED lights have a low Color Rendering Index which most people find unnatural and cold. He also mentions that LEDs have a poor efficacy value, meaning that the amount of light produced per watt is low and does not perform as well as it should (Nelson, 2010). LED technologies are still in their infancy, but show rapid progress for the future of light efficiency.

Figure 16: LED Lamp

3.2.4 Insulation

This section primarily deals with the materials used for the thermal insulation within the exterior walls of a recreational vehicle. Insulation will reduce the amount of unwanted heat gain or loss and decreases the amount of energy used in HVAC systems. Close to fifty percent of energy use in this country comes from buildings. Through good design and achieving maximum thermal design reduces the amount of energy that is used by buildings. In this case, thermal performance is much more important than material choice due to the fact that the performance will greatly outweigh the footprint created by 'bad' insulation. The heating and cooling savings economically and environmentally will be high if a high performing insulation material is used. It is important to find a material that can ensure performance over the lifetime of the material (XCO2, 2005). The main points for selecting an insulating material is durability, zero ozone depletion potential, and insulation properties to minimize heat loss/gain. Sometimes, choosing a 'sustainable' material can compromise energy performance. The most important factor when choosing a material is its thermal capacity. Energy saved over the lifetime of the RV is more important than the embodied energy saved during manufacturing of the insulation material because ensuring performance over time is more important (XCO2, 2005).

3.2.4.1 Mineral Insulation

Naturally occurring mineral insulation can be derived and formed into fibers from inorganic materials such as stone and glass. These types of materials are generally referred to as fiberglass, ceramic fibers, and stone wool. Mineral insulation has

Figure 17: Glasswool

excellent thermal conductivity due to its ability to trap air within its porous structure. Its porous structure also allows it to be a great acoustic insulator. Mineral insulators like glasswool and stone wool can take several forms varying in rigidity and density (Isover, 2008).

Glasswool is a product made from natural sand mixed with recycled glass particles and melted in a furnace. The fiber is formed and rolled into a mat that is then cut and packaged. Different melting temperatures and fiber extruding methods change the integrity of the glasswool product. Unfortunately, this method requires an extreme amount of heat during the manufacturing process making the amount of embodied energy high. Glasswool will last a long time as long as it is treated and cared for properly as water and compression can reduce performance. Stone wool has a similar process, where heat and a fiberizing procedure is conducted. The raw materials used are usually basalt or blast furnace slag mixed with fluxing agents and coke. Stone wool also has a high amount of embodied energy due to the amount of heat used for manufacturing (Isover, 2008). It is important to protect oneself when installing stone wool or glasswool insulation due to the fact that when this material is worked with, exposure to the fibers in the air can cause health problems. Health effects from exposure these materials depend on the size of fiber and length of exposure, but they include rash, eye soreness, bronchitis, and asthma. Although long term effects are not known, observations of people working closely with fiberglass for years have not shown signs of respiratory disease, cancer or allergic sensitization (NYC health, 2013).

Ceramic insulation boards are used mainly for extreme temperature applications due to their low thermal conductivity and heat storage. Ceramic boards are lightweight and low density, making it an ideal product for handling, cutting, machining, and acoustic insulation. The main uses for this type of insulation are mechanical and manufacturing purposes where high

temperature insulation is needed such as boiler, water heater, kiln, and industrial furnace linings. Ceramic insulation paints, however, provide an extremely low-weight, highly insulated coating that is only a few centimeters thick. Recently, ceramic insulation paints have become a popular sustainable solution in the United States for top coating purposes on roofs, exterior walls, ductwork, pipes, etc. Once a ceramic coating is applied, microscopic ceramic beads reflect intense heat and UV rays away from the building. However, due to its application techniques, it seems inappropriate to apply to the exterior of a travel trailer as it may become compromised during constant travel (ISBU, 2011).

3.2.4.2 Organic Insulation

There are different types of organic insulation including cellulose, wool, straw, and hemp. Cellulose insulation is organic fiber usually made from recycled newspapers, denim, and other fiber sources. It is blown into wall cavities, roofs, and floors. The thermal performance of cellulose insulation is comparable to stone wool and glasswool, but cellulose insulation can fit better around items in a wall such as pipes and wiring, reducing air infiltration through the structure. A disadvantage to cellulose insulation is that when it is sprayed as loose fill insulation, it will settle over time and needs to be refilled. It also soaks up moisture and takes a long time to dry, compromising its thermal resistance. Since cellulose has to be handled professionally, installation costs are high and finding installers may be difficult.

Sheep's wool insulation is obviously made from the wool fibers of sheep held together by recycled polyester adhesives to make rolls and batts. Sheep's wool is sustainable, renewable, biodegradable, recyclable, and it does not harm installers or occupiers. The naturally occurring bends and crimps in wool fibers create many tiny air pockets, which make it an excellent

insulator. The crimps also help retain its shape and structure instead of settling, like other fibrous insulators. Wool can absorb approximately thirty percent of its own weight in moisture from the air without feeling wet. It also has an extremely low embodied energy, as low as ten percent of traditional insulation materials. Sheep's wool insulation is an excellent product for larger buildings; unfortunately, it does not fit within the design scope of recreational vehicle design (Oregon Shepherd, 2012).

3.2.4.3 Oil Derived Insulation

Many people believe that chemicals that are added to all foam-plastic insulation have a negative impact to the environment. Blowing agents used in extruded polystyrene and flame-retardants that are added contain PBTs. PBTs are toxic chemicals that stay in the environment for a long time and can also become harmful the longer they are present in an ecosystem. PBT stands for Persistent Bio-accumulative Toxic chemicals.

> **Persistence** means a chemical does not readily break down in the environment. PBTs can be transported long distances through air and ocean currents and the atmosphere. They can remain in soil and silt for decades, being absorbed by plants and microorganisms. The persistence threshold for testing and potential regulation by the U.S. Environmental Protection Agency (EPA) is a half-life longer than two months.

> **Bioaccumulation** is the buildup of a substance in an individual organism. If a PBT remains in silt, bottom feeders take in small quantities, which accumulate in

fatty tissue more quickly than they can be metabolized. Predatory fish then eat bottom feeders, storing larger quantities at higher concentrations in their own fat. The higher an animal is on the food chain, the more of the PBT the animal is likely to store and the more harm it may cause. Bioconcentration factor (BCF)—the ratio of a substance's concentration in an organism to its concentration in surrounding water—is a common measure of bioaccumulation; EPA's threshold for concern is a BCF of 1,000.

Toxicity includes harm not only to humans but also to individual animals and entire food chains. Toxic effects may include cancers, physical or behavioral reproductive problems, and damage to endocrine and nervous systems. PBTs known as persistent organic pollutants (POPs) include chemicals used in polystyrene insulation, interior fabrics, paint, carpets, and a multitude of materials containing plasticizers. Polyvinyl chloride (PVC), one of the most common building materials, releases many toxic substances during its manufacture and when it is burned; among these are dioxins—potent, carcinogenic POPs with other far-reaching effects on the immune, nervous, and endocrine systems.

-EBN, 2011

The advantages of foam insulation are that they are one of the most efficient types of insulation per inch of thickness. This means that the amount of insulation offered would offset any embodied energy that foam insulation carries. The big disadvantages are the PBTs that are added. Fortunately, there is an effort to change building codes that would allow manufacturers

to remove some hazardous chemicals from foam insulation. Building codes currently state that foam-plastic insulation needs to meet a specific fire efficacy. Building codes also require that the insulation be separated from the living space by a barrier such as gypsum drywall. Combustion tests done in the past have shown no correlation between foam insulation with or without added carcinogenic fire retardants. Furthermore, the majority of the fire safety is provided by the thermal barrier enclosure of the building. The effort is to be able to use non-FR foam-plastic insulation in situations where there is enough fire safety provided by the thermal barrier (Wilson, 2013). Unfortunately, changing building codes is a lengthy and difficult process so it is unlikely that foam-plastic insulations have removed their carcinogenic substances.

3.2.5 Doors and Windows

Insulating the walls of an RV is a time consuming and expensive task to commit to, but it would be in vain if the doors and windows are not properly insulated first. One of the places in an RV where heat escapes the most is the failed seal around the entry door. Constant opening and closing of the entry door creates fatigue on the seal and over time, it begins to fail. A proper seal around this large opening will drastically increase the heat efficiency of the RV. The door itself can also be replaced, but if the RV is older, it may be difficult to source a properly insulated door that fits correctly. The RV door can also be rebuilt and

Figure 18: Door Insulation

insulated accordingly to one's own standards with sustainable insulation mentioned in previous sections. Regrettably, the tools and knowledge needed to do this conversion is difficult to come across. The image above shows a door insulation project with materials from a local hardware store.

It is difficult to find an older RV with double pane windows already installed. Purchasing newly constructed windows is a viable solution, but one needs to contact the RV manufacturer or a window manufacturer to see if there is a stock size that will fit the particular RV. If window manufacturers cannot provide a replacement for the inefficient single pane windows already installed in the current RV, then there are a few other solutions that can be applied. Hardware stores carry foil-backed insulation sheets that can be easily cut and taped to the interior and exterior of the window housing. Alternatively, the foil-backed insulation can be attached using system where it can become removable, since the foil will block the views to the outside. During winter months, passive solar techniques should be practiced, so a removable system is ideal for letting sunlight during the day and insulating during the night. Other companies also offer clear film that can be placed directly to the interior and exterior of the windows to reduce condensation and heat loss. One more solution would be to create a DIY style of double pane window by custom cutting a sheet of multi-wall sheet of plastic to fit inside of the window area. A proper seal would be required to minimize condensation trapped in the space between both panes.

An often-missed location that is subject to heat loss is the roof hatch that comes standard in almost all RVs. A simple fix to the heat loss experienced by roof hatches and skylights is a custom fitted vent cushion available from several RV supply stores. A fairly inexpensive item, the vent cushion is an insulated block that is placed inside the roof hatch to prevent heat from

leaving through this opening. All-in-all, one should check every opening and make sure that there are no gaps to the outside, and if there are, they should be sealed properly with sustainable weather materials available in most hardware stores.

3.2.6 Furniture and Appliances

The furniture and appliance section of the thesis is where the user can begin to use creativity and imagination to design the interior space of the RV and create a truly individualized custom living area. Any ideas and designs must be carefully planned and thought through completely before application to lower the chances of mistakes during installation. Some application guidelines are outlined in the following sections, but the user has complete control over the final design.

3.2.6.1 Living

The living space is mostly a public entertaining space or an area for people to relax. It could see a lot of traffic if the user is a social person. Since the living space is public, it does not have to be confined to indoors; it can emerge from the RV to embrace the vast outdoor space surrounding the RV. There are many ways to accomplish this task, depending on the complexity of the design. This section suggests the materials and processes used to complete such a task.

Usually, the living space in a house is an area for congregating. It will typically include seating, visual and/or auditory entertainment, and anything else that can encourage a social ambiance. Most likely there will not be much room inside the RV to assign a space to be solely used for a living room, but instead it will probably have to be shared with another space, such as the kitchen or bedroom. The designer needs to incorporate multiuse furniture elements that can

quickly change shape and function whenever a new situation occurs. Since the space can become both a public and private space, careful design principles must be considered to create a successful shared/living space.

Care must be paid to the types of products or materials used for this area of the recreational vehicle. Using principles and materials from the previous sections, the user should be able to design a proper sustainable system for a living room. If the user is going to design and make custom furniture, material and finish choices are an important aspect of the process. When buying furniture, one should look for sustainable practices throughout the entire company. It is important to look for eco-friendly practices from the seller to the manufacturer. For instance, the user should verify if the companies are using sustainable materials for their products, innovative shipping and packaging practices, and even the management of the employees. There are not many companies that offer organic and sustainable furniture, so purchasing something that will be small enough to be of use within a recreational vehicle will be difficult. The use of pre-owned items that can be modified to suit the customized RV is probably the best option in this situation.

3.2.6.2 Sleeping

There are many sources for eco-friendly and organic bedding products. Several large companies are beginning to jump on the 'green' trend and offering organic cotton sheets, eco-foam pillows and mattresses, natural linens, eco-friendly comforters, and many others. As mentioned before, one cannot only pay attention to the materials used, but also the environmental, economic, and social aspects of the products offered by these companies. The possibility of making a DIY mattress is fairly low due to the availability of materials and skills

needed, although it is possible. Furthermore, sleep is an important factor of a healthy lifestyle, so cutting corners on price and material is something that is inadvisable. Depending on the design of the recreational vehicle, the sleeping area is a location that can be implemented to be a multiuse space. Similarly to most homes, some larger RVs are designed so that the private spaces are located away from the public space. If there is an open floor plan in the RV, the user can design the sleeping quarters to be anywhere he or she see fit. The ability to use a space for several purposes is advantageous because the practice utilizes a minimal amount of space in a large way, basically doubling or tripling the space available for other functions.

3.2.6.3 Kitchen

The kitchen can consist of a myriad of items helpful for cooking. It is imperative that the adventurous cook learns to consolidate items and appliances to maximize the potential of minimal tools for the kitchen. First, focus should be paid to the surface that will be used for the kitchen area. If the user is going to be spending a lot of time cooking, a large tabletop needs to be a prominent space in the kitchen. For the eco-minded individual, there is a rising market for commercial sustainable kitchen countertops available for domestic use. These products can be used within the recreational vehicle, but some of the countertops are incredibly heavy. If a heavy material is used, then it must be countered with something else to lighten the weight of the vehicle. Finally, kitchen appliances like refrigerators and stoves need a large amount of energy.

3.2.6.3.1 Countertops

The re-use of existing materials is usually one of the best choices for sustainable designs, but if the user does not have access to post-consumer materials, there are other choices.

Whiteley (2014) outlines several types of sustainable countertops for purchase such as paper composites, recycled glass, sustainably grown wood, recycled aluminum, and others.

Paper composites use post-consumer paper products that are certified by the Forest Stewardship Council that are held together with non-toxic resins that are formaldehyde-free. It is important to note that these products will need to be sealed before use as well as at least once every year, and the user should not use harsh cleaning chemicals because they will damage the surface, as this can damage the material.

Recycled glass can be mixed into a concrete or resin base as an aggregate. These countertops can be very heavy, depending on the base that is used. The user should look for a concrete base that uses post-consumer recycled materials such as fly ash, which is a by-product of coal, or a formaldehyde free resin as the base. One of the disadvantages to this material is the cost to the consumer.

Sustainable wood countertops can be made from many types of sustainable wood products. Butcher block countertops can use reclaimed and reused wood made in cubes or long strips. Using reclaimed wood decreases the need to cut down new trees, minimizing deforestation. Also, older woods have a tighter grain and are usually a better quality lumber. If other wood is used, refer to earlier section on material to see types of quickly renewable and sustainable woods to search for. To protect and preserve the wood, annual sanding and refinishing needs to be done.

Stainless steel and aluminum countertops are nonporous and are easily cleaned. They are lightweight products that can be cut and molded to any size and configuration. Stainless steel and aluminum can also be used for sinks, light fixtures, and other hardware. These products can be made from post-consumer materials and are fully recyclable after use (Whiteley, 2014).

3.2.6.3.2 Kitchen Appliances

The kitchen appliances that are included are completely up to the user. Understandably, it is difficult for people to leave behind the items that make life easier. A fully stocked kitchen with multiple appliances is something that most people have become accustomed to. The size of the kitchen and the amount of storage utilized correlates to the overall size of the recreational vehicle. If one is lucky or can afford a larger RV, more components can be utilized in the kitchen. But if the only available RV is small, then a minimal approach must be taken towards a kitchen. Only the most useful items should be stored and used. It is critical for the user to be completely organized with their appliances and equipment in the kitchen. The user should remember that food safety is one of the most important aspects in travel culture. Refrigerated food needs to stay at a temperature between 35º and 40ºF to prevent the growth of bacteria. A refrigerator needs to be properly insulated and have an energy star rating for efficient performance. A top feed refrigerator is more efficient than a front feed refrigerator due to the fact that cold air is denser and stays at the bottom rather than escaping every time the door is opened. Adding a temperature control unit to a small top feed freezer can easily convert it to a top feed refrigerator.

Food temperature while cooking is an important health factor as well. If meat is not properly heated to certain temperatures, bacteria can linger and create severe health problems. A proper cooking surface or oven is necessary when making dishes containing meats or other animal products. Traditional stoves use thermal conduction and convection to transfer heat to a vessel for cooking. The stove uses an energy source, either electrical or propane, to heat a vessel which in turn heats the food contained within the vessel. This method of cooking is inefficient because there is a large amount of heat loss. New technology developed within the past fifty

years have made it possible to transfer heat by using an electromagnet that creates an electric current in a cooking vessel made from a ferrous metal. The electric current heats the vessel directly, rather than a third party heating element, making induction heating a more efficient heating source (Meals on Wheels, 2014).

Figure 19: Energy Star Logo

The kitchen design will depend solely on what the user feels comfortable using, as long as he or she has the electric and propane energy to support it. Minimizing the impact of using many appliances and efficient heating and refrigeration will decrease the effect to the energy systems in place. Using energy star rated appliances and understanding sustainable concepts for low-impact use will allow for a sustainable kitchen.

3.2.6.4 Entertainment

Entertainment can consist of several different mediums. From the printed to the digital, the choice all depends on what the user wants. If a person is content with reading a book and enjoying nature, it means that they do not have to worry about using many resources. There are others, however, that want to be able to watch television or listen to the radio at times. Fortunately, technology has advanced far enough to provide products that are portable and energy efficient. Recently, it has become common to have a LED, LCD, or Plasma display, flat-panel televisions in the home. These televisions are much more energy efficient than typical rear projection and tube televisions. It is important to choose electronics that have been classified with an "Energy Star" rating by the Environmental Protection Agency. The EPA rates a product's energy efficiency compared to similar products. Energy star ratings are awarded to

products that meet strict qualifications including efficiency, lifetime, quality, and power use. Although heavily criticized for their testing methods, the Energy Star seal is commonly used as a means of comparing efficiency in common household products (How a Product Earns the Label, 2014).

3.2.7 Design Considerations Regarding Materials

Design considerations in regard to materials are given for the three scenarios described at the beginning of this chapter. An initial inspection needs to be completed to see what areas of the RV will require special attention in regards to each scenario.

STRUCTURE	$$$ Budget	$$ Budget	$ Budget
Insulation	Foam Insulation	Organic Insulation	Existing Insulation
Subfloor	Organic Plywood	Salvaged Plywood	Existing Subfloor
Flooring	Bamboo	Cork	Reclaimed Wood
Walls	Organic Plywood	Organic Plywood	Salvaged Plywood
Windows	Argon / Double Paned	Double Paned	Single Paned
Lighting	LED	CFL Bulbs	Fluorescent Bulbs
Finishes	American Clay	American Clay	Low VOC Paint

Table 1: Structure

3.2.7.1 Materials under Scenario #1

Under Scenario #1, the interior of the RV would have luxurious amenities and materials to provide the user with a legitimate 21st century off-the-grid experience. The entire interior would need to be removed to replace insulation and subfloor material with an efficient sustainable option. Important care has to be exercised in removing the interior walls so that they are not damaged. The old insulation has to be properly discarded in an appropriate manner. In

replacing the insulation, one must first see what the correct thickness of insulation is needed. For Scenario #1, Glasswool insulation is recommended due to its uncomplicated installation. The subfloor material can be replaced with a RevolutionPly plywood material offered by Patriot Timber Products based out of North Carolina. This plywood comes from sustainable wood sources and contains no tropical hardwoods. The plywood can be installed throughout the base of the RV and the flooring materials can have a mixture of tile, cork, and interface carpet. Recycled glass tile can line the floor and walls of the bathroom, cork flooring can be installed in the kitchen area, and interface carpet tiles can be situated in the bedroom area. After the walls are properly placed back into the support structure, the interior walls can to be painted with American Clay earth plaster finish to provide a safe and attractive interior.

Lighting throughout the RV can be replaced with highly efficient LED track lighting. The spots of existing fixtures can be reused for the track lighting so that the wiring does not have to be reinstalled. The LED track lighting can be attached to the AC convertor that can be installed with the solar power feed. Energy used throughout the RV needs to be carefully monitored and the appliances that are purchased must be energy star certified. The high budget of this scenario can allow a larger amount of solar panels to power more equipment like television, laptop, radio, cooktop, small refrigerator, and a few small kitchen appliances.

In the bedroom area, the cushions and bedspread can be made from organic materials. Upholstery material is mostly made from blends of synthetic and organic materials to cut down on costs and to make the fabrics last longer. In this scenario, organic cotton can be used to cover an Enviro-Fiber Foam cushion system. The Enviro-Fiber Foam is an alternative to polyurethane foam, which contains many volatile chemicals.

The windows can be replaced with operable double-paned windows. Replacing single-paned windows with double-paned windows can increase the insulation properties of the openings throughout the RV. Existing doors can also be restored, replacing the current insulation with Glasswool insulation.

3.2.7.2 Materials under Scenario #2

In Scenario #2, the budget constraints play a major role in the design of the space. The RV can have similar elements as Scenario #1, but at a lesser price and less extravagant. First, the subfloor may not need to be replaced, only repaired with salvaged plywood. The actual flooring material can be cork throughout the bathroom and kitchen, providing a soft and water resistant floor. Replacing the insulation may not be necessary; therefore, the walls can remain intact. The interior bathroom walls can be lined with linoleum to maintain a water resistant barrier from the shower and steam build-up. The rest of the interior walls can be painted with American Clay earth plaster finish to provide a level of insulation. In the bedroom area, sample tiles of interface carpet can be used for the flooring.

Light fixtures may not need to be replaced, but the light bulbs can be replaced with LED bulbs. It is suggested to purchase LED lights that are described as 'warm' light to provide the user with a light that is closer to an incandescent bulb. If the current lighting in the RV is connected to a 12V/DC power supply, the correct type of bulb needs to be purchased. Unless the user wants to complete a DC to AC power conversion for the LED lights, they will need to purchase LED lights that work with 12V systems. The appliances that are used within the RV need to be Energy Star certified and carefully monitored as to not run out of stored power throughout the day.

Similar to Scenario #1, the upholstery materials used in the bedroom area can be made of organic cotton material. There are several retail sources from where organic cotton can come from, so it is up to the user to choose from which upholster they want to work with. Scenario #2 can use Enviro-Fiber Foam for the custom cushions made for the RV.

3.2.7.3 Materials under Scenario #3

Scenario #3 can include the same material choices as Scenario #2, except for the sustainable upholstery material. Reclaimed wood can be used throughout the RV as needed to repair and build, LED lights can be installed, and Energy Star appliances can be used. For the bedroom, it is recommended not to utilize new sustainable fabrics for the upholstery. Instead, used bedding can be obtained for this project. Anything that can be reused or repurposed should be used in this scenario. Creativity will need to be used for repurposing items to integrate them into the RV.

BEDROOM	$$$ Budget	$$ Budget	$ Budget
Floor	Interface Carpet	Interface Carpet	Existing
Multiuse Furniture	Adjustable Table to bed	Adjustable Table to bed	Adjustable Table to bed
Bedding	Enviro-Fiber Foam	Enviro-Fiber Foam	Enviro-Fiber Foam
Upholstery	Organic Cotton	Organic Cotton	Hemp
Heating	Radiant Heating	Catalytic Heater	Space Heater

Table 2: Bedroom

KITCHEN	$$$ Budget	$$ Budget	$ Budget
Floor	Cork	Cork	Existing / Linoleum
Sink	Stainless Steel	Stainless Steel	Existing / Salvaged
Appliances	High End Energy Star	Energy Star	Energy Star
Countertops	Paper Composite	Stainless Steel	Aluminum / Reclaimed

Table 3: Kitchen

BATHROOM	$$$ Budget	$$ Budget	$ Budget
Floor	Cork	Cork	Linoleum
Walls	Recycled Glass Tile	Recycled Glass Tile	Linoleum
Toilet	Incinerating Toilet	Chemical Toilet	Chemical Toilet
Shower	Low Flow Shower	Low Flow Shower	Low Flow Shower
Sink	Low Flow	Low Flow Stainless Steel	Existing or Salvaged

Table 4: Bathroom

3.3 Systems

A system is usually a set of interacting components forming a whole. Crucial systems needed for the operation and usages of the RV are reviewed in this section. There include electricity, human waste, water, temperature conditioning, and biodiesel conversion. Each of the kinds of systems will include options that will need to be researched further by the user to see if it is the best selection for the use of the RV being renovated. Each RV renovation will be different due to the choices made by the user, meaning that the following options may or may not be applicable to the RV renovation.

3.3.1 Energy Systems

Energy systems are crucial to the modern lifestyle humanity has acclimated to. Most Americans take the electricity that magically comes through the wall for granted. They usually do not know what kind of systems are implemented by the city to gather or create the electricity that is used to power most, if not all, electrical contraptions commonly found throughout modern homes. Electricity is not something that has much history in the course of humanity. In the past, people gathered power from water, wind, and the sun, which are natural sources that provide a mechanical advantage or heat from essentially free and everlasting sources. Humanity as a whole has deviated from these natural sources of energy mostly because of the costs and unavailable technology that are needed to implement to worldwide energy independence. Fortunately for this project, one can diverge from customary energy sources and assign individual off-the-grid electrical systems (Smith, 2004).

3.3.1.1 Solar

Access to the energy of the sun has been exercised extensively since the beginning of time. Nearly everything on this planet flourishes from the mighty power of the sun. There are many ways to take advantage and harness solar energy through heat transfer and solar gain, but transferring that energy into electricity needs a special type of technology.

Solar power is the act of converting sunlight into electricity through either the use of photovoltaics or concentrated solar power. Unfortunately, size is an issue with travel trailers; so concentrated solar power is not a viable option. For the remaining option, a panel is constructed of an interconnected array of photovoltaic cells that produce electrons when light hits the surface. These electrons are then captured by contacts and the electric current results.

Figure 20: Photovoltaic Panels

Photovoltaic panels are normally used to collect direct solar radiation and convert it into direct current (DC) electricity. For practical residential use, a direct current (DC) to alternating current (AC) inverter is needed. Batteries are required to store excess power during the day for use when there is no direct sunlight (Center for Sustainable Systems, 2012).

Space and power load are important aspects to consider when making a decision on what kind of photovoltaic panels to purchase. The owner of the RV needs to understand how much power will be needed when operating appliances, lighting, cooling, heating, and other systems within the RV. This will directly affect the size of the photovoltaic system to invest in. If the user only has a few small lights, small electronics, and the usual peripherals that usually come built into an RV, then an 80-130 watt system is adequate. If the user is going to be staying for extended amount of time, where a microwave, TV, coffee machine, and other electronics are going to be used, then a larger system of over 400 watts is needed. Unfortunately, by using a larger system, more roof space and battery storage is required, and more weight is added overall.

Most RV lights and accessories will run off DC power and do not need to be attached into an inverter, but for anything else that is applied aftermarket, an AC inverter needs to be used. Also, a solar regulator will display and control the charge placed on the heavy duty deep-cycle batteries. The regulator will charge the batteries slowly because permanent battery damage will occur if charge is not controlled.

3.3.1.2 Wind

The BWEA, British Wind Energy Association, compares two types of domestic scale wind power generation; small-scale and micro-scale. Small-scale wind power is can be categorized into wind turbines that generate less than 50kW of electricity, 16 meter diameter fins, and 200 square meters rotor area, generally for buildings and small dwellings. Micro-scale wind turbines generate under 3.5kW of electricity, 4 meter diameter fins, and 15 square meter rotor area (BWEA, 2006). Siting is an essential element to study in order to gather the most incoming wind possible. Aspects to consider for ideal sites include wind speed, wind direction, height, physical obstructions, mounting location, vibration, wildlife, noise, and maintenance access. Assuming the user can find an ideal site with strong wind, no obstructions, and a good mounting location, there is still something else to consider, power. The equation for power available from wind is: $P=1/2\rho\pi r^2v^3$

Figure 21: Wind Power

Where P is power from wind, ρ is density of air (a constant), r^2 is the area of circle of turbine blades, and v^3 is the wind speed cubed. Blade diameter cannot be too large, since they will be traveling in or on a small RV. This number is squared, so the larger the blades, the higher the power, which is unfortunate in this scenario since size is a factor. The other important number is this equation is wind speed. Since that number is cubed, doubling the wind speed produced eight times more power. Under a certain wind speed, the wind turbine will not produce

electricity when power generated is lost to friction and electrical resistance. One option is a small roof-mounted turbine on top of the RV that can generate electricity while driving at high speeds, but will not be used while stopped. It will also be difficult to find a location to mount while the RV is stopped for an indefinite length of time. In conclusion, a small wind turbine is not as efficient as a larger one since wind power is proportional to the area of the turbine blades. Although the wind speed can be high at times or driving, the stress placed on the turbine will likely damage it and render it useless. It is possible to have both solar and wind power in the same system, but price and size are both a large factor for this decision (Martin, 2007).

3.3.2 Human Waste Management System

Most RVs are equipped with three tanks: fresh water, greywater, and black water. Fresh water tanks should be filled with potable water from a clean source. Greywater tanks are connected to sinks and showers to store water that has been lightly used. Black water tanks are used for storage of wastewater containing human waste and is only connected to the toilet. Black water contains pathogens that have to decompose before they are safely disposed of. The process of decomposition takes longer when water is introduced, hence the black water tank that has to be emptied periodically. Using composting and incinerating toilets is advantageous because they do not use water. Unfortunately most commercial composting and incinerating toilets are expensive and difficult to maintain.

3.3.2.1 Composting Toilets

Composting toilets use a natural process to transform human waste into a valuable additive to soil and crop fertilizer. Commercial composting toilets have a system that composts

internally and the toilets do not need to be maintained very often. The negative side to a commercial composting toilet is that it will cost around $1,000 to buy and consumers have complained of failure with the system. Joseph Jenkins (2005), the author of The Humanure Handbook, a book about human feces and the art of composting it, has devised a simple manner of DIY sawdust toilet making guidelines that only include a five gallon bucket, a regular toilet seat, and a dash of sawdust. The composting toilet introduced by Jenkins is more of a waste receptacle rather than a composting toilet. After one does their business in the toilet, the next step would be to cover the waste with sawdust, peat moss, wood pellets, or other organic material. As the bucket becomes full, it needs to be emptied into a composting area and left for about a year before it can be used as fertilizer. Someone who is constantly travelling usually does not have a permanent outdoor composting rig set up for this type of toilet. Regardless, it is an incredibly simple solution to one of life's daily occurrences.

Commercial and self-built composting toilets will both essentially work in a similar way by using natural thermophilic bacteria to break down the harmful pathogens present in human fecal matter. To have a proper human waste compost station, the following key concepts must be kept in mind:

a) **Isolation**: The material should be left to compost in isolation, without potential contact from people, until it is fully composted and safe to handle.
b) **Ventilation**: The toilet needs a flow of fresh air, to add oxygen and remove odors. All vents should exit the living space.
c) **Moisture**: A composting toilet should not be too wet. Urine diversion helps with excess moisture problems. If the toilet does not divert the urine, or if a small amount

of water is added, the material will need more dry material added or extra heating and mechanical mixing.

d) Temperature and time: The rate of decomposition is a combination of temperature and time: the hotter the compost pile, the more quickly the process happens, or if the pile is not hot, the longer it takes. If a humanure compost pile is not monitored for high temperatures it should be isolated for a long time to ensure full decomposition. In a mild climate this takes a year, while in areas with cold winters it may be 2 years.

e) Bulking agent: In a *composting toilet* sawdust covers the material creating air gaps for aerobic bacteria to break down the material. Toilet paper and feces compost through the same process a household food scrap compost bin undergoes. In a *dry toilet*, ash or lime is mixed with soil and added to create a dehydrating environment for breakdown and die off of pathogens. Dry toilets are often used in arid, dry climates where lime and ash are more available than sawdust. Toilet paper cannot be added to a dry toilet, so it is usually burned or buried.

-Greywater Action, 2014

It is not practical to have a sawdust toilet if the user will be traveling for longer than a week at a time. If the user has a permanent human waste compost station that they return to constantly and can empty the waste bucket into, then a sawdust toilet would be something to consider. But, if a traveler does not come back to the same location at regular intervals, then a more complex and expensive composting toilet will be needed.

3.3.2.2 Incinerating Toilets

Incinerating toilets are systems that burn human waste rather than flushing it down with water. They can be powered with propane gas, electricity, diesel, or other energy sources. The way that incinerating toilets work is by placing a small paper liner similar to a coffee filter in the bowl to catch the waste droppings and a helical screw pushes the waste, or a hinged trap door drops the waste, into an incinerating chamber where it is turned into ash. Some advantages of using an incinerating toilet are that they do not use water, the waste is turned into an ash that is quick and easy to discard, the toilet is portable and can be easily installed in remote areas, and it is relatively odorless compared to other self-contained toilets. Unfortunately, incinerating toilets destroy any nutrients in the waste, rendering the byproduct unusable for soil replenishment; require a large amount of energy; and are highly priced.

According to a study completed during the 1970s in Kentucky, six incinerating toilets were heavily tested. Two of those were a popular brand that is still on the market today: Incinolet. The users of the Incinolet toilet complained about having to scrape partially burned waste from the incinerating chamber walls, high operating costs, and intermittent performance. Incinolet accordingly added a catalyst to aid in the incineration of the waste, but the overall design of the toilets has not changed (Environmental Protection Agency, 1999). Overall, the high price sticker of this toilet, below average performance, maintenance costs, and the use of additives make the incinerating toilet a subpar choice for a portable toilet.

3.3.2.3 Portable Toilets

Portable toilets can come is many different variations and sizes. The most common type is used with a chemical solution that covers human waste and must be serviced regularly. These are traditionally known as Porta-potties and are used in larger settings such as worksites where several people are using it. Smaller versions are available which use similar chemical formulas. These chemicals normally contain formaldehyde, a volatile chemical that is banned in certain states. There are alternatives to this chemical that use an enzyme that is environmentally friendly and can break down waste matter easily. These types of fluids are biodegradable and work through a fully biological process of friendly bacteria that is safe for humans and wildlife. Though it is safe to use, it is still important to follow manufacturer's disposal directions (Go Outdoors Guide, 2014).

Figure 22: Chemical Toilet

Another type of portable toilet is the kind that uses a small bag beneath the seat to collect waste. This kind of toilet bag is common with individuals that participate in camping trips lasting several days. The sealable bag contains a powder that turns human waste into a stable gel that can easily be transported to a safe waste deposit location. The material of this disposable bag is landfill safe, which means that it can be thrown away with common trash. This type of toilet is reserved for short trips because the bags are one time use.

These types of portable toilets are reserved mainly for short trips because of the amount of maintenance needed after each use. If the user will be taking longer trips or if the RV will be used as a primary residence, composting or incinerating toilets are the practical choice.

3.3.3 Water Management Systems

There are a few different systems that can be incorporated into water management for an RV trailer. As stated before, RV trailers usually come with three tanks: potable water, greywater, and black water. Black water storage will only be necessary if there is a normal water flush toilet. Greywater tanks are used to store water that drains from sinks and showers so that it can be properly disposed of. This water can be used for toilet flushing and plant watering. If the RV trailer incorporates a waterless toilet, the black water tank is not necessary and that space can be used to store other components.

3.3.3.1 Water Circulation

Water pumps for recreational vehicles are usually low cost, low energy devices used to keep constant pressure within the water lines. The water pump brings water to the sinks, showers, and toilets in the RV from the clean water storage tank. This device is small and runs off the same 12V battery power other interior lights do, which means it can be run from solar power as well. There are several manufacturers that offer small RV water pumps, but one needs to do a small amount of research before purchasing. Things to look for include operating noise, amount of pressure, and water flow. Some people may want higher pressure than others and that all varies on the size of the RV and amount of water travelling throughout the vehicle. A small DIY project one can do is to install a foot pump for a sink and only use the water pump where there is a constant need of water pressure.

3.3.3.2 Water Filtration

A system for water filtration can be used in an RV, but diligent care must be paid to the system, or else harmful bacteria can enter through the water. Rain, lake, well, and directly into campsite hydration system are main sources of water that a traveler can tap into. Each of these water sources requires different levels of filtration for different uses. Hooking directly into a campsite's water line is a best scenario because, if it is city water, it is usually clean and has already been treated to high standards. The user will need to verify where the water source is, because some campsites may not be close enough to city water and could be using well water. A small carbon water filter can be used to remove unnoticeable traces of minerals and chemicals used in the filtering process of the location. A more intricate system has to be used if a person is trying to benefit from free water from rain or a nearby lake.

Trying to gather water from rain requires a system to be set into place to contain the water that falls from the sky into a receptacle that will contain it. It can be anything as simple as a tarp with a funnel on the end to a permanent install on the RV using rain gutters that are attached to plumbing into a collection tank. From this container, a choice has to be made whether the water will be clean potable water or used for other purposes like washing dishes or taking showers. From this collection container, a system of filters needs to be set up. A simple aggregate screen filter needs to be added before and after the collection container to seep out larger contaminants such as sand and dirt. A lifetime member of Lance Owners of America, an online community for Lance RV owners, named Rick (2007) came up with a solution to getting water from a stream, which can also be applied to rain water collection. A water pump is attached after the screen filter to pull the water out of the container and sends it to the first filter, which is a simple inexpensive filter used to keep sediment out of the more expensive filters.

Rick uses a 5 micron pleated washable cartridge followed by a ½ micron carbon block filter that is used to remove much smaller particulates and bacteria in the water. After this filtration step, the user can likely use this water for washing dishes, taking showers, or flushing toilets. If the water is to be used as potable drinking water, an extra step needs to be included to further filter any extra possible contaminants. Rick uses a ½ micron silver/ceramic Bio-Guard micro filter that "removes 100% cryptosporidium and Giardia cysts and >99.99% of particles ½ micron in size including pathogenic bacteria such as E. Coli, Salmonella, etc." (Rick, 2007). There are also more expensive microbiological filters that can filter contaminants as small as .019 microns in size. The location of the tanks, filters, and pumps are up to the user and all depend on the size of the RV, so careful research has to be allocated to this project since contaminated water is a health hazard.

3.3.3.3 Water Heater

By living in a developed country, heated water is a luxury that many of us have taken for granted for most of our lives. Many people enjoy taking long hot showers or washing dishes with hot water. In an RV, it is enough of a difficult task to time a shower with the amount of water available, let alone making sure it is hot. If space allows for it, RVs could carry a hot water tank that works similarly like the ones in most homes. But, just like most homes, hot water tanks are usually large, heavy, inefficient, and use a large amount of electricity. A better solution is to use a point-of-use tankless water heating setup that provides hot water when needed rather than storing water for later use. Most tankless water heaters operate from natural gas and depending on the size, are fairly inexpensive. The advantage of having a demand water heater is that water will be heated at the exact moment it is being used. Another system that can

be installed is a hydronic heating system available from a few manufacturers. Hydronic heating systems operate on gasoline or diesel making them more BTU-dense than propane gas. These systems can provide constant heated water to all zones in the RV. Hydronic heating system is an expensive upgrade and a large space is needed to house all the components needed (UHI Worldwide, 2012).

3.3.4 HVAC Systems

Heating and cooling is not always a necessity for people who are constantly on the move. It is more of a luxury that has recently been implemented into our lives. For people who are constantly moving around the United States, it is not difficult to find a location to hide away from the warmer or colder months. That is one advantage of an off-the-grid lifestyle, having the freedom to pick up and leave whenever one sees fit. Unfortunately, not everyone has the opportunity to life a nomadic lifestyle and there will be times when heating or cooling the RV will be necessary for both comfort and survival.

3.3.4.1 Natural ventilation

Depending on where a traveler ends up, there will be days when the weather will feel so wonderful that one will not be able to endure being inside of a mobile metal box and experience the outdoors. But if one were so inclined to stay indoors, it is not a difficult task to open a few windows to let the breeze blow transversely through the travel trailer. Opening a door and, if available, a roof hatch will create a chimney effect which will draw hot air up through the roof hatch.

In general, wind moves in predictable patterns. Location and orientation are important concepts to be familiar with when trying to maximize ventilation. Current wind speeds and direction can be found online through an interactive windmap developed by Fernanda Viégas and Martin Wattenberg, a visualization research team from Google. It is available through their collaborative website at hint.fm/wind and it provides a visualization of real-time wind current derived from data captured by the National Digital Forecast Database. Once the traveler has figured out the wind direction, the orientation in which the travel trailer is aligned is the next step. One must be careful to find a clear path from which the wind is traveling. Trees, mountains, and any other obstructions that will hinder wind travel are to be avoided. The opposite should be done in more windy months. More wind in winter months means more heat loss through convection as wind blows around an RV. During winter months, care needs to be paid to orient towards the sun, which is a topic that will be covered in the *Efficient heating systems* section below.

3.3.4.2 Efficient heating and cooling systems

Recently, heating and cooling has become a necessity rather than a luxury for most indoor places one visits. A large amount of energy is needed to power air conditioning and heating elements to make a habitable space comfortable for people. Conditioned spaces do not have to be energy extravagant if the user follows certain principles and is willing to sacrifice a little comfort for energy savings. Simple solar concepts previously mentioned can drastically reduce the amount of used to heat and cool an RV. Positioning windows to allow direct sunlight to enter through the fenestration of the dwelling will heat the interior and if the proper insulation is used, the heat will be contained throughout the day. Finding natural elements to block direct

sunlight needs to be considered in summer months when direct sunlight has to be blocked from entering the RV so as to keep the interior from becoming hot.

During times when direct sunlight cannot be controlled by the user, either in winter or summer months, technological advances will have to be put into place. Cooling during hot climates is a challenge during the day when the sun is pounding on the RV. Proper insulation is important to provide a shell that can contain a conditioned space. Air conditioning devices are usually installed on the existing roof vents or skylights of an RV. Air conditioning is a huge energy user when the owner is trying to minimize energy use. In most cases, the electronics used within a recreational vehicle will be fairly small and not used for long periods of time. Air conditioning can end up being used throughout the day in hot climates, making it the most energy-sucking device within an RV. There are two ways that an air conditioner can circulate air, ducted and non-ducted. Ducted devices are usually installed in larger RV units and have a system of ducts that blow conditioned air throughout the vehicle. Non-ducted units are attached to the roof vent and blow air directly from the unit. There are also HVAC units that have both heating and cooling elements in the same package.

Cooling and heating does not have to be accomplished solely by forced air conduction; it can be done through radiant heating and cooling. Radiant heating and cooling is achieved by treating a thermal mass substance and running it through another vehicle, such as piping, that will evenly heat or cool the air around the pipe. Radiant heating can be accomplished by applying a radiant floor system between the substrate and floor layers. The base of the radiant floor needs to be insulated properly as to not lose heat from below the RV. A thermal mass is strongly suggested. Unfortunately, thermal mass materials are heavy and usually not used in the

construction of RVs. As can be seen, heating and cooling is a system that uses a large amount of energy to convert thermal energy.

If the user will be traveling through winter months with cold weather, a heating device will be necessary to survive through cold nights. If the traveler uses forced air heating, such as a space heater, there is a risk of depleting the stored battery power through the night. A forced air furnace can also quickly deplete the stored propane, making it difficult to refill when far away from civilization. A catalytic heater does not require electricity to run and does not use an open flame for heat, minimizing the amount of propane used. Catalytic heaters require oxygen to run so it is imperative to provide a source of fresh air for the heater. If a catalytic heater is used in a confined space, the amount of oxygen in the space will be depleted and can kill the user. Fortunately, most modern catalytic heaters have a safety oxygen sensor that will automatically shut off when oxygen levels drop below a safe level. The safety tips included by the manufacturer of catalytic heater must be obeyed at all times for safety reasons (Carper, 2012).

3.3.5 Biodiesel

Biodiesel is a biofuel that is made from plants that contain oil in their seeds, such as soybeans and canola, which is used as a fuel source for diesel engines. It can also be processed from used cooking oil. The process used for converting used cooking oil into biodiesel is called transesterification and it separates the glycerin from the oil, leaving behind methyl esters, which is the technical term for biodiesel. Biodiesel can be used in standard diesel engines as a substitute for petroleum, which is a naturally occurring substance that releases harmful carbon dioxide when burned. Biodiesel has a higher combustion quality and a better lubricity than petroleum, when used properly (Detchon, 2014).

In general, the public has a misconception about biodiesel and that they will need to have a highly expensive conversion procedure for a car to be able to process biodiesel. However, biodiesel can be used successfully without the need of a conversion process. All that is needed is a diesel engine and a few inexpensive fuel filters. The only reason one would consider a conversion process is if the user were to begin using straight vegetable oil, or SVO. Straight vegetable oil can be problematic in cold weather. It will thicken and not be able to easily pass through fuel pump and fuel lines. For this reason, a conversion process will be needed. The conversion process varies from a small do-it-yourself venture to a professional installation that can cost up to several thousand dollars. An alternative to having a conversion done to the car is to convert the fuel instead. Several online forums speak about adding paint thinner to the vegetable oil to prevent the coagulation of the fuel. However, this is something that needs to be tested before implementing into the engine to counteract engine failure.

The ability to use biofuels depends on the vehicle that is procured. If the RV is a truck camper or a motorhome, then it may be difficult to find a diesel one. A pull behind camper can be used with most vehicles as long as they have the towing capacity for the RV, many of which are not diesel engines. Diesel engines are more efficient than gasoline engines and can be converted to use only vegetable oil. Traveling purely on vegetable oil has a minimal carbon footprint with hardly any pollution from the vehicle. The only emission from a SVO vehicle is water. (Detchon, 2014).

3.3.6 Design Considerations and Regulations

The design guidelines provided by this thesis are meant for guiding the user to create a unique space fit to their own specifications. If the user objective is to create a space that modifies

the integrity of the RV, such as the structure, plumbing, electrical, fuel, or other systems included in the RV, then the user needs to cross reference the Code of Federal Regulations, Title 49 Part 571 (RVIA, 2015). The RVIA provides certification for motorhome manufacturers specifying safety standards for all life threatening systems within an RV as well as complying with road regulations. For an RV to be legally allowed on the road, or for living full time, the user must comply with certain construction guidelines including earthquake and wind loads, adequate moisture barriers, air circulation, material choices, front and rear visibility, sewage, water circulation, electrical systems, and many more safety standards defined by the Code of Federal Regulations for motor vehicles.

As reference, this thesis uses manufacturing practices outlined by the CFR; Code of Federal Regulations part 3280 – Manufactured Home Construction and Safety Standards. This section of the CFR details design standards ranges from sizes of electrical conduit to size requirements of an acceptable occupied room. Since recreational vehicles are not classified as permanent homes, they do not have to comply with residential building codes. However, it is important to review residential building codes and use them as reference to design guidelines regarding standardized heights and sizes for countertops, seating, tabletops, countertops, electrical outlet locations, proper storage for potentially dangerous components, appliance use, hot water heater locations, etc. If the RV includes spaces for basic functions supporting daily routines, such as cooking, sleeping, lounging, toiletry, or water usage, the RV must be able to establish a safe environment. A subset of the 3280 standards is listed below (eCFR, 2015):

a) Standard 3280.111: Toilet Compartments

   Each toilet compartment must have a minimum width of 30 inches, with a minimum clear space of 21 inches in front of each toilet. A toilet located adjacent to a wall must have the

center-line of the toilet located a minimum of 15 inches from the wall. A toilet located adjacent to a tub must have the center-line of the toilet located a minimum of 12 inches from the outside edge of the tub.

b) Standard 3280.112: Hallways

Hallways shall have a minimum horizontal dimension of 28 inches measured from the interior finished surface to the interior finished surface of the opposite wall. When appliances are installed in a laundry area, the measurement shall be from the front of the appliance to the opposite finished interior surface. When appliances are not installed and a laundry area is provided, the area shall have a minimum clear depth of 27 inches in addition to the 28 inches required for passage. In addition, a notice of the available clearance for washer/dryer units shall be posted in the laundry area. Minor protrusions into the minimum hallway width by doorknobs, trim, smoke alarms or light fixtures are permitted.

c) Standard 3280.504: Condensation Control and Installation of Vapor Retarders

Ceilings: In zones with coefficient of heat transmission (Uo) value 2 or 3, ceilings must have a vapor retarder with a permeance of not greater than 1 perm installed on the living space side of the roof cavity. For manufactured homes designed for Uo-value zone 1, the vapor retarder may be omitted.

Exterior walls: Exterior walls must have a vapor retarder with a permeance no greater than 1 perm (dry cup method) installed on the living space side of the wall; or unventilated wall cavities must have an external covering and/or sheathing that forms the pressure envelope. The covering and/or sheathing must have a combined permeance of not less than 5.0 perms. Formed exterior siding applied in sections with joints not caulked or sealed, are not considered to restrict water vapor transmission; or wall cavities must be constructed so that

ventilation is provided to dissipate any condensation occurring in these cavities. Homes manufactured to be sited in "humid climates" or "fringe climates" are permitted to have a vapor retarder installed on the exterior side of the wall insulation or be constructed with an external covering and sheathing with a combined permeance of not greater than 1.0 perms, provided the interior finish and interior wall panel materials have a combined permeance of not less than 5.0 perms.

d) Standard 3280.609: Water Distribution Systems

Water supply: Piping systems shall be sized to provide an adequate quantity of water to each plumbing fixture at a flow rate sufficient to keep the fixture in a clean and sanitary condition without any danger of backflow or siphonage. The manufacturer shall include in his written installation instructions that the manufactured home has been designed for an inlet water pressure of 80 psi, and a statement that when the manufactured home is to be installed in areas where the water pressure exceeds 80 psi, a pressure reducing valve should be installed.

Hot water supply: Each manufactured home equipped with a kitchen sink, and bathtub and/or shower shall be provided with a hot water supply system including a listed water heater.

e) Standard 3280.903: General Requirements to Withstand Transportation Shock and Vibration

The cumulative effect of highway transportation shock and vibration upon a manufactured home structure may result in incremental degradation of its designed performance in terms of providing a safe, healthy and durable dwelling. Therefore, the manufactured home shall be designed, in terms of its structural, plumbing, mechanical and electrical systems, to fully withstand such transportation forces during its intended life. Particular attention shall be given to maintaining watertight integrity and conserving energy by assuring that structural

components in the roof and walls (and their interfaces with vents, windows, doors, etc.) are capable of resisting highway shock and vibration forces during primary and subsequent secondary transportation moves.

3.3.7 Design Considerations Regarding Systems

Design considerations regarding systems are given for the three scenarios described above. Simple illustrations are provided to visually describe the five systems (energy, human waste, water management, HVAC, and biodiesel) under the three scenarios.

3.3.7.1 Systems under Scenario #1

For Scenario #1, an incinerating toilet can provide the user with an almost waste-free use, eliminating the need for a wastewater receptacle. Water from the shower and sink can end up in a container solely reserved for greywater. The roof can also be able to collect rainwater on rainy days, which can pass through an aggregate filter to end up in the greywater container. This greywater container would need to be connected to a filtration system consisting of several stage filters to convert collected water into clean usable water. This water would not be potable, but can be used for dishwashing, cleaning, showering, etc. A separate potable water tank can be provided that contains more filters to provide clean potable water. Storage for bathroom supplies can also be provided. Hot water is a necessity, so a propane on-demand hot water heater can be installed between the bathroom and kitchen to provide both areas with hot water.

Energy use will likely be higher than the other scenarios; therefore a large capacity solar power system is recommended. The solar panels can also act as a rainwater collector if combined with gutters running into a collection container. Deep cycle batteries should be used for overnight energy storage, but it is important to research what kind of battery types are best to

use and how many are needed to supply enough energy for the RV to function appropriately. The amount of power needed depends on the average load applied by the equipment and lights being used in the RV. A generous over-estimate is also suggested for the use of unexpected devices and appliances.

A roof mounted HVAC system can be easily installed if the RV has a roof vent. There are several types of RVs and most have an area for HVAC system installation. If an RV is equipped with HVAC, a technician should inspect it to see if the unit is functioning properly and efficiently. It is likely that it will need to be replaced by a modern unit that is more energy efficient. If the windows are replaced, they can be replaced with operable windows to allow fresh air to enter into the RV. During winter months, the RV should be oriented towards the south to be able to gather the most direct sunlight into the space to warm the interior. In the summer months, it is suggested to orient the RV away from the sun or near large obstacles that block direct light to lessen the heat gain into the RV. An operable awning can be installed to block direct sunlight and also create an outdoor space for gathering. The awning can also be used to gather rainwater into a proper container.

In order to be mobile, the user will need some sort of vehicle that is either towing a pull-behind trailer or that is integrated with the RV. If the engine on the vehicle is a diesel engine, it is possible that it can be converted into one that accepts biodiesel or vegetable oil as fuel. Biodiesel and SVO are sustainable options to gasoline-powered engines. SVO can be obtained from restaurants or other places that use vegetable oil and most places will likely donate it since they have to pay to properly dispose of it (Detchon, 2014).

3.3.7.2 Systems under Scenario #2

Scenario #2 uses a smaller budget therefore cannot have as many amenities as the first scenario. The toilet used in this scenario can be a chemical toilet, which is easy to maintain and inexpensive to buy. Chemical toilets use minimal amounts of water and the waste material can be disposed of easily. A filtration system can be put into place in scenario #2, just not as intricate a one as from scenario #1. It can still filter water, but not potable water. This water can be used for washing dishes and cleaning around the house. It can be a form of clean greywater, but not potable water. Hot water in the kitchen and bathroom is needed and a small, propane powered, on-demand, hot water heater can be installed to provide the user with hot water.

Electricity will be used in scenario #2, so a small solar power setup can be installed on the roof of the RV to provide enough power for the few appliances in the RV. Since this is a smaller setup, only a few deep cycle batteries need to be used. Propane gas can be used for heating and a small propane gas heater can be installed for cold winter months. During the warmer summer months, operable windows can be used to provide the RV with ventilation. An air conditioner is not necessary, but it can be helpful if the user is uncomfortable during the summer. To lessen the impact of the summer sun, an operable awning can be installed and oriented towards the south during the day. During the winter months, as previously mentioned, the RV should be oriented towards direct sunlight without any obstructions.

A diesel engine is not necessary in this scenario, but if one can be obtained, it is suggested that biodiesel be used. Diesel engines are more efficient than gasoline engines and can be converted to use only vegetable oil. Vegetable oil engines virtually run with no cost to the user, providing greater ecosavings compared to regular gasoline engines.

3.3.7.3 Systems under Scenario #3

The final scenario also has a limited budget, and therefore cannot have as many gadgets as the other scenarios. A chemical toilet can still be used because it is inexpensive and easy to maintain. Scenario #3 cannot afford a water filtration system; therefore the RV will have to be connected to a potable water source and care needs to be taken to conserve water. Since this scenario does not have a water filtration system, wastewater will need to be properly disposed of.

Solar power can still be used to power a few appliances. A small solar power setup can be inexpensive and if properly preserved, can provide power for a few days. Propane gas should be used for heating water using a small on demand water heater. The propane gas can also provide energy for a small heater during the winter as well. During summer, air conditioning is not necessary if the RV has operable windows. If not, a small box fan can be used to bring fresh air from an open door. The same concept of orienting the RV towards or away from the sun to take advantage of solar gain should be applied here as well.

Since the budget is limited in the scenario, it is not expected to convert the RV engine or pull vehicle to biodiesel or vegetable oil. However, biodiesel can be used with any diesel engine, hence; if a diesel engine is obtained, then biodiesel should be used with that vehicle.

SYSTEMS	$$$ Budget	$$ Budget	$ Budget
Electric	Large Capacity Solar	Solar Power	Solar/Site Hookup
Human Waste	Incinerating Toilet	Chemical Toilet	Chemical/Site Hookup
Potable Water	Multi-Stage Filter	Stored/Site hookup	Stored/Site Hookup
Greywater	Collect and Filter	Collection Only	Collection only
Water Heater	Hydronic Heating	On-Demand	Small On-Demand
HVAC	Roof-Mounted HVAC	Portable AC	Operable Windows
Biodiesel	Straight Vegetable Oil	Biodiesel	NONE

Table 5: Systems

3.4 Guidelines Brochure

Environmentally Responsible Nomads:

A guideline for the renovation of a recreational vehicle using sustainable principles

Introduction

The goal of this document is to provide a set of design guidelines to direct the renovation process of a recreational vehicle in a way that the vehicle is in harmony with its ephemeral environment. The guidelines include material suggestions, insulation properties, passive solar techniques, heating and cooling, electronic appliances and devices, water and waste management, and photovoltaic energy options. They also provide design principles, used in interior design, that deal with issues of space management and multi-use of furniture.

Choose an RV

Class A – Motorhome: A Class A motorhome will usually have the same shape as a large bus and is the most spacious of motorhomes.

Class C – Mini Motorhome: A Class C motorhome is slightly smaller than the Class A bodies with a distinctive overhang bunk over the driver compartment.

Class B – Van Camper: A Class B camper is a smaller motorhome that resembles a large van with a higher roof.

Conventional Travel Trailer: The conventional travel trailer is one of the most common RVs that can be towed by any vehicle with a hitch.

Fifth Wheel Travel Trailer: This style of travel trailer needs to be towed by a pick-up truck with a special fifth wheel hitch in the bed of the truck.

Pop-up trailer: Pop-up trailers are a smaller version of the conventional travel trailer. They are designed to be lightweight and easy to transport.

Truck camper: This style of camper is fully sustained by the pickup truck used to transport it. It does not feature an extra axle so size is limited to the pickup truck bed.

Illustrations from www.rv-coach.com

Inspect the RV

No matter how the RV is obtained, it needs to be inspected and checked through the entire body to find what needs to be fixed and if the fixes can be afforded. Buying an RV is similar to buying a car or a house. Consider that an average person can inspect simple cosmetic problems, but a qualified technician can look at mechanized items, such as brakes, engines, axle, and the condition of gas and water pipes.

Set Sustainable Design Goals

There are many third party certifications for sustainable products that one cannot trust solely on their claims of being "green." Some of the time, these eco-labels apply to certain aspects of the product, such as the material or manufacturing process. It is important to research multiple options when sourcing a sustainable material. In-depth research must be done before a material can be considered sustainable. This is usually done through an environmental life-cycle assessment chart. According to the IDSA's Okala guide (2013), the sustainable design goals include:

-To make ecological design easy to teach and understand
-To increase the understanding of the significance of design in the global ecological crisis
-To impart a thorough understanding of ecological impacts and methods to evaluate the ecological performance of any product
-To prepare designers with an ability to integrate ecological design strategies with strategic business and market planning
-To inspire design professionals to use this inclusive design process

Materials for flooring, interior finishes, lighting, insulation, doors, windows, furniture, and appliances are suggested by following the environmental life-cycle assessment chart by the Industrial Design Society of America.

Choose Materials and Systems Considering Environmental Life Assessment

Materials- The raw materials that make up a product should be renewable or sustainably harvested.

Manufacturing- Find a product with the least impact on the environment.

Location- The proximity of the product's raw materials origin and production is important.

Installation- Look for products and contractors that focus on occupant health during installation.

Maintenance- Avoid products that must be cleaned or repaired frequently with harmful chemicals or energy-intensive practices

End of life- Reusing the material is the option with the least environmental impact.

IDSA's Okala guide (2013) - Life Cycle Wheel

Design Systems

Budget plays an important part in the design considerations within the "Systems" category. Water, waste, electrical, and HVAC are essential to some, but optional to others. As budget allows, include sustainable elements to lessen the environmental impact.

Water and Waste System: Most RV units have a waste tank where human wasterwater is stored for proper disposal at a diclosed location, usually within an RV park. If possible, wastewater should be kept separate from potable water.

Electrical System: Recreational vehicles normally come with two electrical systems, a 12-volt DC system that runs electrical for the engine, and a 120-volt system that powers appliances and other components within the RV. Figure out the size of the power system by taking an inventory of the electrical components in the RV and their corresponding power consumptions. If possible, consider using solar charging technology and LED lights.

HVAC System: Most RVs come with equipment that is inefficient and outdated. Consider replacing it with a more efficient system such as 'evaporative cooling.' Proper insulation is very important. Consider adding a plastic cover and using thick curtains on windows. Replacing the seal around the door can reduce air leaks and drafts.

Design Functional Spaces

Designing a small space takes extraordinary organizational skills and an eye for detail. The design has to account for multiple scenarios of travel and weather conditions. Essentials should have higher priority than non-essentials, so the primary user should evaluate what is an essential item and what is not. For designing the functional spaces, it is suggested to divide the interior into relevant sections.

As reference, this thesis uses manufacturing practices outlined by the CFR: Code of Federal Regulations part 3280 – Manufactured Home Construction and Safety Standards. This section of the CFR details design standards ranges from sizes of electrical conduit to size requirements of an acceptable occupied room. Since recreational vehicles are not classified as permanent homes, they do not have to comply with residential building codes.

For an RV to be legally allowed on the road, or for living full time, the user must comply with certain construction guidelines including earthquake and wind loads, adequate moisture barriers, air circulation, material choices, front and rear visibility, sewage, water circulation, electrical systems, and many more safety standards defined by the Code of Federal Regulations for motor vehicles.

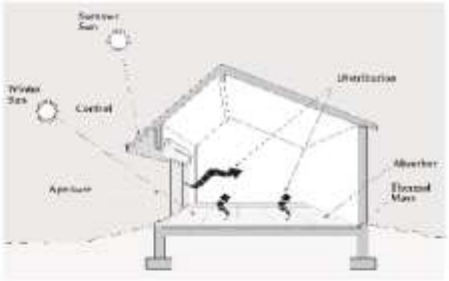
Passive Solar Techniques

Winter

Orientation - Long East/West to allow southern sun exposure
South Facing Windows - To allow sunlight inside as heat
Thermal Mass - To absorb, store, and distribute heat
Insulation - Proper insulation minimizes interior heat loss

Summer

Orientation - Elongated East/West to block southern sun exposure
Shading - Proper window overhangs to block direct sunlight
Ventilation - Operable windows allow for air circulation
Insulation - Proper insulation minimizes interior heat gain



Passive Solar Techniques (source: wikipedia)

Consider Available Budget:

$$$ Budget: Full-time living situation with a large budget for off-the-grid equipment.

$$ Budget: Full-time living situation with a partial budget for off-the-grid equipment.

$ Budget: Part-time living situation with a low budget for off-the-grid equipment.

STRUCTURE	$$$ Budget	$$ Budget	$ Budget
Insulation	Foam Insulation	Organic Insulation	Existing Insulation
Subfloor	Organic Plywood	Salvaged Plywood	Existing Subfloor
Flooring	Bamboo	Cork	Reclaimed Wood
Walls	Organic Plywood	Organic Plywood	Salvaged Plywood
Windows	Argon / Double Paned	Double Paned	Single Paned
Lighting	LED	CFL Bulbs	Fluorescent Bulbs
Finishes	American Clay	American Clay	Low VOC Paint

BATHROOM	$$$ Budget	$$ Budget	$ Budget
Floor	Cork	Cork	Linoleum
Walls	Recycled Glass Tile	Recycled Glass Tile	Linoleum
Toilet	Incinerating Toilet	Chemical Toilet	Chemical Toilet
Shower	Low Flow Shower	Low Flow Shower	Low Flow Shower
Sink	Low Flow	Low Flow Stainless Steel	Existing or Salvaged

KITCHEN	$$$ Budget	$$ Budget	$ Budget
Floor	Cork	Cork	Existing / Linoleum
Sink	Stainless Steel	Stainless Steel	Existing / Salvaged
Appliances	High End Energy Star	Energy Star	Energy Star
Countertops	Paper Composite	Stainless Steel	Aluminum / Reclaimed

BEDROOM	$$$ Budget	$$ Budget	$ Budget
Floor	Interface Carpet	Interface Carpet	Existing
Multiuse Furniture	Adjustable Table to bed	Adjustable Table to bed	Adjustable Table to bed
Bedding	Enviro-Fiber Foam	Enviro-Fiber Foam	Enviro-Fiber Foam
Upholstery	Organic Cotton	Organic Cotton	Hemp
Heating	Radiant Heating	Catalytic Heater	Space Heater

SYSTEMS	$$$ Budget	$$ Budget	$ Budget
Electric	Large Capacity Solar	Solar Power	Solar/Site Hookup
Human Waste	Incinerating Toilet	Chemical Toilet	Chemical/Site Hookup
Potable Water	Multi-Stage Filter	Stored/Site hookup	Stored/Site Hookup
Greywater	Collect and Filter	Collection Only	Collection only
Water Heater	Hydronic Heating	On-Demand	Small On-Demand
HVAC	Roof-Mounted HVAC	Portable AC	Operable Windows
Biodiesel	Straight Vegetable Oil	Biodiesel	NONE

Chapter 4: Design Demonstration (Implementing Design)

In this chapter, the implementation of the design considerations is demonstrated assuming the characteristics of Scenario #3, a part-time living situation with a limited budget.

4.1 Choosing an RV

A twenty-one foot 1967 Airstream Safari is available for the project. This airstream RV is a pull behind conventional travel trailer. The trailer is used as a case study to demonstrate the concepts and techniques that are outlined in this thesis. The case study is a hypothetical design for a user who will use this trailer for part-time living and has a limited budget. A photo of the trailer is shown in Figure 23.

Figure 23: The 1967 Airstream Safari

4.1.1 Inspecting the RV

The selected Airstream was inspected and determined that it needed many repairs. There was no water or waste management system in place since the last tenant had previously removed it. There was no existing furniture or kitchen counters to reuse. The only furniture that was left inside was an antique rotting chest of drawers and a homemade worktable. The tires were old

and oblong shaped because of long-term storage, the interior walls were filthy from years of built-up grime, the floor had many weak spots, several windows were missing, some cabinets were being held together by duct tape, and many other problems existed that were going to have to be fixed or repaired.

Figure 24: Original Airstream Interior

4.1.2 Cleaning and Repair

The cleaning began by clearing the clutter from the interior of the airstream to get a sense of the scope of work that needed to be completed. There were a few pieces of furniture that had to be removed. It should be noted that if there is anything inside the RV that can be reused, it should be reused. Sustainability is not about gadgetry or green trends, it is about reducing the carbon impact through actions. Older furniture was usually made from high quality wood chosen to last a long time. Odds are that older furniture, even in bad condition, can be used as something else. Drawers from the chest pictured above can be installed under a countertop to make interesting kitchen storage. A set of rollers purchased from a nearby hardware store is inexpensive and relatively easy to install.

After sweeping and removing all loose items and trash, the built-in pieces that had been constructed by the previous tenant were carefully dismantled. The dismantling was done because some of the wood was very likely going to be reused for future projects. Conveniently, there was some storage space where the renovations were to be completed.

Figure 25: Gutted Airstream Interior

The next step was to clean the walls. The interior walls seemed like they had never been cleaned. Some areas had a thick buildup of grease and grime that needed some heavy cleaning. Unfortunately, most home cleaning solutions include harmful chemicals that contribute to air pollution and are sometimes deadly if ingested or combined. It is important to recall here that the most toxic cleaners are corrosive drain cleaners, toilet bowl cleaners, and degreasers. Chemicals included in these cleaners can cause immediate burns on skin, eyes, and if swallowed, the throat and stomach. Cleaners that include bleach and ammonia are highly toxic when used at the same time. Chlorine bleach used with ammonia can cause chloramine gas that is severely

harmful to the lungs. Combining chlorine bleach with certain acids typically found in toilet bowl cleaners creates chlorine gas, a poisonous gas first used in World War I by the Germans.

A few different natural homemade cleaning solutions were tested on different areas of the walls. Mixtures of lemon juice, baking soda, hydrogen peroxide, and vinegar were tested to see which would work the best. Figure 26 shows three solutions used to test which cleaning compound was going to be chosen to clean the interior walls of the airstream.

Figure 26: Interior Cleaning Tests

The first image on the left was created using only lemon juice. The middle image shows the results of a paste made of hydrogen peroxide and baking soda. The image to the right used baking soda mixed with lemon. As can be seen, the mixture using hydrogen peroxide worked the best on the stains on the inside of the Airstream. Cleaning the walls took several hours of hard scrubbing. During the cleaning, there was no chemical smell or abrasive chemical burning on the hands. The sole purpose for the box fan was to remove the hot air from the inside of a metal container in a southern summer day.

During the initial inspection, it was determined that a few areas of the subfloor needed to be replaced because of mold build-up and water rot from previous installs. Since this Airstream

is from the 1970s, it is important to note that asbestos, a highly toxic mineral fiber used in floor backing, may have been used. Asbestos is highly toxic and should be removed by a professional. The PVC floor was carefully removed to inspect the subfloor material for any other signs of rot or distress. The areas where water and moisture were prevalent were mostly affected. The portions of subfloor that needed to be repaired were replaced with existing plywood from a table that was previously built in the airstream. To prevent future moisture buildup in areas where water was constantly present, the floor material choice would need to be waterproof and breathable. Due to its strength and waterproof nature, cork was chosen for the kitchen and bathroom floors. The floor on the bedroom area needed to be comfortable and warm. Interface carpet tiles were the perfect solution to this problem because of their sustainable principles and their connection to Auburn University design schools. Through this connection, carpet tile samples were abundantly available for educational purposes.

Figure 27: Cleaning Interior Walls

The interior walls of the airstream were in good condition. Replacing airstream walls is a difficult process because they are curved and riveted in place. If they need to be replaced, follow manufacturer instructions and purchase a well-made riveting gun.

4.2 Designing Functional Spaces

Designing a small space takes extraordinary organizational skills and an eye for detail. The design has to account for multiple scenarios of travel and weather conditions. Essentials should have higher priority than non-essentials, so the primary user should evaluate what is an essential item and what is not.

STRUCTURE	$$$ Budget	$$ Budget	$ Budget
Insulation	Foam Insulation	Organic Insulation	**Existing Insulation**
Subfloor	Organic Plywood	Salvaged Plywood	**Existing Subfloor**
Flooring	Bamboo	**Cork**	Reclaimed Wood
Walls	Organic Plywood	Organic Plywood	**Salvaged Plywood**
Windows	Argon / Double Paned	Double Paned	**Single Paned**
Lighting	**LED**	CFL Bulbs	Fluorescent Bulbs
Finishes	American Clay	**American Clay**	Low VOC Paint

Table 6: Structure – Applied Guidelines

For designing the functional spaces, it is suggested to divide the interior into relevant sections. The airstream used for this case study has an open floor plan, giving complete control over the layout. The open area is divided into three relevant sections: bathroom, kitchen, and bedroom. In each of these spaces, a list of essential items is made to organize the spaces.

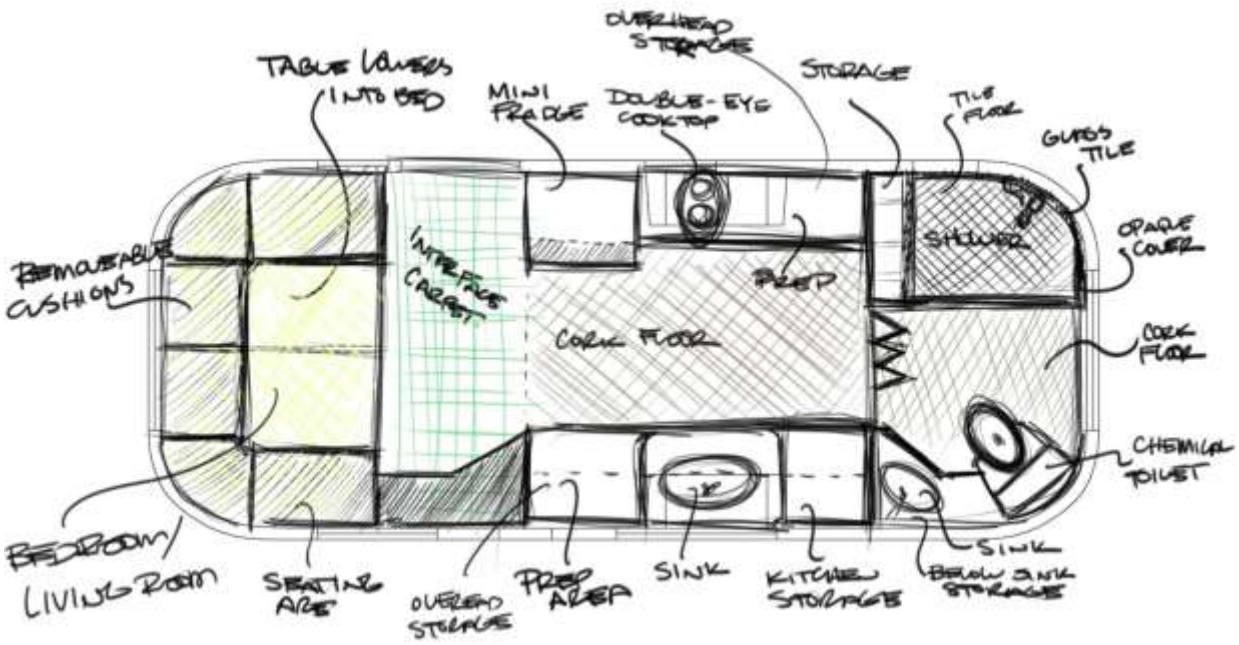


Figure 28: Preliminary Sketch Plan

4.2.1 Section 1: Bathroom

The interior skin of the bathroom needed to be waterproofed since there will be sizable amount of splashing water around the space. Cork was chosen for the floor material because it is warm and naturally water resistant. The interior wall material was a linoleum laminate that was originally used as a waterproofing membrane in the bathroom. Recycled glass tile was used to create a warm, elegant feel to the bathroom while also providing a clean, waterproofed interior envelope.

The bathroom area needed several essential items to be designed such as shower, toilet, sink, and space for storage. Since this Airstream was not going to operate as a permanent dwelling, products were selected for temporary use. A compostable toilet needs constant use to work properly and the waste cannot be used as compost for approximately a year after the last human waste was dropped into the mix. Chemical and incinerating toilets are the best solution

for temporary situations. An incinerating toilet is much more efficient and easier to manage than a chemical toilet, making it the best choice. Unfortunately, due to the high cost of incinerating toilets, one cannot be used in this situation. A less expensive option is a chemical toilet. Chemical toilets will need more maintenance and planning, but are a better choice nonetheless.

The chemical toilet will need to use sustainable formaldehyde-free chemical solutions that are easy to use and discard. A chemical toilet is easy to use; two separate holding tanks need to be filled with a mixture of water and a special chemical that breaks down waste matter. There are companies that sell special sustainable chemical toilet solutions that do not contain formaldehyde or other harsh chemicals. After the chemical toilet has been filled, then normal usage can follow. It is important to note that a specific chemical toilet paper must be used. Depending on the use, the chemical toilet should not need to be emptied for a couple of days at a time. When full, the chemical toilet needs to be emptied in an appropriate waste site. See the instructions included in the chemical toilet and the solution used for correct dumping instructions.

The sink and shower needed two important elements: water in and water out. Water can be drained into a greywater container to use for flushing the toilet. Before it is used for flushing, the water should be lightly filtered to remove aggregates introduced while washing. The actual showerhead acquired was a small, low flow, hand showerhead that approximately uses 1.6 gallons of water per minute. Water for the shower and sink comes from the water pump located in the kitchen area, near the fresh water tank. PVC piping was routed to the bathroom to provide fresh water for the shower and sink. The sink in the bathroom was installed using a faucet with an aerator installed to lower the amount of water passed through without affecting water pressure.

Finally, a stand-alone hot water heater was installed in the kitchen, between the kitchen sink and the bathroom sink, to provide on demand hot water. The on-demand water heater needed to be connected to a propane tank to work properly, so a gas line was installed from the front of the trailer to the rear, where the water heater is located. This on-demand water heater provides hot water when it is needed, rather than storing hot water in a tank. A tank-less water heater is essential to RV travel because it diminishes weight carried.

BATHROOM	$$$ Budget	$$ Budget	$ Budget
Floor	Cork	**Cork**	Linoleum
Walls	Recycled Glass Tile	**Recycled Glass Tile**	Linoleum
Toilet	Incinerating Toilet	Chemical Toilet	**Chemical Toilet**
Shower	Low Flow Shower	Low Flow Shower	**Low Flow Shower**
Sink	Low Flow	**Low Flow Stainless Steel**	Existing or Salvaged

Table 7: Bathroom – Applied Guidelines

4.2.2 Section 2: Kitchen

Household kitchens are usually the soul of the house; integrating social with private, they are an elemental liaison of the home. There are several parameters when designing a kitchen, but capturing the essence of the user is one of the most important elements to consider. The kitchen is a sacred space so that after several meals, a person becomes a part of the kitchen. Knowing where everything is located and stored becomes second nature to the chef. An efficient kitchen is difficult to design in a home, where space is not as limited as in an RV. In such a smaller space, the user is going to have to remove the unnecessary tools that are taken for granted in an everyday kitchen life. Separating themselves from these items will make organizing such a small kitchen much easier.

A list of essential items was created to analyze which items were necessary for living in an RV for three days, one week, one month, and finally, a permanent living situation. It turned out that most essential items for living in an RV were very similar, no matter the allotted time. The only items that changed were the ones that could be replaced by disposables like paper or plastic plates and cups. Main essential appliances such as refrigerator, stovetop, and toaster oven stayed the same. Finding ways to store these items became a challenge. Not only were large appliances being stored, there needed to be storage for small utensils for cooking and eating as well. Fortunately, this was going to be a very minimalist design, with as little adornment and utilities as possible.

The kitchen area was designed with careful consideration for storage and counter space due to the size considerations of the RV. Counter space is necessary for prepping and managing meals. In most traditional kitchens, quartz or granite countertops are desired because of their easy-to-clean nature and strength. Unfortunately, these stone countertops are incredibly heavy, which means they should not be used for an RV kitchen. Stainless steel or aluminum countertops are lightweight and easy to clean. They are also easy to fold and cut to fit into most custom applications. For this implementation, a lightweight countertop was custom made out of fiber reinforced honeycomb panels wrapped in a stainless steel envelope with built-in sink and a lowered double burner induction cooktop. Below the countertop, storage space was created for appliances and supplies. Across from the sink countertop, on the entry side, more counter space was built for prepping and storage. A small set of cabinets were built and installed above the window for additional storage space. All cabinet doors were installed with self-closing and self-locking mechanisms to keep the doors closed during travel. The entry side of the kitchen also houses a small energy star certified refrigerator and built-in toaster oven.

KITCHEN	$$$ Budget	$$ Budget	$ Budget
Floor	Cork	Cork	Existing / Linoleum
Sink	Stainless Steel	Stainless Steel	Existing / Salvaged
Appliances	High End Energy Star	Energy Star	Energy Star
Countertops	Paper Composite	Stainless Steel	Aluminum / Reclaimed

Table 8: Kitchen – Applied Guidelines

4.2.3 Section 3: Living / Bedroom

Upon entering the RV, the user is welcomed with a soft-carpeted floor with the bedroom and dining area to the right and the kitchen directly to the left. The space to the right in the RV is a space that serves two purposes. A custom-built, multi-use piece of furniture takes up most of the space upon entering the RV. This custom-made piece of furniture has two purposes. One is a communal dining table with cushioned seats around it, similar to a restaurant booth with seating on three sides. The table in the center is on an adjustable center stand that can quickly be raised and lowered according to the use it needs to serve. When the table is lowered, a cushion can be placed on the table, flush with the seat cushions, to transform it into a comfortable bed. Underneath the seating area there is storage space to accommodate approximately two people's clothing, shoes, and other essentials.

Multiple materials were used in the construction of this multi-use piece of furniture. The base of the seating area was constructed using reclaimed organic plywood. Internally, there had to be space for storage, therefore, the joints had to be reinforced with brackets to provide stability without using cross bracing. The seating area was constructed with sealed bamboo plywood, granting a smooth surface for easy removal of the cushions. Enviro-Fiber Foam upholstered with organic cotton fabric makes up the cushions for seating and lying on.

BEDROOM	$$$ Budget	$$ Budget	$ Budget
Floor	Interface Carpet	**Interface Carpet**	Existing
Multiuse Furniture	Adjustable Table to bed	Adjustable Table to bed	**Adjustable Table to bed**
Bedding	Enviro-Fiber Foam	Enviro-Fiber Foam	**Enviro-Fiber Foam**
Upholstery	Organic Cotton	**Organic Cotton**	Hemp
Heating	Radiant Heating	Catalytic Heater	**Space Heater**

Table 9: Bedroom – Applied Guidelines

In the middle of the seating area, there is an adjustable table that raises and lowers according to the intended use. Custom-made from aluminum, the table can be raised when needed for dining or working purposes and lowered to provide a bed for the user. A steel telescoping tube, centrally located on the table, allows for the table to move vertically with a hand-tightening knob. When it is lowered, a cushion can be placed on the table, providing a flush surface for sleeping on with plenty of storage located beneath the sleeping area.

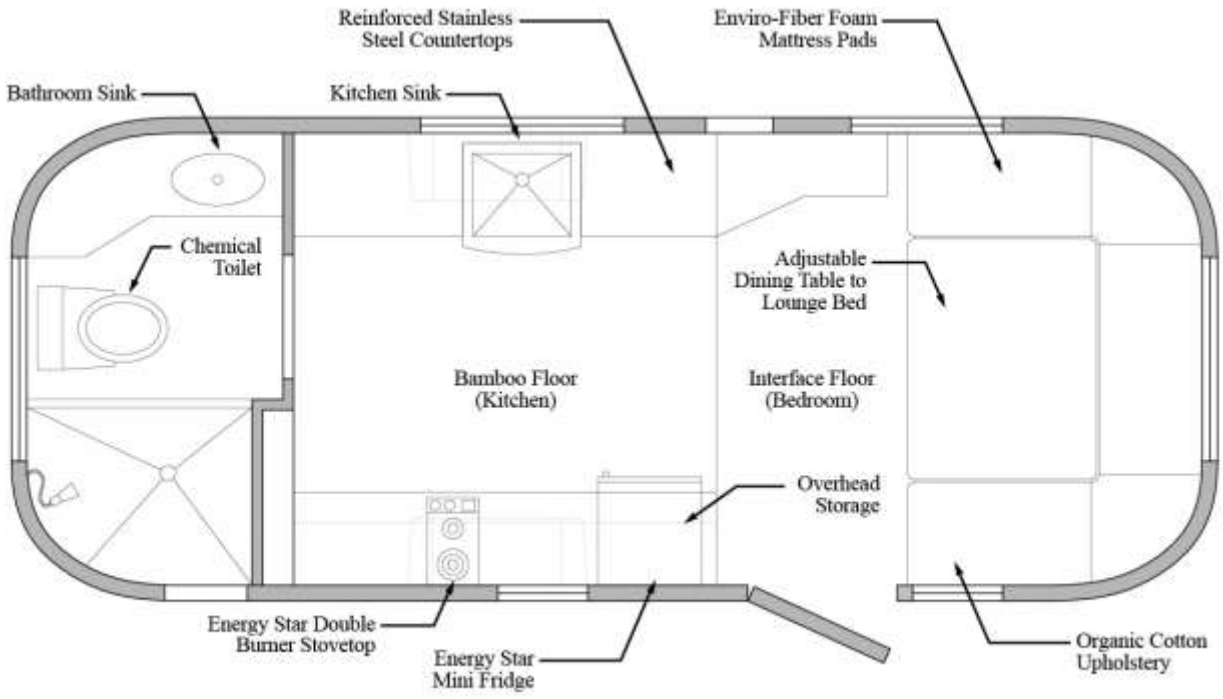


Figure 29: Preliminary Floor Plan

4.3 Systems

The systems used within the RV are selected for a specific intended use of a particular client in accordance to their financial situation. Budget plays a large part in the design considerations within the "systems" category due to the fact that the systems explained in this thesis are expensive because of their complexities. Water, waste, electrical, and HVAC systems are essential to some, but optional to others. The budget allows for the major systems to have a small amount of sustainable elements included within them to lessen the environmental impact.

SYSTEMS	$$$ Budget	$$ Budget	$ Budget
Electric	Large Capacity Solar	Solar Power	**Solar/Site Hookup**
Human Waste	Incinerating Toilet	Chemical Toilet	**Chemical/Site Hookup**
Potable Water	Multi-Stage Filter	Stored/Site hookup	**Stored/Site Hookup**
Greywater	Collect and Filter	Collection Only	**Collection only**
Water Heater	Hydronic Heating	On-Demand	**Small On-Demand**
HVAC	Roof-Mounted HVAC	Portable AC	**Operable Windows**
Biodiesel	Straight Vegetable Oil	Biodiesel	**NONE**

Table 10: Systems – Applied Guidelines

4.3.1 Waste Management and Potable Water System

Waste management is an important element that all RV units come with. Most RV units have a waste tank where human wastewater is stored for proper disposal at a disclosed location, usually within an RV park. Under scenario #3, the RV will not spend much time in an RV park, so the wastewater design needed to be able to be disposable and reusable. Toxic wastewater usually comes from the toilet because human waste quickly grows pathogens that are harmful to humans. Therefore, a chemical toilet was installed in the bathroom of the RV to lessen the amount of wastewater introduced into the system. A small amount of water is needed to flush

the chemical toilet, but the waste is stored within the unit, thus eliminating the need for a black water container. Greywater can be used for the flushing aspect of the chemical toilet.

Wastewater introduced in the bathroom and kitchen come from the sink and shower. This water drains into a greywater container located outside in the rear of the RV. Before the water is drained into the greywater container, a large aggregate filter removes any food particles present in the water. This filter needs to be cleaned often to decrease clogs in the line. The greywater is then filtered through once more to remove residue left in the greywater so that it becomes non-potable water for cleaning and watering. The greywater container can then be emptied into another container with a much more elaborate filter to remove chemicals and bacteria, making the water safe for cleaning, showering, and flushing the chemical toilet. It is important to note that this water is not potable and cannot be consumed. Potable water is stored in an indoor container and will need to be bought or filled from an appropriate water source.

Access to clean potable water is one of the most important privileges people can have. A clean water tank is connected to the kitchen and bathroom sinks in the RV. Water pressure is modified through a small water pump located outside of the potable water tank. The clean water travels through its own PVC pipe path to each sink where a hot and cold faucet is located. Water circulation was slightly altered in the RV to provide three water containers. As mentioned before, an on-demand water heater was installed between the kitchen and bathroom to provide hot water instantly to each source.

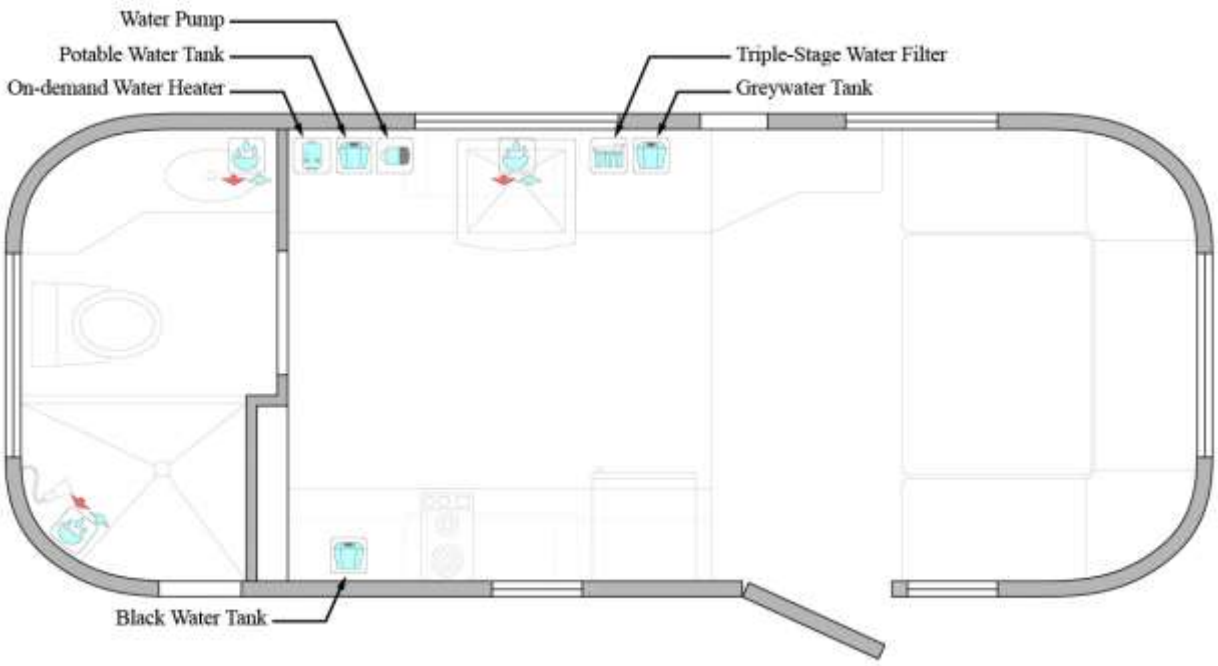


Figure 30: Water Management Plan

4.3.2 Electrical System

Recreational vehicles normally come with two electrical systems, a 12-volt DC system that runs electrical for the engine, and a 120-volt system that powers appliances and other components within the RV. Usually, power for the 120V system is derived from an external source such as a generator or campsite plug-in. The electrical scenario currently being studied allows for both campsite plug-in and solar charging. To figure out the size of the solar powered-system, an inventory is taken of the electrical components in the RV and their corresponding power consumptions. Solar technology has been steadily improving, providing a clean and silent solution for electrical needs. Size constrictions of solar panels vary with the amount of power needed to allow for multiple appliances to be used at the same time.

For an "all-on-all-time" scenario, a total power of 4,389 watts and 6,709 watt-hour energy is needed. However, not all appliances need to be on simultaneously and at all times. A 320W solar charging kit can provide the energy required by the bedroom and restroom sections,

and the water pump, exhaust pump, and the LED lights in the kitchen section. Several retailers sell solar kits that include the equipment necessary for a complete solar power build. Usually included in these kits are solar charging panels, an inverter for AC power, a digital regulator, smart battery charger, cables, and mounting hardware. Upgrades to certain components can be applied to provide the user with a larger wattage for bigger loads. Deep cycle batteries are essential for solar power storage due to their high amp hour capacity. The location of the batteries needs to be near the inverter to avoid high cable costs and voltage drop. In the power inventory posted above, the daily watt-hours used come to approximately 6,000 watt-hours. A deep cycle battery running at 100 amp-hours, which equals about 1200 Watts, will be dead too quickly. Therefore, seven or eight deep cycle batteries must be connected in parallel to provide the approximate daily wattage needed. It is important to reiterate that the calculations provided for power use are approximated and should not be taken literally. Additionally, only a certified professional should provide and install solar components.

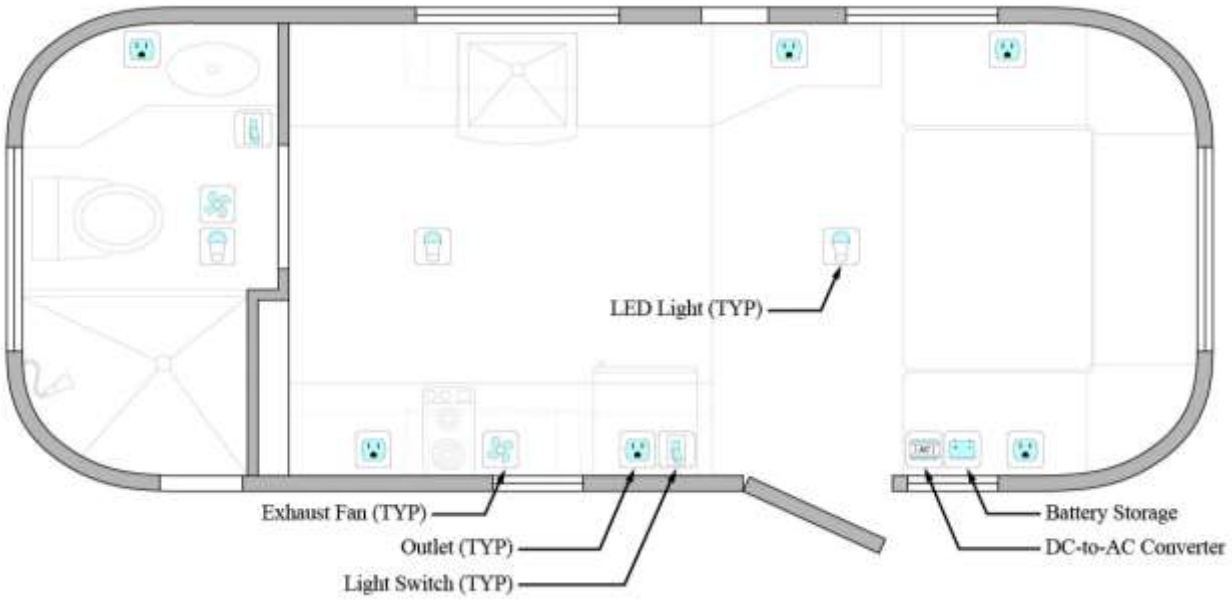


Figure 31: Electrical System

4.3.3 HVAC Systems

Heating and cooling for recreational vehicles has not changed much in the past few decades. Most RVs come with equipment that is inefficient and outdated, HVAC systems that consume high amounts of electricity to cool a space. Since solar power is the primary source of energy to be used in this RV, a high drainage of electricity in hot weather would consume most of the available electricity being produced, thus denying other appliances from working properly. A different approach was researched to understanding efficient heating and cooling systems in small spaces with low wattage consumption. An ancient cooling method called "evaporative cooling" has been shown to be an appropriate process for efficient cooling.

4.3.3.1 Cooling

An evaporative cooling system was decided to be implemented for the RV's HVAC system. Evaporative cooling differs from the standard refrigeration cycle used by most air conditioning devices by using water as the cooling medium. Typical air conditioning works by using a compressor to pump refrigerant gas to high pressure and temperature where it enters a condenser that uses a simple thermodynamics concept of heat exchange to remove the heat from the refrigerant, returning it to a liquid. The refrigerant is then pumped to an evaporating coil, where it returns to a gas state, absorbing heat along the way and cooling the surrounding air. This method uses a large amount of energy to complete the heat exchange, which is not an ideal scenario. On the other hand, evaporative cooling is a method that was developed in ancient times to cool residences by using wind chimneys that brought hot air through underground cooled water and discharged cool air into the building (Meisel, 2010). Throughout the years, the concept has not changed, though the equipment has evolved to allow it to be a portable device.

Evaporative cooling systems work by introducing hot, dry air from the exterior and misting it with water from a spray pump onto a filter. As the air is forced through the filter, the water evaporates, which cools the air coming out of the cooler. The air cannot be restricted within the space, or else the cooling effect will be less. The advantage of using this cooling method is not only measured in cooling effectiveness, but also in sustainability since it does not use refrigerants that are toxic to the ozone. Along with most products, there are some drawbacks to using evaporative cooling methods. For example, a constant amount of water is necessary to run the device and locations with high humidity reduce the effectiveness of the evaporation process. A chart (See Fig. 32) is provided showing the efficiency chart of an evaporative cooler (On the Move, 2014). It is also important to properly maintain the device by cleaning or replacing the filters when necessary. The air that enters the space is also relatively high in humidity; therefore a dehumidifier may be beneficial to the indoor air quality.

Efficiency Chart

Expected Cooler Efficiency Temperature Output *Fahrenheit*

Outside Air Temperature F	% Relative Humidity																
	2	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80
125	83	86	90	93	96												
120	81	83	86	90	93	95											
115	78	80	83	86	89	91	94										
110	75	77	80	83	85	87	90	92									
105	72	74	77	79	81	84	86	88	89								
100	69	71	73	76	78	80	82	83	85	87	88						
95	67	68	70	72	74	76	78	79	81	82	84	85	87				
90	64	65	67	69	70	72	74	76	77	78	79	81	82	83	84	86	
85	61	62	63	65	67	68	70	71	72	73	74	75	76	77	79	81	
80	57	58	60	62	63	64	66	67	68	69	71	72	73	74	76	76	77
75	54	55	57	58	59	61	62	63	64	65	66	67	68	69	70	71	72

Figure 32: Efficiency Chart (On the Move, 2014)

4.3.3.2 Heating

Winterizing an RV is a major improvement during the winter that can save money and resources. There are several things that the user can do and make so that the winter is comfortable and the RV more efficient to heat. Insulation is important, but if the budget does not allow for a complete insulation replacement, then there are other projects that can be done to increase insulation properties of windows, doors, and floor of the RV. Adding a plastic cover to the windows is an inexpensive way to insulate without having to change to double pane windows. Also adding a thick curtain material such as polar fleece can drastically reduce drafts. Replacing the seal around the door can also reduce the means of which heat escapes the RV. A more involved manner of insulating the RV is by constructing trailer skirts that wrap around the base of the RV. This project greatly reduces heat loss through the floor by reducing draft underneath the trailer. One manner of accomplishing this is by constructing a wooden strip that is custom fit to the base of the trailer to block wind from passing through underneath and creating an envelope that can hold heat inside. Ideally, the trailer skirt should be buried in a trench cut around the base of the trailer, but is not practical if it is constantly moving. An example of this wooden trailer skirt is shown in figure 33. Finally, another easy DIY project is to make foam inserts for opening such as vents and unused windows. Using foams previously mentioned, one can make inserts that use hook and look to fasten into place and create an insulated barrier. Properly winterizing the RV can save money and resources during critical winter times (Winterizing, 2015).

Figure 33: Trailer Skirt

Heating practices can vary depending on the location of the RV. Understanding passive solar practices can lessen the daytime use of the heating device that is chosen for the project. Passive solar design refers to the use of walls, floors, and windows to collect and store energy from the sun to provide heating to an enclosed space. The use of natural ventilation and heating has played an integral part in human survival through several millennia. Unfortunately, as reliability in technology increased, dependence on nature decreased. Recently, people have adapted technologies that work together with nature to provide energy, heating, cooling, insulation, materials, and much more. Using natural sunlight to heat a space is not a new concept. Solar practices had been utilized since the beginning of humanity for warmth and that concept is also used in architectural designs. Simple ideas such as using thermal mass, sun-facing windows and thermal chimneys have greatly reduced operating costs in homes as well as larger commercial buildings. Incorporating these practices into an RV is easily done. In order to accomplish this, an understanding on the site where the RV will be parked is necessary. The RV should be positioned in an east/west position with the largest window area facing south to capture as much winter sun as possible. It is best to avoid objects, such as trees, that can block the sun during the day. Thermal mass, another common option, is used in larger buildings to store heat and slowly releasing it through the night. Thermal mass consists of materials such as masonry, concrete, brick, stone, or water filled containers. Including materials such as these in this project would add too much weight for an RV to handle; thus, the concept is not appropriate for this scenario. There are also several DIY projects that can be found on the Internet such as window mounted solar heater boxes and solar water heaters. As a last resort, a compact ceramic space heater can be purchased at many hardware stores, although it will use a considerable amount of electricity in the RV (Meisel, 2010).

4.4 3D Model/Prototype

To demonstrate the implementation of the design, a 3D computer model of the RV is created using the software Rhino and V-Ray for view renderings. Figure 34 shows an external view of the RV. Figures 35-37 shows the floor plan along with section views showing some important dimensions. These dimensions are important to note because they need to follow architectural standards provided by The American Institute of Architects (2007), a book detailing acceptable materials, practices, sizes, and many other architectural details to properly construct buildings to be occupied by people. Figures 38 and 39 illustrate the interior of the RV. Figures 40 and 41 show the adjustable bed/table. Figures 42 and 43 depict the kitchen area showing the black water tank storage and the countertops. The views of the dining/bedroom area are shown in figures 44 and 45. The bathroom area is shown in figure 46. The interior views also call out vital locations where essential equipment is stored, such as water filtration system or solar power batteries.

A physical model was also used to demonstrate scale and the use of space. The physical model was constructed using laser cutting and 3d printing technologies available at Auburn University. The physical model is a 1”=1’-0” scale representation of the actual RV and shows the relative scale and sizes of the equipment and furniture used within the RV. Figures 47 and 48 show pictures of a lateral view and a top view of the physical model.

Figure 34: External view of the RV

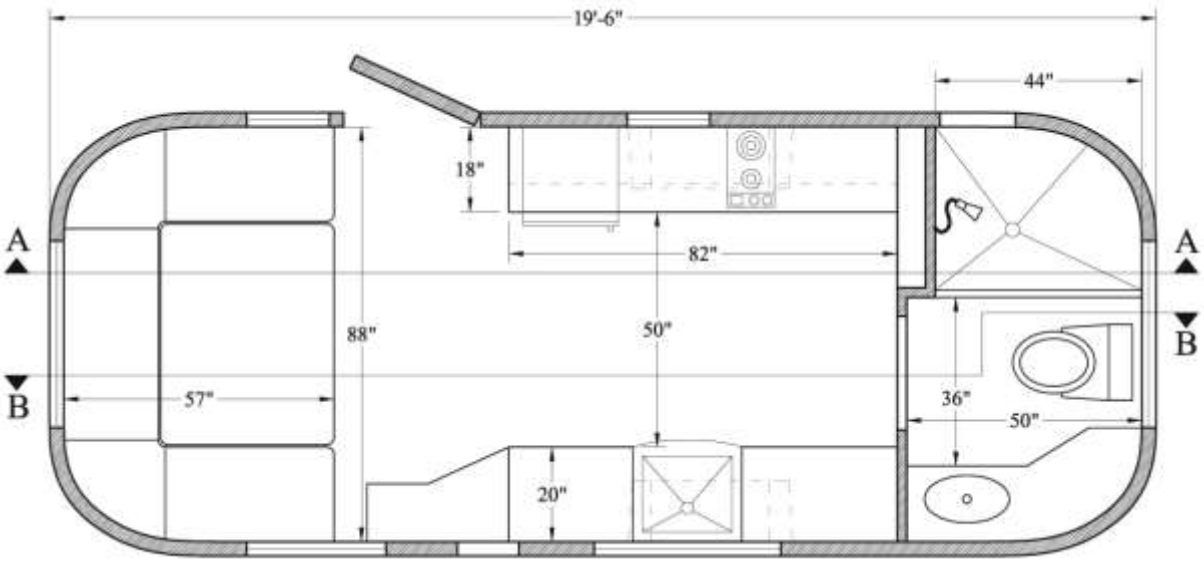


Figure 35: Floor Plan of the RV

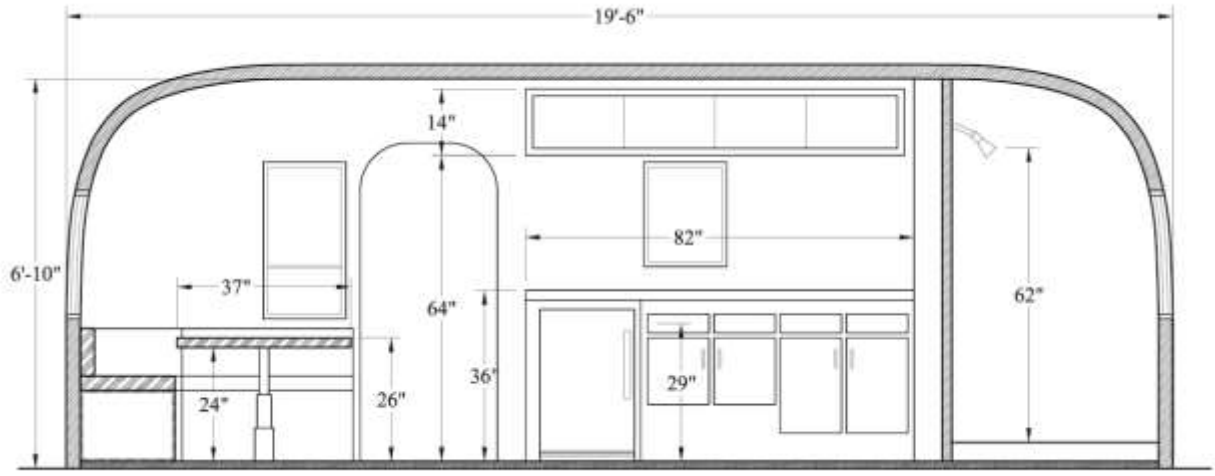


Figure 36: Section A-A of the RV

The sections pictured above and below show both longitudinal sides of the interior of the RV. The dimensions called out are to display understanding of important sizes in relation to the user. Standard reaching, sitting, and table heights are important to follow and can be found by looking through the Architectural Graphics Standards, by The American Institute of Architects (2007).

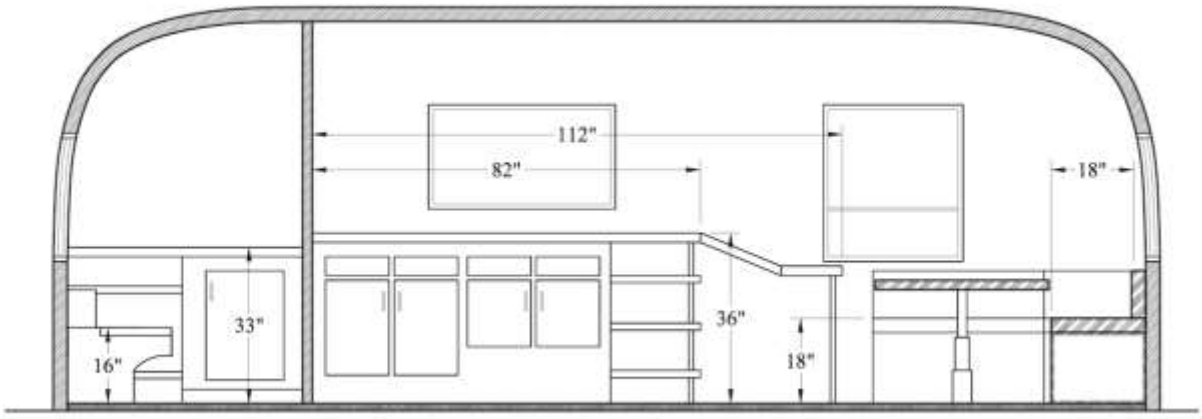


Figure 37: Section B-B of the RV

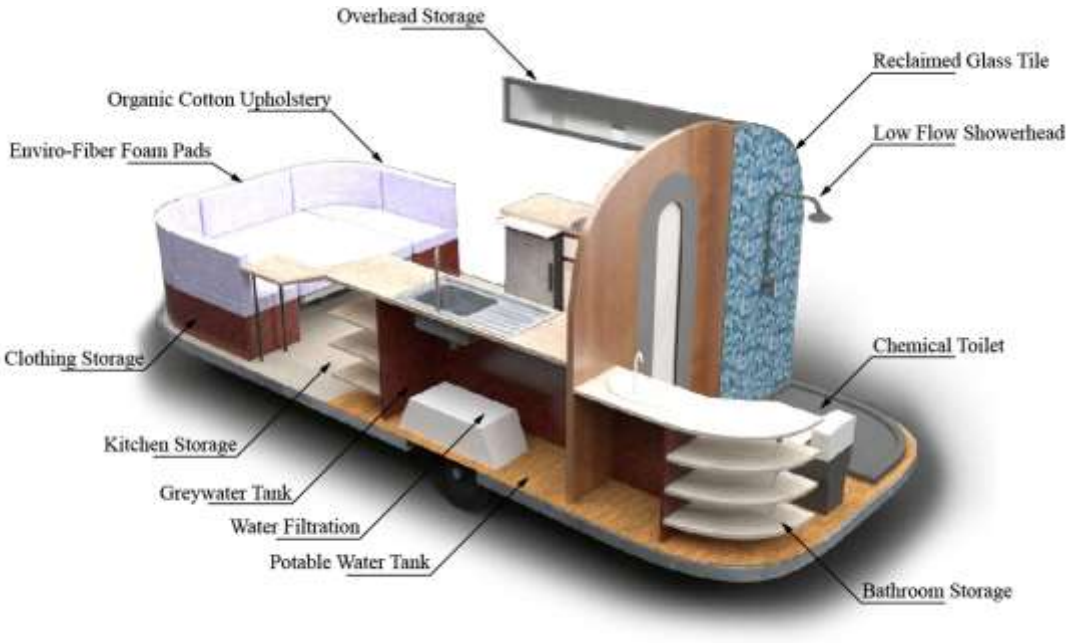


Figure 38: Interior of the RV (front view)

Figure 39: Interior of the RV (back view)

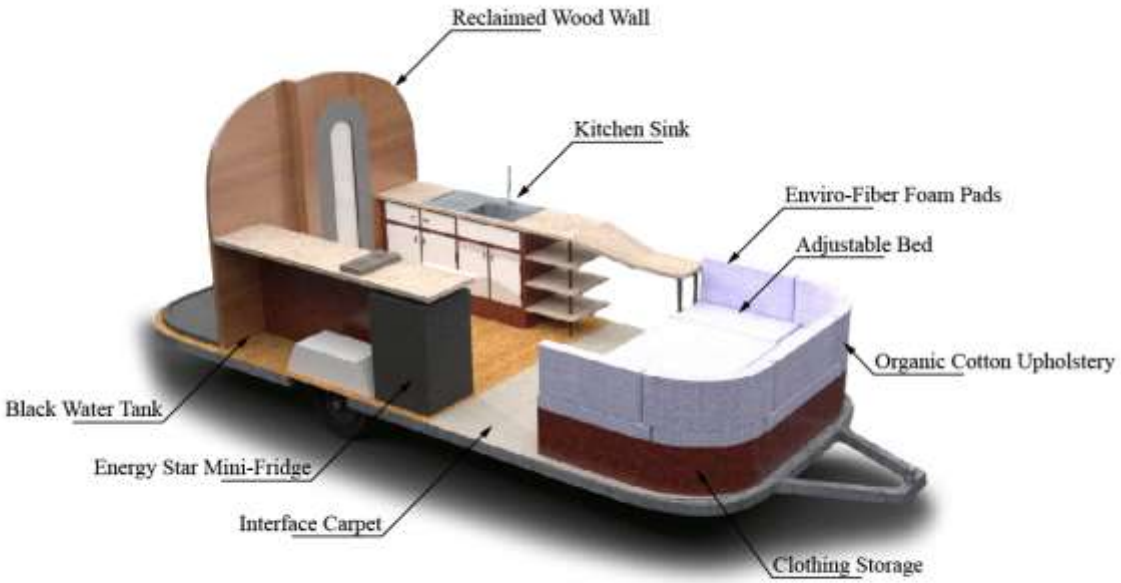


Figure 40: Adjustable Bed/Table (bed view)

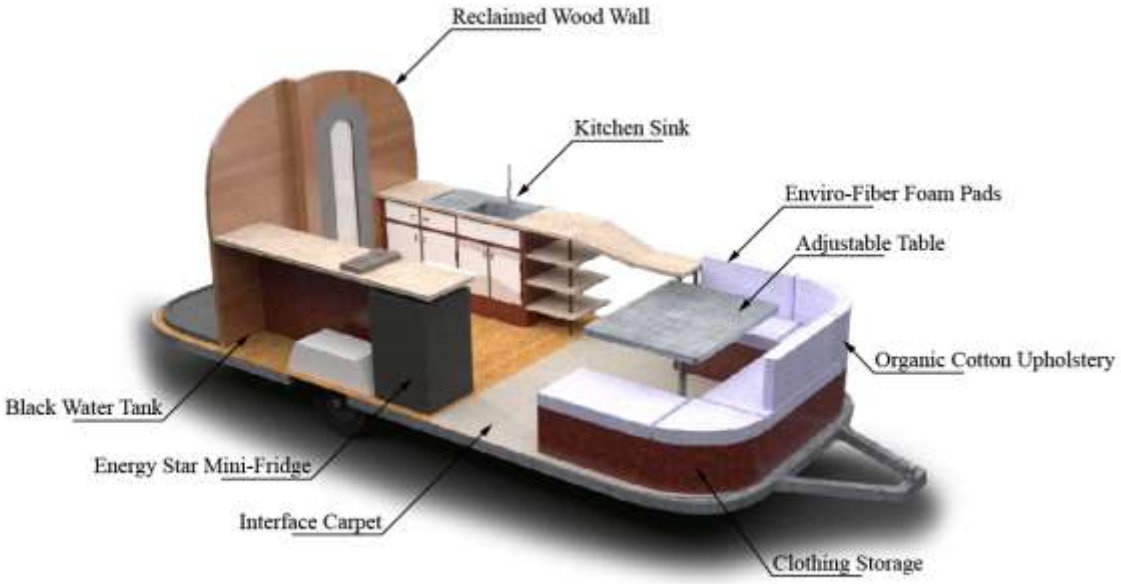


Figure 41: Adjustable Bed/Table (Table view)

Figure 42: View of the kitchen area

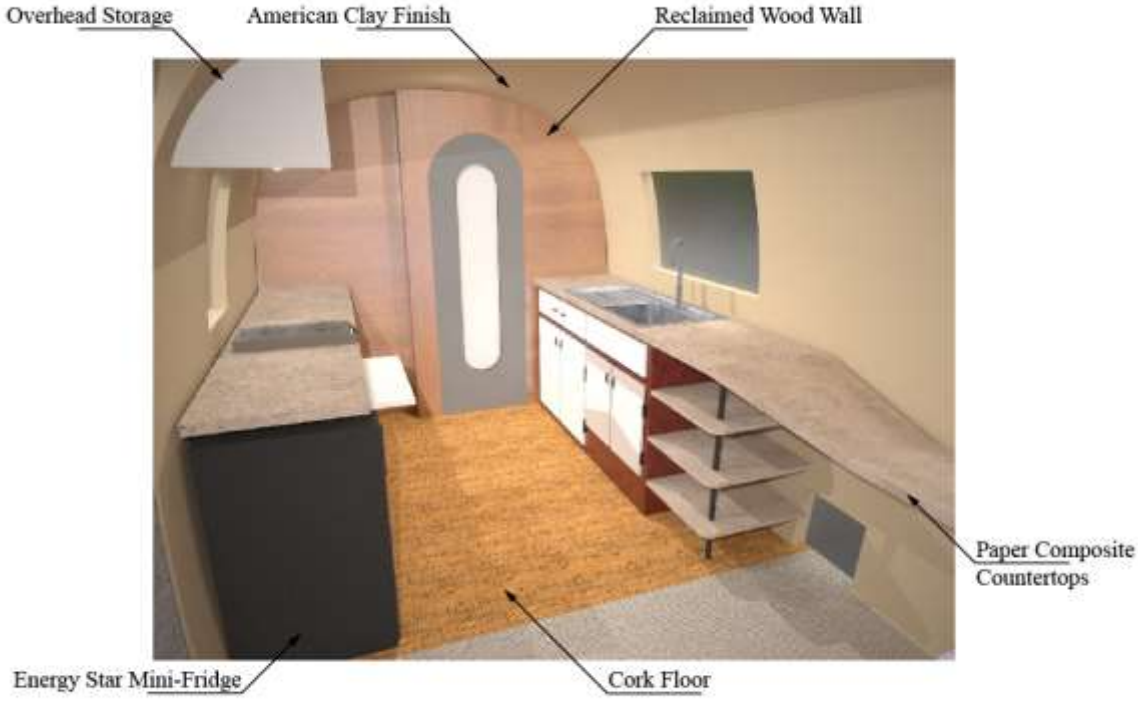


Figure 43: View of the kitchen area

Figure 44: View of the dinning/bedroom area (dinning view)

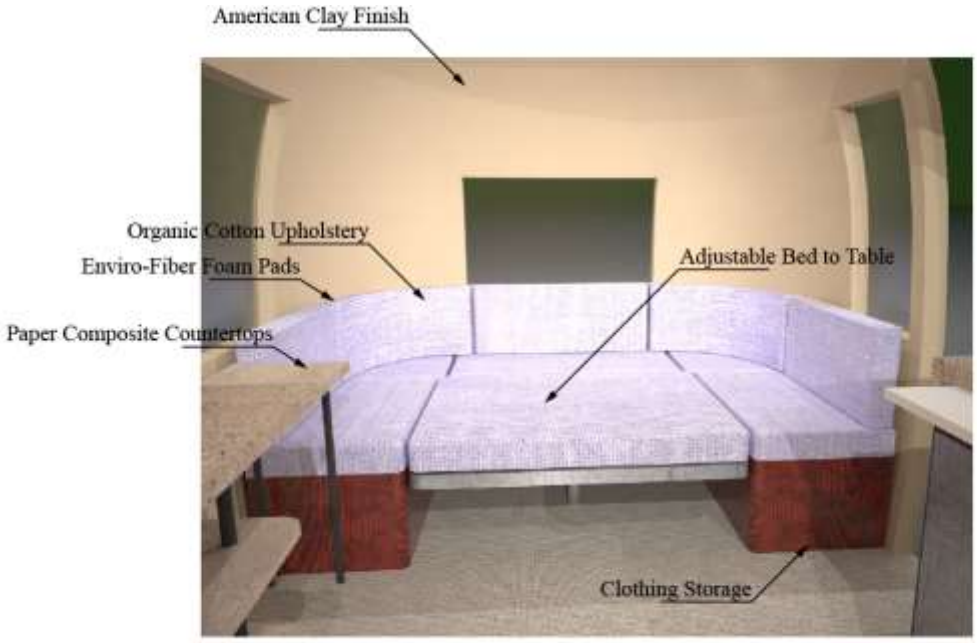


Figure 45: View of the dinning/bedroom area (bedroom view)

Figure 46: View of the bathroom area

Chapter 5: Conclusions

In this thesis, design guidelines to direct the renovation process of a recreational vehicle in a way so that the vehicle is in harmony with its environment were developed and described. The guidelines were established for a person with basic understanding of design and construction to analyze an existing recreational vehicle and properly renovate it using sustainable practices. Through the Internet and books, an investigation was conducted to identify efficient and sustainable materials and methods for usage in interior and exterior renovations. The guidelines were developed to direct the user in terms of material selection and considerations for the design of the energy, water, and waste systems.

Since choosing materials and systems highly depends on the available budget and usability time of the recreational vehicle, three scenarios were developed (*large budget-full time living*, *partial budget-full time living*, and *low-budget-part time living*). Materials and systems were suggested for each of these three scenarios, and systems guidelines were provided with an emphasis on water and electricity consumption. Assuming the *low-budget-part time living* scenario, the implementation of design considerations was demonstrated in detail using an actual twenty-one foot 1967 Airstream Safari. To design the functional spaces, the interior was divided into three relevant sections (bathroom, kitchen, and bedroom). Following the guidelines, essential items were identified for each of these spaces. Materials were selected and the systems designed.

In conclusion, this thesis allows a person to accomplish an overall sustainable dwelling, lower performance costs and improve the interior environment. Knowing the sustainability

characteristics of the researched materials and systems prepares the user to recognize the overall sustainable impact of a product and process without simply following what the media recommends. The guidelines also provide a dialogue between the user and the recreation vehicle to create a living situation that complements a physical place with an abstract sense of familiarity to a portable home. By providing the user with a detailed example, the user learns how to choose the right systems and materials.

It is important to mention that the research of trending materials and systems should be a nonstop process since available technology improves drastically over short time periods. A continuously successful integration of systems and materials can create an environmentally conscious travel home only if the user understands the sustainable concepts defined in this thesis.

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