DESIGN OF A SOLAR HOUSE

BY

MICHAEL ROBINSON

A THESIS
SUBMITTED TO THE FACULTY OF

ALFRED UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE

IN

ELECTRICAL ENGINEERING

ALFRED, NEW YORK

SEPTEMBER, 2012

DESIGN OF A SOLAR HOUSE

BY

MICHAEL ROBINSON

B.S. ALFRED UNIVERSITY (2011)

SIGNATURE OF AUTHOR (Signature on File)

APPROVED BY (Signature on File)
DR. XINGWU WANG, ADVISOR

(Signature on File)
DR. JIANXIN TANG, ADVISORY COMMITTEE

(Signature on File)
DR. WALLACE LEIGH, ADVISORY COMMITTEE

(Signature on File)
DR. JOE ROSICZKOWSKI, ORAL THESIS DEFENSE

ACCEPTED BY (Signature on File)
DOREEN D. EDWARDS, DEAN
KAZUO INAMORI SCHOOL OF ENGINEERING

ACKNOWLEDGMENTS

I would like to thank Dr. Wang and my committee members for the guidance and help throughout my thesis work. I would also like to thank Joe Terranova, Avery Sandler, and Erik Wake for additional help with the thesis work. The biggest thanks goes to family and friends for their support while I was school pursuing my degree.

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

ABSTRACT

The Solar Decathlon has been created by the U.S. Department of Energy to test the design, build, and operation of an energy efficient house. The newest addition to the international solar decathlon competition has been moved to China. The competition will take place August 2013 in Datong China. The goal of the houses being built is to create a house that is both energy-efficient and architecturally pleasing to the public.

The house will be attached to the solar decathlon's electric grid, septic, and water systems. Since the house will be attached to the electric grid, electricity will always be available for use. However, the whole purpose is to have a net electrical use of zero. To have a net electrical use of zero, the house needs to be able to produce its own electricity through solar panels, and consume the least amount of energy through the houses appliances. During the competition week, the house will be put under mini contest that will test the functionality of the house.

Building the house will need to be designed to be structurally sound on its own foundation, so it will withhold the weight of the house and all of the housing systems within. Not only does the house need to be strong but needs to be tight, so there is no energy lose or energy gain between the outdoors and in. Getting the house to Datong China has to be ready to be built upon arrival since only a week is given to build the house on site. Therefore, the house will be partially built before shipping.

To overcome most of the major loads in the house, smart energy systems will be used from the hot water system, to the lighting of the house. A monitoring, and control system will be used to control the amount of energy being used at one time by the major electrical load appliances. Also each appliance will be the most energy efficient to help drive down the amount of energy needed for each appliance.

INTRODUCTION

The U.S. Department of Energy Solar Decathlon is an award-winning program that challenges collegiate teams to design, build, and operate solar-powered houses that are cost-effective, energy-efficient, and attractive. Solar Decathlon China is the most recent addition to international Solar Decathlon competition. The Solar Decathlon China will take place in Datong China August 2013. The Solar Decathlon educates students and public about the cost-saving products available by clean-energy products. The solar houses demonstrate the energy efficient construction and appliances with renewable energy systems.

A. Solar Decathlon Energy Efficient

During the Solar Decathlon competition the main goal is to be the most energy efficient, throughout the week of competition. Each house is looking to have a net energy usage of zero. Each house is looking to be able to produce enough energy to cover the day-to-day consumption used by each individual component; therefore each individual component needs to be energy efficient to consume the least amount energy from the grid. Since AC power is available from the grid, the goal is to balance the energy produced with the energy consumed. Not only does the energy consumption matter but also the engineering and looks of the house matter. Throughout the contest week each house is tested for durability and functionality. The contest week uses the components of the house to simulate the use of the home by residents. The Decathlon combines the communication and the work between students within an individual school or across multiple disciplined schools to create one functioning home.

BUILDING CONSTRUCTION

A. Foundation

1. Temporary House Foundation

The foundation for the solar decathlon house will be similar to the foundation of a trailer home. The temporary foundation will use concrete pillars and steel I-Beams to support the load of the house during the competition. The house will use a total of three steel I-Beams. The steel I-Beams will utilize a tie-down system, used for trailer homes. The tie-down system will use metal straps that wraps around the I-Beam, and is connected to an anchor in the ground. The tie-down system keeps the I-Beam from moving side to side when building the home together on the support beams. Since the foundation is only temporary, the concrete pillars do not need to be below frost level, otherwise holes would have to be dug to get the concrete below the frost line preventing the frost from pushing the pillars up in the winter. With the temporary foundation, electrical wiring and plumbing can be run under the house and to its respected spot. With main feed to the house on the back corner of the house, the feed to the main panel would be ran under the house and up to the panel.

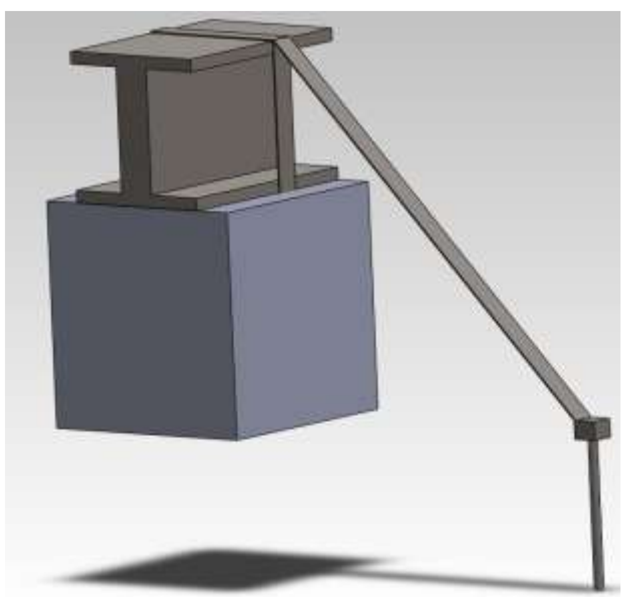


Figure 1: Foundation Tie-Down.

On top of the concrete pillars and steel I-Beams, the floor joist structure will be placed. For the house flooring, we wanted to have a maximum live load of 60 lbs/ft^2; so we had to look at the size of the boards we would use for the flooring. For joist spacing of 16" the maximum span could be is a little less than 14ft. With the house using a span of 14ft would work to create sections within the house. 2"X10"s will be used for both the house flooring/foundation and for the decking to give a maximum live load of 60 lbs/ft^2.

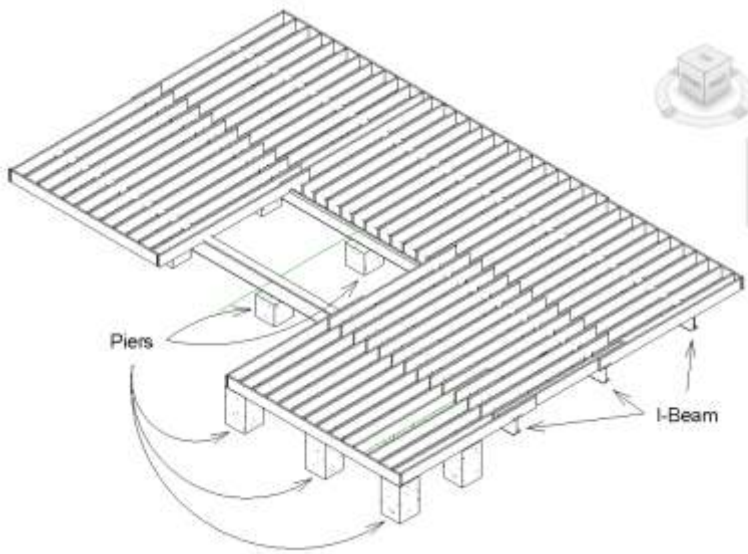


Figure 2: House Floor Joist & Foundation.

On the front right section of the house an I-Beam will not be used because there is not enough room for an entire I-Beam. Therefore, concrete pillars will span be the entire height, from the ground to the bottom of the floor joists. The concrete piers will be used to take the load of the house. The outside sill and joists will rest on these pillars.

Figure 3: Foundation & Joist Right Side View.

2. **House Decking**

Besides having the foundation, a decking system is needed to elevate the pedestrians into the home, since the house is elevated off the ground. The decking will use 2"X10"s like the house flooring, and will be built in a similar manner. Instead of making a decking utilizing both a stair section and a ramp section, for handicap accessibility, the decking will have only two ramp sections. The ramp sections will provide easy accessibility for handicap persons and nice walkways for everyone else. Along the decking sides, there needs to be a railing system for safety. 4"X4"s will be used as up pillars, for the structure for hand rails and side rails. For the foundation of the decking, small concrete pads will be used to sit the decking joists on. The decking will also use some 4"X4" rails that go completely down to the concrete pads to give extra support where otherwise wouldn't be. In the front of the house there could be a main entrance and in back of the house could have a main exit, both in which being a ramped section, for handicap accessibility and ease of use, therefore reducing traffic at one entrance.

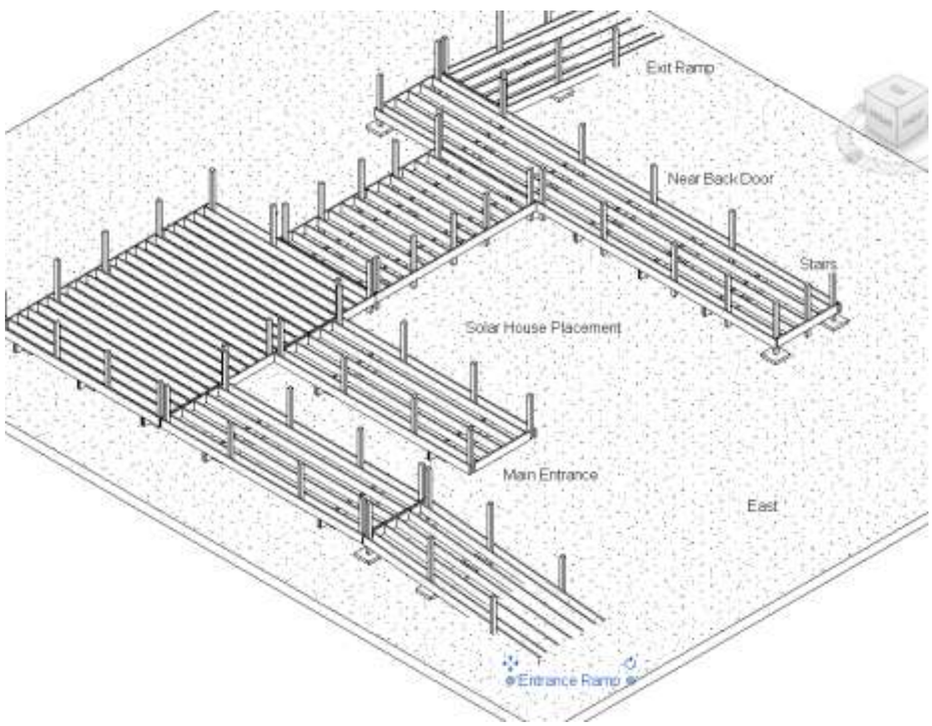


Figure 4: Decking Formation.

B. Stucture

1. 2”X4” vs. SIP Panel Construction

There are two styles of building that can we used for the housing structure. There is the traditional building style in the United States, using 2”X4”s for wall studs and framing. Another way, and quicker construction, is using SIP panels for walls, and ceilings that are pre-manufactured.

a. 2”X4”

The structure for the solar decathlon house could be made out of 4”X4”s and 2”X4”s. The house would be built with traditional American building techniques. The corners and connection points between the building sections will be a 4”X4” for better structure support. Between these points the walls will be 2”X4” stud framing. The stud framing will be 16” on center which will work with batt insulation. On top of the studs and the corner beams there will be a double header to help bring everything together structurally. On top of the header, each section of the house will have its own roof. The roof rafters will be made of 2”X10”s, which will also be spaced at 16” on center to support the weight on the roof between the solar hot water collectors and the solar panels.

Figure 5: Whole House Framing.

Framing around windows and doors will need to be properly fitted to support the load equally to the floor around the void made by the windows and doors, to prevent sagging. The windows would need an upper header, and a lower sill to continue framing around the windows, and to support the window. Utilizing a double stud on the sides of the windows, the support of the wall is not placed on the window itself. The double stud has a stud that is continuous beside the window from floor to top header. While a secondary stud goes from the floor up to the header above window, to support the header and the forces pushed onto it. A standard double hung window size for the installation would be around 36" by 5.5' but can be a wide range of sizes. The doors would have a similar build structure as the windows but would not have support under it like the windows, since the door would be a wide open void in a wall. Door sizes however, would need to a minimum of 30" wide unless it is handicap accessible, which in that case would need to be 36" to allow wheelchairs through. A door height would be best between 7' and 8'.

The back section roof facing south will have a pitch around 30^0 to match the angle of the sun during the competition. additional framing will be placed in the center of the house to reduce the load on a particular spot to a more uniform load across the entire floor area. The load will need to be spread out because in that area a large window atrium could be used, to help heat the house using the sun.

Using wood stud framing and batt insulation the insulation value of the house would be between an R-12 and R-16. Using fiberglass batts the R value would be between R-3 and R-4.3 per inch thick. Cotton batts, which are recycled from blue jeans, would have an R value around R-3.7 per inch thick. Cotton batts are also more fire resistant than fiberglass insulation. Blown in cellulose insulation's R value would range between R-3 and R-3.8 per inch thick. Cellulose insulation is messy and harder to control for a simple house construction like this.

b. SIP Construction

Structural Insulated Panels, SIPs, are easier and allow for quicker building of a home. Within the panels, all electrical boxes are pre-connected with flexible metal conduit. The wiring is routed according to wiring diagrams. Even with everything pre-assembled, modifications are able to be done onsite while building. Windows and air conditioning / heating units are precut by machine, when made in the factory. Plumbing within the SIPs is possible, however with the house design, the water and sewer runs can be run from under the home, to prevent the mixture of electric with water. When constructing the home, before shipping to Datong, the wall panels would be best connected using screws. However, once the house is shipped and is in Datong for final construction, the corners and connection points between the individual SIPs will need to be glued and screwed together. Gluing the panels together allows the house to have a sealed building envelope, preventing heat loss or gain of the house.

Once the walls are up, finishing the walls is simple and easy. On the inside, sheetrock/gypsum board, or any other interior finish can be applied for a smooth and pleasant looking wall. On the outside, OSB board or plywood can be used to tie everything together for more structure and allow for the finishing of the outside with either a board siding, the hardie plank or another style of siding.

The insulation factor of the SIPs is a little better than the traditional building with batt insulation. The panel has an R value of R-18 for a 4.5 inch thick panel. Between the two styles, both are relatively similar by thickness. However, using SIPs is quicker and easier.

The SIPs are connected with a 2x stud every 4ft, to join panel to panel. The panels come with finished sides of plywood to fasten sheetrock and other materials to it. Having the plywood sides makes hanging large heavy components up on the walls easy and no need for additional support.

2. Interior & Exterior

The interior and exterior of the house will be covered in fire resistant material to increase the house's fire protection. The interior and exterior materials will also help tie everything together making an even stronger house.

a. Interior

On the interior of the house 5/8" sheetrock could be used. The sheetrock will be a good finish to hide and cover up any necessary spots and give a better finished look to the house. The sheetrock would also be fire resistant, creating a better fire resistant house. The walls would be able to be painted and made more homely. With a sheetrock finish, mudding and taping needs to take place. However, with mudding the drying time is directly related to the temperature and humidity in Datong. The longer the mud takes to dry the more time it takes to complete the house, however with having a set amount of time to build the house, the delay will need to be avoided. A wood interior could be used to avoid time delays, because the wood finish could be nailed to the wall and have no drying or finishing time to it.

b. Exterior

The exterior of the home could be pre-covered in an OSB, plywood material and then followed with a finishing material. Using OSB or plywood would allow for the structure to become sturdier and all tied back together. The OSB or plywood would give the outside walls a sturdy and smooth surface to mount any kind of siding to. Hardie Plank could be used to cover the walls. The hardie plank is a fire retardant material to increase the fire protection that much more. Over the OSB, plywood, any kind of siding can be used, either a wood siding, bamboo siding, or anything that will look nice and presentable.

C. House Assembly

Putting the house together there are two ways in which the house can be put together on site at the solar decathlon in Datong. One method is to assemble the house in a modular way. The modular assembly can be used if the solar house is built by Guilin University of Technology in China, GUT. The second method is to ship wall sections to Datong China, if Alfred State College is to build the solar home.

1. Step 1

The first step would be to take the front left modular section, if built by GUT, or the left sections of panels, if built by Alfred State. The front left section is the smallest section of the house and a good starting point to build from. This section has three sides to line up and will help square up the house. This section will be assembled onto the flooring, and the section will consist of the outside walls, with the structure support. The roof then can be added to the wall sections if the house is built in wall sections. Within the section the electrical components will already be wired and ready to be hooked up to the rest of the house.

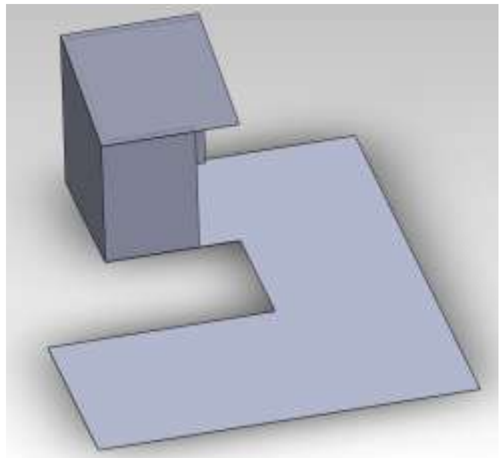


Figure 6: House Assembly Step 1.

2. Step 2

Step two will be similar to step one. The second step will take the front right section of the house and have it placed on the flooring. The whole modular section would be placed into place. With a sectional assembly the roof and wall stud structure will be assembled and placed onto the house foundation. This section will be able to be lined up with the first section to assure they are plumb and square with each other, ensuring a correct fit with the last section.

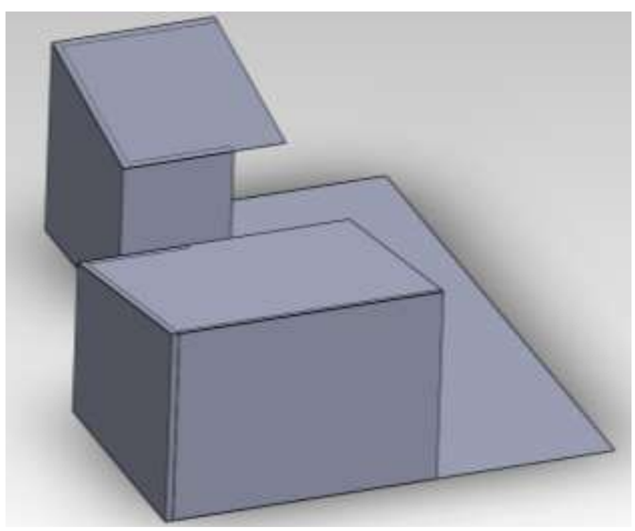


Figure 7: House Assembly Step 2.

3. Step 3

The last step to assembling the house would be to bring in the third and last portion of the house. The third portion is the heaviest of all the sections because this section has the largest roof area of all the modular sections, and has the most square footage of the home. With the other two sections already in place, the last section has multiple points to matchup to.

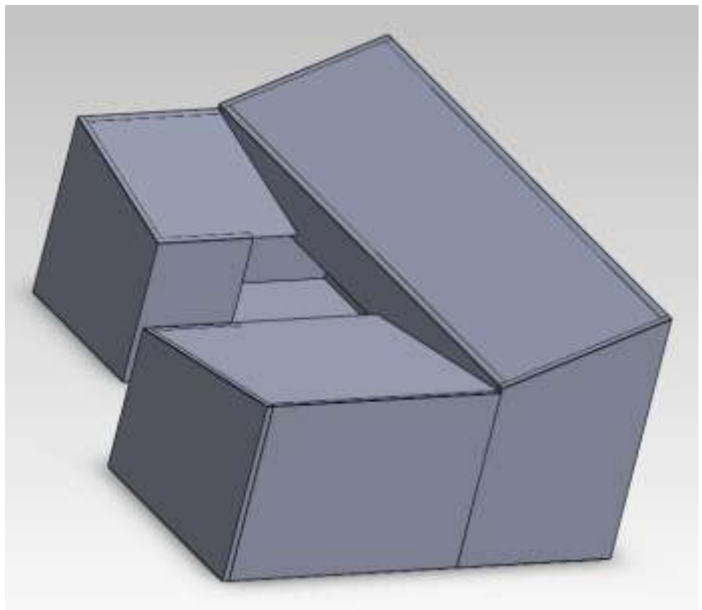


Figure 8: House Assembly Step 3.

4. Shipment of Components

If the solar house is built by Alfred State, in order to get the solar home from the United States to Datong China, the house would need to be shipped on a container ship. There are two standard container sizes, a 20 and 40 foot long container. The openings and cross-sectional areas are the same between the two, the length however between the two are different. The inside width is 7.71 feet and an inside height of 7.8 feet. Due to the size of the house sections, the house will not be able to be placed in the container in section of pre-assembled modular walls. Therefore, each individual wall section would be placed into the container not attached to its matting wall or walls. With the wall height of the main floor of two meters tall, the walls will be able stand upright with room to spare. The house walls and roof rafters should be able to be packed into one 40 foot container. However, the remaining floor, floor joists, and decking would not be able to be packed into that same container. Therefore, an additional container would be needed. The flooring joists are so big that the floor would not be able to be taken pre-assembled. The same goes for the decking around the house. Therefore, these parts for these two components can be put into the same container together.

D. Wire Connection for Outlets and Switches

Using FMC, flexible metal conduit, wire inside of the flexible metal conduit cover contains the necessary wire for wire the home; therefore once the FMC wire is run, no additional wires would need to be run. Using an octagon metal box, as a junction box to connect between modular sections of the home so the house can be wired prior to shipping the house over to China.

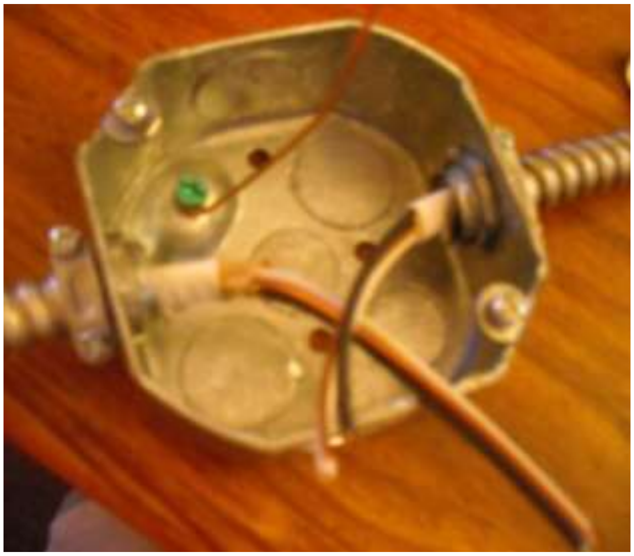


Figure 9: Octagon Box With FMC Wire Connected, Junction Box.

When feeding the FMC into the box, roughly about 6 inches of wire is left, and the outer cover is stripped revealing only the neutral (white), hot (black) and ground (bare) wire are left. Within the box a ground wire is attached to the box using a ground screw. For the junction box, the two hot wires are stripped around 5/8” to expose the bare wire and using a wire nut to connect the wires. The neutral wires are done the same. The ground wires from both the cables and the ground wire in box are all twisted together tight. Therefore when everything is connected the circuit is completed. When the FMC wire is connected to a junction box or outlet box, the FMC needs to have a staple or mount holding the FMC from being able to move and come loose.

Figure 10: Wires With Wire Nuts.

Wiring outlets is done in a similar manner as the junction box. Electrical wires are brought to the electrical box with the FMC wire and connected to the outlet. For connecting the outlet to the supply the neutral wire is connected to the same side as the ground screw. Like in the junction box, a ground screw is used with a ground pigtail connecting the ground wire of both wires, the ground screw on the outlet and the ground screw connected to the box all together.

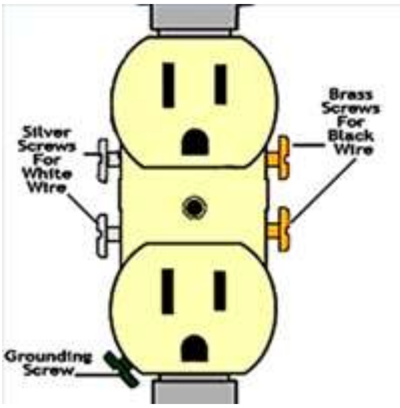


Figure 11: Electrical Outlet Screws.

Connecting the wires to the screws on the outlet is done by using a pair of needle nose pliers to round the end of the wire to wrap around the screw. Once the wire is around the screw, the needle nose pliers are used to squeeze the wire tight around the screw. Doing this makes the wire tight enough that even if the screw comes loose the wire will not come off. Since the outlet has four screws, this allows for the outlet to be used in the middle of a run and at the end.

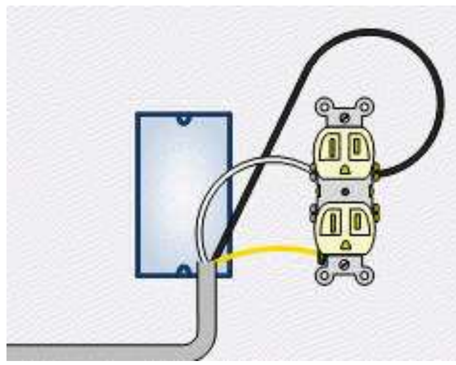


Figure 12: Electrical Outlet at End of Run.

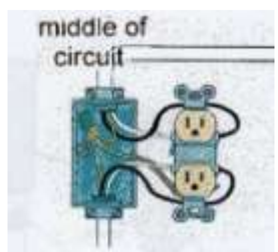


Figure 13: Electrical Outlet in Middle of Run.

Wiring for the lighting in the solar house will be wired similar to the junction box. The power feed will be fed into the box through the FMC cable from the electrical panel. In a similar way the junction box was wired the lighting box will be wired. The power for the lights will be in the ceiling "Power in the light," and then using a 2 wire, the neutral wire will be connected to the hot wire in the box and fed down to the lighting switch. From the lighting switch the hot wire will be fed back up to the light to complete the circuit to the light.

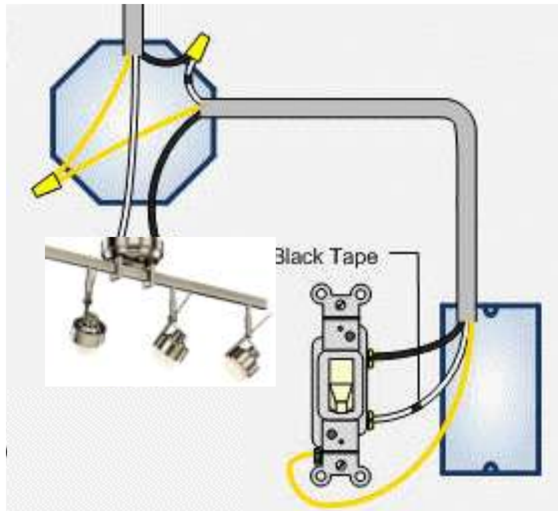


Figure 14: Light Switch With Power In Light.

When multiple lights are connected together, the lights are connected the same way the outlets are. The lights are connected together keeping all the neutral wires and all the hot wires connected together, and using pigtails connecting the wires to the lights.

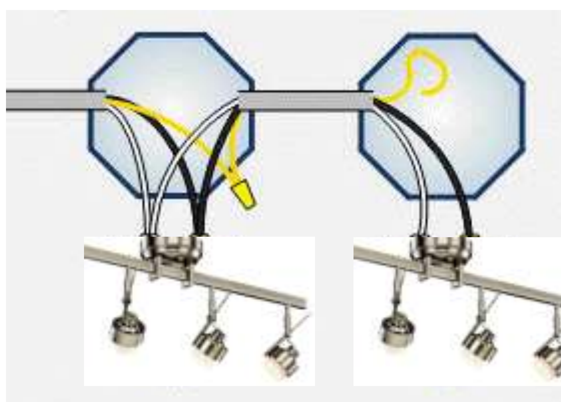


Figure 15: Multiple Lights on One Circuit.

E. Glass Atrium

In the very center of the house, a glass atrium is being placed. The glass atrium will be used as a heat source throughout the day. However, initial calculations have been done on the glass atrium, and the atrium will draw in too much heat, and make the cooling system run more than it is desired, using more electricity than planned. To overcome this issue, several options need to be looked at to reduce the amount of energy brought into the house.

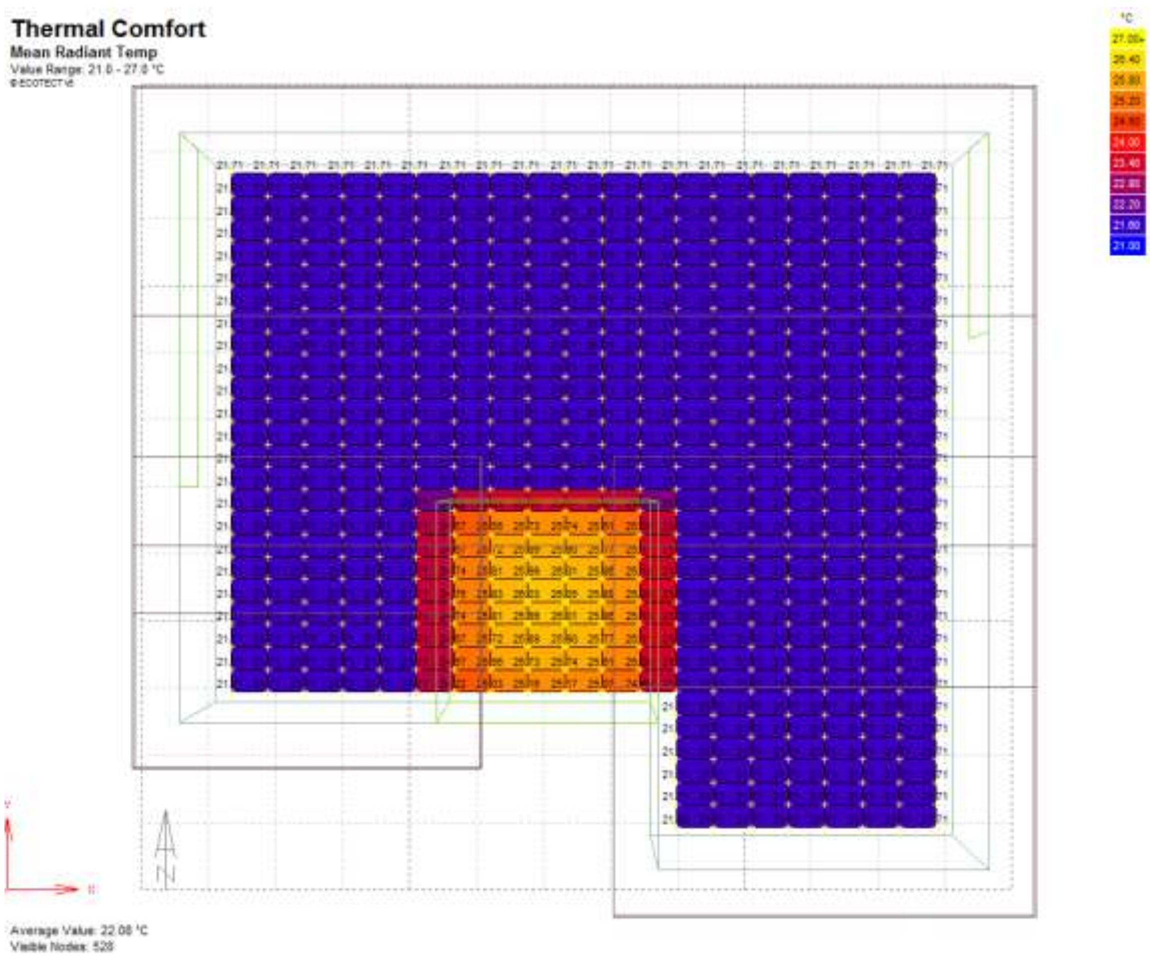


Figure 16: Glass Atrium Thermal Increase.

Using Ecotect from autodesk a simulation of the fully enclosed glass atrium in the middle of the house can be viewed according to weather data for Datong China in August. The simulation shows the increase in temperature at noon on the 7th of August. In the atrium the temperature within reaches an increase of almost 30℃, and an increase in the house around 21℃.

One option to decrease the amount of sunlight the glass atrium would capture is to use three sides of the atrium, on the bedroom, hallway, and living room walls, as a large window. Using the large windows would still allow natural light and warmth into the house on the three portions of the house. By removing the other sides of the atrium, the interior is not continuously increasing in temperature; the interior of the house is being warmed just when the sunlight is coming directly through the windows. Inside of the new void a little pond for looks could be placed, and utilize the roofs to funnel the rain water into the pond area.

Another option that would help the most would be to use thin film solar panels between two panes of glass of the atrium. With the double layer of glass and the thin film between the panes, not all the light will be passed through to atrium. And the thin film panels will create a voltage and current depending on the amount of sunlight on the atrium. Using the thin film, the film would act like a set of blinds behind the glass. The thin film would help control the amount of light allowed through into the atrium. Therefore, allowing for not too much heat to be produced and allowed into the house.

The option that would help the best is to remove most of the atrium. Placing large windows on the interior sides of the house where the atrium normally would have been in contact with the interior of the house would reduce the heat gain. Keeping these windows here would still allow for sunlight to be allowed into the house throughout the day. The windows then could still have thin film solar panels and/or blinds to control some of the sunlight. The windows would allow for some warmth to enter the house, however the amount of heat would not be anywhere's close to the amount of heat the atrium would produce. Since the atrium would be continuously warming up throughout the day, the heat would expand into the house, but with the only the windows only direct sunlight would be allowed to pass through.

F. House Roof Design

The roof design of the solar house has had a few design suggestions. Whether the roof top is a funnel type roof suggested by Guilin, the roof funnels everything to the middle from the back and the sides, or suggested by Alfred State a saw tooth style of roof.

1. Funnel Roof

With a funnel style roof, designed by Guilin, the roof top has some advantage and some disadvantages. The large back section of the roof is a good use for solar panels to collect sunlight to create electricity to overcome the energy consumption of the house throughout the testing week of the house, through the mini contests. Also with the funneling, water from when it does rain can be collected in one centralized location. The funnel style roof design would allow for 28 solar panels to be placed on the large back section of the house. An additional set of four panels then could be added with the 28 panels to make 32 panels in total that could be used. When attaching components to the roof, most components need to be facing South. Due to the West side slanted down towards the middle, additional panels would cast shadows on the panels behind if spaced too close together due to having to put the panels at an angle to face the sun.

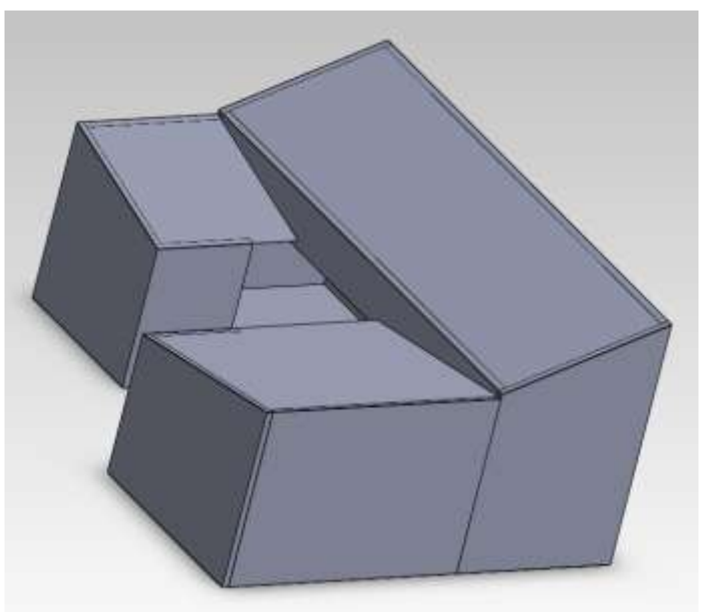


Figure 17: Funnel Roof Design.

2. Saw Tooth Roof

A saw tooth design also has its own advantages and disadvantages. With a saw tooth style roof not only will the large back section be facing the South, at the correct angle, but also the two side sections. With having the West wing set at the correct angle to the sun, the issue with casting a shadow is avoided since the panels will be flat on the roof. With the saw tooth design, when it rains the water would travel down both the East and West sides, and be collected in two separate locations. With the availability to add even more panels to the roof, with the saw tooth design, 41 panels could be placed on the roof top.

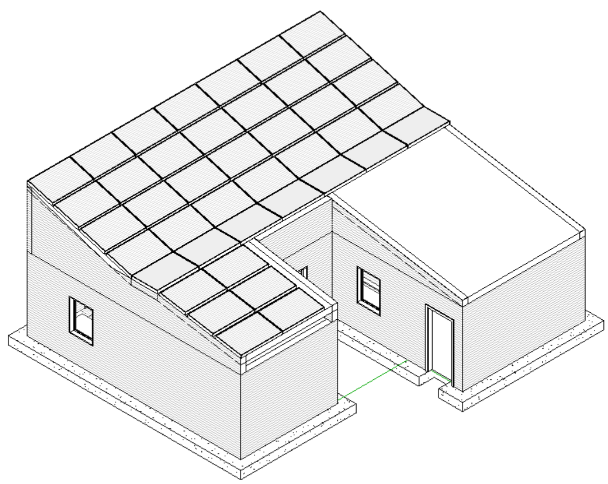


Figure 18: Saw Tooth Roof Design.

ELECTRICAL LOADS AND HOUSE SYSTEMS

For the solar decathlon house, the house is going to be viewed in China and connected the Chinese AC grid. The Chinese grid is 220V and 50 Hz compared to the standard 120V 60 Hz in the United States. For wiring the electric in the solar home all wiring would be done in FMC wire. FMC is flexible metal conduit. FMC is a raceway of circular cross section made of helically wound, formed, interlocked metal strips. With the FMC wire there should not be more than four quarter bends (totaling 360 degrees) in one run. Using FMC cable with metal octagon boxes and metal outlet boxes the two should work nicely together with connectors. The electrical loads will be drawing electricity from the grid to power the components within the house. Whereas some of the systems will help maintain functionality of the house and limit the loads in which the house sees. The electrical schematics where drawn using a version of SmartDraw software.

A. Electrical

1. Electrical Outlets

For electrical outlets the spacing between outlets cannot exceed 6ft (1.82m). Each wall has to have an outlet; a wall is defined as a wall over 2ft (.6m) in length. Also the wall must be a fixed wall, so the back side of a lower cabinet in a kitchen would be classified as a wall. Standard gauge wire used for outlets is 12 AWG 2-wire with a 20 Amp breaker. Wiring within the house will be run throughout the walls and ceiling throughout the house. Using the FMC wire the wire has no problem going through the wall’s interior material. Some electrical outlets need to be a GFI outlet. A GFI outlet is a Ground Fault Interrupt outlet. A GFI is used when an outlet is within 3ft (.91m) from the edge of a water source. Each breaker for each outlet circuit will be a GFCI breaker, Ground Fault Circuit Interrupt. The GFCI will keep the circuits from shorting out shocking people. Duplex receptacle outlets will be used for all receptacles except for GFI outlets. The duplex receptacle is an outlet with a two sets of outlets, seen in figure 11.

a. Electrical Outlet Schematics

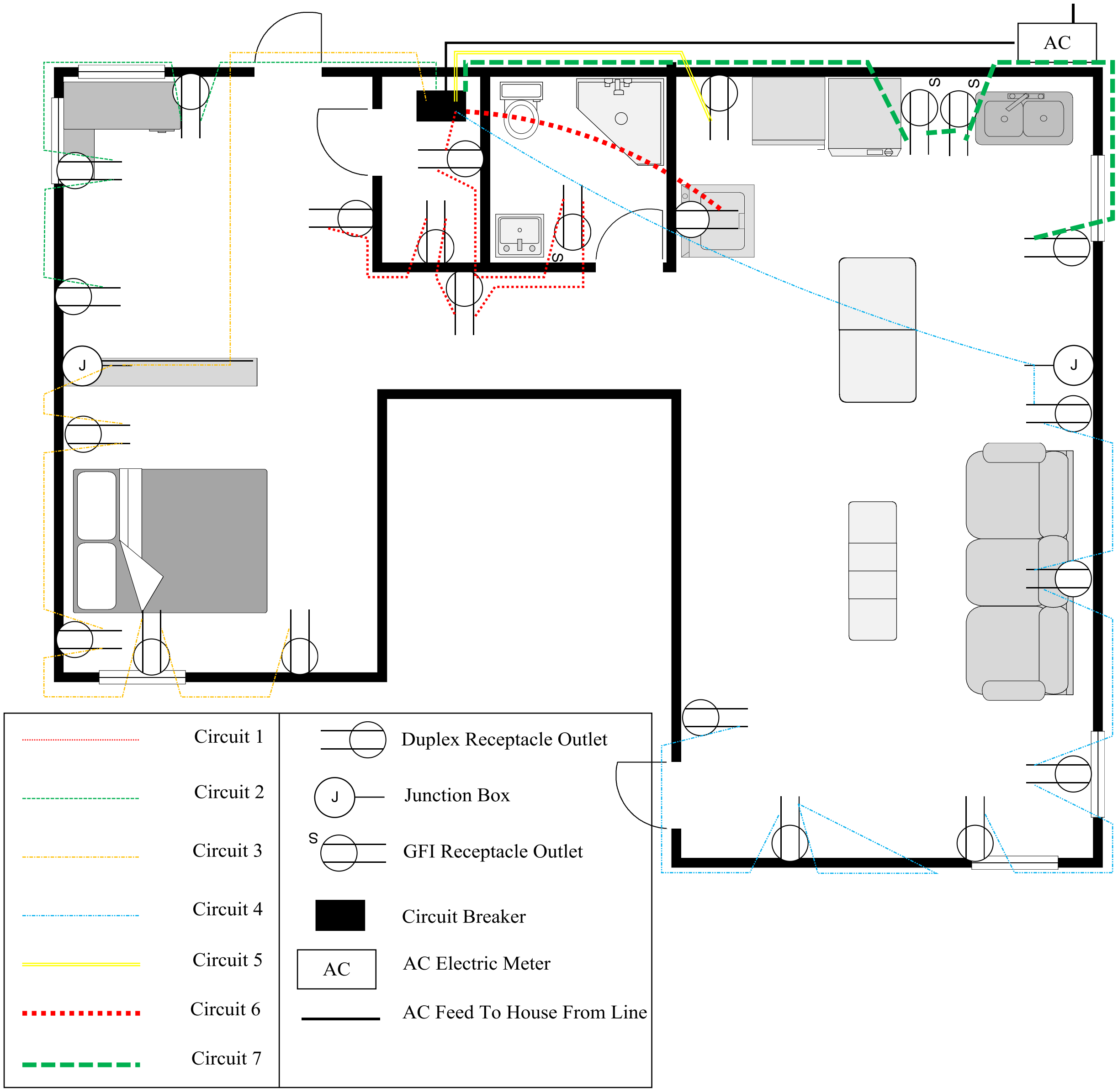


Figure 19: Whole House Schematic.

Throughout the solar home, there are multiple outlet circuits. Each outlet circuit is broken up by rooms and applince due to the fact that some circuits draw more current than others. Like in normal houses, rooms and floors are broken down into their own circuit, however due to the fact that the solar house will be reassembled using house modulars, thre is the need for additional circuits.

i. Bedroom Circuit

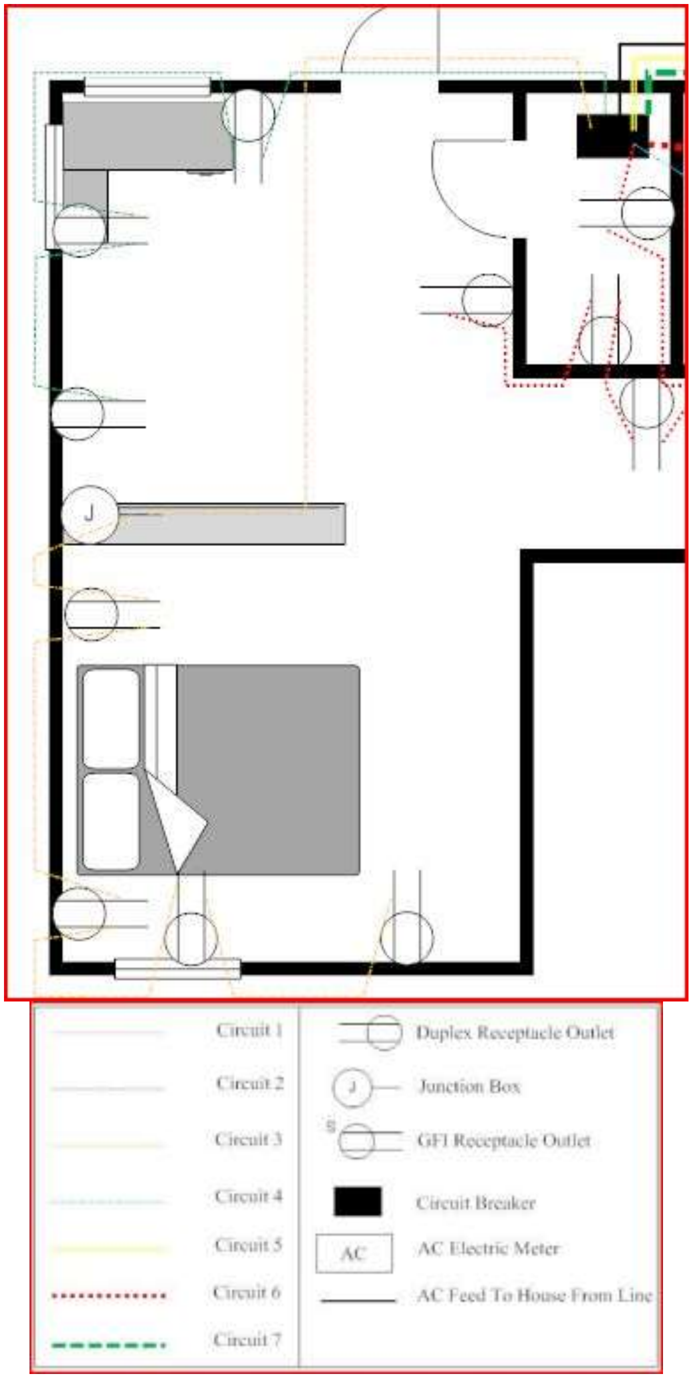


Figure 20: Bedroom Outlet Circuit.

For the bedroom circuit, a feed line comes from the electrical junction box and running the FMC wire through the wall and through the rafters in the ceiling of the office. After running from the breaker through the office towards the bedroom, the FMC will connect to a junction box. The junction box will be on the office side of the junction between the house sections. Therefore, when the house is connected back together, the junction box will connect to the FMC in the bedroom. From the junction box, the wire will run within the walls of the bedroom. The outlets should not be off the floor more than 20in (.5m). Since the outlets need to be spaced no more than 6ft in distance between each other, there will be two outlets on each side of the bed and two more outlets on the South facing wall of the bedroom.

ii. Office Circuit

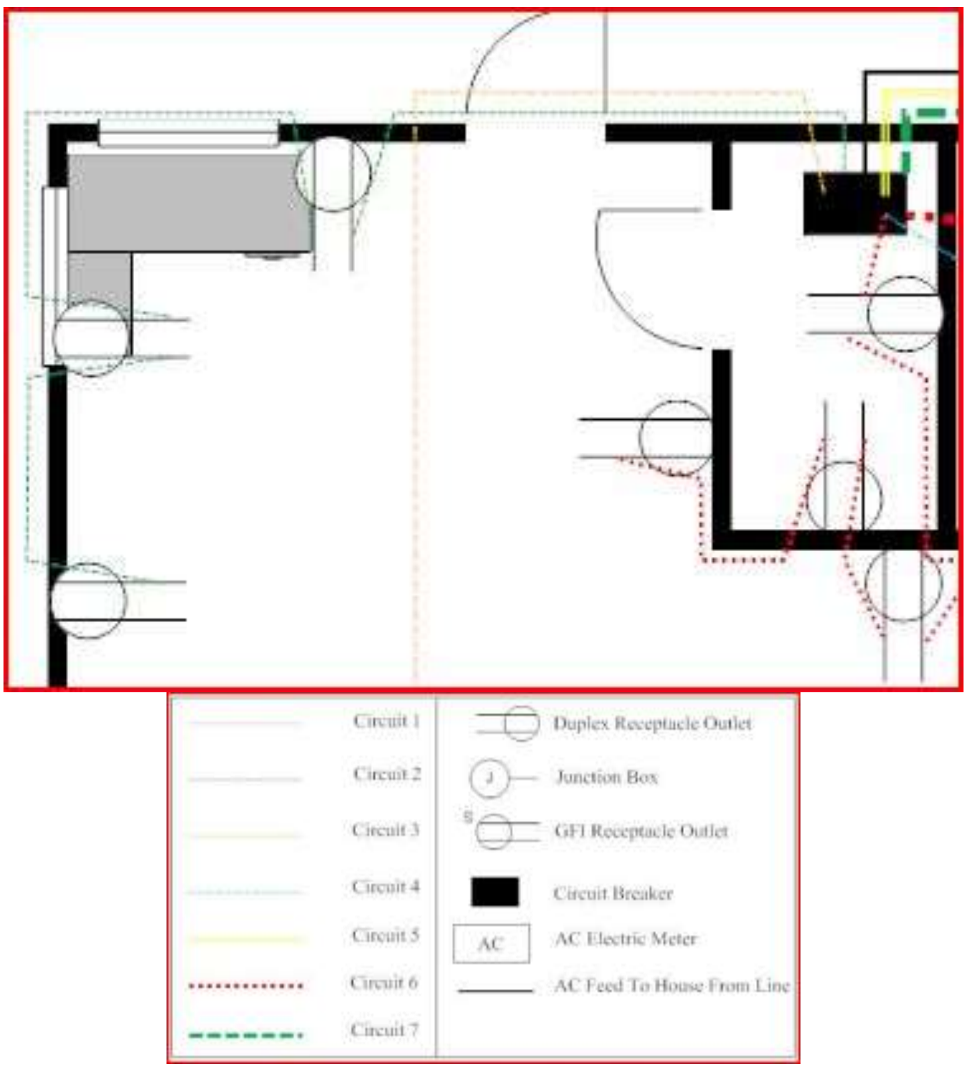


Figure 21: Office Outlet Circuit.

The office outlet circuit will start from the utility room circuit breaker panel and go through the back wall of the house, up and over the back door frame and then back down the wall to the first outlet. From the first outlet the FMC will continue through the wall and around the corner to the other two outlets.

iii. Utility Room, Bathroom, and Hallway Outlets

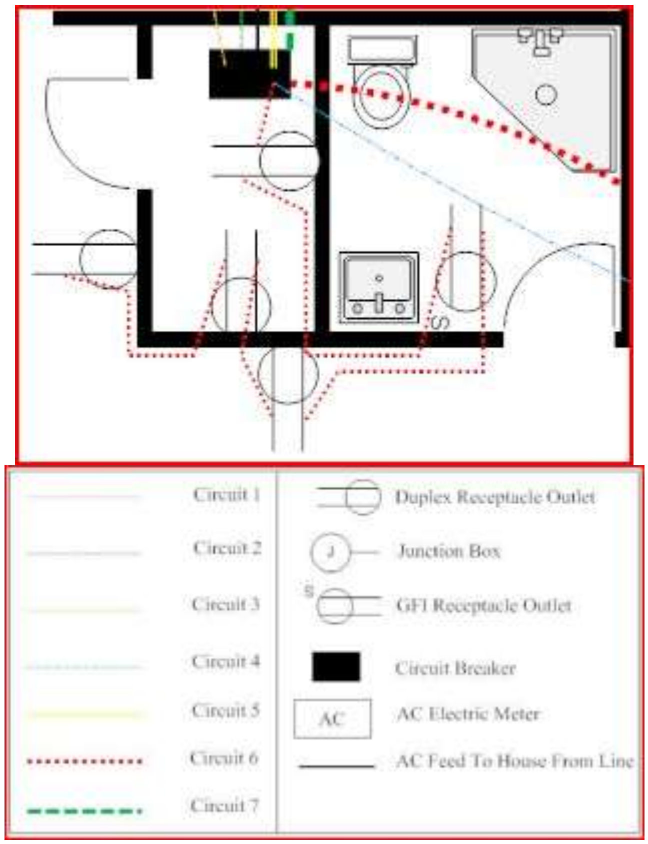


Figure 22: Bathroom And Hallway Outlets.

Since the hallway the wall area is longer than 6ft in length, an outlet is needed to meet code. Along with the hallway, inside the utility room, and the bathroom will need outlets. Inside the bathroom a, GFI, ground fault interrupt, outlet will be used to since it is within 3ft of the sink. A GFI outlet will prevent short circuiting and the risk of electric shock. The outlet feed will begin in the utility room and go to the bathroom outlet and run back along the hallway and around the corner.

iv. Living Room Outlets

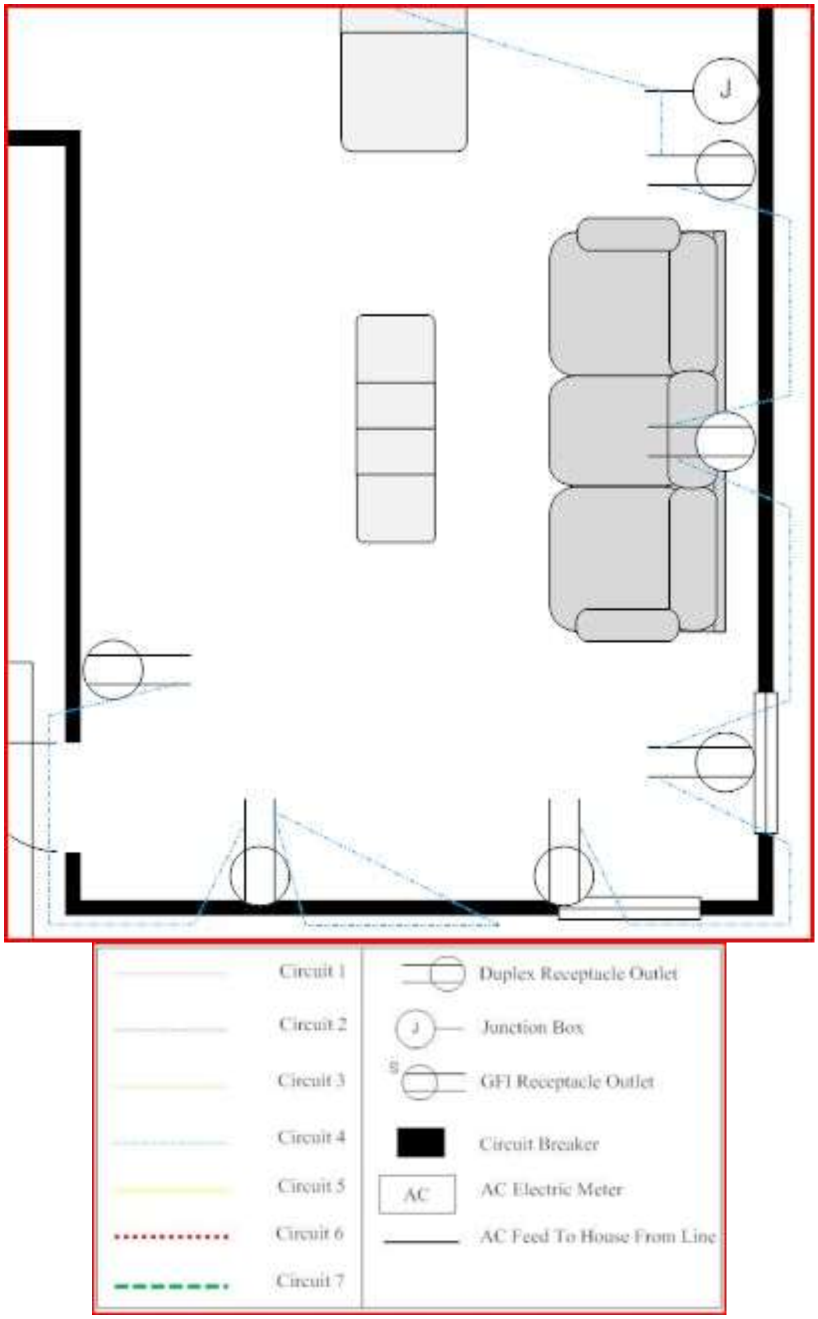


Figure 23: Living Room Outlets.

The outlets for the living room will be in the similar way like the bedroom. Since the living room will be its own modular section when the house is assembled, the feed for the outlets will be run to junction box close to the junction between the two sections of the house. From the junction the FMC line will then run down the wall to the first outlet on the run. Feeding the power will be fed from the first outlet to the next five outlets through the wall. When the power gets to the last outlet, the feed will have to run up and over the front door framing and then back down to the last outlet.

v. Kitchen Outlets

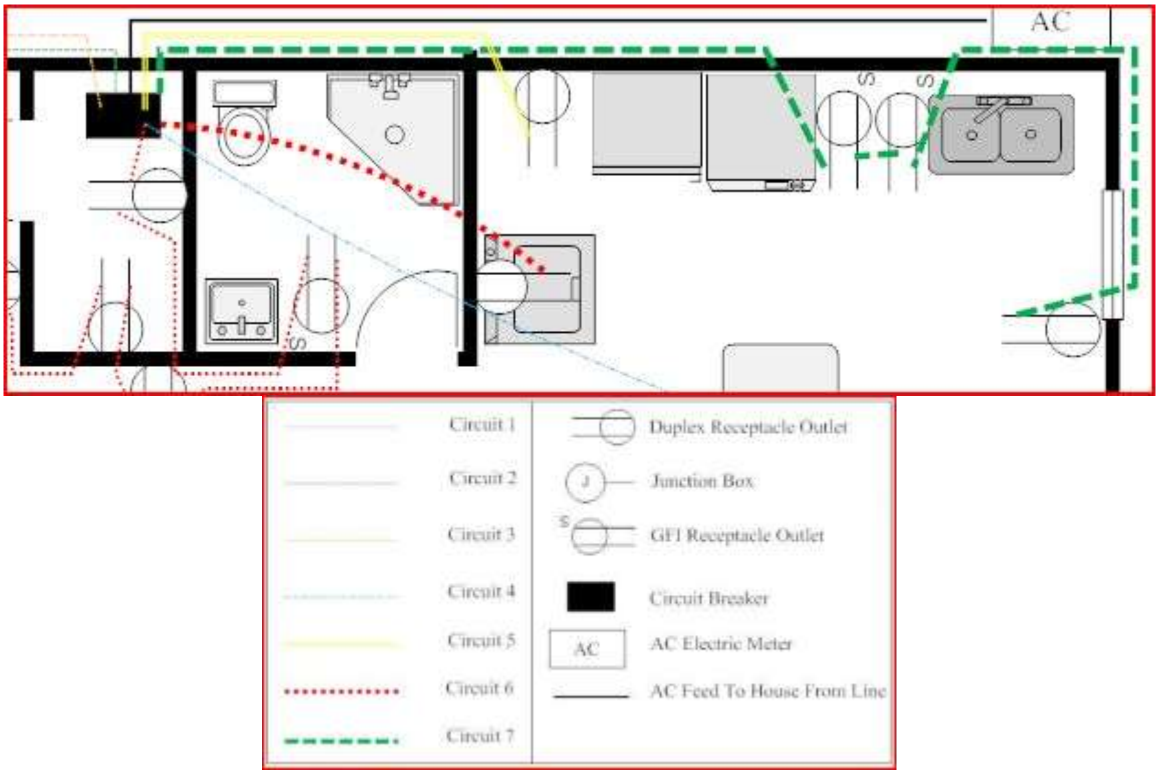


Figure 24: Kitchen and Appliance Outlets.

The kitchen has the most amount circuits of the whole house. Within the kitchen there are a total of three individual circuits. There is an outlet circuit for running outlets above the countertop. Two of these outlets will be a GFI. These outlets need to be a GFI outlet to meet code, since the outlets will be within 3ft of water. On the same outlet run as the GFI outlets will be an additional outlet on the right side of the kitchen. Another circuit within the kitchen is the Refrigerator and Microwave circuit. The third circuit in the kitchen is for the washer dryer unit. The washer and dryer circuit will be run with an 8 AWG gauge wire with a 35 Amp breaker in the circuit breaker panel. The circuit needs an 8 gauge wire because of the high current of the dryer.

b. Loads of Outlet Circuits

Table 1: Outlet Circuit Estimation.

Outlet Loads						
Circuit	**Size of breaker (Amp)**	**Volts**	**Number of Outlets**	**Estimated Current per Outlet (Amp)**	**Estimated Load per Outlet (W)**	**Total Load of Circuit (W)**
Bedroom	20	220	4	1	220	880
Office	20	220	3	1	220	660
Utility Rm./Bath	20	220	5	1	220	1100
Living Rm.	20	220	6	1	220	1320
Kitchen	20	220	3	1	220	660
Washer & Dryer	35	220	1	22	4700	4700
Fridge & Microwave	20	220	1	7	1600	1600
					Total	10920

When estimating the loads on the electrical outlets each outlet that does not have a dedicated load on it, the estimated amperage for each of these outlets is 1 Amp. The actual amount of current being pulled from the outlet would be less than the estimated one amp. If the estimation is larger than the single unit would be seeing, the load for the circuit would be overestimated. Therefore, if something was plugged into each electrical outlet and all circuits were being used at the same time the estimated total load on the electrical system would be 10kW. However, during the solar decathlon competition, every outlet should not be in use at the same time. But, the outlets are needed to pass electrical codes.

c. Safety Protection

Just like in every home, safety factors are considered and implemented. For the solar home multiple safety factors will be looked at. First, electrical circuits utilize a safety factor, typically 1.25. The safety factor can give you an idea of what the maximum current one would want to put onto a circuit, to give room for overdrawing on the circuit. For a 20 Amp breaker utilizing the safety factor of 1.25 the maximum current the circuit should be designed for is 16 Amps. This is found by taking the breaker nominal value and dividing it by the safety factor. The same would be done for the other circuits within the house. In the outlet circuits each circuit would have 20 Amp breaker, therefore the maximum current that would be wanted to run on that circuit is 16 Amps. Knowing that 16 Amps can be ran on one circuit and an estimated 1 Amp draw per outlet, determines there could be a total of 16 outlets on the one circuit. However, due to code, there cannot be 16 outlets on one circuit. Therefore, each circuit was designed to meet both code for electrical outlets and to be under the maximum current the circuit should handle. Making sure the size of the breaker is large enough while being able to have the enough outlets that still meet the code requirements.

Ground fault protection will be utilized throughout the house as well. For all the outlet circuits back at the breaker panel, each breaker will be a GFCI, ground fault circuit interrupt. This will ensure that every electrical outlet circuit will be protected for short circuiting and electrical shocking of pedestrians while in the home. The GFCI is a breaker that when it detects short circuiting, the breaker will "trip" and cut power to all the electrical outlets on that circuit. The breaker will also work like a typical circuit breaker. A circuit breaker "trips" when the current in the circuit is over the nominal value of the breaker. The breaker trips preventing damage to the circuit and electrical components within the house. In the kitchen the electrical outlets, within 3ft of the sink, will be GFI, ground fault interrupt, outlets. The GFI outlets acts the same as the GFCI breaker, in that when there is a detection of a short the outlet itself will trip and will need to be reset. Using both a GFCI breaker on all electrical outlet circuits and GFI outlets in the kitchen provides both double security of electrical shorting and shocking within the house, protecting both pedestrians and electrical components within the house. The GFCI breakers will be a Square D breaker available from Schneider Electric.

2. Electrical Lighting

For the lights the standard gauge wire used for outlets is 14 AWG 2-wire with a 15 Amp breaker. Wiring within the house will be run throughout the ceiling of the house. The lights for the house will all be high efficiency lights to keep energy consumption down. For some rooms more than one circuit will be needed. The lighting switch for each light will be a proximity sensor switch. So when the room is not in use for a set amount of time, the lights will turn off saving a little power at a time. However, once someone enters the room the lights will turn back on again. The proximity sensor switch is a manual-on and auto-off switch, made by Square D, which is part of Schneider Electric. The switch will have a time out of up to 30 minutes and will be able to be turned on and off manually when the day starts and when the day ends.

a. Lighting Schematic

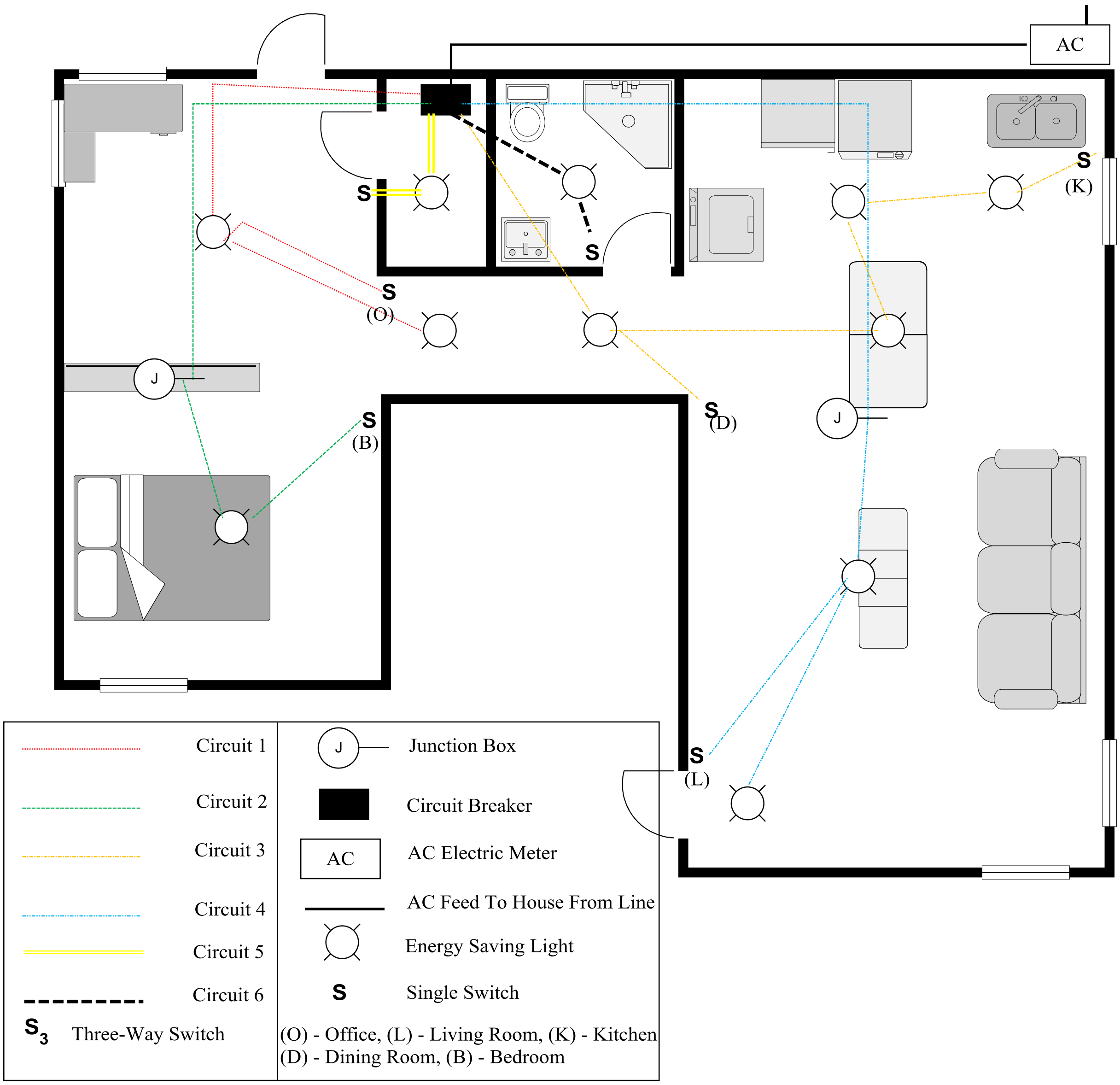


Figure 25: Electrical Lighting Schematic.

The lighting circuits for the house are broken up into six different circuits. The bedroom and living room both are their own circuit, mainly because due to the modular assembly, the circuit as to be disconnected and then reconnected once reassembled in China. With the multiple circuits the control of the wiring for the lights can be managed much easier.

i. Bedroom, Office & Utility Room Lights

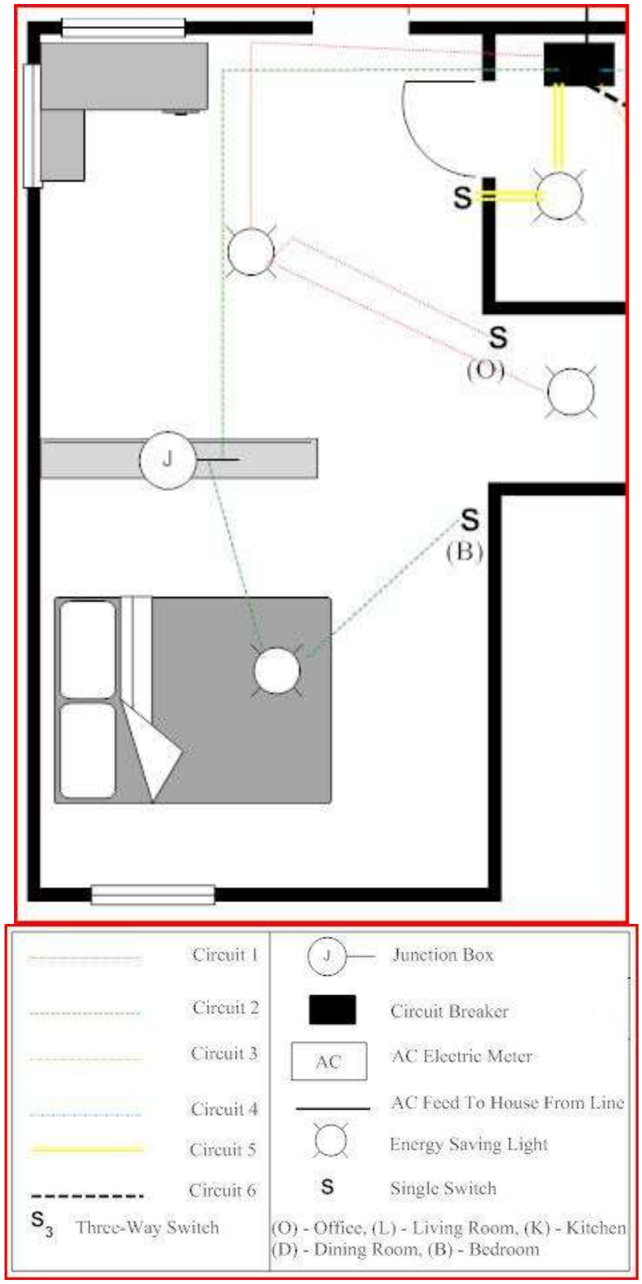


Figure 26: Bedroom, Office & Utility Room Lights.

For the bedroom lights the feed for the lights will be brought through the ceiling to a junction box between the main section and the bedroom sections of the house. From the junction box the power will be fed to the light and then down to the switch. With this setup the power will be in the light, and only one wire will be needed to run a connection down to the switch. With the power in the light, the neutral wire being fed to the switch will be connected to the hot wire in the light, the neutral wire acting as a hot wire will be connected to the switch and the hot wire from the switch will then supply power to the light. The hot wire from the switch and the neutral wire from the feed line will be connected together to complete the circuit. The switch will be on the corner of the bedroom on the support beam by the glass enclosure.

The office lights will be similar to the bedroom lights. The power will be fed to one light then the power fed to the switch for the office via the neutral wire. The hot wire will return to the light hot. From there, using a pig tail, to feed the first light and continuing the feed to the next light. On the office side of the hallway, there is another light on the same circuit. This light is there for when traveling from the bedroom to the kitchen at night, the light in the hallway will give some light on the other end of the hallway to find the next light switch. In the utility closet, a light is needed for work while in the room therefore a light switch will be located on the outside of the room next to the door for easy access.

ii. **Living Room Lights**

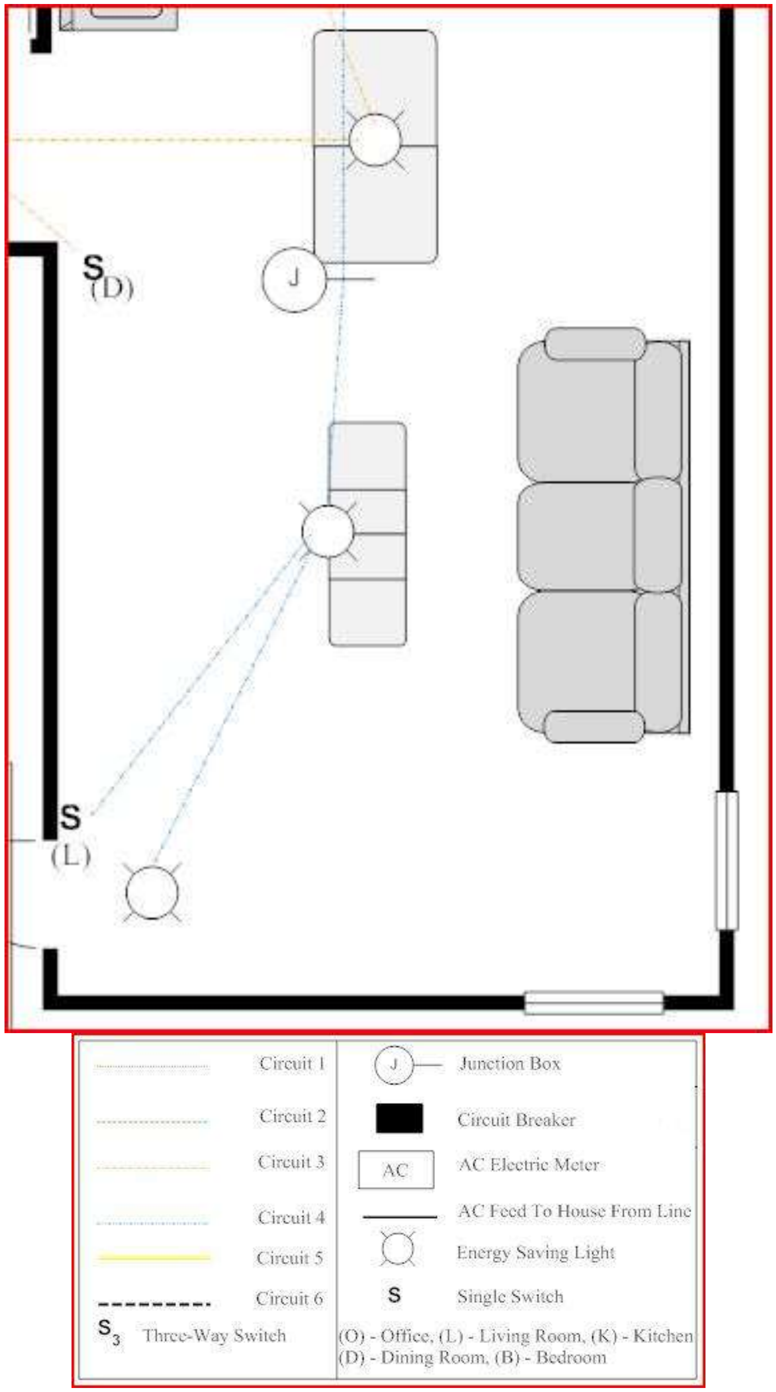


Figure 27: Living Room Lighting.

The living room lights will be similar to the Bedroom lights, in the way the power will be in the lights and the use of a junction box will be used to feed power to the lights. A Switch by the front door will control both lights in the living room, much like the office lighting did. A light by the front door will give enough light to see when entering into the house. While the light in the middle of the room will give off light while sitting in the living room.

iii. Kitchen & Dining Room Lights

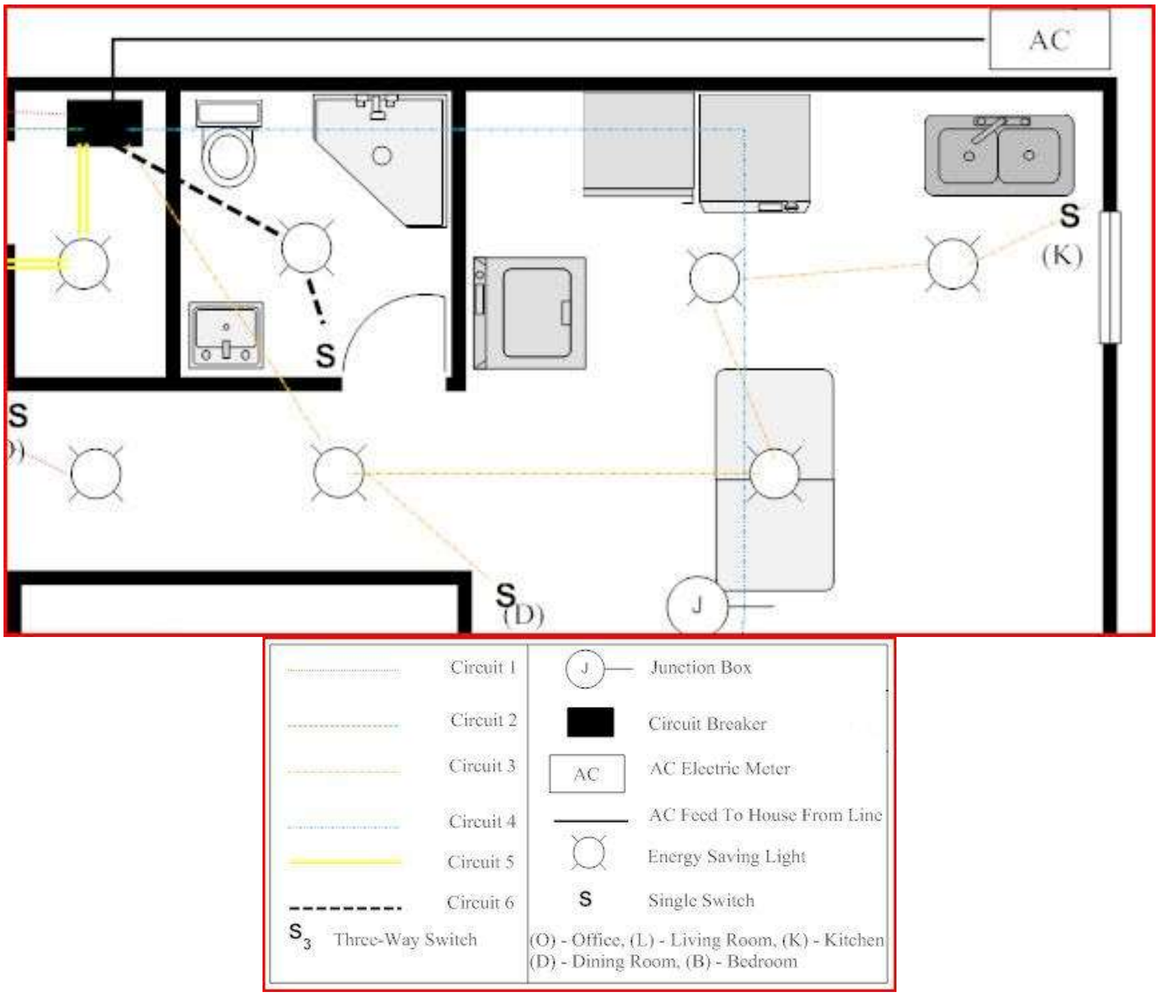


Figure 28: Kitchen and Dining Room Lights.

For the kitchen lights, the lighting will be split into two sections. One set of lighting will be by the sink, counter and refrigerator and the other over the dining room table. The set of lights by the kitchen counter will be on its own switch and the light over the dining room table its own. Having the two different sets will allow for using the lights while eating and then have that set off while cooking and preparing food. Doing so will reduce the amount of power used by the house when there is no need for the lights.

b. Loads of The Lighting Circuits

Table 2: Lighting Loads.

Light Loads				
Circuit	**Size of Breaker (Amp)**	**Number of Lights**	**Estimated load per light (W)**	**Total load of circuit (W)**
Bedroom	15	1	50	50
Office	15	1	50	50
Utility Rm./Bath	15	2	50	100
Living Rm.	15	2	50	100
Kitchen	15	4	50	200
			Total	500

The lights used in the solar decathlon house will be high efficiency lights, utilizing light emitting diodes, LEDs. Using LEDs will give off enough lumens while consuming a low amount Watts. If every light was to on and left on all at the same time the total load on the house would be around 100 Watts.

c. Lighting Units

Lighting for the solar decathlon house will be needed for during the day and night to meet the necessary standard lighting lux of a room. Light bulbs for the house can range from compact fluorescent lights, CFL's, Incandescent light bulbs and LEDs. Each room of a house has its own standard light level needed to perform standard tasks.

i. CFL

The compact fluorescent light, CFL, is more energy efficient and longer lasting replacement for incandescent lamps. A CFL that is a replacement for an incandescent lamp that has a built in ballast that can last 60,000 hours. CFLs compared to incandescent lamps use 20-30% of the energy.

ii. LED

Light emitting diodes, LEDs, use the least amount of energy of all the lighting lamps. High power LEDs produce light while consuming very little energy, while lasting up to 60,000 hours. Newer high power LEDs produce up to 100 lumens/Watt, therefore using much less power per lumen compared to incandescent lamps.

iii. Incandescent Light Bulbs

Incandescent lamps are the oldest form of lighting technology. These lamps are also the least efficacious and have the shortest life span. Incandescent lamps have a tungsten filament, which current is passed through, making the filament hot and glow. Over time the filament evaporates and breaks. Incandescent light bulbs produce enormous amounts of heat from the burning of the filament.

Lights have a measured amount of lumens produced depending on the size of the light bulb. The higher the wattage of light bulb the higher the average lumens produced, and the more energy consumption of the light bulb. CFLs and Incandescent light bulbs both produce the same amount lumens for the same rated wattage, however the amount of watts actually used in a CFL is much less. One Lux is equivalent to one lumen/m^2.

Table 3: Lumens By Different Bulbs.

Light Bulb Size	Lumens Produced
60 W	800
CREE XP-E LED @ 5W	500
CFL 12W	500

Depending on the standard amount of lux needed for each room, and the area of the room the number of lumens needed is found. Using the total number of lumens needed, the number of lights for each room is found.

Table 4: Standard Light Levels With Needed Lamps.

	Standard Lux	Area (m^2)	Lumens Recommended For Room	Number of Lights Needed		
				Incandescent 60 W	LED	CFL
Bedroom	200	10	2000	3	4	4
Office	500	11	5500	7	11	11
Hallway	100	4	400	1	1	1
Bathroom	850	4.5	3825	5	8	8
Kitchen	850	10	8500	11	17	17
Dining Room	450	5	2250	3	5	5
Living Room	200	13	2600	4	6	6
			Totals	34	52	52

The total number of lights needed to illuminate the house for each style of light ranges due to the lumens produced by the light. For incandescent light bulbs 34 light bulbs would be needed which is much less than the other two light form, but uses ten times the power. LEDs and CFLs both would need 52 light bulbs but the LEDs would consume a third of the power the CFLs would consume.

Table 5: Power Consumption Per Light.

	Power Rating (W)	Number Bulbs	Total Power Consumption (W)
Incandescent	60	34	2040
LED	5	52	260
CFL	12	52	624

The LED lighting for solar decathlon house will be a new and different style of lighting. Normal lighting that uses LEDs are replacement bulbs that use a standard light socket connection, or are a pot light that is wired in and has a built in AC-DC converter. However, for the solar decathlon house, the use of CREE’s XP-E LEDs a new lighting element can be produced. With the LEDs an 80° diffusion lens will be used to distribute the light evenly down onto the floor. A fan like aluminum heat sink would be used to help dissipate the excessive heat from the lamp.

The light intensity produced from each LED lamp is roughly 100 lumens per Watt. Connecting five to 10 of these lamps together will give enough lumens recommended for each room; therefore these lamps set to one Watt would be able to dissipate 500 to a 1,000 lumens. If the lights are set to run at 5W per LED, the lamps could dissipate 2,500 to 5,000 lumens per light fixture. Since the LEDs run off DC, and the house will be running AC, the AC must be converted to DC. Using a bridge rectifier the AC is brought to a positive ripple. The addition of a capacitor then smooth's out the ripple to a more continuous DC voltage.

Table 6: LED Lights Needed Per Track When running At 5W Per LED.

	LEDs Needed	Number Of Lights Per Track	Number Of Tracks
Bedroom	4	5	1
Office	11	6	2
Hallway	1	1	1
Bathroom	8	10	1
Kitchen	17	10	2
Dining Room	5	5	1
Living Room	6	5	2

With the LED lighting, a track lighting system could be used to connect between five to 10 LEDs. With the track lighting either the lights could be hung downwards from the track, or the lights could be manipulated to shine in the necessary directions needed to cover the entire room.

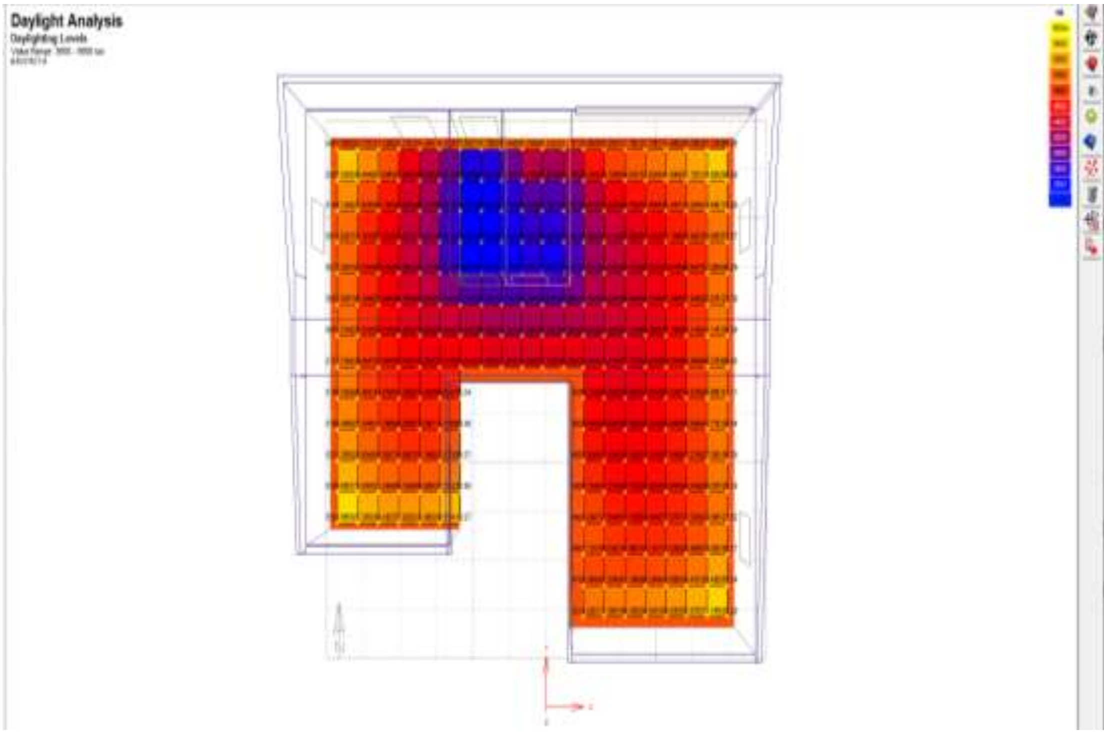


Figure 29: Ecotect Daylight Analysis.

Ecotect analysis shows the bathroom and utility room receiving around 3,600 lux while the highest point can reach up to 5,600 lux, which are by the outside windows on the perimeter of the house.

B. Solar Village Connections

All utilities that will be provided to the solar house will have their own connections to the solar village. The utilities provided by the solar village are the electric, sewer, and water supply. The connections of these amenities will be connected either behind the house or under the house. Only water, electric, and sewer connections will be provided, other amenities desired for the competition must be pre-arranged.

1. Electric Connection

The electric connection between the solar house and the solar village grid could be placed in the back of the house. The electric meter could be outside the house to free up space within the utility room of all components, and makes the connection easier. From the electric meter, underground conduit will be run under the house and up through the interior wall, between the bathroom and utility room. Feeding the conduit under the house prevents the possibility of damage to the wire due to traffic of viewers.

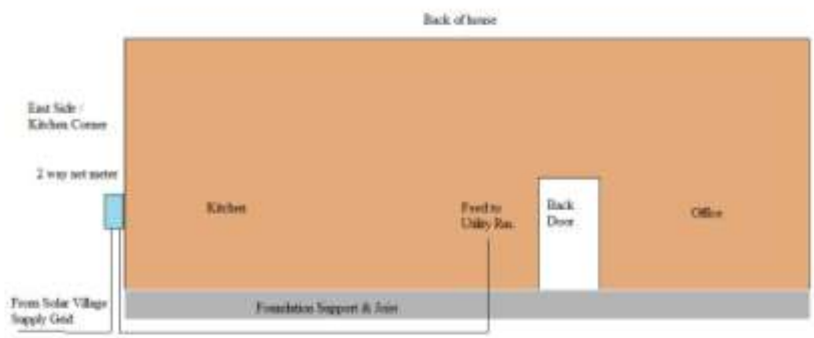


Figure 30: Electric Feed To House From Solar Village Grid.

The electrical feed from the solar village grid could also be fed underground, in a similar way like before when the meter was outside, and then run up into the house into the utility room to where the two way net meter would be located. However with running the electrical feed under the house both options would have to keep the main water supply a minimum 30 inches away from each other.

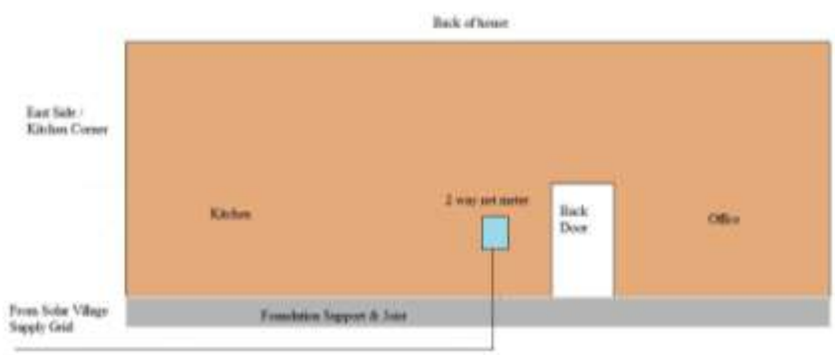


Figure 31: Electrical Feed To Utility Room.

2. Sewer Conection

Sewer connections from the solar house will all come together at one location, and leave the house. From all of the corresponding sewer starts, the plumbing will be ran down under the house within the spacing between the ground and the floor joists. All plumbing will have to have a pitch to it. With a pitch to the piping, the sewer runoff will be allowed to flow. If the piping was to have no pitch or too little of a pitch, sewer can become blocked or partially filled. All plumbing has to have the same pitch all going towards the main drain. Once reaching the main drain out the sewer will leave the house through underground plumbing. For the plumbing to function properly, all plumbing runs need to have their own ventilation. Ventilation is needed for the sewer to flow through the plumbing, otherwise the plumbing would work like a vacuum and no flow would be possible.

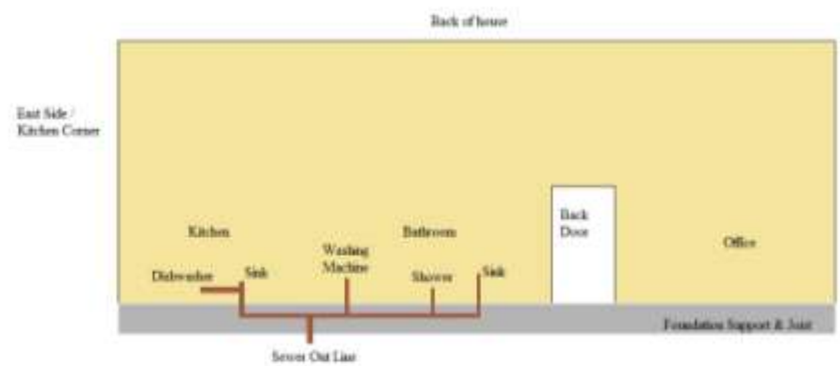


Figure 32: Sewer Runs.

3. Water Connection

Water supply to the house will also be supplied underground, to prevent damage from pedestrians. The water supply will then be connected to the house's supply line under the house. From the connection under the house, cold water supply then would be ran to the hot water heater, the sinks in the bathroom and kitchen, and to the bathroom toilet and shower. From the hot water tank, the hot water runs will then supply hot water to the same locations of the cold water.

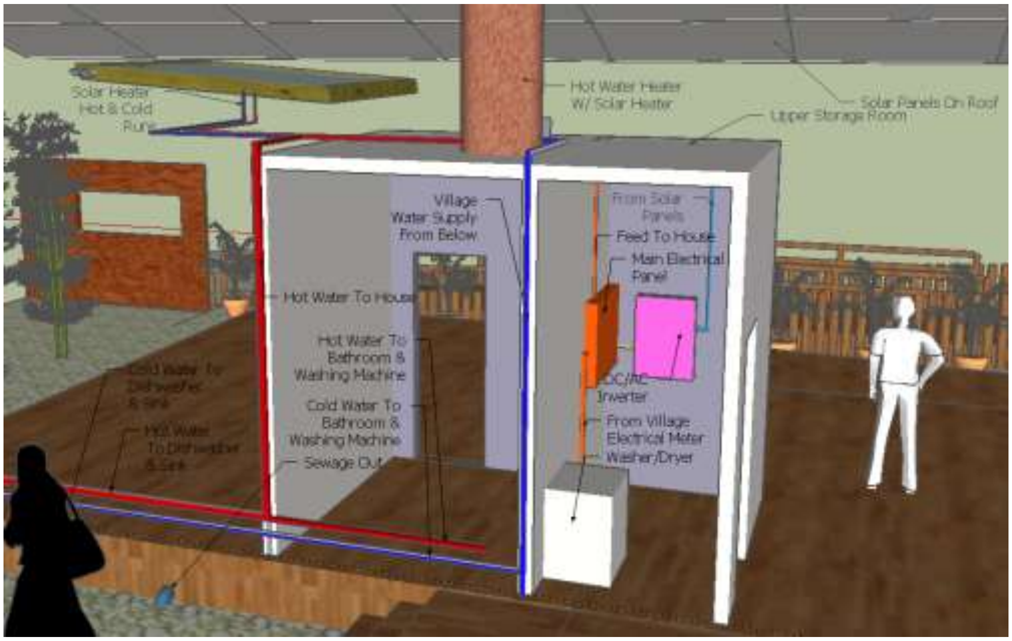


Figure 33: Water Supply.

C. Hot Water System

There are a few ways to heat water for the solar decathlon, by either using a solar pre heat system, solar with an on demand heater or only solar collectors. Each has its own advantages and disadvantages. With a hot water system, 1 BTU raises 1 pound of water 1°F. 1 gallon of water is 8.345 pounds, therefore 83.5 BTUs will raise 10 gallons of water one degrees F. To have enough water for mini contests and for the random water draws, up to three draws back to back, therefore an 80 gallon tank should be used. With the use of solar for hot water, either an active or passive solar system could be used. A passive system uses no additional energy to move the water throughout the system, while am active system uses a pump to circulate the water.

1. Solar Preheat

Using a solar preheating system the water would be warmed using the solar collectors, and then a traditional electric hot water heater would be used to get the water up to the desired water temperature. Therefore, with an 80 gallon tank and 40 gallons are heated to half of the desired temperature the heating element would need to heat the remaining 40 gallons. With an 80 gallon tank, the heating element(s) within the tank have an average power consumption of 5kW.

Therefore, if the tank takes an hour to raise the remaining water to the desired temperature there would be an additional 5kW of energy consumed by the house. The water tank in the house would both have to hold the water at its set point and not lose the water temperature over time, while also creating more of an energy draw on the house that is not expected.

2. Solar with On-Demand Heater

With a solar heat system with an on demand heater the solar collectors can heat the water and hold the water in a hot water tank to keep the water from losing its temperature. Then once hot water is needed the water runs through the on demand heater to increase the water temperature to or above the desire point. On demand systems are good because they can raise the water temperature 40°F while still keeping a good flow rate of water. To get the necessary water out during the water draws the water has to have at least 4 gallon/minute flow rate. With a flow rate of 4 gallons a minute, the normal increase in water temperature is 60°F. However, with the on demand system the power consumption of the heater is around 30kW, much more than what a normal electric hot water heater would use. But the on demand system would be on for less time than the hot water tank would be on for.

3. Solar Heat Only

The hot water system is important system for the solar house. It’s important because within the solar house competition, there is a hot water mini challenge. Having the competition, means there is a minimum standard in which is needed to be reached. Using a traditional electric hot water tank to heat the water takes a lot of energy however, since the main goal of the competition is to consume the least amount of energy, a traditional electrical tank would use way too much electricity. Therefore, a solar hot water heater system from Apricus would be better suited for the task. Using two 30, or more, evacuated tube systems to heat water in the hot water tank, would ensure the water reaches the necessary temperature. The evacuated tube systems would attach to the roof of the front section of the house, on the East side next to each other. Apricus system could be used because, for other solar decathlon houses in previous decathlons their systems have been used to meet the demands of the competition.

Figure 34: Placement of Solar Hot Water Collectors on Funnel Roof Design.

The hot water tank system takes the cold water into the house and feeds it through the hot water tank and through the solar collectors. Using a controller unit the water from within the tank can be circulated through both collectors and back into the holding tank to heat the water within. The controller will continue to circulate the water throughout to turn the tank temperature up to its desired temperature. Once hot water is wanted within the house, the water from the tank will then go out the hot out point to the rest of the house.

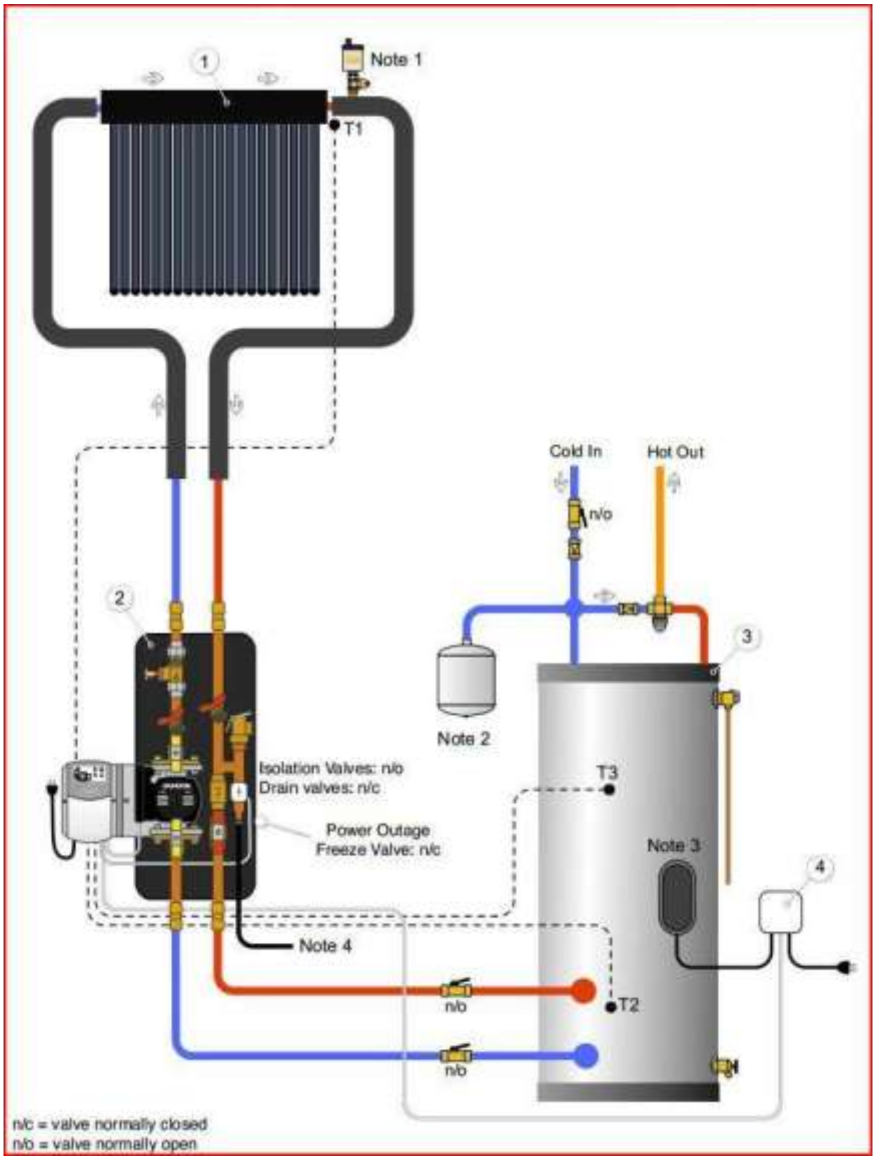


Figure 35: Solar Only Hot Water System.

According to the manufacture, the output of a 30 evacuated tube collector is 3412 BTU/hour. With the output of one collector, and a 40 gallon tank the water will increase 10.2°F per hour. With an eight hour day, the water temperature would increase 81.77°F. Therefore, if the cold water into the house is around 40°F, in the eight hours, the water would increase in temperature to 121°F. If two collectors are used, the water temperature would increase 20.4°F per hour making the water in the tank, after eight hours, reach 203°F. With a single solar collector, and an 80 gallon tank, the water would increase 5.1°F per hour. Therefore, over eight hours the water would increase 40.8°F making the temperature in the tank 80.8°F. However, using two collectors the water would increase in temperature 10.2°F per hour. Over eight hours, in the 80 gallon tank, the water temperature will increase 81.77°F, making the water temperature in the tank 121°F which is over the needed water temperature of the hot water for the competition, and will hold enough extra water for in the case of multiple water draws back to back.

D. Water Usage

Water usage in the solar house would be a mix between the use of hot water and cold water directly into the house. When using warm water, the water would be a mix between hot water from the hot water system and the cold water therefore while estimating the water usage, half the water is the hot water system.

For a family of three, if everyone was to shower in the day using 20 gallons for each shower the water used from the hot water is around 30 gallons total. However, for the toilet only cold water would be used for that, and estimating that each person is to use the bathroom 10 times during the day the toilet would use a total of 30 gallons. The dinner party cooking is only twice throughout the judging week. Therefore, the actual water usage is 28 gallons for that one time cooking, and is not considered for everyday use.

Table 7: Estimated Water Usage for a Family of Three

	Times Used a Day	Amount of Water Used Per Use (Gal)	Total Water Used (Gal)	Water From Hot Water Heater
Shower	3	20	60	30
Toilet	30	1	30	
Bathroom Sink	9	2	18	9
Kitchen Use	10	2	20	10
Dinner Party Cooking	14	2	28	14
General Cleaning	1	10	10	5
Washing Machine	2	45	90	45
Dishwasher	1	5	5	2.5
Watering Plants	50	0.2	10	
			271	115.5

A washing machine uses around 45 gallons for each use so the washing machine will use the most water of the components to use water. Watering plants will use around .2 gallons per plant therefore with an estimated 50 plants around the house the plants would 10 gallons total of cold water.

Therefore, each day the house would use around 250 gallons of water a day for a house of three people on average. Between 100 and 120 gallons of hot water would be needed in a day from the hot water system. Having an 80 gallon storage tank supply the 120 gallons throughout the day, with the water at least 120°F, the hot water system would be used very little throughout the day and the system would be able to maintain its 120°F water temperature.

E. Major Electical Loads

Table 8: Major Loads On House

Appliance	Peak Power (W)	Total Power (W)	Hours Per Day Running	Hours Per Week Running	Energy Used Per Week (W-h)
AC / Heater					
Option 1:					
2-10000BTU	1000	2000	8	56	112000
Option 2:					
12000BTU	1200	1815	8	56	101640
6000BTU	615				
Washer/Dryer	6500	6500	4	16	104000
Dryer	3500	3500	2	8	28000
Washer	1200	1200	2	8	9600
Dishwasher	1000	1000	1	5	5000
Refrigerator	75	75	4	28	2100

AC Option 1 w/ Washer & Dryer	156.7	kWh/week		22.3857	kWh/Day
AC Option 1 w/ Wash/Dryer	223.1	kWh/week		31.8714	kWh/Day
AC Option 2 w/ Washer & Dryer	146.34	kWh/week		20.9057	kWh/Day
AC Option 2 w/ Wash/Dryer	212.74	kWh/week		30.3914	kWh/Day

The major loads on the solar house are the big loads that have to be in the house and will be used to test the functionality of the house and the ability of the house to keep a net of zero consumption. The major loads correlate back to the mini contests to test the house as if someone was to be living in the house. Depending on the combination of the components chosen the load can range between roughly 21 and 32 kWh/Day consumed. Of course every day will be different depending on the contests that day and the weather. Also the amount of energy created throughout the day from day-to-day using solar panels will be different depending on the weather.

The estimated time for the refrigerator running throughout the day was estimated for the refrigerator to be running for a half an hour at a time every 2.5 hours. The air conditioning and heater units were also estimated for running a total of 8 hours a day, which will also depend on the weather like a lot of things. The washer and dryer both are estimated to have one hour cycles. Since there are two loads of laundry a day, decided in the mini contest rules, the hours correlate to that. The dishwasher however is thought to have an hour long cycle and will only be used on the party night contest.

The house has been calculated that it needs roughly 18,000 BTU's for cooling and heating, found by Dr. Wang's Sp. 2012 ELEC 220 class looking into the heating and cooling. Therefore, there is one option of having 2-10,000BTU wall hung units, one in the living room and one between the office and bedroom. The other option would be to have one 12,000BTU unit in the living room and a 6,000BTU unit between the bedroom and office.

In a normal house hold, the energy consumption is drawn throughout the day is focused towards the middle of the day. The reason the draw is mainly in the middle of the day to the afternoon is because the heating and cooling of the house is needed more when the house is being used and the outdoors temperature reaches its maximum point. Between heating and cooling, using the washing machine and other electrical devices, the use of electricity is at its greatest point.

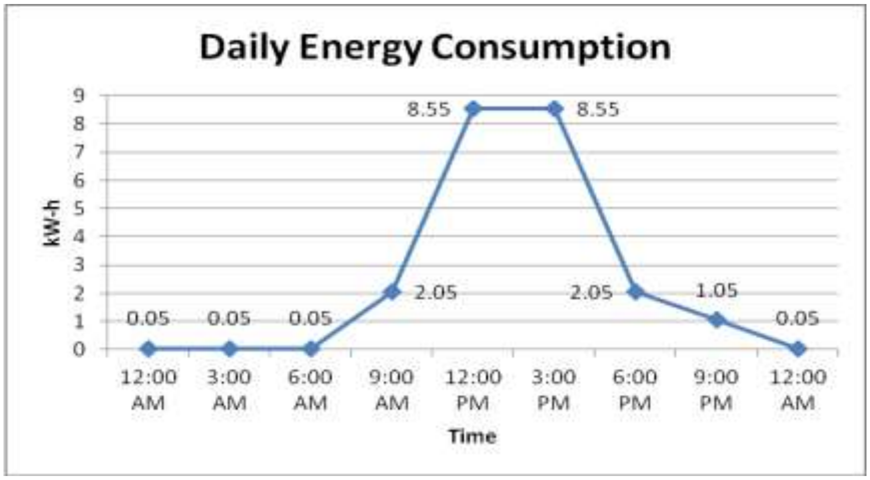


Figure 36: Estimated Traditional Daily Energy Consumption.

Since the solar house will be generating its own power to feed back to the grid, the electrical draw of the house does not want to have a giant spike in it. Estimating the energy usage throughout a normal day is graphed in figure 36. In the middle of the day and early afternoon is the best and most productive portion of the day to produce electricity. A large spike uses up a large amount of energy and the system can not recover to a net energy use. Therefore, smaller more manageable electric spikes throughout the day would be best. Having smaller spikes throughout the day will help with the regeneration of electricity. Using a little energy at a time and then having the solar panels produce that amount back to maintain a net energy use of zero would be best. With having one huge spike within the day would draw a lot of energy and therefore the rest of the day would be spent trying to generate all the energy back that has already been consumed.

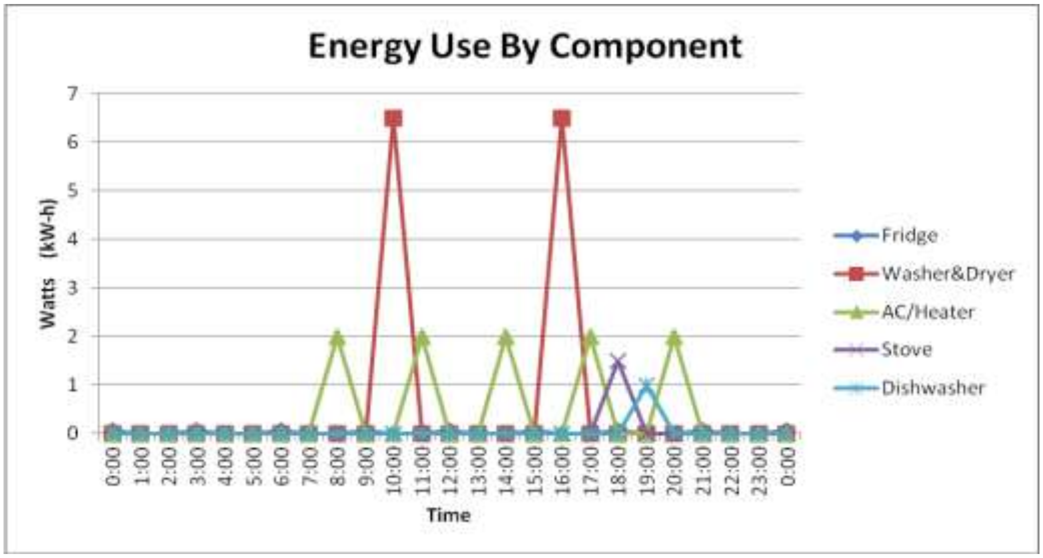


Figure 37: Energy Use by Component Throughout Day.

Each component has its own maximum point in which it would reach while operating. Creating a time schedule of when components are able to run throughout the day, enables the ability to estimate the smaller energy spikes throughout the day. Since each has its own maximum energy use point and instead of having everything run at the same time, creating a scheduled time in which components can turn on and operate will reduce the number of spikes to smaller more manageable spikes..

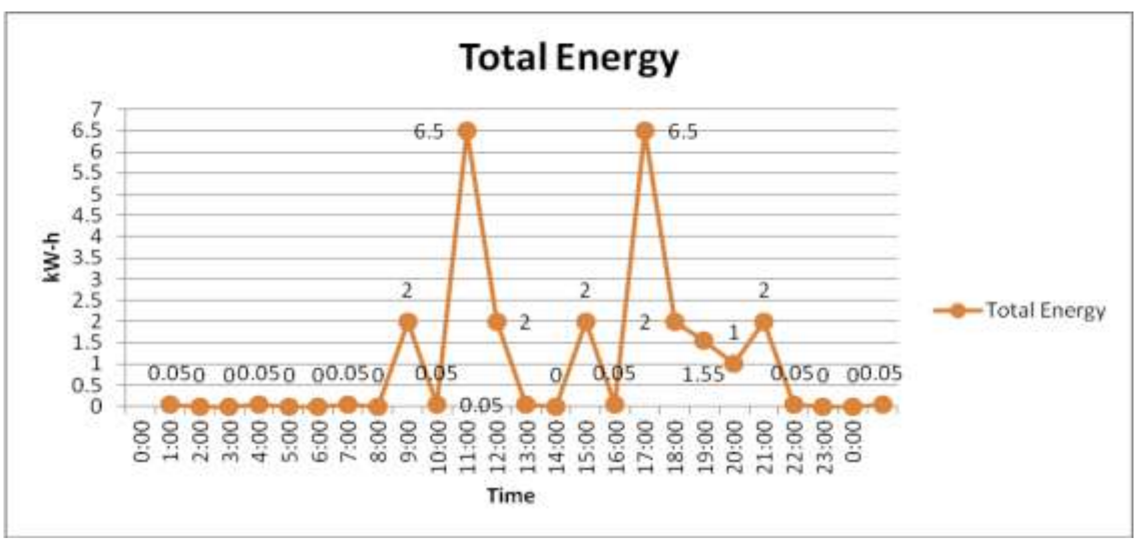


Figure 38: Daily Energy Consumption.

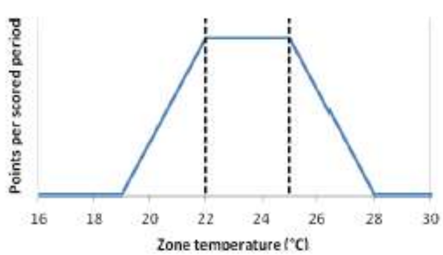
As seen in the daily energy consumption, with all the electronic components turning on throughout the day, instead of all at the same time, the estimated energy consumed is much smaller. With the energy consumption spread out throughout the day, there are much smaller mini spikes throughout the day. The largest spike throughout the day is during wash times.

F. Mini Contests

During the month of the China Solar Decathlon, one week will consist of mini contests, testing the durability of the house and acting as if people were living within the solar house. There are a total of 10 contests. The main two contests of the competition that are a big concern, that consume the greatest amount of electric energy are the comfort zone contest, and the appliance contest. Within each of these two contests there are multiple sub-contests. The comfort zone contest is split into two sub-contests, the temperature and humidity. The appliance contest is broken down into five sub-contests, refrigerator, freezer, clothes washer and dryer, and dishwasher. All contests combined total 1,000 points for full credit.

1. Comfort Zone Contest

The comfort zone contest is out of a total of 100 points, and the temperature sub-contest is 75 points out of the 100 points. All points are earned at the end of the scoring period by keeping the interior dry-bulb temperature between 22^0C and 25^0C. Partial score can be earned when the interior dry-bulb temperature of the house is measured between 19^0C and 22^0C or between 25^0C and 28^0C.



Full points:	22	°C	≤	Temperature	≤	25	°C
Reduced points:	19	°C	<	Temperature	<	22	°C
or	25	°C	<	Temperature	<	28	°C
No points:				Temperature	≤	19	°C
or				Temperature	≥	28	°C

Figure 39: Comfort Zone Scoring Chart.

Through some rough calculations, done by Dr. Wang's spring 2012 ELEC 220 class, calculated the heating and cooling capacity needed for the entire house to be around 18,000 BTU's. With the estimated size of heating and cooling needed units were then looked at to compare both the heating and cooling capacities versus the energy consumption. Instead of having to run duct work throughout the home from the heating and cooling units, wall units were chosen. Wall units come in common sizes of 6000, 10,000, 12,000 and 18,000 BTU/hr. Knowing the common sizes for wall units, the consideration of one or multiple units was looked at. Multiple options were looked at. Three options were considered. One option was using two 10,000 BTU units. Another option was to use one 12,000 BTU unit and one 6,000 BTU unit. The third option was using one 18,000 BTU unit. Using one 18,000 BTU unit, with a power rating of 1,800 Watts, would not be practical, because one side of the house would be over cooled and heated, and would consume too much electricity. For the second scenario of using two 10,000 BTU units would be more useful because the heating and cooling would be split between the two sides of the house. Each unit would consume around 1,000 Watts. The third option would be to have a 12,000 BTU unit at 1,200 Watts and a 6,000 BTU unit at 600 Watts. Using the two different sized units will allow for when more activity is going on in the living room and kitchen side the unit will be able to handle the load, while the other side would not be used as much.

2. Appliance Contest

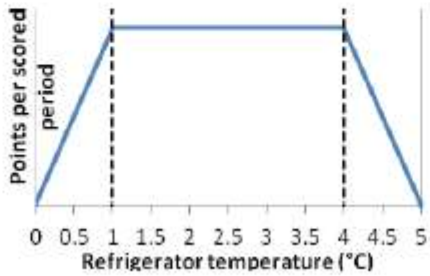
The appliance contest is out of a total of 100 points and each sub-contest has its own score towards the 100 points.

a. Refrigerator & Freezer

10 points are earned for the refrigerator sub-contest, if the refrigerator keeps an interior temperature between 1^{0}C and 4^{0}C. Like the temperature sub-contest, partial points can be earned by keeping the temperature a little above or a little below. Partial earning of points are earned if the temperature is kept between 0^{0}C and 1^{0}C or between 4^{0}C and 5^{0}C. Another restriction to the refrigerator contest is the minimum volume of the fridge shall no less than 170L.

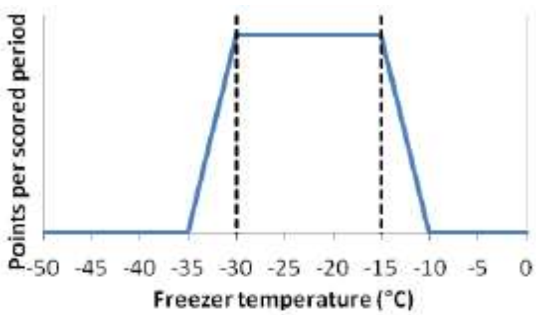
The freezer sub-contest is also worth 10 points out of the 100 total points in the appliance contest. The freezer needs to be able to have a measured interior temperature between -30^{0}C and

-15⁰C. The minimum volume of the freezer is to no less than 57L. The automatic defrost function may be disabled as well.



Full points:	1	°C	≤	Temperature	≤ 4	°C
Reduced points:	0	°C	<	Temperature	< 1	°C
or	4	°C	<	Temperature	< 5	°C
No points:				Temperature	≤ 0	°C
or				Temperature	≥ 5	°C

Figure 40: Refrigerator Scoring Chart.



Full points:	-30	°C)	≤	Temperature	≤ -15	°C
Reduced points:	-35	°C)	<	Temperature	< -30	°C
or	-15	°C)	<	Temperature	< -10	°C
No points:				Temperature	≤ -35	°C
or				Temperature	≥ -10	°C

Figure 41: Freezer Scoring Chart.

The issue with the refrigerator is that the refrigerator runs all day and every day. Therefore an energy efficient unit is needed to consume the least amount of energy throughout the day while being large enough to meet the contest rules. The insulation of the refrigerator was looked at and determined that refrigerators that have water and ice dispensers are less efficient. Therefore, refrigerators with these features were not looked at.

b. Clothes Washer

Points are earned by the clothes washer when, laundry is washed through the washer in one or more complete, uninterrupted, “normal” cycle(s) within a given period of time. A total of 20 points, of 100 points, can be earned by the washer. The laundry load is defined as six bath towels. The washer is to automatically operate and have at least one wash and rinse cycle. During the contest week, teams are required to do two loads of laundry a day. Teams will have the option to combine double loads and wash them together in one load. The drying portion of a combination washer/dryer unit has to be disabled, to verify that the laundry is wet when the wash and rinse cycle is done. The completion of a wash cycle has to have an audible or visible completion signal.

c. Clothes Dryer

The clothes dryer can earn up to 40 points of the total appliance contest score. The clothes dryer earns the points by having a total weight of the laundry load is less than or equal to the original weight of the towel. The drying of the towels is to be completed within a specified period of time. Partial points are earned when the towels are dried to the point when the towel weight is between 100% and 110% of the original towel weight. Full points are earned if the weight of the dried towels are less than 100% of its original weight.

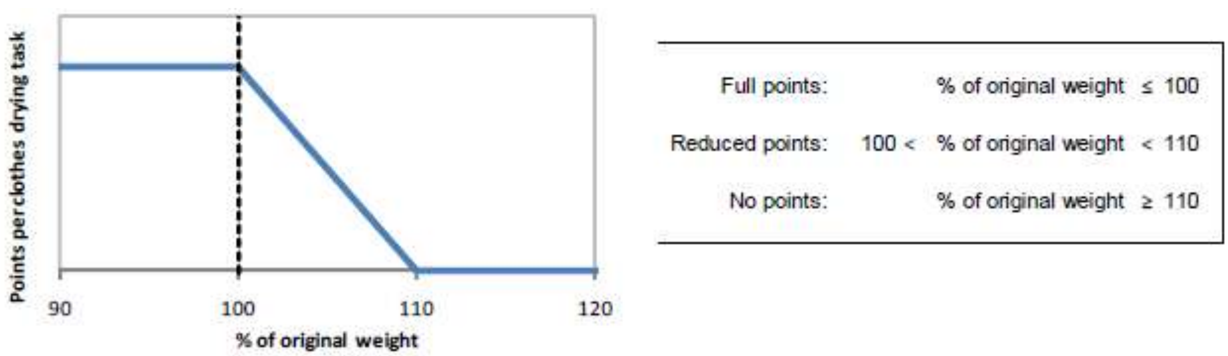


Figure 42: Clothes Dryer Scoring Chart.

Two options were looked at for the washer and dryer units. One option was to have an individual washer and dryer, the other option was to have a combination washer / dryer unit. Using an individual washer and dryer will increase the space used within the house. However, a combination washer and dryer unit would only take up half the space of an individual washer and dryer. The combination washer/dryer unit is self-contained all within within one unit. Therefore, there would be no need to switch over the laundry. However, the energy consumption of a washer / dryer combination unit is around 6.5kW.

d. Dishwasher

The dishwasher earns 20 points when the washer completes a full, uninterrupted cycle within a period of time. During the cycle, the dishwasher must reach 50^{0}C at some point during the cycle. Half of the points are earned if the temperature sensor reaches 45^{0}C but not 50^{0}C. The dishwasher must have a minimum capacity of six place settings. The drying cycle of the washer must be disabled during the competition.

e. Hot Water

The hot water contest is measured by judges taking water draws throughout the day. Each draw throughout the day will be at least 60 L (15.8 gal) of water, that must be delivered within 10 minutes. The average temperature of the water needs to be at least 45℃ (113°F) for full points and must not fall below 38℃ (100°F). Partial points are earned for an average water temperature delivered between 38℃ and 45℃. The hot water draws are designed to simulate washing and bathing that would occur during the day in a normal home. However, the water draws will have different schedules from day to day, to simulate the variation in normal routines. The maximum number of draws in one day will not exceed three, but could occur back to back. Therefore, the hot water tanks need to be large enough for three draws but not just large enough because of the new incoming cold water in the tank will lower the water temperature. With a 303 L (80 gal) hot water tank, there would be enough if there was three draws consecutively, and still have half a hot water tank of hot water to run other appliances, and not start with complete cold water in the tank.

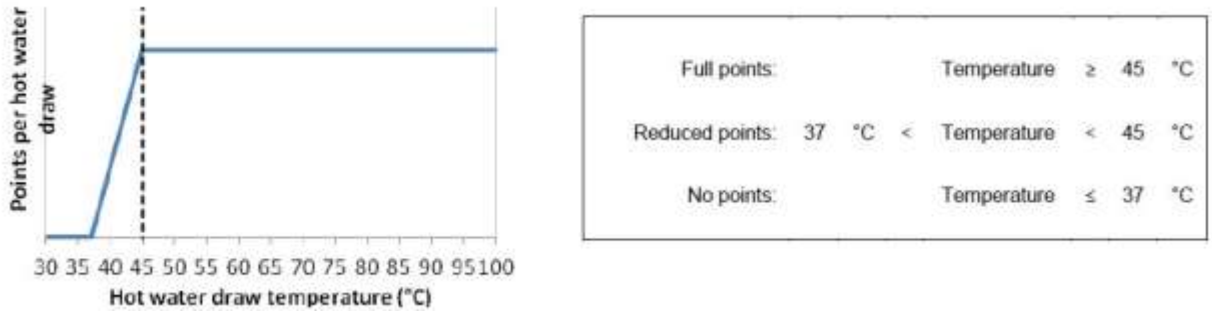


Figure 43: Hot Water Scoring Chart.

G. Components For Wiring Home

Table 9: Wiring Components For Solar House

Circuit	Wire Size	Breaker Size	Length Of FMC Wire (ft)	Outlet Boxes	Junction / Octagon Boxes	Switches	Lights
Outlet Circuits							
Bedroom	12 AWG	20 Amp GFCI	45	4	1		
Office	12 AWG	20 Amp GFCI	37	3			
Utility/Bath	12 AWG	20 Amp GFCI	26	5			
Living Room	12 AWG	20 Amp GFCI	77	6	1		
Refrigerator/Microwave	12 AWG	20 Amp GFCI	17	1			
Kitchen	12 AWG	20 Amp GFCI	26	3			
Wash/Dryer	8 AWG	35 Amp	12	1			
		Total	240	23	2		
Light Circuits							
Bedroom	14 AWG	15 Amp	41		2	1	1
Office	14 AWG	15 Amp	26		2	1	1
Utility Room	14 AWG	15 Amp	15		1	1	1
Living Room	14 AWG	15 Amp	55		3	1	2
Kitchen/Dinning Rm	14 AWG	15 Amp	55		4	2	4
Bathroom	14 AWG	15 Amp	16		1	1	1
		Total	208		13	7	10
		Totals	448	23	15	7	10

For the solar house, a total of about 450 ft of electrical wire will be used. Using 12 gauge wire for the outlet circuits, just under 250 ft will be used. Having a spool of 250 ft of 12 gauge wire will give room unseen measurements or troublesome wiring issues. For the lighting circuits just over 200ft or 14 gauge wire is estimated to be needed for the wiring lights and switches. Having a 250ft spool of 14 gauge wire will also allow for additional unseen factors.

H. Solar Panels and Grid Tie

Since the main goal of the Solar Decathlon competition is to have a net energy use of zero, with all the electrical components within the house drawing energy from the grid, there would be no possible way to have a net energy use of zero, without the production of electricity. Therefore, the use of solar panels will be used to create energy to feed back into the grid. On the back portion of the solar home will be room for 28 solar panels. The roof angle will be roughly 30^0 to match the angle of the sun during the duration of the solar decathlon. The amount of energy created will depend on the weather of Datong during the solar decathlon. With an average of 21 to 32 kW consumption per day is easily obtainable with a solar panel array.

1. Solar Panels

The solar panels that will be used are a standard 1m by 1.6m 220W panels. Using the area on the back roof there should be enough room for 28 panels, leaving a little over an inch between panels. Using 28 panels that are rated for 220W's the total energy that could be created would be a little over 6.1kW.

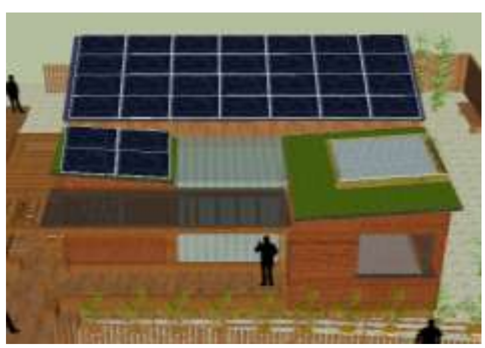


Figure 44: Solar Panel Layout for Funnel Roof Design.

Using 28 solar panels, when all the panels are in direct sunlight and are at maximum production, the system can create 6.1kW every hour. Therefore, if the panels are at maximum production for four hours, and producing 6kW every hour, the system would produce 24.4kW.

When mounting the panels to the roof, the panels will be connected to a rail system. The bottom rail will have a stop preventing the panel from sliding down and off the roof if the mounting bolts holding the panel to the rails came loose. Besides the stop rail the upper rail will have mounting bolts holding the panel to the rail.

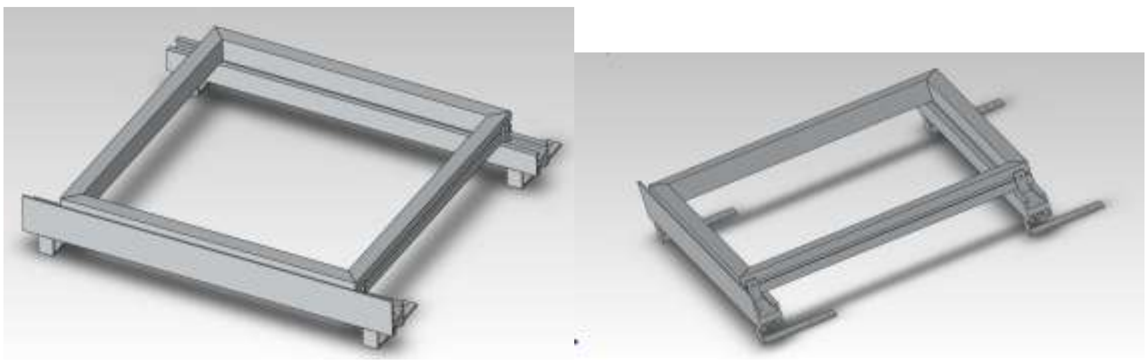


Figure 45: Solar Panel Mount.

The mounting rails and panel will need to be connected to the roof in some way. Therefore a roof bracket will be implemented to connect to the rails. There will be a bracket every 3ft to take the load of the panel and connect it securely to the roof.

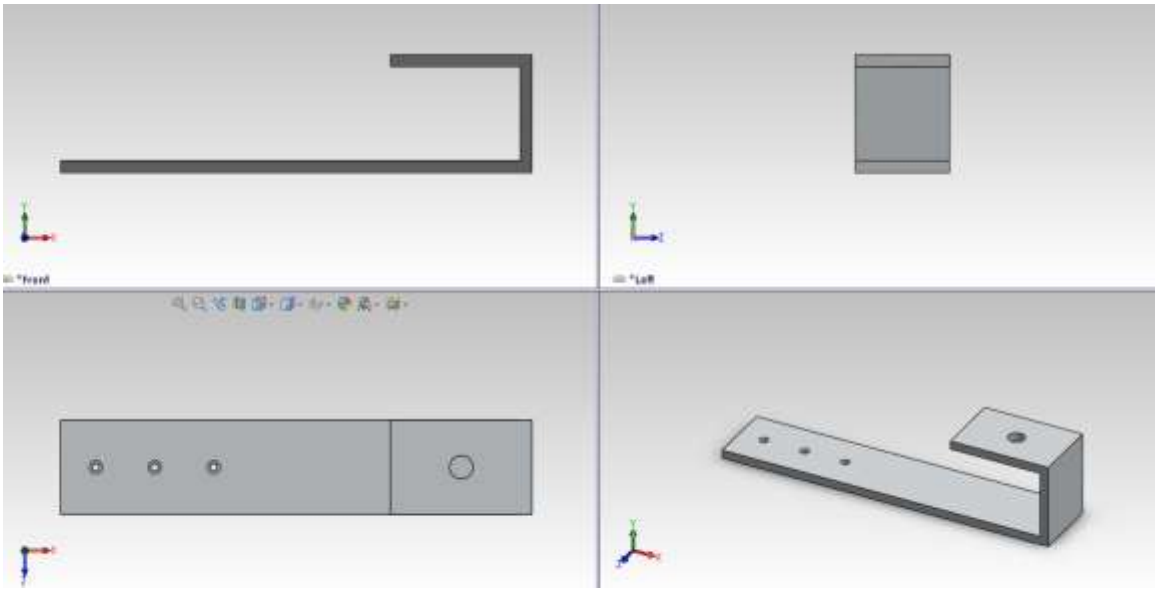


Figure 46: Solar Panel Rail Mounting Bracket.

Depending on the material the roof is covered with, whether its shingles, terracotta, or a tin roof, the only part that would change is the mounting bracket. Everything else would be able to stay the same and connect the same way.

The solar panel that would work for this application would be a Kyocera KD220. The panel has a power rating of 220W, 30 Volts and 8 Amps is the maximum power measurements. The panel also meets the 1m by 1.6m size.

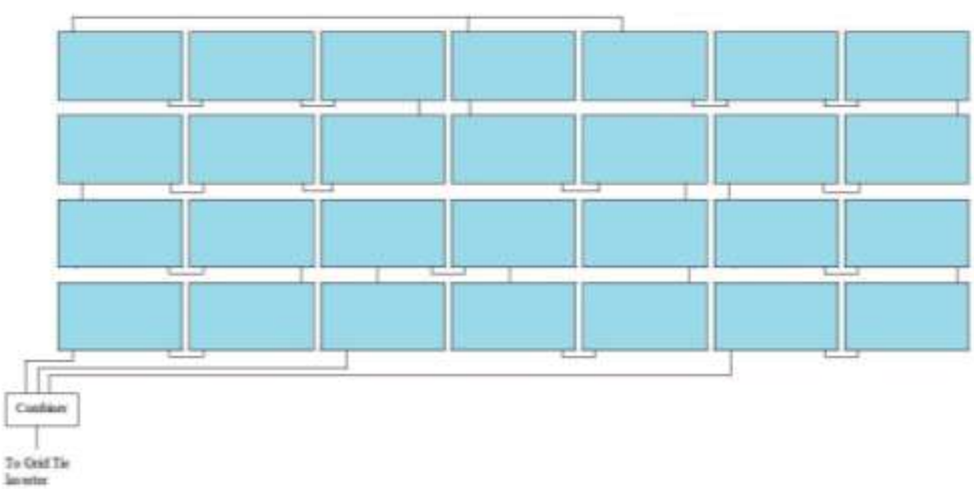


Figure 47: Solar Panel Wiring.

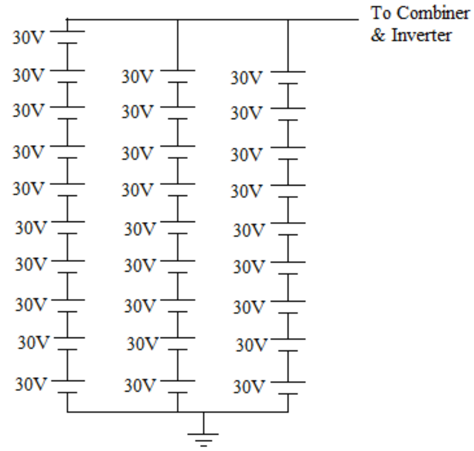


Figure 48: 28 Panel Equivalent Circuit.

The wiring of the solar panels on the solar house will be a combination of connecting them in parallel and series. The solar panels are going to be broken up into three sections. The panels are split into groups with a minimum of eight panels per group. These eight panels will be connected in series with each other in increase the voltage to at least 270V, therefore, more than the rated voltage of the line coming in. Each group will be in parallel with each other, to help boost the current from the panels, and keep the voltage the same. However, if there is the need for additional panels, panels can be added to the West front section of the house, above the bedroom. These panels would have to raised on one side to level then to make the panel face South to be productive. Since a 28 panel system is not equally divided, a combiner would be used to combine the arrays of panels into one line to the inverter.

a. Additional Panels

i. Funnel Style Roof

Additional panels could be used to increase the overall production of the house throughout the day. However, the grid tie inverter would need to be upgraded, and there would be a need for additional roof area to place these solar panels. The amount of additional panels is determined by the amount of area available for these panels.

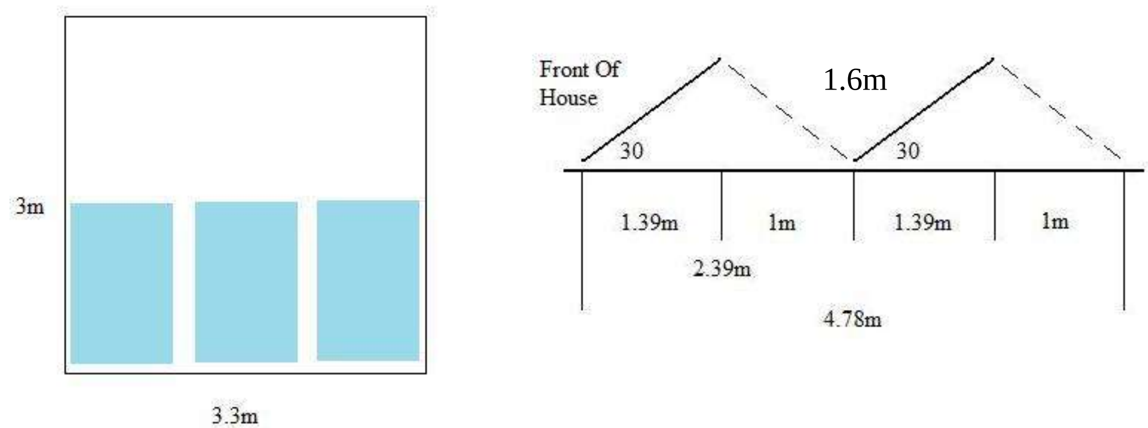


Figure 49: Additional Panels, West Wing Upright.

The front West wing of the house could be used for these additional panels. The area of the West roof is 3.3m by 3m. Using the same panels as before, measuring 1m by 1.6m, the panels could be placed either on their 1m side of on their 1.6m side down. Placing the panels on its 1m side down, against the roof, the panel would take up 1.39m when the panels are angled at 30°. The shadow from the panel in front to the back panel would be 1m in length. The distance the panel would take up is found by $((\sqrt{3})/2)*(\text{panel upright length})$. The upright length of the panel would be 1.6m in this case. The shadow distance is found by $(\text{panel upright length})/1.5$. Using the panels upright like so, allows for only one row of panels to be used otherwise the second row would cast a shadow on the main panels on the main roof. Putting the panels upright allows for three panels to be aligned across the front of the house to capture more sunlight.

Changing the panels on the West wing of the house to lay on their long side, the 1.6m side, only two panels can be placed across the front of the house. However with only having two panels on their longest side, the panel's upright length is much less, casting a smaller shadow.

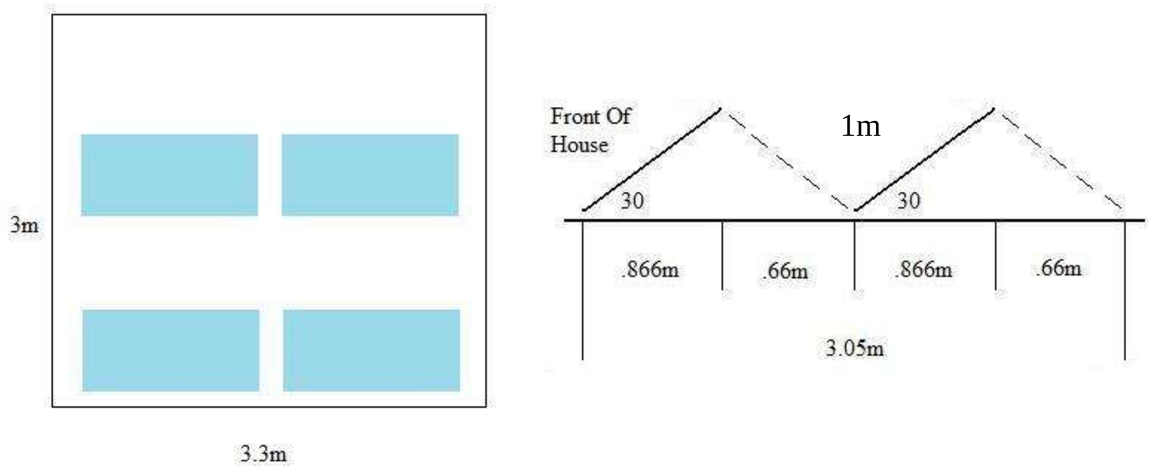


Figure 50: Additional Panel, West Wing Sideways.

With the panels on their side the shadow cast by the panel is only .66m and the distance the panel would take up at 30° would only take up .866m. Therefore, with much less distance being used by the panel itself and the shadow casted by the panel. This set up allows for two rows of two panels, side by side, to be used versus one row of three panels. Having one more panel will allow for a possible additional production of 220W.

With having an additional four panels, the wiring would have to be changed to tie the other panels to the inverter. To tie the additional panels to the inverter with the other panels the four panels would be added to one of the strings from before.

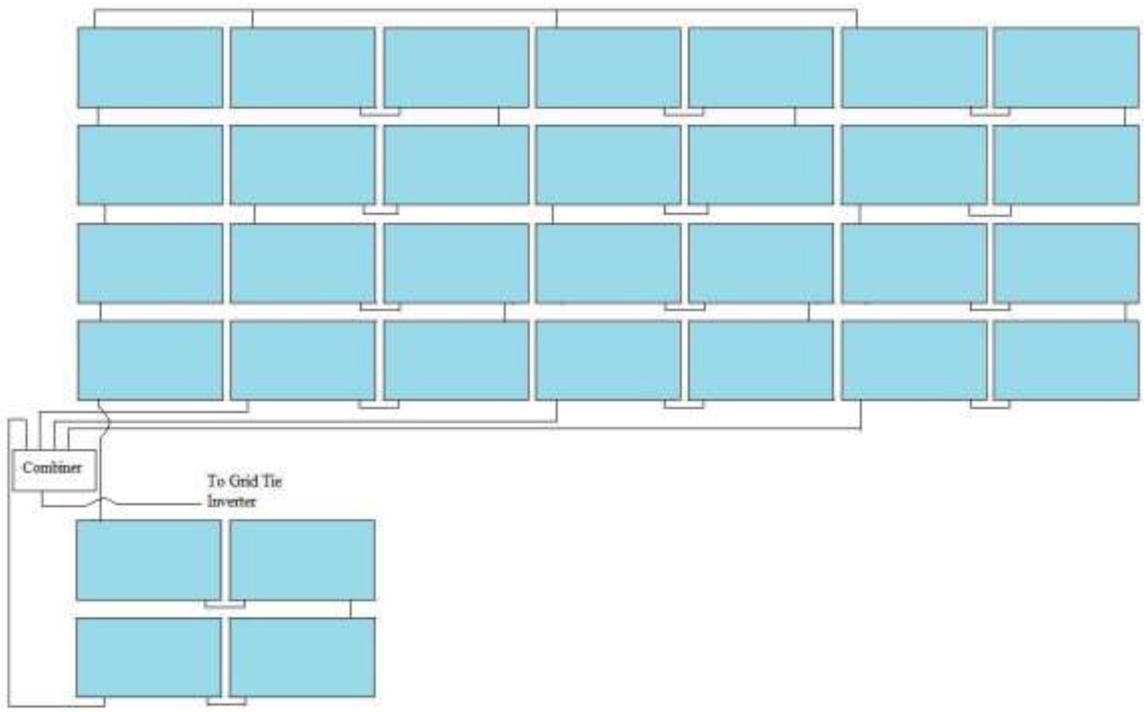


Figure 51: Funnel Roof Additional Panel Wiring.

The original wiring had two runs with of nine panels to have a voltage of 270V, and one run of 10 panels. With the additional four panels, the panels could be split up evenly into four runs of eight panels each. Therefore, keeping the voltage of all the runs at 240V and the current roughly the same when brought together.

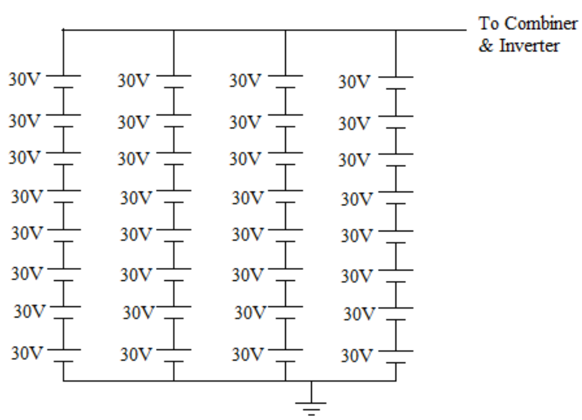


Figure 52: 32 Panel Equivalent Circuit.

With adding four more panels, the total number of panels would be 32. Each panel is rated for 220W; therefore, the power production of the system needs to be upgraded to a 7kW system with a 7kW inverter. Therefore, with a 7kW system the system at maximum production would create 7kW every hour, so to create 24kW the system would need to be in direct sunlight for 3.4 hours.

ii. Saw Tooth Style Roof

With the saw tooth style roof there is room to place a total of 41 solar panels flat on the roof. With being able to place the panels flat on the roof, and the roof sections both set at 30°, shadowing from panels will be avoided while also allowing for all panels to be perpendicular with the sun. With 41 panels and using 220W panels the system will then be bumped up to a 9kW system. Like in the 6kW and 7kW systems, in direct sunlight the maximum production is 9kW every hour. Therefore to have a net energy of zero, and produce 24kWs, the solar panels would need 2.6 hours at maximum production.

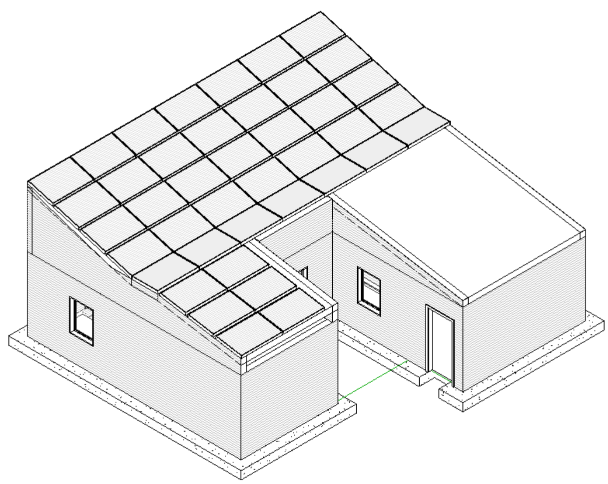


Figure 53: Saw Tooth Panel Layout.

Wiring for the saw tooth roof is different than the wiring for the 32 panel roof layout because it is 41 panels, therefore each run will not be all the same. A combiner would be used again to combine the four arrays of panels into one line to the inverter.

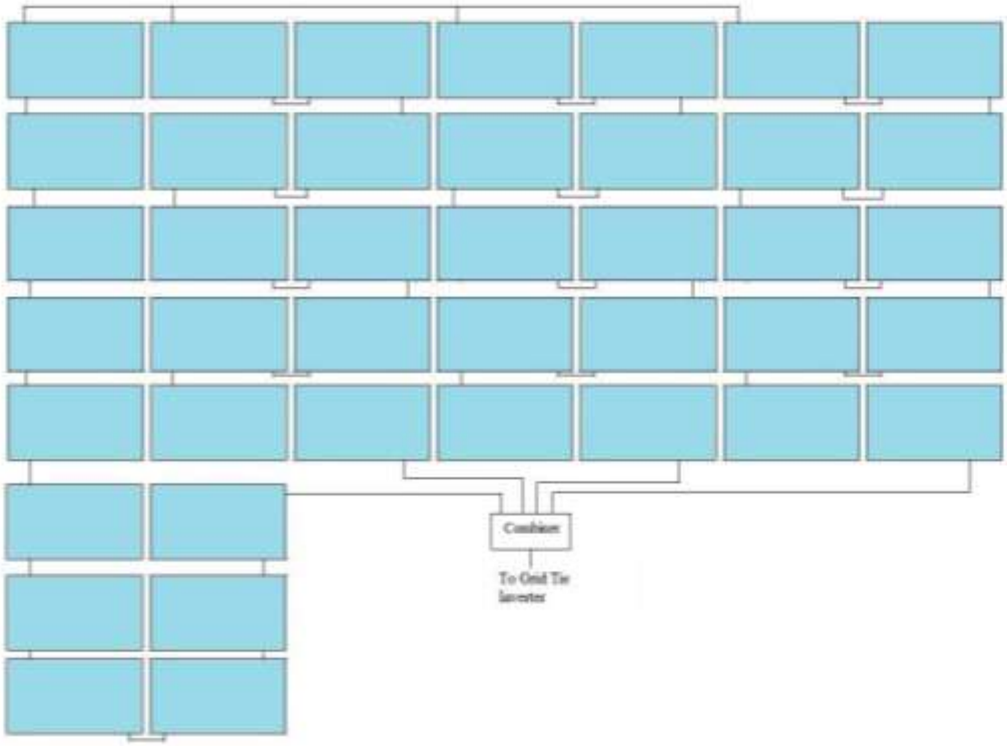


Figure 54: 41 Panel Wire Layout.

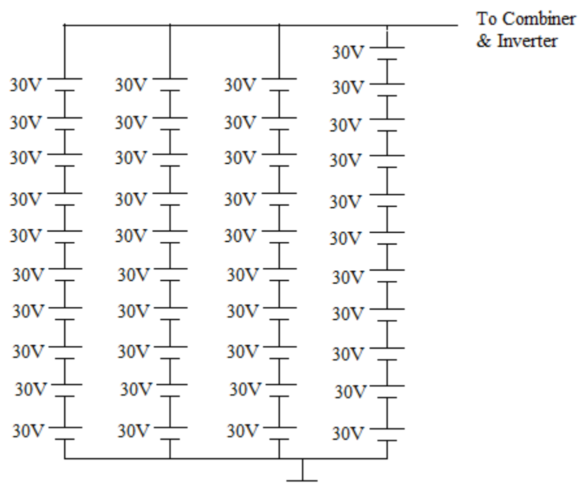


Figure 55: 41 Panel Equivalent Circuit.

2. Grid Tie Inverter

The grid tie inverter will take the DC from the solar panels into the grid tie and transforms it to AC power. With the solar decathlon being in China the frequency is 50Hz and

220V. Also with 28 panels at 220W, 6kW of power could be produced by the panels therefore a 6 kW inverter is needed. For the grid tie inverter, a 5 kW inverter from Schneider Electric would work. The inverter has a max DC power input of 5300W. The 864-1039 Xantrex grid-tie solar inverter would take the DC from the solar panels and convert the power to AC and feed the electric back to the grid. The inverter also outputs 220V at 50Hz AC which is what Datong China's grid operates at. For the house to have a net of zero energy, for the day, the solar systems would need a little over six hours of maximum output from the panels to meet this goal.

Figure 56: Schneider Electric 5kW Xantrex Grid-Tie Inverter.

With one of the other two paneling setups, the 32 panel arrangement would need a 7kW inverter to convert the DC to AC at China's voltage and frequency. With a 7kW inverter system instead of taking six hours to produce the estimated 30kW per day, it would only take four and a half hours. The Schneider Electric 5kW grid tie inverter would need to be replaced with a 7kW inverter. An inverter from SunnyBoy, the Sunny Mini Central 7000TL, would work. The inverter is transformerless, and meets the standards for China's grid connections. The inverter has an efficiency of 98%.

With the saw tooth roof style, and 41 panels the system could produce up to 10kW. This system would need an even larger inverter, however to produce the estimated 30kW would only take three hours to produce, at maximum production. For the saw tooth roof design the panels could produce up to 10kW, therefore an even larger inverter is needed. The SunnyBoy Sunny Mini Central 10000TL, system is equivalent to the 7000TL unit. The 10000TL is also transformerless, and meets the grid standards of China. The unit, like the 7000TL, also has a peak efficiency of 98%.

I. Atrium

1. Thin Film

A glass atrium in the center of the house was looked at initially as a heat source throughout the day. However, through initial calculations the glass atrium would draw in too much thermal energy into it and the house. By collecting too much heat into the atrium and into the house, the atrium makes the cooling system turn on more throughout the day than desired, and using more electricity than planned. To overcome this issue, thin film solar panels could be placed between two panes of glass, to form the atrium. The outside layer would be Corning solar glass and inside pane would be a standard pane of glass. The Corning solar glass in front of the thin film solar collector would be used to allow as much sunlight through as possible to the window pane. With a double layer of glass and the thin film between the panes, not all the light will be passed through into the atrium. The thin film panels would create additional electricity depending on the amount of sunlight on the atrium. Using the thin film could be used to control the total amount of light coming through the panes of glass. The thin film between the panes would act like a blind restricting sunlight into the atrium. The thin film solar panels could also be used in all of the standard windows throughout the house. Using the thin film can restrict all of the light or allow some light through the other windows. On doors that face South or partially South, the thin film technology could be used. The back doors and windows should not have the thin film placed within them because they are facing north and will not receive any sunlight on them, and the windows could be used as emergency exits to exit the house.

2. Thermal Panels

On front of the glass atrium in the middle of the solar house could be a set of thermal panels from rigidized metal. The thermal panels will help collect heat from the sun, to be use to help heat the house, if there is the need to heat the house. The thermal panel pumps air from the panel into the house. The use of the thermal panels will also help reduce the amount of sunlight being obtained by the glass atrium. Since we already know the glass atrium is going to collect too much heat, the thermal panels will reduce the amount collected, by blocking some of the sun's rays. The panels will also allow for better control of the amount of heat allowed into the house through its pump. The active system would utilize an electric blower to move the warm air into the house.

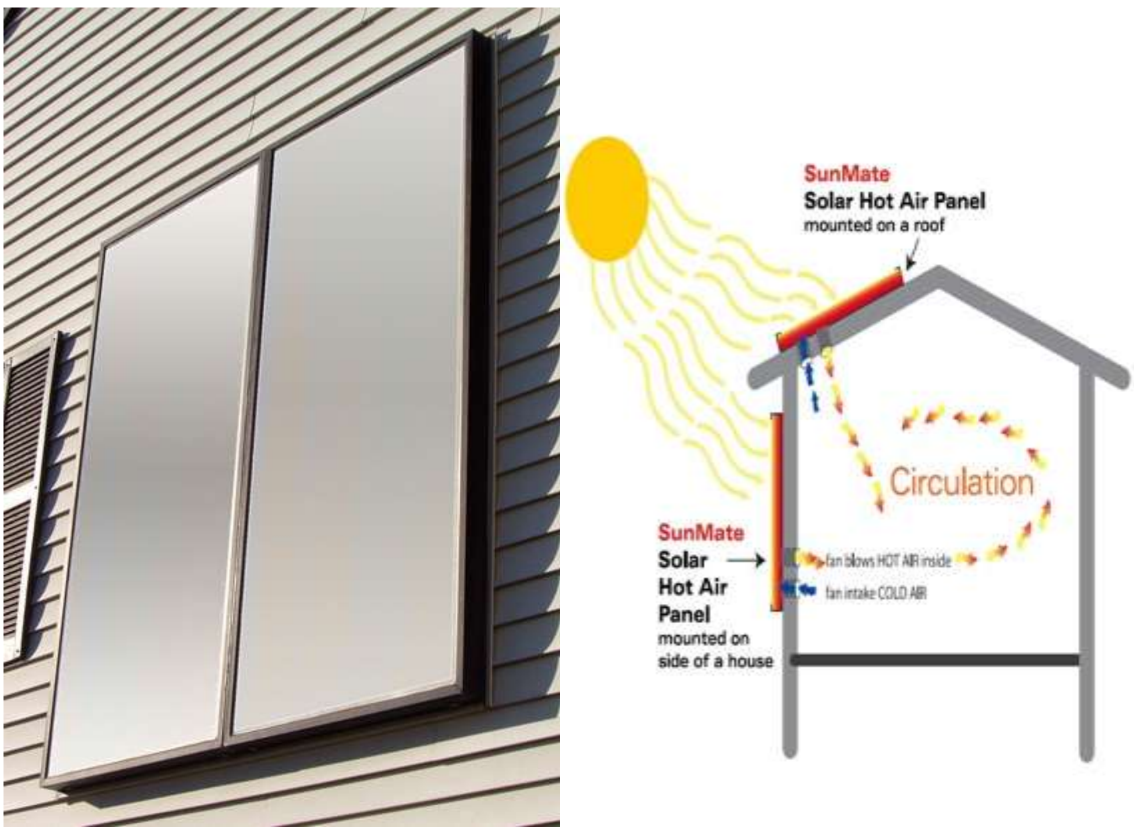


Figure 57: Thermal Panels.

J. Control Systems

The control system within the house will both monitor and control the electrical devices. The control modular will displace the amount of energy being consumed by the house and the amount of energy being produced by the house.

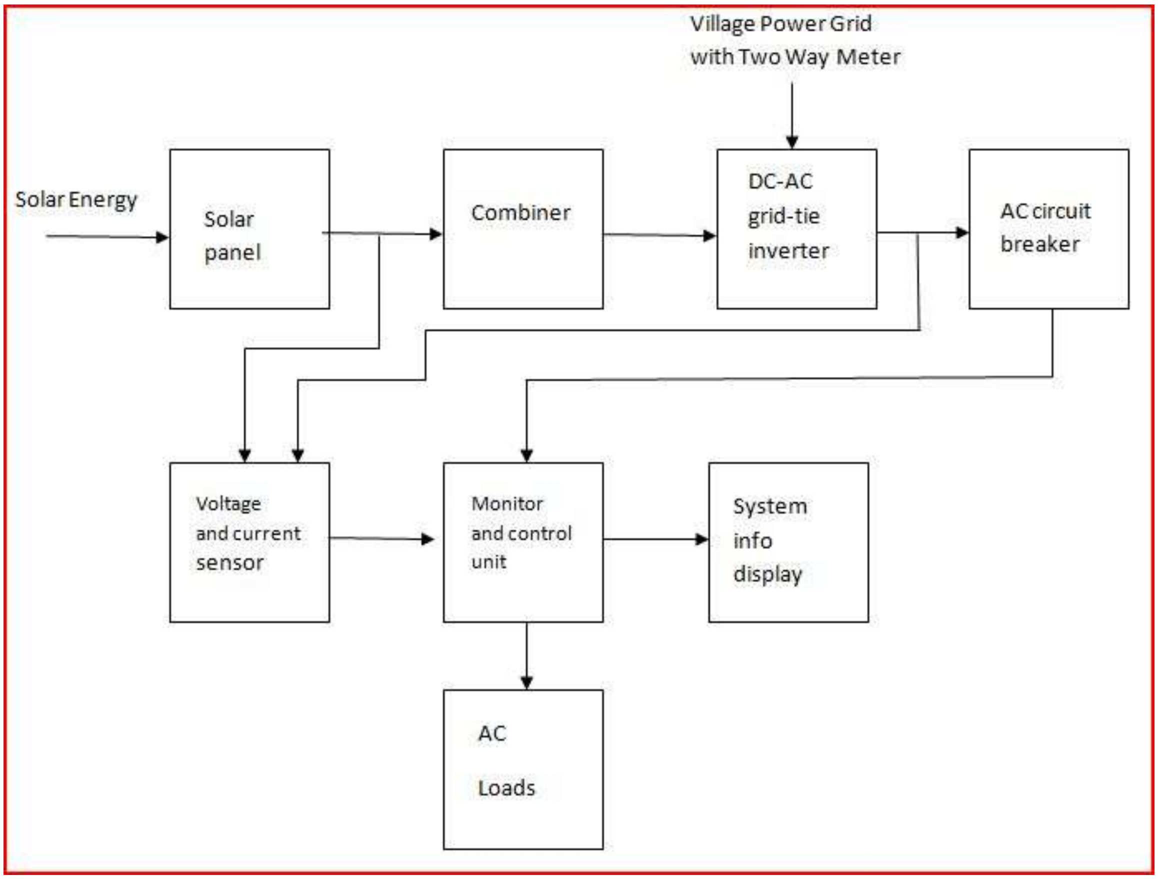


Figure 58: Energy Management Block Diagram.

The control unit for the application would be a building controller from Schneider Electric. Using a building controller unit from Schneider Electric the unit heads the entire system while being able to be accessed to a network for viewing and programming. With the controller unit, an expansion I/O unit(s) the controller is able to be programmed to handle to more than 8 nodes.

Using a Schneider Electric Room Controller, the controller would communicate back to the controller for heating and cooling within the rooms. The controller could also be equipped with passive infrared for demand based occupancy control.

The system needs to be able to control the large loads within the house. Since there are two main extremely large loads, the AC/heaters and the dryer, and two relatively large loads, the stove and washing machine, we do not want the two extremely large loads running at the same time and same with the smaller large loads. Being able to control the two larger loads, keeping them from running at the same time, will allow for the energy draw on the house to be minimized somewhat.

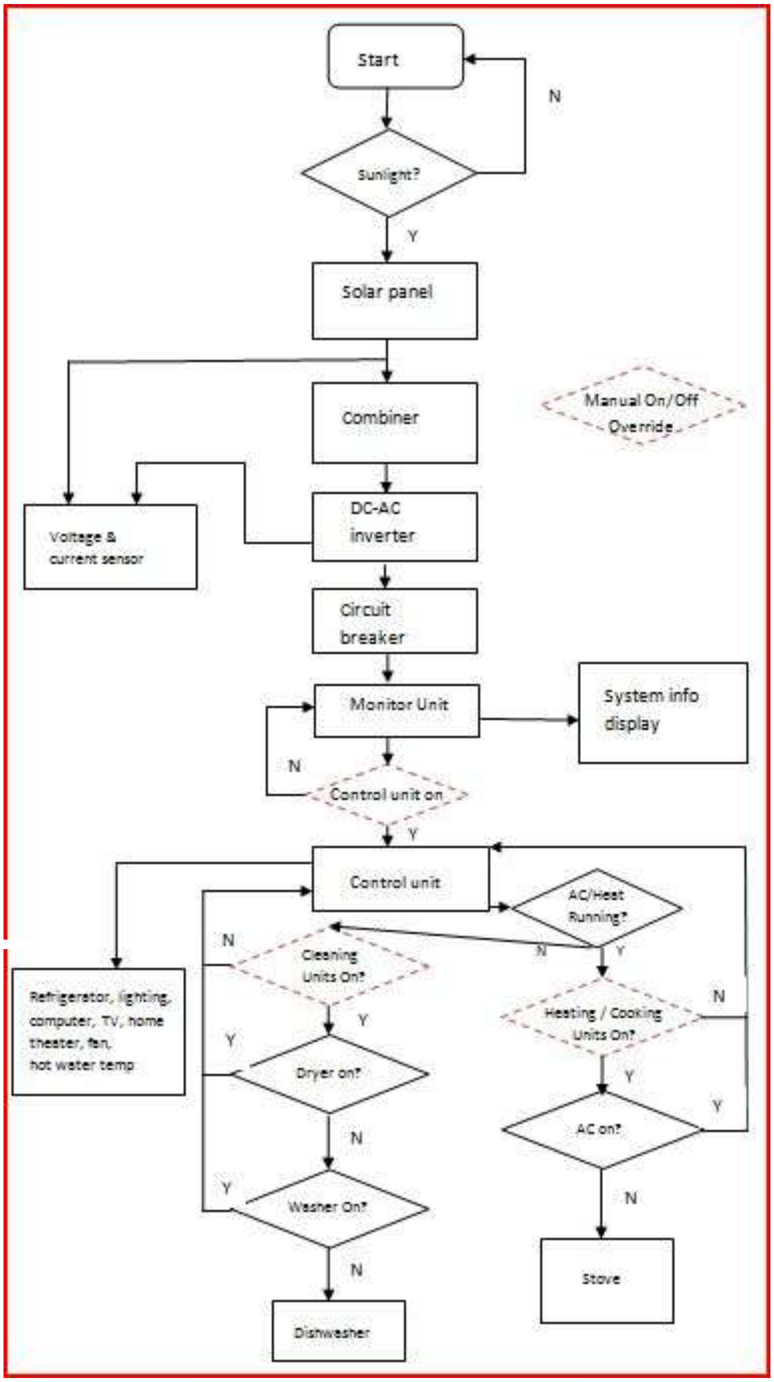


Figure 59: Energy Management Flow Chart.

Since the washer/dryer unit and the AC/heating units are the two largest energy consumers, both units would not want to be on at the same time, otherwise there would be an extreme amount of energy being drawn all at once. Therefore, the controller would sense and see if the AC/heater unit is on, if the unit is one then the washer/dryer would not be able to be turned on. Using the controller to control where electricity goes throughout the day will help minimize spikes. With the minimized spikes, one large spike in the middle of the day will be avoided, reducing the extreme draw on the grid all at once during the day. Though the controller would want to be used the continuously, during the judging period a particular component may need to be used, therefore an override switch to turn on and off the controller unit. Having an override switch will allow for different components to be used whenever needed throughout the house to meet possible unseen use. To make the controller unit more human interactive, there would be a master shutoff of the controller unit, “control unit on”. However, within the controller there could be two additional shutoffs to be able to override the control system come the need to use a particular unit during the competition week for judging. A manual override could be used to control the use of the AC/heater units and the stove. The other override will be to control whether the cleaning units are able to be turned on. While a checker to see if either the AC/heater unit is running or stove, to ensure that both the washing machine and the AC unit is not running at the same time.

The use of lighting and/or power relay panel will give the opportunity to program up to 16 relay channels using the controller. Using a relay panel will allow to turn off some circuits within the house, during the overnight hours to conserve electricity. Conserving this little bit of energy may not be a whole lot but would add up for a little in the long run. Circuits for like the television and computer will cut the power to those lines, preventing the computer and television from consuming electricity, that are not needed during the night.

CONCLUSION

With continued work between Guilin University of Technology, Alfred State College and Alfred University, team Alfred and Guilin will have a chance at doing well at the competition in August 2013 in Datong China. Using many new and up to date solar technologies both students and the public will learn of all the available technologies in the evolving field.

By choosing a solar system that will be large enough to overcome the energy usage of the house to meet all the expectations required within the house. The house could have a zero energy balance between the energy used and the energy created. Using a control system to limit the amount of energy being used from component to component will prevent the house from using too much energy from day to day.

Energy efficient components will be needed to keep the amount of energy used to a minimum. Of the required components needed for testing the functionality of the house, the components will need to be large enough to receive full points while not drawing too much energy to consume more than being produced. Having the house's lighting efficient enough that the house is able to reach the recommended lighting levels while not drawing too much from the grid.

Having the ability to decide whether to keep or modify portions of the house are nice when it comes to the look, the engineering, and overall functionality of the house. From the house producing too much heat because of one feature and making it work to the houses advantage.

Continued work to keep well-functioning components working in the house and new ideas available for possible addition or subtraction of the house. Having many possibilities of features is good to have when designing a well-designed and well-engineered home.

FUTURE WORK

Work on the glass atrium, to prevent the house from being overheated and all the other possibilities that could be done to improve on its design even more. Whether it's to add, modify or remove features creating a friendlier engineered design.

The best way to build and get the house sections to Datong whether best built by Alfred State College or by Guilin University. Whether to build the house completely from scratch on sight or to design a likable form of building between the two schools.

Lighting units that would be produce enough lumens while uses the least amount of electricity to run. Better hot water functionality to produce enough hot water needed for testing the functionality of the house and the needs within the house. Deciding how to get enough solar panels, and place the panels properly around the house. Once have enough panels, the need to have a large enough grid tie inverter to overcome the daily energy use and ensure the proper connection back to the grid.

REFERENCES

1. Tie Down Engineering, "Manufactured Housing Anchor Installation Information" (2009) Accessed on: May 2012 Available at: http://www.tiedown.com/pdf/d12.pdf

2. Michael A. Neiderbach, Alfred University, Alfred, NY, June 2012, Private Communication.

3. Schneider Electric "LPB Lighting Control Relay Panel with Native BACnet Protocol," 63249-420-355, Schneider Electric, La Vergne, TN, June 2011.

4. National Fire Protection Association, *National Electrical Code 2008, 1st ed.*, pp 1-822. NFPA, Quincy, MA, 2008

5. "Square D Ceiling Mounted Ultrasonic Occupancy Sensor," Schneider Electric Document Number 1200HO0604R1/07. Schneider Electric, LaVergne, TN.

6. U.S. Department of Energy, "Solar Decathlon China Rules" (2012). Accessed on: February 2012. Available at: http://www.solardecathlon.gov/rules.html

7. Structural Insulated Panel Association, "What Are SIP's?" (2011). Accessed on: June 2012. Available at: http://www.Sips.org/about/what-are-sips

8. Thermocore, "Installation Manual" (2010). Accessed on: June 2012. Available at: http://www.thermocore.com/installation-manual.php

9. The Engineering ToolBox, "Maximum Floor Joists Span" (2011). Accessed on: April 2012. Available at: http://www.engineeringtoolbox.com/floor-joists-span-d_1479.html

10. "Occupancy Sensor Selection Guide" Schneider Electronic Document Number: 1200SM0701R8/08. Schneider Electronic, Palatine, IL.

11. Xingwu Wang, Alfred University, Alfred, NY, August 2011-August 2012, Private Communication.

12. Dr. Wang's Sp. 2012 ELEC 220 Students, "Solar House Project Report" Alfred University, Alfred, NY, May 2012.

13. SMA Solar Technology, "SMA Solar Technology" (2012) Accessed on: May 2012. Available at: http://www.sma-china.com.cm/index.php

14. Kyocera, "Current Products" (2012). Accessed on: May 2012. Available at: http://www.kyocerasolar.com/residential-solutions/solar-panels/current-products.htm

15. Schneider Electric, "Products and Services" (2012). Accessed on: May 2012. Available at: http://www.schneider-electric.cn/sites/china/en/products-services/products-services.page

16. Apricus, "OG-300 Direct Flow Solar Hot Water Systems Schematics and Parts Lists" (2011). Accessed on: May 2012. Available at: http://www.apricus.com/userfiles_us/A7-05.4.10.1-PB-1.0-Apricus_OG300_Direct_Flow_Parts_&_Schematics.pdf

17. George Richardson, Alfred State College, Alfred, NY, March 2012, Private Communication.

18. Craig Clark, Alfred State College, Alfred, NY, March 2012, Private Communication.

19. The Engineering ToolBox, "Illuminance – Recommended Light Levels" (2011). Accessed on: April 2012. Available at: http://www.engineeringtoolbox.com/light-level-rooms-d_708.html

20. Joe Terranova, Alfred University, Alfred, NY, January 2012, Private Communication.

21. Leslie Higgins, Apricus, Brandford, CT, May 2012, Private Communication.