# OFF-GRID TINY HOUSE SMART RESIDENTIAL ENERGY MANAGEMENT SYSTEM

David G. Alexander[1]


## INTRODUCTION

Students at California State University (CSU), Chico designed, built, and tested an off-grid solar powered tiny house and competed in the 2016 Sacramento Municipal Utility District's (SMUD) Tiny House Competition. Top tier research institutions, predominantly undergraduate universities, and community colleges from all over California competed against one another in a variety of performance and aesthetic events in SMUD's first ever competition. One of the main goals of the CSU, Chico's Tiny House was to design and implement an autonomous energy management system to maximize energy capture, use, and efficiency and provide a seamless, comfortable, and uninterrupted indoor living environment. This system, smart residential energy management system (SREMS), was designed to monitor and sense solar energy collected and stored, indoor heating and cooling loads, occupant cooking and personal water heating needs, and electrical outlets and to determine and allow energy related activities given the amount of stored energy. Thermodynamic and heat transfer models were developed to predict heating, cooling, and appliance requirements. These models were used to size the solar array, battery storage, and appliances. SREMS was installed in the tiny house and its performance was tested and validated during the week long SMUD Tiny House competition. Results showed close correlation with the predicted energy requirements of the models, and the tiny house maintained net-zero energy use even during overcast and rainy skies throughout the three-day event. The CSU, Chico team won best control system and best technology at the statewide event. This paper describes the design, installation and testing results of CSU, Chico's Tiny House SREMS.



## KEYWORDS

Solar PV, energy management, tiny house, student competition, renewable energy, sustainability


## TINY HOUSE BACKGROUND AND COMPETITION

The Tiny House movement began gathering popularity and interest in the early 2000s, largely focusing on environmental, economic, and psycho-social impacts of living simply (American

1. Department of Mechanical and Mechatronic Engineering, California State University, Chico, dgalexander@csuchico.edu

Tiny House Association, 2016). The movement is both a philosophy and a practical call for change. Individuals tired of trying to keep up with a consumer driven society downsize and throw away most possessions in order to live in a 100 to 400 square foot house. Others focus on reducing waste and energy. While there is no uniform size that qualifies as "tiny," 500 square feet is a commonly used cutoff (American Tiny House Association, 2016). With this growing interest in living "tiny" and minimizing one's economic, environmental, and energy footprints, a growing number of innovations and unique applications have developed causing people to rethink what it means to own a home and furnishings and how much energy one really requires to live a happy and productive life, and what exactly does it mean to live happily. Can living simply lead to living more happily and more contentedly? (Rossi, 2016 and Priesnitz, 2016)

Perhaps more interestingly and certainly more impactful, the questions that the Tiny House movement has raised brought attention to issues about homelessness, poverty, affordable housing, and local community as well as global warming and resource scarcity (Mingoya, 2015). Can the Tiny House movement help solve some of these global and local problems?

In an effort to support the Tiny House movement and promote the creation of innovative ideas to reduce energy consumption and minimize environmental impacts, Sacramento Municipal Utility District sponsored the first ever Tiny House Competition. Ten universities and community colleges in California formed student teams to design, construct and operate solar powered, net-zero energy houses on wheels. Judging criteria focused on four main categories, architecture, communications, home life, and energy. Each category assessed points based on performance or aesthetic design and the team earning the most overall points wins. One of the primary areas of innovation and design that the CSU, Chico Tiny House team focused on was house and occupant energy management.

One of the challenges that the team had early on was to design the energy requirements of the house for a defined user and given geographic location while also designing the energy system to compete in various events specified by the competition organizers. Some of these events had specific power and energy requirements, durations, and times of use that were not necessarily consistent with the occupant's energy usage but which were normalized in order to compare one house against another house. Additionally, SREMS was designed with the end-user in mind and not the competition organizer's scoring events though it could be used to monitor energy use and inform the team about their performance or predicted performance.

Early in the design of the Tiny House, the team contacted local and regional building materials suppliers, contractors, and solar PV system retailers. As a result of forming these early contacts, the team received a donated solar PV system. The sponsor provided the team with what it estimated would be an appropriately sized system, including a Zantrex SW4024 Inverter, 60A MPPT Outback Flexware Charge Controller, DC Connect Breaker Box, Solar Array Combiner Box, 15A DC Outback Breakers, 10-255W Canadian Solar Panels, and mounting hardware. This was a significant contribution to the team and established the operating limits of the AC electrical system as the maximum output of the inverter was 4,000 W.

The following sections detail the engineering specifications, modeling, and design decisions that resulted in the selection of solar PV array configuration, energy storage, heating and cooling system, water heater, cooking element, and entertainment systems.

## ENGINEERING SPECIFICATIONS

Table 1 lists the performance requirements and engineering specifications along with metrics used to validate compliance, methods or devices used to measure performance, the condition(s) under which the engineering specification was to be measured and the target performance value or range for all key systems or designs. The requirements were formulated largely based on the competition requirements. In some cases, a performance requirement was intended to represent the typical tenant energy use for a particular activity and the measured "simulation" load.

**TABLE 1.** Competition performance requirements, resulting engineering specifications and design validation testing (Ford, et al, 2016).

| Requirement | Engineering Specification | Metric | Method/Device | Condition | Target |
|---|---|---|---|---|---|
| **Zero-Net Energy** | Energy | V, A | Digital Multi-Meter | Given geographic location | Energy Produced = Energy Consumed |
| **Thermal Comfort** | Temperature | °F | Thermocouple, Data logger | Daily from 7am to 7pm | 70°F - 78°F |
| **Hot Water Shower Simulation** | Temperature, Flow rate | °F, GPM | Bucket, Stopwatch, Thermometer | STP | ≥ 110°F, 8 gal in 10 min twice daily |
| **Refrigeration** | Temperature | °F | Thermocouple, Data logger | Timed average | 34°F - 40°F |
| **Freezer** | Temperature, weight | °F, lb | Thermocouple, Data logger, Scale | Timed average, ambient water temperature | -20°F to 5°F, freeze 1lb of ice daily |
| **Cooking** | Temperature, volume, time | °F, GPM | Thermometer, Scale, stopwatch | Start from ambient temperature | ½ gal to 212°F in 5 min daily |
| **Work Simulation** | Length, time | Inches, hours | Run for target time | Looped video ≥13" screen, ≥75% brightness | 3 hrs daily |
| **Entertainment Simulation** | Length, time | Inches, hours | Run for target time | Looped video ≥20" screen, ≥75% brightness | 2 hrs daily |
| **Charging Simulation** | Power, energy | kW, kWh | Plug in | Simulated load provided by SMUD | Fully charge daily |
| **Lighting** | Intensity | Lux | Light meter | Any time of day | ≥800 lumen/$m^2$ |

## THERMAL COMFORT

Heating and cooling loads were modeled based on locating the house in the San Francisco Bay Area with two live-in occupants. A simple steady-state, 1-D heat transfer model was developed to determine the maximum power requirements to maintain the living space at the required temperatures during the winter and summer. Thermal resistances of the building materials and estimated convective heat transfer coefficients for forced convection on the exterior walls and natural convection on the interior walls were found from (Bergman et al. 2012). Thermal resistances for the five windows were determined from the window materials and given sizes and used to determine an overall heat loss or gain. Table 2 shows the total thermal resistances for each section of the tiny house and the total heat loss in winter and total heat gain in summer.

**TABLE 2.** Tiny House thermal resistance and heat loss per structural section including total heat loss based on prescribed temperature difference during the summer and winter.

| House Section | Total Resistance $R$ (°C/W) | Heat Loss – Winter (W) | Heat Loss – Summer (W) |
|---|---|---|---|
| **Floor** | 0.173 | 193.6 | 83.52 |
| **Wall** | 0.069 | 484.8 | 209.2 |
| **Ceiling** | 0.312 | 107.2 | 46.29 |
| **Windows** | | 235.2 | 101.5 |
| **Radiation** | -- | -- | 2660 |
| **Total Heat Loss** | | 1021 | 3100 |

Total heat loss $(\dot{Q})$ through a section was determined from the following relationship (Bergman et al, 2011).

$$\dot{Q} = \frac{\Delta T}{R_{tot}}$$

Where $\Delta T$ is the temperature difference between the required indoor temperature and the outdoor temperature, $R_{tot}$ is the total thermal resistance of the building materials and the thin film convective layer.

Summer heating loads included direct incident solar radiation on the roof and walls, whereas during the winter, radiation from the insulated roof was considered negligible compared to the conduction losses through the walls, sides, roof, and floor.

To meet the heating and cooling loads simply and compactly, a Ramsond 27GW3 ductless mini-split combined air conditioner and heater with a seasonal energy efficiency rating of 13 and power input requirements of 800 W for cooling and 810 W for heating at 110 V was selected. The mini-split has a rated cooling and heating capacity of 9500 Btu (per hour). Maximum rated current is 7.4 A for heating and 7.3 A for cooling. The typical allowance for the residential cooling equipment energy efficiency ratio is approximately 0.875 of SEER or 11.375, which is equivalent to a coefficient of performance (COP) of approximately 3.55. Therefore, for every 3.55 units of heat removed from the inside space, the AC unit consumes 1 unit of power. The rate of heat removal at 800 W of input power is 2,840 W for the AC unit, which compares to a modeled cooling rate of 3,100 W during the highest temperature extremes as per Table 2. Whereas 810 W of input power to the heater, the mini-split outputs 2,876 W of heat during the lowest temperatures for the winter season. With the addition of the solar panels on the roof and the fact that not all walls receive direct solar irradiation, the ductless mini-split was predicted to provide adequate thermal comfort throughout the year.

## SHOWER AND COOKING SIMULATION

The competition required that each house heat one half gallon of water from ambient temperatures to boiling in five minutes to simulate cooking and heat 8 gallons of water in ten minutes from ambient temperature to 110°F to meet a typical shower requirement. The power required to meet the cooking and shower loads was determined from the heat capacity and mass of water and found to be approximately 2,000 and 4,000 W, respectively. The power requirement for the simulated shower was at the limit of the inverter. In order to meet the 5 minute time requirement, the decision was made to use a tank water heater that would maintain the water available for a shower at 110°F and with a maximum power rating of 1,600 W. Although less efficient overall, the competition heating requirement would be met without exceeding the inverter capacity.

## BATTERY SIZING

Sizing the batteries required analyzing all AC electrical loads and their estimated time of operation and balancing this with the estimated average incident solar radiation captured. Table 3 lists all AC electrical loads and run times based on estimated tenant usage. With an estimate of the total energy used by occupants on a daily basis, the size of the energy storage system could be estimated.

**TABLE 3.** Typical AC loads and run times.

| Description of Load | Power (W) | Usage (Hrs/Day) | Daily Energy (AC Wh) |
|---|---|---|---|
| Refrigerator | 115 | 8.000 | 920 |
| Air-conditioner | 803 | 2.000 | 1606 |
| Lighting (LED) | 10 | 5.000 | 50 |
| Heating Element | 2000 | 0.083 | 166 |
| Laptop computer | 45 | 3.000 | 135 |
| Television | 33 | 2.000 | 66 |
| Hot Water Heater | 2000 | 1.000 | 2000 |
| Phone Charging | 10 | 2.000 | 20 |
| TOTALS | 5016 | | 4963 |

The batteries were sized to supply one full day of energy estimated at 4,963 Wh according to the use profile in Table 3. Additionally, conversion efficiency of the Xantrex inverter was considered at 90% resulting in 5,514 Wh. Total stored energy was then divided by 24 V to arrive at a battery Ah requirement of 230. Recognizing that battery capacity is significantly affected by low temperatures, a 1.3 multiplier was used to increase the available stored energy for the winter months plus a 100% increase in stored energy was applied to prevent deep discharges in order to extend battery life. The resulting battery capacity was determined to be 597.4 DC Ah. After extensive research, the battery that was selected and purchased was a 24 V, 510 Ah, 6 hour discharge rate, sealed lead acid, forklift battery made by GB Industrial Battery, model number 12-85-13. This battery weighed 1094 lbs. and was designed to provide one day of autonomous energy with only 50% depth of discharge.

## SOLAR PANEL CONFIGURATION

The solar panel configuration was sized to recharge the battery energy in one day and to operate within the limits of the inverter. To determine the number of panels needed, the daily energy required to fully recharge the battery pack was divided by estimated battery efficiency resulting in 5514 Wh. Next, the battery and charge controller efficiency was assumed to be 80% which further increased the total required capture of energy to 6893 Wh. The number of peak sun hours were estimated from (PVWatts, 2016) and determined to be 5.1 hours in a day on average. Dividing the peak sun hours per day by the total required energy to be captured resulted in an average power produced by the PV solar array of 1351.6 W.

Power generated from solar modules is effected by the operating solar PV cell temperature. The temperature loss coefficient accounts for the reduction in solar cell power with increasing temperature. Kallio (2016) developed an empirical model of cell temperature that includes the effects of convection by using a local wind velocity $V_w$ correlated to ambient air temperature $T_{amb}$, and irradiance $G_t$.

$$T_{cell} = T_{amb} + \frac{G_t}{800}(0.105V_w^2 - 2.58V_w + 28.8)$$

Given a wind velocity of 3 m/s, ambient temperature of 29 °C, and solar irradiance of 1,000 $W/m^2$, cell temperature is estimated at 56.5 °C. This increased operating cell temperature was then used to estimate a temperature loss factor from the following relationship.

$$f_{loss} = 1 - f_{Pmax} * (T_{cell} - T_{amb})$$

Where $f_{Pmax}$=0.0043. The resulting percent loss in power was 86.5%, which was used to increase the amount of power needed from the solar PV array to 1563.4 W. Finally, a shading coefficient and derating factor were used to further increase the required power to 2043.6 W as summarized in Table 4. Meeting this power demand requires approximately 9 solar PV panels with an output of 255 W each.

Next the number of series connected panels was determined based on the maximum open circuit voltage of the string, which is impacted by temperature. Maximum open circuit voltage $V_{(oc,max)}$ was determined from the cell's lowest operating temperature, which was determined to be -3 °C during winter in Sacramento, CA, according to SolarABC. With an open circuit voltage Temperature coefficient $\beta_{oc}$ = 0.0034°C$^{-1}$ and open circuit voltage at standard temperature $V_{oc}$,25°C = 39.04 $V$ the following relationship was used to determine the maximum module open circuit voltage,

$$V_{oc,max} = V_{oc,25°C}\left(1 - \beta_{oc}(T_{cell} - 25)\right)$$

The resulting operating module open circuit voltage was found to be 42.8 V. From the estimated open circuit voltage per module, the number of series and parallel modules could be determined.

## SOLAR PV MODULE SERIES AND PARALLEL CONFIGURATION

The maximum voltage and current of the PV array is constrained by the charge controller. The maximum input voltage for the FLEXmax 60 is 150V. Therefore, the maximum number of PV modules that can be connected in series is three resulting in a series string voltage of 128.3 V. The charge controller's maximum rated current is 60 A and each PV module will provide a maximum current of 9.58 A. While the maximum number of parallel strands of PV modules could be six based on maximum allowable current of the charge controller, the Tiny House Team received only 10 PV modules from their donor. Additionally, the ten PV modules were an estimate for the total amount of energy needed by the house. In an effort to use as many of the PV modules as possible, the optimum configuration was determined to be three parallel strands of three series connected PV modules for a total nine modules in the array. Table 4 lists the configuration parameters of the PV array including peak sun hours per day, temperature loss factor, shading coefficient, system derating factor, number of series and parallel connected modules, and maximum current and voltage.

**TABLE 4.** Solar PV Sizing and Configuration Parameters

| PV Array Sizing | Efficiency or Loss Factor | Result | Units |
|---|---|---|---|
| Daily AC Load (Wh) | -- | 4963.0 | AC Wh/day |
| Inverter Efficiency and Increased Energy | 0.9 | 5514.4 | DC Wh/day |
| Battery/controller efficiency and Increased Energy | 0.8 | 6893.1 | DC Wh/day |
| Peak sun (PVWatts, 2016) and Resulting Power | 5.1 hr/day | 1351.6 | W DC |
| Cell Temperature (Kallio, 2016) | | 56.5 | °C |
| Temperature Loss Factor and Resulting Power | 0.893 | 1563.4 | W DC |
| Shading coefficient and Resulting Power | 0.9 | 1737.1 | W DC |
| System derating factor and Resulting Power | 0.85 | 2043.6 | W DC |
| PV module STC power rating | | 255.0 | W |
| $V_{oc}$, max @ -3 °C | | 42.8 | $V_{oc}$ |
| Number of series modules | | 3.0 | |
| Max $V_{oc}$ per string | | 128.3 | V |
| Number of parallel modules | | 3.0 | |
| Max current per string | | 9.6 | A |
| Max array current | | 28.7 | A |

## RELAY SIZING

A main feature of SREMS is its ability to autonomously track energy use and limit or notify the user when extreme conditions exist or are anticipated, for example, if the heating element is being used and the thermostat triggers the air conditioner to turn on, SREMS will prevent the inverter from being overloaded by preventing the air conditioner from turning on. The user is notified of such a conflict in power demand through the SREMS interface. The ability to perform this level of energy management requires that SREMS sense all electrical circuits containing power consuming appliances and outlets as well as control electrical relays that enable or disable circuits from being energized.

Both high and lower power relays were used to control the demand and regulation of power. Low power control was achieved using a 16-channel 12V relay module board with a power converter and optocoupler protection connected to a Grove Pi I/O board which was controlled with software through a Raspberry Pi. High power relays were also connected through the Grove Pi to the Raspberry Pi which provided the 5 V signal to control all relays. Low power relays controlled the entertainment, AC/heater, cellphone charger, laptop, lights, refrigerator, and freezer loads while the 30 A high power relays controlled power to the water heater and heating element.

Current sensors were used to sense all outlets and high power appliances with the input routed to the Grove Pi and made available to the Raspberry Pi for monitoring and control. Additionally, seven thermocouples were wired through the Grove Pi to monitor the AC/heater, refrigerator, freezer, hot water tank, cold water tank, outside air, and PV panel. Since the mini-split had its own thermostat, SREMS only monitored whether it was on or off and made adjustments accordingly.

## RESULTS

The Chico State Tiny House team designed and fabricated their tiny house and created an electrical system that would capture radiant solar energy and power the home to provide a comfortable living environment. Students from majors in construction management, civil engineering, mechanical engineering, mechatronic engineering, communications and political science organized around the vision of creating a living environment that maintains all the comforts for a typical house in the U.S. but with a fraction of the energy and carbon footprint. Over the course of two years, students met on weekends and evenings to design and build their tiny house. Figures 1 through 10 show the Tiny House team and the result of their dedication to build and create a one-of-a-kind house.

The house measures 22 ft. 9.25 in. long and 7 ft. 9.25 in. wide for a total external area of 177 sq. ft. The roof is slanted with a minimum ceiling height of 8 ft. increasing to almost 10 ft. across its width. The Exterior is pine wood siding with corrugated metal accent features. The roof is designed to capture rain water while securing the six PV solar panels raised up approximately 6 inches from roof top as seen in Fig. 5. The additional three PV solar panels are designed to be stored in the house when moving the house and installed in a fixture next to the house. Figure 6 shows the three panels secured to the outside sill of the house during competition.

The interior is designed with a fully functioning bathroom, kitchen, and living area. Figure 8 shows the kitchen area with sink, a heated cooking surface, microwave oven, and

**FIGURE 1:** Weekend build team standing on top of the trailer that became the Tiny House on wheels.


**FIGURE 2:** Students supporting the walls and securing them in place.

**FIGURE 3:** Traditional construction techniques were used including a vapor barrier, flashing, and wood siding.

**FIGURE 4:** Exterior roof and walls completed.

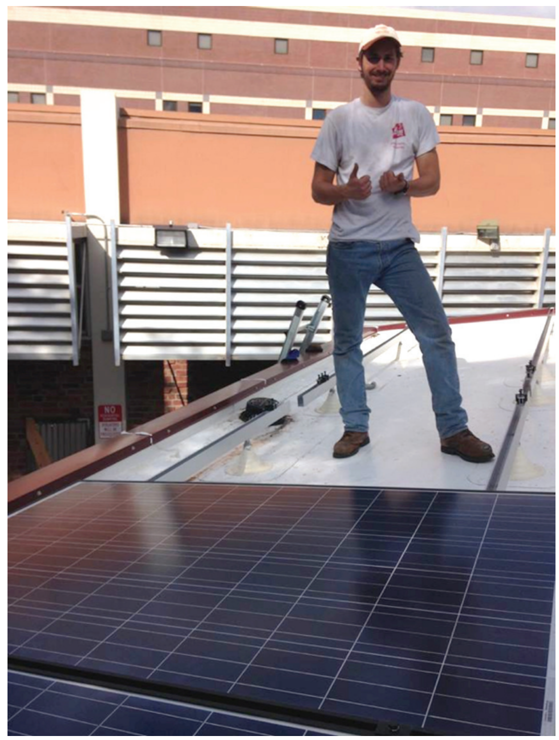
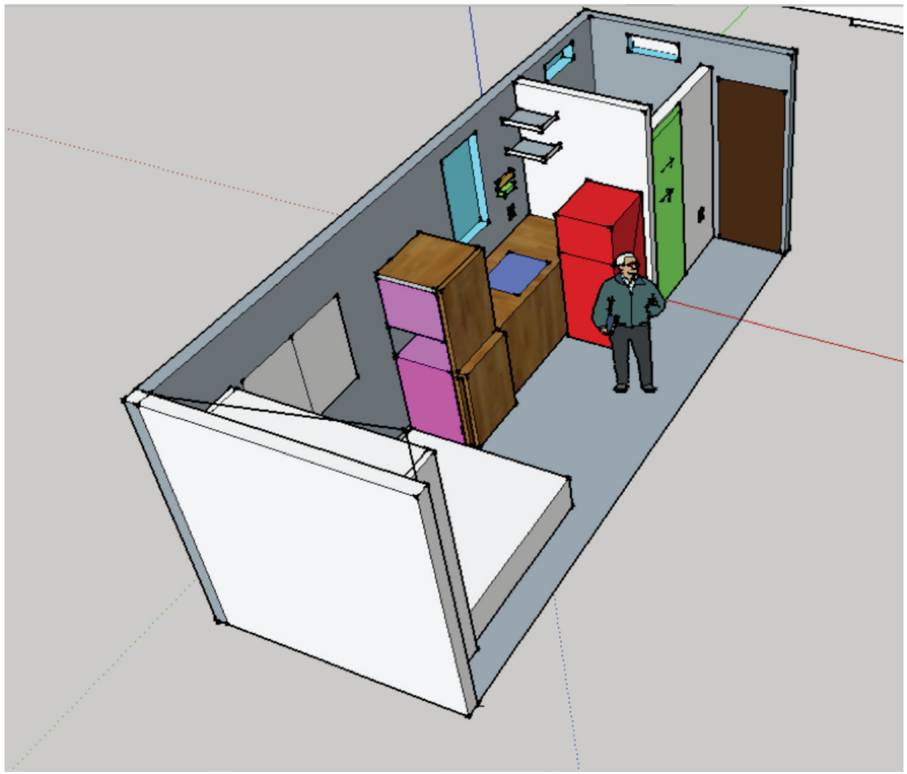


**FIGURE 5:** Six Canadian Solar 255 W PV panels were installed on the roof.

**FIGURE 6:** Three additional solar PV panels were placed next to the house to capture radiant energy (Photo: Chico State Tiny House Club Facebook page).

**FIGURE 7:** Initial CAD rendering of interior living space with Murphy bed folded down from the wall. Kitchen area was modified to accommodate more counter space by using a smaller refrigerator as depicted in Fig. 8.



counter space. This area opens up to the main living space that contains a movable couch and furniture that makes way for the Murphy bed mounted on the end wall as seen in the CAD rendering in Fig. 7 and photograph of the interior living space in Fig. 9.

**FIGURE 8:** Kitchen area including wood lattice divider behind which is the solar PV connects and SREMS. (Photo: Chico State Tiny House Club Facebook page)

**FIGURE 9:** Living area with murphy bed installed behind the couch in the background (Photo: Chico State Tiny House Club Facebook page).

The house was completed in time to compete in SMUD's Tiny House Competition against nine other schools. The event took place over three days in a parking lot at Cosumnes River College, Sacramento, CA. Competition judges measured performance of the appliances and monitored temperatures and energy use and ultimately awarded points based how well teams met the competition's specified performance targets.

**FIGURE 10:** Tiny House Team at SMUD's Tiny House Competition (Photo: Chico State Tiny House Club Facebook page)

A main competition goal was for every tiny house to generate more energy than it consumed, i.e. net-zero energy during the three-days of testing at the event. The Chico State Tiny House and SREMS performed exceedingly well despite many hours of rain and cloudy, sunless skies. While all the data that was collected by SMUD at competition has not been shared with the team, yet. The following tables highlight some of the data from competition. Data were collected on Wednesday, Thursday, and Friday and used to evaluate each team's total energy use and consumption. As a result of sunny, clear skies and excitement for the event, there were multiple personal devices being charged by the house before realizing the potential impact to the net-zero goal of the competition. Additionally, SREMS was not initially configured correctly and the house consumed much more energy than would have been allowed to had the system been functioning as designed. Once these issues were resolved, the house energy came closer in balance. As seen in Table 5, energy consumption on Wednesday was significantly higher than the other two days of competition. The team might have recovered by generating more energy in subsequent days except on Friday the weather was cloudy and rainy the entire day, which resulted in a total net loss of energy. However, given that on all three days of the competition the same number and frequency of energy performance events took place, the house could have achieved net-zero energy operation. Table 6 illustrates the PV power generated by the nine solar panels, the AC loads that were demanded during the competition, and the result of interior air temperature regulation.

**TABLE 5.** Daily energy generated, consumed, and net energy stored during the three day competition.

| | Wed | Thu | Fri | Totals |
|---|---|---|---|---|
| Energy Generated (kWh) | 4.6 | 4.95 | 0.99 | 10.54 |
| Energy Consumed (kWh) | 6.98 | 5.02 | 2.05 | 14.05 |
| Net Energy Stored (kWh) | -2.38 | -0.07 | -1.06 | -3.51 |

The interior temperature was regulated for optimal occupant comfort as per competition requirements. Table 7 shows the minimum, mean, and maximum temperatures recorded during the competition. The interior space was required to be within 70 to 78 °F. The mini-split was able to maintain the interior temperatures as specified by the competition.

SREMS allows the resident to monitor and control energy consuming devices and energy producing devices in the home. Energy is stored from the solar PV array and made available for any device while SREMS monitors power demand from all appliances. Residents are able to view the battery's state of charge as well as the temperature inside and outside the tiny home, total energy used and produced, and much more via the SREMS graphical user interface (GUI). A resident could also control various appliances such as the refrigerator and freezer as well as the air-conditioner and heater. Figure 11 is a screen capture of the graphical user interface of SREMS where the user has the ability to enable or disable manual mode and monitor the outlets and appliances being monitored.

A high level schematic of the electrical system is illustrated in Figure 12 depicting the core of the SREMS system including solar PV panels/combiner box, charge controller, battery bank, DC disconnect, inverter, breakers, outlets, appliances, high power relay, Raspberry Pi controller, Grove Pi I/O, touch screen interface, power supply, and low power relay board.

**TABLE 6.** Daily data collection by SMUD organizers including PV power generated, AC loads, and daily temperature logs.

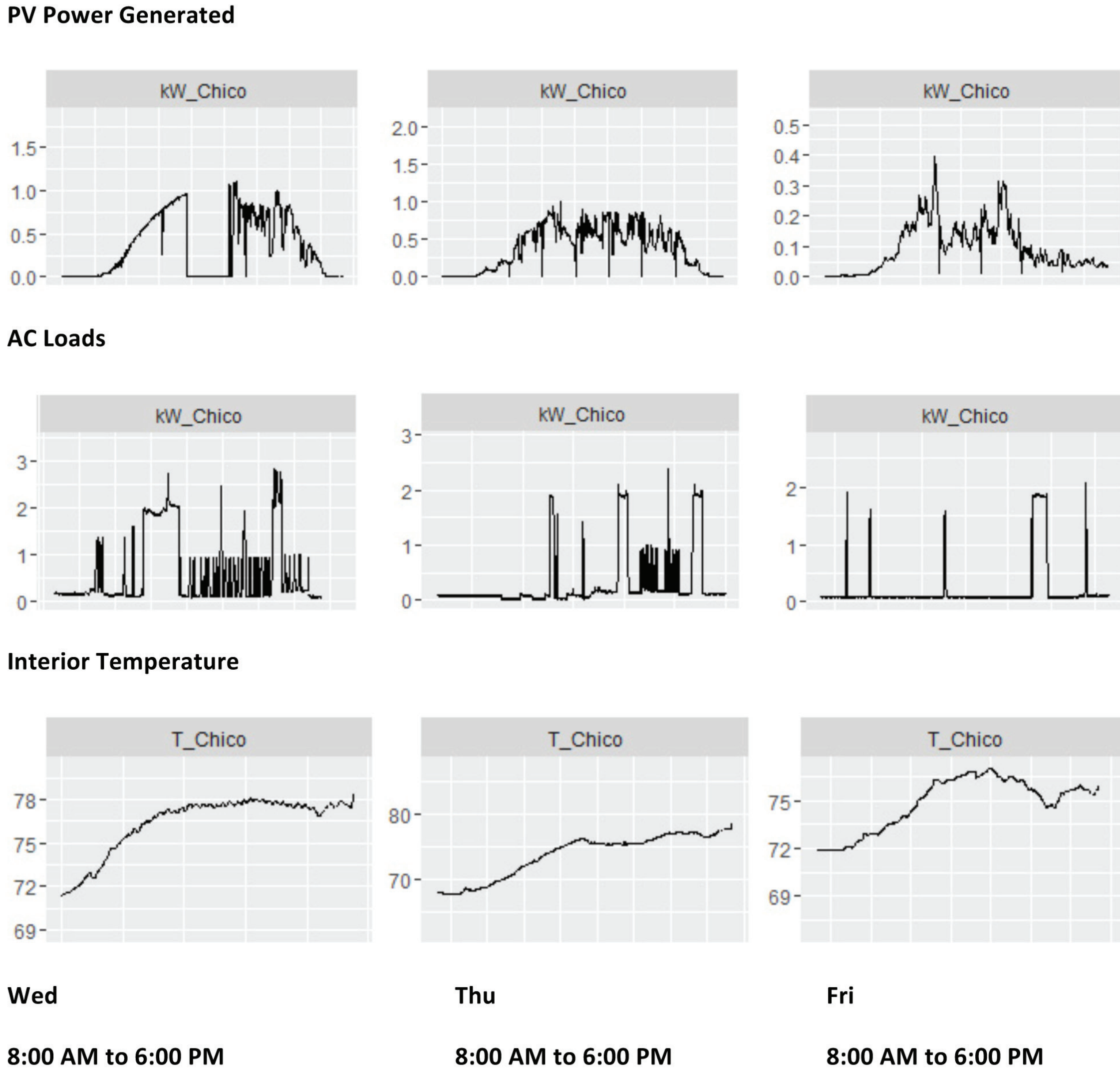


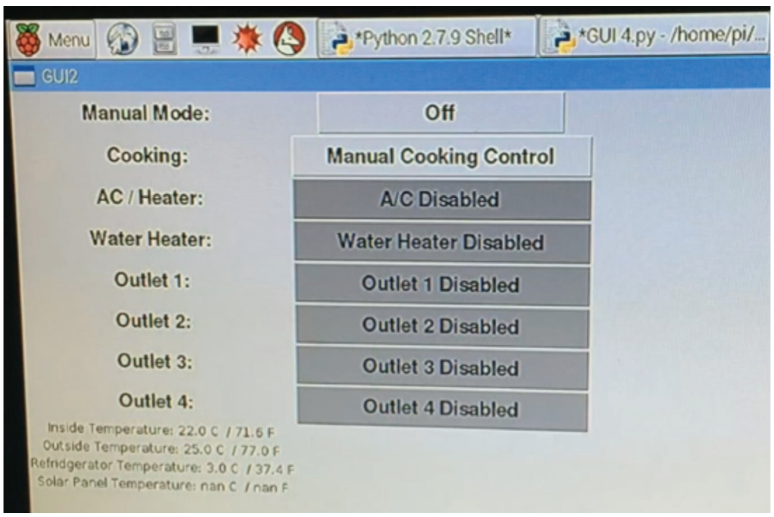

**TABLE 7.** Thermal comfort performance event.

| Interior Temperature (°F) | | | |
|---|---|---|---|
| minimum | 72.3 | 67.8 | 71.9 |
| mean | 76.4 | 73.8 | 74.9 |
| maximum | 77.8 | 77 | 76.7 |

The Raspberry Pi is plugged into the outlet that is shared with the cooking/fridge outlet, which also shares power for the 12 V power supply that provides the necessary power for switching relays on the low power relay board. The high power relay receives power directly from the breaker box through to the water heater where the control signal that switches the relay is provided by the low power relay board.

The Raspberry Pi maintains the software and graphical user interface to inform and respond to occupant energy changes and requests. Figure 13 shows the physical layout of the main solar PV electrical connections as well as the location of the SREMS touch screen interface. These components are in the kitchen hidden by the wood and fabric lattice screen visible in Fig. 8.

**FIGURE 11:** Screen capture of the SREMS graphical user interface showing control of power and sensed temperatures (in lower lefthand corner of image).




SREMS performed all energy related monitoring of the tiny house and prevented the inverter from being overloaded due to too many appliances commanding power at the same time. All outlets were monitored and the total energy stored in the batteries was accounted for in order to optimize energy usage in the house. The energy management system helped the team win first place for best control system and best technology in a tiny house.

## CONCLUSION

The student leaders and participants did an outstanding job of coordinating all the work, reaching out to the local community for donations and support, and fund raising throughout the two years of the project. With this enthusiasm and energy, the Tiny House Club became a recognized student organization on campus and created a strong following of multi-disciplinary members determined to create unique and low environmentally impacting tiny houses. A benefit of the publicity was that the Yuba City chapter of Habitat for Humanity contacted the team and after several meetings and discussions, CSU, Chico decided to donate their Tiny House to them for use as a demonstration house.

The Tiny House Club is now focused on participating in the next Tiny House competition and are excited to create a new and improved design. In the meantime, a sub-team of students will be working on SREMS to improve the control and decision making of the system to optimize energy use and maintain occupant comfort and electrical needs. While the CSU, Chico Tiny House was designed to be net-zero, this was not verified. A thorough testing plan will be developed to investigate the various simulated operating conditions of SREMS in order to understand the amount of energy required for average daily living. This type of information will be incorporated into a predictive algorithm that includes seasonal fluctuations and weather forecasting to develop a comprehensive energy management system for achieving true net-zero operation.

**FIGURE 12:** Overall Electrical Layout.

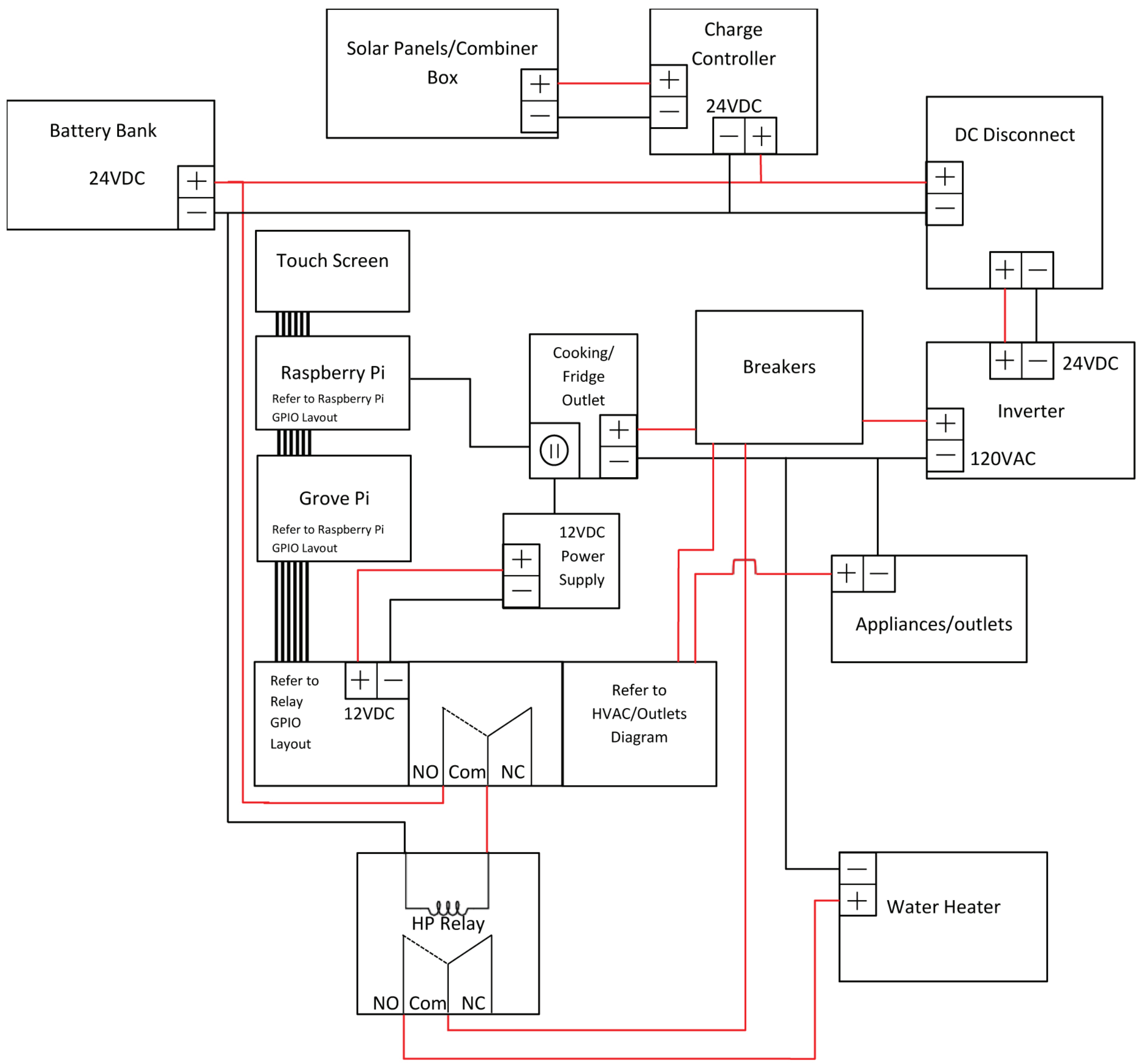
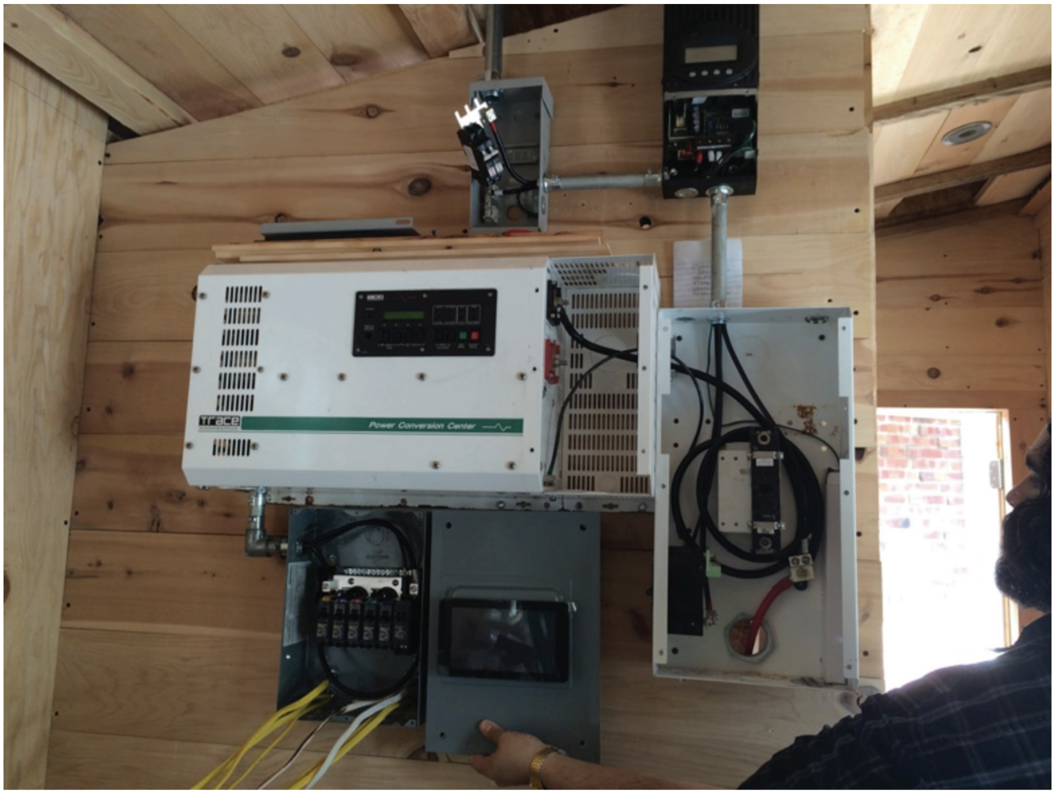


**FIGURE 13:** Installation of main solar PV electrical components.




## REFERENCES

American Tiny House Association, http://americantinyhouseassociation.org/, last accessed 11/29/2016.

Rossi, A., "What It's Really Like to Live and Travel in a Tiny House," SmarterTravel.com, Feb 3, 2016.

Priesnitz, W., "Tiny Houses, Tiny Neighborhoods," www.life.ca/naturallife/1404/tiny-houses-tiny-commuities.htm, last accessed 11/29/2016.

Mingoya, C., "Building Together. Tiny House Villages for the Homeless: A Comparative Case Study," Massachusetts Institute of Technology, Master in City Planning, 2015.

Ford, R., Gomez, M., Hamilton, A., Thomas, B., and Wizza, R., "Off Grid Smart Energy Management System for Tiny House," Final Design Report submitted for partial fulfillment of senior capstone course requirements, May 2016.

Bergman, Levine, Incropera, and Dewitt, "Fundamentals of Heat and Mass Transfer, 7th Edition," John Wiley and Sons, 2011.

Kallio, G., "PV Module Energy Balance," Solar Engineering Course Lecture, California State University, Chico, CA, February 2016.

SolarABC, http://www.solarabcs.org/, accessed 11/30/2016.

PVWatts Calculator, http://pvwatts.nrel.gov/, accessed 11/30/2016.