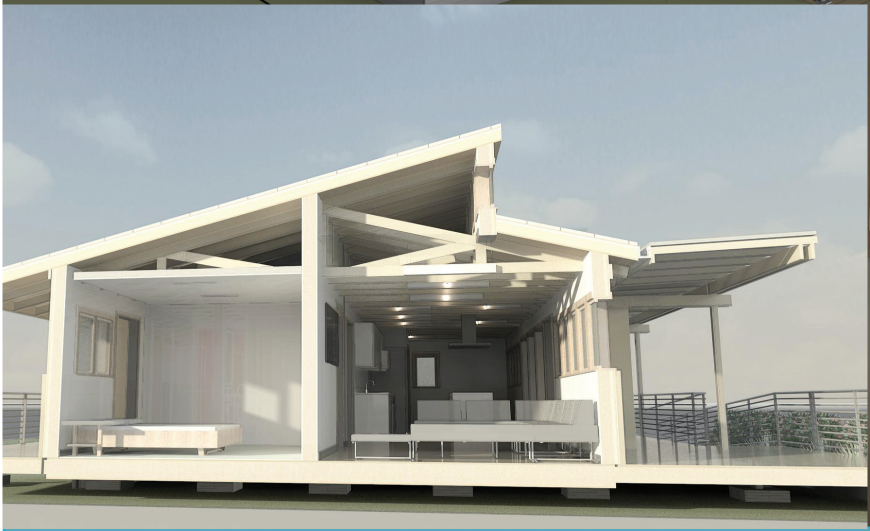

surviv(AL)House

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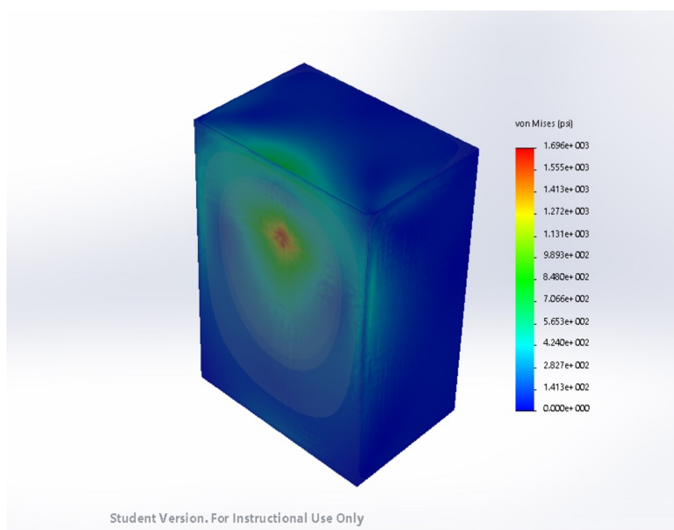
STRUCTURE

The walls are made of staggered 2x4 wooden studs with 2x6 wooden bottom and double top plates to form the frame. There are 4 roof truss structures that will be lifted individually for transportation. In each roof module 1 eye bolt is installed in each corner as crane lift points. This will facilitate simple vertical lift and assembly of the roof trusses.

DISASTER SAFETY

With the increasing prevalence of strong storms and tornados in Alabama, interest in tornado resilience for residential and commercial buildings is proliferating. The tornado outbreak of April 21, 2011, with dozens of tornados across central and northern Alabama, prompted UAB Engineers to develop light weight, tornado-proof composite panels [1]. The composition of thermoplastic and fiberglass resins and fibers used in the panels are stronger per-unit density than the steel used in many current shelters and weigh 80 percent less. This makes them ideal for use in construction and retrofitting of existing structures, and the panels have already been used in a newly constructed home in Alabama. The engineering team decided that building the entire house as a tornado-resistant structure is costly and will make the house unaffordable for many families. Instead, the house is equipped with a "safe room" that is accessible through the bathroom area for the entire family to retreat to in case of a tornado emergency.

A closet in the **s u r v i v (A L)** House was designed as a tornado shelter with UAB Tornado-Proof Panels as a key component. The panels are anchored from within with a student-designed steel frame and built in a way that it can be closed in with standard flooring and drywall. This can hide the true protective nature of the room and leave a visitor none the wiser.



The completed safe room design was modeled by an engineering student in the computer-aided design program SolidWorks. The design was then tested using industry-level FEA (Finite Element Analysis) to determine if the safe room could withstand the stresses and loads experienced from flying tornado debris. The above study is intended to simulate the effect of debris impact during an extreme weather scenario. Per FEMA standards, the load applied to the rear wall of the safe room is 656 lbf and distributed across an area equivalent to the cross-sectional area of a standard lumber 2x4. This loading is reflective of a four-foot-long section of lumber striking the safe room at 100 mph. The max stress experienced in the rear wall was 1696 psi, resulting in a factor of safety (FS>>10). The result of the testing show that the design of the safe room is more than able to withstand an impact from flying tornado debris.

Perhaps the most important characteristic of a safe room is its anchoring system. FEMA has published plans that detail different anchoring options. During the competition, no ground penetration is allowed; therefore, the safe room will only be a demonstration unit. For the competition, the tornado-resistant panels will be installed on a wood frame. Once the house is back in Birmingham in its permanent location, proper anchoring will be installed on the safe room.

POWER GENERATION

Panasonic Co. was generous to donate the PV system for the house. We took advantage of the offer and installed 30 panels of the type N330 HIT photovoltaic panels [2]. Each panel provides 330W of peak power at a rated 19.7 percent conversion efficiency. The total installed peak capacity is 9.9 kW. The panels are specifically designed to provide high efficiency at high temperatures. That is a great feature for Southern climate. The 30 PV panels are arranged in two branches of 15 panels. Each panel is equipped with Solaredge OP400-MV-MC2SM-2NA 400W power optimizers [3]. The optimizers are basically maximum power point tracking (MPPT) units for each individual panel. The two branches are connected to one Solaredge SE7600 A-US inverter [4] rated at 97.5 percent efficiency.

The team decided not to use any battery storage for the competition. However, after the competition, the house will employ a battery bank to make it off-grid. We plan to use the house as a research facility for research on the 'home of the future' by installing a combined heating, power and cooling (CHPC) on the house.

POWER USE APPLIANCES

Appliances for **s u r v i v (A L)** house were chosen primarily based on energy usage, target market fit, and practical application. Most appliances were supplied by Beko [5] and met the team's requirements for style, energy efficiency, and eco-friendliness. Each of the products Beko donated are Energy Star certified. In the interest of using less space, Team Alabama chose an all-in-one washer and dryer from LG; two units take up far too much space and produce more heat than desired. The LG unit is designed to be quiet and ventless and is easily hidden behind a folding door in the kitchen.

LIGHTING

The lighting fixtures and lights selected for the house are all dimmable LED lights. A light intensity control sequence has been incorporated in the central control and monitoring unit. The sequence is devised to ensure low energy use while keeping recommended light levels in the house. The system is based on ambient light sensing, as well as occupancy sensing. The lights are also connected to the power management system that makes decision about distribution of power among power use points (loads) in case of a rapid rate of depletion of stored energy. The control sequence is explained in the 'Whole-house monitoring and control system' section of this report.

THERMAL COMFORT INSULATION

WALLS

Selecting insulation material for the house is a multi-faceted task. The ultimate goal is to keep the inside conditions at a comfortable range by limiting heat transfer through the house's envelope, and two minimizing infiltration of unconditioned outside air to the house through gaps, cracks, and openings. In order to achieve these goals, conscientious decisions must be made. Health concerns are the most important factors, and most commercially available insulating materials have deficiencies in that area. Construction-phase issues include, skin- and eye-irritant chemical fumes, micro fiber inhalation, and skin abrasion. Post-construction issues include flammability, off-gassing, end-of-life environmental issues, and also the same issues as those during construction-phase whenever repair and replace work is required. On the other hand, there is the issue of achieving the highest R-value that is possible in a most compact space, and so hard choices have to be made. Usually, environmentally benign materials don't provide high R-values or lack other required features such as fireproofing. The exterior vertical walls of the house are built in a staggered double 2x4 stud manner with 2x6 plates on the top and bottom of the wall frame. This provides a cavity space for insulation equal to 5.5 in (14 cm). This cavity is filled with 1 in (2.5 cm) of closed-cell foam sprayed on the ZIP sheathing system. A 2 in (5 cm) layer of fiberglass batt insulation is installed over the spray foam.

Wall layer (outside to inside)	Thickness In (cm)	R-value $\frac{°F \cdot ft^2 \cdot h}{BTU}$ ($\frac{°C \cdot m^2}{W}$)
Cement board	5/16 (.8)	.15 (.026)
Air gap (average)		.15 (.026)
Rigid foam	1 (2.5)	5.0 (.88)
ZIP sheathing	¾ (1.9)	.9 (.16)
Closed-cell foam	1 (2.5)	6.5 (1.14)
Fiberglass batt 1	2 (5)	6.7 (1.16)
Fiberglass batt 2	3 (7.6)	11 (2.25)
Plywood	½ (1.3)	.62 (.11)
Gypsum wall board	½ (1.3)	.45 (.08)
Total:	9.5 (24.3)	25.638 (5.9)

An additional 3" (7.6 cm) layer of fiberglass paper-faced batt insulation is in place. Then in order to provide a rigid backing to prevent gypsum boards from cracking due to transportation-induced vibration, ½ in plywood sheets are installed to close the wall cavity. Gypsum board is installed on the plywood sheets. On the outside of the exterior sheathing, a 1 in (2.5 cm) slab of rigid foam insulation provides an additional R-5 insulation to the wall. Table 1 shows the thickness and R-value of each individual layer of the vertical exterior walls. Since the house is built in several modules for transportation, there are seams where the modules come in contact. All seams are sealed with weather-resistant tape.

ROOF The sloped roof of the house was built with two layers of rigid polyurethane foam. The first layer is 3" think and the second layer is 2-1/2" thick, for a total of 5-1/2" insulation on the outside. The rigid boards were arranged in a staggered manner so that a continuous seem in the direction normal to the surface of the roof was avoided. For added insulation and increased air sealing effects, 1-1/2" of spray foam insulation was applied to the underside of the roof. Table 2 shows the roof layers and the total R-value of the roof construction.

Roof layer (outside to inside)	Thickness In (cm)	R-value $\frac{°F \cdot ft^2 \cdot h}{BTU}$
PV panel shading		
Metal roof sheet	.025 (.063)	negligible
Weatherproofing sheet	.06 (.15)	negligible
Plywood	½ (1.3)	.62
Rigid foam – layer 1	3 (7.6)	15
Rigid foam – layer 2	2.5 (6.4)	12.5
Plywood	½ (1.3)	.62
Foam insulation	1 (2.5)	6.5
Plywood	½ (1.3)	.62
Total:	8.7 (22.1)	35.9

FLOOR

The underside of the floor of the house is sprayed with 5 in. of closed-cell foam. This provides and R-value of 32.5 $\frac{°F \cdot ft^2 \cdot h}{BTU}$. When the plywood and finish flooring are added to the floor layers, a total R-value of 33 is achieved.

AIR TIGHTNESS

The second requirement for a net-zero energy house is air-tightness or the air change rate per hour (ACH). The Solar Decathlon rules require a measured air tightness of less than or equal to .05 CFM per ft^2 of the house when depressurized at 50 Pa using the blower door test. For **s u r v i v (A L)** House, that is equal to ~50 CFM of infiltration or approximately 3.7 ACH.

Traditional houses have no significant provision for this issue. In fact, in traditional house design the occupants only rely on infiltration for air change to replace the stale air inside the house. Our energy analysis shows that the effect of infiltration is significant. During summer, hot and humid outside air can infiltrate into the house and cause discomfort and create additional load for the air conditioning system. The **s u r v i v (A L)** House uses several different approaches to address the infiltration issue. The first line of defense is the ZIP system sheathing that combines water protection and infiltration protection when meticulously taped at the seam. We use the provided weather proof tape to seal all the seams. The interface between frame plates and floor boards were caulked by applying silicone sealant. Any nail or screw holes were patched carefully. In the areas where cutting through the envelope was necessary to provide access to inside of the house for vents, electrical wires, pipes, eye bolts and other needs, spray foam was applied to seal the gaps. The separation surfaces between house modules were taped and sealed. On the roof, two layers of weather proofing sheets were applied. In addition, on the inside of the walls, 1 in of closed-cell foam insulation was sprayed to create air-tightness. Under the floor was sprayed with 5 in of closed cell foam, and on the underside of the roof deck, 1 in of foam was applied. At the time of writing this report the result of blower door test is not available.

AIR CONDITIONING SYSTEM

The house features a ductless variable refrigerant flow (VRF) air conditioning system, which has one outdoor and 4 indoor units. Each bedroom has a 9,000 Btu/h (3/4 ton) indoor (evaporator) unit. The open dining-kitchen-living area is equipped with two 12,000 Btu/h (1 ton) indoor units. The size of the heat pump unit was selected based on the detailed energy modeling that was performed on the house. A ductless (mini-split) system was selected for ease of installation, superior control over zone comfort, and energy efficiency. When compared with ducted forced air systems that are popular in North America, ductless systems have many advantages. They bring modulating compressors to residential market. This reduces the energy consumption by the system. It is very costly and almost impossible to create several zones in a house when ducted systems are used. Several rooms and areas are heated or cooled while unoccupied. This amounts to unnecessary use of power. Another advantage of ductless systems is space-saving. Ducts occupy valuable space in a house. When houses of the future are built based on needed space rather than on tradition, footprints will get smaller and wise use of space will be vital. Ductless systems only need small-diameter refrigerant lines instead of bulky ducts. Another handy feature is individual remote controls for the indoor units.

Carrier Co. donated the heat pump system to the team. The outdoor unit is a 38MGRQ36D-3 multi-zone heat pump [6]. The indoor units are 40MAQB09B—3 [7] and 40MAQB12B—3 [8]. In addition to being controlled by individual remote controls, the air conditioning units are incorporated into the central control system of the house. Their temperature setting and fan speed settings are controlled based on occupancy in the zone. More details on how the air conditioning system is tied to the central control system is given in the 'Whole-house monitoring and control system' section.

ROBOT COOLER

The **s u r v i v (A L)** House introduces a few innovative devices as added features to the house. 'Robot cooler' is one of those devices. The robot cooler is a small portable evaporative cooler on wheels that can travel inside the house. The role of the robot cooler is to provide the occupants with localized cooling while watching TV, working on a computer, or performing similar tasks that are usually performed in a stationary position. By providing localized cooling, the house can save energy by adjusting the set temperature of the house. The temperature in the occupied zone can be changed to save energy while the robot cooler is providing local cooling. The robot cooler can find its way to the occupant upon request and start delivering the required cool breeze.

DESICCANT DEHUMIDIFICATION SYSTEM

Weather in Birmingham, AL, is hot and humid in summer, while winters are mild. **S u r v i v (A L)** House was designed with humidity and a cooling-dominant climate in mind. Nearly half of the cooling load is due to dehumidification. In order to reduce the load on the cooling system, a regenerative liquid desiccant dehumidification system was designed and built by students as their senior design project. Calcium chloride was selected as the desiccant due to its properties and harmlessness to occupants. The design incorporates an evacuated tube solar collector for regeneration of liquid desiccant system from low to high concentration. The schedule of the system allows for system usage in the evenings and during the night, and regeneration during the day using solar energy. The system uses minimal amount of electrical power for the liquid pump and its fan.

ENERGY RECOVERY VENTILATOR

Fresh air needs to be allowed into the house in order to prevent high levels of carbon dioxide and other pollutants. An energy recovery ventilator (ERV) is installed in the house for that purpose. The Panasonic ERV is a FV-10VE1 ERV [9] for temperate climate which delivers 50 to 100 CFM of air into and out of the house. The system has control knobs to select air flow rate. It is also equipped with a timer ranging from 10 to 60 minutes. The flow of fresh air into the house is controlled by the level of CO2 in the house. When the ERV is triggered, it will run for 30 minutes before it stops. The ERV is also linked to the central control system for control and monitoring of its operation to ensure safe levels of carbon dioxide is maintained in the house. More details on control schedule of the ERV is presented in the 'Whole-house monitoring and control system' section.

HOT WATER

We selected a heat pump water heater for the house because of its advantages over a simple electric water heater. The HP water heater is a GEH50DFEJSR GeoSpring hybrid electric water heater which has 50 gal capacity [10] with several modes of operation i.e. Heat pump mode, Hybrid mode, High demand/ Boost mode, Electric/Standard mode, and Vacation mode. The water heater comes with Wi-Fi connection that allows seamless incorporation into the central control system of the house. The energy factor of the water heater is 3.25 and in heat pump mode it uses only 550 W.

WHOLE-HOUSE MONITORING AND CONTROL SYSTEM

Siemens Corporation assisted Team Alabama in designing a monitoring and control system that encompasses many if not all power users/generators in the house. A centrally-located LCD monitor presents essential data to the occupants for making best decisions regarding comfort and energy efficiency. The sensors/controllers installed include current transducers, CO_2 sensors, occupancy sensors, dimmer switches, light sensors and timers. The temperature and humidity of each zone is measured and provided by the indoor air conditioning units. The ERV is controlled based on the CO_2 level in the house. Once the level passes the 1000 ppm limit recommended by ASHRAE, the ERV system will turn on. The ERV operation is timed, and it will continue to operate for a programmed length of time no less than 30 minutes. Carbon dioxide monitoring is important because the **s u r v i v (A L)** House is quite airtight unlike most traditional home constructions. Figures 3 – 5 show control sequence of ERV, lighting and air conditioning system. Tables 3 and 4 present additional info on power distribution priorities and definitions of charge and discharge levels.

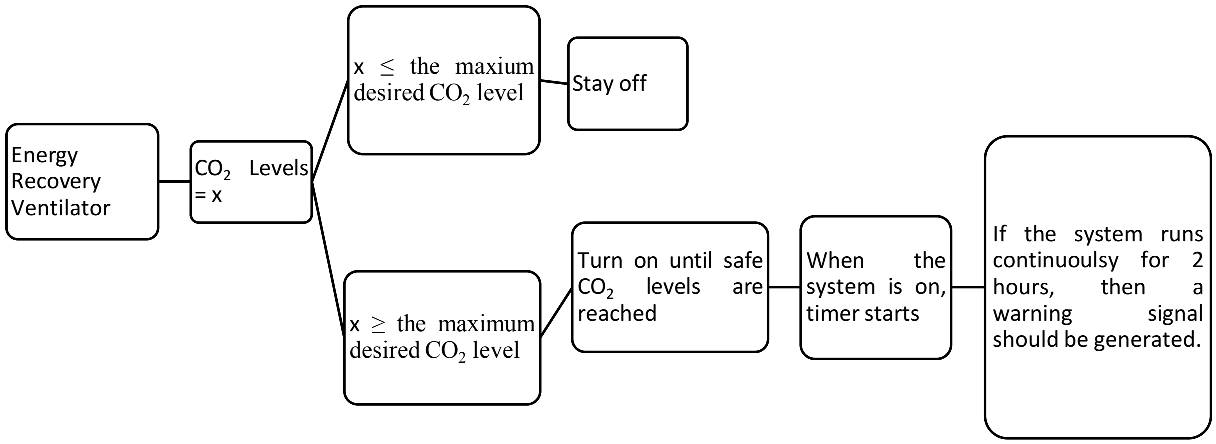


Figure 1. Control sequence of ERV

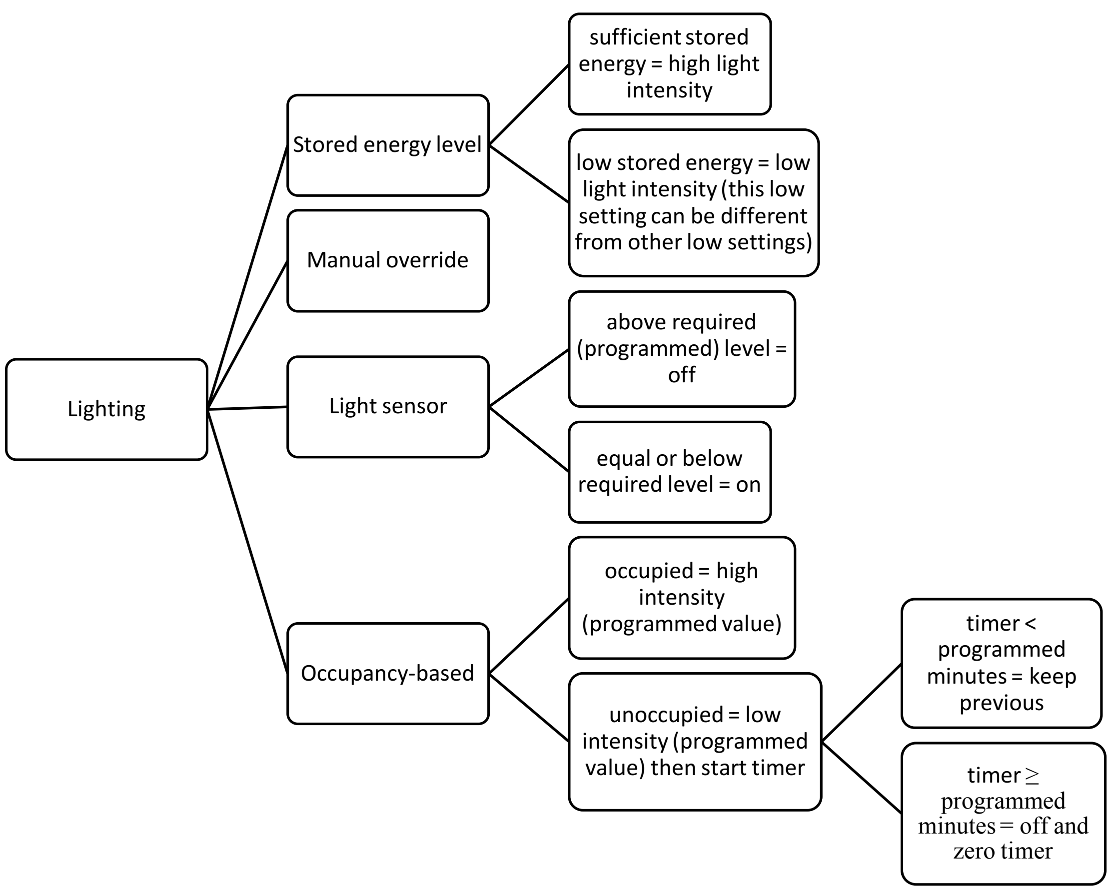
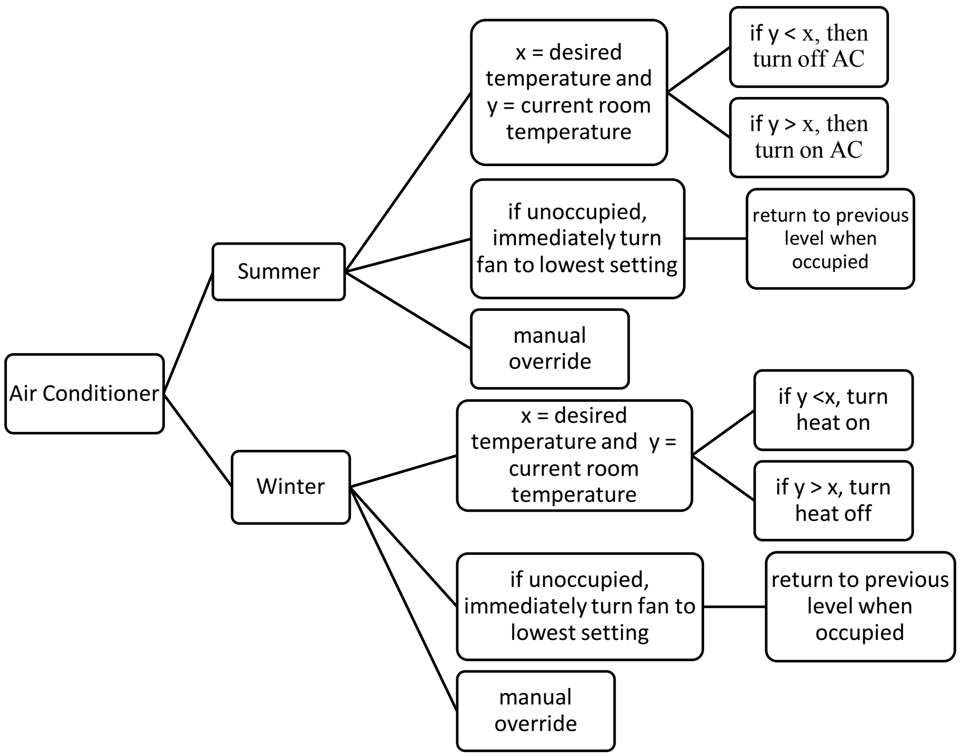


Figure 2. Control sequence of lighting

Figure 3. Control sequence of air conditioning system



In addition to monitoring the on and off status for the ERV and the elapsed time that the system is on, there will be a screen that allows for the usage of the power by the appliances and systems to be monitored. There will be a detailed breakdown of how much power is used by each appliance or system. This will make it easy to judge if the available power supplies are being used as efficiently as possible. The monitoring system will also display a warning if the stored energy is depleting quickly (battery state of charge or the ratio of the rate of power use over the rate of power generation). This warning would indicate that the remaining stored energy (for after the competition) has been set aside to power essential equipment such as the refrigerator, and is preventing non-essential equipment such as the washer and dryer, dishwasher, and water heater from running. In the above Table, if $B < 0$ no action will be taken, no matter what the value of A is. Also, no action will be taken if $kW_{gen} \leq 0.25$.

A measured-signal scanning delay of 1 min is programmed into the system. Power management is done by providing on/off signals to switches/relays cutting off power to the corresponding circuit.

Table 1. Power use priority level list

Load type	Discharge level	action
Refrigerator	any	Always on
Lighting	7	Dim minimum
ERV	6	Turn off
A/C	5	Turn off
Wall outlets except for heavy current takers	4	Turn off
Water heater	3	Turn off
Stove/oven	2	Turn off
Dishwasher and Clothes washer/dryer	1	Turn off

Table 2. Charge level and discharge rate definitions

Power management criteria (A "OR " B)		
Criterion A	Criterion B	
Battery charge state	Ratio of use to generation $B = \frac{kW_{used} - kW_{gen}}{kW_{gen}} \times 100$	Level number
65%	25%	1
60%	30%	2
55%	40%	3
45%	40%	4
45%	45%	5
40%	50%	6
35%	50%	7

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