



RESILIENCE



U.S. Department of Energy
Solar Decathlon 2021

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The SPARC house was designed and built for the permanent residents and temporary workers of mountain communities, and specifically for those of the West. With this opportunity to create a home that brings people together in pursuit of the adventure and sense of peace offered in the wilderness comes an immense responsibility to protect that environment and accept its power for destruction. This inherent responsibility is now underscored by the unprecedented rate of global climate change due to human activity.¹ Increasing climate volatility and impact of extreme weather events requires that any house built, in the mountains or across the country, must be resilient in that it can withstand extreme weather and other physical events, recover quickly when the physical events lead to disasters, and mitigate risk of disasters by directly addressing its own global warming effect.²

HAZARD ASSESMENT

In mountain communities of the West, as is the case for many locations across the country, the prevailing disaster risks that must be considered in design include physical and ecological events and potential disasters such as extreme temperatures, wildfires, flood, and drought. The location

of the town of Fraser along the Fraser River put the community at high risk of flood but the specific location of the house limits its exposure to the direct impacts of this risk. The community and the house are at highest risk for extreme weather and winter conditions, and secondary effects from wildfires. The highest likelihood effects of such events are house damage, poor indoor and outdoor air quality, electricity grid stress or outages, water restrictions, and access restrictions.

A relative comparison of the risks of pertinent hazards for Fraser are shown in the following table. The categorization of low, medium, and high risk for the community was informed by



the 2013 Grand County (Fraser) Multi-Hazard Mitigation Plan.³ The hazard rating is the average of the probability of occurrence and the likely magnitude of the event. The SPARC House design response to the risk prioritization is shown for high and medium risks.

Details of the design response are discussed below in three layers:

1) The house is designed to be durable to withstand primary risks of poor air quality, loss of access

to services, and extreme winter conditions, and protect occupants and systems during events.

2) The house is designed to be able to recover quickly from events that might cause damage to the physical structure and systems.

3) The house is part of a global effort to mitigate the hazard event risks to the Fraser community and the world imposed by climate change.

Table 1: SPARC House responses to risk prioritization

Hazard Event	Hazard rating for community	Hazard rating for house	Example impact of high-medium risk events (non-disaster)
Cyber attack	Low	Medium	Economic harm; failure of resilient systems implement using controls
Disease outbreak	High	High	Constrained mobility or resources; poor indoor air quality
Drought	Low	Low	-
Earthquake	Medium	Medium	Safety of occupants; damage to structure
Flood	Medium	Low	-
Hazardous materials (transportation)	High	Medium	Poor outdoor and indoor air quality
Landslide	Low	Low	-
Lightning	Medium	Low	-
Mountain Pine Beetle Infestation	Medium	Medium	Increased wildfire risk
Severe Winter Weather	Medium	Medium	Electric grid stress or outage; constrained mobility or resources; indoor freeze damage/flood
Wildfire	Medium	Medium	Fire risk; poor indoor air quality
Windstorm	Medium	Medium	Damage to structure

WITHSTAND

Low maintenance aspects

The design of the SPARC House is heavily invested in the longevity of the structure. Beginning with a standing seam steel roof with a lifespan of approximately 50 years the SPARC House is designed to be low maintenance and longlasting. The standing seam protects the roof from corrosion by eliminating exposed fasteners, is an integral component for a site exposed to harsh winter weather. In line with that philosophy, the other active systems were designed to limit roof punctures. Permanent tie off points were added to the roof for easy inspection. The walls were similarly protected from precipitation with a pine tar coating that seals wood against moisture. The lower walls are further protected from moisture with corrugated steel wainscotting.

On the inside, the conditioned spaces are wrapped in a continuous vapor barrier that prevents moisture from travelling to the envelope. Lighting fixtures, energy recovery ventilator (ERV) supply diffusers, and heat pump line sets are placed in the wall utility chases to prevent air barrier penetrations in the ceiling, which can increase the risk of moisture accumulation in the attic and on the roof structure. Should moisture

reach the attic, accumulation is prevented with the use of gable vents that move air (and moisture) through the attic. For routine inspection of the house two access panels were created for the owners to inspect the attic routinely for signs of moisture accumulation. The continuous layer of insulation is applied with

attention to maintaining R-46 or higher at the eaves. This detail will help limit ice damming, and prevent related damage to the roof and adjacent walls. Gutters are not used on the house to prevent the need for ongoing maintenance and repair; instead, a covered deck pathway to the main and ADU entrances is planned.

In order to prevent water damage from burst pipes inside the walls, the plumbing systems have been located in a “wet core” that uses the living spaces as an additional thermal buffer.

Moving outside the house, an important maintenance practice for mountain homes is creating a

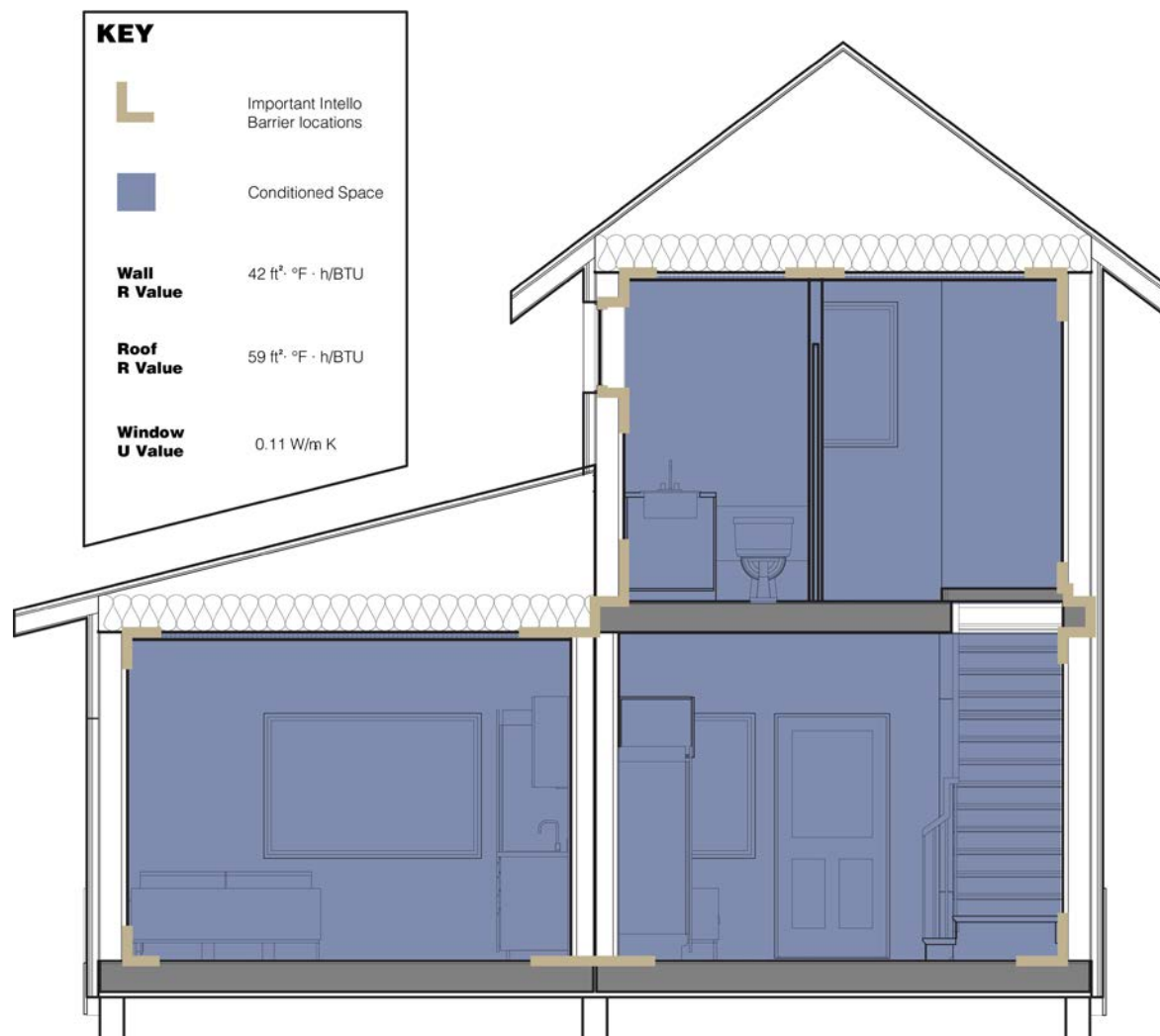


Figure 3:
SPARC House
section view
showing critical
vapor barrier
wrap points

low ignition home and defensible space for wildfire protection. Materials such as metal roof, multi-pane windows, and metal wainscot and decking will reduce the likelihood of ignition from an ember. Dead trees were removed from the site, and pruning and thinning maintenance will be ongoing by the homeowners.⁴ The SPARC House contributes to the broader community's ability to withstand events and disaster-level grid outages by participating in demand response events automatically, as determined by predicted or actual electric utility grid stress. Controllable loads such as the electric tank water heater and thermostatically controlled heat pumps can be automatically controlled for load management automatic demand response from the utility via the home automation system Home Assistant ("HASSIO").

The addition of a home automation system for load management and automatic demand response requires consideration of the risk of cyber attack. Automation systems have become a target for hackers. Hackers who gain access to home Internet of Things connected devices can use the targeted devices as a botnet⁵ or ransom⁶ them. Although we certainly do not anticipate that the SPARC House will become a target, reasonable measures have

been taken to ensure the home owners have continuous control and privacy in their home. To this end we have implemented the open-source home automation system (HEMS) Home Assistant ("HASSIO"). Open-source systems are preferred in the software community because they are regularly maintained when bugs are found and are rigorously tested by a large user base.

On the system level we will provide the users with remote control to their home through an Nginx server that provides end-to-end encryption of any requests to Home Assistant meaning that communication with Home Assistant cannot be monitored. At the device level, whenever possible, locally based controls will be used. This means that systems like the Lutron lights and Schuler heaters will only be able to be remotely controlled through the Home Assistant application. Some systems such as the Nest thermostat require cloud-based interfaces, although the security of Home Assistant would prevent access to other home devices through the Nest. In the event of a cybersecurity breach, physical controls such as wall mounted light switches are always available to the homeowner.

RECOVER

Performance During Event

When an event does occur, a combination of design strategies are used to ensure the SPARC House remains safe and functional. The SPARC House's ability to maintain a safe and functional environment during a grid outage requires that the house can be islanded from the grid. As a demonstration of feasibility in such a house, the permanently installed SolarEdge Inverter will be connected to a SolarEdge backup interface, which in turn will be connected to the HEMS as shown in Figure 5.

Critical loads may include one heat pump in addition to a small appliance circuit (computer and cooktop), a lighting circuit, and a refrigerator/freezer.

Time to Recovery

The ability of SPARC House to recover from catastrophic events is determined by its ability to operate safely for the occupant during the event and the time it takes to "return to normal". A primary aspect of the house's time to recovery is the ability of the house to endure the length of extreme weather events and grid outages with power supplied to the critical energy systems needed to supplement the

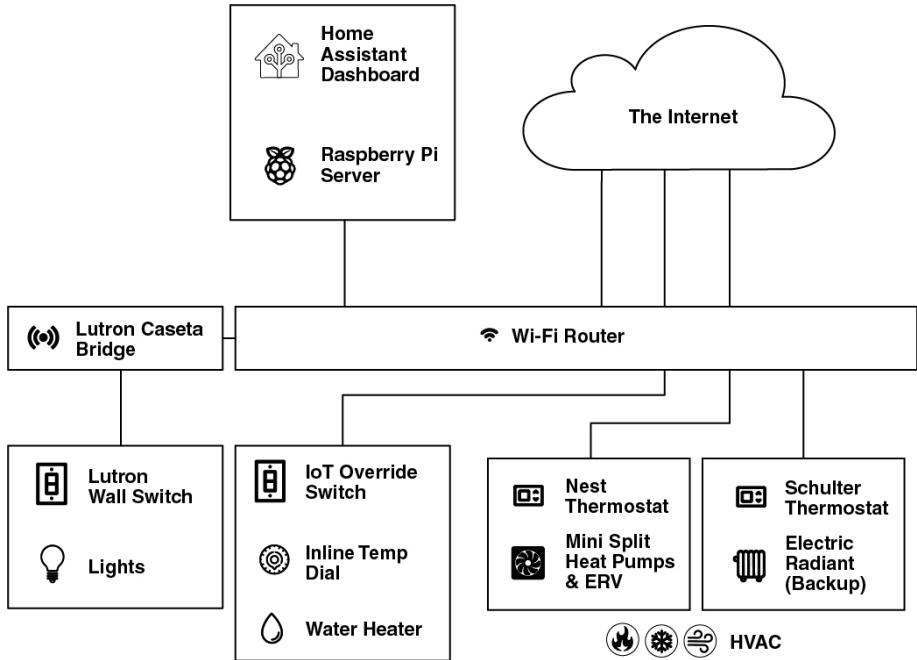


Figure 4: SPARC House controls diagram

previously described passive systems. For example, space heating must be maintained at a minimum temperature of 40-50 degrees Fahrenheit to prevent water freezing in pipes, and occupants must be able to stay in the home to interact with passive systems to conserve use of solar and battery electricity. The battery control strategy proposed for both normal operation, automatic demand response, and critical load management is outlined in Figure 6.

The HEMS will be responsible for the scheduling of battery charge and discharge. Under normal operating conditions the local

utility of Fraser, Mountain Parks Electric, does not provide a time of use pricing scheme. Therefore the battery is incentivized to charge at full power any time the state of charge (SOC) is less than the desired upper bound, and the battery is not being requested to power other loads. Should Mountain Parks Electric start utilizing a time of use price structure, the battery can be heuristically scheduled through the HEMS to charge at full power during the cheapest tier and at a reduced rate at the next lowest tier until fully charged. Conversely it may be scheduled to discharge during the most expensive tier. Model Predictive Control (MPC)

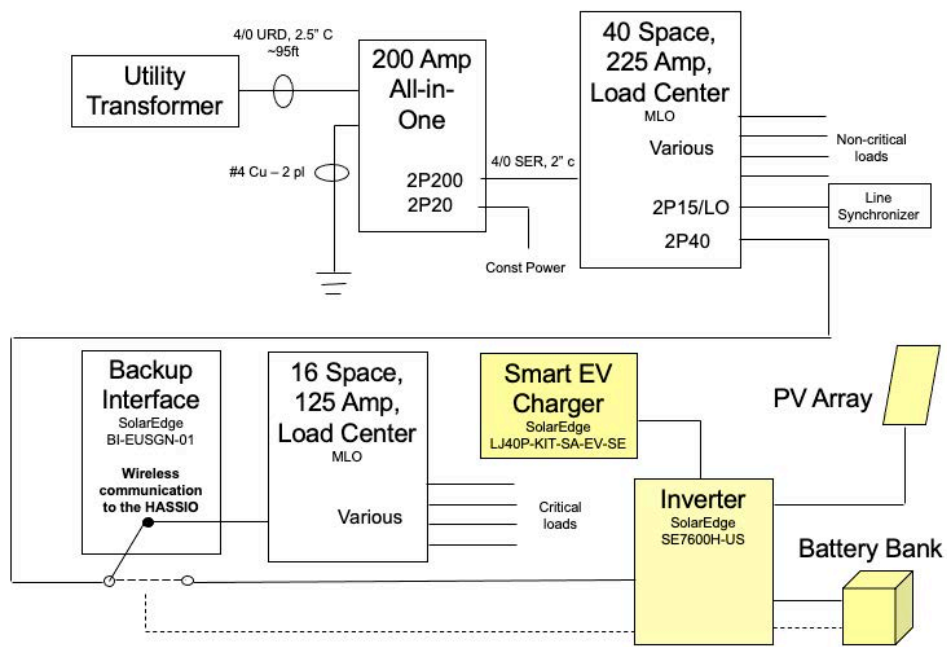


Figure 5: SPARC House one line diagram

Energy	<ul style="list-style-type: none"> An all-electric house means that both the solar panels and battery can be used to run any equipment type during reduced grid electricity supply. A multi-layered energy storage approach increases the time or loads for which the solar and battery can provide electricity: <ul style="list-style-type: none"> Thermal (electric tank water heater) Thermal capacitance; resistance (drywall and tile allow for some preheat; building envelope with R-42 walls, R-59 roof, and <0.11-0.16 U-factor windows slows heat transfer) Battery (home batter for demonstration; car battery to be used in future by homeowner).
Light	<ul style="list-style-type: none"> Daylight availability in all spaces allows for functionality during the daytime hours of a grid outage without need for electric lighting.
Heat	<ul style="list-style-type: none"> Three distinct house modules allow for all but one to be closed off temporarily to consolidate the floor area that needs heating or cooling during a grid outage. High efficiency, low-temperature performance heat pumps means heat can be supplied in extreme winter conditions and in limited use with solar and storage during a grid outage. Three separate single-zone heat pumps allow occupants to selectively heat zones and reduce the maximum power draw to the rated power of just one unit. A layered, semi-redundant heating system (electric resistance) with thermal capacitance in bathrooms (tile floor), and radiant heaters above beds allow for location-specific use of heating to reduce total heating energy needed during grid stress or outages.
Fresh air	<ul style="list-style-type: none"> Operable windows allow for admittance of fresh air during temperate outdoor conditions without the need for active energy supply. To protect the occupants from smoke and air pollutants caused by wildfires, the heating and air conditioning are separate from the ventilation system. In bad air quality conditions, the ventilation can be reduced at the discretion of the occupants. The ERV installed allows for the MERV8 filter, used for general energy efficiency, can be replaced with a MERV13 filter for greater air filtering.
Water	<ul style="list-style-type: none"> A 50-gallon water heater was installed and may be drained in the case of a power or water outage. The house exterior is painted with black pine tar to absorb and reradiate heat, which can be used for passive heating/drying and as a radiator for melting snow for consumption. Water is not required for space heating or cooling.
Food	<ul style="list-style-type: none"> A tabletop hydroponic system uses little space and water to enable supply of, even if a small amount, fresh food. Small appliances in the ADU such as a hot plate can be used temporarily by all occupants to limit the need for cooking energy in a grid stress out outage scenario.

Table 2: SPARC House recovery strategies during an event

Battery Control Narrative

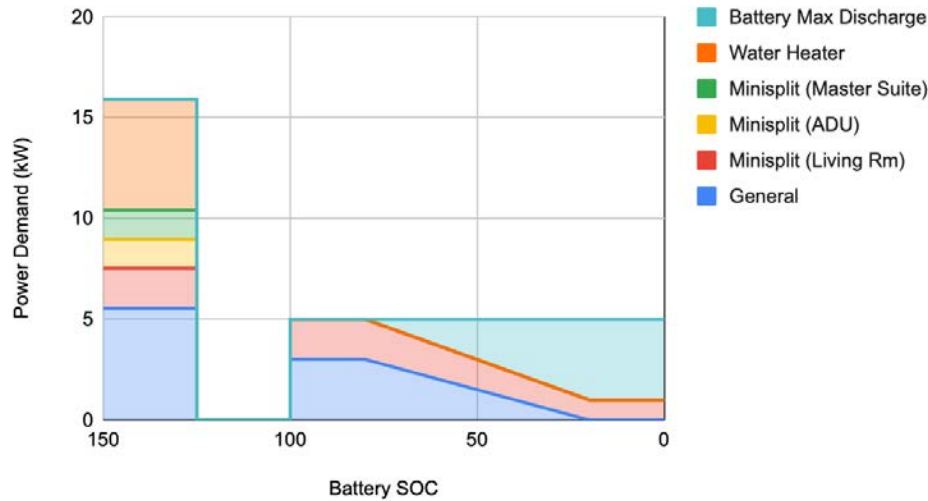


Figure 6: SPARC House battery control narrative

and Reinforcement Learning are becoming increasingly common control strategies in academic research and may be a viable option in the future but at this time, it would not guarantee immediate and significant payoff for the homeowners without knowing the exact parameters of any potential time of use pricing scheme.

When the battery is fully charged and demand response is requested from the local utility, load shed can be achieved by reducing power consumption of current loads, supplying power to the home through the battery, or some combination of the two. When the home is operating in battery powered mode and the battery is at or above the

maximum desired state of charge the home can safely power all loads at normal operating

conditions. For example, if the home switches to battery powered mode at full SOC then the heating setpoint can remain at the typical 68 degrees Fahrenheit. However, as the battery SOC decreases loads will be scheduled at reduced capacity until a safety minimum is reached. For heating this means that the HEMS will maintain a setpoint of at least 52 degrees Fahrenheit for as long as it is physically capable of maintaining the load in order to prevent water freezing in pipes. At any point between the minimum acceptable SOC and the desired maximum SOC the setpoints for each system will be extrapolated. This strategy will be applied across all variable power loads

such as the HVAC and lighting. In order to maintain occupant comfort in case of a HEMS outage (i.e. internet outage), each system will maintain physical controls located in the home such as wall mounted light switches and thermostats. Occupants can then manage loads either directly or through the HASSIO interface schedule the use of the most important loads for the type of outage and weather conditions.

MITIGATE & INNOVATE

The SPARC House was designed to respond to the needs of the global and Fraser community,

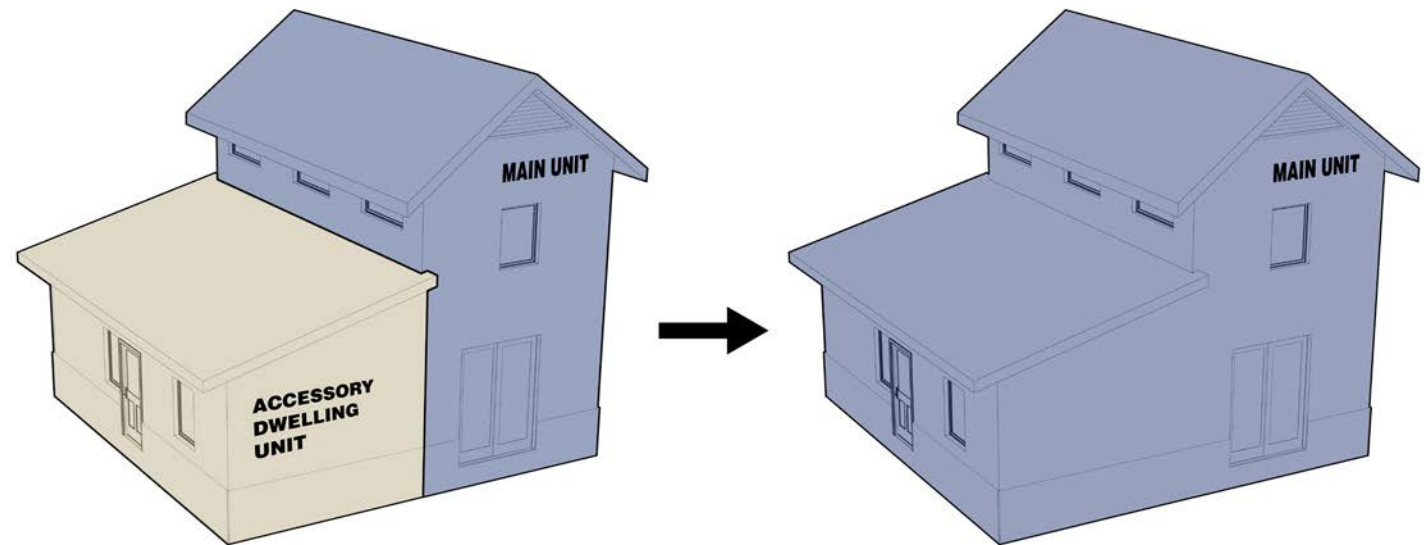


Figure 7: The attached ADU can easily be replicated as or converted into a 3rd module to reflect occupant needs

and to support the productive and healthy lifestyle of the actual homeowners. These perspectives are discussed below.

Global Community: Resource Management

Material and resource selection for the SPARC House were made to reduce both global warming potential and cost relative to default products and processes that were considered.

Example selections that gave a cost and a resource management advantage to the house concept are:

- Use of stick built construction with mineral wool and sheep's wool insulation; foam only in critical air gaps and continuous insulation detailing
- Factory-built panels to minimize construction waste
- Use of beetle killed pine, which makes use of abundant material produced in the area
- Ikea furniture used to support a manufacturer who has initiatives to make affordable, long-lasting products⁷
- No water used for heating, cooling, or landscaping, and low water use appliances and fixtures used

- For replicability, scale up and down module count and positioning for different homeowner needs while quickly moving toward an all-electric zero energy plus housing market.

Fraser Community: Housing and Job Supply

The SPARC House and replicated models will increase the supply of attainable housing options for both permanent residents and temporary workers. The house also aims to serve as a model for a panelized, grid-integrated house with solar and storage that increases the demand for local prefabrication, and microgrid and energy storage development. Additionally, the house provides an example of a house that can support living, working, and playing to reduce the need to commute.

The SPARC House is designed for work, sleep, and play, and can be a place where the occupants can stay for many days on end, and can safely and effectively do so even in extreme weather conditions or grid events.

Homeowners: Health and Wellbeing

Turning inward to the real homeowners, the SPARC House must be a place that supports their health and wellbeing. This is accomplished through the

use of healthy materials such as continuous sheeps wool interior insulation, and low- and no- VOC interior materials. The abundant use of operable windows allows for a constant connection to views, daylight patterns, and outdoor

air, in addition to their energy saving benefit. When needed, the all-electric equipment can be powered by the electric grid, home/car battery, or solar panels to ensure a continuous safe and functional environment.

Endnotes

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