ENGINEERING NARRATIVE
D8 SUBMISSION

UNIVERSITY OF WYOMING (UWYO)
U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON BUILD CHALLENGE 2023

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Overview

These are the key features of the Wind River house:

- *Climate Zone: 6B*
- *Heating Degree Days: 4084 7796*
- *Cooling Degree Days: 1266*
- *Floor: R-20; Walls: R-30; Roof: R-50*
- *Windows: Alpen Tyrol (triple-pane)*
- *Airtightness: 0.25 ACH. The tightest home in Wyoming!*
- *Heating load: 10,286 kWh; Cooling load: 4,458 kWh*
- *Annual energy use: 13,102 kWh*
- *Annual energy production: 23,646 kWh. Net-positive!*

I. Structural System

All structural documents are prepared and revised by a professional engineer (John Nicholas, PE, of Stahly Engineering; he is a graduate of the UW Architectural Engineering program).

Figure 1. Traditional framing (2x6 studs)

The structural system is relatively standard, following the project's philosophy to show Wyoming homebuilders that they can build a Zero-energy house with available equipment and typical construction methods.

The foundation is an insulated slab-on-grade foundation with strip footers below the frost line around the perimeter. These were designed based on a soil bearing pressure of 1,500 PSF. Foundation walls are 4,500 PSI concrete, while the floor slab is 3,500 PSI. The slab is 4" thick with #3 rebar at 18" O.C. each way.

The walls are 2x6 construction. The wall section includes continuous exterior insulation and rainscreen cladding. The loft and upper roof are supported by heavy timber columns and glulam beams, which are visible in the finished interior. The largest glulam beam is 5-½ x 19-½, spanning 31'–6".

The lower roof (an eccentric gable) is made of pre-engineered trusses spaced 24" O.C. The upper roof (shed) is made of 16" i-joists spaced 24" O.C. A snow load of 57 PSF governed the design. The overhangs are designed for an ultimate wind load of 106 MPH (3-second gust).

Figure 2. Insulated attic space

II. Occupant Comfort

A major element of comfort is airtight construction. The Wind River house also has a super-tight envelope that reduces air infiltration**. Based on our blower door results (0.25 ACH), the Wind River home has the tightest envelope in Wyoming.** Fresh air is delivered at low velocity by a CERV system (described below).

The Wind River house includes mechanical cooling, even though a review of recent home listings in the Lander area shows that many of the homes put up for sale do not have any form of cooling (Figure 3). Out of the minority of buildings on sale in Lander that have a cooling system installed, most use different cooling equipment than the heating system, which incurs additional costs.

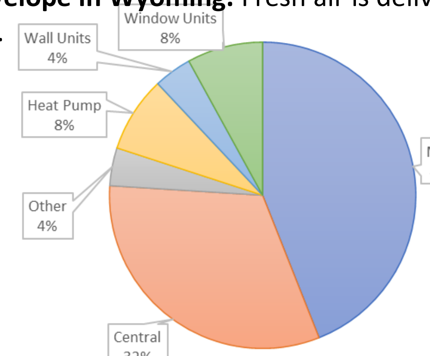


Figure 3. Cooling systems for recent listings in Lander [1, 2]

Weather station data from the past 70 years have shown rising average 10-year summer temperatures in the Lander area (Figure 4). Therefore, current buildings must be future-proofed by having some form of cooling. The Wind River Home addresses this by using the same system (air-to-water heat pump) for both heating and cooling via reverse operation. Hence, the building can maintain the desired temperature without the need to invest in separate systems. The radiant cooling and heating floor system allows for this functionality and eliminates issues with draft and vertical temperature gradients that are experienced in traditional mechanical systems.

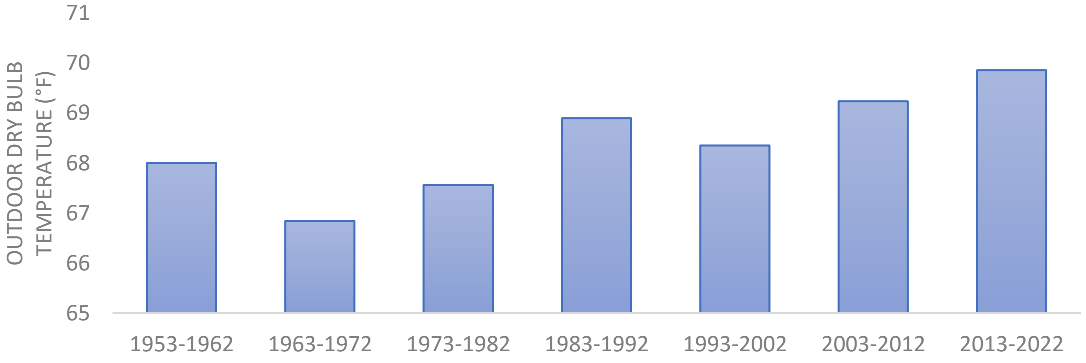


Figure 4. Ten-year Average Summer Temperatures for the last 70 years in the Lander Area [3]

Traditional mechanical systems are also a major source of internally generated noise, as they use fans to circulate large amounts of air. The radiant floor system eliminates this issue. Occupants of retrofitted buildings have positively highlighted the quiet operation of radiant systems [4].

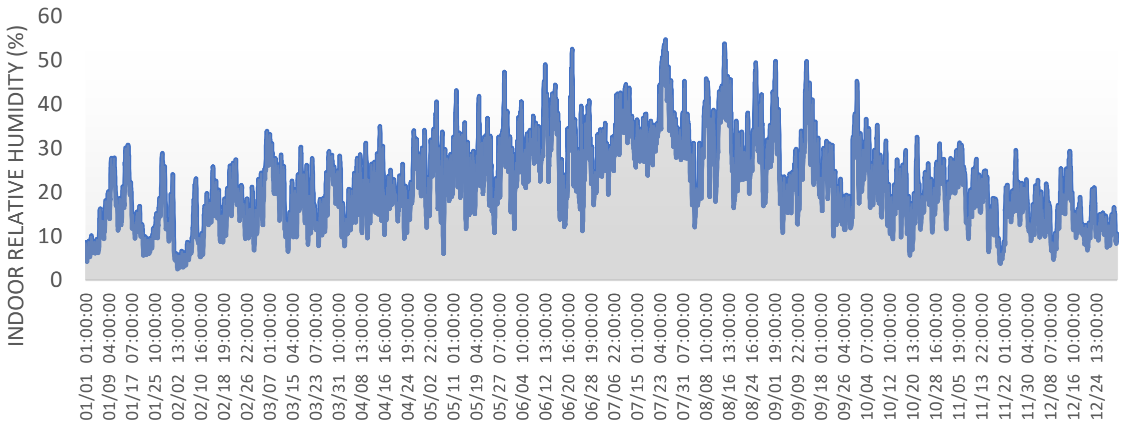
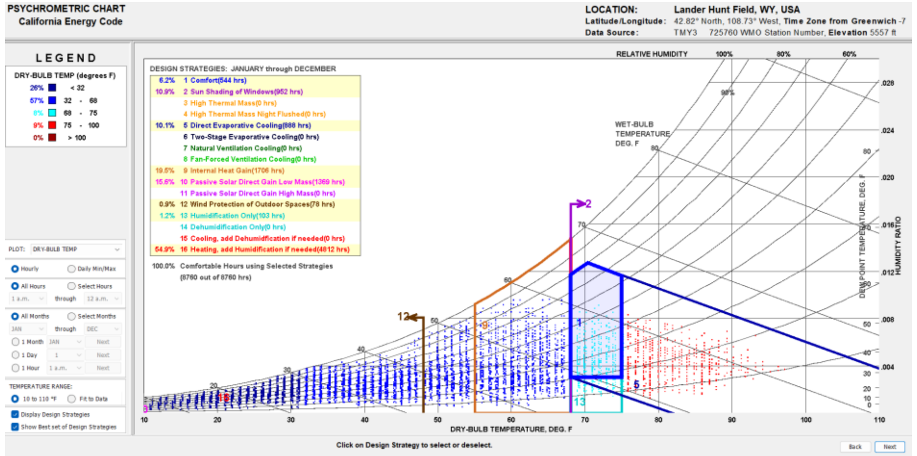


Figure 5: Daily Averaged Indoor Relative Humidity from Energy Model



Our modeling shows indoor RH rarely goes above 50% (Figure 5). This is because there is never enough water in the air during heating to raise the indoor humidity levels (Figure 6).

Figure 6: Psychometric chart showing there is no need for dehumidification indoors.

III. Passive Heating and Cooling Strategies

The heating and cooling design are centered around splitting the house into three thermal zones (Figure 7). The zones are separated based on the amount of solar heat gain experienced by each zone. Zones 1 and 3 will experience significant passive solar heat gain, while Zone 2 will not.

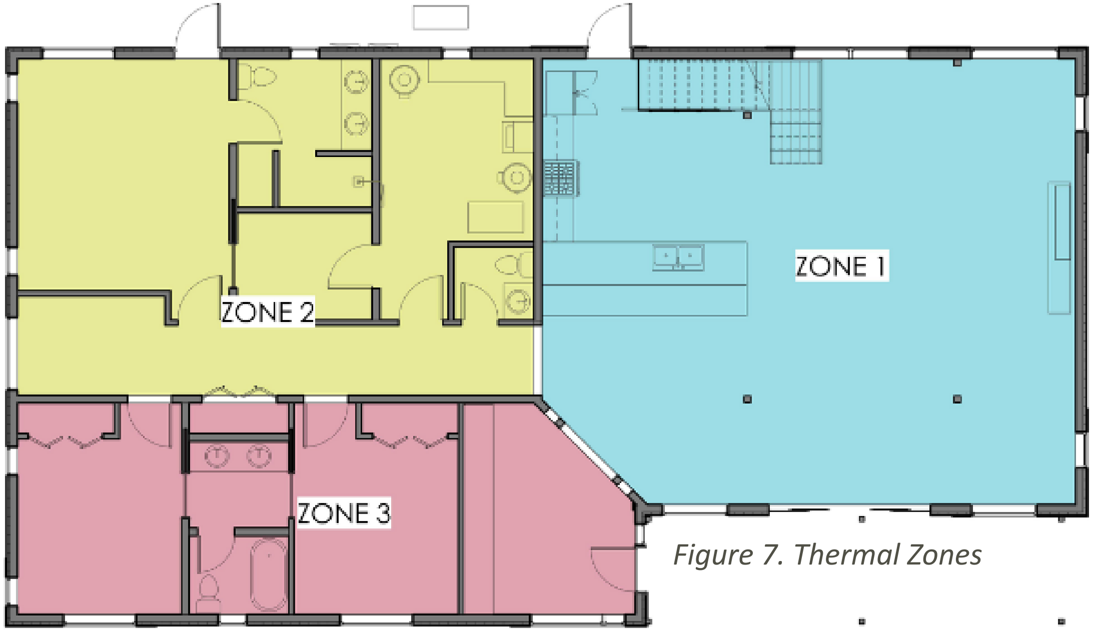


Figure 7. Thermal Zones

While solar heat gain is critical in the winter to reduce mechanical heating loads, mitigating unwanted heat gain in the summer is equally important. To accomplish both goals, the roof angles and window placements were specifically designed to fully shade south-aspect glazing during the summer (Figure 8). A mechanically retractable awning over the south patio helps this process. During the winter months, however, the windows become fully exposed, maximizing heat gain (Figure 8). This passive heating strategy is improved by installing heavy, interior curtains on the south glazing that can be used to further insulate the home at any time.

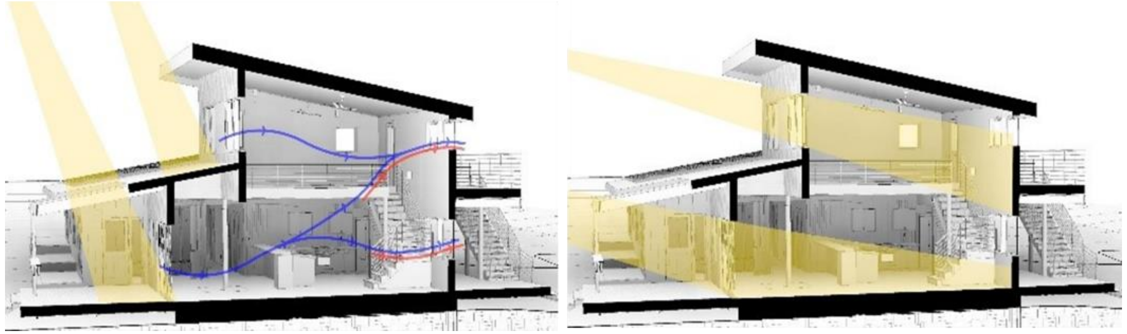


Figure 8. Left - Summer; Right – Winter

IV. Mechanical Systems

Hydronic Heating/Cooling

Despite the efficient passive solar heat gain strategy, a mechanical heating and cooling system is needed to offset the environmental extremes Lander experiences.

The primary method of heat distribution consists of a hydronic in-floor heating and cooling system (Figure 9).

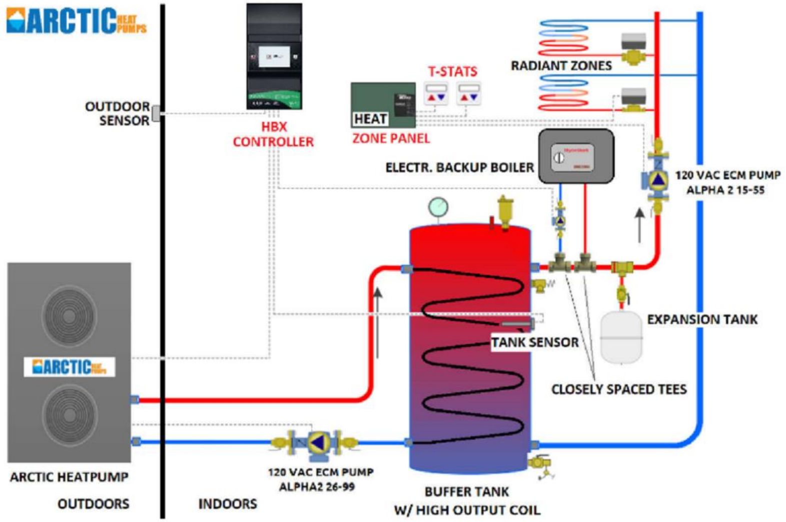


Figure 10. Artic Heat Pump Diagram

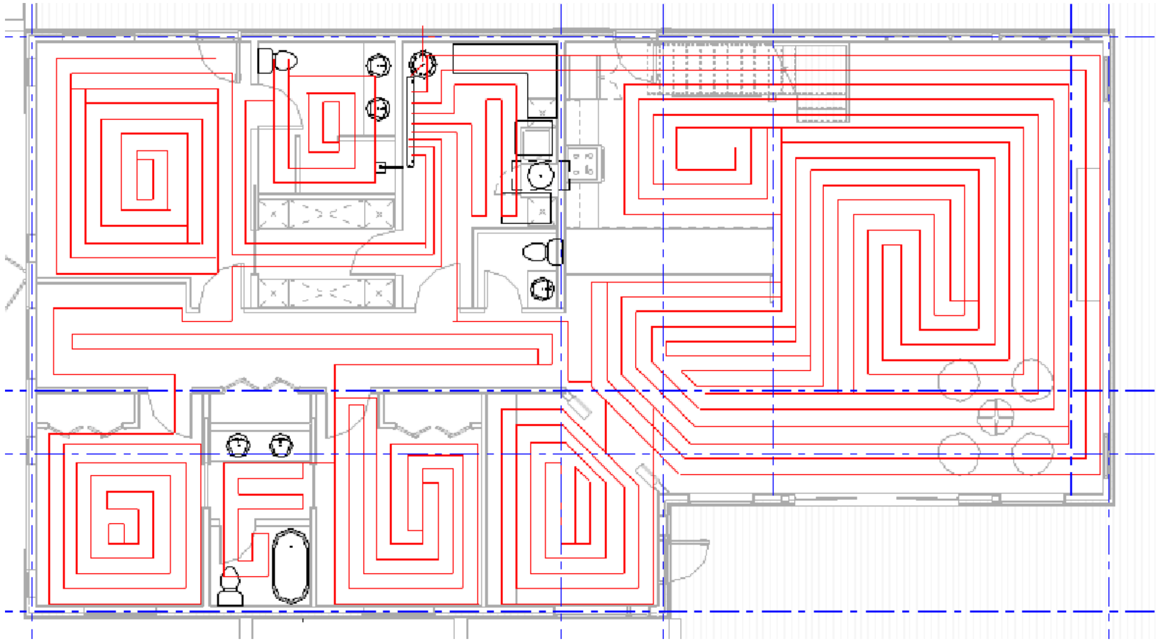


Figure 10. Map of Radiant in Floor Heating

The operation relies on the ARCTIC air-source heat pump, which extracts heat from outdoor air with a COP between 3.1–4.0. The air can be as cold as -22°F and still maintain a COP of 2.0. The extracted heat is then used to warm glycol that is stored in a buffer tank before being distributed throughout the home via hydronic coils. The fully insulated coil system is installed within the concrete slab flooring, and the glycol radiates heat through the slab to all thermal zones of the house (Figure 10). Each zone is connected to individual buffer tanks that allow for customizable heating temperatures.

The concrete slab has a high thermal mass, allowing it to passively store and radiate heat from day to night. The hydronic system only needs to run for about 2-3 hours a day during the winter. In the summer, the heat pump cycle can be reversed to provide cooling to the home. In general, the hydronic heating and cooling system limits energy usage while still providing reliable warmth throughout the year. A backup electric boiler is also available to supplement the heat pump system during particularly hot or cold periods. However, these situations are rare, and the heat pump system can handle over 90% of the heating and cooling loads.

Mechanical Ventilation

The Wind River home has an extremely air-tight envelope, meaning that mechanical ventilation is critical for the efficient and safe operation of the home. This task is handled by the CERV heat recovery ventilation unit, which pre-heats incoming cold, fresh air and recovers nearly 90% of the heat from exhaust air (Figure 11). This unit also monitors VOCs (volatile organic compounds) and CO_2 levels.

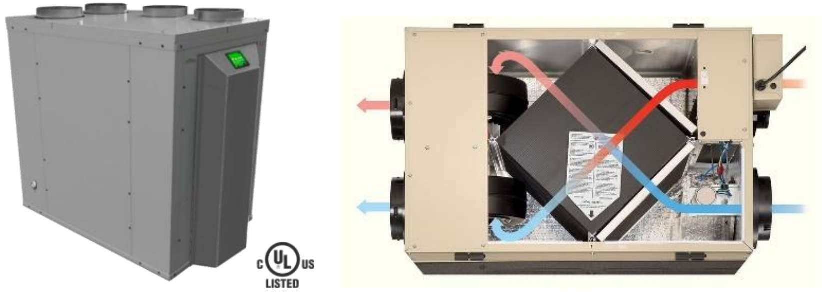


Figure 11: CERV Energy Recovery Ventilation System

Passive Ventilation

In addition to mechanical cooling, natural ventilation is an essential process during the summer. Since the Wind River home is located at the top of Red Canyon, a breeze often develops later in the day. The Wind River home was designed to harness this breeze to provide natural cooling and ventilation to the home during the warmest part of the day (Figure 8).

IV. Plumbing System

The Wind River house is situated 11 miles outside of Lander, meaning city water must be transported to the site and stored in cisterns for domestic use. Thus, water conservation is essential during home operations. The dishwasher and washing machine are optimized for water efficiency, and plumbing fixtures were chosen for low-flow water usage, saving nearly 10-20% in water consumption compared to average fixtures. The spaces requiring water are also located close together. This minimizes heat loss from hot water plumbing and reduces costs associated with extensive plumbing routes.

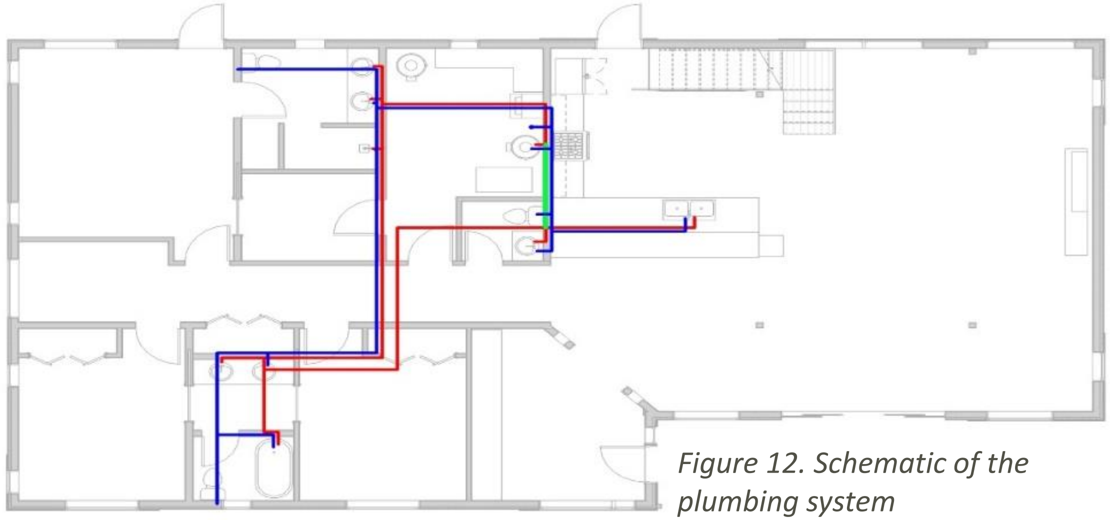


Figure 12. Schematic of the plumbing system

Hot water delivery is accomplished by the innovative Rheem hybrid heat pump water heater, which can generate hot water at a COP of 3.5. The hybrid functionality allows the water heater to pull heat from either the interior space or from the outdoor air source heat pump. The hot water plumbing is then routed through the warm attic space (Figure 14), which improves heat retention and ease of maintenance. A hot water recirculation line provides instant hot water to all fixtures, reducing the amount of waste while waiting for hot water to arrive

Figure 13: Rheem hybrid heat pump water heater

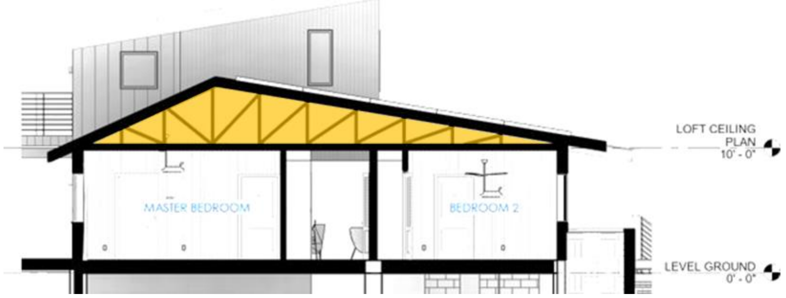


Figure 14: Warm attic

VI. Electrical System

Solar Array

The most effective strategy to achieve net-zero energy for a house is to implement solar panels. The Wind River home uses an oversized photovoltaic array to capture nearly 3000 hours of annual sunshine in Lander. The panels are secured flush to the south-aspect roof, creating a tilt of 9.5°. In addition, the entire home is oriented 15° southeast due to regional climate conditions: daily afternoon storms during the summer and autumn months result in a loss of solar energy gain later in the day. By shifting the home's orientation slightly, this loss can be mitigated by an increase in solar energy production during the morning hours.

Figure 15. A photo of installed solar panels.

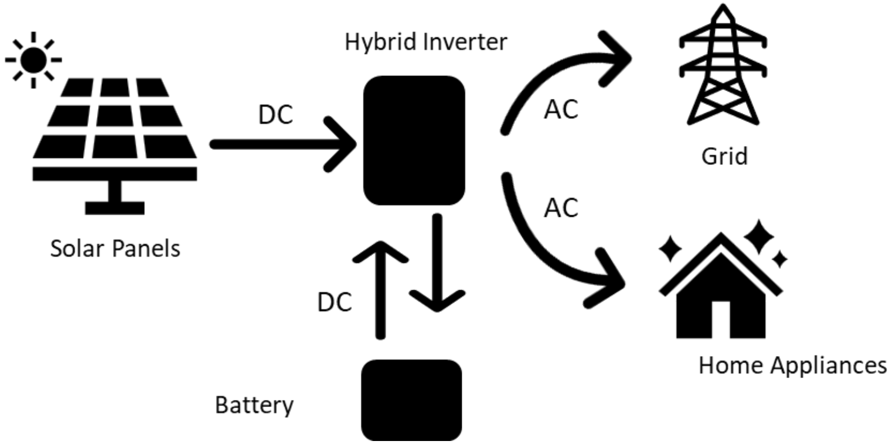


Figure 16: Diagram of hybrid inverter interaction

To obtain maximum energy generation to power the home, we chose Q.PEAK DUO XL-G10.3 solar panels. Each panel can produce up to 480 W, and with 32 modules covering nearly 795 ft^2, the entire solar array can generate 15.36 kW at peak production. On a sunny day, over 200 kWh can be produced reliably.

Solar energy is directed to the Sol-Ark 15k hybrid inverter, which can direct solar energy to the batteries, convert solar energy to power the house or feed energy back to the grid. This allows the home to be fully operational "off-grid" for extended periods. The KiloVault HAB batteries allow for the storage of 15 kWh between two units, which is enough to power the house for an amount of time.

Electric Vehicle Charging

The home will have a wall-mount Tesla J1772 charger located in the garage. The electrical system is rated for high amperage performance and can deliver up to 20-30 miles of driving per hour of charging.

Lighting System

LED lights are utilized throughout the home, and they are connected to Lutron Caseta dimming switches, which allow for variable lighting conditions. This process can occur manually via light switches, a phone app, or by programming the lights to automatically dim on a specified schedule.

VII. Energy Performance

The Wind River home is designed to be a net zero home, harnessing both active and passive solar energy for electricity generation and passive heating respectively. It also has a tight and well-insulated envelope in addition to energy-efficient windows. An energy model was created using OpenStudio and EnergyPlus [5]. It estimates the energy supply from the solar panels and energy demand for heating and cooling, water heater, major appliances within the home, charging an electric vehicle to run 20 miles a day, interior lighting, and other internal loads. The result of the simulation shows that the Wind River home produces more energy than it uses

Building Envelope

The Wind River home has a well-insulated envelope with R-values of 30, 20, and 50 for the walls, floors, and roof respectively. The envelope is also airtight, with the blower test recording a leakage of just 0.25 ACH.

Fenestration

The Wind River home allows for passive heating through ample fenestration on its south façade. A downside to this is an increase in the cooling load, especially during the summer months. But since the climate of the site location experiences approximately three months of summer, the benefits of heating far outweigh this downside.

The home also has energy-efficient windows installed. The specifications of each window and the corresponding Window-to-Wall Ratio (WWR) are given in Table 1.

To reduce its effects on the cooling load during the summer, the Wind River home would incorporate retractable deck shading on the south façade of thermal zone 1 (Figure 17).

Based on the energy model, the energy-efficient windows contribute an annual sum of 29, 870 kWh of passive heating (Figure 18).

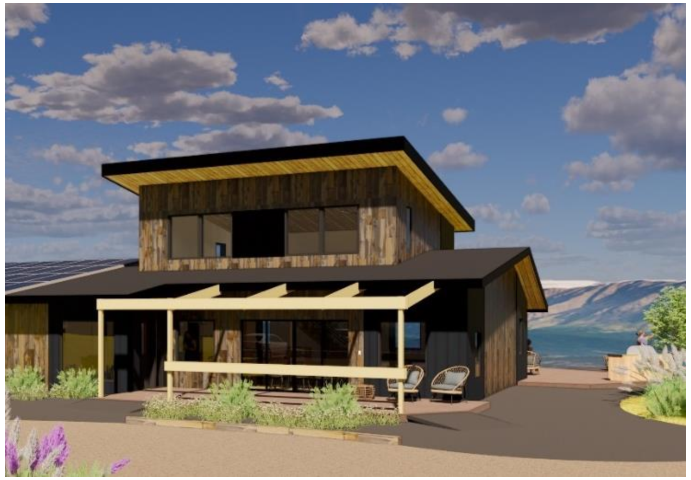


Figure 17: Retractable deck shading infrastructure for summer passive heating reduction

Table 1. Window Specifications

Thermal Zone	Orientation	Location	WWR	Window Size (in x in)	Type	Quantity	U-Factor (Btu/h*ft²*F)	SHGC
Zone 1	***South***	*Living Room*	0.29	53.5 × 59.5	Fixed	2	0.14	0.45
		Dining		119 × 83.5	Left - Fixed Right - Operable	1	0.15	0.39
		Loft		95.5 × 59.5	Left - Operable Right - Fixed	1	0.15 0.14	0.39 0.45
		Loft		95.5 × 59.5	Left - Fixed Right - Fixed	1	0.14	0.45
	East	*Living Room*	0.04	29.5 × 35.5	Fixed	2	0.14	0.45
		Loft		23.5 × 53.5	Fixed	1	0.14	0.45
	North	*Living Room*	0.16	71.5 × 47.5	Left – Operable Right - Fixed	1	0.15 0.14	0.39 0.45
		Living Room Stairs		47.5 × 47.5	Fixed	1	0.14	0.45
		Living Room		24.0 × 72.0	Door Glass	1	0.36	0.34
		Loft Stairs		47.75 × 47.5	Left – Operable Right – Fixed	2	0.17 0.14	0.24 0.45
		Loft		24.0 × 72.0	Door Glass	1	0.36	0.34
	West	*Loft*	0.07	23.5 × 53.5	Operable	2	0.15	0.39
Zone 2	***North***	*Mech Room*	0.13	23.5 × 35.5	Operable	1	0.15	0.39
		Master Bathroom		23.5 × 35.5	Operable	1	0.15	0.39
		Master Bedroom		59.5 × 47.5	Operable	1	0.15	0.39
		Master Bedroom		24.0 × 72.0	Door Glass	1	0.36	0.34
	West	*Master Bedroom*	0.16	23.5 × 47.5	Operable	2	0.15	0.39
		Book Nook		59.5 × 47.5	Operable	1	0.15	0.39
Zone 3	***West***	*Bedroom 2*	0.11	23.5 × 47.5	Operable	2	0.15	0.39
	South	*Bedroom 2*	0.18	59.5 × 47.5	Left – Operable Right – Fixed	1	0.15 0.14	0.39 0.45
		J & J Tub		23.5 × 35.5	Operable	1	0.15	0.39
		Bedroom 1		59.5 × 47.5	Left – Fixed Right – Operable	1	0.14 0.15	0.45 0.39
		Entry		53.5 × 71.5	Fixed	1	0.14	0.45
	East	*Entry*	0.34	24.0 × 71.5	Operable	1	0.15	0.39
		Entry		24.0 × 72.0	Door Glass	1	0.36	0.34

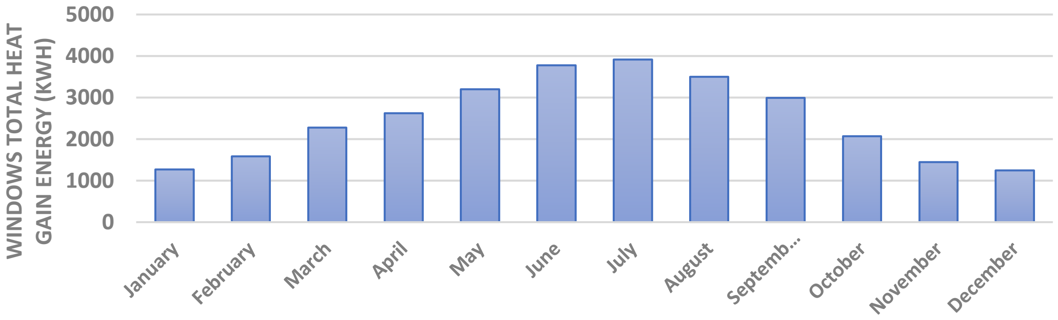


Figure 18: Passive solar heating

Internal Loads

Estimates are based on typical home appliances. The type of appliance, wattage, and operation schedules are presented in Table 2.

We assumed a household of 4 would be the typical occupant size for the Wind River home. Table 3 shows the assumptions for internal gains and schedule for the home occupants.

For interior lighting, estimates were made based on the floor area in each zone and assuming a 15W LED light bulb is used throughout the home (Table 4). Thermal zone 1 is assumed to require fewer bulbs per floor area because it gets a lot of sunlight from the south-facing windows.

Electric Vehicle and Solar PV Generation

Certain assumptions were made for electric vehicle charging. The electric vehicle type was assumed to be a Tesla Model S Standard Range Sedan. It has a power consumption of 75 kWh and a mileage of 270 miles on a full charge. The charge type is assumed to be the wall connector which charges at a rate of 44 miles per hour. For the decathlon competition, the home is required to charge the electric vehicle to cover 20 miles a day. It would take the wall connector approximately 30 minutes each day to charge up to 20 miles. This adds up to 5.6 kWh or a power input requirement of 12222 W. While the solar PVs can generate 15360 W. The amount it produces each day would vary based on the amount of sunlight it receives.

Energy Simulation Results

The temperature setpoint for the simulation was set at 74 °F for cooling and 68 °F for heating, this temperature was maintained for all the thermal zones with the setpoint not met during occupied heating being 2.67 hours and that for cooling is 13.33 hours for the whole year (Figure 19).

Table 2. Loads for Appliances

Appliance	Power (Watts)	Schedule
Induction Range	105.0	Weekdays; 7:00 – 8:00, 18:00 – 19:00 Weekends; 7:00 – 8:00, 12:00 – 13:00, 18:00 – 19:00
Fridge	70.0	8 hours every day
Heat Pump Water Heater	2055	4 hours every day
Dishwasher	247.0	Weekdays; 7:00 – 8:00, 18:00 – 19:00 Weekends; 7:00 – 8:00, 12:00 – 13:00, 18:00 – 19:00
Washer	600.0	Weekends; 9:00 – 10:00
Dryer	825.0	Weekends; 10:00 – 12:00
TV (40-inch)	34.2	Weekdays; 19:00 – 21:00 Weekends; 9:00 – 12:00, 18:00 – 21:00
Computer (15-inch)	60.0	Weekdays; 19:00 – 21:00 Weekends; 9:00 – 12:00, 18:00 – 21:00

Table 3. Internal Load from People

Thermal Zone	# Occupants	Activity Level (Watts per person)	Schedule
Zone 1	4	130	Weekdays; 6:00 – 7:00, 18:00 – 21:00 Weekends; 7:00 – 21:00
Zone 2	2	130	0:00 – 7:00, 21:00 – 24:00
Zone 3	2	130	0:00 – 7:00, 21:00 – 24:00

Table 4. Internal Loads from Interior Lighting

Thermal Zone	Location	Assumption	Floor Area (ft^2)	# Bulbs	Power (Watts)
Zone 1	***Kitchen***	1 bulb/50 ft^2	374	7	105
	Dining		270	5	75
	Living Room		420	8	120
	Loft		322	6	90
Zone 2	***Master Bedroom***	1 bulb/25 ft^2	210	4	60
	Master Bath		153	3	45
	Book Nook		140	3	45
	Mech Room		170	3	45
Zone 3	***Bedroom 2***		165	3	45
	Bedroom 1		105	2	30
	J & J Tub		165	3	45
	Entry		165	3	45

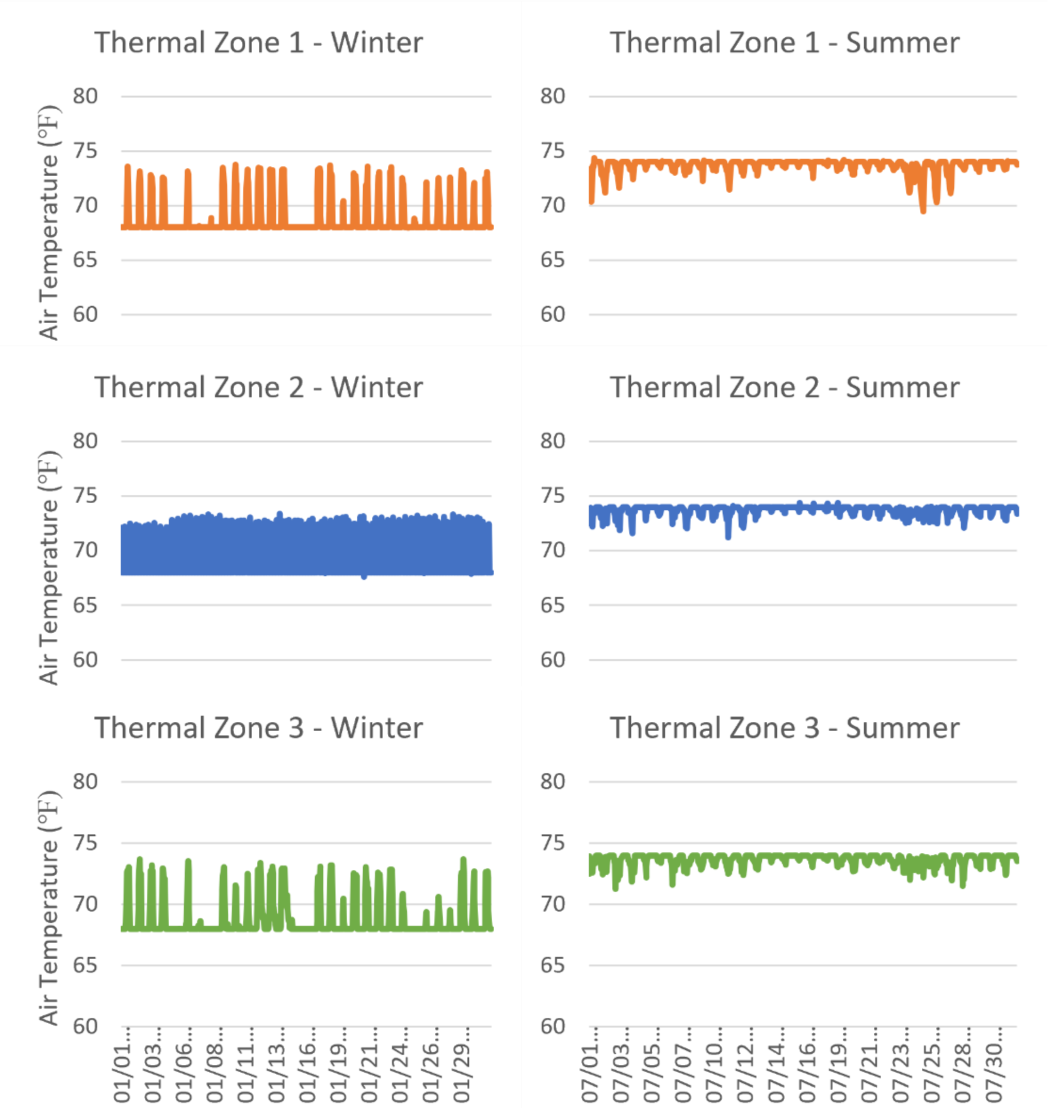


Figure 20. Indoor air temperatures for a typical winter (January) and summer (July) for each thermal zone

Peak cooling occurs in July, while peak heating occurs in January (Figure 20). Due to longer periods with low outdoor air temperature, more heating is required in this region compared to cooling. Hence, the additional cooling due to passive solar heating is minimal compared to its contribution to minimizing the heating demand for most of the year.

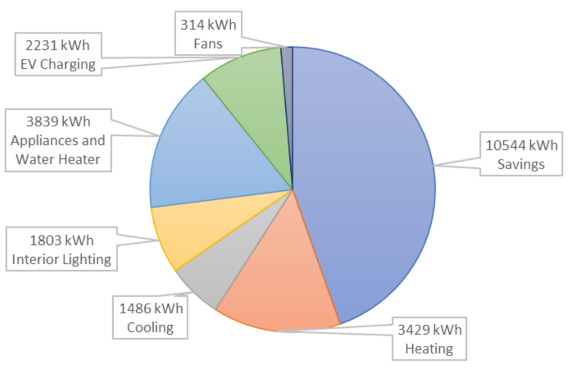


Figure 21: End Use by Category

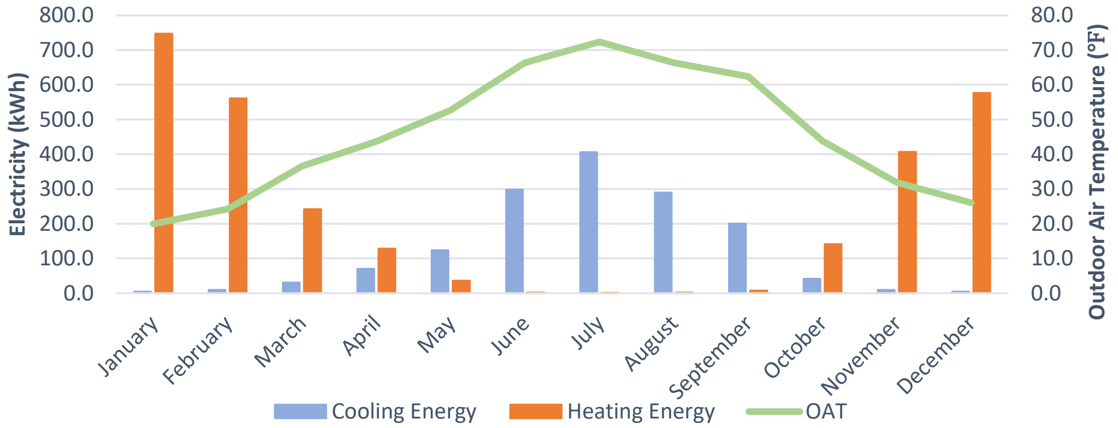


Figure 22: Annual Heating and Cooling Energy vs Outdoor Air Temperature

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