SILO

Engineering Narrative

Missouri University of Science and Technology

Intro

The team approached this project with the purpose to design and build a net zero energy home that reflects the future of residential engineering and automation. A Smart Innovative Living Oasis, SILO, showcases technology that is on the forefront of energy production and conservation. SILO is designed for a couple in their late 40's and early 50's who are ready to cut unnecessary space, upgrade quality, and live sustainably. The team is broken up into many sub-teams that are able to utilize talent from every area of study at Missouri S&T and facilitate the flow of ideas through the team as a whole. The coordination within the team exemplifies the coordination of the home's systems.

Structural Design

A unique challenge this competition presents is that of transportation. The team's structural engineering students were focused on ensuring that construction, transportation, and deconstruction are streamlined and effective while capturing the ideas of our architects and designers. The result is a modular design in which the house is able to separate from a permanent foundation in Missouri and load onto three trucks. The house is comprised of two modules and a roof section. The first module is the wet module containing the kitchen, bathroom, and mechanical room. The second module consists of the master bedroom and office. Ten feet of suspended floor joists span the middle area between the two modules which is then covered by the curved roof section. These modules then sit on a temporary foundation made of steel I-beams that mimic the shape of the permanent concrete foundation. In order to streamline the construction process at competition the temporary foundation sits on forty five screw jacks which are pre-leveled prior to setting any modules.

The walls of the modules are constructed with standard wood frame construction. Today, many efficient homes use structurally insulated panels (SIPs). Using SIPs can simplify construction, provide a high R-value, and help keep homes air tight. While this option seems practical, it does not allow for flexibility in design within the walls if any changes occur after the construction of the SIP. Standard wood framing was chosen for this flexibility. Six inch thick walls were built to allow plenty of space for insulation to achieve a high R-value. As in any home, the windows and doors are the weakest points in regards to heat gain and loss. The thick walls help counteract any additional heat transfer in or out of the home. A higher R-value for the walls were not used because after a certain R-value the effectiveness of the wall decreases as the weakest points outweigh the strongest.

The walls and roofs of the house are wrapped in an exterior ZIP plywood sheathing which serves a dual purpose of an exterior sheathing and a vapor barrier. These ZIP plywood boards make the construction process faster as they have the vapor barrier built into them. Additionally, these panels serve as an extra reinforcing method for the walls and roofs during transportation.

System Integration

A driving force in the engineering design of SILO is creating a cohesive network of systems that function cooperatively to maintain occupancy comfort. One example of this is the integration of the mechanical, electrical, and the student designed home automation systems. Effective output and ease-of-use was the driving factor of the design process of the home automation system. There are two integral parts to the home automation system: the physical control hub and the data center. The physical control hub contains the Amazon Echo, Nest thermostat, Lutron light switches, and the Leviton speaker system. The data center contains a sensor network which collects and sends data. The data obtained tracks the house's overall usage which allows the user to make changes to their lifestyle to further save energy. In addition to connecting the systems to one another the team's engineers and architects worked cooperatively to connect the structure and floor plan of SILO. This is seen in SILO's open floor plan, high central ceiling and large windows. The open floor plan and high ceilings make the rooms seem larger and more spacious. The large windows allow natural light to flood this open space to avoid the need for artificial lighting during the day.

The mechanical room is located on the east side of the wet module and is separated from the living space by a covered breezeway. It is designated to consolidate equipment from SILO's heating, ventilation and air conditioning (HVAC), greywater reclamation, and electrical components. The layout of the room keeps equipment accessible, such as the circuit breakers and control panels. Additionally, the team confronted a common problem of sound pollution created by mechanical equipment. The design of SILO's mechanical room minimizes sound pollution in the home due to the breezeway separating it from the interior space.

Mechanical Design

The team used the RTS (Radiant Time Series) method from ASHRAE to determine the heating and cooling requirements to keep the house within the desired temperature range. The selection of equipment for the HVAC system was guided by the goal to integrate various systems into the home automation system. An integral part of the system is the Nest thermostat which allows the home automation system to receive and record data about temperature, humidity, and CO2 levels. One use of this information is letting the homeowner know if an aspect of the system is malfunctioning. Using the sizing results from the RTS method the team researched HVAC equipment compatible with the Nest thermostat. The team selected a 2 ton, two stage heat pump and a variable speed air handler from Carrier. The heat pump has a SEER of 16.0.

In addition to the central HVAC system, SILO incorporates an Uponor hydronic radiant flooring system. The radiant flooring serves as the primary heating component and is capable of maintaining the desired comfort zone. By heating from the floor up, stratification is minimized within the home. Uponor's Quik Trak technology allows for simple installation and effective coverage designed to evenly condition the space in which it is installed. To address the modularity of SILO, the radiant flooring system is separated into two zones. One zone serves the wet module and the other serves the bedroom module. In this way, the entirety of SILO may be conditioned.

To increase the effectiveness of heating and cooling the home the supply air travels under the house and the return air travels through the rafters. This reinforces the concept of heating from the floor up like the radiant flooring. A Carrier ERV is incorporated into the HVAC system to reduce the heating and cooling loads placed on the active HVAC equipment. This is accomplished by exchanging heat energy and humidity between exiting and incoming air streams to retain the conditioned air in the home while at the same time replacing exhaust air with fresh outdoor air.

The main objective of the competition is to create a solar powered net-zero home. The photovoltaic array is able to produce the electricity needed with twenty four 335 watt panels. The panels were sized based on appliance usage ratings, average sun hours of Denver, a tilt angle optimal for efficiency, and yearly tracked data from Missouri S&T's solar villages. After the team knew the amount of energy that was required, they were able to plug different panel wattages into a program with the latitude, inverter efficiency, and panel angle to get an expected output of the array. The team could then verify the array was large enough to provide for the house.

The panels each have an Enphase IQ6+ micro inverter attached. These microinverters are the first part of a robust system from Enphase. The microinverters are able to communicate with the Enphase Envoy, which is the control system. The controls are able to monitor the energy production and energy consumption of the house in real time. The photovoltaic system then can to produce the perfect amount of energy for the house by shutting down specific panels. In some areas selling back to the electric company is not accepted at different times throughout the day. Using this system would allow individual panels to shut down when necessary.

The batteries are equally competitive. It is the first residential battery to be UL 9540 certified which ensures the homeowner that the batteries are made with safety in mind. The lithium iron phosphate battery is considered an “AC battery” since the battery contains its own inverter that will take AC energy and transform it into DC for storage. When the power is needed then the power can be reverted back to AC to be used in the house with a round trip efficiency of 96%. This is 6% more efficient than the nearest competitor. The storage system is built with modularity in mind, which means that the battery comes in a small form that can be easily added to. On top of that, installation is as simple as mounting the bracket, connecting the AC wiring, and securing the battery onto the mounting bracket. SILO is, in fact, the first house to utilize the battery in the world. The batteries also have the ability to connect to the Envoy, adding another key part to the communication process. The Envoy is programed to charge the batteries prior to shutting down panels and is also programed to pull energy from the batteries before pulling from the grid.

In designing the domestic and waste water handling systems, the challenge of SILO’s modularity and transportation presented an opportunity for multiple sub-teams to collaborate for a solution. The mechanical, architectural, and structural teams worked together to determine a floor plan that maintained the architectural team’s goals for the design of the house while containing all water handling systems and equipment into a single “wet module.” This simplifies transportation and assembly and disassembly by eliminating the need to separate plumbing lines. The wet module contains SILO’s mechanical room, bathroom, and kitchen. The placement of the wet module satisfies the goal for the orientation of the bathroom and kitchen with respect to living spaces. This also allowed for the domestic water, wastewater, greywater, and fire suppression tanks to be effectively concealed beneath the front deck for competition. The mechanical sub-team used current international plumbing code guidelines to determine the required waste pipe sizing, trap sizing, and vent sizing as well as how to route the water line to most effectively vent and drain.

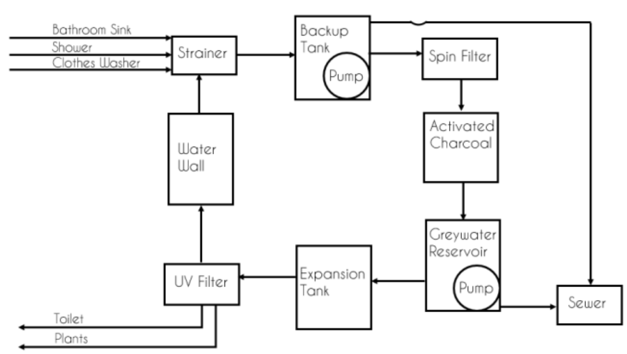

Figure 1: Greywater Oneline

Water conservation is an important aspect of this project and is reflected in the design of SILO’s plumbing system. The mechanical sub-team performed an analysis on the expected water usage for a two person household containing fixtures equivalent to those in SILO. The total water usage was estimated to be 151 gallons per day (GPD). Eliminating blackwater fixtures such as the dishwasher and toilet, the team estimated that 54 GPD to be recoverable as greywater. To take advantage of this available water source the team designed a greywater reclamation system. The system is an improved design from the team's previous house, the Nest Home's greywater system. Water is directed into the system from the washer, shower, and bathroom sink. An issue the team encountered is how to filter the greywater before it is stored in the reservoir tank while preventing bottlenecking in the system. The solution, seen in Figure 1, is to include a preliminary tank concealed beneath the back deck that the greywater may drain to by gravity. In the event that the flow of water is too great to pass through the filters, the preliminary tank provides a space in which surplus water may remain in holding which prevents loss of recovered water. If the flow remains too great an overflow to the sanitary sewer is built in. From the holding tank a pump passes the greywater through a spin filter and an activated charcoal filter, removing suspended particulates, chlorine, and volatile organic compounds. Another challenge faced in designing a greywater reclamation system is that of retention. Dependent on location and local statutes, uncirculated greywater has a limited retention time. To address this problem, a circulation loop passes the greywater through an ultraviolet light filter designed to inactivate harmful organisms that may be present in the water. The loop includes the water wall which doubles as a water feature for SILO. While the greywater is protected from human contact, the water wall aerates and continually moves the greywater preventing anaerobic bacteria growth. Water circulated through the UV filter and water wall is again passed through the initia filters before returning to the reservoir tank. The recovered water is utilized for irrigation in gardens and the green walls around the house.

Energy Analysis & Model

The Team has done various calculations and models to see how the house will use its energy.

REScheck

Generated by REScheck-Web Software

Compliance Certificate

Project SILO 2017

Energy Code:	**2015 IECC**
Location:	**Denver, Colorado**
Construction Type:	**Single-family**
Project Type:	**New Construction**
Orientation:	**Bldg. faces 180 deg. from North**
Conditioned Floor Area:	**981 ft2**
Glazing Area	**42%**
Climate Zone:	**5 (6020 HDD)**

Compliance: Passes using UA trade-off

Compliance: **1.6% Better Than Code** Maximum UA: **314** Your UA: **309**

The % Better or Worse Than Code Index reflects how close to compliance the house is based on code trade-off rules.
It DOES NOT provide an estimate of energy use or cost relative to a minimum-code home.

Envelope Assemblies

Assembly	Gross Area or Perimeter	Cavity R-Value	Cont. R-Value	U-Factor	UA
Wall South Kitchen/Bath: Wood Frame, 16in. o.c. Orientation: Front	270	36.0	0.0	0.045	7
Accordion Door: Glass Orientation: Front	98			0.300	29
Front Door: Solid Orientation: Front	21			0.170	4
Wall North Bedrooms: Wood Frame, 16in. o.c. Orientation: Back	208	36.0	0.0	0.045	9
Office Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	12			0.300	4
Wall West Entry: Wood Frame, 16in. o.c. Orientation: Left side	238	36.0	0.0	0.045	5
Curtain Wall: Metal Frame, 2 Pane w/ Low-E Orientation: Left side	130			0.300	39
Wall East Bath: Wood Frame, 16in. o.c. Orientation: Right side	238	36.0	0.0	0.045	5
Curtain Wall: Metal Frame, 2 Pane w/ Low-E Orientation: Right side	109			0.300	33
Curtain Wall Door: Glass Orientation: Right side	21			0.300	6
Wall West Bedroom: Wood Frame, 16in. o.c. Orientation: Left side	90	36.0	0.0	0.045	4
Wall East Bedroom: Wood Frame, 16in. o.c. Orientation: Right side	90	36.0	0.0	0.045	2
	52			0.300	16
Wall South Bedroom: Wood Frame, 16in. o.c. Orientation: Front	50	36.0	0.0	0.045	2
Wall North Bath/Entry: Wood Frame, 16in. o.c. Orientation: Back	30	36.0	0.0	0.045	1
Wall North Center: Wood Frame, 16in. o.c. Orientation: Back	214	36.0	0.0	0.045	1
Curtain Wall: Metal Frame, 2 Pane w/ Low-E Orientation: Back	121			0.300	36
Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	11			0.300	3
Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	11			0.300	3
Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	11			0.300	3
Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	11			0.300	3
Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	11			0.300	3
Window: Metal Frame, 2 Pane w/ Low-E Orientation: Back	11			0.300	3
Wall South Center: Wood Frame, 16in. o.c. Orientation: Front	31	36.0	0.0	0.045	1
Floor: Steel Frame, 16in. o.c., 2x6, Over Outside Air	993	26.0	0.0	0.058	58
Ceiling: Flat or Scissor Truss	683	38.0	0.0	0.030	20
Ceiling: Structural Insulated Panels	310		36.0	0.029	9

Compliance Statement: The proposed building design described here is consistent with the building plans, specifications, and other calculations submitted with the permit application. The proposed building has been designed to meet the 2015 IECC requirements in RES*check* Version 5.5.0 and to comply with the mandatory requirements listed in the RES*check* Inspection Checklist.

Energy Analysis Results and Discussion

The Team used REScheck and pvwatts software tools to calculate panel sizing. From previous experience these results were fairly under-estimated compared to the actual measured electrical load needs found at competition. SILO will include more panels than needed from the calculation. The consumption values were measured during the competition over an eight-day period.

Electrical Calculations

Total Contest Week Consumption = (8 days)*(Estimated Consumption)* (Estimated Daily Use)*(Quantity)

Mechanical Load Estimates				
Item	#	Load Value (W)	Estimated Use (hours)	Total Contest Week Consumption (kWh)
HVAC / ERV	1	8,300	8	66.4
			Total	66.4

Appliance Load Estimations			
Load Type	Load Value (W)	Estimated Competition Use (hours)	Total Contest Week Consumption (kWh)
Washer	1,200	5	6
Dryer	6,240	5	31.2
Oven	9,600	2	19.2
Garbage Disposal – 1/3 HP	800	0.5	0.4
Radiant Water Heater	8,000	5	40
Water Heater	4,500	3.15	14.175
Television (40”)	-	5	0.42
Computer	100	5	1.5
Refrigerator	-	-	12.56
Induction Cooktop	3,700	5	18.5
Dishwasher	1200	0	0

143.955

Other Load Estimations				
Item	#	Load Value (W)	Estimated Competition Use (hours)	Total Contest Week Consumption (kWh)
Lighting (LED)	24	324	31	10.044
Electrical Vehicle Charger – Level II	1	6,480	6	38.88
			Total	48.924

Overall Consumption Estimate	259.279 kWh

Days in Competition = 9 (days)

Sun Hours/Day in Denver, CO = 4.87 $\left(\frac{\text{sun hour}}{\text{day}}\right)$

Ideal Panel Angle in Denver, CO = 40°

Efficiency Adjustment = 20%

$$\text{Array Size Estimate Before Adjustment} = \frac{\frac{\text{Overall Consumption Estimate}}{\text{Days in Competition}}}{\frac{\text{Sun Hours}}{\text{Day}}\text{in Denver, CO}} = 5.916\text{kW}$$

$$\text{Adjusted Array Size Estimate} = \frac{(\text{Array Size Estimate Before Adjustment})}{0.8} = 7.394\text{kW}$$