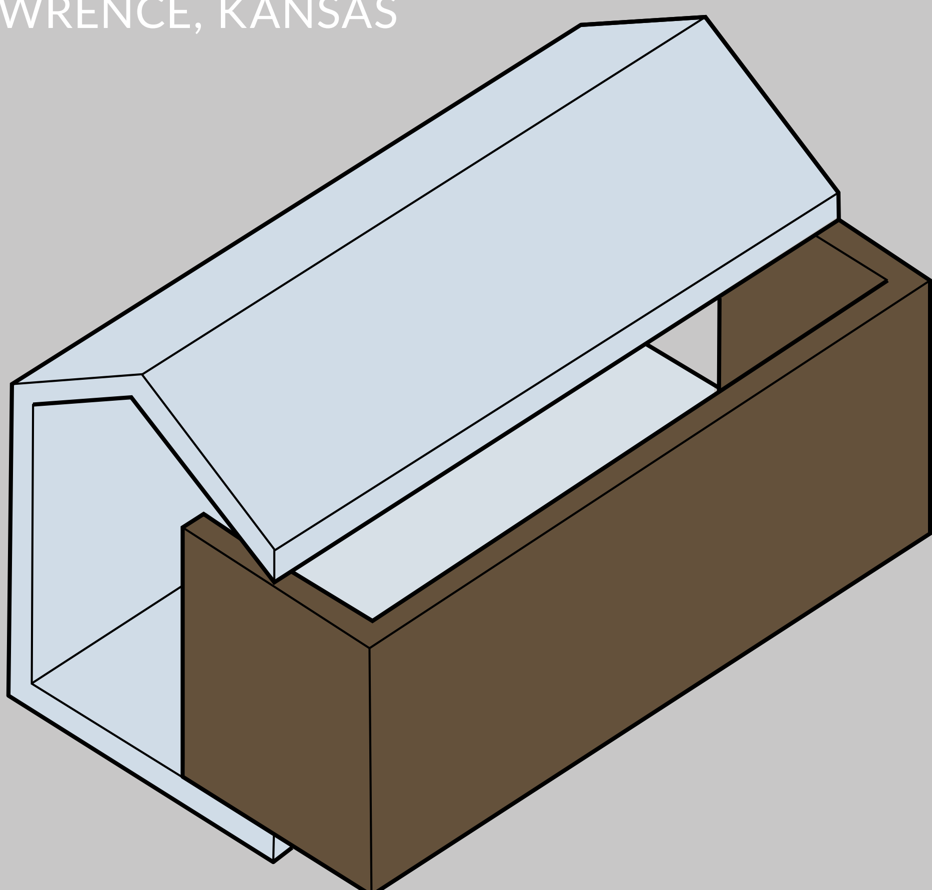
KU SCHOOL OF ARCHITECTURE & DESIGN
The University of Kansas

ENGINGEERING
JURY DOCUMENTATION

Dirt Works Studio

HAVEN STUDIO

LAWRENCE, KANSAS



ENGINEERING

Haven Studio, rendering of the southeast corner showing the main entrance

Approach

The overall approach to engineering Haven Studio focused on right-sizing all elements for their needs. This typically translated into keeping things to the minimum size necessary to achieve the intended purpose, which reduces the resources required to achieve the project's goals and creates a more efficient final product. The narrow footprint of the home provides comfortable, multipurpose rooms while avoiding unnecessary energy loads and embodied energy resources.

Prefabrication

The project utilizes prefabrication as the main construction method. This method allowed work to begin on the home's construction before the team received the permit, shrinking the overall onsite construction time significantly and minimizing material waste. During the Fall 2022 semester, students constructed the floor structure within the KU Designbuild Center, allowing students to achieve near factory perfect level and square. After the foundations were poured, the floor was then lowered into place and quickly sheathed to be ready for wall installation. The Baltic birch cabinet wall in the studio space is the primary design feature of the interior. Students prefabricated these during the Fall 2022 semester to speed up installation in the house. Students also prefabricated the interior partitions, ceiling framing, and steel window wall frame so that they could be set in place quickly.

The Dirt Works Studio team is partnered with Build SMART, a local company that prefabricates highly insulated, airtight, wall and foundation insulation systems. The construction of the wall assembly combines a variation on traditional stick construction with continuously insulated nailbase panels, integrated windows and doors, and their sister-company Prosoco's high-performance liquid-applied flashing. The prefabricated panel's precision creates an airtight fit that would be difficult to achieve in the field. The primary benefit of this system is that all the exterior wall panels, interior partitions, ceiling, and window wall frame were able to be installed in one day. Since the walls were erected so quickly, the house was subjected to the elements for much less time.

Envelope Design and Structural Strategy

Haven Studio's building envelope is greater than the sum of its parts. Contractors are typically hesitant to use SIP panels on their own, but in combination with light wood frame construction, this is a repeatable envelope strategy that can be utilized by any contractor. The nailbase panel portion provides a layer of continuous insulation and an extra layer of sheathing, eliminating thermal bridging and adding additional rigidity to the structure, enhancing its durability. The stick frame portion has the advantage of being familiar to all contractors, as is particularly useful during MEP rough-in. This hybrid assembly allows for mechanical, electrical, and plumbing to run through the stud walls and still retain continuous unbroken insulation. Using Prosoco's high-performance liquid-applied flashing and the prefabricated panel's precision creates an airtight fit. Because of this, low- and no-VOC finishes were selected throughout the project to maintain good indoor air quality.

The team proved the repeatability of this envelope strategy through the roof assembly. The roof was constructed onsite, with traditional rafters framing into the panelized wall system. The rafters were then sheathed and covered with eight inches of exterior rigid timber insulation, before sheathed again with ZIP sheathing. Like the stick frame elements of the wall panels, the rafters were infilled with cellulose batt insulation. The combination of insulation materials provides an R-50 for the roof, far exceeding the code minimum. This verifies that the envelope strategy can be repeated by any contractor, even without access to the prefabricated panels.

Typically, Build SMART uses rigid foam insulation in their wall assemblies. We collaborated with them to use an innovative wood fiber rigid insulation board from TimberHP. The timber insulation is new to the US market, having proven successful in Europe. Traditional insulation materials such as rigid foam and fiberglass are not very sustainable from an embodied carbon perspective, and insulating materials such as Polyiso are not recyclable. Timber has the added benefit of sequestering carbon through its utilization. The timber board is also made without many VOC emitting chemicals, making it healthier for occupants. The six inches of rigid timber insulation in the walls provides an R-22 rating. TimberHP is developing a batt insulation version of the product to be able to have a house fully insulated by timber that the team would spec for future projects, but for this project the batt insulation is cellulose from EcoCell. Cellulose is made of recycled materials, has a Class-A flame spread rating, and emits no harmful air particulates. The cellulose batts provide an R-20 rating. An essential element for sustainability is the health and safety of contractors installing products. Cellulose has the added benefit of being safe to install, especially compared to other batt insulations such as fiberglass. Having worked with it, the team can verify the manufacturer's claim that the cellulose does not itch or irritate the skin. These two insulation strategies provide a combined R-value of R-42 for the walls, far exceeding the code minimum. The highly insulated walls will also reduce noise infiltration.

The envelope design is completed through the selection of five, quad-pane insulated glass panels from Alpen HPP that are direct glazed using structural silicone to a custom steel frame. The interior of the quad pane glazing units are comprised of

Haven Studio, photo of installing the ridge beam onto the Build SMART prefabricated wall panels.

thin glass sheets with gaps filled with argon gas to create a low U-factor. The window wall draws in ample natural light from the south, visually expanding the modest interior space, and providing opportunities for passive solar heating throughout the winter months when the sun angle is low but is protected from overheating in the summer with an appropriately sized roof overhang. The protective and well-insulated northern façade is free from openings that might contribute to energy loss during the substantial number of heating degree days. The steel frame was custom built by students and galvanized and powder coated to protect it from the elements.

Structurally, the project is simple. The foundation is comprised of twenty-one concrete piers. These piers allow the house to sit up above the ground to protect it from water. The house was designed to be able to move, if necessary, should the site change use. The home's narrow fifteen-foot-wide form is not difficult to structurally span, which eliminates interruptions to the interior spaces. A forty-foot ridge beam made of three LVLs sistered together spans the length of the house to support the roof.

Solar System

The home's solar system is comprised of twelve solar panels on the south-facing portion of the gabled roof, with microinverters to transform the current from DC to AC. The slope of the roof was carefully designed to be the optimal angle for fixed solar panels. Due to being tied to the electrical system of the KU Designbuild Center, the team decided to intentionally oversize the solar system of Haven Studio, with excess energy being used to offset energy loads in the existing building. This will have the added benefit of reducing the energy bills for the KU Designbuild Center. Since the house remains connected to the grid, a battery system was not included. Even when drawing electricity from the grid, 44% of the energy produced in Kansas comes from renewables (EIA.gov). The home's energy load will be reduced by thoughtful passive strategies and carefully selected active systems and offset by the robust solar energy collection system. The reduced energy loads will minimize the required size and cost of the energy generation systems to ensure a net-zero energy home, especially in future iterations where the solar system might not be tied to an existing building. The strategies implemented will help the home to achieve a low HERS rating score, provide occupant comfort, and lower the home's carbon footprint.

Mechanical Active and Passive Strategies

Passive strategies for Haven Studio include highly insulated and airtight walls and the beneficial heat gain from large strategically located glazing. The building envelope reduces air leakage of conditioned air and thermal bridging from the outside. Penetrations through the envelope have been minimized through the selection of systems and careful

Haven Studio, mini split condenser unit attached to the standing seam north wall.

design of mechanical, electrical, and plumbing elements within the home. The beneficial heat gain from the large southern windows will reduce the loads placed on the mechanical system during the substantial number of heating degree days.

Active strategies for Haven Studio include a heat pump mini-split system that heats and cools the home, while an energy recovery ventilation (ERV) system with an integrated HEPA filter helps to efficiently draw in fresh air. The heat pump mini split works by extracting energy from outdoor air on heating degree days and energy from the indoor air on cooling degree days. This is an energy efficient way to provide comfortable temperatures within a space. This mini split is the perfect system for such a small space as it can completely climate control the whole building with little energy consumption. The unit has two main components, the outdoor condenser and the indoor fan coil unit. The condenser works by using a compressor located inside the unit to compress or expand the refrigerant found in the lines that run from the outdoor condenser into Haven Studio. The fan coil works to blow air already inside the home over the refrigerant line which will heat or cool that air and distribute it into the main living space. The ERV works by exchanging energy from outgoing indoor conditioned air to incoming fresh air, reducing energy loss by pre-conditioning supply air with heat and humidity from the return air. It controls ventilation and humidity, removes odors and contaminants from the space, and improves the functionality of the other HVAC components. The mechanical system can be controlled through a single device mounted on the wall to adjust for occupant comfort.

These mechanical systems are above the bathroom in the mechanical loft. The equipment was selected to efficiently fit into the tight space while providing easy access. They can all be accessed for maintenance, via a ladder, through an access panel. The condenser for the mini split is located on the north side of the building and elevated off the ground to protect it from snow. Throughout the building's life, its mechanical systems will be used as a teaching tool for future students and explained with permanent diagrams.

Electrical Active and Passive Strategies

The electrical system is tied to the existing KU Designbuild Center which eliminated the need to establish a new utility line. The solar system is deliberately sized to not only provide for all the electrical needs within the home but also to offset some of the existing KU Designbuild Center energy demands, creating a net-positive building. This solar system was also designed to clip to the standing seam metal roof and eliminate unnecessary penetrations through the envelope that inevitably lead to air leakage. The appliances within the home were selected for their high energy efficiency rating and all appliances fall under the Energy Star label. The lighting is comprised of only LED lights equipped with daylight and occupancy sensors that ensure spaces are properly lit only when needed, reducing energy consumption. The dryer, like the mini split, utilizes a heat pump that extracts heat from the air to dry the clothes making it more efficient than a traditional dryer, and since it is ventless, it eliminates exhausting heated air directly outside.

Plumbing Active and Passive Strategies

The plumbing's passive strategy is to locate all the plumbing needs along the north wall. This allows the project to have more efficient runs. This also allowed the team to minimize roof penetrations by creating a single vent stack. The hot water heater is located in the loft above the bathroom, keeping it close to the shower and sinks to minimize travel distance and receive hot water faster. All plumbing fixtures are designed to be low flow, and the toilet is a dual flush model to conserve water consumption in the home. The plumbing is tied to the existing KU Designbuild Center which eliminated the need to establish a new utility line.

Operational and Embodied Carbon

Haven Studio utilizes a dual pronged strategy to emphasize reducing both operation and embodied carbon. To reduce operational carbon, the team utilized several strategies. The heat pump systems and Energy Star appliances are more energy efficient than standard systems. The highly insulated walls and quad-pane glazing maintain the interior temperature well to reduce the demand on the mechanical system. Most of the time, the house will utilize natural daylighting with minimal supplement from artificial systems, but the lights in the house are dimmable LEDs that will use less energy. The bathroom fixtures are low flow to be more efficient with water use.

Embodied carbon is addressed primarily by using natural materials. All the wood and paper products in the project are from FSC certified forests. The rigid timber insulation from Timber HP is a significant improvement, in terms of embodied carbon, compared to traditional rigid insulation, which is typically made from extruded

Haven Studio, inside the mechanical loft showing the hot water heater, ERV and fan coil unit for the mini split.

Haven Studio, photograph of TimberHP Insulation and EcoCell Cellulose Insulation.

polystyrene (EPS). EPS requires a lot of environmentally damaging chemicals in its manufacturing process, and polyisocyanurate insulation cannot be recycled.

Lighting Strategy

Utilizing natural daylight, the large quad-pane window wall and glazing integrated into the exterior doors light the main living space throughout the day. The light fixtures are all dimmable and low-energy LED, this improves occupant comfort by adjusting the light level to be appropriate to the task and use as little energy as possible. The dimmable fixtures adjust the level according to the amount of available daylight from sensors integrated into the fixtures. The occupancy sensors in the project allow users to not have to think about turning the lights on or off as they move through the home, saving energy as the lights will turn off when spaces are not being used. The daylight and occupancy sensors will work together to provide appropriate artificial light to address user needs.

Students worked with lighting consultants to develop a lighting strategy with all fixtures being Energy Star compliant. This strategy involves three types of lighting fixtures in the main space. The general illumination of the space is provided by the recessed can lights which create general illumination of the living space and can be dimmed to fit occupant needs. Each can light has an illumination value of 535 lumens, and are contained within a housing that can be in contact with insulation and is airtight. Task lighting for the table is provided by the hanging pendant lights that hang from the center of the space. Lights located beneath the upper cabinets provide lighting for kitchen tasks.

The strategy for lighting prioritizes adjustability not only with the inclusion of daylighting and occupancy sensors, but also with the option to white tune the recessed can lights. These adjustments can be made by mobile app as well as through a smart home system like Amazon Alexa or Google Home. The can lights within the sloped roof can fully adjust the angle so that they point down rather than across. Between all of these methods the lights are incredibly adjustable to the preference of the occupants while remaining energy efficient.

Integration

The engineering strategy was highly integrated into the architecture of Haven Studio due to close coordination between the architecture students on the team working with our professional engineering consultants. Typically, in architecture education, students are introduced to the basics of different MEP systems, with the expectation that they can draw general diagrams to show how the systems apply to their project. To help the team dive more into the specifics of MEP systems and successfully integrate our systems into the project, the Dirt Works Studio partnered with Henderson Engineers. This partnership was beneficial to the students who now possess in-depth knowledge about these systems. This will translate into the students becoming better designers and integrating these systems more effectively into their future projects. This partnership also taught students the soft skills of communicating with professionals to coordinate a project and advocate for design integration, something that students will do daily in their professional lives.

Maintenance and Operability

The house was designed to be easy to maintain. The design philosophy was to create a smart design, but a "dumb" house that does not utilize many moving parts that would require upkeep. The fully tiled bathroom is a durable surface that will withstand wear and tear as well as being easy to clean. The whole north wall is comprised of cabinetry or clad with Richlite, and 2/3 of the south wall is glass, so there is very little exposed drywall that would need to eventually be repainted. The mechanical systems will be controlled from a single panel that connects to both the ERV and the heat pump mini split system to easily adjust for occupant comfort. The MEP equipment in the loft is all easily accessible through an access panel, where each piece of equipment is within arm's reach. The occupant and daylight sensors will keep the LED lights functional for an exceptionally long time, as they will only be on when needed.

On the exterior, the thermally modified ash rainscreen will protect the wood without chemicals and will not need to be refinished over time. Additionally, thermal modification will protect the wood from pests. The standing seam roofing will hold up for years without needing to be replaced. The landscaping will utilize minimal maintenance natives that will not require as much water or upkeep as a typical lawn.

Innovation

The team looked to use innovative and sustainable design strategies and products wherever possible. The house uses timber rigid insulation from TimberHP, a product new to the US market but successful in Europe. The company produces insulation from wood fibers instead of foam and fiberglass which are unsustainable, unrecyclable, and contain high embodied carbon. Additionally, timber sequesters carbon, preventing it from being released into the atmosphere. The insulation is also made without many VOC emitting chemicals, making it healthier for the occupants. The house uses TimberHP for its rigid insulation in the walls, floor, and roof. TimberHP is developing a batt insultation that could be used in future builds. The house instead uses EcoCell, a cellulose insulation made from recycled fibers and paper. This is more sustainable than the typical fiberglass batt insulation and emits no harmful particles into the air.

The quad-paned glass panels from Alpen HPP ensure that the home does not become susceptible to heat and energy loss at the window wall. The gaps between each thin pane of glass are filled with argon gas to create a low U-factor. This allows the house to integrate architectural design and connection to nature with energy efficiency.

The use of heat pump systems in the design also plays a big role in new innovative products. Heat pumps are a more recent addition to mechanical systems that allow heat energy to be taken from outside air and be used to condition the indoor air. This reduces the demand on the mechanical system of the house. By using a heat pump mini-split system, the team is promoting its use to a wider market. The house also uses a heat pump dryer which is quite uncommon but similarly advertises the benefits.

Microinverters are used in the solar panel system to convert the direct current (DC) energy into alternating current (AC) energy. Microinverters differ from traditional string inverters because they operate at the panel level rather than the system level. With string inverters, because they are wired together and fed into a single inverter, the energy output is dependent on the worst-performing panel. Each solar panel had its own microinverter which allows the maximum amount of energy to be produced from each panel. This grants the system the greatest efficiency even when panels may experience shading or technical issues.

In the team's build process, prefabrication was the center of the construction process. This newer technique allowed the team to build smaller elements of the house prior to receiving the permit. Upon receiving the permit, the team was able to quickly assemble the prefabricated elements of the house requiring significantly less on-site time and energy. This build proved the success and efficiency of prefabrication and demonstrated it as a feasible construction strategy.

Analysis

To make informed decisions and ensure that Haven Studio would meet the goal of being net-zero, cove.tool energy modeling was used to build a representative energy and daylighting model. Cove.tool analyzes a variety of inputs in the areas of envelope, energy consumption, building systems, and energy production to determine the building's net energy use intensity (EUI). Based on the current energy model of the project, the building's net EUI is currently -1.45 kBTU/ft2/yr.

An analysis of some of the inputs that resulted in this value begins with the building's envelope. Based on the R-values of the continuous rigid timberboard and cellulose batt insulation, the walls achieve an R-value of 42, and the roof achieves an R-value of 50. The quad pane insulated glass units have a U-value of 0.1 and a SHGC of 0.33 working to passively heat the home without compromising the envelope's thermal resistance. These values set the baseline for the home's ability to resist temperature fluctuations that occur in the exterior climate.

Inputs that affect energy consumption begin by establishing an occupancy schedule that mimics the normal 40-hour work week occupancy of two adults. Accounting for daylighting and occupancy sensors which will reduce lighting power consumption, in addition to efficient lighting systems and appliances. These factors contribute heavily to the demand for energy in the home annually.

The efficiency of the building systems affects Haven Studio's energy consumption. Cove.tool requires designation of system types, coefficient of performance values of the mechanical systems, and anticipated infiltration values which have been determined based on the

Baseline Energy

Proposed Whole Baseline EUI

-1.45

LEED Points - EAc2 Credit

No LEED data available for this project

CO2 Reduction %

102

Single Family Home -1.45 kBtu/ft²/yr

Electricity $-153.56 /yr

Gas $0 /yr

2030 Baseline Emissions 2.7 Tonne CO2e/yr

-0.1 Tonne CO2e/yr

You Saved 0 Trucks of Ice/yr

Cooling

Your cooling load is not dominating your energy use. This is because your HDD are higher than your CDD days.

Heating

Your heating load is dominating your energy use. This is because your HDD are higher than your CDD days. You can reduce your heating load by facade, HVAC system or reducing infiltration.

Lighting

Your lighting load contributes to 6.06% of the total EUI. You can reduce your lighting load by reducing your lighting power density and having daylight and occupancy sensors in the Engineering Inputs.

Equipment

Your equipment load contributes to 19.98% of the total EUI. You can reduce your equipment load by reducing your appliance power density in the Engineering Inputs.

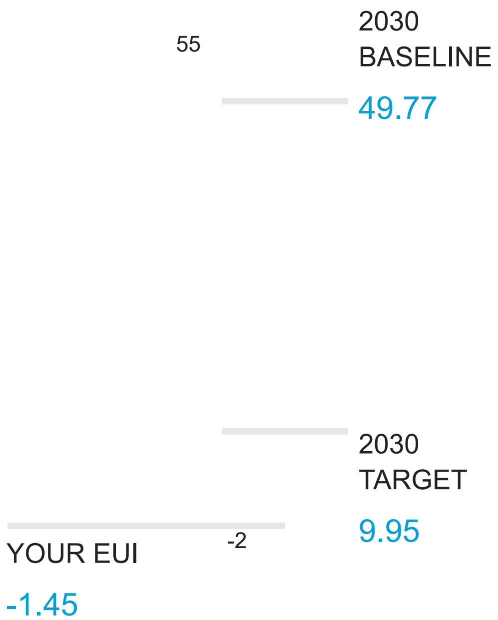
values of the blower door test.

To calculate the amount of energy the project will produce cove.tool required a variety of factors that determined the efficiency and amount of solar energy produced. The surface area of the solar panels is 241 ft2 in total, at a fixed angle of 31 degrees. The panels are moderately ventilated due to the use of standing seam clips that hold the panels off the roof. The panels have a listed module efficiency of 19.79%, however the closest efficiency value available is 17% meaning that the estimated output of the panels is conservative.

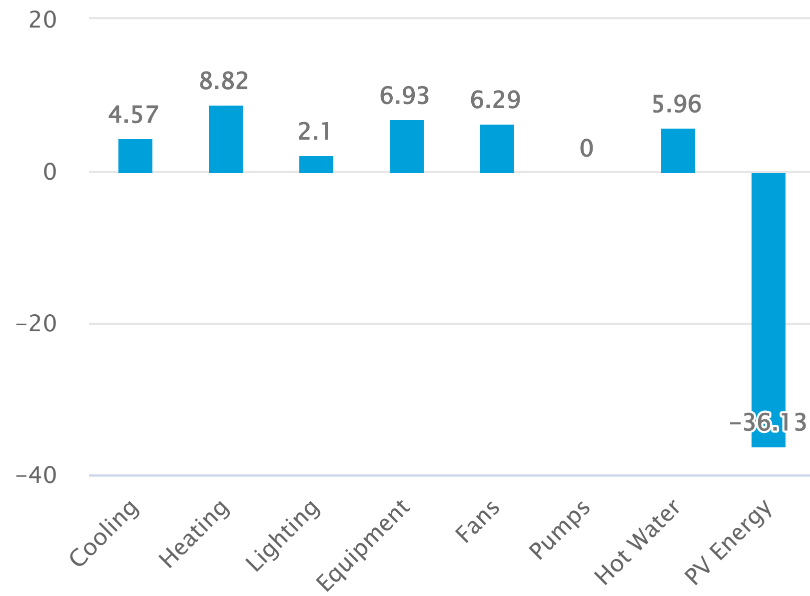
Based on these inputs, cove.tool estimates the number of kBTU/ft2/yr in the categories of cooling, heating, lighting, equipment, fans, and hot water. It also calculates the number of kBTU/ft2/yr that the solar panels are estimated to produce. The cooling energy required is 4.57 kBTU/ft2/yr. The heating energy required is 8.82 kBTU/ft2/yr. The lighting only makes up 2.1 kBTU/ft2/yr. The equipment in the home uses 6.93 kBTU/ft2/yr . The fans use 6.29 kBTU/ft2/yr. The energy required to heat water in the home is 5.96 kBTU/ft2/yr. Lastly the amount of energy produced by the solar panels is 36.13 kBTU/ft2/yr. When adding all energy consumption values and subtracting the energy generation value, the resulting value is -2.41 kBTU/ft2/yr.

Analyzing these values, the heating load of the home is the largest consumer of energy, in-line with the climate data for

Benchmarking Energy



Proposed Whole Baseline EUI Breakdown



Hot Water

Your hot water load contributes to 17.19% of the total EUI. You can reduce your hot water load by reducing your domestic hot water demand and using a more efficient hot water generation system in Engineering Inputs.

Fans

Your fan load contributes to 18.14% of the total EUI. You can reduce your fan energy by switching your fan flow control accordingly in the Engineering Inputs. Total Outdoor Air for the project is 41.06 CFM.

Pumps

Your pump load contributes to 0.0% of the total EUI. You can reduce your pump energy by adjusting pump control for cooling/heating in the Engineering Inputs.

PV Energy

The current Photovoltaic panels offset -36.13 EUI off the building.

Lawrence, Kansas. There are more heating degree days than cooling degree days, which creates a higher demand for heating the home annually. The lowest value is the lighting which results from the ample daylighting received through the windows, reducing the need for artificial light throughout the day and the occupancy and daylight sensors help reduce overall lighting energy consumption.

Based on the cove.tool energy model, Haven Studio is anticipated to be a net-positive building.