ENCITY

JURY NARRATIVES

Washington State University
U.S. Department of Energy Solar Decathlon 2017

ENGINEERING

INTRODUCTION TO ENCITY

EnCity is a prototype for pocket neighborhoods of tiny homes situated on urban infill lots to increase urban density A concept that breaks the mold of traditional city housing. Carefully engineered synergistic systems create a resilient, durable, efficient, and comfortable community. Sustainable materials with long lifetimes were selected, carefully choosing materials whose finish is simply the natural material and require little finishing. Throughout engineering our systems, we focused on maintaining comfort within the home while searching for efficiencies.

Designed with Passive House principles and innovative high-performance technology, EnCity is engineered to use less energy than it produces annually, sharing energy among tiny houses and selling excess back to the grid.

SYSTEMS OVERVIEW

STRUCTURAL

The project's structural system is a modular frame and infill panel system. The frame consists of laminated veneer lumber members with infill panels made of dimensional lumber and plywood. Frame elements are thicker than dimensional lumber and are spaced wider than traditional light wood frame. The infill panels that fit in between the frame members act as shear panels to resist lateral loads while also augmenting the frame's strength.

The foundation of the project is an insulated slab system that consists of high density geofoam that supports and insulates 4" thick nail laminated (tiny house) and laminated strand lumber (clubhouse) floor panels that form a continuous slab to distribute loads across the geofoam.

The project also encapsulates areas with dense mechanical and plumbing systems into small prefabricated volumetric modules that are also integrated into the overall structural system.

PASSIVE HOUSE & BUILDING ENVELOPE

The strategy was to create a continuous layer of insulation around the outside of the structural shell to reduce thermal bridging. A ventilated cavity between the insulation and a closed rainscreen and membrane roofing. The system is designed to keep 99% of the water out while providing rapid drying capability.

The building envelope begins with the exterior side of the structural shell which is coated with Prosoco liquid applied water/air membrane to form a continuous barrier. Seams are sealed with Prosoco's flashing system. All elements of the envelope were carefully selected to be vapor permeable and for the most part hydrophobic, in order to allow rapid drying and discourage mold growth.

The rest of the envelope is configured into prefabricated cassettes that are bolted to the structural frame. Wall cassettes include hydrophobic rock wool insulation (R-30) and the shou sugi ban rain screen cladding. Roof cassettes are similar (R-48) but also include a continuous air ventilation cavity under the roofing membrane with attachments for the solar panel system.

Windows and doors are high-performance triple glazed units from Schuco. Except for the egress window and skylight, the window units are parallel opening windows that create more open area for ventilation in less space while still providing security so that passive ventilation is possible within an urban environment.

HEATING/COOLING AND VENTILATION

For heating and cooling at extreme high and low temperatures, a Mitsubishi M-series, split mini-ductless unit was selected for both the clubhouse and tiny home. These units were selected because they utilize heat pump technology, provide adequate heating and cooling capacity, and allow for control through our smart home system.

Ventilation loads are reduced because EnCity is equipped with mechanical Schuco windows programed to retrieve weather data, sense air pressure, and open/close accordingly. This allows for automated proper cross ventilation without the need to utilize any air conditioning except at peak summer temperatures.

To manage additional ventilation needs we chose both through wall and centralized heat recovery ventilation units. The Zhender Comfoair 70 through wall unit in the tiny home provides a decentralized ventilation system that is adaptable and eliminates the need for ductwork which takes up valuable space while recovering energy used to heat and cool the space while also providing humidity control.

The clubhouse uses a Zhender Comfoair 200 ERV that is installed within the ceiling of the mechanical module. This centralized location allows for short duct runs and utilizes space that would otherwise be wasted. Like the through wall unit, it recovers heating/cooling energy as well as maintaining humidity while providing ample fresh air to occupants.

Together the mechanized windows, energy recovery ventilation, and mini-split heating/cooling provide a healthy and comfortable environment in both the tiny house and clubhouse.

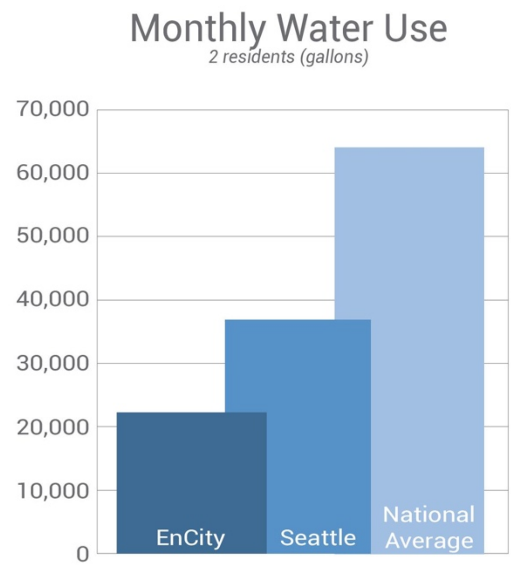
PV SYSTEM

In order to reach our engineering goal of an energy net zero home, we simulated predicted energy consumption both in the final resting place and during the competition period. After careful analysis, we selected and installed 30 Itek Energy 290W All Black SE solar panels, and a complete Outback Power SystemEdge 830NC system. This factory tested, pre-wired and pre-configured system offers system monitoring and control via web interface. This was imperative for our design in order to communicate with our smart home system and manage the buying and selling of energy.

Our smart home system monitors energy use throughout the home, PV power generation, and battery capacity/charging. Aggregating the data, our smart home systems assists in scheduling buying from and selling to the grid, and optimizes energy use throughout the EnCity community. In order to combat the unreliability of solar power in the Pacific Northwest, we selected an integrated battery system with 12 EnergyCell Nano-Carbon batteries. This allows us to sell energy at peak times, buy energy at off-peak times, and continue to power EnCity in the event of inclement weather.

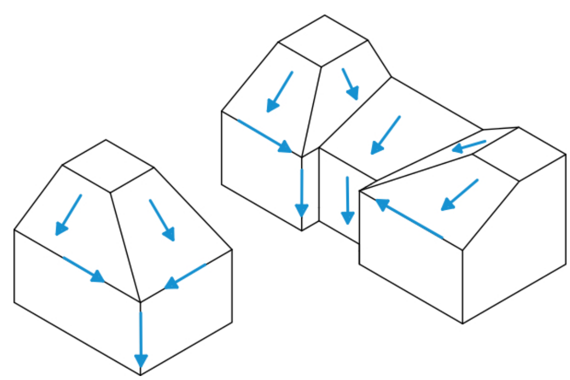
PLUMBING & WATER TREATMENT

EnCity is engineered to use more than 50% less water than the average Seattle home, and more than 70% less water than the average American home. High efficiency and water saving appliances were selected for both the tiny house and the clubhouse, reducing EnCity's water footprint.



For the tiny home, we selected an innovative Sanden hot water heater that utilizes CO_2 as a natural alternative to other harmful chemical refrigerants and an outdoor heat pump unit for optimal energy efficiency. To minimize excess energy draw from continually heating water we designed a structured plumbing recirculation loop with a motion sensor. This sensor activated when a resident stands in front of a faucet which then triggers the recirculation pump to move water in the line back to the water heater, priming the line to ensure hot water is delivered as soon as the faucet is turned on, minimizing water wasted waiting for it to heat up, and excess energy spent continually heating water.

To further reduce our water footprint, we designed the roof and gutter system to effectively capture the abundant rainwater of the Pacific Northwest.



Although we experience abundant rainfall, Washington state imposes the strictest water reuse standards in the country, requiring a four-step treatment process. To effectively and safely treat and reuse water on site, we chose to use the Imber InRoom Reuse System. The Imber InRoom Reuse is an innovative, patent-pending compact self-contained water treatment system. The system is gravity fed, taking water from sinks, washing machines, air handling units, and storm water into the collection stage. From the collection stage, water enters the treatment module, designed specifically to adhere to Washington state water reuse standards, water undergoes a thorough four step treatment process consisting of filtration, coagulation, oxidation, and finally disinfection.

Water is then kept in the storage module, treated to WA Class A reuse water standard this water is suitable and ready to reuse within the home for flushing toilets and all irrigation purposes. The system can treat 1 gallon per minute, conservatively treating 700 gallons per day, well over EnCity's estimated water use. Consuming a maximum of 330 watts during treatment an average of 5-20 watts on standby, and generating just 30 watts of waste heat, it is a complete and efficient water treatment system that enables EnCity to reuse water for all toilet flushing and irrigation needs.

SMART HOME - SMART GRID

In order to orchestrate all of the technology implemented in EnCity, we designed and built a complete smart home application and system. This system provides an integrated user interface allowing for seamless interaction with the home, saving residents money in utilities annually. Today, smart home users must access separate apps for controlling lights, charging an electric car, or monitoring solar energy production. Our smart home system differentiates itself by integrating all of our technological innovations into a single mobile application, a one-stop shop for information about and real-time control of the smart home and all its connected components.

Despite the simple front-end that engages and informs the user without overwhelming them with unnecessary information, the back-end of our application uses deep learning algorithms that understand users preferences and proactively minimizes the house's energy consumption without compromising human comfort or security. The artificial intelligence powering our application is built using decision trees and neural networks, optimized for maximum energy savings and offering a high, data-driven lifestyle.

Using a meshed network of 64 sensors, strategically installed at different locations throughout the house and furniture, the smart home monitors temperature, illuminance, and humidity inside the house and community building. After elaborate calculations, each sensor is precisely placed to achieve perfect reliability of measurements while ensuring economical construction. The sensors use Z-Wave communication for speed, efficiency and high interoperability among the diversity of sensors in the home. The smart home learns human activities by observing a sequence of triggers from the distributed motion sensors, accurately figuring out room occupancy, and ongoing activities within the room.

Based on intelligent judgement and knowledge acquired through reinforcement learning, the smart home system can automatically adjust thermostats, open or close blinds, dim lights, and start charging the electric car in anticipation of a trip later in the day. Apart from the internal web of sensors, the smart home application connects with the outside world through reliable third-party APIs for current weather and forecasts, and adapts its decisions to cater to the residents' life. All the machine learning is done through an in-house computer, keeping the data secure, accessible only by the resident themselves.

The smart home is tightly coupled with the energy system powering the house, and driven by financial incentives. The application has a sophisticated 'Smart Connect' algorithm – that is aware of the price at which electricity is being bought and sold at the grid level, and based on that information it uses its own solar-generated power, or buys from the grid when it is cheaper to do so. The Smart Connect algorithm is designed from the bottom up, such that net cost of power drawn from the grid remains zero while ensuring top performance and longevity of batteries and the solar power system. The Smart Connect feature of our algorithm relieves the user from a constant anxiety of when to charge and when to draw from the grid, which often leads to financial miscalculations when trying to handle multiple apps to keep their smart home running.

Despite advancements and automation, the smart home application never usurps the resident's authority or undervalues their privacy. The resident can override any decision made by the smart home application. The application is installed on an encrypted fifth generation iPad with latest security features to proof it against cyber-attacks and unauthorized access. The window blinds sensors and door sensors not only contribute to automation of in room lighting but are also security features against physical intrusions. The application can be extended to ringing alarms or informing law enforcement officials in case of intruders. The smart home application also monitors CO_2 levels in the house – for fire security and health of the residents.

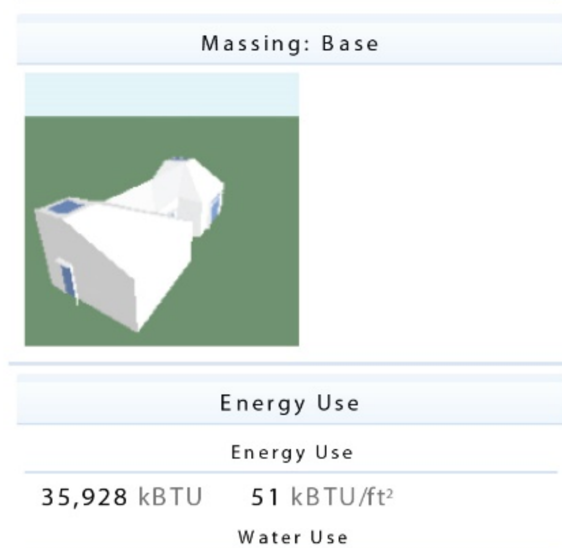
All sensor activities, such as opening of blinds or doors, room temperature or thermostat settings are configurable as push notification alerts on the user interface. The application intelligently understands which notifications are getting more attention from users, and which notifications seem to be less useful to the user. Thus, it quickly adapts to eliminate approximately 68% of unnecessary notifications and shows only meaningful notification to the resident. Thus, in all ways imaginable, our smart home application is designed to be simultaneously invisible, informative and indispensable. It creates an extremely non-invasive and seamless experience for any resident - such that the resident begins to interact with data, save energy, and reap other benefits of a very sophisticated automation and AI-technology without being heavily tied down by a steep learning curve of multiple apps, or exposing private data to third parties.

ENERGY ANALYSIS

The overall engineering goal of EnCity was to be energy net-zero annually, producing as much energy as it consumes. In order to accomplish this and properly size our systems, we completed an energy model and analysis.

Our modeling process entailed exploring various building forms, creating a baseline model of the selected design, employing optimized envelope design and efficient mechanical systems, predicting annual electricity demand for Spokane to size the PV system and predicting the house performance during competition week.

Through modeling, several roof forms were explored for the clubhouse building, the final roof form was selected for minimum loads and optimized daylighting.

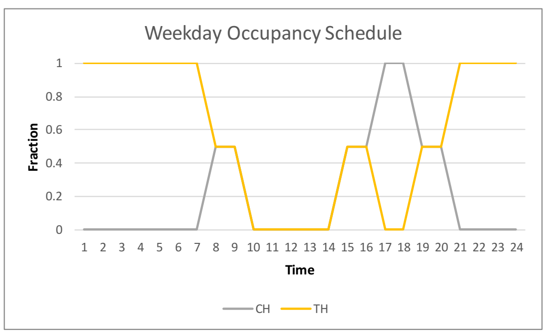


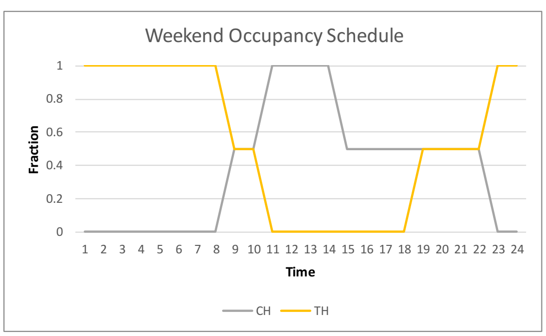
Club house roof from chosen after explorations

For annual simulation, the city of Spokane, the TMY3 Weather File for Spokane International Airport was used and two occupants were assumed. Additionally, the following loads and operation schedules were assumed:

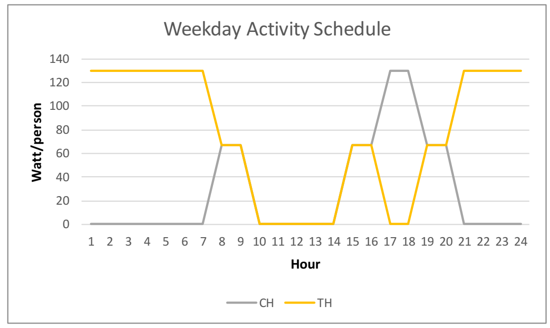
Loads assumed in annual simulation		
	Clubhouse	Tiny home
Equipment power density	0.28 W/ft^2	0.2 W/ft^2
Lighting power density	0.8 W/ft^2	0.8 W/ft^2
Infiltration rate	0.2 cfm	0.2 cfm
Heating set point	68 F	68 F
Cooling Set point	74 F	74 F

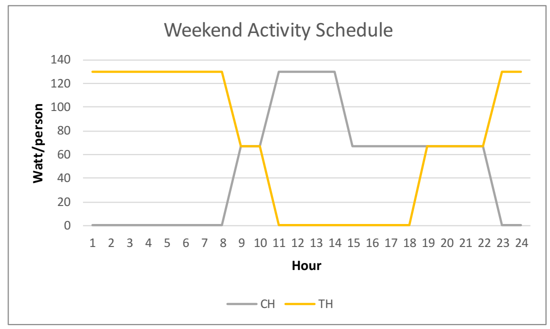
OCCUPANCY



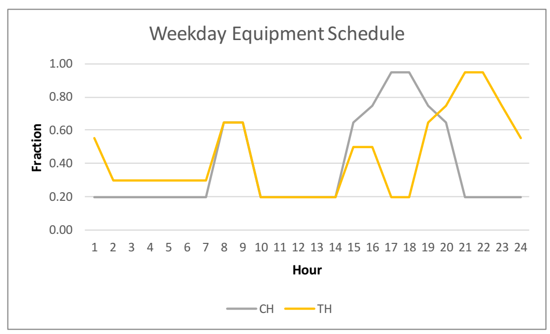


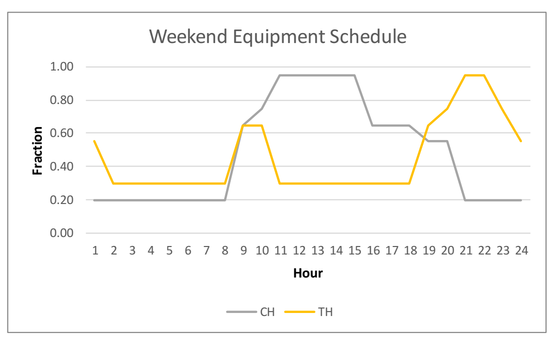
OCCUPANCY ACTIVITY



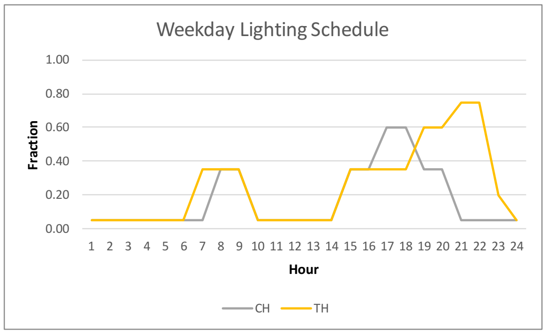


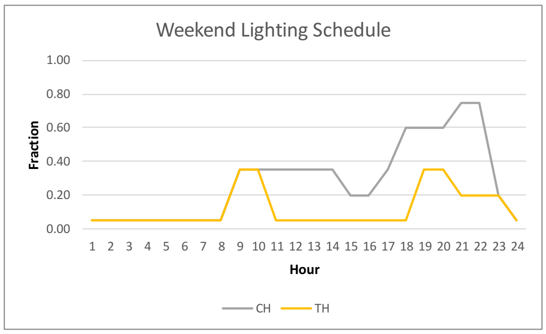
EQUIPMENT





LIGHTING





Annual simulation results indicate that with EnCity's optimized envelope, both annual and peak loads will be reduced by more than 50% from the city of Spokane baselines.

Annual EnCity loads City of Spokane (KBtu/year)		
	Clubhouse	Tiny Home
Heating (kBtu)	7,725	3,931
Cooling (kBtu)	2,022	730

This simulation indicates EnCity's reduced need for heating and cooling, guiding the selection of our HVAC system as discussed above. Furthermore, we simulated performance during competition week in Denver, Colorado to ensure optimal performance during the competition.

COLLABORATION

Throughout our engineering process, we extensively researched market leading technology and techniques, collaborating across campus, leveraging Washington State University research in Mechanical Engineering, Materials Science, Computer Science, and Smart City Integration to engineer and integrate all of our systems.

CONCLUSION

As urban density continues to increase, the market will continue to demand sustainable solutions that challenge traditional city housing options. EnCity exemplifies how sustainable tiny homes can be constructed in a way that minimizes energy draw, fosters the development of communities and creates resilient cities.