SUN CATCHER COTTAGE

TEAM ILLINOIS

U.S. Department of Energy
Race to Zero Student Design Competition

ILLINOIS SOLAR DECATHLON

RACE TO ZERO
U.S. DEPARTMENT OF ENERGY
STUDENT DESIGN COMPETITION

ALLERTON
PARK & RETREAT CENTER

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1.1 TEAM PROFILE

Team Illinois is comprised of 28 undergraduate and graduate engineering and architecture students from the University of Illinois at Urbana-Champaign. These students represent Illinois Solar Decathlon, the student organization that has competed in the U.S. Department of Energy Solar Decathlon in 2007, 2009, 2011, and SD China 2013.

The objectives for Team Illinois in entering the U.S. Department of Energy Race to Zero Student Design Competition were to 1) develop Illinois Solar Decathlon's capabilities and skillset for future Solar Decathlon competitions, and 2) develop complete construction documents, energy analysis, and financial analysis for the Sun Catcher Cottage, which is a real project Illinois Solar Decathlon hopes to begin constructing soon.

As an entirely student-run team, Team Illinois was managed by Illinois Solar Decathlon. Similar to past Illinois Solar Decathlon project teams, the team was divided into six subteams:

1) Architecture
2) HVAC/Energy Analyis
3) PV/Electrical
4) Lighting/Appliance/Home Automation
5) Water
6) Finance/Sponsorship/Construction Management

No work for the Race to Zero competition was performed in conjunction with any academic classes; however, team members had the option to receive one hour of academic credit for their work on this project.

Illinois Solar Decathlon's 2011 competition home, Re_home.

Illinois Solar Decathlon's 2013 competition home for SD China, Etho.

1.2 TEAM MEMBERS

Team Leaders

Matthew McClone, LEED AP BD+C, *Project Manager*
Civil & Environmental Engineering
Graduate Student

Connor Bogner, *Assistant Project Manager*
Electrical Engineering
Sophomore

Chen Ge, *Competiton Chair*
Mechanical Engineering
Graduate Student

Faculty Advisor

Dr. Xinlei Wang
Agricultural & Biological Engineering
Professor, Bioenvironmental Engineering

Subteam Leaders

Ryan Christensen, *Architecture Lead*
Architecture & Business Administration
Graduate Student

Xinshi Zheng, *HVAC/Energy Analysis Lead*
Civil & Environmental Engineering
Graduate Student

Michael Replogle, *PV/Electrical Lead*
Electrical Engineering
Senior

Nicholas Alexander, *Lighting/Appliance/Home Automation Lead*
Electrical Engineering
Junior

Sierra Young, *Water Lead*
Civil & Environmental Engineering
Graduate Student

John Brosnan, *Finance/Sponsorship/Construction Management Lead*
Civil & Environmental Engineering
Graduate Student

1.2 TEAM MEMBERS

Architecture

Kasey Colombani
Architecture
Senior

Vichithra Hitihamiarachchilage
Architecture
Graduate Student

Sean Killarney
Architecture
Senior

Robert Moy
Architecture
Freshman

Priscilla Zhang
Architecture
Junior

HVAC/Energy Analysis

Sheel Shah
Electrical Engineering
Junior

Stacy Lee
Civil & Environmental Engineering
Sophomore

PV/Electrical

Susan Chen
Electrical Engineering
Sophomore

Lukasz Kosakowski
Electrical Engineering
Junior

Rachel Smith
Architecture
Junior

Qing Lin
Materials Science & Engineering
Freshman

Water

Charles Hummel
Agricultural & Biological Engineering
Freshman

George Yonke
Mechanical Engineering
Junior

Lighting/Appliance/Home Automation

Seul-Gie Hong
Civil & Environmental Engineering
Graduate Student

Catherine Nguyen
Industrial Engineering
Freshman

Logan Rowe
Mechanical Engineering
Graduate Student

Finance/Sponsorship/ Construction Management

Carson Masterson
Civil & Environmental Engineering
Graduate Student

Kevin Fuller
Civil & Environmental Engineering
Junior

Alex Smart
Civil & Environmental Engineering
Junior

1.3 INDUSTRY PARTNERS

Skidmore, Owings & Merrill LLP

Luke Leung
Director of Sustainable Engineering

Jeff Seger
Mechanical Engineer

Brandon Stanley
Electrical Engineer

Patric Galloway
Plumbing & Fire Protection Engineer

Arathi Gowda
Senior Architect

Stephen Ray
Technical Advisor

Allerton Park & Retreat Center

Derek Peterson
Associate Director

Kennedy Hutson Associates

Kennedy Hutson
Owner and Principal

U.S. General Services Administration

Fred Yonke
Project Architect

Newell Instruments

Ty Newell
Vice President and Professor Emeritus UIUC

Hardt Electric Inc.

Mike Nicolosi
Project Manager, Sustainable Division

RATIO Architects

Ed Scopel
Associate Principal

1.4 ACADEMIC INSTITUTION PROFILE

University of Illinois at Urbana-Champaign

As a prominent midwest institution for research and development, the University of Illinois continues to push the standards of technology, architecture, and their integration into society. In 2008, the chancellor signed the American College and University Presidents' Climate Commitment, pledging to be carbon neutral by 2050. To meet this goal, the university has been upgrading existing buildings to energy efficient standards, creating micro power plants on and off campus, and converting the vast transportation fleet to be completely biodiesel. Come spring of 2015, construction of a 5.87 megawatt solar farm will break ground, marking the first of many sustainable power plants providing for the campus. The university has begun integrating the rooftops of existing buildings with solar arrays, a challenge of balancing Georgian style architecture with 21st century technology. The newly built Electrical and Computer Engineering Building meets LEED Platinum standards and net-zero energy, one of the largest net-zero buildings in the world. As mentioned, the University's Allerton Park is currently in the process of becoming net-zero, emphasizing the initiative to be net-zero both on and off campus.

Relevant Coursework

The School of Architecture at the University of Illinois provides a rigorous level of coursework through building technology courses, structural courses, and design studios. Undergraduate architecture students are required to take such courses as Anatomy of Buildings, Construction of Buildings, Environment Tech HVAC, and Environment Tech Lighting and Acoustics. These courses help build the technological background of architecture students from the University of Illinois.

DOE Building Science Training Course Requirement

Team Illinois upholds education with highest regards and continues engage students in competitions, community projects, and workshops. The DoE Race to Zero Design Competition allows students to apply their college education to current sustainability issues. Developing the know-how to address these topics involves participating in weekly team meetings, independent research, and Race to Zero webinars. Team Illinois routinely gathered to watch the DoE Race to Zero webinars to develop their understanding of building sciences. All participants, as certified by team advisor Dr. Xinlei Wang, have engaged in and completed DoE Race to Zero building science certification.

1.5 PROJECT SUMMARY

Project Summary

In the summer of 2014, Team Illinois was offered an opportunity to engage student members in the design process of building a net-zero sustainable home. Allerton Park in Monticello, IL proposed a deep energy retrofit of a cottage built in the 1940s to provide lodging for artisans and visitors of the park. The project allowed exploration into the struggles of updating existing homes to the efficiency standards set today, all within an affordable budget. Since this past summer, Team Illinois has developed a design for a net-zero sustainable home applicable to the hundreds of thousands of outdated midwestern homes. The Sun Catcher Cottage will serve as guide for future retrofits and is expected to break ground August of 2015.

Relevance of Project to the Goals of the Competition

First and foremost, Team Illinois' goal is to educate both the public and students about the benefits and feasibility of sustainable building. Team Illinois understands that global change requires global awareness and therefore seeks to take on projects that draw recognition. The Sun Catcher Cottage will serve as a model for hundreds of thousands of midwestern homes awaiting an affordable deep energy retrofit.

Design Strategy and Key Points

The design focuses on maintaining what was there before. The building's footprint and many of the existing materials have been maintained in order to limit wastes from demolition and to lower the costs and environmental impacts of requiring new materials. High efficiency systems were incorporated in order to create a building that is a high performance version of its former self.

Project Data

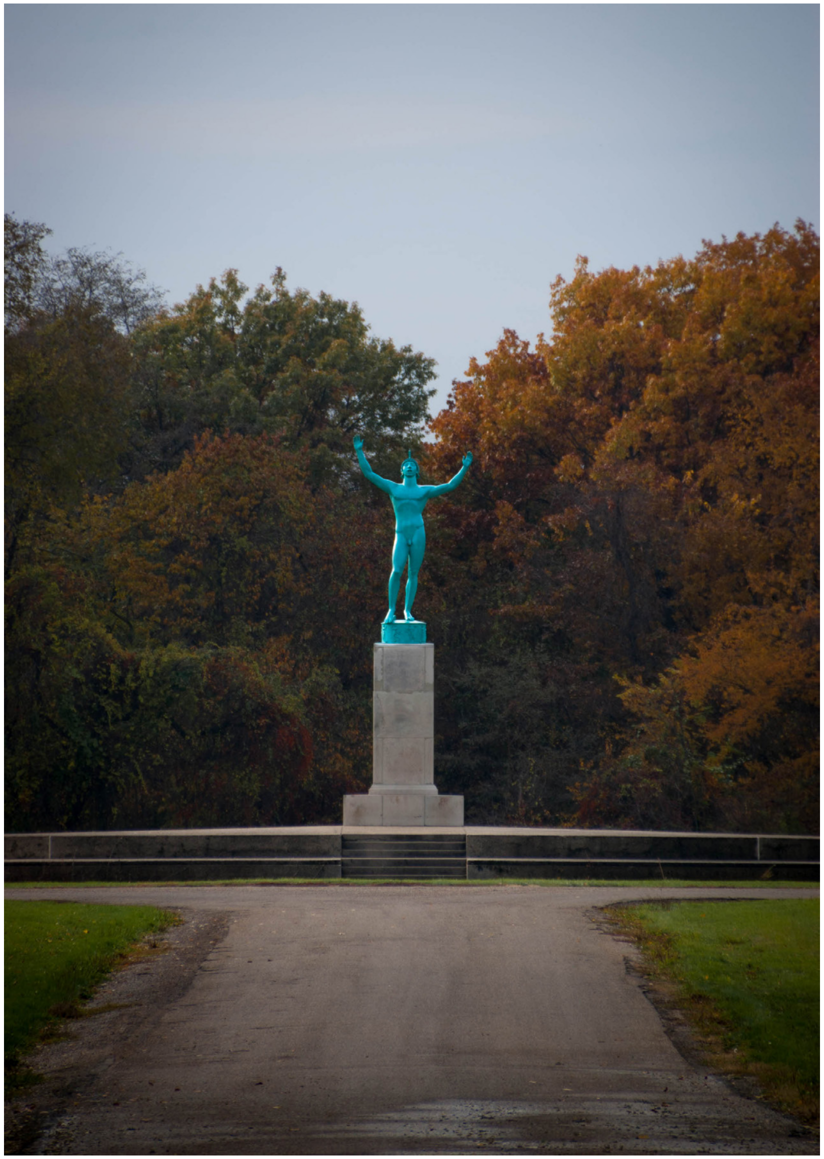
Location: Monticello, IL
Climate Zone: 5B
Square Footage: 1718 SF
Bedrooms: 2 Baths: 2 Stories: 2
HERS Score w/o PV (with PV): 30 (-7)
Estimated Monthly Energy Cost: $15.49

Technical Specifications

Total Wall Insulation (Continuous) = R 63.2 (R 20.7)
Continuous Foundation Insulation = R 20.7
Total Roof Insulation (Continuous) = R 88.2 (R 15)
Window Performance U-Value / SHGC= 0.170 / 0.190
ASHP Mini-Split SEER / HSPF = 19.0 / 10.0

2.1 PROJECT INTRODUCTION

In a clearing hidden behind acres of Ash and Oak trees stands a bronze sculpture titled the Sun Singer. Created by Carl Milles in 1929, the Sun Singer is one of the main features at Allerton Park for its beautiful and dramatic portrayal of the death of Paganism. Milles chose Apollo, the Greek god of the sun, music, poetry, and civilization to captivate the essence of Allerton Park.



2.2 PROJECT LOCATION

Allerton Park

Robert H. Allerton Park was built by the late Robert Henry Allerton in the late 1800's. Once over twelve thousand acres, Allerton Park became an outlet for Robert Allerton's artistic interests. He developed extensive landscaping and looked to conserve the natural aspects of the park as he believed in the artistic power of nature.

The park was publicly donated to the University of Illinois in 1946. Since then, the University has looked to continue Robert Allerton's vision for the land. They have worked to promote a sustainable approach to nature while keeping a focus on art and culture. Allerton Park has enacted many sustainable energy projects including a pair of solar arrays, which have acted as a teaching environment for many University of Illinois students.

This sustainable approach has been formalized in a Climate Action Plan for Robert Allerton Park and Conference Center at the University of Illinois at Urbana-Champaign in 2013, and more recently in the Allerton Master Plan developed by Ratio architects this year. Both documents set forth a set of recommendations for continuing the sustainable initiatives of the park.

The Sun Catcher Cottage retrofit has been included as part of this Allerton Master Plan, making this project extremely realizable and attainable.

2.2 PROJECT LOCATION

Monticello, IL

The Sun Catcher Cottage is located in the central Illinois town of Monticello. A smaller town of approximately 5,500 residents, Monticello is the county seat of Piatt County. One of Monticello's most notable landmarks is the over 1,500 acre Robert Allerton Park, registered as a National Historic Place by the National Park Service. The Suncatcher cottage is located just outside of the park which creates a strong tie to the cultural significance which lies within and around Allerton Park.

Like much of Central Illinois, the area around the Sun Catcher Cottage is dominated by vast agricultural lands. Specifically, the site is surrounded on all four sides by farmland used to grow both corn and soybeans on a rotational basis. This presents a unique opportunity to integrate the Sun Catcher Cottage into this unique landscape. Furthermore, this enables the building to stand tall as a landmark within this endless landscape.

The climate within this region varies widely throughout the year. With hot, humid summers and cold, dry winters, this site represents a challenge to condition spaces during all seasons. Furthermore, Illinois sees a large amounts of thunderstorms and tornadoes throughout the year.

Average Annual High Temp.[1]	*61.7 F*
Average Annual Low Temp.	*41.7 F*
Average Annual Precipitation	*41.4"*
Average Annual Snow Fall	*23.2"*

[1] *Illinois State Water Survey - University of Illinois at Urbana-Champaign. (n.d.). Retrieved March 18, 2015, from http://www.isws.illinois.edu/atmos/statecli/cuweather/cu-averages.htm*

2.3 PERFORMANCE DESIGN GOALS

Team Illinois set out to renovate a house to improve its performance to outstanding levels. Performance is paramount. In order to judge the quality of the house's performance, Team Illinois looked to various energy and building standards as baselines. Throughout the design process, Team Illinois kept these standards top of mind to help inform the design process. This house has been designed to achieve each of these standards.

LEED

Set forth by the United States Green Building Council, LEED is a green building certification with the aim of improving the energy performance in the built environment. It recognizes high performance in areas such as materials and resources, energy and atmosphere, water efficiency, indoor environmental quality, and many more.

WaterSense

WaterSense, an Environmental Protection Agency partnership, aims to take a more responsible approach to water usage. By choosing products certified with the WaterSense label, Team Illinois looks to incorporate a more sustainable consumption of one the Earth's most precious resources.

PHIUS

The Passive House Institute US is an extremely stringent energy standard that looks to certify passive buildings, which have an extremely airtight envelope, balanced heat and moisture recovery, high performance windows, and continuous insulation. Team Illinois designed this house to achieve all passive house performance standards.

ENERGY STAR

ENERGY STAR, set forth by the US Environmental Protection Agency, is a program that looks to reduce energy loads and energy costs by certifying products and homes.

DOE Zero Energy Ready Home

The goal of the DOE Zero Energy Ready Home is very straightforward and effective. Its aim is to certify houses that are so energy efficient that the energy demands of the house can be met through the use of renewable energy sources.

2.4 ARCHITECTURAL DESIGN GOALS

General Strategy

The main architectural goal of the Sun Catcher was to develop a Net Zero home that responds to the site while creating livable spaces inside which can be comfortably used by all occupants. The main idea was to take an existing building and perform a deep energy retrofit. Rennovatons are a large and challenging topic within green building, and Team Illinois looked to take on and address these issues through this project.

By doing so, Team Illinois looked to address the large topic of the growing age of homes in the United States. What can any exisitng home be doing in order to bring itself closer to Net Zero? Team Illinois looked to answer this question from the get go.

This is a real project. It represents real conditions and problems that need to be dealt with. Team Illinois did not have the luxury of orienting the building in an ideal fashion or choosing a site with favorable conditions. By developing this project with a realistic approach, Team Illinois is developing strategies that can be reproduced across the country.

Site Specific

The current structure stands vacant after having been a farmhand house for the bulk of its existence. Understanding this context and the environment in which it lies, Team Illinois has decided to rebuild the house to represent the traditional farmstead. Visually resembling a barn, with its red siding and white trim, Team Illinois was able to not only connect the house to the surrounding but also utilize the resources present within the community. This also enables the house to maintain a historical connection to its previous use.

The historical aspect of the site proved to be a driving factor in the design of the building. Various strategies were discussed, including the usage of SIP panels, expanding the footprint of the house, and even demolition and starting fresh. However, Team Illinois felt that keeping as much of the original building as possibe was important in order to preserve this farmhand house.

Developed for use as an artists in residency program, the Sun Catcher looks to create productive work spaces while also having relaxing living spaces overlooking the iconic prairie landscape. Spaces with varrying scales are provided in the loft area, office, and existing garage to accommodate all forms of artistry. Other strategies have been implemented to provide the occupant with extreme comfort rain, sleet, or shine.

The Sun Catcher is a full project ready to be built with construction documents having been reviewed at multiple stages for both design and code compliance. With a Monticello, IL building permit application filled out, this project is completely realizable.

2.5 ENGINEERING DESIGN GOALS

Indoor Air Quality

Sun Catcher is designed to ensure excellent indoor air quality for occupants. This should be achieved by an optimized HVAC system, as well as appropriate building materials and IAQ control strategies.

Space Conditioning

Illinois could be extremely cold in winter while having a rather hot summer. Space conditioning is a key element to ensure occupant health and comfort in Sun Catcher. The space conditioning, or HVAC system in Sun Catcher, should be designed to maintain indoor thermal comfort and good indoor environment, in the meantime being energy efficient.

Energy Analysis

Whole-house simulations have been conducted to demonstrate Sun Catcher's energy performance. REM/Rate annual energy simulation shows that Sun Catcher is qualified for DOE Zero Energy Ready Home certification. Hourly energy simulation has also been conducted to understand Sun Catcher's energy performance in depth.

Lighting, Appliances & Home Automation

The design goals of Lighting, Appliance and Home Automation is to maximize energy efficiency and without sacrificing functionality and display cutting edge technology where possible. The size of the appliances chosen were conservative to best meet the needs of the residents. The lighting goal was to broaden the number of lighting options in an efficient manner. The goal of home automation was to better inform the user of the house's energy consumption. Given this information the home automation system was designed to equip the resident with the necessary tools to eliminate wasteful energy consumption.

Domestic Hot Water

The heating of domestic water typically accounts for 15 to 25% of the total energy use in a residential home, and reducing this significant contribution to overall energy use is a primary goal of hot water distribution design. Specifically, a well-designed distribution system minimizes the wait time for hot water, the length of each hot water run, and the residual hot water loss in the pipe. Additionally, designing a system that requires minimal homeowner maintenance, reduces the potential for leaks, and has increased ease of installation is key for a renovation project like the Sun Catcher. It is also important to develop a strict criterion for choosing the most efficient hot water equipment, taking into consideration demand, geographical location, and price. To help achieve these goals, designing a home to meet WaterSense Specifications and LEED for Homes will ensure that the Sun Catcher uses the least amount of water, both indoors and outdoors, without sacrificing performance. Also, heat recovery from discarded hot water can significantly help lessen the energy load on the water heater, decreasing the overall energy requirement of the domestic hot water system.

Net-Zero Water

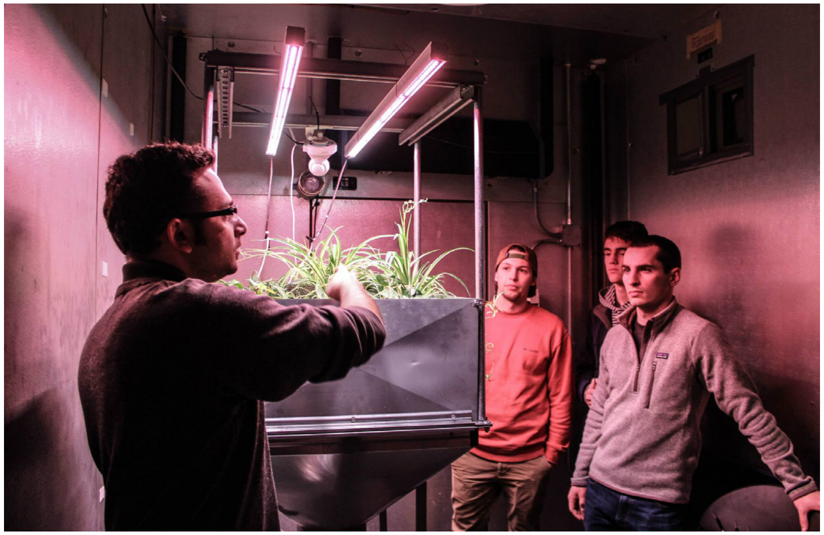
In addition to the goals of the DHW system, employing water reuse technologies to achieve net-zero water is a secondary goal of this renovation project. Creating a self-sustaining home that does not rely on public water supply is becoming increasingly important, especially considering potential strains on the water supply and more frequent drought periods due to climate change. The Illinois Department of Public Health has very strict guidelines regarding residential water reuse, but the Sun Catcher aims to pioneer the way to practicing rainwater capture and reuse systems in Illinois. Not only will achieving net-zero water alleviate demand from municipal water supply, it also allows for on-site stormwater management and reduces the burden on local water treatment plants.

2.6 INTEGRATED DESIGN PROCESS

Team Approach

Team Illinois is just that, a team. Everything was done collectively. It is not different subteams that come together to form a team. It is a team first. Architects did not go on educational trips only when the topic focused on architecture. In the same vein, engineers did not go to events only when the topic was focused on engineering. Team Illinois went to events and trips when the topic was green building. Everyone had something to contribute to each aspect of the project, and everyone was encouraged to share their contribution during the meetings throughout the year.

Team Illinois after a weekly general meeting.



Team Illinois learning about green walls while on tour of green building technologies at neighboring Purdue University.

Collaboration

Team Illinois started with the understanding that the whole should be greater than the sum of the indivudal parts. In order to create this synergy, collaboration became absolutely necessary. The organizational structure of the organization enabled this collaboration throughout the competition.

Every week during the school year, Team Illinois sat down as an entire group, including all subteams and disciplines, in order to bring everyone up to speed on each others' progress. This briefing was followed by coordination breakout sessions where different disciplines from engineers to architects to business students worked together to solve some of the critical design problems presented.

Weekly subteam lead meetings on top of the general meetings enabled Team Illinois to collaborate on specific design issues. More importantly, these meetings enabled Team Illinois to plan for each other. Planning these events to prevent bottlenecks and best utilize resources required high levels of integration.

2.7 BUILDING LAYOUT: SITE

Overall Goal

With the Sun Catcher, Team Illinois looked to expand the living space of the home by reaching outside the traditional walls of the house. Providing living space outside enables the resident to truly experience the marvel and agriculture that is the heart and soul of the Midwest.

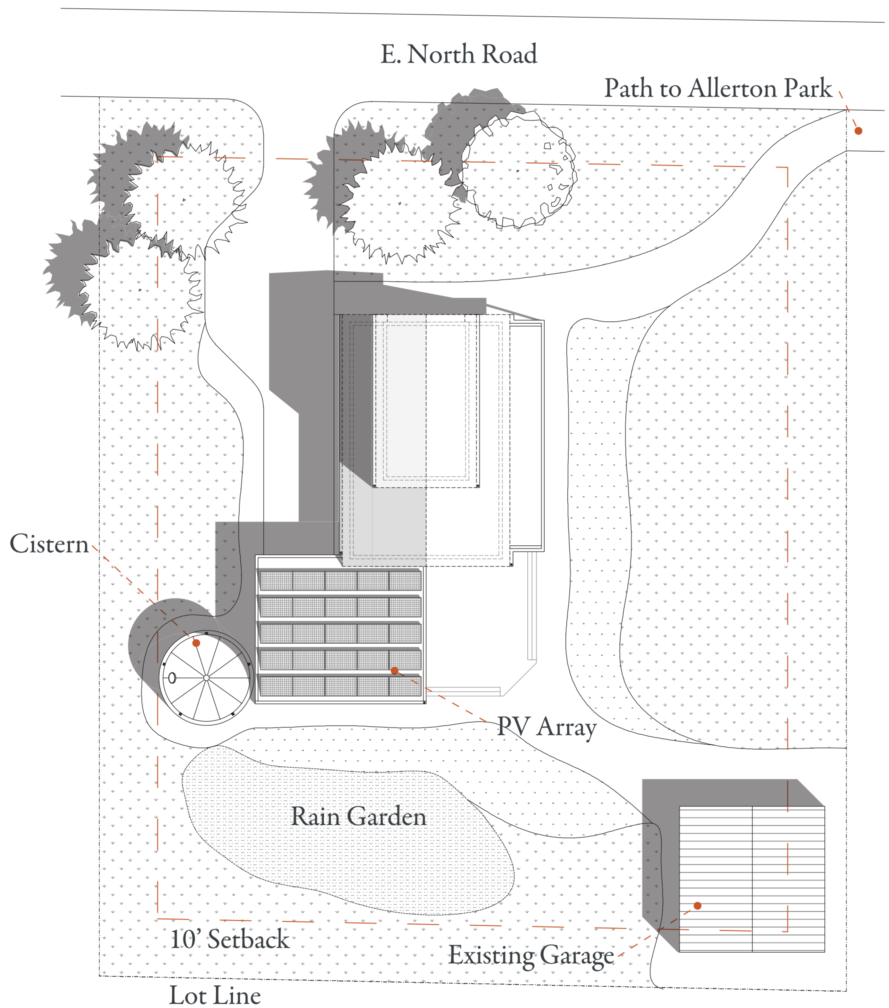
Looking further at the site, Team Illinois looked to bring the prairie back to Illinois by reintroducing native grasses and eliminating non-native species in order to reduce site maintenance and to connect the natural beauty of the prairie to the site's surroundings.

Features

Reintroducing these native grasses allowed the site to support a natural rain garden. By doing so, the Sun Catcher Cottage looks to manage all rainwater and runoff on the site. This is especially important given the agricultural usage of the surrounding area.

To encourage a more sustainable form of transportation, the Sun Catcher site deemphasizes the driveway and street by facing the building's entrance towards the East of the site. On the Northeast corner of the site, there is a planned path for walking and biking conecting the site directly to Allerton Park. Team Illinois looked at this as the main access point to the site as many of the guests of the house will be visiting the park on a regular basis.

Wind, which comes predominantly from the Northwest and Southeast is blocked by trees on the Northwest and an existing garage on the Southeast. Little existing natural shading is present on the site, which is optimal for photovoltaic performance. To provide relief for occupants, a large patio covering is included on the south of the site.



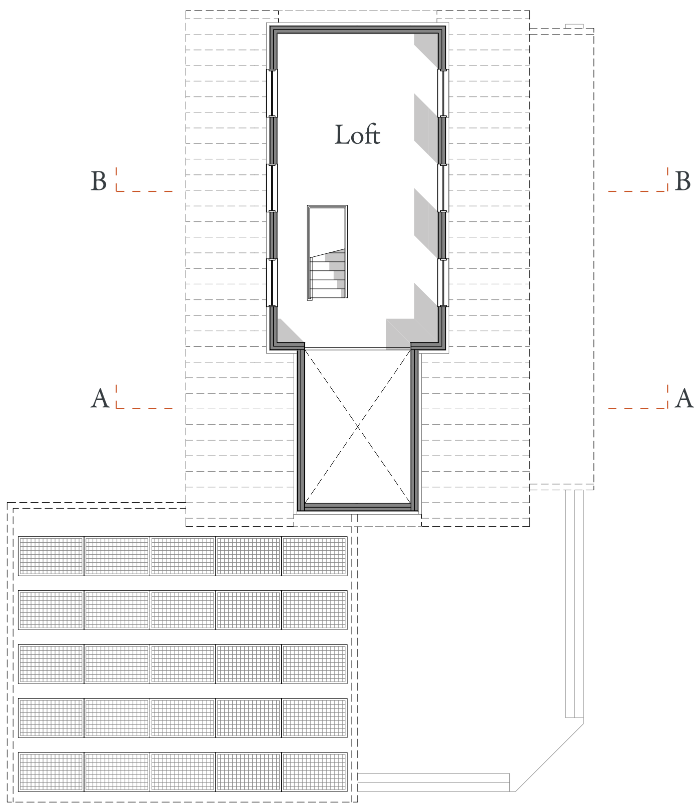
Site Plan *Scale: 1/32" = 1'-0"* N

2.7 BUILDING LAYOUT: PLANS

The existing plan of the building is very small; a challenge faced when planning to renovate. In order to overcome this, Team Illinois looked to open up the space by eliminating the wall between the kitchen and family room while also creating a vaulted ceiling within this space. We further expanded the usable space of the building by incorporating additional exterior living spaces, which extend horizontally off the house reaching out into the landscape.

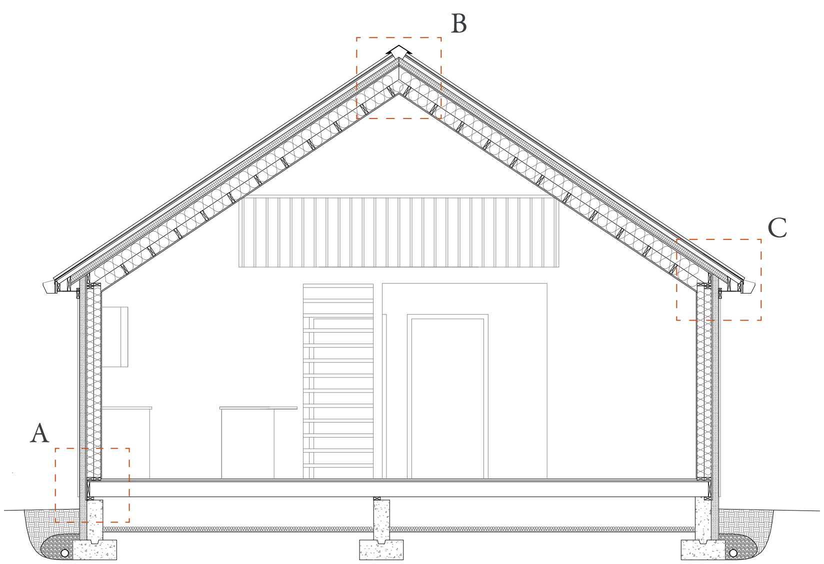
We organized the spaces in such a way as to situate the living spaces on the south side of the building in order to capitalize on natural daylighting. The space flows effortlessly between the interior and exterior through the large fenestrations on the southern façade which open not only onto the large deck but also out into the vast expanse of farmland beyond. This strategy takes a space limited by its small foundational footprint and expands it into a vast landscape as far as the eye can see.

First Floor *Scale: 1/16" = 1'-0"* N

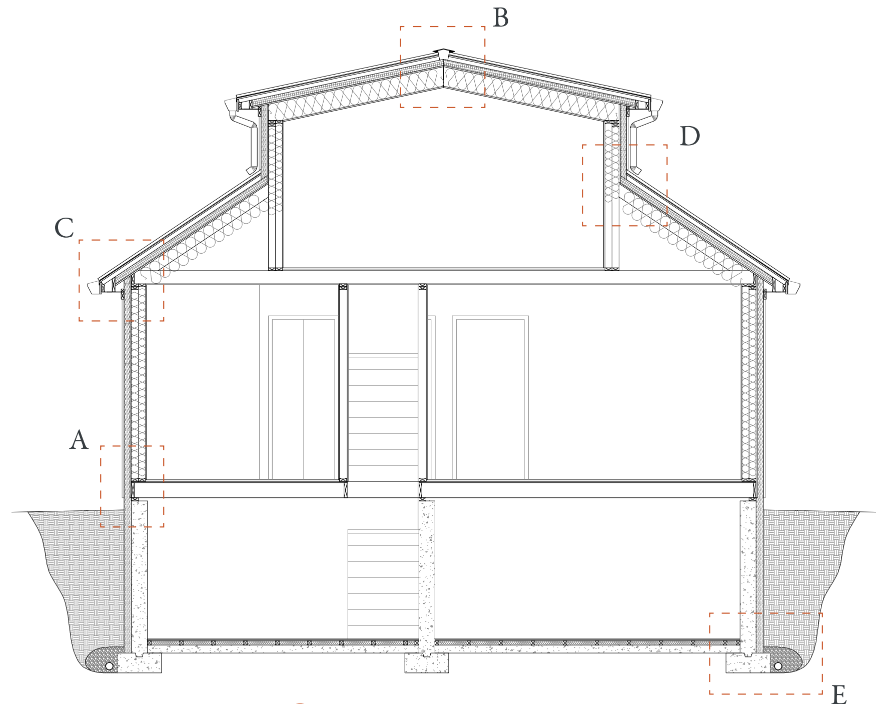


Loft *Scale: 1/16" = 1'-0"* N

2.7 BUILDING LAYOUT: SECTIONS



Building Section A-A *Scale: 1/8" = 1'-0"*



Building Section B-B *Scale: 1/8" = 1'-0"*

The bones of the existing structure are tight and choppy without a natural flow to the organization of the building. To open up the space, we transformed the southernmost portion of the building into a vaulted space for the living area. This enables the most utilized spaces of the house to remain open and feel much larger. The space becomes much brighter as well as the ceilings and windows allow light to penetrate deeper into the building. The opening to the loft enables the natural circulation of hot air out of the building when a window in the loft is open during the summer.

Again addressing the issue of space presented by the existing footprint, we looked to create a loft within the northern part of the building. This creates a large amount of flexible space on the second level while also maintaining an open connection to the living space below through a balcony overlooking these spaces. The loft also creates a larger scale workspace unique from the more intimate office area below it.

2.7 BUILDING LAYOUT: ELEVATIONS

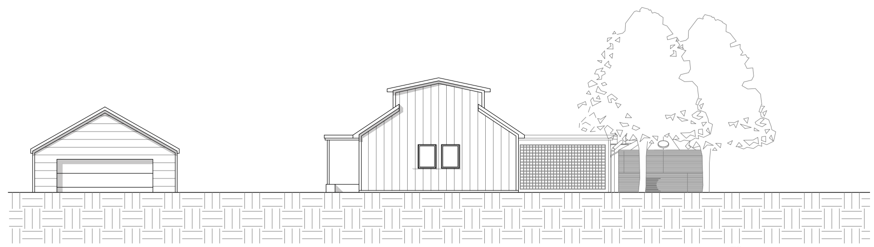
Overall Goals

Alluding to one of the most recognizable architectural forms in the midwestern landscape, the Sun Catcher is designed to resemble traditional barn architecture. As a nod to the history of the site, Team Illinois utilized repurposed barnwood siding with white trim and a white vented metal standing seam roof that remains sensitive to this iconic American form. The metal roof also lowers required roof maintenance while also standing up better to harsh wind and elements which can be present in this setting.[2] While the scale of the building itself is quite small, it becomes much larger in its context; a resolute monument within this vast landscape reaching out above the corn and soybean fields.

The exterior patio features a solar awning which serves multiple functions for the home. Due to the East-West orientation of the building, solar collection was initially not the most ideal energy solution. By providing this awning on the south of the site, not only was this concern addressed but it also addressed the concern of limited interior space while connecting the living space with the natural environment.

West Elevation

South Elevation



North Elevation

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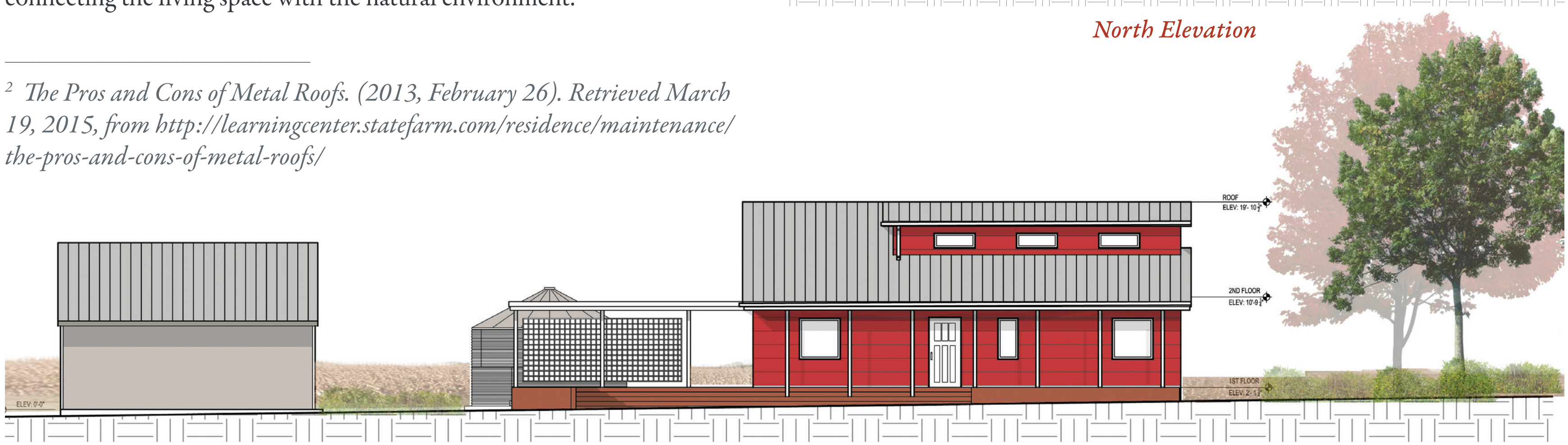
[2] *The Pros and Cons of Metal Roofs. (2013, February 26). Retrieved March 19, 2015, from http://learningcenter.statefarm.com/residence/maintenance/the-pros-and-cons-of-metal-roofs/*



2.7 BUILDING LAYOUT: RENDERINGS

2.8 SUSTAINABILITY & SENSIBILITY

Governing Approach

Team Illinois' sustainable approach started from the beginning with the decision to renovate a vacant house as opposed to starting from square one. By saving this house from falling into complete disrepair, Team Illinois is eliminating the amount of landfill waste that would result from its demolition.

The most sustainable building is the one that already exists.

At every opportunity, Team Illinois looked for ways to reuse and adapt the materials already present on the site. This holds true within the house as well as outside. Abiding by this philosophy enabled drastic reductions in the amount of new materials that needed to be created for the construction of this house. Materials were only eliminated from the site if they were damaged beyond repair or had no other usable purpose within the new building.

Some of the trees on the site, which need to be taken down, will be chipped and used as ground covering throughout the site in order to limit the amount of non-native manicured grass within the site. Other areas of the site include native grasses and plants, which flourish within this prairie environment.

Any materials not sourced from the site were obtained from sensible, sustainable sources. For example, Team Illinois was able to repurpose weathered wood siding from an old barn being torn down within close proximity to the site. This also eliminates waste from the demolition of that site as well as eliminating transportation costs and energy usage.

Further materials include a closed-cell insulation which is composed off recycled plastics and renewable soy oils which is a nod to the soy fields which surround the site. Team Illinois was able to refinish the wood floor on the first floor, and for the second level, utilize a renewable bamboo flooring to match the newly refinished floors.

Team Illinois also implemented a green wall within to create an interaction between the inhabitant and nature and to help improve our air quality in a natural, sustainable way.[3]

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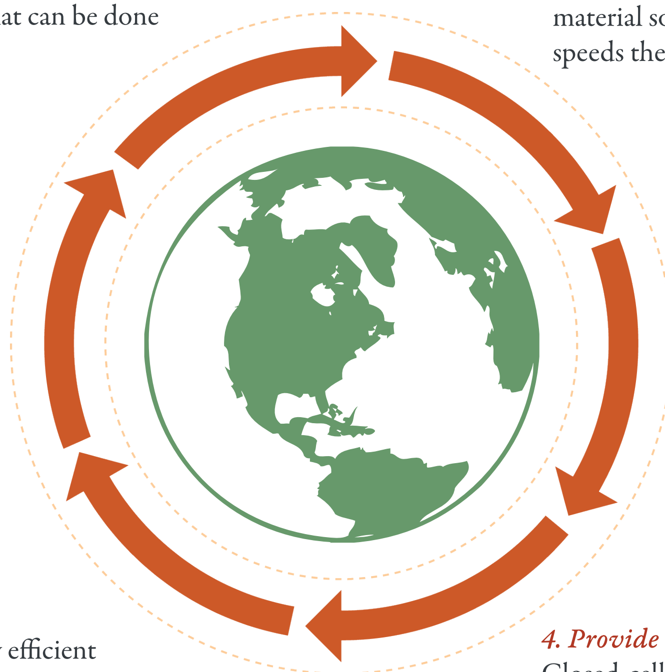
[3] *Indoor Air Quality. (n.d.). Retrieved March 19, 2015, from http://www.greenovergrey.com/green-wall-benefits/indoor-air-quality.php*

2.9 SCALABLE STRATEGY

1. Assess the site.
What can be reused? How does the orientation affect design decisions both architecturally and systematically. If the building has poor solar orientation, what can be done to improve this?

2. Repurpose existing materials.
Every exisitng site and building provides a wealth of building materials that should be treated as the go-to material source. This lowers costs, eliminates wastes, and speeds the rennovation process.



3. Build out exterior walls.
Older buildings tend to have thinner exterior walls made of 2x4's which do not hold enough insulation to provide adequate thermal protection. Build out a 2x4 wall on the inside of the exterior wall to provide space for adequate cavity insulation and to eliminate thermal briding.

4. Provide unified barriers and continuous insulation.
Closed-cell spray foams with environmentally friendly blowing agents, such as Demilec's Heatlok Soy 200, provide a quick and easy way to seal the building, making it airtight and vapor proof with exceptional thermal performance.[4] When sprayed over exisitng sheathing, this strategy eliminates human error caused with taping and sealing while also speeding up the process as well.

5. Improve building systems.
Once well insulated, look to utilize energy efficient appliances and fixtures to eliminate the energy demands of the house.

6. Utilize renewable resources.
Photovoltaic systems are an effective and clean solution to eliminate the need to source power from the grid.

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[4] *Heatlok Soy Technical Data Sheet. (2015, February 16). Retrieved March 18, 2015, from http://www.demilec.com/documents/Tech-Library/Heatlok-Soy/Heatlok-Soy-(S)-TDS.pdf*

3.1 ENVELOPE DESIGN

Refurbished Envelope

The driving criteria for the design of the Sun Catcher's envelope was extreme performance with a strong emphasis on sustainability. Like the rest of the building and the site, the envelope represents Team Illinois' goal to reuse as much existing resources as the site could provide. The existing structure of the building was in such great shape that Team Illinois was able to reuse a vast majority of the 2x4 wall framing and sheathing as well as the exisitng roof trusses and sheathing.

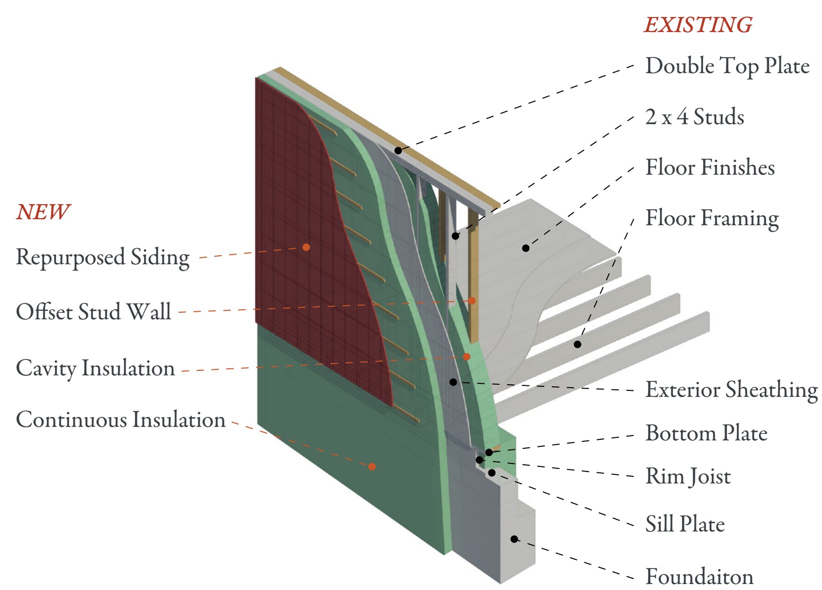
Team Illinois quickly came to the conclusion that the exisiting framing was not going to be adequate to achieve desireable thermal insulation. As a response, the idea to build an alternating stud wall inside the existing structure was developed. This strategy enabled extreme thermal performance as well as eliminated thermal bridging.

In an effort to ease the process of providing an air barrier, vapor barrier, and continuous insulation, Team Illinois utilized closed-cell spray foam. Heatlok Soy-200, by Demilec, is a recycled closed-cell foam using an environmentally friendly soy oil based blowing agent. Utilizing a closed-cell spray foam takes care of all three of the barriers in one pass. This reduces the amount of labor required to install the weather barriers and continuous insulation to one simple pass around the building. In addition, this type of continuous insulation provides extremely high R-values to the thermal enclosure.

Looking up to the roof, Team Illinois borrowed from existing barns throughout the region by providing a vented standing metal-seam roof. While initially more costly than a traditional shingled roof, metal roofs last longer and with less maintenance. They also prove to be more durable in harsher climates, such as the high winds common in the area around Monticello.

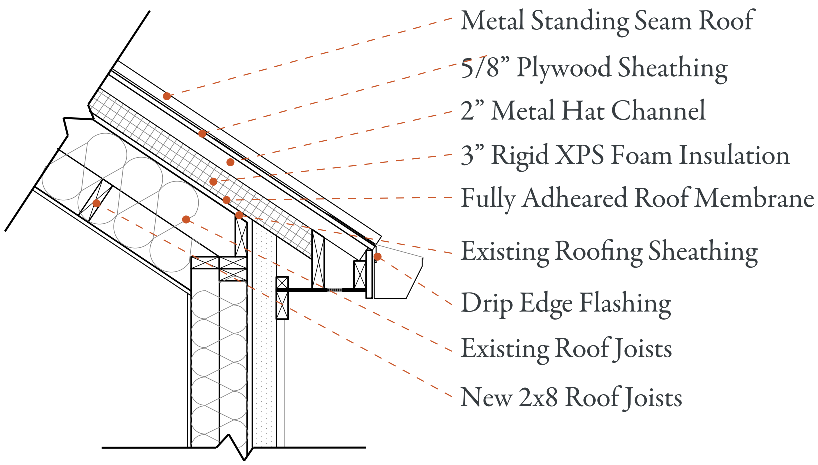
Traveling down the building envelope presented Team Illinois with the greatest challenge: how to retrofit an existing foundation. In order to address this issue, Team Illinois decided to excavate around the foundation wall in order to apply insulation and waterproofing to the exterior of the basement walls. Inside, at the slab, a built-up insulated flooring system was utilized on top of a waterproof membrane in order to help keep the basement dry and insulated.

All of these strategies look to provide the Sun Catcher with first class thermal insulation while keeping sustainability at the forefront of design decisions.

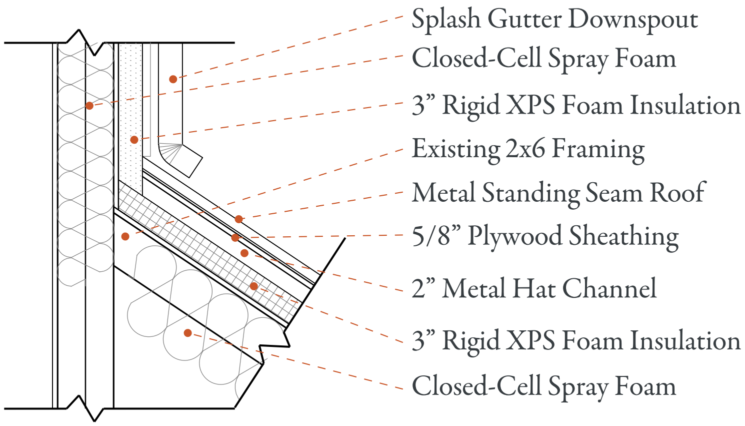


Typical Wall Axonometric

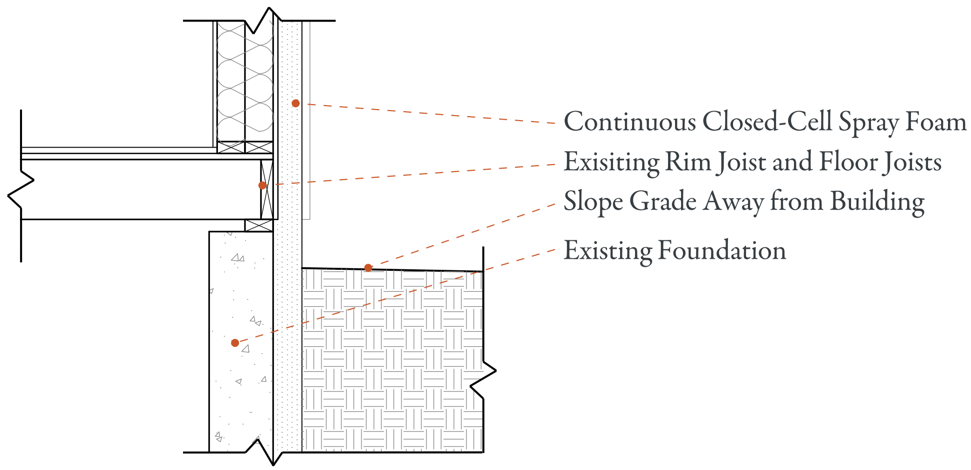
3.2 ENVELOPE DETAILING



Eave Detail *Scale: 1/2" = 1'-0"*



Flashing Detail *Scale: 1/2" = 1'-0"*



Rim Joist Detail *Scale: 1/2" = 1'-0"*

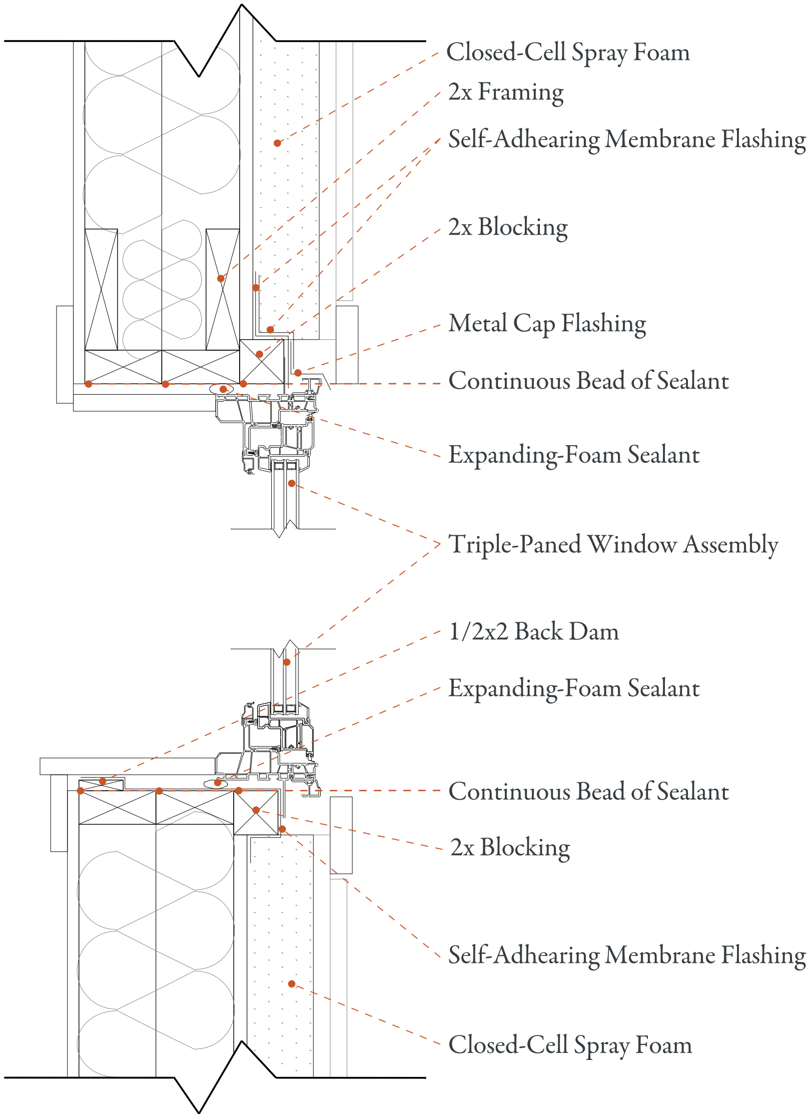
3.3 AIR TRANSPORT

Tight Envelope

Air tightness is a crucial element to any high-performance building. High levels of air leakage are very dangerous for a building in terms of energy consumption as well as structural integrity. It is relatively straightforward. The more conditioned air that escapes a building, the more energy is needed to reconditon the new unconditioned air. Furthermore, mositure travels in the air. Air leakage through the building has the potential to transport large amounts of water through a building envelope which can cause moisture damage to structural members within the envelope. To prevent air leakage, buildings are often wrapped with an air barrier. This is effective only if all the seams are properly taped and sealed, which is a labor intensive process.

Team Illinois looked to avoid this traditional approach to air sealing by providing an air barrier through the use of closed-cell spray foam applied to the extrior of the building. At 1 1/2", closed-cell spray is a certified air barrier. The Sun Catcher provides 3" of closed-cell spray foam to guarantee a strong air barrier that is quicker and less cumbersome to install than the traditional approach.

By providng this air barrier, the Sun Catcher will eliminate unnecessary energy usage associated with conditioning air in a leaky building. Coupled with air monitoring devices and an active air handling mechanical system, Team Illinois has provided an air-tight assembly that eliminates the threats of air flow through the envelope while providing superb air quality and monitoring within.



Window Details *Scale: 1-1/2" = 1'-0"*

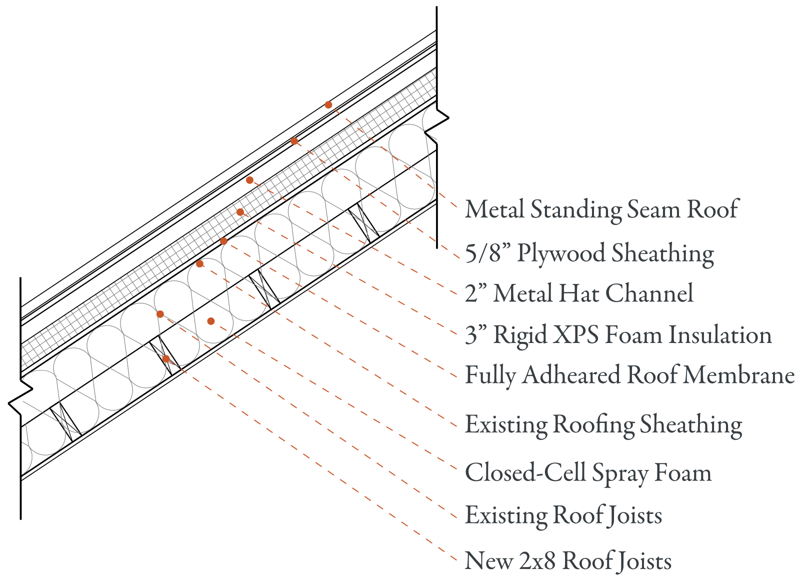
3.4 MOISTURE MANAGEMENT

Water Control

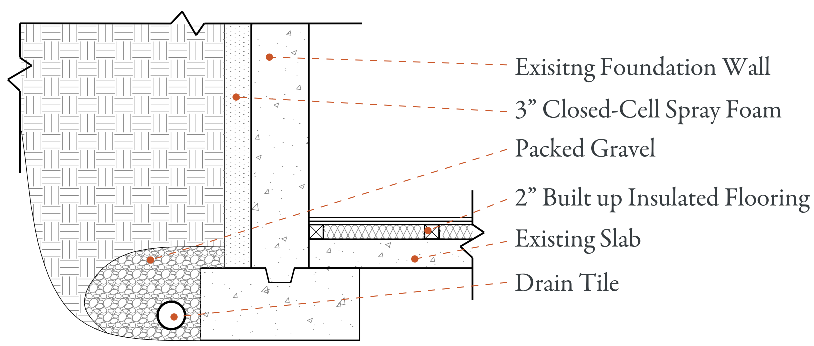
The Sun Catcher's envelope addresses moisture management by providing all the necessary factors which create an effective rain-managed wall. An effective rain-managed wall protects the building from moisture which can prove disasterous to the structural integrity of buildings while also leading to the build up of mold which is detrimental to ocupant health. Team Illinois' strategy eliminates these potential threats by providing bulk rain shedding, a drainage plane, space for drainage, flashings and opening for drainage.

Bulk rain shedding is provided by the standing metal seam roof and weathered, repurposed barnwood siding. The closed-cell spray foam insulation provides a drainage plane for water to run down the outside of the building instead of collecting in the buildings structure. Battens, which support the siding, provide a gap from the drainage plane enabling water to travel out of the envelope system. Furthermore, flashing and taping is implemented at every perforation and juncture of the building envelope to shed water out and down. Furthermore, drainage tile at the footing, as well as a site sloping away from the building, helps to guide water away from the building.

Mositure in the basement is handled through a water barrier applied continuously to the exterior side of the foundation wall. The earth around the foundation wall is excavated in order for this application as well as to provide any foundation repairs, to install drainage tiling, and to help grade the site away from the building.



Typical Roof Detail *Scale: 1/2" = 1'-0"*



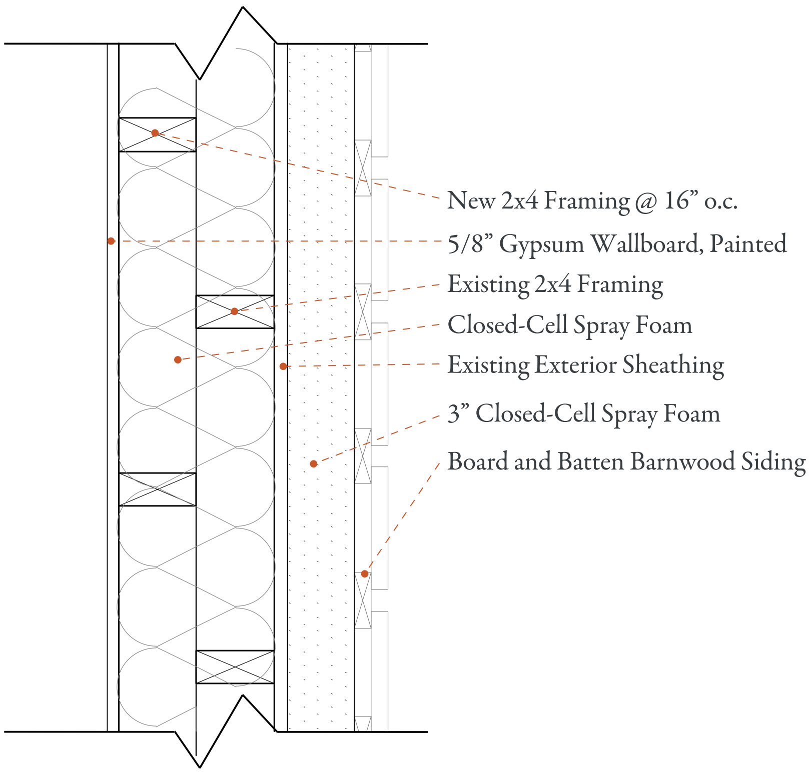
Footing Detail *Scale: 1/2" = 1'-0"*

3.5 THERMAL AND HYGROTHERMAL CONTROL

Thermal Design

Thermal control is essential for the performance of any Net Zero home. The Sun Catcher is no exception to this. With outstanding thermal performance, the Sun Catcher is able to reduce the loads of the HVAC system, leading to lower energy demands for the home.

Such thermal properties are attained through the application of the Sun Catcher's scalable strategy described earlier. By providing an alternating stud wall, the thermal envelope is able to increase cavity thickness while also eliminating any thermal bridging.[1] Thermal bridging is further addressed through 3 inches of continuous closed-cell spray foam insulation applied to the outside of the building. This continuous insulation, rated at R 20.7, exceeds standards and shifts the insulative properties towards the exterior of the structure. By having a larger proportion of insulation outside the cavity, the Sun Catcher is able to keep the structural framing warm which pushes the dew point outside of the building. This prevents moisture build up within the wall assembly and protects the building, not only thermally, but structurally as well.



Typical Wall Detail *Scale: 1-1/2" = 1'-0"*

Thermal Performance

Roof Cavity Insulation	*R - 73.2*
Roof Continuous Insulation	*R - 15.0*
Wall Cavity Insulation	*R - 42.5*
Wall Continuous Insulaiton	*R - 20.7*

[1] Double-Stud Walls. (2013, November 1). Retrieved March 18, 2015, from http://www.greenbuildingadvisor.com/green-basics/double-stud-walls

4.1 IAQ DESIGN: OUTDOOR AIR QUALITY EVALUATION

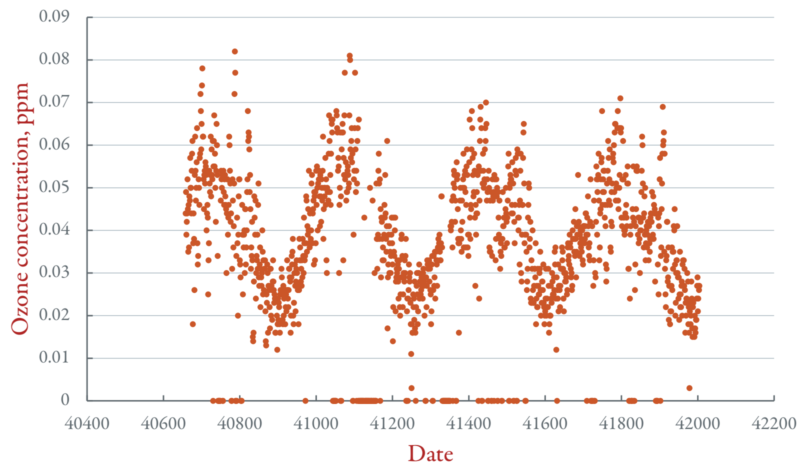
Overview

The outdoor air quality in central Illinois has been evaluated by the historical daily air quality index (AQI) data obtained from US EPA.[1] According to the data, from January 2009 to December 2014, the outdoor air quality is considered generally acceptable. In this five year period, only nine days had an AQI exceeding 100, which is regarded as "unhealthy" for sensitive groups (AQI 101-150).[2]

Ozone

Ozone is the main problem in this region, which accounts for 80% of the five year period as the main pollutant in AQI as specified by EPA. Illinois Depart of Public Health (IDPH) recommends that ozone levels should not exceed 0.08 ppm for acceptable indoor air quality.[3] By referring to historical ozone concentration data in the nearest EPA air quality monitor site, as shown in the figure to the right, it could be found that high concentrations of ozone usually occur during summers. Since the ozone problem only occurs for a very limited time for Sun Catcher occupants, it is suggested that a mechanical device specifically for ozone removal, though possible, is unnecessary as long as occupants are aware of this issue and minimize window-opening during high ozone concentration periods.

Figure 4.1.1: Daily Max 8-hour Ozone Concentrations from 2011 to 2014



Source: Air Quality Monitor Site 170191001 of Champaign County

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[1] *U.S. Environmental Protection Agency. (2014, October 8). Air Data. Retrieved from U.S. Environmental Protection Agency: http://www.epa.gov/airquality/airdata/*

[2] *U.S. Environmental Protection Agency. (2014). Air Quality Index: A Guide to Air Quality and Your Health. Research Triangle Park, NC: U.S. Environmental Protection Agency.*

[3] *U.S. Department of Energy. (2013, July 15). Weather Data. Retrieved from Office of Energy Efficiency & Renewable Energy: http://apps1.eere.energy.gov/buildings/energyplus/weatherdata_about.cfm*

4.2 IAQ DESIGN: INDOOR AIR POLLUTION CONTROL

Whole House Ventilation

The Sun Catcher is designed to achieve an air-tightness of 0.6 ACH50. Natural ventilation through infiltration is virtually impossible and undesirable. To ensure indoor air quality and provide adequate amount of fresh air, whole-house mechanical ventilation should be realized. Sun Catcher is equipped with three pairs of Lunos e2 ventilation fans for balanced whole-house ventilation to provide adequate ventilation rate, meeting the ASHRAE 62.2 – 2010 required minimum whole-house ventilation rate, as shown in Appendix ventilation sizing. The Lunos fans can also provide higher total ventilation rate of up to 75 CFM for Sun Catcher to remove indoor air pollutants as well as cumulated Carbon Dioxide effectively when needed. By installing at proper locations in Sun Catcher, these decentralized, through-wall fans will ensure fresh air is delivered at a desired speed and place, while being extremely energy efficient. The Lunos e2 fans will be installed with pollen filters, which will achieve an MERV rating of 10 to ensure fresh air quality.

Local Exhaust Fans

Exhaust fans will be installed in the bathrooms and the kitchen. These exhaust fans will be able to remove air pollutant or odor at sources. Each bathroom fan will be able to provide an intermittent ventilation rate of 80 CFM, and the range hood will be achieve a ventilation rate of 290 CFM. Detailed information of the local exhaust fan products could be found in Section five space conditioning. All exhaust air outlets of local exhaust fans have a back-draft damper to prevent unfiltered outdoor air entering the building. All exhaust air outlets will be on the roof.

Air Makeup System

The Sun Catcher is designed to be air-tight. When indoor exhaust fans are operating with large ventilation rate, negative air pressure inside the building will occur and may result in unwanted consequences, such as reducing the exhaust fans' capability of removing indoor air pollutants. As a result, the team has specified an air makeup system for the range hood to balance the indoor air pressure with the outdoor pressure. The air makeup system will be comprised of a motorized air damper and a switch assembly. The assembly will sense the operation of the range hood and control the motorized air damper to provide fresh air to make up the pressure loss. The motorized fresh air damper will be closed tightly when not in use, and the air inlet of the makeup system will be filtered to achieve MERV 10.

Space Conditioning Equipment

The Mitsubishi indoor units in Sun Catcher will be equipped with a sophisticated multi-part filter system to remove contaminants from the air. A hybrid catechin pre-filter and a Blue enzyme anti-allergen filter with antioxidants will absorb odor-causing gases. The hybrid catechin pre-filter could also be replaced by a Platinum Catalyst deodorizing filter to increase deodorizing performance by advanced nanotechnology.

4.2 IAQ DESIGN: INDOOR AIR POLLUTION CONTROL

Indoor Air Quality Sensors

Sun Catcher will also be equipped with an integrated indoor air quality sensor to monitor the building's IAQ performance. Details could be found in Section LAHA.

Eco-wall

A living eco-wall will be installed in the center of the first floor in Sun Catcher. Certain indoor air pollutants can be removed from the indoor environment by plant leaves.[4] Sun Catcher's eco-wall will consist of plants capable of removing indoor air pollutants such as Formaldehyde, Carbon Monoxide, VOCs, Trichloroethylene, Benzene, Toluene and Xylene. Peace lily, Boston fern and English ivy will be planted in order to remove Formaldehyde. VOCs will be removed by Golden Pothos and Devil's ivy. Trichloroethylene will be removed by Chrysanthemum and Mother-in-law's tongue. Benzene, Toluene and Xylene will be removed by Kimberly Queen Fern. By supporting biodiversity with an eco-wall, Sun Catcher will obtain superior air quality through natural means.



The Golden Pothos, Spider Plant, and Peace Lily pictured left to right.

Rendering of the eco-wall in the interior of the Sun Catcher Cottage.

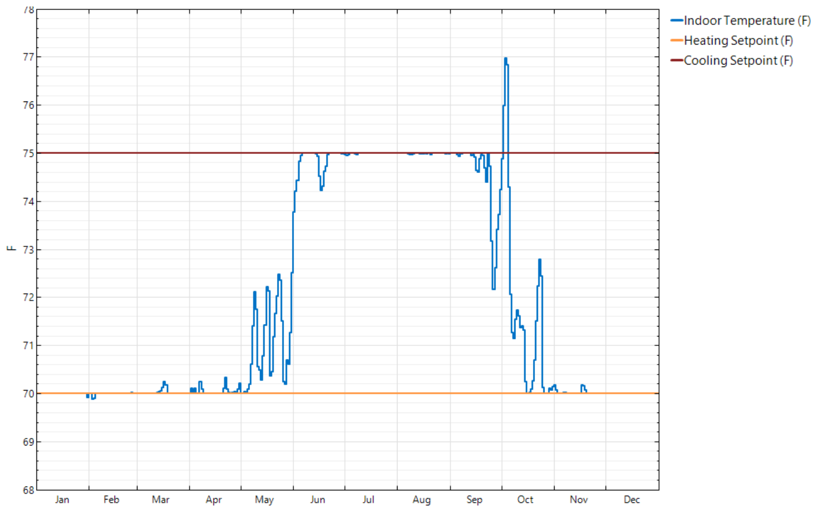
[4] *Wolverton, B. C., Johnson, A., & Bounds, K. (1989). Interior Landscape Plants for Indoor Air Pollution Abatement. National Aeronautics and Space Administration.*

4.3 INDOOR AIR TEMPERATURE AND HUMIDITY CONTROL

Temperature Control

The main heating and cooling equipment, as discussed in Section Space Conditioning, is the tri-zone Mitsubishi mini split ASHP system. The latest Mitsubishi "Hyper Heat" Technology enables the ASHP system to function with outdoor ambient temperature as low as -13 °F. Three electric baseboard heaters with a total output of 5 W has also been specified for backup heating to ensure occupant safety when the ASHP system stops working during extreme cold days below -13 °F, which is still possible in Illinois. The effectiveness of the HVAC system for indoor temperature control has been evaluated by simulation, as shown in Figure 4.3.1. According to Illinois Department of Public Health Guidelines for Indoor Air Quality[5], the acceptable indoor temperature range is between 68 to 75 °F during winter and 73 to 79 °F during summer. The HVAC system of Sun Catcher is capable of achieving this target, according to the simulation result.

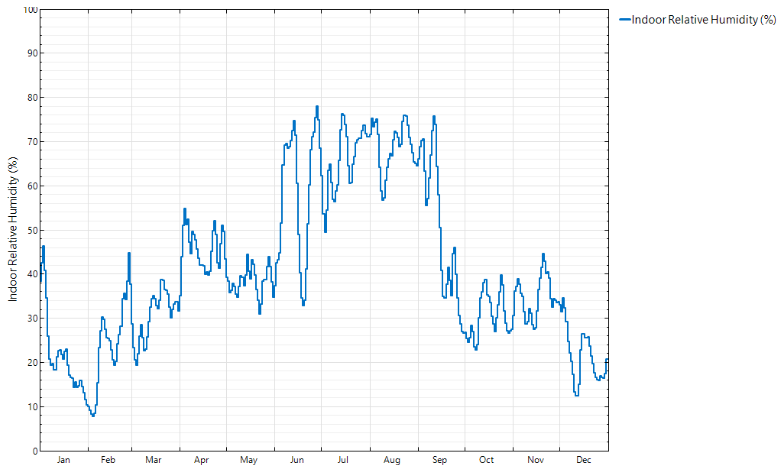
Figure 4.3.1: Daily Indoor Temperature Profile



Humidity Control

The indoor humidity level has also been evaluated. Figure 4.3.2 shows the simulation results. It has been found that during the winter and summer Sun Catcher requires additional dehumidification and humidification, respectively. As mentioned in Section Indoor air pollutant control, as well as in Section Space conditioning, the Lunos e2 system is able to provide a total ventilation of up to 75 CFM for summer venting. Besides, all windows in Sun Catcher are operable to provide natural ventilation. The winter dehumidification demand will be fulfilled by the Oskar portable humidifiers, as will be discussed further in Section 5, Space Conditioning.

Figure 4.3.2: Daily Indoor Humidity Profile



[5] *Illinois Department of Public Health. (2011, May). Illinois Department of Public Health Guidelines for Indoor Air Quality. Retrieved from Illinois Department of Public Health: http://www.idph.state.il.us/envhealth/factsheets/indoorairqualityguide_fs.htm*

4.4 EPA INDOOR AIRPLUS CERTIFICATION

Beyond ENERGY STAR Home, Sun Catcher is designed to meet the requirements of the EPA Indoor airPLUS program. This is achieved by implementing the following measures:

Moisture Control

A sump pump with a passive radon vent will be installed in the basement. A polyethylene sheeting is installed on top of a 4-inch-deep layer of aggregate under the basement slab. The basement and the crawl space are insulated, sealed and conditioned. The installation of the rain-water harvesting system protects the home from water splash damage. Kitchens, bathrooms, entry, laundry, and utility rooms contain hard-surface flooring. Piping in exterior walls are insulated with pipe wrap.

Radon Control

Radon mitigation is required in Sun Catcher as it is located in Radon Zone 1. A sump pit has been identified in the basement of Sun Catcher. A sealed radon suction pipe will be installed on the sump pit to vent Radon out of the roof passively, as shown in Appendix CD.

Pest Barriers

The pathways for pest entry will be minimized. All penetrations and joints between the foundation and exterior wall assemblies will be sealed. All sump covers will also be sealed. All exhaust and intake grilles have corrosion resistant insect or bird screens.

Combustion Pollutant Control

No combustion heating equipment located in conditioned spaces. Sun catcher is completely electrified.

HVAC Systems

The ASHP Mini Splits system is sized properly using the ASHRAE SLF load calculation method, which can be found in the appendices. Ducts of local exhaust fans will be insulated, located and installed properly. Air-tightness will be ensured and room pressure differentials will be minimized. The mechanical whole-house ventilation will meet all requirements of ASHRAE 62.2 – 2010. Outdoor air inlets have been carefully placed to ensure proper distance between exhaust sources. Local exhaust ventilation has been specified in each bathroom and the kitchen to meet ASHRAE 62.2 – 2010 section 5 requirements. The Lunos e2 system will have an MERV of 10 by adding pollen filters.

Low Emission Materials

No composite wood will be included in the construction materials for Sun Catcher. The interior paints and finishes will not contain VOCs. All floors are made of either bamboo, porcelain, or utility floor tiles. Walls will be composed of either gypsum board, ceramic mosaic, porcelain or reclaimed wood. In addition, Sun Catcher does not utilize carpets.

Home Commissioning

In addition to ENERGY STAR requirements, Sun Catcher will be ventilated with outside air at the highest rate practical during construction and installation of building products, as well as during the period between finishing and occupancy. A copy of the Indoor airPLUS Verification Checklist and the HVAC system design documentation with performance test results will be provided to the occupants. Operation and maintenance instruction manuals for all installed equipment and systems that are relevant to Indoor airPLUS and ENERGY STAR requirements will also be provided.

5.1 HVAC DESIGN PROCESS

Heating and Cooling Load Calculation

To size HVAC equipment properly, Team Illinois has conducted a heating and cooling load calculation based on the Residential Load Factor (RLF) method in ASHRAE.[1] The design conditions are summarized in Table 5.1.1. Calculation results could be found in Table 5.1.2. The details of the load calculation could be found in Appendix: Heating and Cooling Load Calculation based on RLF method according to ASHRAE.

Table 5.1.1: Heating and Cooling Load Calculation Design Conditions

	Heating	Cooling
Latitude	40.4°N	
Elevation	764 ft	
Indoor Temperature	70°F	75°F
Indoor Relative Humidity	30%	50%
Outdoor Temperature	-0.5°F (99.6%)	90°F (1.0%)
Daily Range	N/A	19.2°F
Outdoor Wet Bulb Temperature	N/A	75.1°F (MCWB at 1%)
Wind Speed	15 mph	7.5 mph
Design ΔT	70.5°F	15°F
Enthalpy Difference	20.59 Btu/lb.	12.89 Btu/lb.

Climate Data Source: UNIV OF ILLINOIS WI, IL, USA WMO# 725315

[1] *American Society of Heating, & Refrigerating and Air-Conditioning Engineers. (2013). 2013 ASHRAE Handbook-Fundamentals. Atlanta: ASHRAE.*

Table 5.1.2: Heating and Cooling Loads Summary

	Heating Load, Btu/h	Cooling Load, Btu/h
Envelope	12660	4162
Infiltration/ventilation	4135	366
Internal Gain	N/A	1892
Distribution loss	0	0
Total Sensible Loads	**16795**	**6420**
Total Latent Loads	**1302**	**1354**

Ventilation System Sizing

The minimum required whole house ventilation rate for Sun Catcher is specified to be 39.68 CFM according to ASHRAE 62.2 - 2010.[2] Details of the whole-house ventilation requirements could be found in the appendices. Local exhaust fans are required for each bathroom and the kitchen. Energy Star recommends that intermittent exhaust fans in thebathroom should be at least of 70 CFM rating to pull at least 50 CFM when measured.[3] The range hood in the kitchen should have a minimum intermittent rate of 100 CFM when integrated with the range.[4]

[2] *American Society of Heating, Refrigerating and Air-Conditioning Engineers, & American National Standards Institute. (2010). Ventilation and acceptable indoor air quality in low-rise residential buildings. Atlanta, GA: American Society of Heating, Refrigerating and Air-Conditioning Engineers.*

[3] *Bathroom Exhaust | Building America Solution Center. (n.d.). Retrieved from https://basc.pnnl.gov/resource-guides/bathroom-exhaust*

[4] *Kitchen Exhaust | Building America Solution Center. (n.d.). Retrieved from https://basc.pnnl.gov/resource-guides/kitchen-exhaust*

5.1 HVAC DESIGN PROCESS

Equipment Selection Criteria

Careful selection of HVAC equipment is key in the tradeoff between occupants' living experience and energy performance. HVAC equipment in Sun Catcher is selected based on the following design principles.

Decentralization

A decentralized HVAC system is preferred in Sun Catcher. Decentralization will enable occupants to have zonal control of temperature and indoor air quality to stay comfortable. Although Sun Catcher is relatively small, providing zonal comfort control in major types of spaces could enhance occupant living experience.

Minimal Ducts

Duct loss could account for more than 30% of space conditioning energy consumption.[5] Sun Catcher aims to minimize the use of ducts in the HVAC system to improve its energy performance and to simplify maintenance requirements.

Energy Efficiency

To reduce the energy consumption of Sun Catcher, energy efficiency of HVAC equipment will be crucial. Therefore, heat pump technology is one of the most favorable options for Sun Catcher.

Heating Load Dominate

The proposed HVAC system should ensure thermal comfort of occupants in Sun Catcher in the local climate. This refers to the extremely cold winter of Illinois. The HVAC system will first ensure occupant safety in winter, and then consider occupants' thermal comfort in mild and warmer seasons.

Replicability

Team Illinois hopes that Sun Catcher could be a replicable model house for net zero homes in US. Although specifically-tailored HVAC system might be ideal for a particular house, the team prefers to implement common HVAC products in Sun Catcher in an effort to guide homeowners in the US to a similar approach.

[5] *Ductless, Mini-Split Heat Pumps | Department of Energy. (n.d.). Retrieved from http://energy.gov/energysaver/articles/ductless-mini-split-heat-pumps*

5.2 HVAC EQUIPMENT

Heating and Cooling

A tri-zone Mitsubishi ASHP mini split system is selected as the main heating and cooling equipment in Sun Catcher to meet the design loads. The configuration of the mini split system has been summarized as:

1 × MXZ-3C24NAHZ Outdoor Unit
3 × MSZ-GE06NA Wall-mounted Indoor Units

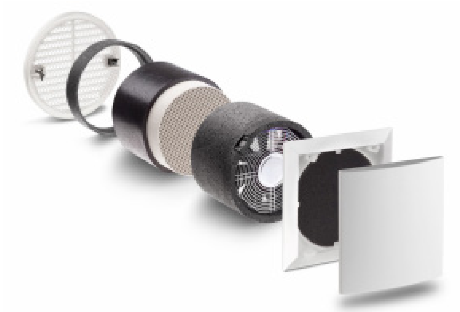
Having three 0.5 tone wall-mounted MSZ-GE06NA indoor units, this tri-zone mini split ASHP will be able to condition the main bedroom, the great room and the loft effectively and distribute heating and cooling uniformly in Sun Catcher.

The outdoor unit MXZ-3C24NAHZ, facilitated with the latest Mitsubishi hyper-heating inverter technology, will be able to operate below -13 °F, which is ideal for the cold winter of central Illinois. The whole system will be able to achieve a seasonal energy efficiency ratio (SEER) of 19.0 and heating seasonal performance factor (HSPF) of 10.0. Heating capacities of the system at 47 °F range from 7,200 to 30,600 Btu/hr, and the cooling capacities range from 6,000 to 23,600 Btu/hr. Considering the heat pump technology is less effective under colder ambient temperatures, the system is slightly oversized to compensate. Manufacturer's manuals of the mini split system can be found in the appendices.

Although the Mitsubishi ASHP mini split system will be able to deal with the cold winters in Illinois, given the historical weather data[6] as well as the concern of more extreme weather due to climate change, a backup electric heater system has been specified for an added level of safety. The backup system will be of 5 kW capacity, with three Cadet electric baseboard heaters located in two bedrooms and the great room installed under windows.

Whole-house Ventilation

Three pairs of Lunos e2 fans will be installed in Sun Catcher to provide adequate supply of fresh air of up to 60 CFM. Lunos e2 is a decentralized, through-wall heat recovery ventilation system providing continuous ventilation without the need for ductwork. Each pair of Lunos e2 fans will be comprised of one supply fan and one exhaust fan wired together with a controller and a transformer. Within each fan there is a ceramic regenerative heat exchanger that is charged every 70 second cycle, after which the fan reverses and the incoming air absorbs the stored heat on its way in and recovers this heat. The Lunos e2 fans have a very high heat recovery efficiency of 90.6% with an extremely high fan efficacy of 3.6 CFM/W.



Three Lunos e2 ventilation fans will provide whole-house ventilation.

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[6] *NSRDB update - TMY3: Alphabetical List by State and City. (n.d.). Retrieved from http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/by_state_and_city.html*

5.2 HVAC EQUIPMENT

Local Exhaust Fans

Intermittent exhaust fans will be installed in the kitchen and bathrooms to remove air pollutants and odors generated within the building. The team has specified an Energy Star qualified range hood Broan PM300 with a very quiet 290 CFM centrifugal blower for the kitchen. Two Broan XB80 bathroom fans, which is recognized as Most Efficient of Energy Star 2015, will be installed in two bathrooms to provide 80 CFM exhausting capability. The Broan XB80 has an efficacy of 13.8 CFM/W. The range hood, Broan PME300, also has an efficacy of 2.9 CFM/W.

Air Makeup System

To avoid negative air pressure inside Sun Catcher when the range hood is operating, an air makeup system will be integrated into the range hood system. The air makeup system the team specified is the Residential Makeup Air System (RMAS) from CCB Innovations. The RMAS system consists of a motorized fresh air damper and one RMAS Switch Assembly. The RMAS Switch Assembly will sense the operation of the range hood and control the motorized fresh air damper to provide fresh, clean air to balance the pressure change in Sun Catcher.

Portable humidifiers

As discussed in Section 4: Indoor Air Quality Evaluation, additional humidification is likely to be needed occasionally during the winter. The most effective way to meet this demand is using portable humidifiers. The team has specified three Oskar humidifiers to provide adequate humidification capacity in major living spaces of Sun Catcher. These cool mist evaporative humidifiers are very energy efficient and stylish.

5.3 HVAC SYSTEM ENERGY PERFORMANCE

The overall performance of space conditioning system in Sun Catcher has been evaluated by BEopt 2.3, an hourly whole building energy simulation software dedicated for residential buildings developed by NREL. An advantage of the BEopt software is that it can model ASHP system under extremely low temperature, which enables the team to predict the heating energy consumption more accurately. The hourly heating and cooling energy consumption profile could be found in Figure 5.3.1. As expected, Sun Catcher's heating energy consumption is much more significant than the cooling consumption. The overshooting of energy consumption during the end of January is due to the use of electric baseboard heaters, as the ASHP could not function since the outdoor temperature drops below -13 °F. However, this is very occasional.

Figure 5.3.1: Hourly heating and cooling energy consumption profile

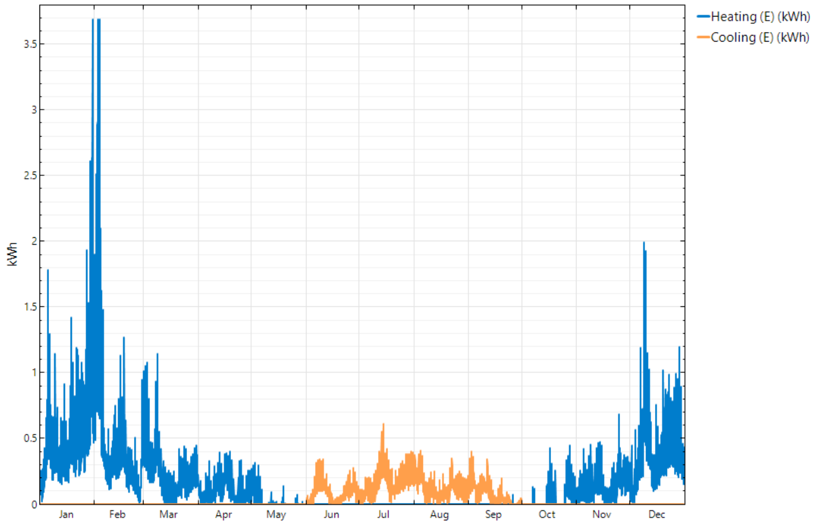
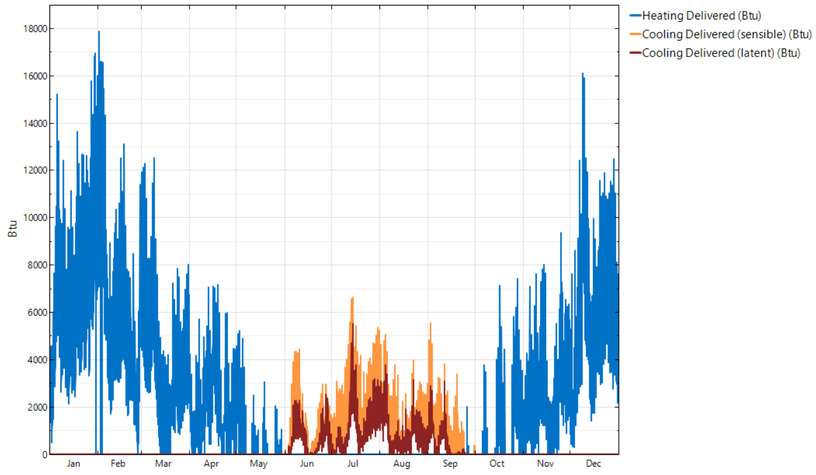


Figure 5.3.2: Hourly heating and cooling delivered



5.4 HVAC SYSTEM INSTALLATION, OPERATION & MAINTENANCE

Installation

The installation of the HVAC equipment in Sun Catcher should be done by qualified professionals according to the manufacturer's manual to ensure quality-delivery. The team has proposed installation locations for these equipment in or around Sun Catcher, as shown in Appendix CD Mechanical. Caution should be exercised to ensure the airtightness of the building, since there are a few through-wall units in HVAC System.

The mini split system should be installed according to the relevant Mitsubishi installation manual to maximize its performance. The backup electric baseboard heaters will be installed under the windows to provide the most effective heating. Digital thermostats will be installed for baseboard heaters to ensure energy efficiency and user controllability.

Operation

Each pair of the Lunos e2 ventilation fans can be set to 10 to 25 CFM to enable occupants to increase the whole-house ventilation rate up to 75 CFM for summer venting. Since the mini split system is sized primarily by heating loads, during mild summer days when cooling demand is relatively low, operable windows could be open to utilize natural ventilation to cool the building without the need for air conditioning. Every Oskar humidifier has a built-in humidistat that can automatically maintain the room humidity at desired level. The evaporation speed could be increased if very dry conditions occur. The ductwork of local exhaust fans and the air makeup system will be R8.4 insulated and be installed according to Energy Star Home standard.

The decentralized space conditioning system in Sun Catcher will provide very high degree of flexibility in terms of operation and control. The tri-zone ASHP mini split system enables occupants to have zonal thermal control in major types of spaces in Sun Catcher via wireless remote controllers with different operation modes. Each pair of the Lunos e2 ventilation fans can be set to 10 to 25 CFM to enable occupants to increase the whole-house ventilation rate up to 75 CFM for summer venting. This also provides controllability for occupants to regulate ventilation rate according to indoor activity level. All equipment specified for space conditioning in Sun Catcher have a low noise rating during operation. For complete operation and control details for the space conditioning system, refer to Appendix. Manufacturer operation manuals.

The performance of the proposed HVAC system has been evaluated by simulation. These results, including daily indoor temperature and humidity levels throughout the year, are discussed in Section 4: Indoor Air Quality.

Maintenance

Go to the appendices to view the complete HVAC maintenance plan.

6.1 ENERGY ANALYSIS METHODOLOGY

DOE Zero Energy Ready Home Performance Path

The DOE Zero Energy Ready Home Performance Path provides the Sun Catcher to assess its energy performance through RESNET-accredited Home Energy Rating Software. The team will use REM/Rate to demonstrate the energy performance of Sun Catcher, together with the evaluation of energy efficiency strategies implemented in the house.

The HERS Index of the DOE Zero Energy Ready Home Target Home is determined by configuring the Sun Catcher with the energy efficiency features of the DOE Zero Energy Ready Home Target Home as defined in Exhibits 1 and 2. This Target Home configuration has been simulated by REM/Rate, which results in a HERS rating of 51. Details of Target Home simulation results could be found in Appendix: Target Home REM/Rate.

A size modification factor is calculated using the following equation:

Size Modification Factor = $[CFA_{Benchmark\ Home} / CFA_{Home\ To\ Be\ Built}]^{0.25}$*, but not to exceed 1.0*

Where:

$CFA_{Benchmark\ Home}$ *= Conditioned Floor Area of the Benchmark Home, using Exhibit 3*

$CFA_{Home\ To\ Be\ Built}$ *= Conditioned Floor Area of the Home to be Built*

For Sun Catcher, Size Modification Factor = $(1600/1718)^{0.25} = 0.98$**.**

The HERS Index of the DOE Zero Energy Ready Home Target Home is calculated as:

DOE Zero Energy Ready Home HERS Index Target = HERS Index of DOE Zero Energy Ready Home Target Home x Size Modification Factor

HERS Index Target for Sun Catcher = $51 \times 0.98 = 49.98$

Hence Sun Catcher need to achieve a HERS Rating of less than 50 without renewable energy in order to be qualified as a DOE Zero Energy Ready Home.

Energy Efficiency Design Process

The energy efficiency design process of Sun Catcher focused on the passive building components firstly, such as walls and windows, as these are typically more difficult to retrofit in the future. The energy efficiency design process could be broken down into five steps:

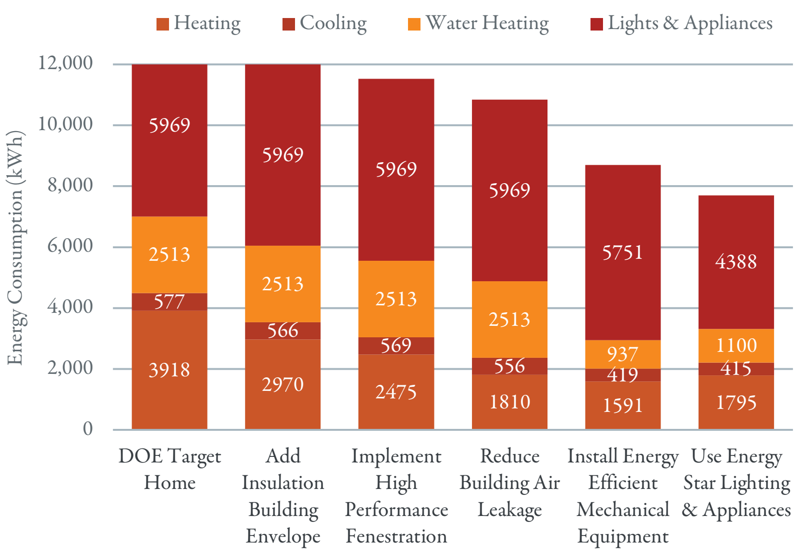
1) Add Insulation Building Envelope
2) Implement High Performance Fenestration
3) Reduce Building Air Leakage
4) Install Energy Efficient Mechanical Equipment
5) Use Energy Star Lighting & Appliances

6.2 HERS RATING

HERS Rating without PV

Figure shows the design process. By implementing all these measures, Sun Catcher will be able to achieve a HERS rating of 30 with an annual energy consumption of 7,698 kWh. Details of energy efficiency design of building envelopes, fenestration and air-tightness have been discussed in Section 3: Envelope Durability The energy performance of HVAC system has been discussed in Section 5, and lighting, domestic water and appliances will be discussed in Section 8. The appendices show the detailed energy analysis report for Sun Catcher without renewable energy and the drafted DOE Zero Energy Ready Home Certificate with HERS Rating.

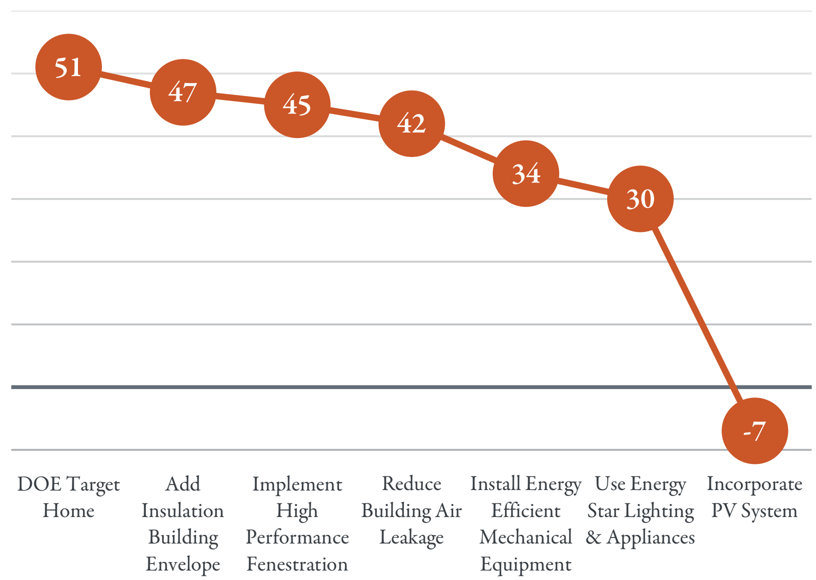
Figure 6.2.1: Energy Efficiency Design Process (REM/rate)



HERS Index Analysis with PV

By incorporating the proposed PV system into REM/Rate modelling, Sun Catcher will achieve a HERS rating of -7, with a net annual energy consumption of -1156 kWh, as shown in the Appendix. The details of the proposed PV system for Sun Catcher will be discussed further in the following part of this section. The HERS Rating of Sun Catcher throughout major energy efficiency design processes could be found in Figure 6.2.2.

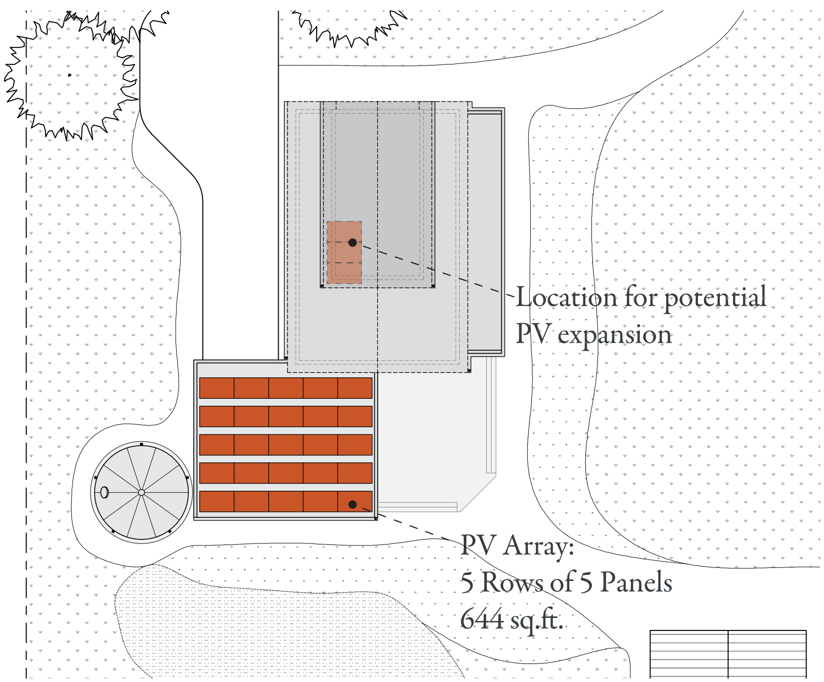
Figure 6.2.2: HERS Rating Breakdown



6.3 PHOTOVOLTAIC SYSTEM OVERVIEW

Site Analysis

When assessing the value of a new photovoltaic system, one must first address the viability of the site location. Utilization of the Renewable Energy Ready Home (RERH) Solar Site Assessment tool confirms that the Sun Catcher Cottage is in an ideal location for supporting a solar energy system with zero percent annual shading. Although the lack of external shading deems this a perfect location for photovoltaics, it also includes an East-West facing roof, which can be problematic when attempting to design an efficient photovoltaic system. Assessing this site via PVwatts reveals numerous financial incentives for installing residential photovoltaic systems.[1]



PV System Overview

To ensure the SunCatcher Cottage is photovoltaic ready, the Solar Photovoltaic RERH specifications were followed and documented in the appendices. The photovoltaic system of the Sun Catcher Cottage has been designed using System Advisor Model to achieve net-zero energy use through the integration of 25 SolarWorld SW 275 Mono modules. In order to negate the non-ideal East-West facing roof, the 6,880 kW array is located on the southern patio cover and consists of five rows of five modules covering 644.4 sq. ft.

Furthermore, the SunCatcher Cottage's integration of micro-inverters allows for a design that maintains net-zero energy despite system degradation or future addition of loads within the house; i.e. electric car, artist equipment, et cetera. In the case of an increased load the homeowner has the ability to implement additional modules along the western side of the upper roof (11.8° pitch). Although a west-facing module immediately drops roughly 15% in efficiency (per Hardt Electric), the very low pitch of that roof section makes it the most practical location for any expansion. In addition, west-facing modules would provide the opportunity to direct a portion of the excess production (291 kWh/yr./module) toward the afternoon hours; a period during which the grid can benefit from some extra production.[2] When extrapolating this concept to mass residential installs, shifting production to afternoon hours can have a significant impact.

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[1] *PVWatts Calculator. (2014, September 1). Retrieved March 11, 2015, from http://pvwatts.nrel.gov*

[2] *Fischer, B., & Harack, B. (2014, December 1). 9% of solar homes are doing something utilities love. Will others follow? Retrieved March 11, 2015, from http://blog.opower.com/2014/12/solar-homes-utilities-love/*

6.4 PHOTOVOLTAIC SYSTEM COMPONENTS

Photovoltaic Modules

The SunCatcher Cottage makes use of mono-Silicon photovoltaics. The SolarWorld SW 275 Mono-Silicon module was chosen for its superior efficiency, competitive cost, and 25-year warranty. Additional support for the implementation of mono-Silicon modules is the current market dominance and its recognition as the industry standard. More importantly, Allerton Park has an existing 16.5 kW photovoltaic system utilizing these same modules, implementation of them will provide a familiar aspect to the park's staff that will maintain the new system (per Derek Peterson). The 275W modules were chosen over 250W modules to aid in restricting the array area to the patio cover while maintaining net-zero energy.

Inverters

There are two types of inverters used in the industry today: string inverters and micro-inverters. String inverters involve conversion from AC to DC at the array level whereas micro-inverters invert current at each module and all transmission in the array is in AC. Currently, string inverters are more efficient and cost effective, but micro-inverters are quickly catching up in both these aspects. Micro-inverters are touted to be the best technology in the near future because of key inherent advantages. Using micro-inverters negates the need for cumbersome DC wiring and thus reduces transmission losses.[3] System reliability is usually higher and control, monitoring, and servicing can be conducted at the individual module level via the new Enphase Envoy monitoring system to be installed in the SunCatcher Cottage.

Given the intended use of the SunCatcher Cottage, Derek Peterson expressed great interest in the prospect of expanding the proposed system to help offset energy use elsewhere in the park. The additional modules would need to be positioned on the upper west-facing roof, in which case module-to-module optimization becomes a key factor in utilizing micro-inverters.

In the general case, the use of micro-inverters creates a hasty yet simple design process to address the cases of diverse homes around the world. The Enphase M250 micro-inverter was chosen specifically for its ease of installation, ability to monitor the system remotely, and 25-year warranty. More importantly, the Enphase M250 accepts a range of inputs (210W-300W), which allows for pairing with the SolarWorld SW 275 W module. It is important to note that the SolarEdge Power Optimizer was considered for use in this project with a complementing string inverter. However, the costs associated with expanding a string inverter system along with the cost of power optimizers for each module were not competitive enough to the costs and benefits of implementing micro-inverters. In addition, due to the discrepancies between the energy modeling software (rem/rate and BOPT), the home photovoltaic system might need to be resized after collecting data from the first year energy consumption; again, this is a very simple procedure with micro-inverters; not necessarily with string inverters.

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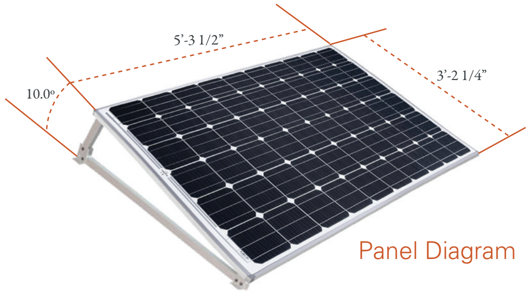
[3] *Meahlum, M. (2014, September 12). Micro-Inverters vs. Central Inverters - Energy Informative. Retrieved March 11, 2015, from http://energyinformative.org/are-solar-micro-inverters-better-than-central-inverters/*

6.5 PHOTOVOLTAIC PANEL ORIENTATION & SPACING

Tilt

The modular tilt of photovoltaic modules is a design parameter that cannot be ignored. Theoretically the optimum annual tilt angle for Monticello, IL would be a 40-degree tilt. Due to our spatial limitations on the patio cover such an angle would cause a significant amount of self-shading between rows. As a result, a lower tilt angle of 10 degrees was used for the solar array, and each module in the array was oriented in the landscape position. In addition, this low tilt angle helps to avoid the harsh wind loads associated with the location in rural Illinois. Further support for a lower tilt angle came from Hardt Electric, a local photovoltaic installer, who advised to use no more than a 15-degree tilt on all residential installs to maintain the aesthetic appeal of the home. It is for these reasons that a tilt of 10 degrees was chosen for this system. To achieve this tilt, the Unirac Solarmount racking system has been implemented.

Please note that seasonal tilt was analyzed for the SunCatcher Cottage; simulation results indicated about a five percent increase in production at the expense of a significant jump in racking costs and potential equipment failures. With this in mind, seasonal tilt was determined to be non-ideal for this location unless implementing an easily accessible ground mounted system.



Panel Diagram

Row Spacing

Row spacing is also a very important consideration when trying to negate the effects of self-shading. In order to design an efficient system we must, ideally, optimize the distance between rows such that there is no self-shading. However, since this system has a spatial limitation it is not possible to achieve an ideal distance between rows and reach net-zero energy at the same time. Based on the dimensions of the proposed patio cover, an 18" buffer zone was established around the edge of the patio cover (not required in Illinois, but generally considered a best-practice). The remaining space was optimized for 10 degree tilt spacing via the calculations shown in the appendices. It was found that there was room for a maximum distance of 1.39 meters (4'6", front of one row to the beginning of the next) between rows, leading to a ground coverage ratio of 0.71875m-1. In between each row there is 0.41m (1'4") of space, which was deemed to be an appropriate amount of room to allow for maintenance of the modules.

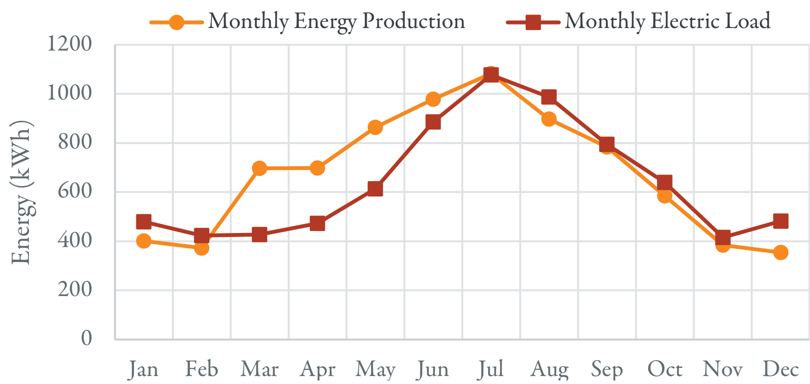
6.6 PHOTOVOLTAIC PRODUCTION ANALYSIS

The estimated annual energy demand of the SunCatcher Cottage was calculated to be 7,698 kWh/yr. (via REM/Rate). SunCatcher Cottage's solar power system is estimated to produce 7,804 kWh/yr., thus reaching the goal of net-zero energy use.

Table 6.6.1: System outputs from System Advisor Model

Metric	Value
Annual Energy	7,804 kWh
Capacity Factor	12.9%
First Year kWhAC/kWDC	1,134
Performance Ratio	0.83
Levelized COE (nominal)	8.41 ¢/kWh
Levelized COE (real)	6.48 ¢/kWh
Electricity Cost Without System	$691
Electricity Cost With System	$188
Net Saving With System	$503

Figure 6.6.1: Monthly Energy Production versus Monthly Electrical Load for Year 1



Due to the low net-metering rate in the Monticello area, the SunCatcher Cottage's photovoltaic system was sized to match the annual demand. As shown below, the SunCatcher Cottage will over produce during the early months of the year in order to compensate for the high summer load. Overall, the SunCatcher Cottage's photovoltaic system will yield an annual savings of $503. The only cost the homeowner pays the utility company is a $15.49 monthly service charge, which is reduced in December to account for net-metering credits, and a small additional fee during the first two months of the year to make up for underproduction (please refer to financial section for a more detailed cost analysis). Considering the unique occupational schedule of this home, it is ensured that the SunCatcher Cottage will consistently perform beyond net-zero standards.

Table 6.6.2: Projected Monthly Utility Bills

	Year 1 Monthly Net Metering Credit (kWh)	Year 1 Monthly Sales/ Purchases with System ($)
January	0	-20.86
February	0	-19.24
March	245.38	-15.49
April	445.19	-15.49
May	663.31	-15.49
June	719.02	-15.49
July	683.36	-15.49
August	559.43	-15.49
September	520.26	-15.49
October	446.00	-15.49
November	401.60	-15.49
December	262.18	-8.18

6.7 HOURLY WHOLE-HOUSE ENERGY SIMULATION

BEopt 2.3 Energy Simulation

In addition to REM/Rate annual energy simulation, the team also conducted an hourly whole-house energy simulation using BEopt 2.3 to obtain a more precise and comprehensive prediction of energy consumption in Sun Catcher. BEopt 2.3 is developed by NREL. It can use established simulation engine EnergyPLUS to provide hourly energy simulation result to assist building energy performance analysis.

The annual energy consumption of Sun Catcher in BEopt is different from what REM/Rate predicts, as shown in Table 6.7.1. Figure 6.7.1 shows the hourly energy consumption profile of Sun Catcher. One of the advantages of using BEopt is that it can model mini split ASHP under extremely low temperature, which is the case for Sun Catcher. Figure 6.7.2 shows that except for the winter, Sun Catcher is producing more energy than it consumes. However, the PV output prediction, which is 7,749 kWh/year, is more realistic than the REM/Rate prediction of 8,854 kWh/year.

Table 6.7.1: Energy Simulation Annual Result

Heating (kWh)	Cooling (kWh)	Hot Water (kWh)	Lighting & Appliances (kWh)	PV (kWh)
1158.9	277.7	1415.3	4125.2	7749.3

Figure 6.7.1: Hourly Energy Simulation Result from BEopt

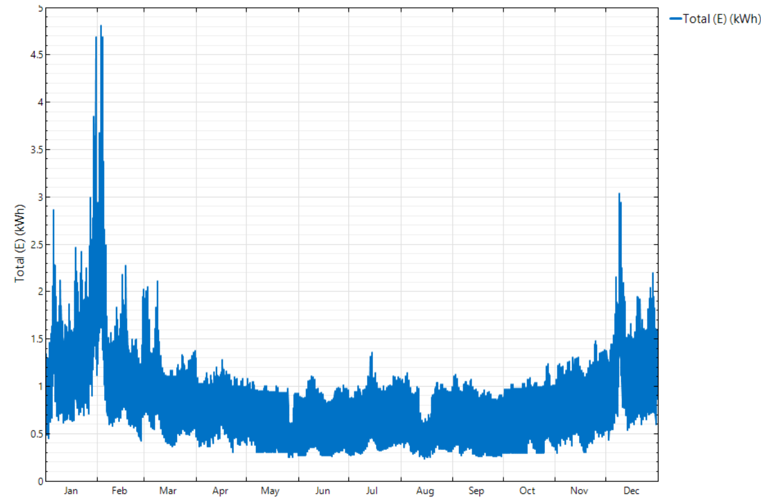
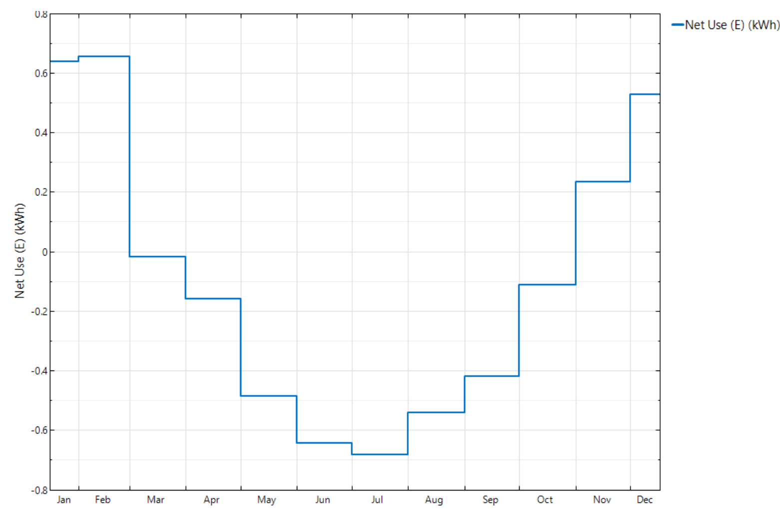


Figure 6.7.2: Monthly Net Use Result from BEopt

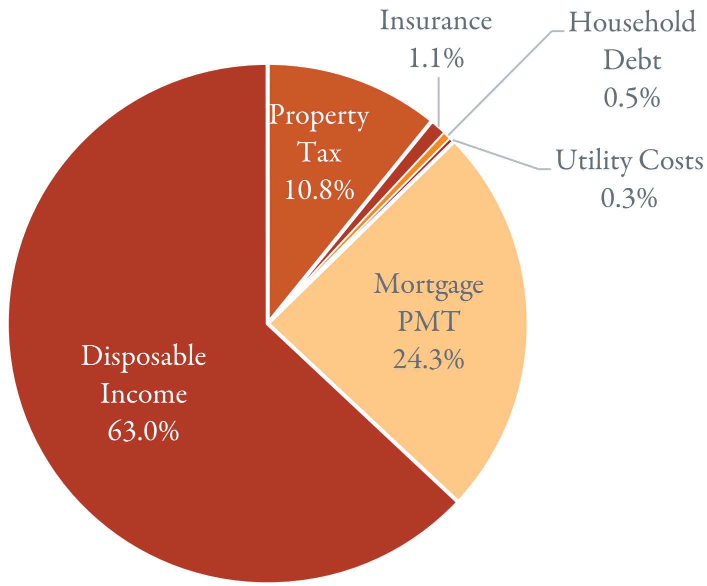


7.1 FINANCIAL OVERVIEW

The main challenge with designing and constructing a Net Zero home is whether the end price is economically feasible. Great designs are able to optimize the building's performance while remaining affordable. The main task of the FSCM sub team was to set and enforce a budget. The FSCM sub team worked closely with each sub team to ensure the project would come in under the maximum allowed budget, which was based on the median family income for the area where the home will be constructed.

By working backwards from the debt to household income ratio, the maximum budget was calculated. This approach resulted in a construction cost that could not exceed $220,000. Based off this figure, Team Illinois was able to design a home that was Net Zero and economically feasible.

While the design was tailored to Allerton Park, the end goal was to have a house that was not only an economically viable option for Allerton Park, but also a design that can be scaled nationally. The end goal is to show that a retrofit is the most environmentally friendly and economically feasible option to update millions of outdated homes across the United States.



7.2 CONSTRUCTION COST

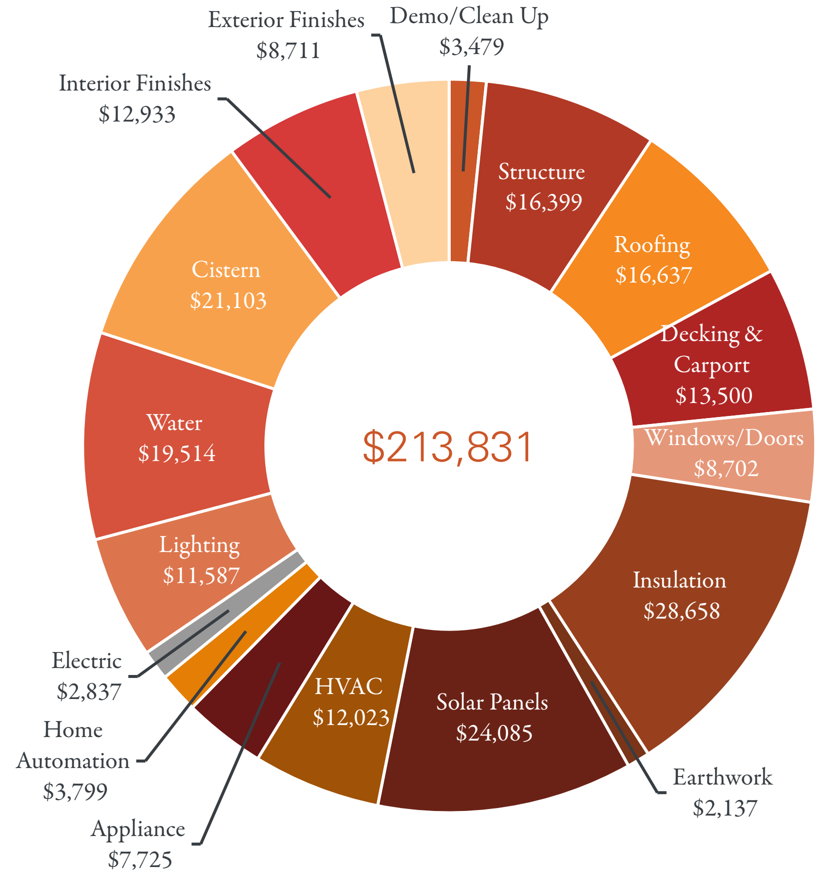
Methods for Calculating Construction Costs

The primary method for calculating construction costs was using the RS Means 2014 edition. Any cost not found in the RS Means was calculated through research or direct contact with a company to provide a quote. The cost for each item was estimated by summing the price per unit for labor, materials, and equipment, then multiplying by the quantity for that item. Labor overhead and profit were also computed based on the crew required to perform each operation. Each line item also included a location adjustment factor; Champaign, IL was used since there were no factors listed for Piatt County where Allerton Park is located.

Affordability

The total construction cost breakdown is shown to the right. As expected, a significant portion of the cost comes from insulation and finishes since the Allerton house has been unoccupied and unmaintained in recent years. A couple of the other significant line item costs that would not be found in a normal home were the solar panel and net-zero water components.

Each of these large cost items were necessary in order to reach Net Zero. The challenge when designing the house was to balance the cost and efficiency of those major items. By optimizing these major cost contributors, the total construction cost came in under budget at $213,831, meaning it will be below the maximum debt to income ratio.



7.3 FINANCIAL BREAKDOWN

Table 7.3.1: Construction Cost Breakdown

Demo/Clean Up	$3,478.97
Structure	$16,399.36
Roof	$16,636.53
Patio	$13,499.80
Windows/Doors	$8,702.31
Net Zero Water	$36,928.13
Insulation	$28,658.30
Earthwork	$2,137.42
Finishes	$21,644.79
Solar Panels	$24,085.47
Appliances/Home Automation	$15,212.94
Wiring/Lighting	$14,423.57
HVAC	$12,023.49
Total Cost	**$213,831.08**

Table 7.3.2: Median Family Income

MHI*	$6,000.00

**For Piatt County*[1]

Table 7.3.3: Loan Breakdown

Interest Rate	4.50%	
Period	30	years
Present Value	$359,984.99	
Loan Amount	$287,987.99	(20% DP)
Payment	**$1,459.19**	**monthly**

Table 7.3.4: Calculating Property Tax

Value of House	$359,984.99	
Assessment Value	$119,995.00	Approximately one-third of Value of House
Tax Rate	6.50%	Single Family Home in Monticello
Property Tax	**$7,799.67**	**yearly**

Table 7.3.5: Calculating Debt to Income Ratio

Property Tax	$649.97
Insurance	$65.00
Household Debt	$30.00
Utility Costs	$15.49
Mortgage Payment	$1,459.19
Debt to Income Ratio	**37%**

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[1] FY 2015 Income Limits Documentation System. (n.d.). Retrieved March 12, 2015, from http://www.huduser.org/portal/datasets/il/il2013/2013MedCalc.odn

7.4 SOLAR INCENTIVES

Incentives Overview

The final debt to income ratio came out to 37%. However, this ratio does not factor in the rebates and tax incentives for installing solar panels. The tables to the right show the impact these rebates and tax incentives have on the principle balance.

The federal government offers a tax rebate equaling 30% of the solar panel cost, including cost of installation.[2] The state of Illinois offers a rebate for the lowest of these three options: 25% of the project, $10,000 maximum, or $1.50/W.[3] For this project, the lowest of the three options was 25% of the project. Finally the utility company, Ameren Illinois, offers a rebate for residential efficiency topping out at $2,400.[4] The Sun Catcher Cottage qualifies for the whole $2,400.

Table 7.4.1: Photovoltaic Incentives

PV State	$6,338
PV Federal	$7,605
Utilities	$2,400
Total	**$16,344**

[2] *Residential Renewable Energy Tax Credit. (2015, February 16). Retrieved March 12, 2015, from http://programs.dsireusa.org/system/program/detail/1235*

[3] *Solar and Wind Energy Rebate Program. (n.d.). Retrieved March 12, 2015, from https://www.illinois.gov/dceo/whyillinois/KeyIndustries/Energy/Pages/01-RERP.aspx*

[4] *Ameren Illinois (Electric) - Residential Energy Efficiency Incentives. (2014, October 14). Retrieved March 12, 2015, from http://programs.dsireusa.org/system/program/detail/3171*

Impact of Incentives on Principal

The reduction in principle assumes the owner receives the state and utility rebate at the beginning of year two. The owner pays the entirety of these rebates along with the 30% tax break as the thirteenth payment. This results in a significant reduction in the remaining principle on the loan. If the owner continues to pay the same payment as before, the mortgage will be paid off about forty months early. The owner can also choose to refinance in order to have a lower monthly payment; however, there are fees that come with refinancing and there is no guarantee they will be able to receive the same 4.5% interest rate. The new monthly payment was calculated using 4.5% as the interest rate.

Table 7.4.2: Impact of Incentives on Principal

Present Value After Year One	$283,342
Subtract Incentives	$16,344
New Present Value	$266,997
Number of Remaining Mortgage Payments	309.5
New Monthly Payment if Refinanced	**$1,375**
Debt-to-Income Ratio if Refinanced	**36%**

7.5 THE BUSINESS CASE FOR ENERGY EFFICIENT RETROFITS

In the United States there are 83,392,000 single-family homes with a median age of 35 years old. According to a 2009 U.S. Department of Energy survey, homes built prior to the 1970s oil embargo consume roughly a third more energy than homes built in the 2000s. Since 22% of the United States energy consumption coming from homes and the vast majority of homes are underperforming, there is a massive opportunity to improve home efficiency through retrofits and decrease the overall energy consumption in the United States.

In 2006, the total home equity in the United States was $13 trillion, or roughly $170,000 per homeowner. Following the housing market crash, the 2011 equity total was just $6.5 trillion or roughly $87,000 per homeowner. Owners became more cautious with what they were investing in their home because homes were no longer inevitably going rise in price. In 2006, home improvement costs were roughly 37% of homeowner expenditures and in 2012 that number fell to 26%.[5] The new necessity in homes was to receive a more tangible "return" on investment in order to justify spending money. Luckily for sustainable practices and technologies, improving home efficiency has clear and quantitative results, which is why between 2005 and 2012, money spent on replacing or upgrading systems jumped 10% with a dollar amount of $2 billion even during the economic downturn.

Now is the time to push for a massive retrofit of United States homes. Rising population in urban areas, massive energy demands and the neglect of millions of homes are all reasons to renovate the aging home population. Inadequate home totals have increased by 7% since 2007 and a vast majority of homes are not up to modern efficiency standards. The solution is not as simple as demolishing and rebuilding the current stock of homes. According to the Environmental Protection Agency (EPA), the average waste generated by demoing a home is 50 lb/sf where as the average waste generated by renovating a home is only 24.05 lb/sf Demand for housing options in urban areas will also continue to rise as more than the current 80.7% of Americans will move into urban areas in the coming years.[6] New construction typically takes 6 months to complete whereas the deep retrofit of the Sun Catcher Cottage would take approximately three months; therefore, time also favors the renovation of existing homes.

Advancements in organizational techniques and operations within the renovation industry are necessary for the future success of the United States housing stock. Compared to single-family homebuilders, contractors serving in the renovation industry were at a much higher risk. In 2007, before the recession, more than two-thirds of all remodeling companies were self-employed and less than half posted annual revenues above $250,000 – for single-family contractors, nearly 85 percent were earning more than $250,000.[7] To emphasize how divided out the industry was, the top 50 general remodeling companies generated less that 8 percent of total industry revenue. Looking back, the remodeling industry should have know that more than 25% would fold in the recession due to low revenue streams.

Fortunately, 2015 presents an opportunity for the industry. According the Metrostudy Residential Remodeling Index (RRI), the winter of 2015 marked a 97.2 percent on the RRI, which is the highest it has been since the remodeling market peaked back in 2007 at 97.2 percent also. Predictions say a full recovery is expected by the third quarter of this year.

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[5] *The US Housing Stock Ready for Renewal. (n.d.). Retrieved from http://www.jchs.harvard.edu/sites/jchs.harvard.edu/files/harvard_jchs_remodeling_report_2013.pdf*

[6] *World Urbanization Prospects. (n.d.). Retrieved from http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pd*

[7] *Energy Efficient Business Case for Energy Efficient Building Retrofit and Renovation. (n.d.). Retrieved from http://energy.gov/sites/prod/files/2013/12/f5/business_case_for_energy_efficiency_retrofit_renovation_smr_2011.pdf*

7.6 ALLERTON PARK'S SUNCATCHER COTTAGE BUSINESS PLAN

Sun Catcher Cottage will be operated as an Artist in Residence accommodation for four months of each year, during non-peak season at Allerton. This home will be developed with 2 bedrooms and a loft, useable by Artists with a family, or even two artists at once. By using this home for an Artist in Residence program during non-peak season, Allerton can offer housing for a valuable program at very little cost, as well as use the lodging space efficiently.

During peak lodging months at Allerton the cottage will be used as a transient-style home, vacation home, or overflow lodging for the Retreat Center. Having the Sun Catcher Cottage will expand Allerton's lodging capacity and design. Allerton does not currently offer weekly vacation rentals, nor does it offer accommodations with kitchens and outdoor space. The added factor of being a net-zero solar home will add value and attraction as a lodging space. Allerton will also offer the option of smaller meetings or gatherings in the home.

Other comparable sites offer 3 bedroom homes from $150-$220/night. The following Sun Catcher Cottage budget is based on a rate of $175/night. Allerton generally operates at 40% occupancy during peak season; however, this budget is based on 30% peak season occupancy.

Based on an interest rate of 2% and only considering the construction costs, Allerton Park will begin making a profit after the 33rd year of operation. While this might seem like an extraordinary long payback period, the period of usefulness is technically as long as the University remains in operation since the cottage is owned by the University. Therefore it is a worthwhile endeavor for Allerton Park to undertake.

Table 7.6.1: Sun Catcher Cottage Projected Budget

	Artist in Residency Program (off season)	**Reservable Space (peak season)**
Months/Year	4	8
Occupancy	100% (2 artists)	30% projected
Lodging Income	N/A	$12,600 240 days at 30%; 72 overnights at $175/night
Lodging Expenditures	$1,200 25% of lodging expenses	$5,000 40% of income
Net Income Lodging	($1,200)	$7,600
Conference Income	-	$3,500 20 conferences/gatherings at $175
Conference Expenitures	-	$1,400 40% of income
Net Income Conferences	-	$2,100
Annual Net Income	**$8,500**	

Note: this budget does not include energy sold to the energy provider, Ameren. It is not included in this budget because the amount per year is relatively small and variable due to weather. Over time, combined with cost savings due to no electricity bill, this amount will be significant.

8.1 DOMESTIC HOT WATER DISTRIBUTION SYSTEM

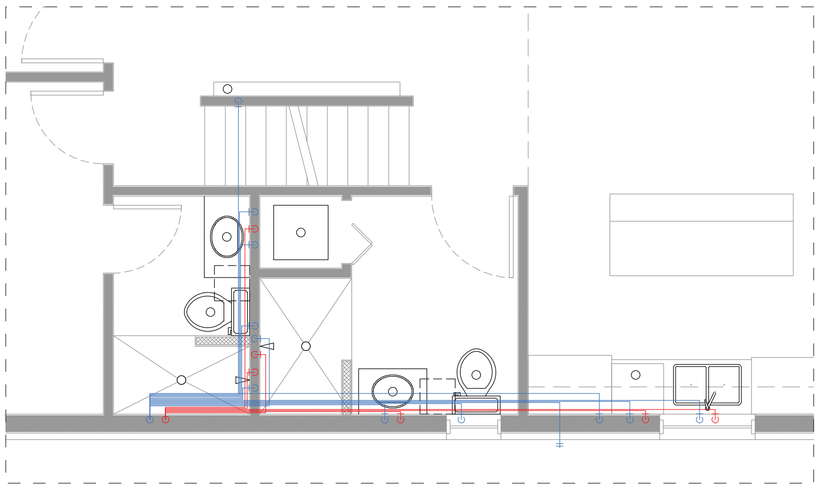
Design Strategies Employed

From the beginning of the design process, various strategies were implemented to create the most energy-efficient hot water distribution system possible. When developing the layout of the home, all fixtures that require hot water were located entirely on one side of the home in close proximity to the water heater. This allowed for the shortest possible travel distance, and minimized the energy required to distribute the hot water along lengthy runs. Also, shorter hot water runs store less hot water in the pipe and reduce stand-by losses.

The domestic hot water system is comprised of cross-linked polyethylene piping (PEX), an alternative to traditional copper or PVC piping. A whole-home PEX manifold system was designed to run a separate line to each fixture. Due to its flexible nature, PEX can sweep around obstructions and eliminate the need for sharp elbows and fittings, thereby reducing friction losses. Also, because PEX comes in long continuous coils, there is no need for joints, eliminating any solvent, chemical, or solder joining. To ensure minimal heat loss throughout the system, R-4 insulation was specified along all hot water runs. To minimize water use and demand, all fixtures are WaterSense labeled and all appliances are ENERGY STAR certified. In general, using PEX, in combination with the above strategies, will enable quicker and more efficient hot water delivery than conventional rigid metal piping systems.[1]

1. Design Guide: Residential PEX Water Supply Plumbing System. (2006, November 1). Retrieved from http://www.huduser.org/portal/publications/pex_design_guide.pdf

To capture heat from discarded hot water, a gravity-film heat exchanger (GFX) will be installed. Hot water from both the shower drains as well as the clothes washer will pass through the GFX assembly, which extracts heat out of the drainwater and transfers it to incoming cold water. The GFX is particularly efficient during events where the need for hot water coincides with the generation of waste heat, which is why it is installed on the shower and clothes washer drains. Showers and laundry account for nearly 65% of domestic hot water use, thus the installation of a GFX system can produce energy savings from 30-45%.[2]



Domestic Hot Water Distribution Layout.

2. Heat Recovery from Wastewater Using Gravity-Film Heat Exchanger. (2001, May 1). Retrieved from http://gfxtechnology.com/Femp.pdf

8.1 DOMESTIC HOT WATER DISTRIBUTION SYSTEM

System Performance and Loads

The efficiency of a hot water distribution system depends on the estimated wait time, as well as the volume of water sitting in the pipe at any given moment. The longest estimated wait time for hot water is the kitchen sink is 5.58 seconds, which is well within the acceptable performance range.[3] The dishwasher has the highest volume of hot water stored in a single PEX run at 0.210 gallons, well below the maximum 0.5 gallons required by WaterSense. These metrics indicate that the distribution system will operate efficiently, and deliver hot water on time while minimizing losses. Below is a table summarizing the estimated wait times, length of each hot water run, volume of water in each pipe, and required supply flow rates and velocities.

Table 8.1.1: Domestic Hot Water Distrubution System Performance

Fixture	Fixture Type	Min Pipe Diameter (in)	HW Run (ft)	Vol. in Pipe (oz)	Vol. in Pipe (gal)	Fixture Max Flow Rate (gpm)	Min Estimated Wait Time (s)	Supply Flow Rate (gpm)	Supply Velocity (ft/s)
Main line w/9 port manifold	-	3/4	5.00	26.73	0.210	-	-	-	-
Single Basin Sink w/ Faucet	F2	1/2	9.75	11.51	0.090	1.5	3.60	2.2	3.59
Single Basin Sink w/ Faucet	F3	1/2	10.25	12.10	0.095	1.5	3.78	2.2	3.59
Shower Head	F4	1/2	6.42	7.57	0.059	2.0	1.79	2.0	3.27
Shower Head	F4	1/2	5.00	5.90	0.046	2.0	1.38	1.8	2.94
Double Basin Sink w/ Faucet	F5	1/2	21.58	25.47	0.199	2.2	5.58	1.8	2.94
Dishwasher	F6	1/2	19.00	22.42	0.175	-	-	-	-
Clothes Washer	F9	1/2	11.50	13.57	0.106	-	-	-	-

Due to the unique use of the home, there will be high variability in daily water usage as the occupants rotate in and out of residency. The NREL tool for generating realistic hot water events was used as an estimation method for potential hours of peak demand and loads.[4] For a 2-bedroom home in the Central Illinois Bloomington-Normal area, the maximum monthly average hot water demand was 134.68 gallons. There were two peak windows of demand: 25.4% of hot water used between 8am and 12pm, and 21.0% between the hours of 4pm and 8pm. These realistic load estimations were taken into account when choosing the hot water equipment.

[3] *Domestic Water Heating Design Manual – 2nd Edition, ASPE, 2003, page 234*
[4] *NREL, Tool for Generating Realistic Residential Hot Water Event Schedules. www.nrel.gov/docs/fy10osti/47685.pdf*

8.2 DOMESTIC HOT WATER HEATER

Heat Pump Water Heater

Currently, two of the most sustainable domestic hot water heater options are solar hot water collection and heat pump water heaters. While both systems eliminate the need for natural gas, direct solar-powered systems have a relatively constant need for clear skies and sunlight in order to heat the water, which becomes an issue in the winter. In a Midwest climate, heat pump water heaters provide the most consistent source of water temperature on an annual basis, while saving a considerable amount of energy. Heat pump water heaters utilize basic thermodynamic principles to produce high coefficients of performance while minimizing energy usage. While a heat pump water heater may cost more upfront than a solar thermal system, it is an all-in-one unit, making it easier to install and maintain.

The Whirlpool 50-gallon Hybrid Water Heater has an energy factor of 2.75, highest in its price range, and it is an ENERGY STAR qualified appliance. Additionally, the hybrid water heater can operate on several different modes: efficient, hybrid, electric, and vacation, which makes it very well suited for the periodic residency schedule of the Sun Catcher Cottage.

Whirlpool 50-gallon Hybrid Water Heater.

Table 8.2.1: Heat Pump Water Heater Technical Specificiations

Family Size	Gallons	Width	Height	EF: Efficiency	EF: Hybrid	EF: Electric	1st HR Rating/Gal Efficiency	1st HR Rating/Gal Hybrid	Annual Cost
3-4	50	22”	63”	2.78	2.75	0.83	42.1	67.5	$192

8.3 WATERSENSE

Compliance with WaterSense Specifications

- All fixtures in the bathroom, including faucets and showerheads, as well as the kitchen sink are WaterSense labeled.
- Both the dishwasher and clothes washer are ENERGY STAR certified appliances.
- The maximum volume of water stored in any pipe or manifold is 0.21 gallons, which occurred in the main line feeding the manifold from the water heater. This is well below the minimum required 0.5 gallons.
- Greater than 75% of the landscape will be native grasses and adaptive plants, eliminating the need for an irrigation system that uses additional water. All irrigation will be supplied from a greywater drip irrigation system.
- The use of PEX will help achieve the “no leak” inspection requirement, as the use of flexible tubing to bend around obstructions eliminates the need for additional fittings and joints and potential for leaky connections.

Homeowner Water Conservation Best Practices

In addition to meeting all WaterSense requirements, the following best practices can help the homeowner conserve additional water:

- Reduce showering time
- Turn off faucets when not in direct use (i.e. Brushing teeth, washing dishes)
- Wash clothes only on a full load
- Soak pots and pans instead of running water over them while scraping food off
- Wash fruits and veggies in a container instead of under running tap
- Empty unused water from glasses/pitchers onto plants
- Keep a pitcher of cold water in the refrigerator instead of running water from tap until it’s cold
- Don’t use running water to thaw frozen food; place it in fridge to thaw
- Rinse razor in cup rather than running under faucet to rinse after shaving
- Use a reusable water bottle rather than buying plastic ones (it takes more water to make the bottle)
- Do not pre-rinse dishes before putting in dishwasher
- Only run dishwasher on full load
- Capture water from faucets while waiting for it to get hot and use it to water plants
- Water plants before sunrise or after sunset to reduce loss to evaporation

8.4 NET-ZERO WATER

Achieving Net-Zero Water

To reach net-zero water, rainwater will be captured off of cottage and patio roof, immediately pre-treated, and stored in an on-site cistern. A post-mounted first-flush diverter will divert the first 26 gallons of rainwater away from the cistern, and the Graf Optimax Pro self-cleaning filter will be installed for water to pass through before entering the cistern.

When rainfall is insufficient to meet household demand, water pumped from a deep well will be pumped in to supplement captured rainwater. Stored water from the cistern will be pumped into the home, immediately treated to potable standards, and stored in a pressurized storage tank. The point-of-entry filtration system consists of a sand filter, 20 micron, 5 micron, and activated carbon filters, as well as the Sterilight Platinum SPV-740 UV System, rated NSF Class A at a 40 mJ/cm2 dose for disinfection.

Water entering through the home passing through the UV treatment system will supply the kitchen sink, dishwasher, clothes washer, bathroom faucets, and shower. Greywater from the clothes washer, showers, and bathroom sinks will pass through a filter and released via a Flotender Greywater drip irrigation system. Additionally, a AQUS sink-to-toilet system will pump filtered sink water into the toilet tank to reduce potable water use by an estimated 5,000 gallons annually, for a bathroom serving two people.

During a storm event with high amounts of rainfall, an overflow spout will run from the cistern pre-filter as well as from the top of the cistern to the septic field to avoid flooding and overflow. Any stormwater not captured and stored in the cistern will be managed on-site through infiltration through a rain garden, and runoff will be controlled by a landscape dominated by native plants and grasses.

Why is Net-Zero Water Important?

Creating a self-sustaining home that does not rely on public water supply is becoming increasingly important, especially considering the increased potential for water supply shortages due to climate change and increasing populations. Rainwater is a very clean source of water that is highly underutilized, and by capturing and using this water on-site it reduces runoff, prevents sediment transport, and reduces demand for well water, keeping the ground water levels sustained. Team Illinois has been engaging in conversation with the Illinois Department of Public Health regarding state guidelines and requirements for on-site rainwater capture and use. When the Sun Catcher is granted a conditional permit, it will be a very early adopter of water reuse technology in Illinois, which will serve as a model for other homes wishing to install a similar system.

8.5 APPLIANCE OVERVIEW

Appliance Selection

The appliances of the Sun Catcher Cottage were selected to both suit the general design case: a family of three or four; and the intented usage of the cottage for the Artists in Residency program and temporary occupants. Team Illinois chose the most energy efficient appliances possible while still maintaining an economical budget. The refrigerator, dishwasher, clothes washer and dryer are all ENERGY STAR certified.

The capacity of the appliances are kept to a minimum, but large enough to the demands of the cottage's intented occupants. An induction cooktop with two burners and a microwave convection oven will better satisfy cooking needs than a six-burner range with full-capacity oven. The dishwasher can occupy up to fifteen place settings which is more than enough to handle the dishes and kitchen tools of the residents. For the washer, Team Illinois chose a smaller size of 4.1 cubic feet. The conservative size of 9.9 cubic feet was chosen for the refrigerator.

Appliance List

Appliance	Cost	Brand	Energy Consumption
Refrigerator	$509	Frigidaire Top Freezer Apartment Size Refrigerator	416 kWh
Dishwasher	$500	Samsung 24" Built-in Dishwasher	106 kWh
Induction Cooktop	$649	Summit SINC2220 (2 Burner Built In)	354 kWh *equation calculates for cooking, a combination of range and oven
Microwave Convection Oven	$540	GE Profile™ Series 1.7 cu. ft. Over-the-Range Microwave Oven w/ Convection	-
Clothes Washer	$850	Whirlpool® Duet® 4.1 cu. ft. Front Load Washer	143 kWh
Clothes Dryer	$1,799	7.3 cu. ft. HybridCare™ Duet Dryer with Heat Pump Technology	796 kWh
Total	**$4,847**		**1,814 kWh**

8.6 APPLIANCE BREAKDOWN

Heat Pump Clothes Dryer
Included in the Sun Catcher Cottage is the Whirlpool HybridCare Duet Dryer with Heat Pump Technology. Heat pumps dryers work by utilizing two closed loop systems. The first loop is for drying the laundry, and the second loop contains a refrigerant and is responsible for heating the processed air. Heat pumps dryers work by circulating air, so an added benefit is that no ducts or vents are needed for installation. Whirlpool's HybridCare Duet Dryer is exceptionally eco-friendly and has three modes; Speed, Eco, and Balanced. Speed mode decreases the time it takes to complete a cycle, but uses the most energy. Eco mode takes a longer time to finish drying, but uses the least amount of energy. Balanced mode is a combination of speed and efficiency. Whirlpool estimates that the HybridCare Duet Dryer will consume 40% less energy than the standard dryer.[5]

Clothes Washer
The Whirlpool Duet Washer features advanced water and energy saving techniques such as automatic load size detection and regulated water levels. The washer also employs a direct drive motor which uses fewer moving parts. As a result, the appliance's life span is increased.

Convection Microwave Oven
The GE Profile Series over-the-range convection microwave oven combines three ovens functions into one unit to provide cooking versatility. There is a convection cooking mode for even baking all around, a fast bake mode that combines both convection and microwave cooking, and a warming mode that can keep foods at a desired temperature until the user is ready to eat.[6] Sensor cooking controls automatically adjust the remaining time and power needed to finish cooking. With its powerful features and compact design, the convection microwave oven is an energy efficient alternative to a traditional oven.

Induction Cooktop
The Summit SINC2220 12" induction cooktop provides two cooking zones. Schott Ceran glass panel and touch sensor controls allow for easy and comfortable use of the appliance. This method reduces the cooking time and energy consumption of conventional electric smooth-tops or coil elements. This cooktop also has safety features such a child lock, an automatic safety switch-off and a residual heat indicator.

Refrigerator
The Frigidaire refrigerator was chosen due to its sufficient storage and energy efficiency rating. Additionally, the refrigerator satisfies the Americans with Disabilities Act (ADA) Standards which implies that it is accessible to people with disabilities.

Dishwasher
The Samsung built-in dishwasher Team Illinois has chosen is Consortium for Energy Efficiency (CEE) qualified. This product satisfies the requirement based on the Commercial Kitchen Initiative developed by CEE. The washer has also met the required idle energy rate and water consumption requirements.

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[5] *Whirlpool® HybridCare™ Clothes Dryer Earns 2014 ENERGY STAR Emerging Technology Award. (n.d.). Retrieved March 19, 2015, from http://www.whirlpoolcorp.com/whirlpool-hybridcare-clothes-dryer-earns-2014-energy-star-emerging-technology-award/*

[6] *GE Profile™ Series 1.7 cu. ft. Over-the-Range Microwave Oven w/ Convection - Stainless Steel. (n.d.). Retrieved March 15, 2015, from http://www.sears.com/ge-profile-8482-series-1.7-cu-ft-over-the/p-02281063000P?prdNo=4&blockNo=4&blockType=G4*

8.7 LIGHTING

Lighting Selection

Several factors were taken into account when determining the lighting needs of the cottage. Needless to say, to meet a net zero goal, energy consumption played a big role in Team Illinois' decision. Environmental impact, total cost over the lifetime of the bulbs, special features such dimmability, ease of use, and thermal emissions were also taken into consideration. Pursuing LEDs for the Sun Catcher Cottage was not only be the most energy efficient option but will also have numerous other benefits. LEDs are the most cost efficient option and will not introduce harmful substances such as mercury into the environment. Furthermore, they contribute the smallest thermal load and turn on without delay.

The cottage's primary audience will be artists-in-residence. Therefore, consistent lighting is of high priority. To achieve such lighting a Z-Wave compatible wireless light sensor, is placed within the room where the artist may work. This enables the artist-in-residence to set a desired light level and as the exterior light contribution changes the LEDs will compensate accordingly. This is just one example of several potential lighting schemes available at the Sun Catcher Cottage.

Lighting Design

When determining the quantity of lights required, each room was calculated separately. Team Illinois considered the type of room in question, whether it was a bedroom, kitchen, hallway, closet or bathroom and determined the maximum lighting that will ever be necessary in each location. Since the cottage utilizes dimmable LEDs, as long as the maximum lumen requirement is met for each room, a comfortable lighting level can be selected by the residents.

While standard omnidirectional LED bulbs are capable of providing sufficient and consistent lighting for open rooms, different scenarios call for different levels of lighting, size of bulbs, and varying degrees of beam spread. With this in mind, Team Illinois chose to integrate Molex Transcend, a versatile lighting module (VLM). VLMs are low profile and low voltage LED modules which magnetically cling to a preset track. This energy efficient lighting device proves useful not only in situations where there are space constraints such as over the kitchen counter but also in scenarios where one may desire to alter the color, beam spread or location of a light. Swapping out or moving a module is as easy as peeling off or sliding a magnet. Since Team Illinois' chose to integrate track lighting into the cottage, current limiting devices were put in place to ensure no rail exceeds 2 Watts per linear foot.

8.8 HOME AUTOMATION

Home Automation Selection

The purpose of Team Illinois' home automation system was to accomplish a variety of goals. First and foremost, Team Illinois wanted the user to gain the necessary understanding and control to act in an energy efficient manner. In order to make energy conscious decisions, the user must be fully familiar with the home's energy consumption. This involves energy consumption feedback from major energy loads throughout the home. Equipping the home automation system with sufficient control, such as remotely activated outlets allows the user to better parallel the home's energy consumption with the user's energy needs. Another vital goal is user friendliness. Due to the artisans' short stays, it is imperative that ease of operation is maximized so the user can begin using the house in an energy efficient manner as soon as possible.

Home Automation Design

Team Illinois chose the Home Automation system VeraEdge to accomplish its goals. This system consists of one central device that coordinates the communication between various sensors and controllers. The VeraEdge utilizes Z-Wave as its mode of communication with the other devices in the home automation system. This system is easily accessed by a smartphone app that is compatible with iOS and thus will be controlled by an iPad Mini. The thermostat can be programmed to adjust the temperature based on the weather outside, or cool/heat the home for a period of time before the user arrives home. The energy outlet monitors provide feedback about the energy consumption of major loads to direct the user towards the best places to reduce energy consumption. The light sensor can measure the natural sunlight in a room to help determine the minimum amount of artificial light necessary to maintain adequate brightness.

Another important device employed in this home automation system is the Alima Air Monitor. This air monitor includes one device that evaluates the air quality for an entire house. This device measures carbon dioxide, carbon monoxide, volatile organic compounds and particulate matter. The information compiled by this device is neatly displayed by an app that will be accessible on the home's iPad mini.

Home Automation Devices

Device	Function	Cost
Apple iPad Mini	Home Automation Controller	$249
Alima	Air Quality Monitor	$193
VeraEdge	Home Automation Brain	$150
Z-WAVE Programmable Thermostat ZTS-110	Thermostat	$80
KWIKSET Push Button Level Lock	Automatic Door Lock	$250
SmartSwitch	Energy Consumption Monitor	$60
Evolve LMR-AS	Wirelessly Controllable Wall Switch	$90
Multisensor	Light, Motion, Temperature and Humidity Sensor	$45
Linear WO15Z-1 Wireless Z-Wave Wall Mounted Outlet	Wireless Wall Mounted Outlet	$34
Everspring Z-Wave Smoke Detector	Smoke Detector	$50

9.1 ARCHITECTURAL INDUSTRY PARTNERSHIPS

Skidmore, Owings & Merrill LLP

As one of the largest and most influential architecture, interior design, engineering, and urban planning firms in the world, Skidmore, Owings & Merrill LLP (SOM) was incredibly valuable as an Industry Partner. Team Illinois' primary contact as SOM was Luke Leung, Director of Sustainable Engineering. Team Illinois members went to their Chicago office twice: during the conceptual design phase, and for final review. Through face-to-face interaction as well as email coorespondence, Team Illinois received guidance and advice on the project. SOM reviewed not only the construction documents, but the submission paper to provide holistic as well as specific feedback.

Team Illinois at Skidmore, Owings & Merrill in Chicago for final review of the Race to Zero project.

U.S. General Services Administration

Team Illinois' contact at the GSA was Fred Yonke, Project Architecture in the Customer Project Service and Leasing Division. Fred provided architectural review support throughout the project. Team Illinois received quality control comments on construction drawings from Fred prior to final reviews with SOM.

Kennedy Hutson Associates

As the architectural advisor for Allerton Park and Visiting Assistant Professor at the Illinois School of Architecture, Kennedy Hutson acted as an architectural advisor for Team Illinois. He met with the team during the schematic design phase to provide feedback, and continued to provide advice throughout the duration of the project. Kennedy aided Team Illinois in layout decisions as well as general aesthetics and strategies for the building in the context of Allerton Park and vernacular styles.

RATIO Architects

Having developed the Allerton Master Plan, Team Illinois received knowledge of the direction and planning for the park in terms of the built environment and sustainability goals.

9.2 ENGINEERING INDUSTRY PARTNERSHIPS

Skidmore, Owings & Merrill LLP

SOM's mechanical, electrical, and plumbing engineers reviewed Team Illinois' engineering construction documents, and provided feedback on the various building systems chosen. Advice from SOM resulted in a redesign of the mechanical system and the integration of more energy-saving features in the domestic hot water and rainwater collection systems.

Hardt Electric, Inc.

Chicago-based electrical contractor Hardt Electric, Inc was responsible for design and installation of the exisiting ground-mounted photovoltaic arrays at Allerton Park, and was a very valuable industry partner for Team Illinois' PV subteam. Hardt Electric provided recommendations and advice throughout the project including: tilt angle on residential installs, builder best practices, wind load considerations, and much more. Most noteworthy, collaboration with Hardt Electric provided insight into the logistics and practicality of implementing a residential PV system; an aspect not generally covered in college courses.

Allerton Park and Retreat Center

Allerton Park, specifically Associate Director Derek Peterson, advised Team Illinois on all portions of the design. Team Illinois worked hand-in-hand with Allerton Park to develop the Sun Catcher Cottage retrofit to fit with the objectives of Allerton Park. Derek frequently attended weekly project team meetings, introduced us to industry partners that had worked with Allerton Park, and helped lead site visits to the existing cottage.

Newell Instruments

Ty Newell, Vice President of Newell Instruments and Professor Emeritus of the Department of Mechanical and Industrial Engineering at Illinois, was a valuable advisor for Team Illinois. Having developed Newell Instruments as an engineering research, development, and design firm specializing in sustainable building systems, he provided Team Illinois with general design considerations. Additionally, Ty was a key advisor for Team Illinois' water subteam in their efforts towards designing a net-zero water system and getting it through the approval process with the Illinois Department of Public Health (IDPH). Ty also took Team Illinois on a tour of his passive house, Equinox House, and shared his experiences as the owner of a high-performance home.

Team Illinois touring Ty Newell's Passive House, Equinox House, in Urbana, Illinois.