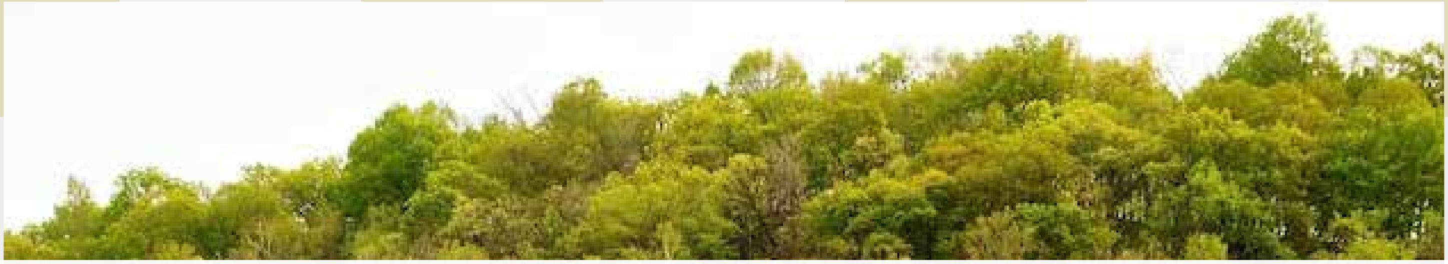

Heritage Homes:

High Performance Living in Harmony with Community

Volume I

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Volume I

Volume II

Heritage Homes: High performance Homes in Harmony with community

H4: Heritage Homes

Project Summary

In late 2014 Penn State's Architecture and Engineering departments joined with the State College Community Land Trust to design an affordable, owner-occupied, high-performance duplex in the Borough of State College, the host municipality of Penn State.

Relevance of Project to the Goals of the Competition

The State College Community Land Trust approached Penn State University with the interest of designing an affordable housing duplex in the State College community. The affordability, size and price of house all fit with the parameters of the competition, and strive to inspire and develop the next generation of residential design and high-performance living in our community.

Design Strategy and Key Points

Throughout the design process, the Race to Zero team carefully balanced the needs of three stakeholders: 1) the Race to Zero competition requirements, 2) the State College Community Land Trust, and 3) the Race to Zero competition team in a whole systems building approach.

Project Data

- Location: 1394 University Drive, State College, PA 16801
- Climate Zone: 5
- Square Footage: 1,440 ft2 per duplex (2,880 ft2 total)
- Number of bedrooms: 3 per duplex
- Number of bathrooms: 2 full bathrooms per duplex
- Number of stories: 1 story with full basement per duplex
- HERS score without PV: 39
- HERS score with PV: -3
- Estimated monthly energy cost without PV: $78.96 @ $0.12 per kWh
  Estimated monthly energy cost with PV: - $1.70 @ $0.12 per kWh

Technical Specifications

- Walls Effective R-value =29
- Foundation Wall Effective R-value = 23
- Slab Insulation = R-10
- Roof Insulation = R-60
- Window Performance
  - South & East Windows: U=0.29, SHGC = 0.500
  - North & West Windows: U=0.24, SHGC = 0.260
- HVAC specifications
  - Heating/Cooling/Ventilation:
    - Basement and First Floor Bedroom: (1) ¾ ton, 24 SEER, 13 HSPF ducted Mini Split Heat Pump,
    - First Floor Main Space: (1) ¾ ton, 33 SEER, 14.2 HSPF wall mounted Mini Split Heat Pump
  - Water Heating: 50 gallon heat pump water heater
    - 3.1 EF

01 // Team Qualifications

Student Leaders

Kyle Macht LEED AP

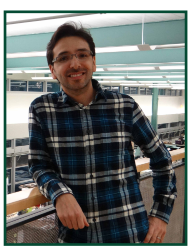
Team Leader
M. Arch Student, M. Architecture Engineering , B. Architecture Engineering.
HERS Rater, Energy Consultant and Home Designer/Builder 5 years.

Chauntel Duriez

Marketing Coordinator
Architecture Master Student, B.Arch

Shivaram Punathambekar

Design Leader
Architecture Master Student, B.Arch



Dario Vargas

Sustainable Site Design Leader
PhD. Architecture Candidate

Ehsan Kamel

Energy Leader
Building Science Leader
PhD Civil Engineering Candidate

Additional Team Members

Negar Ashrafi, Cory Clippinger, Travis Creighton, Dane Dewire, Kassandra Garza, Joshua Horenstein, Jonathan Libman, Greg Lynch, Selby Niumataiwalu, Bradly Pawelczyk, Goli Razaghi Kashani, Reese Wamsley, Wanxin Huang, Issa Ramaji, Yamile Rodgriguez Asillis, Justin Rotella, Laura Searles, Cansu Tari, Yi-Chun Tsai, Shahrzad Fadaei, Victoria Brinemugha, Sarah Wotton, Mosope Ismail.

Our Team

Advisors

Dr. Ali Memari

Head Competition Advisor
Engineering Professor Penn State University

Lisa Iulo

Head Competition Advisor
Architecture Professor Penn State University

Scott Wing

Head Competition Advisor
Architecture Professor Penn State University

Aidan Gilrain-McKenna

Cost Management Advisor
Bachelors of Energy Engineering Student

Sarah Klinetob Lowe

Marketing and Project Management Advisor
PHRC, Budgets and Publications Coordinator
Masters in Architectural Engineering

01 // Team Qualifications

PENNSTATE

College of Engineering and College of Arts and Architecture

The Pennsylvania State University has several entities that are involved in teaching and research related to residential construction and building science, including the Department of Architecture, the Department of Architectural Engineering, the Department of Civil and Environmental Engineering, and the Pennsylvania Housing Research Center (PHRC). Building science-related courses at Penn State include undergraduate and graduate courses on Building Enclosure Science and Design, Air Quality in Buildings, Solar Energy Building System Design, Advanced HVAC Design, Building Load and Energy Simulation, and Technical Systems Integration.

The College of Engineering offers a 12-credit Housing Certificate, and will soon offer a 22-credit Residential Construction minor. The PHRC conducts research and offers training courses on building science, including the course Building Envelope Design and IECC Code Compliance. The PHRC also hosted Peter Yost, the Director of Residential Services for BuildingGreen LLC, as 2014's Distinguished Hankin Lecturer, whose lecture focused on the importance of building science in understanding high performance homes. This lecture was attended by more than 200 students and faculty at the University in November 2014.

As lead faculty member, I, Ali Memari attest that the competition team students have completed the building science webinars or university course equivalences.

What is H4?

In architecture, the challenge is the genesis of design - the initial concepts that generate form and space have the potential to enrich or diminish the building science, engineering and technological aspects of the building. Our project site, sloping to the south and overlooking the Tussey mountain ridge provided the impetus that we were looking for and informed the orientation of the homes. The longer sides facing North-South not only to take advantage of the views, but also from a climatic point of view - allowing the winter sun to penetrate deep within the home and buffering the cold winter wind. In keeping with our dictum of 'Image is informed by place', we researched traditional regional buildings styles, of which the 'Bank Barn' and the 'Pennsylvania Farmhouse' stood out as remarkable precedents - the Farmhouse because of its simple planning and its elegant facade, and the Bank barn because of the way it gracefully utilized the site topography and its roof form reflected the interior plan.

HERITAGE HOMES

H4: High Performance Living in Harmony with Community

Partnership with a 'real' client, a local provider of affordable housing, sensitized the team to the community and heritage of place in a way a hypothetical project could not. It provided cultural context, a very realistic budget, it encouraged the team to minimize energy consumption through passive design as an integral part of our design - from siting and orientation to wall-opening ratios to color selection. The client's input regarding social aspects - clear demarcation of open space between the two houses in the duplex, about the need for individuality, visitability/universal design standards, and the importance of community engagement – allowed the team to embrace a crucial, but often overlooked aspect of housing - social sustainability.

Our Story

"What is the point of buying your first home, if you can't afford to live in it?"

These are the words of Peg Hambrick a board member of the State College Community Land Trust (SCCLT), an organization that is devoted to helping first-time homeowners buy their homes with the assurance that they will be able to live in them as long as they wish. Over the years, the State College Community Land Trust has purchased, renovated and resold houses on properties in the State College Borough while keeping the land in trust to enable numerous families to purchase an affordable home.

The newest venture on the SCCLT is to build their first new house on a piece of land recently acquired in a prime location in close proximity to Penn State University and to various community amenities. SCCLT brought the idea of building a cost-effective, low-income, energy-efficient house to our Penn State faculty members who bolstered the idea by creating a class for the sole purpose of working on this project. The circumstance of the project coincided with the opportunity for competing in the DOE Race to Zero competition to showcase this unique opportunity. In this effort, the SCCLT has created a strong partnership with the Penn State University Architecture and Engineering Departments to design and build this flagship project that will create a new norm of affordable housing with cutting edge efficient design at the forefront.

The first goal of the Land Trust is to ensure affordable housing. We believe that because of the combination of energy efficiency and building technology, collaboration has produced the ideal living situation for the homeowners that the SCCLT serves: a high performance home, in harmony with heritage and environment. The new duplex home will not just provide affordable and sustainable residences for two new homeowners, it will also encourage a feeling of pride of owning a unique, beautiful home. An additional goal is to develop institutional knowledge, and applicable planning for sustainable home systems, that will help the 36 current SCCLT homeowners to make improvements to their homes that will have long-term efficiency payoffs.

"Sustainability" has become a standard term in modern day vernacular, but we are redefining what it means for current and future SCCLT homeowners. If the SCCLT can be equipped with new techniques and we can educate current homeowners in economical ways to maintain and retrofit their homes, we will truly help make their first homes sustainable and affordable for a lifetime while using this new duplex as a trend setter for the greater State College Community.

Read on to learn about our solution to this compelling challenge as we address the demands set forth by the site, the potential owners and the latest energy and building technology. Our team has embraced the rich heritage of State College in the context of Pennsylvania and blended it with the best technologies, ideas and building strategies to create not only an energy and cost efficient house, but a home. This all culminates in a state-of-the-art duplex home that highlights community, durability and comfort, while proudly representing what it means to live in State College in harmony with heritage, home and high performance.

02 // Introduction

Integrative Design Process

Throughout this project our team has been dedicated to a whole-house systems approach [1] facilitated through an integrative design process. From the very beginning we have involved all stakeholders and brought multiple experts to our table. We have worked on a basis of **"Engage Everybody Early on Everything"** [2] a concept set forth by 7 Group, specifically Bill Reed, Andrew Lau, and John Boecker who have worked closely with our advisors. We have collaborated in group infrastructure and interactive meetings including design and project coordination charrettes and open house sessions to continually include members beyond our outlined triad of interests (see the timeline below for more detailed events). We engaged the Quality Management Provisions (QM#2) in our process through awareness of the check list, identifying our target strategy (ENERGY STAR, DOE Zero Energy Ready Home), implementing our key building technology elements, outlining methods, and assigning individuals for curating each step in the development. In this way using integrated project design has allowed us to design a solution that is aesthetically, functionally, technically and economically [3] more successful than a project designed otherwise. Integrative design has engaged the local community allowing our Heritage Homes to reflect the values of place and context.

[1] Whole-House Systems Approach. (2014, May 5). Retrieved March 17, 2015, from http://energy.gov/energysaver/articles/whole-house-systems-approach.

[2]7-groupand B. Reed, The Integrative Design Guide to Green Building: Redefining the Practiceof Sustainability, Hoboken, NJ: John Wiley & Sons, 2009.

[3] L. Iulo, "Energy and the Integrative Design Process: Defining the Team of Experts", In Design and Construction of High-Performance Homes, New York, NY. 2013. F. Trubiano ed. Pp. 193-202.

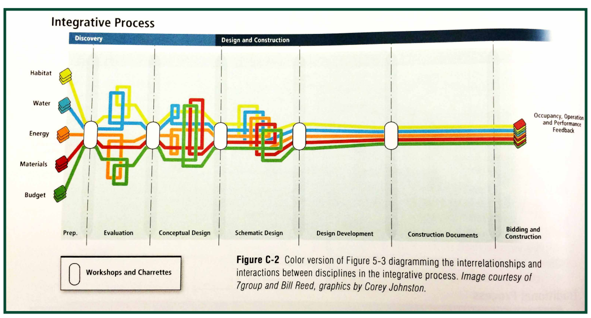


Figure 02.1 Integrative Design Process Diagram, 7 group and B. Reed. [2]

Figure 02.2 Integrative Interactive Meeting.

Timeline for Integrative Process

Every Tuesday from September 20th 2014 to March 17th, 2015 - Our team of students, advisors, industry mentors and Land Trust members met in some capacity to discuss and lay out the competition requirements and previous years' winners and deliverables and talk about how to create a cost-effective net-zero energy house.

Fall Semester

Project Conception

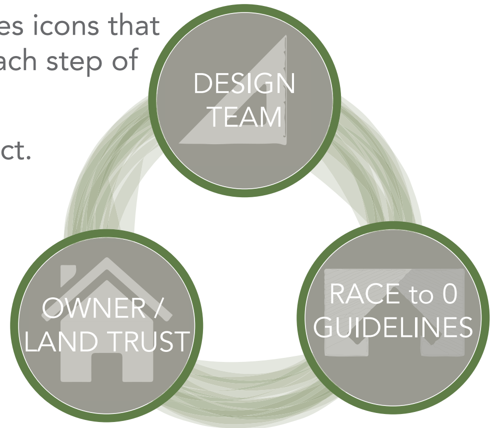
January 8, 2015 - collaborated with the Arch 497E students to form the groups to work on each separate part of the deliverable.

January 13, 2015 - met with members of the State College Land trust to discuss the preliminary ideas and get input on specifications

January 20, 2015 - specifically laid out team goals and deliberated 3 main ideas

The Triad of Interests

Throughout this document our readers will find these threes icons that represent the three interested parties we considered in each step of our work.



The three parties are the major design drivers of our project. The State College Community Land Trust is our client and owner, the Race to Zero competition, which lays out standards for performance, and finally our design team armed with specific expertise. In each section you will see these icons and be able to quickly discern the unique goals that we have incorporated into our integrative design process.

Design Drivers

Design Team

- Capture the unique qualities of the site, including the southern views to the mountains.
- Incorporate a 10 degrees rotation in the classic north-south orientation of the house, maximizing yard, while still having street presence.
- Achieve the Land Trust goals while still being an affordable home from a life cycle cost. We will consider the life of the building and its components, their initial cost, and the energy implications.
- Revitalize local architecture to our area, the bank barn is inspired by original architecture specific to Central Pennsylvania.

Race to 0

- Passive solar design to reduce loads in the home.
- Option for solar PV in the design for future net zero energy home.
- Meet the prescriptive path for the DOE Zero Energy Ready home technical guidelines.

Land Trust

- Design for a duplex that can fit easily into the SCCLT's unique financial agreement structure.
- Create a landmark for the State College Community, a symbol of what affordable housing can be.
- Maintain sensitivity to budget; remain long –term affordable housing, we are not looking at only initial cost.
- Communicate individuality and identity for each of the homes. It is important for each house to read as a separate entity. Ownership is directly ties to identity and individuality.
- Even though the duplex is attached it is important to maintain privacy for the two parties, as well as providing the possibility for storage to be built into the design, maximizing the small footprint.

Therefore

- We have designed a duplex house, facing south, offset 10 degrees from true north, increasing morning passive solar potential and optimizing views.
- Affordability (short and long term). Everything has purpose and fits consistent with the land trust system.
- Performance, looking to the "whole building" approach we are striving to achieve the least expensive way to net- zero, that includes solar photovoltaics in the initial home budget.
- Engaging the community with our design, through a revitalization of Pennsylvania architecture, relating the heritage of the past to the future of affordable housing in Pennsylvania.

February 3, 2015 - met again with the State College Land Trust and also had members of the community to find the most valued parts of owning a low-income house and being a first-time home owner, get further specifications on the ideas, and to determine the most popular ideas.

February 10, 2015 - made the main decisions on the type of design after much deliberation of the 3 main ideas and the most important laid out by the State College Land Trust

March 17, 2015 - Finished writing and drawing to compile all team efforts into one document.

Project Completion

03 // Design Goals

Our Design

Good architecture learns from the past, responds to the present, and inspires the future. Our site in the Great Appalachian Valley creates the challenge to react to the unique geography and the rich socio-cultural patterns in the area. Pennsylvania's long history produced a host of distinctive building styles such as the Pennsylvania Farm house and the Bank Barn that have been re-interpreted to fulfill the expectations of first time owners and young families within high efficiency parameters to contextually root the building to the place.

Sited in a high point in the Nittany Valley, the design balances the need to respond to solar orientation and the southern view of the Bald Eagle mountain ridge while still creating a local street presence from the access road to the East. Our design is a solution to bring together these seemingly separate fragments into a cohesive whole by designing with the site, integrating client needs, imbibing local traditions and re-imagining future living.

Community	Durability	Comfort
Site Design	Efficient Design	Public vs. Private
Public Transportation	Materials and Methods	Indoor Air Quality
Location and Proximity	Envelope	Program Layout
Garden	Sustainable Systems	Views to South
Community Enhancement		Livability

03 // Design Goals

Design Drivers

Design Team

- Design begins with the site; Image is informed by the place.
- Adaptability - design for visitability, family flexibility, and aging-in-place such that the home grows old gracefully.
- Energy-efficiency begins with passive design.

Race to 0

- Set the home within the regional context and current market expectations.
- Provide an opportunity for students to work in a inter-disciplinary team to generate responsible, yet creative housing solutions.
- Realistic, cost-effective solutions towards energy-efficiency.

Land Trust

- Homes should be affordable for the short and the long term (durable, minimum maintenance, inexpensive utilities).
- A home that addresses the problems of inadequate storage and unequal property divisions of a typical cost-effective duplex
- A design that will not bring unwanted attention to the financial conditions of the occupants.

Therefore

- Respect both the permanent (climate, landform) and the transient (historic and current regional) context of the site.
- Incorporate sustainability at all of its three levels - social, economic and environmental
- Integrate passive design and technology with high-performance innovations to achieve a smart, practical energy strategy.

We were presented with a unique opportunity in the program of the DOE Net-zero ready home - the State College Community Land Trust (SCCLT), in partnership with the State College Borough and the Energy Efficient Housing Research Group - EEHR/Penn State Hamer Center for Community Design, plans to design and build a moderately priced, owner-occupied duplex utilizing advanced and long-term cost-effective "green" technology. The brief presented to us by the SCCLT was to develop two units of moderate-income homeownership "green" homes that have at least three bedrooms, 1.5 baths and approximately 1250 square feet of living space for each unit.

> "We especially like the bank barn style because it carries with it a reference to Pennsylvania heritage."
>
> –Ron Filippelli
>
> Board Member of SCCLT;
> Greenbuild project;
> former Borough Council member

03 // Design Goals

03.2 Sustainable Sites

The site is located in State College Borough, a community that has embraced the goals of creating a lasting environmental, economic, community, and organizational vitality by providing quality, innovative, and cost effective services; and by allocating resources efficiently. State College is achieving these goals by pursuing "Sustainable Pennsylvania Community Certification," a program for demonstrating excellence in sustainable community development. Providing affordable options for home ownership is a priority for the Borough, the State College South neighborhood, and Centre County.

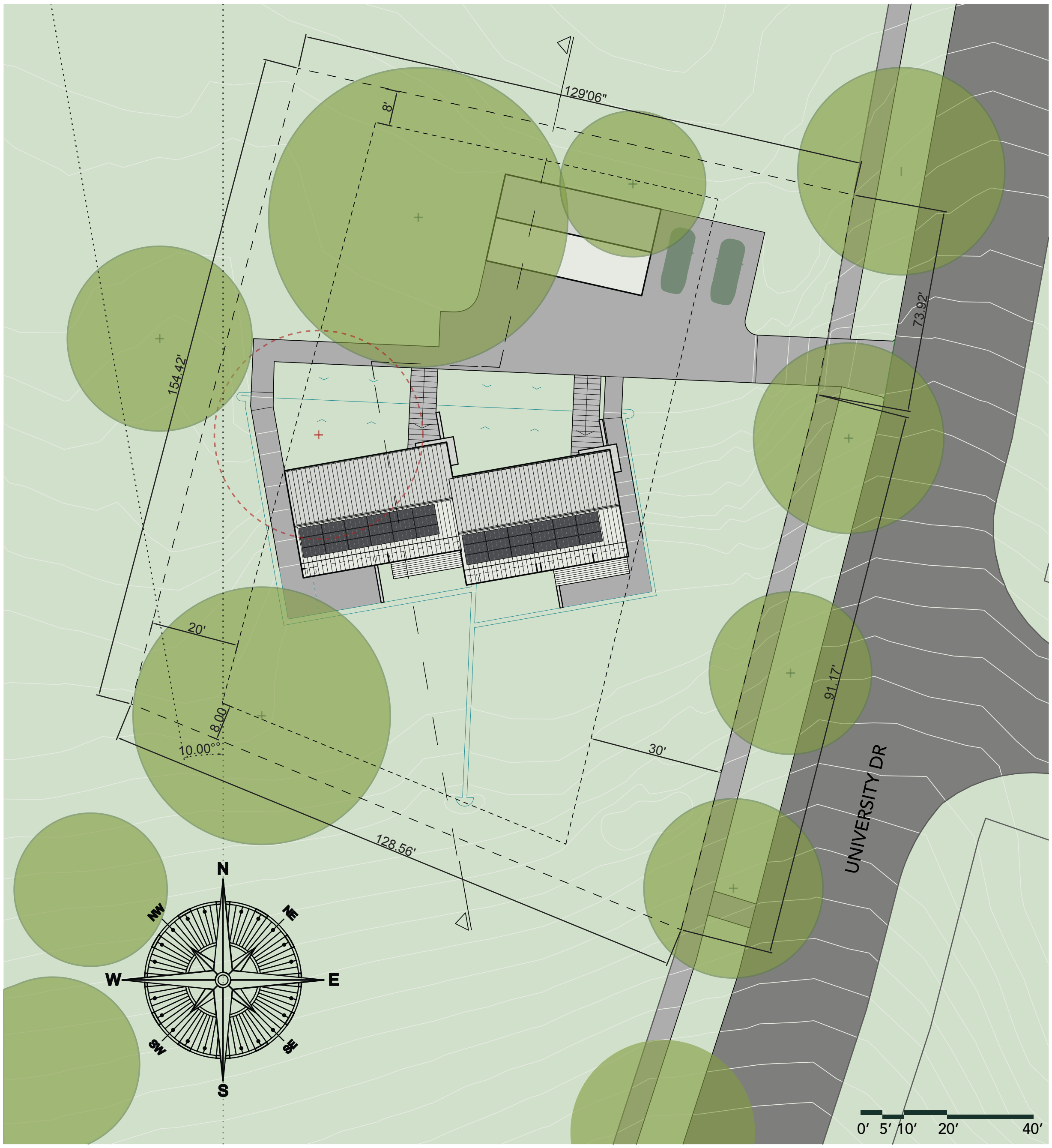
The site's location near commercial developments on South Atherton Street places the homes within a short walk of a pharmacy, several banks, and a number of restaurants and easy biking distance to schools, places of worship and other community amenities. A bus stop located at the site boundary offers access to Penn State's campus and downtown State College, as well as local grocery stores and entertainment.

The State College Community Land Trust (SCCLT), a borough provider of affordable housing, maintains a condition that incoming owners must be first time home buyers with medium income. As such, the project is designed to target young professionals and their families in an affordable, efficient manner. The site conditions allow for a duplex configuration therefore the SCCLT wants to give two families the opportunity to have a home. Encouraging long-term home ownership, the homes and project site are designed to "visitability" standards of universal design and to allow for flexible living and "aging-in-place."

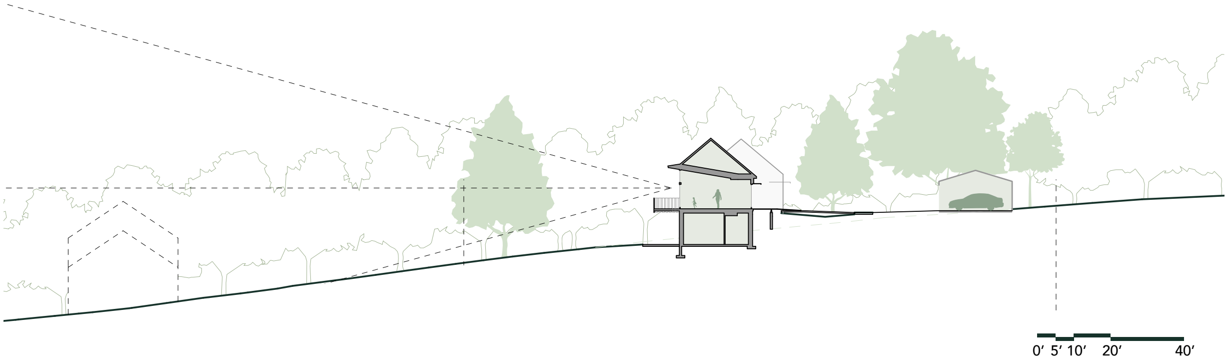
After fulfilling the requirements of local zoning and ordinances and the State College Borough Neighborhood Plan, the team considered views, wind patterns, solar exposure, topography, trees location and division of the property when designing the placement and orientation of the duplex. Taking advantage of the sloping site, sun exposure, and the views towards Mount Nittany, the long facades of the units are facing south angling 10 degrees north-east south-west from true north. This angle helps to have street presence for both units on University Drive while allowing the sun to warm up the spaces of the home earlier in the morning. The lower level of the homes are bermed within the sloping topography while the south side provides a walkout basement. The social spaces within the units are located on the upper level to provide better views towards the mountains over the site that should not be blocked by future constructions.

The site also provides a mass of trees that protect the units from the prevailing western winds. The driveway access is located on the northern portion of the site to avoid traffic interference with Royal Road (perpendicular to the site across University Dr.) This also allows for the carports to be positioned where they do not block the southern views or solar exposure and the design include storage space in them. The sloping topography also gave the opportunity to design a rain garden in the south-eastern corner that receives water from the site and houses. Water is conducted through open channels that meet towards the middle of the site and follow the property lines for the duplex.

The site plan defines three areas: a shared area in the north side where driveway access and carports are located, a west area towards the mass of trees for one of the units and the east area on University Drive for the other. Private areas are well defined so there is a sense of belonging regardless of the ownership of the land.



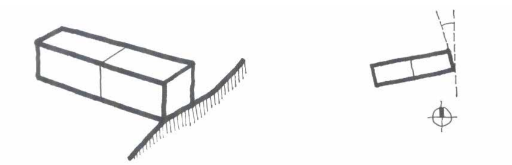
SITE PLAN
FIG.03.2.1



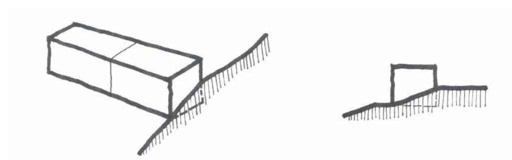
SITE SECTION
FIG.03.2.2

03 // Design Goals

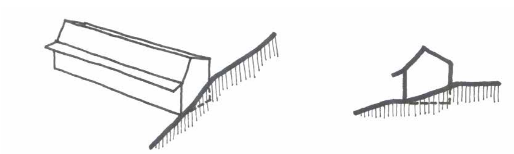
In architecture, the challenge is the genesis of design - the initial concepts that generate form and space have the potential to enrich or diminish the building science, engineering and technological aspects of the building. Our project site sloping to the south and overlooking the Tussey mountain ridge provided the impetus that we were looking for and informed the orientation of the homes - the longer sides facing North-South not only to take advantage of the views, but also from a climatic point of view - bringing in the southern sun, and buffering the cold winter wind from the west (Figs. 3.3.1 - 3.3.4). In keeping with our dictum of 'Image is informed by place', we researched traditional regional buildings styles, of which the 'Bank Barn' and the 'Pennsylvania Farmhouse' stood out as remarkable precedents - the Farmhouse (Fig. 3.3.5) because of its simple planning and its elegant facade, and the Bank barn (Fig. 3.3.6) because of the way it gracefully utilized the site topography and its roof form reflected the interior plan.



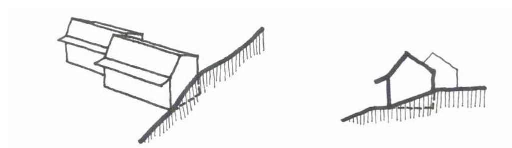
3.3.1 - 10 degree shift in N-S orientation to maximize street presence



3.3.2 - Building bermed as a response to site topography

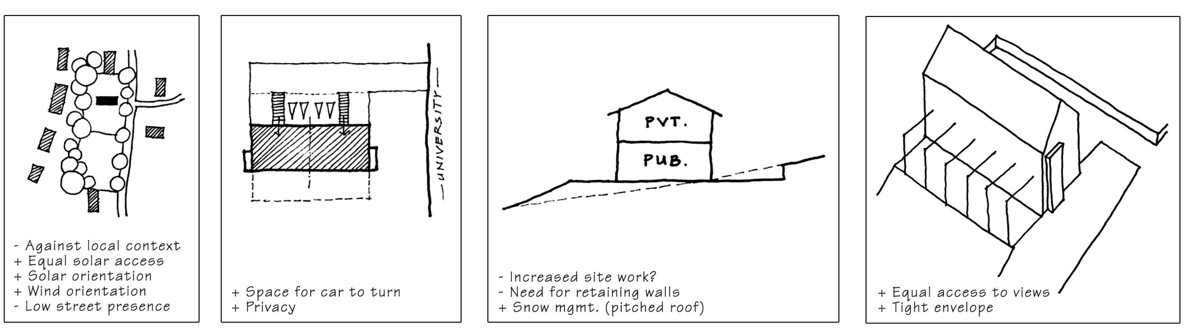


3.3.3 - 'Bank barn' roof form respects historic regional context

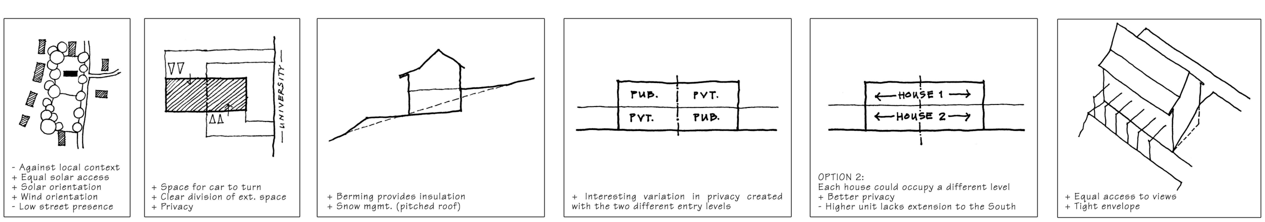


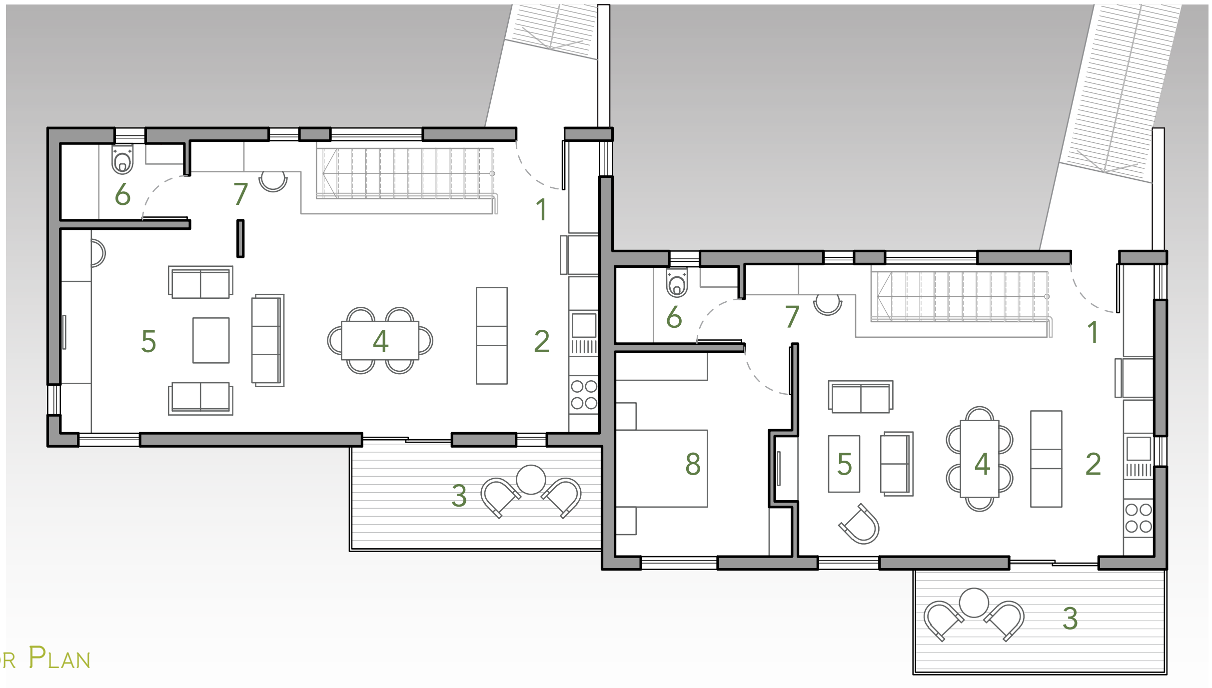
3.3.4 - Units staggered for individuality

5. PARALLEL DIVIDING WALL - 'PENNSYLVANIA FARMHOUSE'

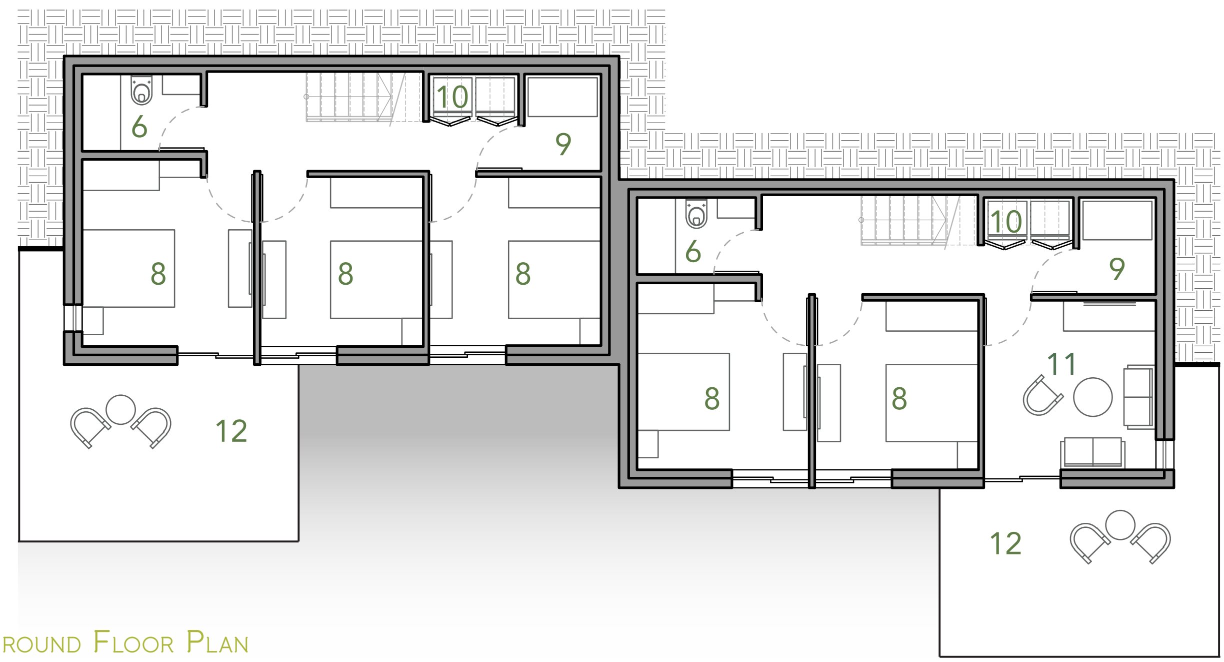


6. PARALLEL DIVIDING WALL - PENNSYLVANIA FARMHOUSE 'BANK BARN'





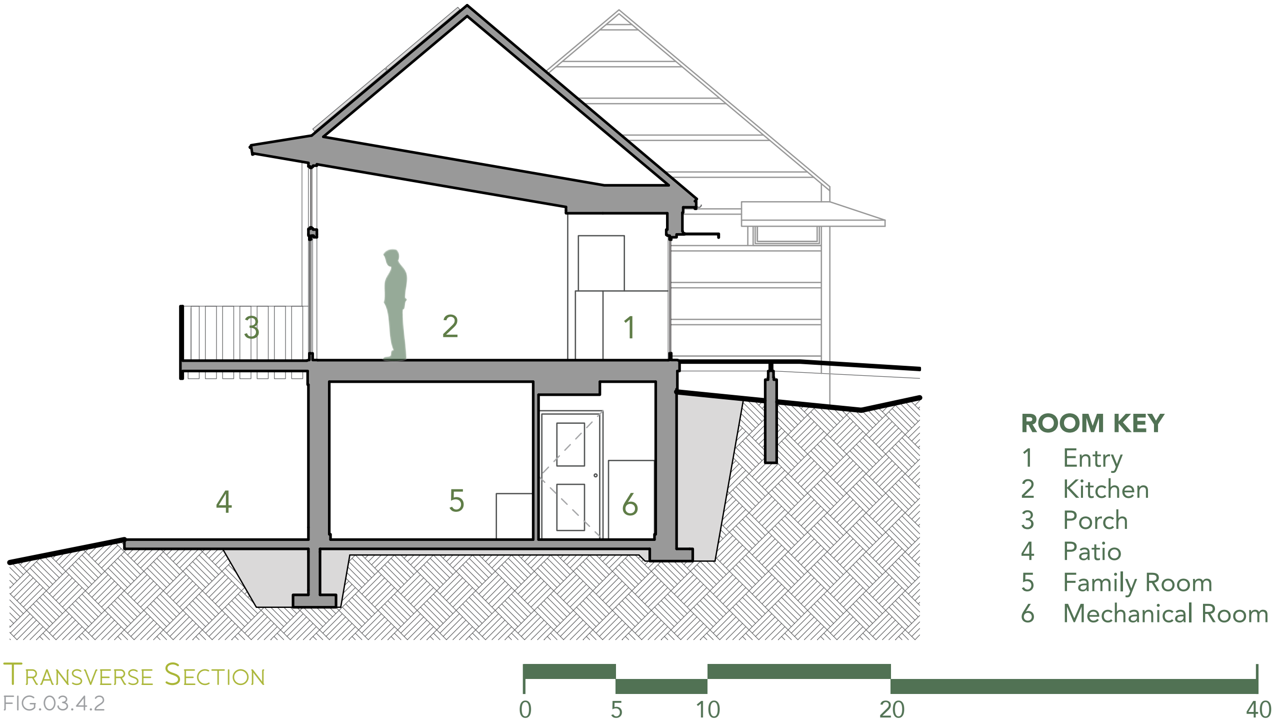
First Floor Plan
FIG.03.4.1.1



3.4.1.2 Ground Floor Plan
FIG.03.4.1.2

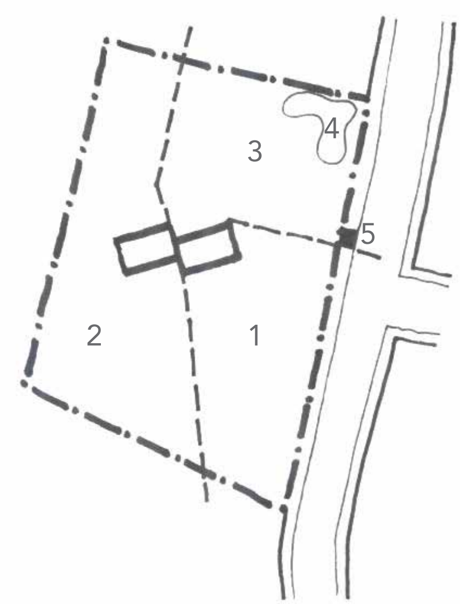
ROOM KEY

1 Entry	7 Desk
2 Kitchen	8 Bedroom
3 Porch	9 Mechanical Room
4 Dining Area	10 Laundry
5 Living Room	11 Family Room
6 Bathroom	12 Patio



TRANSVERSE SECTION
FIG.03.4.2

Partnership with a 'real' client, a provider of affordable housing, sensitized the team to the community and heritage of the place in a way a hypothetical project could not. It provided cultural context and a very realistic budget, and encouraged the team to minimize energy consumption through passive design as an integral part of our design - from the siting and 'right-sizing' to overhang design (3.5.2) and color selection. The client's input regarding social aspects - such as the requirement for clear demarcation of open space between the two houses in the duplex (Fig. 3.5.1), the need for adaptability (Fig. 3.5.3) and individuality (Fig. 3.5.4), visitability/universal design standards (Fig. 3.5.5), and the importance of community engagement (Fig. 3.5.1) - allowed the team to embrace a crucial, but often overlooked aspect of housing - social sustainability.



3.5.1 - Clear demarcation of land illustrating the public and community space

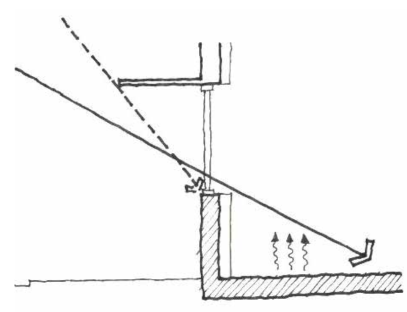
1 - Unit 1 property,

2 - Unit 2 property,

3 - Public space,

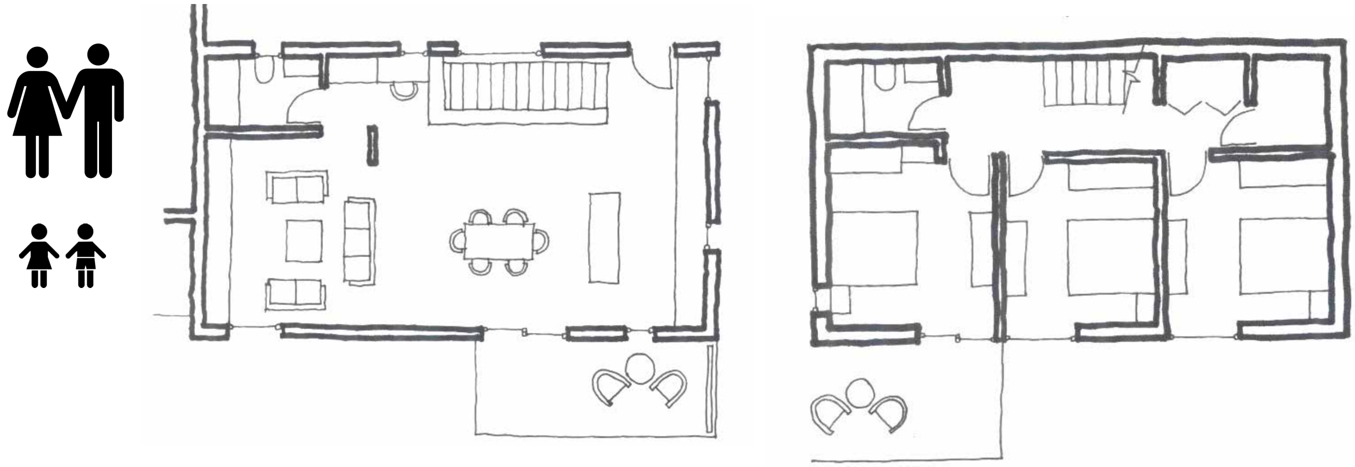
4 - Community 'rain garden',

5 - Bus stop

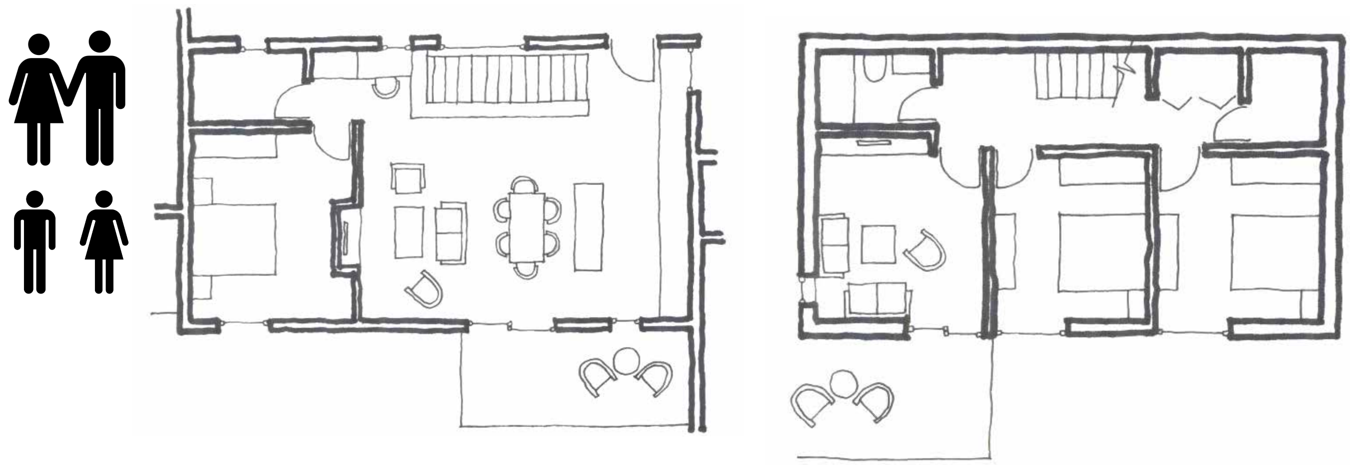


3.5.2 - Overhangs designed as per shading angles, Concrete floor in Ground floor acts as thermal mass

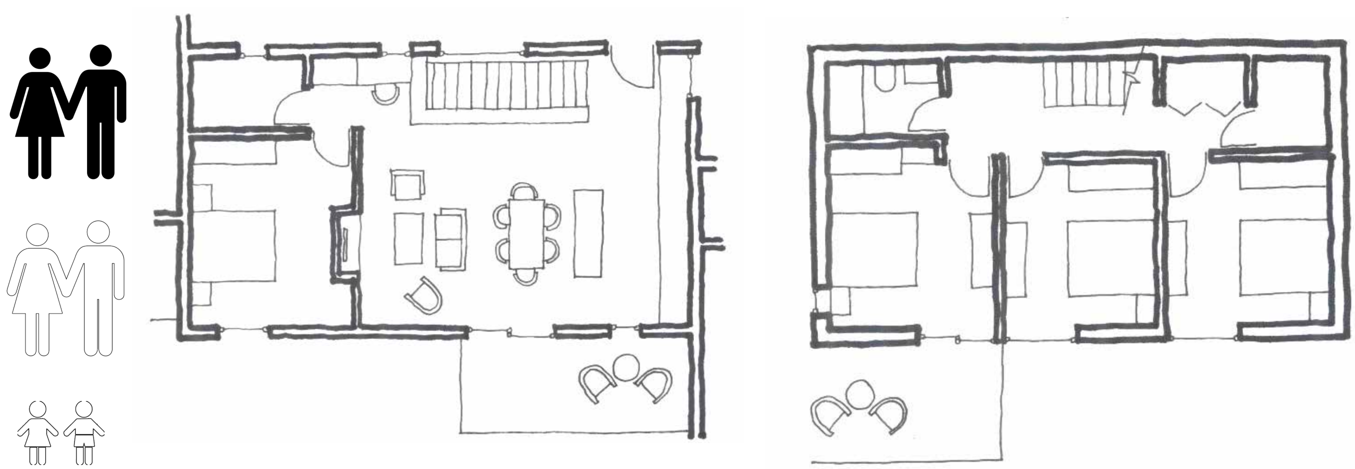
3.5.3 - Adaptability in floor plan expressed in different family scenarios



1) Young family, 2016 - All living spaces in First floor and all Private spaces in Ground floor



2) Family in 2030 - Parents' bedroom in First floor, Family room on Ground floor



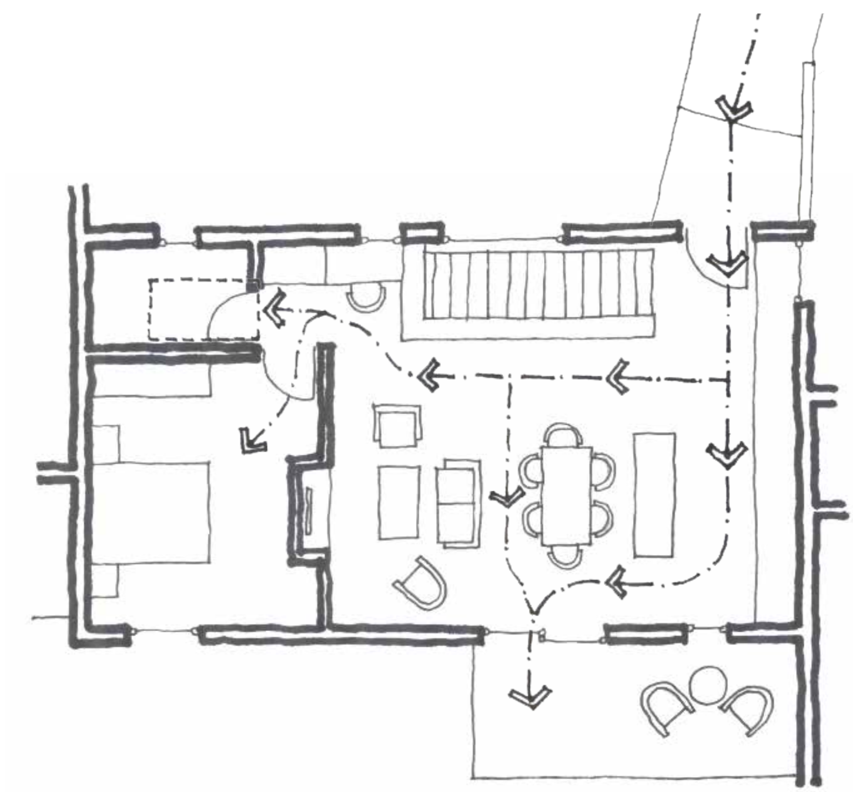
3) Family with visiting children, 2040 - Ground floor Family room reconverted to Bedroom

3.5.4 - Individuality for units in duplex expressed in multiple ways

1 - Shift in plan maximizing street presence and individual identity

2 - Unique batten arrangement for each unit

3 - Asymmetrical opening pattern on facade



3.5.5 - Drawing illustrating design for visitability; including no-step entries, circulation widths and bathroom design

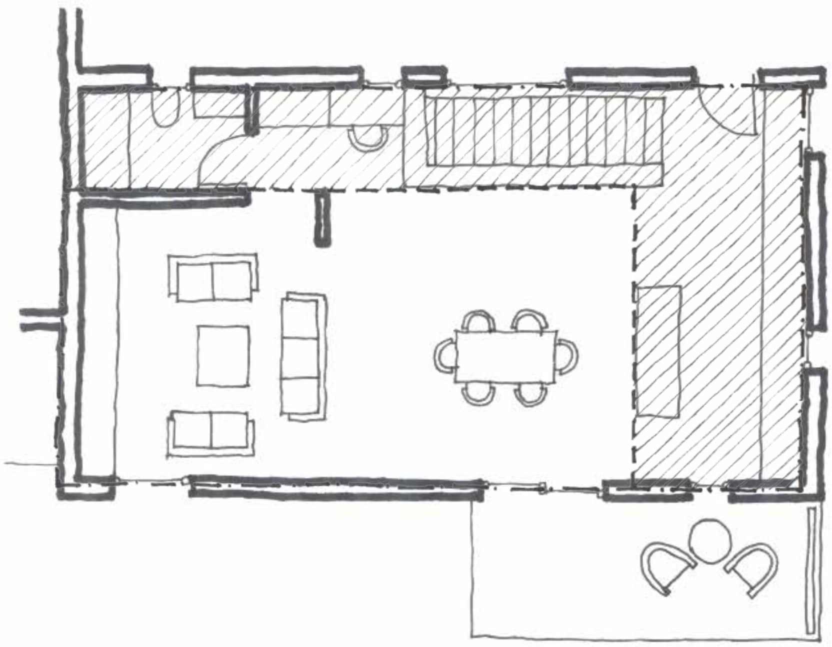
The interior space was similarly a combination of design decisions by the team considering aspects of passive design, indoor air quality and a unique process - a visual preference survey. The team presented the SCCLT with a series of images based on building form, interiors and materials/details; and compiled a series of visual preferences (Fig. 3.5.6) that acted as our guide for further design. Decisions such as the roof and interior space opening up to southern light with a sloped ceiling and transom windows, exterior balconies, board and batten, fiber cement siding, open planning on interior (Fig. 3.5.7 and 3.5.8), etc were all decisions tied to the visual preference survey; which gave the team a collaborative experience of working on a real-world project with clients, mentors, architects and engineers.

Building Form

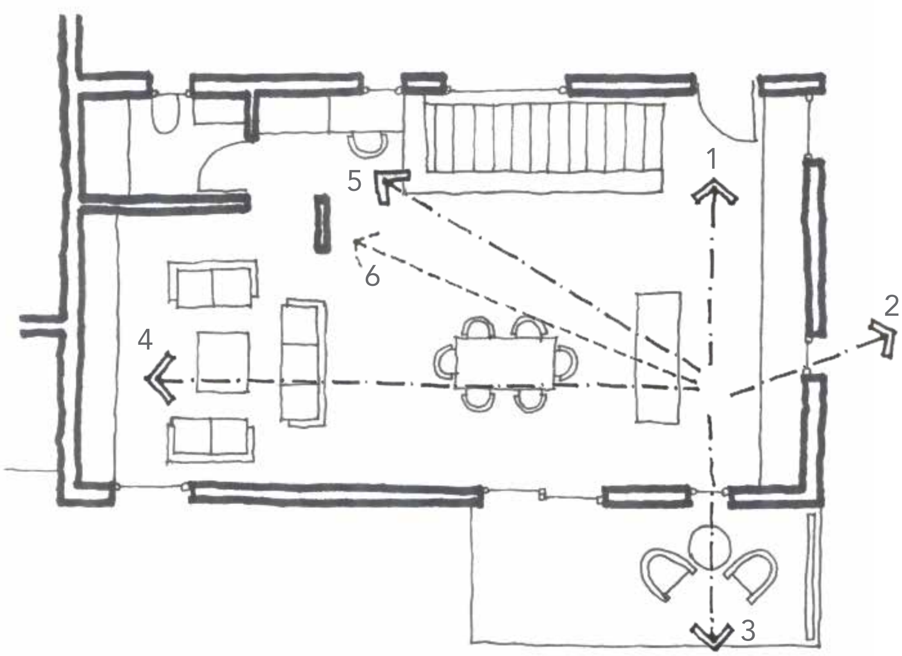
Interior

Exterior

3.5.6 - Combination of most preferred images in the visual preference survey - Large windows and private balconies for building form; Open plan with variation in ceiling height for the interior; and Board and Batten siding for exterior cladding



3.5.7 - Clear segregation of 'service' and 'living' zones ensures open plan with maximum living space and minimal but interesting circulation patterns



3.5.8 - Multiple view sequences from the kitchen

1 - Front door

2 - Site entry

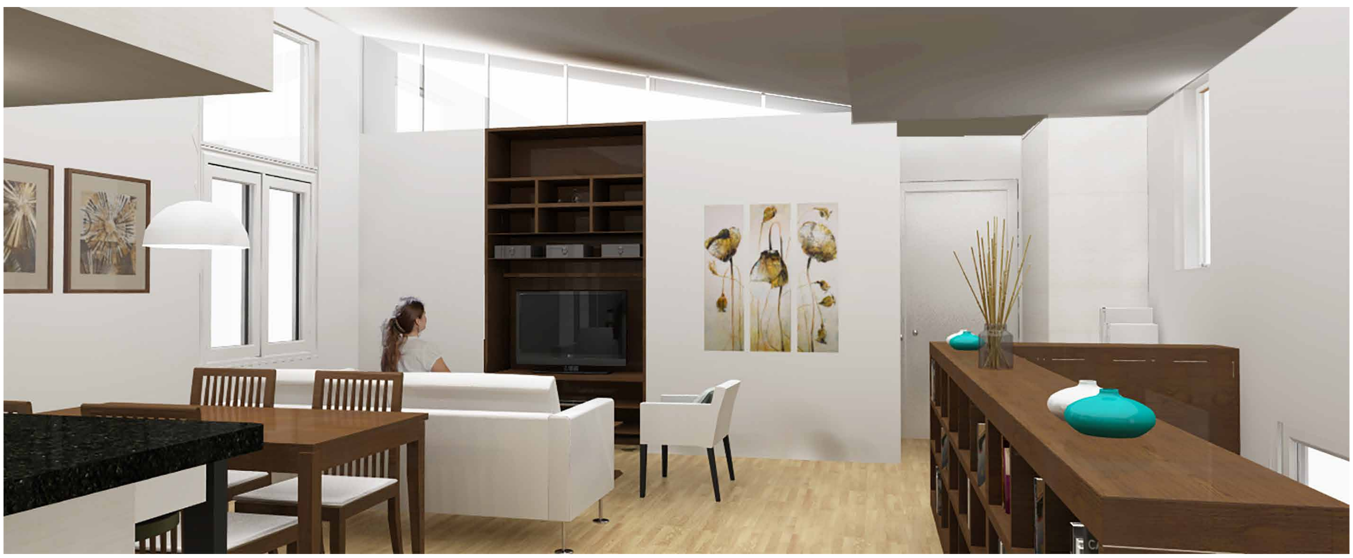
3 - Southern view of the Tussey mountains

4 - Living room

5 - Desk area

6 - Wall panel blocking view to Bathroom door

03 // Design Goals



Reference Appendix 03 for a more in-depth look into our design process.

04 // Envelope Durability

Design Drivers

Design Team

- Consider multiple features for selecting envelope components such as energy performance, cost, and durability.
- Most affordable building envelope over the life of the building.
- Control of the heat, air, and moisture and prevent typical building enclosure issues.

Race to 0

- Enhance building durability using building science concepts.
- Air movement, thermal, and moisture control.
- Proper use of construction details and material specifications.
- ENERGY STAR at a minimum with IECC 2012.

Land Trust

- Avoid major failures in terms of moisture and heat loss.
- Low cost over the lifetime of the home.
- No compromise on tenants comfort.

Therefore

- Consider multiple criteria in material and system selection instead of being focused just on initial cost.
- Most affordable building envelope over the life of the building considering initial cost, energy savings, and maintenance cost.
- ENERGY STAR at a minimum with IECC 2012.
- Apply cost effective construction details to prevent building enclosure failures.

> "What we call "green" improvements: extra insulation, double pane windows, orientation of the house to take advantage of sunlight in the winter; eliminating use of products using formaldehyde or other toxic materials, etc., are becoming common sense choices. Nothing compares to the comfort of a warm home in winter (and a cool one in the summer) without having to worry about the bill!"
>
> –Elizabeth Goreham Mayor of State College Borough; Homeowner with solar photovoltaic panels

Envelope Durability Analysis

In the first section of this chapter covers the main mechanisms affecting the durability of the building enclosure. The second section is mainly focused on a checklist, which is a summary of all the construction details, techniques, materials, and certain inspections considered in the design. In the third section, different properties of various systems and materials are discussed and evaluated. These properties are not limited to durability features. They also include energy efficiency, cost, flammability, local availability, and ease of construction. Moreover, different options are also ranked based on their sustainability properties and their eco-friendly aspects.

04.1 Building Enclosure Durability Considerations

In order to control durability issues in building enclosure, there are three main factors to be controlled including; air movement, thermal performance, and moisture. The latter could be in form of bulk water or vapor. Since these factors can be affected by each other, the combination should be considered as it also affects other controls such as hygrothermal performance, which is is a pressure drive created by differences in moisture contend and a temperature gradient. There were several

04 // Envelope Durability

04.1 Building Enclosure Durability Considerations (cont.)

different enclosure components studied, designed, and selected for this project including above grade walls, below grade slab, roof, and windows. There are several techniques used in this project to choose the best material and configurations that can lead to the optimum whole-house design. In the "Energy Analysis" chapter, it is explained how REM/Rate and BEopt were used however, they don't account for the possible durability failures and have very little to do with building science concepts. Therefore other software programs were used in order to evaluate these components in terms of hygrothermal and thermal performance. Not all of the possible issues are addressed in this section, as they all cannot be considered by existing software, however most of them are discussed in this chapter.

Hygrothermal analysis of wall system

The software used to evaluate the hygrothermal performance of the walls was WUFI® Light version 5.3., which is available for free for students. The results were mainly evaluated based on the temperature, mold growth possibility, and moisture content. The latter was evaluated based on Relative Humidity (RH) and an attempt was made to make sure that condensation, or 100% RH, doesn't occur inside of the control layers, as that could lead to a decrease in thermal performance, a degradation of materials, or possible mold growth. The analysis was conducted for two cold years in Pittsburgh, PA, as State College is close to Pittsburgh in climate. As it can be observed in Figure 04.1.1, the results reveal that the whole wall assembly performs well in terms of keeping the temperature in the desirable range and in keeping the condensation plane outside of the control layers. The highest relative humidity inside the wall is approximately 90% and the only location that experiences the condensation is the exterior insulation, which has the ability to drain exterior of the control layer. Figure 04.1.2 shows the changes in overall conductivity of the wall system throughout two years of the analysis due to the moisture penetration into different layers of the wall system. This is in the acceptable range based on DIN 4108, which is the standard used in WUFI. There are multiple outputs of this hygrothermal analysis that shows the moisture content of different layers, possibility of mold growth, temperature distribution, and details about indoor and outdoor boundary environmental conditions and they are all available in Appendix 04. They all show no issues with hygrothermal performance of the wall system based on building science principles.

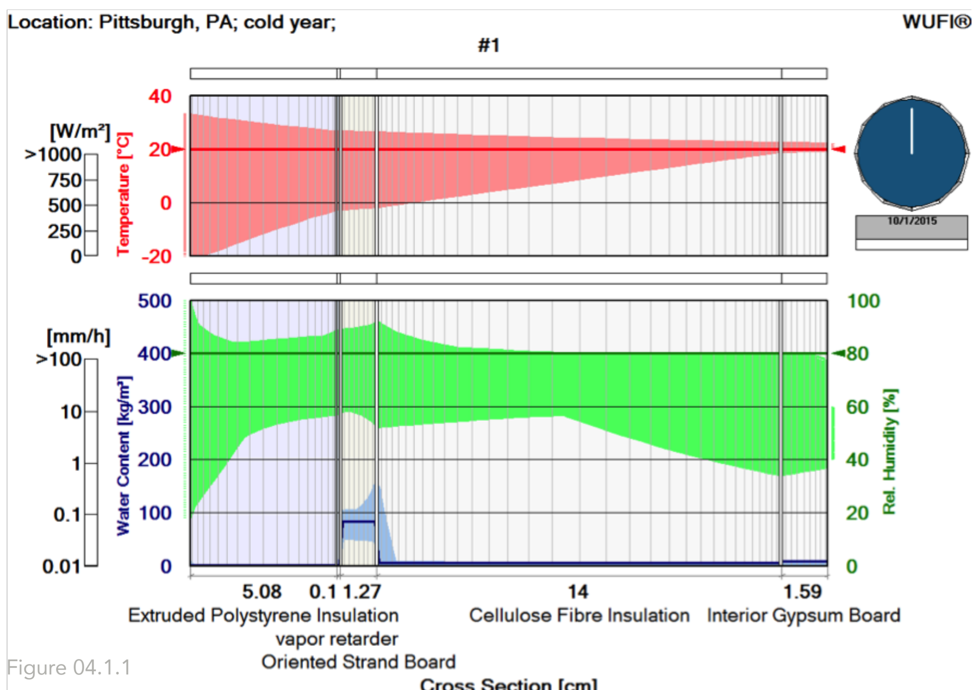


Figure 04.1.1

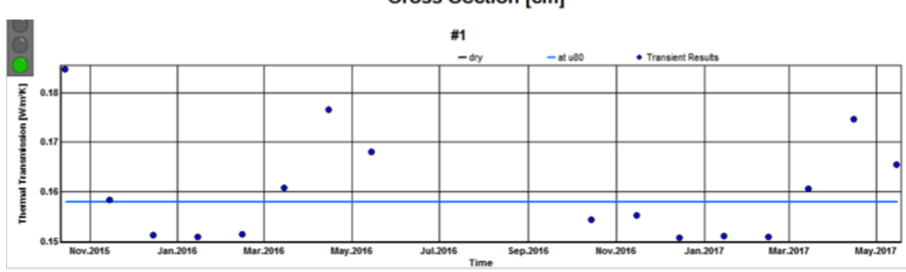


Figure 04.1.2

04.2 Building Enclosure Checklist

In order to be able to control the air movement, thermal performance, and moisture the team decided to prepare a checklist, which is designed specifically for this project. All of these inspections and techniques are based on building science concepts. There are construction details, inspections, techniques, and considerations proposed in this section that can prevent or resolve possible building enclosure issues or failures in this building and similar homes.

Moisture Control

Moisture control is of vital importance for the proper function of buildings. Controlling moisture is critical to protect occupants from adverse health effects and also to protect the building. Many common moisture problems can be traced to poor decisions in design, construction or maintenance. Such problems can be avoided with techniques that are based on a solid understanding of how water behaves in buildings. According to the Institute of Medicine (IOM), damp or moldy indoor environments have a certain relationship with the appearance of adverse health effects in exposed populations. These adverse health effects include upper respiratory symptoms, cough, and asthma symptoms in sensitized persons with asthma. In addition to causing health problems, moisture can damage building materials and components. For example, long periods of damp conditions can lead to mold, bacteria and insect pests. Brick or concrete can be damaged during freeze-thaw cycles and by sub-surface salt deposition.

Moisture problems can be also attributed to condensation. Condensation can occur on the interior side of of window due the interior surface of the glass being below the dew point. Condensation could also occur if the seal of the window's IGU fails. It is also notable that the health problems and building damage due to moisture can be extremely expensive to repair. Moisture control consists of: preventing water intrusion and condensation in areas of a building that must remain dry; limiting the areas of a building that are routinely wet because of their use and of window due the interior surface of the glass being below the dew point. Condensation could also occur if the seal of the window's IGU fails. when they do get wet. To be successful, moisture control does not require everything be kept completely dry. Moisture control is adequate as long as vulnerable materials are kept dry enough to avoid problems. Table 04.2.1 presents the possible problems due to moisture and the preventive actions considered in this design to avoid any failure.

Rain Control

Moisture could be in form of vapor or bulk water. Rain is one of the major sources of the bulk moisture in buildings. The rain control layer is the most important layer among different control layers in a building enclosure. Water penetration is the most noticed problem in a building. If only a few drops of water enter the building, even in the harshest storm, it is considered a failure of the envelope. The reason being, rainwater has a huge impact on building durability and long-term serviceability. In today's modern energy efficient homes, we are controlling air flow at a much finer degree, which means any moisture that does get in the home is harder to dry out. Therefore, it is crucial to control water leakage as much as possible. Table 04.2.1 shows some of these issues and the preventive actions considered in our design.

Air Flow

There are different locations in a building enclosure that are susceptible to air infiltration. Most of the joints and areas around the fenestrations should be sealed to minimize the air infiltration. Windows are one of the most important fenestrations with respect to control of the air flow. One of the building enclosure functions that windows must fulfill is that of an air barrier. As a component of the air barrier system, the connection between windows and other air barrier components is critical to the overall air barrier performance. The air barrier connection between windows and other components must be made in a way that does not compromise other building enclosure functions. Also, the window is the sole air barrier at its opening, unlike walls. Table 04.2.1 shows some of the preventive solutions that should be considered in order to minimize the air infiltration.

04 // Envelope Durability

04.2 Building Enclosure Checklist (cont.)

Thermal Control

Providing thermal comfort while reducing space conditioning costs is one of the primary considerations of high performance buildings. Heat flow occurs through the building enclosure via conduction. Solar radiation is directly transferred into the building through windows. The control of heat flow in a building enclosure assembly can be managed with a thick layer of insulation and reduced thermal bridging and an effective air barrier system. Thermal Bridging results in high heat transfer and can result in the interior temperature to drop below the dew point leading to condensation and possible mold formation. Advanced wall framing, 2x6 studs and increasing spacing can increase the amount of insulation in a wall from 75% wall coverage up to 85% wall coverage resulting in reduced thermal bridging and less heat loss. There are multiple inspections and considerations that should be noted in order to minimize the failures and issues due to thermal bridging and keep the thermal performance on a high level. Table 04.2.1 presents most of the considerations in this design to minimize issues due to poor thermal control of the building enclosure.

Table 04.2.1– Team's checklist for building enclosure durability

	Common Building Envelope Issues	**Preventive Solutions**
Thermal Control		
Insulation	Thermal bridging	2" XPS continuous exterior insulating sheathing completely covers all the framing of the home. This satisfies Item 4.4.1 of Thermal Enclosure requirements in ENERGY STAR. (see construction drawings)
Insulation	Air leakage results in heat loss	ZIP sheathing provides a continuous air barrier with all seams and penetrations to be sealed via ZIP Tape and ZIP liquid flashing which is connected to the gypsum wall board ceiling with spray foam. (see the ZIP sheathing documentation in Appendix 04)
Insulation	Wind washing of attic insulation	ZIP sheathing runs to the bottom of the top chord of the truss, providing an 18" wind break for R-60 loose fill cellulose. This satisfies Item 3 of Thermal Enclosure requirements in ENERGY STAR.
Insulation	Uneven installation of cellulose insulation in attic space	Use gauges every 200 SF to make sure the thickness of the cellulose is even and sufficient.
Air Control		
Air sealing	Air leakage can result in moisture movement to the inside	ZIP sheathing provides a continuous air barrier, all field seams and penetrations to be sealed via ZIP Tape. All attic penetrations and rim/band joists to be sealed with spray foam. (see the ZIP sheathing documentation in Appendix 04) and (see construction drawings for more details)
Air sealing	Forgetting an air barrier behind a tub or similar areas	Lining up all the wall control layers at the ZIP sheathing reduces some of the major issues with missing six sided air barrier behind a tub or similar area. Even so, a fully sealed rigid air barrier is to be installed behind the tub on the ground floor and first floor. This satisfies Item 3.1.1 of Thermal Enclosure requirements in ENERGY STAR.
Air sealing	Leaky air handling unit and supply ducts	Mechanical ductwork is all located within the conditioned boundary, connections and runs are minimized to reduce potential leakage and all the ductwork mini split slim duct are to be sealed with mastic. This satisfies Item 4.1 of HVAC requirements in ENERGY STAR. (see construction drawings for more details)
Fenestration		
Window	Windows inevitable leak and could leak into the house	A back damn and ZIP liquid flashing around windows ensure proper drainage even if a leak were to occur. (see construction drawings for more details)
Window	Condensation can occur on the interior lite of the IGU in cold weather	Fiberglass windows can withstand this potential condensation occurrence.
Window	Air leakage can occur around window frames	All window jambs are to be sealed with low expansion window foam or caulk. This satisfies Item 5.2.4 of Thermal Enclosure requirements in ENERGY STAR. (see construction drawings for more details)
Window	Noise pollution	Deploying our air tight construction methods with thermally broken wall framing provides a great buffer from unwanted noise from University Dr.

Table 04.2.1– Team's checklist for building enclosure durability (cont.)

	Common Building Envelope Issues	Preventive Solutions
Construction and Architecture		
Miscellaneous	Ignoring passive solar design	These homes are optimized for passive solar design while taking advantage of a beautiful view of the mountains. This is all achieved while still providing a street presence for each unit. The southern ceiling of the home is lifted to enhance the view and allows solar radiation to penetrate deeper into the home. This is lifted in a way that does not compromise the simplicity, cost effectiveness, and performance of a vented attic. The southern windows were selected with a high SHGC at 0.5.
Miscellaneous	Excess summer heat gain	The roof overhangs are properly sized to reduce the direct solar radiation in the harsh summer and a low SHGC on the western facade of the home reduced unwanted heat gain later in the day. The western trees also help in reducing unwanted western heat gain.
Miscellaneous	Complex "architectural features" such as bump outs, changes in wall planes, etc. an result in difficult details and can result in improper installation of air boundaries	Each side of the duplex is designed as a simple box without bumps, jogs, or overhangs to avoid these complex building enclosure details. This reduces cost and provides a tighter better performing product. The exterior finishes, which are outside of the control layers, varied in material to provide architectural interest without compromising the simplicity of the building envelope.
Moisture Control		
Water Management	Roof run-off water hitting above-grade walls and foundation	Roof gutters and downspouts are to be installed on the north side, which are directed to rock garden swales providing proper drainage around the home. On the southern side rock gardens control the splash of water coming from the roof. This satisfies Item 3.2 of Water Management requirements in ENERGY STAR. (see construction drawings)
Water Management	Water running to the house from roof rain water and improper drainage	Water is collected in gutters on the north side of the home and is directed around the home via rock garden swales which are located 10' away from the home to keep the drainage away from the foundation. Form-A-Drain allows for complete foundation drainage directing water away from the foundation. This satisfies Item 1.2 of Water Management requirements in ENERGY STAR. (see construction drawings for more details)
Water Management	Rain water penetrating behind the siding	Siding to be installed on 1x4 furring strips with SV5 sturdy strips on the top and bottom of the ventilation layer provides an excellent rain screen allowing for proper drying and continuous drainage plane behind the siding. This satisfies Item 2.2 of Water Management requirements in ENERGY STAR. (see construction drawings for more details)
Water Management	Capillary action from footing to foundation wall	A capillary break is to be installed between footing and foundation wall. Satisfy Item 1.3 and 1.4 of Water Management requirements in ENERGY STAR. The satisfies Item 4.1 of the Thermal Enclosure requirements in ENERGY STAR (see construction drawings for more details)
Vapor Control	Ice dams and moisture accumulating on the underside of the roof deck causing decay and fungi growth	Proper attic ventilation, installing closed cell spray foam to air seal top plates and penetrations in the attic, and a raised heel truss providing full depth of insulation eliminates the possibility of ice dams. (see construction drawings for more details)
Vapor Control	Porous materials are installed in wet environment leads to mold growth	Materials shall be below the specified moisture content before they are enclosed. This satisfies Item 4.4 and 4.5 of Water Management requirements in ENERGY STAR.
Vapor Control	Condensation inside the wall cavity	2" of XPS rigid sheathing external of the major control layers ensures condensation occurs on the exterior of these control layer. A hygrothermal analysis was performed to ensure that the exterior insulation is a high enough R-Value to keep the condensation plan exterior of the control layers.
Vapor Control	Water vapor from internal loads	Fujitsu mini spits have a dehumidification mode to better control the moisture within the building.

04 // Envelope Durability

04.3 Properties of different envelope systems and materials

There are different components and materials in the building envelope including above and below grade walls, roof, windows, exterior cladding, and insulation materials. Based on experience and a thorough literature review, multiple options were studied and pros and cons of these systems were reviewed. The top three options in each category were selected and different properties of these systems or materials were studied and ranked in more detail. The properties and features that were considered in this section include cost, durability, flammability, local availability, eco-friendly, energy performance, and ease of installation. The ranking is relative to the systems considered in the project and is not based on other options available in the market. Research available in literature, industry partners and advisors experience are also considered in order to rank these items.

Insulation material

There were many different insulation materials considered in this project but the final options that were investigated in more detail were; dense-pack cellulose, dense-pack fiberglass, and closed-cell & open-cell spray foam. The properties of these insulation materials are presented in table 04.3.3. R-value determined the thermal performance of these materials. There are several factors that can influence the R-value for instance, when the temperature decreases the R-value of polyisocyanurate decreases too and it can be even lower than that of XPS in colder climates. Therefore, according to different circumstances, different types of materials should be taken into consideration and thus the one with the best performance can be selected. This design project is in cold climate region in central Pennsylvania; therefore considering the factors such as low temperature are essential in selection of materials and systems. The insulation materials presented in table 04.3.3 were considered in our energy analysis and finally dense-pack cellulose insulation and XPS were selected as cavity and exterior insulation, respectively.

Roof Assemblies

Different roof systems were studied in order to evaluate the pros and cons of various options. Attics or roofs can be designed and constructed to be either vented or unvented. The insulation arrangements of vented or unvented roof assemblies show the feasibility for whether or not to have an attic.

Table 04.3.2 presents the comparison of four roof systems based on different criteria including energy performance, cost, durability, local availability, and ease of construction. Finally, the vented roof with attic space was selected as the ultimate option based on these evaluations, whole-house energy modeling, and separate cost analysis. The thickness of the insulation material was another parameter studied in Energy Modeling and after the optimization conducted by BEopt and REM/Rate it was decided to use R-60. Based on the available research in literature cellulose insulation can be used on a ceiling sloped less than 3/12; therefore, there won't be any problem with using cellulose insulation on pitched ceiling in the attic since the slope is less than 3/12.

Wall System

In order to select the best wall configuration, different wall systems were studied and evaluated based on experience and literature (see Appendix 04 for more information). According to the investigation, the three most commonly used systems in cold climate regions of central Pennsylvania were selected and the pros and cons were studied. Table 04.3.4 presents the comparison of three wall systems based on different criteria including energy performance, cost, durability, local availability and ease of construction. The value ranges from one (poor performance) to five (great performance). The staggered stud wall has great performance on the energy conservation and local availability, while the cost is higher than the other two. In order to make the final decision the energy performance versus cost in the long run was studied and is explained in the Energy Analysis section. Overall, after conducting a whole-house energy modeling the 2x6 advanced framing wood stud proved to have great energy performance and was the most cost effective option.

Basement Wall System

In this project, two major basement wall systems were initially investigated including the cast-in-place wall system and the superior wall system. Table 04.3.5 compares these two systems. From the investigation, the conclusion was that the cast-in-place system has superiority over the superior wall system. Constraints in terms of leveling of the site required for crane operation was the main reason for not using superior wall. The next step was choosing between two different configurations of the cast-in-place concrete basement wall. Based on ease of construction and by taking care of possible moisture issues and condensation, it was decided to put the insulation on the interior side. The first option was 4" XPS rigid insulation and the second option was using 2" XPS rigid insulation and adding a 2x4 wood stud with dense-pack cellulose as the cavity insulation. Based on cost analysis, ease of electrical, and energy performance it was decided to select the second option.

Windows Systems

Different windows systems were studied in order to evaluate the pros and cons of various options. Wood, fiberglass and vinyl window frames were selected as the top three options and Table 04.3.6 presents the comparison of these window frame materials based on different criteria including energy performance, cost, durability, local availability, strength, fiberglass window frames were selected as the ultimate option based on these evaluations, whole-house energy modeling, and separate cost analysis.

The window system is not limited to the framing material. The most important part of this system is the glazing. Various glazing types are shown in Table 04.3.1. ENERGY STAR for climate zone 5 requires a maximum U-value of 0.30. In order to achieve this, an insulated glass system consisting of at least double pane and low-E is required. Additional cost and energy analysis indicates that double pane, argon filled glazing system has the best while staying within budget for our project.

04.3.1 - Typical Glazing Characteristics (from center of glazing)

	U-Value (R-Value)	Visible Light Transmittance	UV Light Transmittance	Solar-Heat-Gain Coefficient
Single Glazing, clear	1.0(1.0)	90%	71%	0.86
Double Glazing, clear	0.5(2.0)	81%	56%	0.78
Double Glazing, low-E, high solar gain	0.35(2.9)	75%	47%	0.71
Double Glazing, low-E, moderate solar gain, argon	0.29(3.4)	75%	47%	0.71
Double Glazing, spectrally, selectivelow-E, argon	0.27(3.7)	78%	23%	0.58
Double Glazing, spectrally selective, low-E, argon	0.29(4.0)	71%	16%	0.39
Double Glazing (1 inch.) with clear Heat film	0.21 to 0.26 (3.8 to 4.8)	20 to 80% (varies with glazing type)	<1% (28% to 53%)	0.14-0.57
Triple Glazing, moderate solar heat, argon	0.2 (5.0)	0.44		0.36

The ratings in Table 04.3.1 show an evaluation of windows systems based on a comparative analysis of information on window rating systems done by the National Fenestration Rating Council (NFRC), the Efficient Windows Collaborative, and Energy.gov. These values are an abstracted evaluation based on the information provided by these sources. Taking into account outside factors such as the State College climate, and the type of occupant likely to live in the duplex, the information that we found had to be adjusted. For example, with values such as durability, we recognize that with proper care a material like wood could be extremely efficient (Energy.gov), however due to these outside factors the value of wood decreases as a durable material.

Cladding

Different cladding materials were studied in order to evaluate the pros and cons of various options. Each material presents its own unique set of strengths and weaknesses and would also give the house a different aesthetic. Wood, fiber cement and vinyl were chosen as top three contestants because they allow the widest range of aesthetic options to complement the surrounding context while also balancing cost and energy performance. Table 04.3.7 presents the comparison of these three cladding materials based on different criteria including energy performance, cost, durability, local availability, and ease of construction. Finally, fiber cement was selected as the ultimate option based on these evaluations, whole-house energy modeling, and separate cost analysis.

04 // Envelope Durability

4.3.2 – Comparison of different roof assemblies based on various criteria

	Vented with Attics	Vented without Attics (Cathedral Ceilings)	Unvented with Attics (Cathedral Attics)	Unvented without Attics (Cathedral Ceilings)
	Roof 1B - 30in Blown Cellulose Insulation	Roof 3A - 11.5in Dense Pack Cellulose + 1in XPS inside Engineered I Joist	Roof 6A - 9.25in Dense Pack Cellulose in Dimensional Lumber + 6in XPS Exterior Insulation	Roof 7A - 12in EPS Structurally Insulated Panel
Energy Performance (R-value)	●●●●●	●●●○○	●●●●○	●●●○○
Cost	●●●●●	●●●●○	●●○○○	●●○○○
Durability	●●●●○	●●○○○	●●●●○	●●●●○
Material Embodied energy	●●●●●	●●●○○	●●●○○	●●●●○
Local Availability	●●●●●	●●●●○	●●●●○	●●●●○
Ease of Construction	●●●●●	●●●○○	●●●○○	●●●○○

04.3.3 Comparison of three different insulation materials based on various criteria

				
	Dense Pack Fiberglass	Dense Pack Cellulose	Open-cell foam	Closed-cell Foam
Cost	●●●●○	●●●●○	●●●○○	●○○○○
Flammability	●●●●●	●●●●●	●●○○○	●●○○○
Ease of installation	●●●●●	●●●●○	●●●○○	●●●○○
Local Availability	●●●●●	●●●●○	●●●○○	●●●○○
Durability	●●●○○	●●●●○	●●●●○	●●●●●
R-Value	●●●○○	●●●○○	●●●○○	●●●●●
Energy efficiency (air tightness)	●●○○○	●●●●○	●●●●●	●●●●●
Eco-friendly	●●●●○	●●●●●	●●●○○	●●○○○

04.3.4 Comparison of three different wall assemblies based on various criteria

	Staggered 2x8 wood frame	SIP (ThermaSteel)	Advanced 2x6 wood frame
Energy Performance	●●●●●	●●●●○	●●●●○
Cost	●●○○○	●●●○○	●●●●●
Durability	●●●●○	●●●●●	●●●●○
Local Availability	●●●●●	●●●○○	●●●●●
Ease of Construction	●●●○○	●●●●○	●●●●○

04.3.6 Comparison of three different window frame material

	Wood	Fiberglass	Vinyl
Energy Performance	●●●●●	●●●●○	●●●○○
Cost	●●●○○	●●●●○	●●●●●
Durability	●●●○○	●●●●●	●○○○○
Local Availability	●●●●○	●●●●○	●●●●●
Strength	●●●●○	●●●●●	●●○○○

04.3.5 Summary of the comparison of two below-grade wall systems

	Cast-In-Place (CIP)	Superior Wall
Energy Performance	●●●●●	●●●●●
Economy	●●●●○	●●●●○
Local Availability	●●●●●	●●●●○
Ease of Construction	●●●●○	●●●●●

04.3.7 – Comparison of three different cladding material

	Wood	Fiber cement	Vinyl
Cost	●●●○○	●●●○○	●●●●●
Durability	●●○○○	●●●●●	●●●●○
Local Availability	●●●○○	●●●●○	●●●●●
Construction	●●●○○	●●●○○	●●●●●

04.4 QM #1 Provision

This meets the requirements for ENERGY STAR certification and exceeds the Quality Management provisions outlined in QM#1. The Heritage House exceeds the building envelope, Thermal Enclosure System Rater Checklist levels.

In the context of affordable housing and the goals of our client, the State College Community Land Trust, we have chosen to design to ENERGY STAR standards, along with being a DOE Energy Ready Home. There were multiple influences in this choice; firstly we compared the options, ENERGY STAR, Passive House, NAHB Green, LEED for homes and others. After ample research and deliberation, we found ENERGY STAR to be the most economical choice while still achieving the minimum energy standards required by the DOE for a zero energy ready house. It does not make economic sense for our design to pursue any other standards or certificates and remain in the realm of affordable housing. This home will meet ENERGY STAR standards and will be a DOE Zero Energy Ready Home.

See ENERGY STAR Checklists in Volume II, Appendix 12.

Full works cited in Volume II, Appendix 04.

05 // Indoor Air Quality

Design Drivers

Design Team
- Ventilation for the main spaces of the home.
- High performance ventilation system.
- Low VOC interior finishes and materials, Natural Ventilation.

Race to 0
- EPA's Indoor airPLUS
- ENERGY STAR
- ASHRAE 62.2

Land Trust
- Healthy home
- Reduced allergens
- Natural ventilation

Therefore
- Meet all the requirements for certification.
- High performance ducted ERV to provide fresh air to all the main spaces of the home.
- Low/zero VOC interior finishes and materials.

> I think indoor air quality control is very important since the homes are family homes and having allergies myself, the less allergens the better for health and well being. If a family were to move into a home and realize afterwards that the home was causing allergies/illness to a family member, it would be a financial burden to that family to correct the problem. As a SCCLT homeowner myself, my income is limited and I am on a tight budget and a big expense like that would be very taxing and worrisome to me. Moisture control, especially in a basement, is very important to control mold and mildew.
>
> –Susan Thompson
> SCCLT Homeowner and Board Member

05.1 Overall Indoor Air Quality

Good Indoor air quality (IAQ) is becoming more critical for home owners in todays market. Home owners are searching for air that is comfortable, clean and fresh. IAQ directly affects the health of the occupants, which ranges from fatigue to various respiratory illnesses. Therefore the Hertitage Homes will meet EPA's Indoor airPLUS and ENERGY STAR guidelines.

Different areas of the home produce different pollutants that affect the indoor air quality as a whole, which must be addressed separately. The main indoor air pollution sources are demonstrated in Figure 05.1.1. The three basic strategies the team used to achieve high quality IAQ are source control, ventilation and filtration.

ASHRAE 62.2 requires that natural, or natural plus mechanical ventilation provide whole-house ventilation at a rate of 0.35 ACH, but not less than 15 ft3/min/person. Based on the overall project guidelines, a goal of the Heritage Homes is to meet or exceed the requirements for ENERGY STAR and Indoor airPLUS. ENERGY STAR includes the HVAC system, building materials, radon control, moisture control and pest management. This section considers ENERGY STAR as it relates to purification of the air.

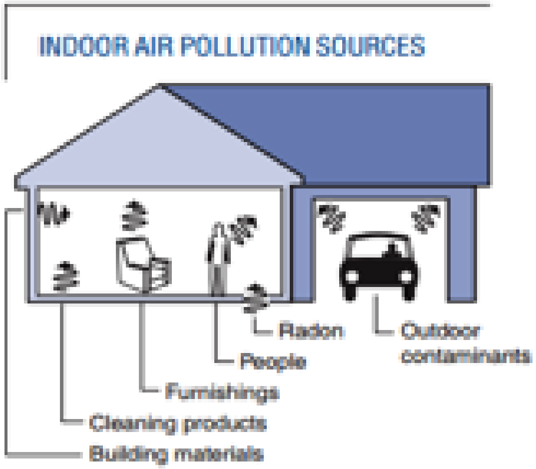


Figure 05.1.1 – Main indoor air pollution sources

05.2 Moisture Control

Moisture control involves maintaining reasonable moisture content, not only inside the home but inside the control layers of the home. We are accomplishing this by satisfying ENERGY STAR's Water Management Checklist. This first involves shedding bulk water that hits the home and properly draining it away from the home. Secondly, all construction materials used in the home should be dried to an appropriate moisture content before the are sealed in. In order to appropriately address moisture control, the following items were analyzed and addressed.

- All surfaces to slope away from the home to ensure proper drainage.
- A 6 mil vapor barrier to be installed underneath the ground floor slab with 2" XPS underneath the vapor barrier keeping the slab warmer decreasing the possibility of condensation and reducing heat loss.
- Capillary break to be installed on top of the footer preventing water from wicking from the ground up into the foundation wall.
- Basement walls to have damp proofing with drainage below grade on the exterior of the wall.
- Exterior walls to incorporate a rain screen outside of ZIP sheathing with properly flashed fenestrations.
- Simple roof design allows for less connections and required flashing.
- All rain water to be drained from roof into rock gardens that direct the water around the homes to a southern water garden.
- Ground water also to be drained to rock gardens via foundation drainage.

Bathrooms and kitchens are known to introduce significant moisture into a home. To address this, each of these spaces need to be ventilated appropriately. Each bathroom is to be outfitted with Panasonic Whisper Green bath fan, which allows the occupant to directly exhaust the excess moisture. The bath fan selected exhausts 80 CFM, which is above the required minimum for intermittent operation of 50 CFM, however, once exhaust ductwork and backdraft louvers are installed the flow will reduce closer to 50 CFM. The range hood will exhaust 100 CFM which is adequate to remove cooking pollutants from the home. The ERV will be used as the rest of the ventilation for the home exhausting stale air from the great room while supplying fresh air to all the bedrooms.

05 // Indoor Air Quality

05.3 Ventilation

An Energy Recovery Ventilator (ERV) was selected as the main ventilation system in order to provide fresh air to all of the spaces of the home while exchanging heat and humidity as the two air streams pass through an enthalpy core. Recovering moisture will allow the incoming fresh air to be closer in relative humidity to the air within the home. The ERV will exhausting stale air from the great room while supplying fresh air to all the bedrooms via the ductwork from the ducted mini-split.

We selected the Fantech SER1504. The ventilation rate and method was selected based on ASHRAE 62.2, which requires a minimum of 7.5 CFM per person + 1 CFM per 100 sq.ft. Based on this calculation our rate would be as follows: 7.5 x 3 + 1440 / 100 = 44.4 CFM of continuous ventilation per home. We plan on running the fan at 117 CFM for 9.1 hours a day, which is an equivalent amount of ventilation. This results in 61% sensible heat recovery and 55% total recovery. The unit also has two washable electrostatic panel type air filters 8.5” x 15” x 0.125” included. Please find more details provided about ERV features in Appendix 05.

Figure 05.3.1 – Fantech ERV SER1504

05.4 Radon Control

A passive radon mitigation system shall be installed. The interior side of our foundation form-work, Form-A-Drain, has a channel that can be used for radon collection. The Form-A-Drain will be connected to a 3” PVC pipe running up through an interior wall of the home (allowing for a larger draft due to the warmer pipe), through the attic, out through the roof. An outlet shall be installed in the attic in close proximity to the radon pipe to allow for a possible installation of a radon fan if the tested radon levels are above acceptable levels once the home is constructed.

05.5 Noise Control

Heritage Homes will reduce sound transmission between the outside and inside. Noise transmission needs to controlled because the two homes will have a common wall, which will be two separate framed walls. Additionally, we want to reduce noise transmission from University Dr. Noise control is accomplished via the use of dense pack and loose fill cellulose insulation, open cell spray foam in the rim and band joists, closed cell spray foam for air sealing, foam filled fiberglass frame air tight windows, and a zip wall system to ensure an air tight well insulated home, resulting in low sound transmission.

05.6 Pest control

All siding and framing is held up 6” at a minimum from the ground plane. A termite barrier is to be accomplished by a pressure treated sill plate and metal flashing below the rain screen. All foundation and wall joints are the be sealed reducing the possibility of pest infiltration. Insect screens to be installed on all air intake and exhaust locations.

05.7 Pollutants

Heritage Homes were designed with the reduction of unnecessary pollutants in mind. Therefore, no combustion appliances are used in the homes, this is the only way to completely eliminate any potential pollutant via combustion.

Instead we considered ideas to naturally clean the air with less expensive and natural methods to attain good indoor air quality e.g cleansing plants. Plants such as Aloevera, Sansevieria Trifasciata 'Laurentii', Spider plant, and Bamboo palm are known to absorb harmful pollutants from the air. There are also microorganisms associated with the plants that are present in the potting soil and these microbes are also responsible for much of the cleaning effects.

Figure 05.7.1 - Plant Types

05.8 Building Materials

No-VOC paints and adhesives are used to furnish final wall surface finishes. Composite wood materials are specified for low-formaldehyde emissions. Marmoleum is to be installed in the first floor bathroom and kitchen as it is made of natural substances and gives out little to no harmful pollutant.

In order to achieve client's expectations, we have two options for interior flooring: Hardwood flooring and "Marmoleum" (Natural linoleum). The diagrams (Decision Webs) below in Figure 05.8.1 shows the comparison between both products. These comparisons are based on six major categories including Energy, Environmental, Social, Financial, Aesthetic, and Technical aspects.

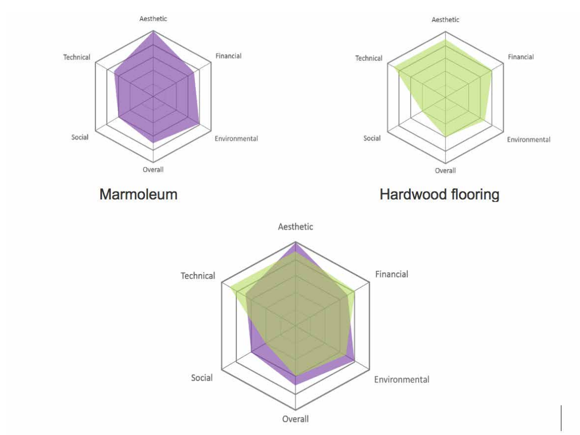


Figure 05.8.1 – Decision Webs comparing different aspects of Marmoleum and Hardwood flooring

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http://www.nrel.gov/docs/fy03osti/26466.pdf
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06 // Space Conditioning

Design Drivers

Design Team
- Site-specific passive design to reduce the heating energy needed by the mechanical system.
- High performance
- Simple design with simple controls to increase usability while decreasing initial cost and maintenance.

Race to 0
- Energy Efficiency
- ENERGY STAR
- Correct sizing

Land Trust
- Affordability over the life of system
- ENERGY STAR
- High performance

Therefore
- Select the most affordable mechanical system when considering the entire life of the system.
- High performance
- Best system to achieve net-zero

> "The fact that this home will have the highest efficiency heat pump available on the market is a big selling point. Heat pumps have become a more desirable heating and cooling system, especially as technology develops, prices drop, and the fact that they are adaptable to different power sources."
>
> –Scot Chambers Green Realtor with Keller Williams, Industry Mentor

06.1 Performance Objective

Heritage Homes were established on the philosophy of creating high performance living in harmony with the community. In order to execute high performance conditioning on these homes, we knew that the house design must be integrated with the mechanical system. Before initiating design, our philosophy was to create a well insulted, air tight home thus minimizing the mechanical loads.

Passive solar design and high performance building envelope methods including building orientation, floor plan layout, window design, and careful, proven details, work together to reduce the heating and cooling loads for the Heritage Homes. From schematic design, an open concept on the main floor was decided not only to maximize the feel of space in the small home, but allow for a simple mechanical system; possibly a wall mounted mini split. A wall mounted mini split can condition the entire main floor comfortably while eliminating the inefficiencies and cost of ductwork. The bedroom floor was designed while allowing for a possible location for ductwork. The bedrooms design strategy was to align to save costs and create smaller duct runs. Considering this from the beginning stages of design allowed Heritage Homes to have a more efficient layout, design, and be more cost effective. This integrative design approach allowed the mechanical system to act as a secondary heating system as we consider the sun our primary heating system.

Our key space conditioning design strategy was to meet the clients' needs while providing the most efficient equipment, yet the most economical over its lifetime. Before initiating design, we knew these residences would be low-load homes. A low-load home reduces the mechanical load by utilizing a tight and systematically designed building envelope in conjunction with a small footprint. This strategy does present a unique set of challenges when designing space and it's associated conditioning systems.

06.2 Heating and Cooling Systems

Since Heritage Homes were designed as low-load homes, there are unique circumstances to consider when selecting the heating and cooling systems. We knew low-load homes should consider variable speed condensers and air handlers that can ramp down capacity to meet the appropriate load. We did not know, yet, which systems were available and their pros and cons. Our industry mentor Andrew Poerschke, from IBACOS, helped us strategize our mechanical options: ducted air source heat pumps (ASHP), mini splits, and high velocity systems. Poerschke informed us that one issue for low-load homes, short throw which can lead to improper mixing causing stratification resulting in a uncomfortable environment.

ASHPs are typically available in 1.5 tons or larger, in the United State, which we believed would be too large for the loads in Heritage Homes. Confirmed with IBACOS, smaller ASHP units are not commonly available within the United States. Yet, even if smaller ASHPs were available, stratification could still be an issue.

When deciding between mini splits and high velocity systems, the choice became less clear. Mini splits are available in smaller BTUs per hour and are capable of ramping down capacity, but the ducted units could still have issues with stratification. High velocity systems allow for low cfm at high velocity which eliminates stratification through better mixing, but proven performance of these systems with respect to low-load homes is preliminary at best. To assist with the decision, we deferred to IBACOS. Poerschke's ongoing research compares mini splits, both wall and ducted, and high velocity systems in a set of town homes in Denver. Initial results point to high velocity systems as an option, but further research is required to prove them as a viable long-term solution. IBACOS may complete their data collection and comparison of these two systems before the Heritage Homes.

06.3 Heating & Cooling Loads

The Manual J, D, T, and S calculation were performed for each zone within the homes using Wrightsoft HVAC Design Software. From the report obtained, the total heating load for both units (East & West) is 19897 Btuh , while the cooling load is 24,372 Btuh. A summary of the load distribution within both units has been averaged out in the Table 1 and Figure 06.3.2 and 06.3.3. Please reference Appendix 06 Wrightsoft Report for more information on Manual J calculation. Manual D calculations were only performed for the ground floor, as referenced above the first floor uses a wall mounted mini split. and Weather data for Williamsport, PA was used as it was the closest in climate to State College, within WrightSoft. The average load for each home is presented in Table 06.3.1.

06 // Space Conditioning

Table 06.3.1 – Combination of East and West units load calculations

Entire House Average				
	Heating		Cooling	
Components	Btuh	% of load	Btuh	% of load
Walls	3247	30.225	1095.5	8.95
Glazing	4165.5	38.85	4456.5	36.575
Doors	0	0	0	0
Ceilings	175	7.2	540	4.525
Floors	771	6.8	37	0.325
Infiltration	422	6.675	100	0.8
Ducts	0	0	111	0
Internal Gains	0	0	4620	35.05
Ventilation	1168	10.25	1226	13.775
Total	9948.5	100	7897	100

Some advantages of mini split slim ducts are as follows:

- Low static pressure requires simple duct design, resulting in less frictional loss.
- High energy efficiency
- Allows for more head room
- Simpler installation

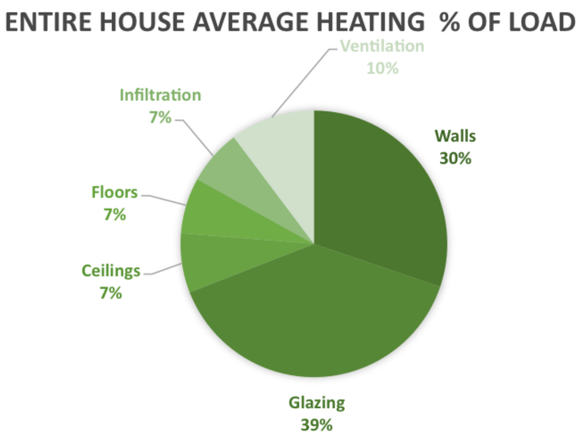


Figure 06.3.2 – Entire house average heating % of load

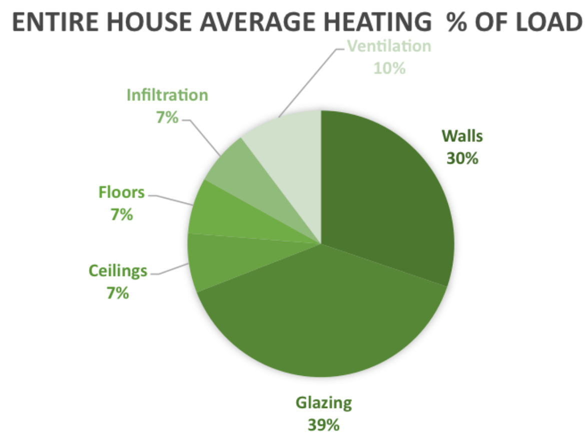


Figure 06.3.3 – Entire house average cooling % of load

Even though mechanical system maybe slightly oversized, the mini splits have variable speed air handler and compressor which can modulate down to the lower required loads.

06.4 Equipment Selection

Most ASHPs aren't able to produce significant heat output at low temperatures and rely on back up electric resistance. The Fujitsu systems selected are able to provide heat output down to 20 F and operate down to -5 F. Therefore, electric back up heat will not be required to satisfy the heat load even on the coldest days. The wall mounted unit was released in spring of 2015 and was introduced to our team by our Industry mentor Pete Vargo. This unit, according to Fujitsu and verified by the AHRI Directory, is one of the highest efficiency mechanical systems on the market. Both systems achieve our design goals including, efficiency, affordability, simple controls and maintenance.

Figure 06.4.1 demonstrates the wall mounted units occupancy sensor which allows the unit to go into a sleep mode and will kick back on once movement is detected.

Features: FUJITSU *AOU9RLFC*	
Cooling Min. ~ Max. Cooling *BTU/hW*	3,100 ~ 12,000
Min. ~ Max. Heating *BTU/hW*	3,100 ~ 22,000
SEER *BTU/hW*	33.0
EER *Clg/Htg*	18.0
Moisture Removal PT./H(l/h)	2.6(1.6)
Noise Level dB (A)	42/41
Refrigerant	R410A

Table 06.4.2

The slim duct (AOU9RLFC) supplies a total of 11,561 Btuh of heating and 12,655 Btuh of cooling to the ground floors in the both units. While the ductless unit (AOU9RLS3) supplies 10,777 Btuh of heating and 11,717 of cooling to the 'great room'. Also, in order to comply with Indoor airPLUS requirements, MERV 13 filters shall be installed.

07 // Energy Analysis

DESIGN DRIVERS

Design Team

- Intertwine efficient "architectural design" and "efficient systems".
- Find the optimum combination of conventional systems instead of innovative and expensive options.
- Use whole-house model for decision making.

Race to 0

- Consider energy efficiency in all aspects of the home.
- Meet the DOE Zero Energy Ready Home HERS rating.
- Zero energy ready.

Land Trust

- Use passive systems including thermal mass and passive solar strategies.
- Having PV panels as an option.
- Tenant's comfort is in higher priority.

Therefore

- Consider the best possible architectural design and passive design solutions in regards to energy efficiency.
- Obtain the optimum building envelope and mechanical systems using BEopt and REM/Rate.
- Optimize energy efficiency in the design by using whole-house modeling while considering the construction and energy related costs.

> If solar doesn't happen because of budgetary constraints, pre-designing the home for future installation of solar photovoltaic panels makes eminent sense. As the homeowners have increasing disposable income they will be able to take advantage of this possibility.
>
> –Jerry Wettstone Realtor, Kissinger-Bigatel & Brower, Board Member, State College Community Land Trust

Standards and Whole Building Approach

One of the major decisions our group has made revolves around the selection of standards that we are using to design. In the context of affordable housing and the goals of our client, the State College Community Land Trust, we have chosen to design to ENERGY STAR standards, along with being a DOE Zero Energy Ready Home. There were multiple influences in this choice; firstly we compared the options, ENERGY STAR, Passive House, NAHB Green etc. At a closer look ENERGY STAR is the most economical choice while still achieving the minimum energy standards required by the DOE for a zero energy ready house. It has been researched and documented that it does not make economic sense for our design to pursue any other standards or certificates and remain in the realm of affordable housing. This research was completed and published by Professor Lisa Iulo and Shahrzad Fadaei.

Although the registration and certification fees for different systems are not more than a couple thousand dollars, in an affordable project these numbers are considerable. In all certification programs, ENERGY STAR is the least expensive one with ½ to 1 cent per square foot. Apart from registration fee, the upfront cost of making improvements is in fact the bigger investment required to get certified. Again, ENERGY STAR is the easiest and most inexpensive system to pursue which is the reason why it has the highest number of certified homes (more than 77k). While programs such as Passive House or Living Building Challenge take a more holistic approach toward sustainability, they are not the best choice for affordable housing, especially in the small scale of our project. ENERGY STAR, which serves as a benchmark for many other certifications including DOE Zero Energy Ready Home, would be the best option for our sustainable affordable homes.

We will additionally be participating in utility incentive programs and looking to engage appliance rebates. Our team has designed with a "whole building approach." In short each piece of our work has influenced another. From the beginning of the design we thought about the building envelope, the mechanical system, the sun, the views, and we thought about all the different parameters that the building interacts with. For example, we wanted to keep our design a simple square make the envelope tighter with fewer connections. We also wanted to raise the ceiling to let sunlight penetrate deeper for increased passive solar gain.. We also specifically shaped the roof to allow for photovaltaics and kept the great room large and open so that it could be controlled by one mechanical system that was premeditated to be mini-splits as we knew this would be a low load home.

Energy Analysis

The two levels of analysis and design that are used in this project to help design an energy efficient house are a "general" level and an "in-depth" level. In the initial level of analysis and design, referred to as "general" analysis, different schemes of the building were investigated in terms of energy consumption and construction cost using BEopt. Although there are rudimentary solutions which can be used to decide which scheme is the most efficient, BEopt was used as it is quantifiable and was useful to the team in finding out the difference between concepts in terms of energy consumption. The second level of analysis and design that is referred to as "in-depth" level was conducted by both BEopt and REM/Rate. It would be a long process to do an optimization by REM/Rate since it can compare just two options; therefore, BEopt was initially used to narrow down the multiple options that were obtained from literature, industry mentors, and advisors by conducting whole-house energy modeling. REM/Rate was used to select the final optimum design and to obtain the HERS score for both Zero Energy Ready and Zero Energy Home. The whole energy analysis process is illustrated in Figure 07.0.1.

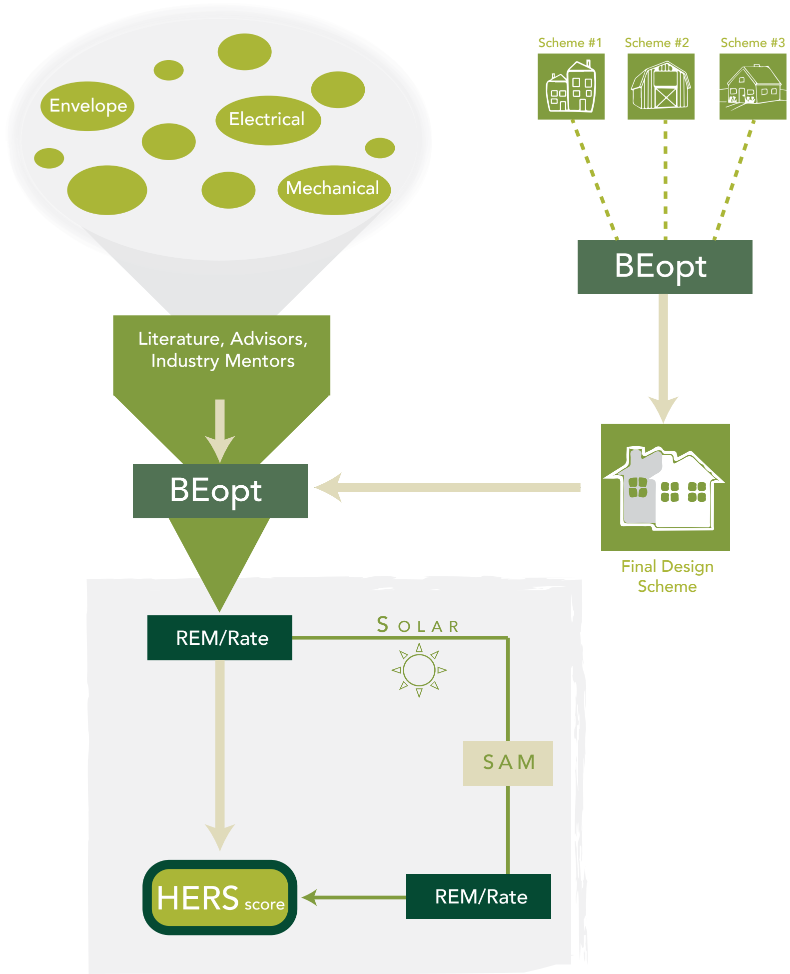


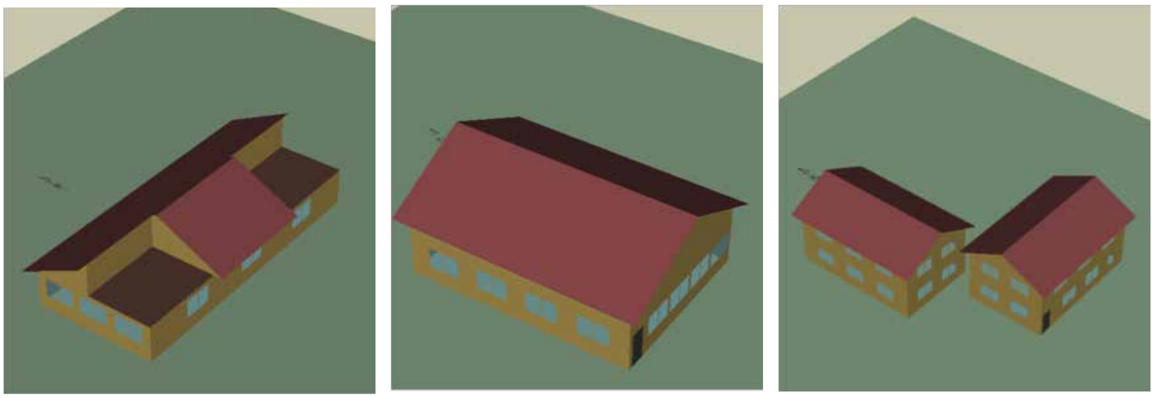
Figure 07.0.1 – Energy analysis process

Energy Analysis

07 // Energy Analysis

07.1 General Analysis

After we proposed our individual concepts for the design of the duplex, we narrowed down the options to three schemes as primary designs to be investigated. The initial analysis revealed that the Farmhouse, Bank Barn, and Split Box, shown schematically below, had energy consumption values of 131.7 MMBtu/year, 159.5 MMBtu/year, and 191.8 MMBtu/yr, respectively. Figure 07.1.1 shows the comparison of source energy consumption per year of the different schemes. Detailed outputs can be found in Appendix 07.



Farmhouse Bank Barn Shifted Box

Figure 07.1.1 – Three primary schemes that were considered in general analysis and design

07.2 Initial Development

Based on the energy analysis outputs, discussion with the State College Community Land Trust (SCCLT), comfort, architectural aesthetics, pros/cons and main goals the team agreed on a single scheme to be developed. Some conditions from the Land Trust were in contrast with an ideal energy efficient design. For example, shifting the two dwellings was important to the SCCLT for privacy purposes which leads to an increase in the building envelopes surface area and therefore heat loss. However, comfort of the tenants is a high priority for the team and based on primary energy analysis it is evident that a slight shift does not have a significant effect on energy consumption. Another constraint in designing a Net Zero house was the high window to wall ratio requested by SCCLT, which is not conducive to energy efficient design. The team tried to solve such issues by improving other areas of the design in order to compensate.

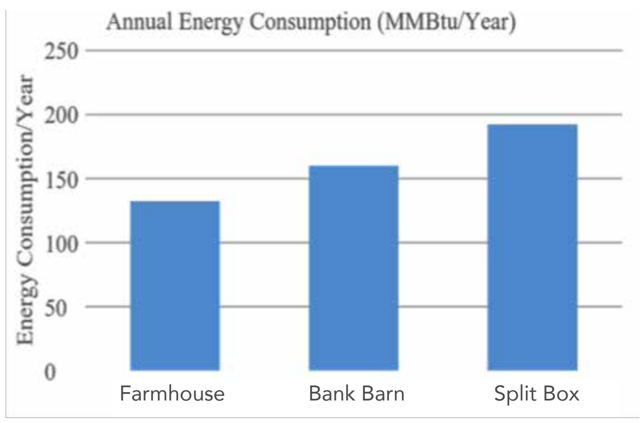


Figure 07.1.2– Annual energy consumption for each scheme

07.3 In-depth analysis

In this secondary analysis level, both REM/Rate and BEopt were used to inform the optimum design in terms of energy efficiency and construction cost. This stage was predominantly about making decisions about the components of the house including; building envelope, appliances, mechanical systems, selection and surface area to wall ratios, insulation materials and ceiling pitch. These areas were investigated based on industry research, previous experience and were informed by the energy analysis. In many cases, innovative and highly effective options were exchanged for more conventional and local options in keeping with the development's affordability goals. The component and system options were narrowed down to 3 or 4 options based on findings in reports and papers published by Building America, DOE, journal papers and other relevant material that are cited in "Envelope Durability" chapter. (energy performance comparisons - Figure D, found in Appendix 07)

07.4 Software

The team used BEopt as the preliminary design tool to make initial design decisions and later as an optimization tool for the building envelope and components. This was in order to select the most cost efficient option for the dwelling over its lifespan. Limitations in BEopt include; not being able to model the sloped lot, boundary conditions of basement walls, overhang lengths for each facade and combined mechanical systems. Due to these limitations and DOE requirements, REM/Rate was used for some optimization and for the final evaluation after BEopt was used to select the most viable options.

Additionally, it is difficult to check the combinations of different items in REM/Rate as it does not have an optimization feature which can compare to BEopt's. REM/Rate is able to output comparisons between two items at a time which was instrumental in deciding aspects of the design and used to inform the BEopt model. BEopt's optimization feature takes into account costs, lifespan and energy consumption. (calibrated energy performance comparisons - Figure E, found in Appendix 07) In doing optimizations in BEopt it can be observed if other systems, such as mechanical, have any influence on the performance of different building envelope configurations.

07.4.1 REM/Rate

In order to ensure the accuracy of the results from the final REM/Rate model, various strategies were instigated. Throughout the REM/Rate process, its outputs were evaluated next to BEopt. Although there are many differences in the input details due to the limitations of both programs, the results were close enough to imply the model was fairly accurate. In order to eliminate any errors from comparing different programs, the initial REM/Rate model was also compared to an existing, accurate ENERGY STAR compliant model from a previous project and was successful in showing very similar results.

07.4,2 Model Accuracy

Several iterations of REM/Rate models were made or altered for many different purposes. The first model was based on modeling the duplex as "Duplex - Whole Building" for initial comparisons and design decisions. Due to the dwelling operating as two separate units and not sharing utilities it was decided a second REM/Rate model was needed to model half the duplex. This eliminated issues with doubling up the miscellaneous electric loads. REM/Rate is innovative enough to allow one side of the duplex to be modeled as "Duplex: Single Unit" and the connecting walls are modeled as party walls between two conditioned spaces. This second iteration was used to output improvement analysis information which was instrumental in informing many design decisions from the building envelope to solar array design. For the final step, due to differences in the design of both halves of the duplex, it was determined that two final REM/Rate models would be made, one for each household. Results from this showed 2% energy consumption difference therefore, the worst case scenario, being the Eastern half, has been used to provide the final results.

07.7 Design Decisions

Comparisons between materials and design strategies were compared in REM/Rate using improvement analysis and fuel outputs. Different wall construction and insulation values were tested along with basement wall design, roof insulation value and window/wall percentages. During the development stage, this information, in combination with optimization results from BEopt were very useful to the building enclosure team and informed many decisions based on the building enclosure and energy and economic efficiency. Some of the results from this analysis can be found in Appendix 07.

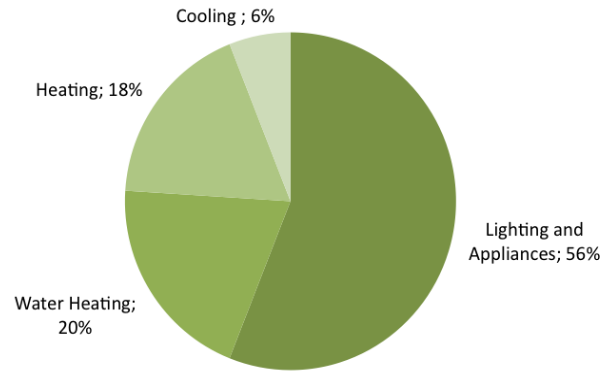


Figure 07.8.1 - REM/Rate Results: Average Duplex, Annual End-Use Cost Graph

Note: More information on the solar array can be found in the next section. The fuel output and building information and assumptions summary can be found in Volume 2, Appendix 07.

07.8 Final Results

The final REM/Rate model used to represent the energy analysis of the duplex in the Eastern half. The annual end-use cost chart for east and west units is demonstrated in Figure 07.8.1. This showed a HERS rating, without a solar array of 37. A solar array is therefore essential to reaching net zero. The HERS score with the solar array is -4. This value is negative as REM/Rate does not consider shading when calculating the efficiency of a solar array.

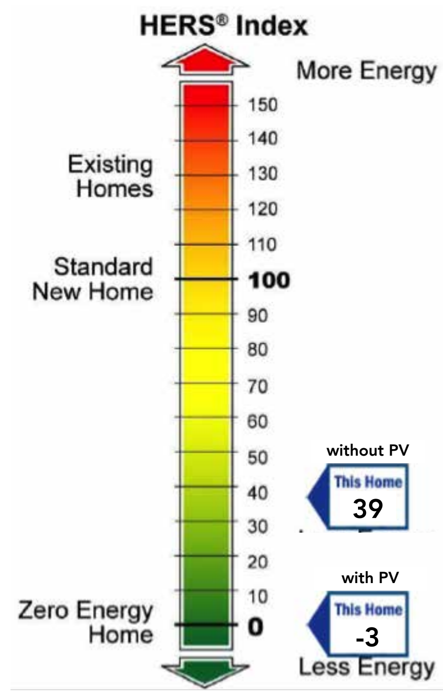


Figure 07.8.2 - HERS index score

07.10 Solar PV Array

07.10.1 Renewable Energy Selection

Solar is the obvious option for this duplex to bring it to Net Zero. During the initial stages of the design, various options were considered in regards to efficiency, location and economic sense. The sites location does not allow for wind or hydro energy, and the economic considerations of the design in order to ensure it is within the requirements of SCCLT eliminate any particularly innovative options due to expense. The site is ideal for solar as it faces south and has a slight downhill slope. Although there is shading from surrounding trees, it is located in a low density neighborhood and therefore is not shaded by any surrounding dwellings. PVwatts gave a 4.15 kWh/m^2/day rating which is significant enough to ensure a successful solar PV array.

07.10.2 Design Decisions

In the early stages of the design process, optimum solar design conditions were kept in mind. They helped inform the building orientation, roof design, building position on site and mechanical design. The building is orientated 10 degrees off south towards the east, which is ideal for morning sun. The roof design is even on both sides to allow for equal distribution between the separate households and has a relatively high pitch which allows the solar panel framing system to be mounted directly on the roof, saving installation cost. The building is positioned as optimally as possible, taking into account setback requirements and surrounding trees. The entire building's mechanical system has been kept electrical to allow a 100% solar power offset. Although a continuous roof would prevent possible shading from the east duplex on the west duplex, the design decision to setback one household was chosen in accordance with SCCLT's and the group's wishes for aesthetic purposes.

07.10.3 Shading Constraints

The shading from the trees on the site was identified early on as a possible hindrance to an efficient solar array. A Solar Pathfinder was used initially to confirm that this would be an issue; however, site conditions were not ideal for getting a reading at roof height. Therefore the information was gathered at ground level and considered informative, but inaccurate. Measurements and photos of the site and trees gave enough information to create an accurate representation of the site in SketchUp which was put into NREL's System Advisor Model (SAM). This, in combination with energy consumption information from REM/Rate was used to design a solar PV array which would satisfy the needs of the duplex. SAM was used as it provides more detailed solar information than the PVwatts Calculator.

07.10.4 Informing the Design

Initially the duplex had a typical water heater and an electric baseboard for the ground floor which are both energy intensive. Through cost benefit analysis it was decided that it would be more cost effective to have a heat pump water heater and a ducted mini split heat pump for the ground floor to reduce the demand on the solar array. DOE recommends developing a better building envelope to reduce the HERS score and hence the dependency on a solar array; however, our analysis through BEopt and REM/Rate showed it was more cost efficient to compensate with a slightly larger array. This allowed the solar area to fit onto the roof.

07.10.5 Selection

Monocrystalline Silicon PV panels were chosen for their high efficiency. SunPower panels were considered the best brand as they are of the highest quality and can be locally sourced and maintained. REM/Rate's results show that 6,968kWh/yr per duplex must be offset by a solar array to reach net zero. As shading is not considered in REM/Rate, SAM was used to calculate a more accurate solar output value of 7,628kWh/year. In discussion with the design team in regards to the roof size, an array of 6.2kW per duplex made up of (18) 345 W panels arranged horizontally in 3 rows of 6 on each duplex was chosen. This then informed the final decision about roof size in regards to aesthetics and accessibility. This 6.2kW PV array gives a negative HERS score in REM/Rate as it does not account for power loss due to shading.

Our industry mentor Jason Grottini, from Envinity, was consulted and helped us in a final solar PV design which satisfies all constraints.

The maintenance required for this solar array is minimal. As the elements have a 25 year warranty, they will not need to be replaced for a while. As the installers are local, any maintenance needed can be easily performed in the future. Due to a clean location and a high roof pitch, clearing or cleaning of the panels from dirt or snow will be infrequent if at all.

Reference http://pvwatts.nrel.gov/

08 // Financial Analysis

Design Drivers

Design Team

- Invest in durability.
- Explore a variety of options.
- Invest intelligently in renewable technology.

Race to 0

- Relate the design of the home to the real word market place of State College, PA
- Create a financial profile that is within the limits of affordable housing.
- Achieve a zero energy ready home.

Land Trust

- Target homeowner is on the low income range.
- Do not focus on initial cost at the expense of durability.
- Invest in elements that make the home unique.

Therefore

- Invest in durability.
- Design for affordable/low income home buyers.
- Utilize renewable technology to the extent that it is cost effective.

> "I have worked for the State College Community Land Trust since 2000. In that time we purchased, renovated, and sold 32 houses in the Borough of State College. In 2014, we were approached by a SC Borough resident who was interested in selling an undeveloped parcel of land to the SCCLT. The SCCLT's vision is to have a uniquely designed, green duplex built to a good standard on the site by June 2017. We are hoping to have sold the two units as soon as they are livable to income-qualified households."
>
> – Colleen Ritter State College Community Land Trust Program Coordinator

08.1 Financial Analysis

The Heritage Homes are designed to be cost effective homes that focuses investment on durability and strive to achieve net zero capability. Financial parameters are based on a "Market Design" approach. Targeted sales and construction prices were derived from the buyer's financial profile, constrained by an annual payment of 38 percent of the household income. This section outlines the financial profile for the target home buyer, describes the dynamic cost structures that arise from a partnership with the State College Land Trust (SCCLT), and breaks down construction costs on an item by item basis.

The financial analysis is based on a financial profile for a typical home buyer in State College, Pennsylvania. Through discussion with our industry partner, the SCCLT, we targeted a range of income levels that span twenty percent above and below the MFI for State College. Target construction budgets were calculated accordingly. Construction cost includes both units of the duplex.

	Target Construction Cost	Target Cost Per Square Foot
MFI for State College: $66,800	$ 297,000	$ 116
High End Income Level: $80,160	$ 380,160	$ 149
Low End Income Level: $53,440	$ 207,900	$ 84

Figure 08.1.1

The non-construction costs of the home sales price are based on financing, marketing, and sales commission costs. Also included is the cost of the solar PV array and the cost of the finished lot. The table below provides a summary of these costs. Due to the nature of the Heritage Homes project, the team has explored different financing options in which some of these costs (finished lot, and solar PV) are excluded from the total sales price. These explorations will be explained later in the financial section.

Total Construction Cost	$154,862.61
Financing Cost	$ 5,322.17
Marketing Cost	$ 3,801.55
Sales Commission	$ 8,363.41
Solar PV Array	$ 34,326.00
Finished Lot Cost	$ 75,000.00

Figure 08.1.2

The unique nature of the Heritage Homes becomes especially apparent in the context of the financial analysis. The chance to work with the SCCLT presents an exciting opportunity to integrate renewable technology into the core financing of the home.

Often, the model for purchasing renewable technology involves financing the technology apart from the home, using a separate loan. This presents a few different problems.

- In State College, the maximum time length for a junior-lien home equity loan is twenty years. This means the home buyer must be able to afford a monthly payment that is proportionally higher compared to the thirty year mortgage time line of the home itself.
- Interest rates are higher for junior-lien home equity loans, due to a higher risk of default payment from the bank. For example, financing options via a home equity loan with a local bank in the State College area were explored. If one were to choose a junior-lien home equity loan to finance a PV system, the maximum length available was 20 years, and the interest rate was 6.49%-6.74%. In order to reach a lower interest rate of 4.44% to 4.69%, the PV panels must be paid back within five years, drastically inflating the home owner's total monthly expenses.
- With a second (junior-lien) loan for the PV panels, the homeowner is committed to annual payments on the home equity loan even if they decide to move and sell their home. The situation results in a positive externalities, as the home owners carry their debt with them when they move, but they do not get the benefits of the PV system they are still paying off.

08 // Financial Analysis

Due to the inflated monthly costs that a second mortgage home equity loan presents, there is little incentive for the home buyer and developer to purchase and sell a home with solar PV installed, especially when dealing in the lower income range. Therefore, the lowest risk and lowest payment option is one integrated thirty year mortgage on the property, rather than a collection of loans.

In partnering with the land trust, Heritage Homes presents an alternative method of financing the solar PV panels, utilizing the financial model of the SCCLT to integrate the solar PV array into the sales price of the home, so that the home and the sustainable technology can be mortgaged as one unit.

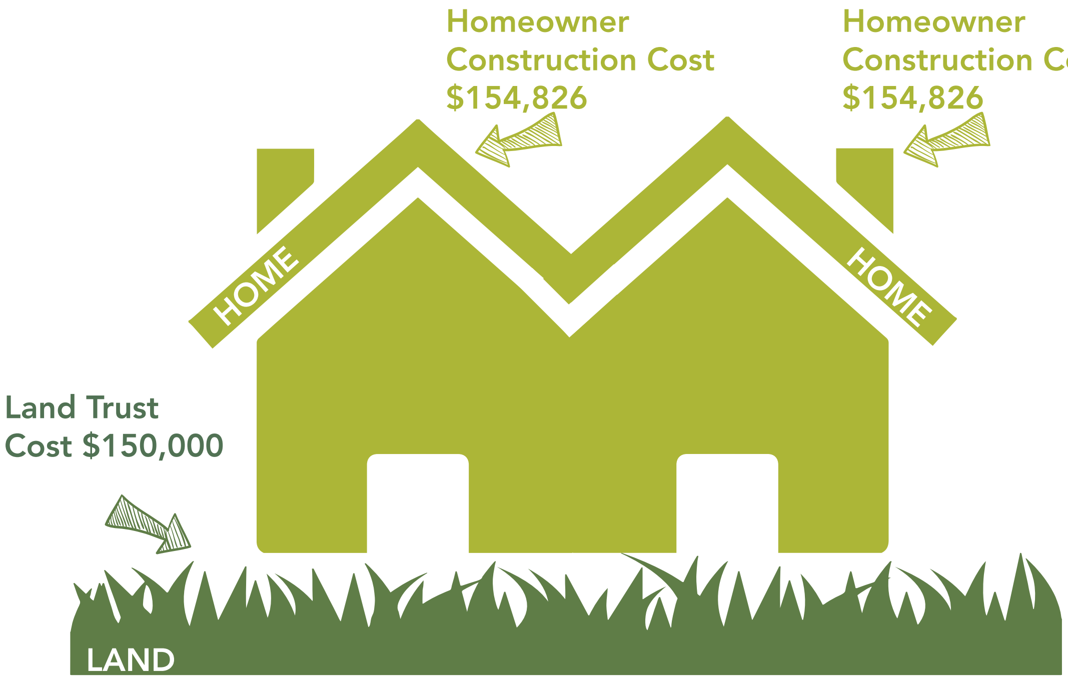


Figure 08.1.3

The SCCLT is a private, non-profit organization whose goal is to acquire and hold land for the benefit of the community and to provide secure affordable access to land and housing for community residents.

The SCCLT purchases homes and the land on which the home resides, then sells the house itself to an income qualified applicant in their program. The land trust maintains ownership of the land, controlling how it will be used in the future. To accomplish this, the SCCLT signs a long-term lease with the new owner of the house assuring them that the property will remain available to them for as long as they remain within the parameters of their land lease. Consequently, the new homeowner need only purchase the improvements to the land, significantly reducing the overall cost of the home.

For the Heritage Homes project, the SCCLT purchased the land for a total of $150,000. Accordingly, each homeowner of the duplex saves $75,000 dollars towards the sales price of their home. With the cost of the land absent, the home buyer has room to add in the cost of the PV array to the sales price of the home. Each PV array costs a total of $34,326 installed, still $40,674 less than what it would cost the home buyer to purchase the land.

Shown in Figure 08.1.4 is a breakdown of four different scenarios for financing the home, using a family income of $66,800 (state college MFI). Two utilize the SCCLT's model, and the other two do not. Each pair shows data with an integrated PV and home mortgage, and with a separate home equity loan for the PV array. After the PV array in addition to the payment of the home, a household debt of $334 per month (0.5% of MFI) is included.

	PV Loan Type	Home Sales Price	Monthly Cost of Home	Monthly Cost of PV (20 yrs)	Annual Cost	% of Income
Cost of Land Included	PV integrated in mortgage	$281,675.77	$ 2,040.51	N/A	$24,486.12	36.66%
	Home equity loan	$247,349.77	$ 1,843.08	$ 314.72	$25,893.60	38.76%
Cost of Land Excluded	PV integrated in mortgage	$206,675.77	$ 1,609.15	N/A	$19,309.80	28.91%
	Home equity loan	$172,349.77	$ 1,411.72	$ 314.72	$20,717.28	31.01%

Figure 08.1.4

The most attractive financing strategy excludes the cost of the land using the land trust's model and integrates the cost of the solar PV array into the total cost of the home. Using the integrated strategy also puts the annual cost of the home within the guidelines of affordable housing, outlined by the U.S. Department of Housing and Urban Development as 30% of the family's annual income.

Using the integrated strategy within the land trust's model, a breakdown of the home owner's 30 year mortgage has been calculated. Below is a table showing the first year's payments.

30 Year Mortgage

	Month	Principal	Interest	Total Payment	Total Principal	Remaining Principal
Year 1	1	$217.73	$620.03	$1,223.69	$217.73	$165,122.86
	2	$218.55	$619.21	$1,223.69	$436.28	$164,904.32
	3	$219.37	$618.39	$1,223.69	$655.64	$164,684.95
	4	$220.19	$617.57	$1,223.69	$875.83	$164,464.76
	5	$221.01	$616.74	$1,223.69	$1,096.84	$164,243.75
	6	$221.84	$615.91	$1,223.69	$1,318.68	$164,021.91
	7	$222.67	$615.08	$1,223.69	$1,541.36	$163,799.23
	8	$223.51	$614.25	$1,223.69	$1,764.87	$163,575.72
	9	$224.35	$613.41	$1,223.69	$1,989.22	$163,351.38
	10	$225.19	$612.57	$1,223.69	$2,214.40	$163,126.19
	11	$226.03	$611.72	$1,223.69	$2,440.44	$162,900.15
	12	$226.88	$610.88	$1,223.69	$2,667.32	$162,673.27
	Total	$2,667.32	$7,385.76	$14,684.31	$2,667.32	

Figure 08.1.5

08.2 Local Tax Summary

Property taxes are based on the assessed value of the Heritage Homes, and are subject to local jurisdiction for the Borough of State College and the Greater Centre County Area of PA. Currently, there is no correlation between borough market values and assessed values. The last assessment on existing homes in the borough was conducted in 1995. Therefore, assessed values range from 25 – 50% of market values. For purposes of the project, the team chose to mark the assessed value of the Heritage Homes at 33% of the market value.

School District Millage rates in the area are especially high for State College home owners. In order to give their home owners a break, the Borough of State College passed the Homestead Exclusion Act in 2006. The act specifies that $25,000 will be subtracted from the assessed value of the home when calculating Borough taxes.

The SCCLT also requires that their homeowners pay taxes on the land, even though they do not have to pay a mortgage based on the cost of the land. According to the SCCLT, the assessed value of the land is $20,000. Therefore, each family in the duplex will pay taxes based on $10,000 in assessed value of the land. The Homestead Exclusion Act does apply to the land tax.

Below is a breakdown of property taxes for a local homeowner with an annual income matching the MFI in State College. The Home Sales price is calculated without use of the land trust's model, so the cost of the land is included in the mortgage for the home buyer. The charts provides a look at what the median home buyer would pay for property taxes on an affordable home in State College.

MFI: $66,800

Home Market Value: $250,000

	Assessed Value of Each Individual Duplex Unit
County and School Taxes	$82,500
Borough Taxes	$57,500
Land	$10,000

Figure 08.2.1

	Millage	Annual Taxes	Monthly Taxes
County	7.84	$ 646.80	$ 54.00
School	39.5056	$ 3,259.21	$ 271.60
Borough	14.4	$ 828.00	$ 69.00
Land Tax (County+ School+Borough)	61.7456	$ 617.46	$ 51.45
TOTAL		$ 5,969.82	$ 497.41

Figure 08.2.3

08.3 Construction Cost Breakdown

On the next page table 08.3.1 details construction costs are based on real time industry prices. All costs are calculated for both units of the duplex. Each homeowner will pay 50% of the total cost.

Initially, the budget was broken down into average percentages compiled by the NAHB in the "New Construction Cost Breakdown." The percentages gave the team target numbers to shoot for during the preliminary design stages.

As design progressed, the team reached out to industry partners for current prices in the Centre County area of PA. Working with industry partners Chad Owens, owner of Timber Rock Homes Construction Company, and Envinity, the team was able to gather unit pricing for materials from recent projects in the local area. The team also reached out to other local construction companies for quotes on various systems and packages.

Utility instillation and permit fees were gathered from the local utilities and authorities in the area.

A more detailed breakdown of construction costs, along with corresponding industry partners for quotes and pricing is available in Appendix 08.

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08.3 Construction Cost Breakdown (cont.)

ACCOUNT / DETAIL		COST	%
Site Preperation			
	Water and Sewer Inspection	$ 2,672.00	1.1%
	Permits	$ 2,111.72	0.9%
	Utility Fees	$ 7,950.00	3.2%
	Landscaping	$ 15,531.00	6.3%
Total		$ 28,264.72	11%
Foundation			
	Excavation and Backfill	$ 16,000.00	6.5%
	Underslab Plumbing	$ 300.00	0.1%
	Footings and Slab	$ 14,248.00	5.8%
	Insulation and Durability	$ 1,757.00	0.7%
	Drain	$ 498.40	0.2%
Total	Foundation - TOTAL	$ 32,803.40	13.2%
Framing			
	Floor Framing	$ 4,335.64	1.7%
	Roof Framing	$ 7,600.00	3.1%
	Wall Framing	$ 14,197.60	5.7%
	Bracing, blocking and waste	$ 1,000.00	0.4%
	Patio	$ 3,913.84	1.6%
	Framing Labor	$ 20,480.00	8.3%
Total		$ 51,527.08	20.8%
Envelope			
	Sheathing	$ 2,004.00	0.8%
	Insulation	$ 8,320.23	3.4%
	Windows and Exterior Doors	$ 7,514.00	3.0%
	Rental and Disposal Fees	$ 275.00	0.1%
Total		$ 18,113.23	7.3%

Figure 08.3.1

ACCOUNT / DETAIL		COST	%
Exterior Finish			
	Roofing	$ 10,899.95	4.4%
	Wall Finishes	$ 6,673.00	2.7%
	Gutters and Downspouts	$ 488.00	0.2%
Total		$ 18,060.95	7.3%
Interior Finish			
	Drywall and Paint	$ 14,196.64	5.7%
	Flooring	$ 8,357.21	3.4%
	Interior Finishes, Doors, and Trim	$ 2,821.20	1.1%
	Lighting Fixtures	$ 10,323.30	4.2%
	Plumbing Fixtures	$ 5,517.40	2.2%
	Cabinetry	$ 8,316.00	3.4%
	Appliances	$ 4,034.09	1.6%
	Interior Labor	$ 3,840.00	1.5%
Total		$ 57,405.84	23.2%
MEP			
	Mechanical	$ 19,605.00	7.9%
	Electrical	$ 13,000.00	5.2%
	Plumbing	$ 9,000.00	3.6%
Total		$ 41,605.00	16.8%
Subtotal		$ 247,780.22	100.0%
Company Expenses			
	Overhead and Profit	$ 49,556.04	20.0%
	Sales Tax	$ 12,389.01	5.0%
	TOTAL COST	**$309,725.28**	

Figure 08.3.1

08.4 Rebate Programs

Two types of rebates were researched for the purposes of the Heritage Homes project; federal and builder rebates. Because the SCCLT is a not-for-profit organization, they do not pay a federal income tax, and therefore do not qualify for federal rebates.

The second type of rebate is a builder rebate. Whether or not the Heritage Homes project will be able to access builder rebates is still a topic of discussion with the SCCLT. Below is an analysis of the potential savings for each unit of the duplex if the project is able to utilize the builder rebates offered by West Penn Power. The rebates includes a base rebate for each newly built ENERGY STAR, as well as additional rebates based on kWhs saved annually.

	Base Rebate	Savings per kWh	Total Additional Savings	Total Savings
West Home	400	$ 0.10	$1,587.50	$1,987.50
East Home	400	$ 0.10	$1,619.70	$2,019.70

Figure 08.4.1

08.5 Solar Payback:

Total kW Output of PV Array	$/kWh	Annual Savings	Payback Timeline
7,628	$0.122	$930.62	30 years

Figure 08.5.1

As per the above table, the homeowner will have paid for their PV panels in a total of thirty years. Thirty years is also the length of the mortgage on the home. This means that in thirty years, the homeowner will both own their home, and pay next to nothing for electric costs. This assumes that the home owners would not be able to receive the federal solar rebate of 30%. This is being investigated by the SCCLT to find a away to make that happen. This also does not include SRECs which would also decrease the payback time.

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09 // Domestic Hot Water, Lighting & Appliances

Design Drivers

Design Team

- Reduce demand and distribution losses to decrease electricity waste.
- Design begins with the site – utilize site potential (lighting based on orientation, slope, shading analysis) to reduce utility bills.
- Incorporate ENERGY STAR certified appliances when possible.

Race to 0

- Maximizing natural daylighting for all regularly occupied spaces.
- High efficiency ENERGY STAR lighting shall be utilized.
- Appliancesto be ENERGY STAR certified.

Land Trust

- Domestic Hot Water system is designed to sufficiently reduce demand and distribution losses.
- Integrated high-performance lighting system that demonstrates affordability and long-term economic efficiency.
- Efficient systems and appliances resulting in lower utility bills.

Therefore

- Modern, energy saving, and economic water heater and lighting systems.
- High performance lighting design.
- ENERGY STAR appliances and lighting.

> "I also like the importance that has been placed on flexible spaces as part of the design. While it is good to designate a purpose for some of the spaces - kitchen, laundry, utilities, etc. - other personal and social spaces can be used in different ways."
>
> –Polly Dunn Board Member of SCCLT; Greenbuild project; Marketing for SCCLT

09.1 Domestic Hot Water

Deciding to go all electric for the Heritage Homes, allowing the homes to be truly net-zero, left the team with four main water heating systems to consider. A standard electric tank water heater, an on demand electric water heater, a heat pump water heater, and a solar thermal water heater with electric backup.

After talking with Brian Ault and Matt Rooke, two of our industry mentors, we decided to rule out an on demand electric water heater for several reasons. The demand on the electric water heater is extremely high, its life expectancy is lower than the other systems, and our industry mentors have experienced problems with them in the past.

After working with Jason Grottini from Envinity, our solar industry mentor, we determined that the initial cost of a solar thermal system was too high for our budgetary constraints of the project, additionally it would not pay for itself when compared to using PV and a standard electric storage water heater.

Figure 09.1.1 Domestic Water Heater [2]

To back up this discussion, Green Building Advisory wrote an article early in 2012 titled "Solar Thermal is Dead", which discussed how PV coupled with an electric tank water heater was now less expensive than a solar thermal system with electric back up. [1] In 2014 a follow up analysis was performed. The analysis shows that PV coupled with electric resistance was 25% less expensive that solar thermal with back up electric over its lifetime. Additionally, they calculated that PV coupled with a heat pump water heater (HPWH) was 50% less expensive compared to solar thermal. [1] This clearly shows that a HPWH is the best option to accomplish our design drivers.

We chose the 50 Gallon GeoSpring Hybrid Electric Water Heater due to its highest performance in the AHRI Directory backed up with excellent reviews. Although we were initially concerned about how much heat the heating system would need to replace as the HPWH would draw heat of the space it would be located, We are confident that our mechanical system could easily replace the heat drawn from the home and put into the water tank.

Model GEH50DFEJSR

- 50 Gallon Capacity
- 3.1 Energy Factor
- Abundant Hot Water with 67 gallons first-hour delivery
- Electronic controls with 4 operating modes including a vacation setting
- Limited 10 year warranty
- 60 3/4 in x 21 3/4 in x 23 1/4 in
- ENERGY STAR
- Made in America

Figure 09.1.2

The Heritage Homes team selected a PEX home run system for water distribution of the Heritage Homes because of its efficient distribution and low cost.

[1] <http://www.greenbuildingadvisor.com/blogs/dept/musings/solar-thermal-dead>

[2] Figure 09.1.1 - iimage: http://www.geappliances.com/ge/heat-pump-hot-water-heater.htm

09.2 Lighting

A family home should be a well-lit, glare free atmosphere to create comfort. The lighting for the space is created to individualize the space based on the people who inhabit it, by providing sufficient lighting as well as having flexibility on the light level and use task lights where need. The least expensive lighting resource is daylight, which is being taken advantage of as much as possible during the day providing consistent lighting to the interior living spaces. Similar characteristics are being mimicked at night, by incorporating cove lighting in the main living areas of the homes. Combined, the day and nighttime lighting scheme provide and ensure maximum comfort and enjoyable atmosphere for the residents.

The living areas and the master bedroom will be lit using cove lights creating an overall ambiance in the space via indirect lighting. Pendants over the kitchen island and the dining table provide direct lighting and character appropriate for an enjoyable cooking and dining experience. Under cabinet lighting and task lighting in the kitchen and study nook workspaces allow for individual lighting needs.

This is a design for the modern family home, by taking not only the comfort and tasks into consideration but also taking costs and efficiency into consideration. Based on the recommendations on the IES handbook, the windows were placed on the southern facing walls to take advantage of the most basic natural light source and also to minimize the usage of artificial lighting during the day.

As LEDs are replacing the older light sources and becoming the new face of efficient lighting, we are also stepping forth in our design following the path to a brighter future. Of the many lighting source options that are being considered, most of the lighting sources used in the houses are LEDs. Other light sources like fluorescent lights are being used in the closets to lower the costs and still provide sufficient light levels. Different lighting sources that are considered in this study are presented in Table 09.2.1 and are compared based on different features including Life Cycle Cost, Energy Efficiency, Color Quality, Maintenance, Long-term cost, Durability, and Low Heat Output

	LED	Fluorescent	Metal Halide	Incandescent
Life Cycle	●●●●●	●●●○○	●○○○○	●○○○○
Energy Efficiency	●●●●●	●●●○○	●○○○○	●○○○○
Color	●●●○○	●○○○○	●●●●○	●●●●●
Maintenance	●●●●●	●●○○○	●○○○○	●○○○○
Long Term Cost	●●●●●	●●○○○	●○○○○	●○○○○
Durability	●●●●●	●●○○○	●●○○○	●●○○○
Heat	●●●●●	●●○○○	●○○○○	●○○○○
Eo-friendly	●●●●○	●○○○○	●●○○○	●●●●○

Table 09.2.1

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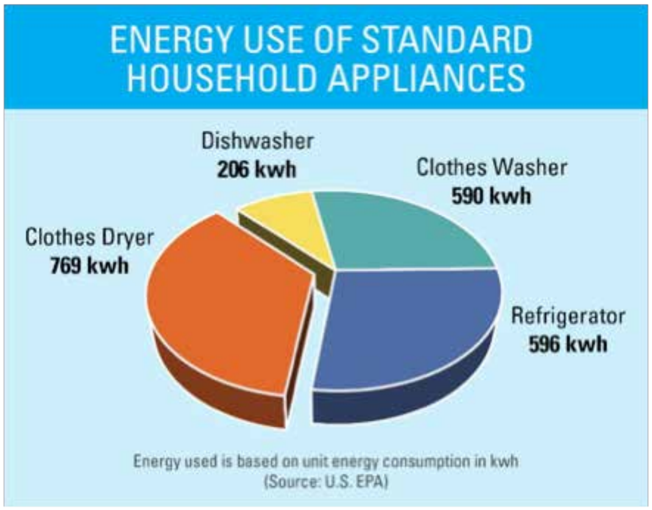
09.3 Appliances

The appliances featured in the Heritage Homes are determined by a set of parameters based on affordability and energy efficiency. For this reason, when possible, only ENERGY STAR appliances are specified for the homes. Additionally, ENERGY STAR appliances use 10-50 percent less energy and water than conventional models without sacrificing features or performance. An induction range is the most efficient cook-top, however we chose to use a standard electric range to save on initial cost. This choice sacrifices some energy efficiency, however the lower initial cost fits within the budget.

Appliance	Size	kWh/yr.	ENERGY STAR	Cost	Characteristics
Range/Oven	30 in.		N/A	$549.99	GE, Model JBP23SRSS, Stainless Steel
Range Hood	30 in.		N/A	$199.00	GE Convertible, Model JV347HBB, Black
Microwave (Over-the Counter)	1.1 Cu. Ft.	279	N/A	$139.00	LG Electronics, Model LCS1112ST, Stainless Steel
Dishwasher	24 in.	170	Yes	$629.10	LG Electronics, Model LDS5040ST, Stainless Steel
Refrigerator/Freezer	23.8 cu. Ft.	501	Yes	$1,079.00	LG, Model LTCS24223S, Stainless Steel
Washer	4.3 cu. Ft.	90	Yes	$719.00	LG, Model WM3170CW, Stackable
Dryer	7.4 cu. Ft.	607	Yes	$719.00	LG, Model DLE3170W, Stackable

Figure 09.3.1 Appliance Schedule.

Furthermore, to achieve true Net-Zero, it's beneficial to have all electric appliances, allowing the PV system to offset all appliance use. The anticipated load for all lighting, appliances, and plug loads is 4449 kWh/yr.



10 // Construction Documents

Design Drivers

Design Team

- Communicate design intent through construction documents.
- Graphic clarity in documentation.
- Sequencing of documents according to construction process.

Race to 0

- Variety of representational methods to facilitate quick reviewer understanding.
- Site/climate-specific detailing takes precedence over generic documentation.

Land Trust

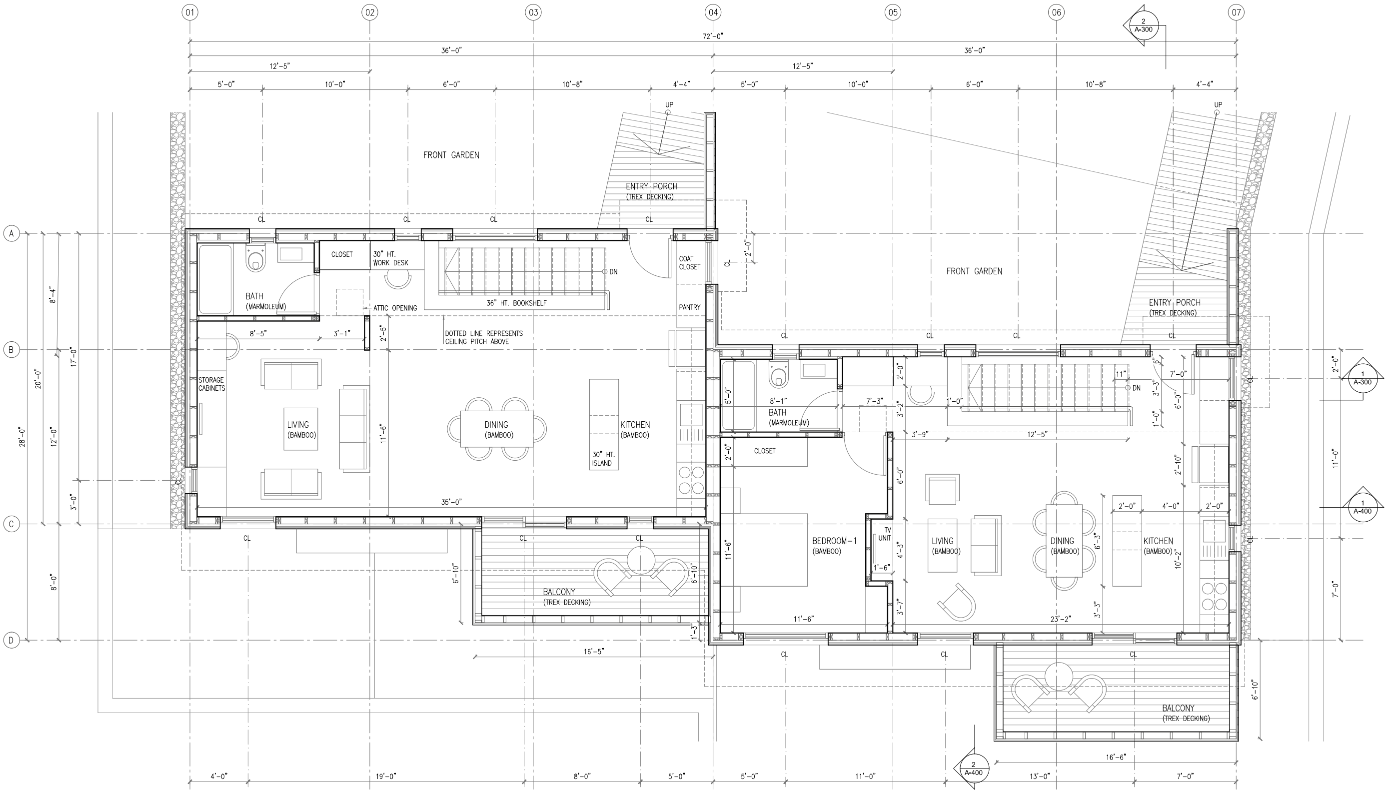
- Should be detailed enough to allow for clarity in pricing by contractor / builder.
- Standardization of information.

Therefore

- Clarity in documentation to convey design intent to builders so as to minimize chances of errors.
- Comprehensive detailing to facilitate third-party understanding.
- Should be detailed enough to allow for clarity in pricing by contractor / builder.

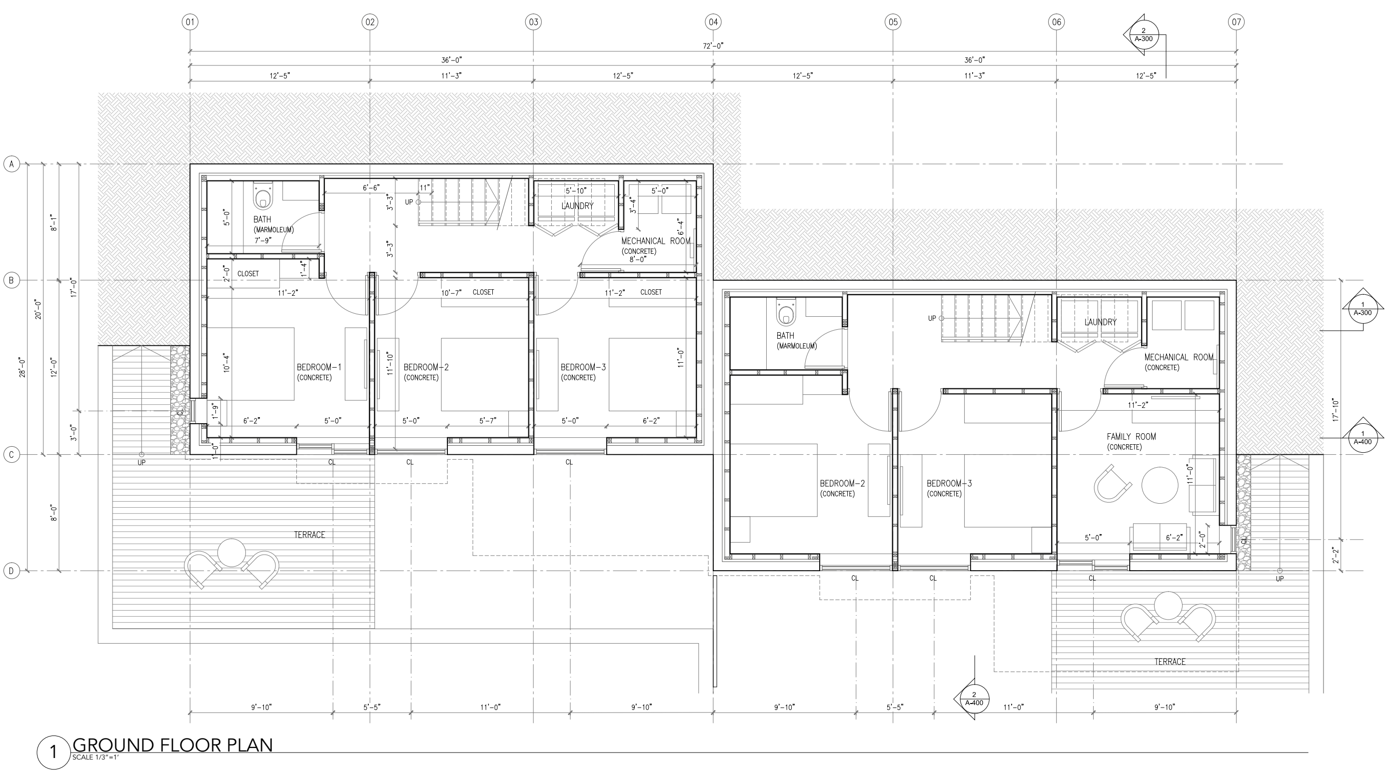
> “I applaud all of you students for taking the initiative to pursue designs that are both high-performance and affordable by developing thoughtful solutions that account for not only the aesthetic value of homes, but the energy-efficiency and cost-effectiveness of the materials and construction methods as well. I have been equally impressed by the documents produced thus far.”
>
> –Chad Owens Industry Mentor, Owner and Builder, Timber Rock Homes

What follows is a sample set of our construction documents. The full set can be found in Appendix 10.



First Floor Plan

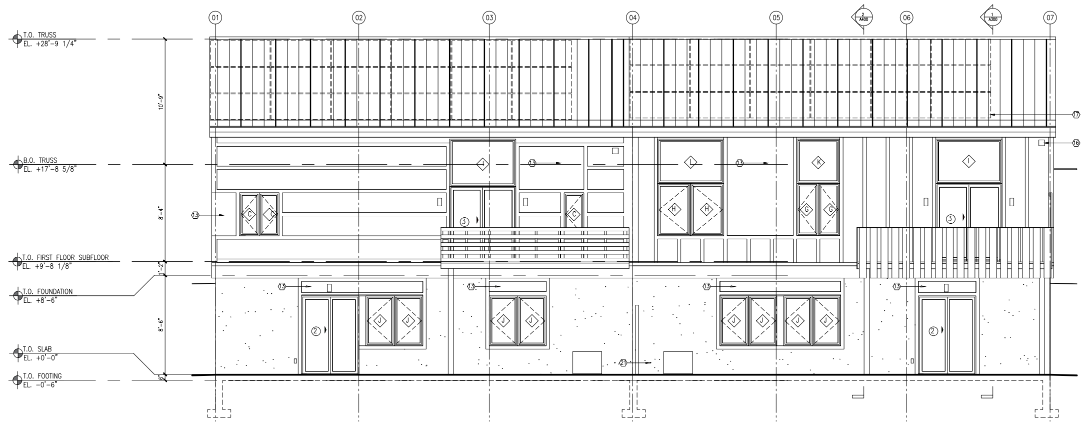
FIG.10.1



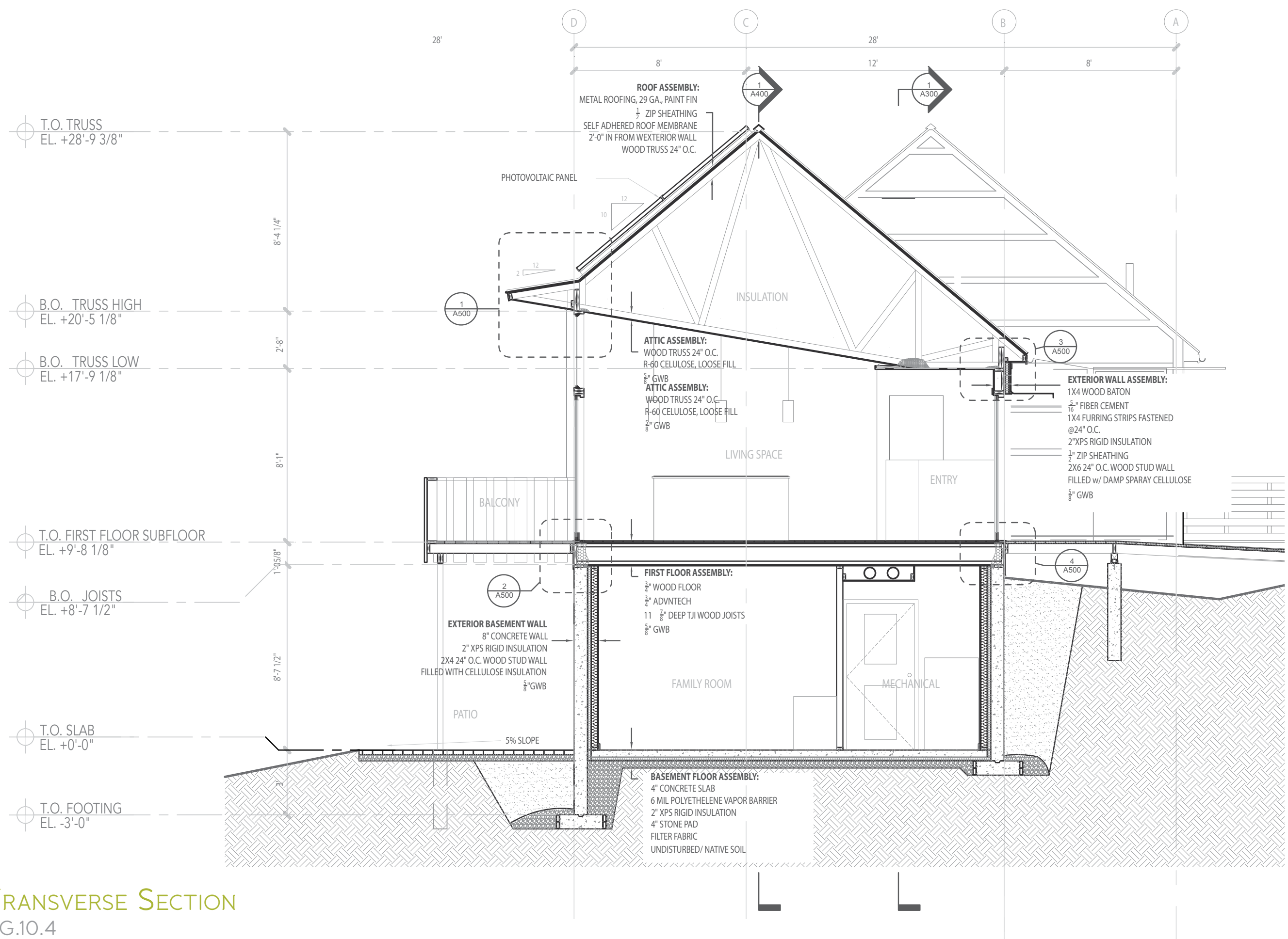
GroundFloor Plan

FIG.10.2

10 // Construction Documents

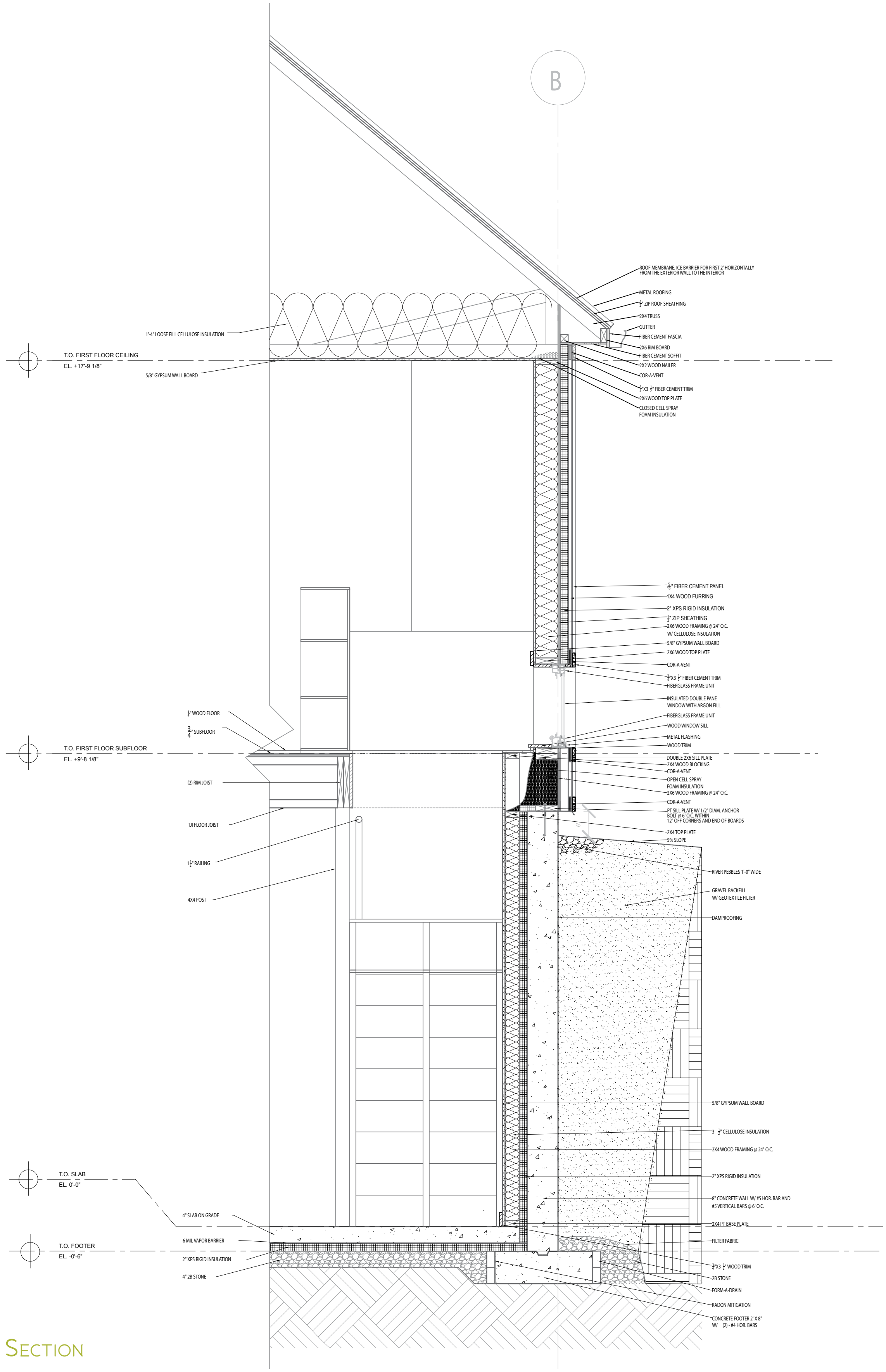


South Elevation
FIG.10.3

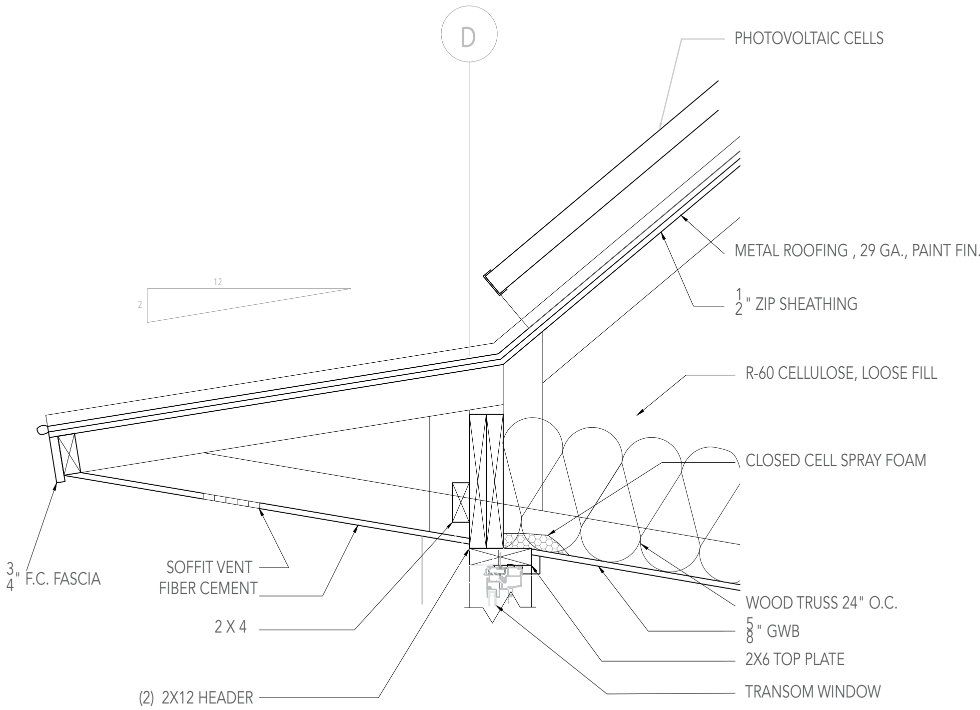


Transverse Section
FIG.10.4

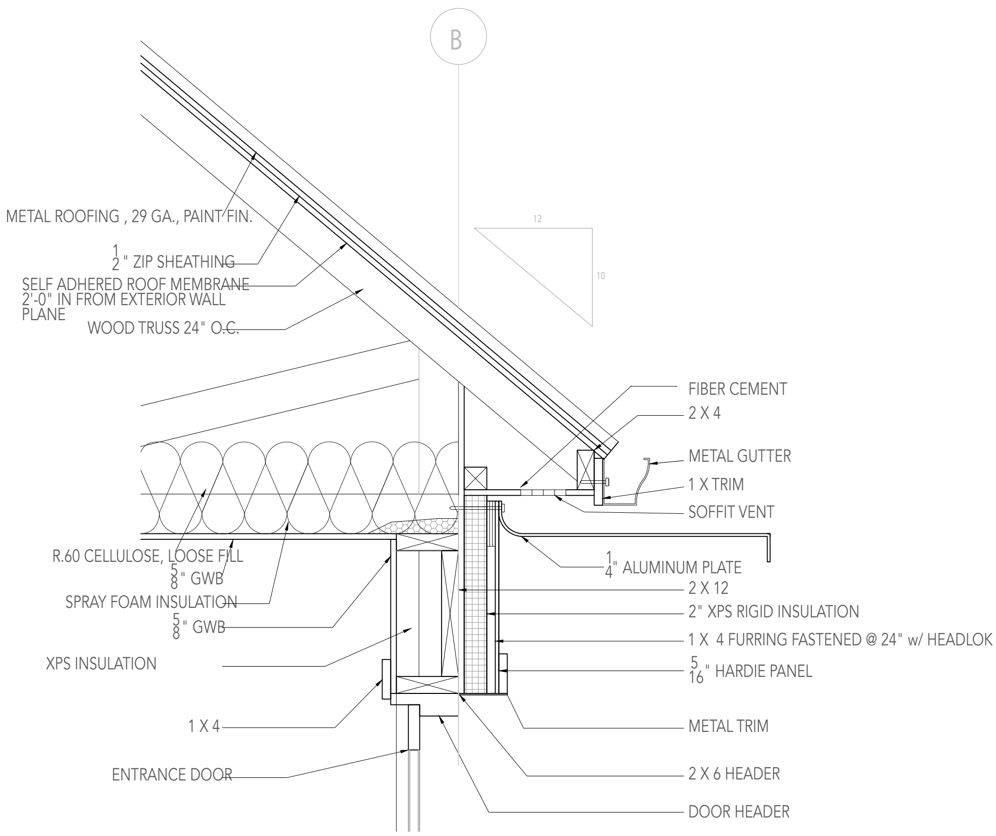
Construction Documents



WALL SECTION
FIG.10.5



South Eave Detail
FIG.10.6



North Eave Detail
FIG.10.7

Mentors

Industry partnerships are utilized to develop and implement design solutions for houses that can be constructed in current day market situations. These partnerships provide a special opportunity for students to gain valuable experience working outside the classroom environment while expanding their personal network of industry relationships. Partners ranging from energy consultants, construction estimators, and lighting designers voluntarily donated their time to share their knowledge and years of experience with students eager to understand the process of constructing an affordable net-zero ready home.

Shown in the picture below is industry partner and Professional Engineer Chad Owens, owner of Timber Rock Homes and Project Engineer of Rare Building Consultants, attending a weekly meeting working hand-in-hand with the financial analysis/cost estimating team to develop "market-ready" detailed cost estimate reports for the two-story duplex.

The following section references all of the industry partnerships who graciously shared their expertise and skills to the team:

Chad Owens

Name of Company: Timber Rock Homes
Title of Contact: Owner
Credentials: Professional Engineer, NAHB Certified Green Professional, and owner of Timber Rock Homes in Bellefonte, Pennsylvania aided in the development of cost estimating.

Peter Vargo

Name of Company: Nu-Tech Energy Solutions
Title of Contact: President/Owner
Credentials: Building Performance consultant & Energy Rater who has carved out a niche in the affordable housing industry over the last 10 years who consulted with the team on energy modeling and calculations.

Ron Quinn

Name of Company: State College Community Land Trust
Title of Contact: Executive Director
Credentials: With more than 15 years of experience in professional performance with pride and integrity for the State College community, Ron served as the primary contact between the Penn State team and the State College Community Land Trust during the competition.

Jason Grottini

Name of Company: Envinity, Inc.
Title of Contact: Director of Operations and Business Development
Credentials: Jason received a Master of Science degree from Penn State University in Environmental Pollution Control Engineering and with years of energy consulting experience helped the team with solar technology cost estimating.

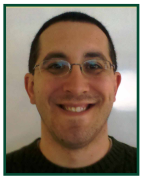
Matt Rooke

Name of Company: Envinity, Inc.
Title of Contact: Consulting Engineer
Credentials: As a HVAC Engineer & Building Energy Analyst, he helped the Penn State team develop cost estimates and designs for the mechanical system.

11 // Industry Partners

Michelle Palm

Name of Company: The HITE Company
Title of Contact: Lighting Design Consultant
Credentials: Professional lighting design consultant with more than 10 years of experience, provided the team with cost estimates for light fixtures used in the home.



Greg Ballas

Name of Company: YBC
Title of Contact: Sales Consultant
Credentials: Greg has more than 15 years of experience in sales and aided in cost estimating.

Gary Golaszewski

Name of Company: The Pennsylvania State University
Title of Contact: Associate Professor
Credentials: An award winning lighting designer with 12 years of professional experience helped the lighting team with codes and developing electrical plans.

Dr. Richard Mistrick

Name of Company: The Pennsylvania State University
Title of Contact: Instructor
Credentials: With a doctorate in Illuminating Engineering, Dr. Mistrick helped the lighting team with day lighting calculations.

Brian Ault

Name of Company: Karpinski Engineering
Title of Contact: Project Engineer
Credentials: Brian is a Professional Engineer with 7 years of experience as a Mechanical Engineer and is an advisor to the mechanical team.

Anne Messner

Name of Company: Borough of State College
Title of Contact: Senior Planner
Credentials: Anne is the planning and zoning officer for the borough of State College, PA who worked with the State College Community Land Trust and the Penn State team to discuss zoning requirements.

Tom Fountaine

Name of Company: Borough of State College
Title of Contact: Borough Manager
Credentials: As past President of the International Town & Gown Association and current Borough Manager for State College, PA, Tom helped the Penn State team with tax assessments required for the competition report.

Scot Chambers

Name of Company: Keller Williams Advantage Realty
Title of Contact: Realtor
Credentials: Specializing in residential and land sales and purchasing for central Pennsylvania, Scot helped the State College Community Land Trust and the Penn State team with locating an appropriate site for the duplex.

Andrew Poerschke

Name of Company: IBACOS
Title of Contact: Building Performance Specialist
Credentials: Andrew aided in the design and performance of the mechanical system as well as the building envelope of the duplex.