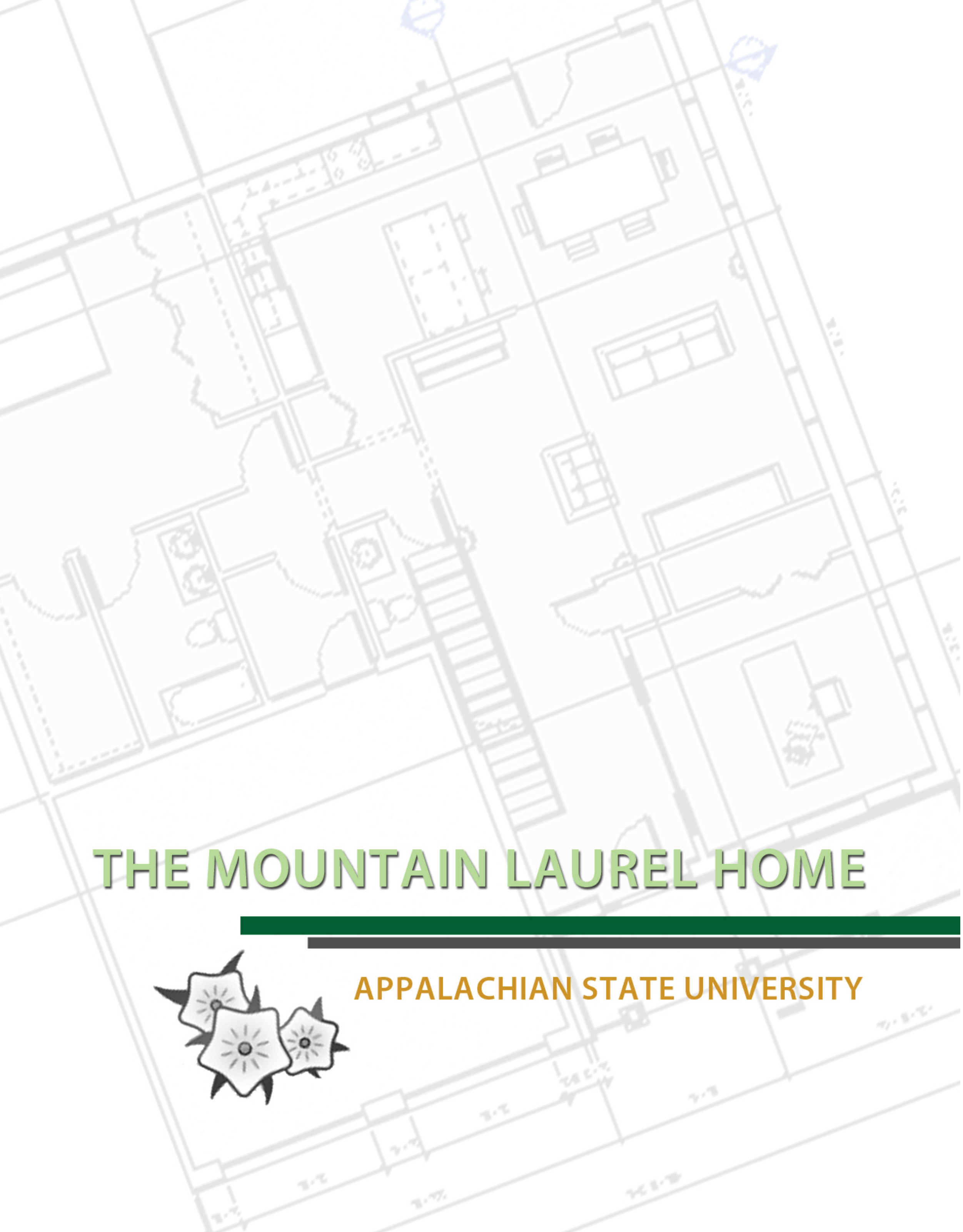

THE MOUNTAIN LAUREL HOME

APPALACHIAN STATE UNIVERSITY

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TEAM QUALIFICATIONS

WHO WE ARE

Appalachian State University's team is composed of undergraduate and graduate students from Appalachian State University's Department of Technology and Sustainable Design. Team members are candidates for degrees in Building Science, Construction Management, Sustainable Building Systems, Appropriate Technology, and Renewable Energy Engineering. We also have strong support from other internal and outside partners, including HVAC technicians at Appalachian State, Dan Ryan Homes, PlyGem, and Edmisten Heating and Air. Most of the students involved in the project were enrolled in TEC 5380 Advanced Building Science, TEC 5260 Renewable Energy Engineering, or TEC 4788 Integration of Energy and Building Systems.

Lena Burkett, Project Manager and Student Team Lead

M.S. Building Science

Hometown: Little Rock, Arkansas

After earning a B.A. in Philosophy, Lena worked for non-profit housing and energy efficiency programs, and became a LEED GA and HERS Rater. She returned to school to prepare for a career in research on building assemblies, systems, and materials. Her interests involve energy efficiency, the built environment, laboratory and field testing, and the history of technology.

Chase Ambler, Certification and Construction Manager

Degree: M.S. Building Science

Hometown: Boone, North Carolina

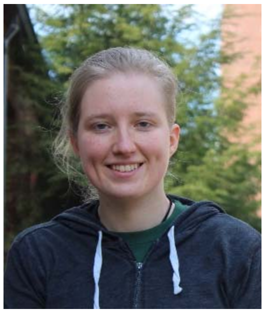
After finishing his undergraduate work at Appalachian Chase worked as a field instructor for the National Outdoor Leadership School in Lander, WY. For the past 20 years he has been a general contractor in Boone, NC, focused primarily on modest sized, efficient homes. His work has included building the first LEED Platinum home in the area in 2009. His focus and experience in efficiency has help balance the work of this team.

Josh Brooks, Construction Estimating Manager

M.S. in Appropriate Technology

Hometown: Ennice, North Carolina

As an undergraduate, Josh served as the chair of the ASU Renewable Energy Initiative where he guided the implementation of renewable energy infrastructure into a growing campus community. Utilizing his Bachelor's of Science degree in History, Josh's main focus is the social and political aspects of energy and sustainability issues.



Chelsea Davis, Energy/ Moisture Analysis Manager

M.S. in Technology: Sustainable Building Design and Construction

Hometown: Greensboro, NC

Chelsea received her undergraduate degree in Civil Engineering at NC State with a minor in Graphic Communications. While volunteering with Habitat for Humanity she developed an interest in reducing low income housing energy usage to limit the stress of high utility bills on homeowners. This interest led her to Appalachian State where she hopes to be able to focus her engineering knowledge to help in improving the built environment to work in accordance with nature instead of in opposition.

Marshall L. Dressler, Plumbing System Design

B.S. in Sustainable Construction Systems

Hometown: Herndon, VA

Marshall is a senior who transferred to Appalachian State from West Virginia University. He is passionate about helping create more sustainable buildings in the future, hopefully integrating renewable energy technologies as well. Upon graduation, he is seeking a career in the field of building science.

Chase Edge, Revit Mechanical and Renewable Energy Systems

M.S. Building Science and Appropriate Technology

Hometown: Fayetteville, NC

Chase has a degree in Civil Engineering Technology from East Carolina University and came to Appalachian State to pursue an advanced degree in sustainable technologies. He has spent considerable time building a building science education and research lab, working on photovoltaic systems, and researching greywater recycling systems.

Pedro Rabelo Melo Franco, HVAC/ Controls

M.S. Renewable Energy Engineering

Hometown: Belo Horizonte, MG - Brazil

Pedro earned a B.S. in Electrical Engineering in Brazil. After working in the fields of automation and control, he came to the U.S. to further his education. Pedro looks forward to returning to Brazil as a renewable energy and control systems entrepreneur.

Brenton Faircloth, Cost Estimating, Financial Valuation, and IAQ

M.S. Building Science

Hometown: Winston-Salem, NC

Brenton has a huge affinity for living things and a passion for working with his hands. His background includes biology, toxicology, environmental monitoring and analysis, appropriate technology, and project management. He strives to make his community a better place through personal attitude, lots of hard work, and innovative solutions.

Kenneth High, Building Science/ Site Plan

M.S. Building Science, MBA Sustainable Business

Hometown: Charlotte, North Carolina

Kenny received his Bachelor of Science in Appropriate Technology from Appalachian State University. His goal is to own and operate his own construction company, specializing in super energy efficient design. When he is not working, Kenny spends his free time in the fast lane as an amateur race car driver in Sports Car Club of America.

David Leonard, CAD/Revit

B.S. Building Science / Sustainable Building Systems

Hometown: Summerfield, NC

David has a background as a laborer in the construction field and will graduate this May with a degree in Building Science. He enjoys spending time in nature as well as in the garage working on various vehicles. He plans to work for a company in Burlington North Carolina doing disaster restoration, and one day move to the coast to continue a career in that field.

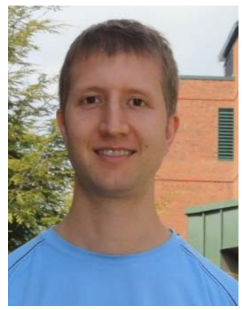
Kaitlyn Morgan, Construction Documentation

B.S. Building Science

Hometown: Lumberton, NC

Kaitlyn looks forward to a career in the field of building science. After graduating in May, she will begin work for Performance Point, an energy services and home energy rating company in the Charlotte area. When not at work, Kaitlyn loves to travel, be outdoors and be on the water.

Brad Painting, HVAC Manager



M.S. Technology, Renewable Energy Engineering Concentration

Hometown: Hudson, OH

Brad studied mechanical engineering in college and worked as a LEED consultant and in various other positions before deciding to further his education in sustainability energy. In his off time he enjoys reading and likes to dabble in various outdoor activities.

Christopher Schoonover, Building Design and Site Layout

M.S. Building Science / Appropriate Technology

Hometown: Menlo Park, CA

Chris's background is in engineering. After 6 years designing dams, he decided that he wanted to shift his focus more toward residential design. When Chris graduates he plans to start a company designing small sustainable properties that incorporate intelligent passive design strategies as well as use technological advances to provide sustainability that is affordable to the general population.

A.J. Smith, Domestic Hot Water, Appliance and Lighting Design Manager

M.S. Appropriate Technology / Building Science

Hometown: Wilmington, NC

In addition to his strong interest in the field of renewable energy, A.J. enjoys cooking and yoga. He is excited about his opportunity to apply his knowledge and skills in Taiwan this summer. He will be doing a Study Abroad with the Green Energy Program at Chien Hsien University in Zhongli.

Jake Smith, Revit Computer Modeling and Renderings

M.S. Sustainable Design and Construction / Building Science

Hometown: Asheville, NC

Jake completed his Bachelor of Science at Appalachian State in Architectural Technology and Design. One day, he would like to own and operate a craft brewery where sustainability only falls second to quality of the product.

Josh Smith, Communication Manager

M.S. Appropriate Technology / Building Science

Hometown: Durham, NC

Josh competed with Appalachian State this past summer in Versailles as part of the Solar Decathlon Europe design and construction competition. His graduate research focuses on variation in solar irradiance in Boone, NC in an attempt to progress system design development. Josh would like to pursue a career in renewable energy system design, technology development, or as a sustainability consultant.

James Harrison Sytz, Water Efficient Design

B.S. in Sustainable Building Systems

Hometown: Cornelius, NC

Harrison has a strong interest in how renewable energy and sustainable technologies can be integrated successfully into today's buildings. He looks forward to working in the energy field after his upcoming graduation.

Jeff Tiller, PE. Faculty Advisor

B.S. and M.S. in Industrial and SysteM.S. Engineering, Georgia Institute of Technology

Hometown: Louisville, KY

Professor at Appalachian State and former Chair of the Department of Technology and Environmental Design, co-founded Southface Energy Institute in 1980, co-founded the North Carolina Energy Efficiency Alliance, authored several Builder Guides to Energy Efficient Homes and other energy and solar publications, commissioned LEED buildings, designed dozens of HVAC systems, performed Building America projects working with IBACOS, certified several hundred Centex Homes as ENERGY STAR, participated in two Solar Decathlon competitions, designed dozens of solar thermal and photovoltaic systems, worked on energy codes in NC and Georgia, and most importantly, taught the field of building science to several thousand students now working or soon to work in the construction industry.

INSTITUTIONAL PROFILE

Appalachian State University has over 17,000 undergraduate and graduate students. The university has made a major commitment to the future of sustainability in its facilities, programs, and academic programs. The university's new Strategic Mission Statement is as follows, "Appalachian State University prepares students to lead purposeful lives as engaged global citizens who understand their responsibilities in creating a sustainable future for all."

The university's Department of Technology and Environmental Design has six unique undergraduate programs that emphasize sustainable design and technology, energy efficiency, and renewable energy technologies. The department's academic and research activities have been a major part of the university's reputation in the fields of sustainability, energy, and renewables. Its mission statement is, "Innovative Solutions for a Sustainable World."

The Building Science program in the department has over 250 students who study Construction Management, Architectural Technology and Design, and Sustainable Building Systems. The principles of high performance buildings are woven throughout many of the courses in the curriculum, including TEC 1708 Construction Technology and Building Codes, TEC 2718 Building Mechanical Systems, TEC 3728 Building Science, TEC 4718 Sustainable Building System and Design, and several architectural studios. The academic programs place a strong emphasis on combining classroom learning with real-world projects, including both integrated design, field research, and actual hands-on construction activities.

The Appropriate Technology program (soon to be renamed "Sustainable Technology") has 200 undergraduate students. In addition to a variety of courses in renewable energy and other sustainable technologies, students take the key Building Science courses that teach construction and building science principles and practices.

Graduate students in the department have the choice of obtaining a Master's Degree in Technology with a specialization in Building Science, Appropriate Technology, Sustainable Building Technology and Design, and Renewable Energy Engineering. The department currently has 35 students in these various degrees.

The department has played an important role in both national and state energy research, development, and policy. Examples include development of the North Carolina State Energy Plan, work on a NC Strategic Plan for Biodiesel Development, development of a residential energy efficient retrofit program and operation of an energy retrofit program for non-profit organizations for Piedmont Natural Gas, work on the national commercial energy code, development of the residential and commercial 2012 NC Energy Code, and development and operation of the North Carolina Energy Efficiency Alliance. Faculty and students conduct a plethora of research activities on high performance buildings.

Among the more visible projects of the department are its entries into the 2009 Solar Decathlon USA and 2012 Solar Decathlon Europe competitions. A number of technology and design ideas from these competitions have been integrated into our Race-to-Zero Design.

In the Solar Decathlon USA, App State's team

won the "People's Choice Award", won first place in the Hot Water competition, placed second in Communications, and third in Architecture. In the Solar Decathlon Europe event, our team placed first in "Net Energy Balance" due to the high efficiency envelope and innovative PV system with integrated electrical storage.

FACULTY CERTIFICATION OF BUILDING SCIENCE

Jeff Tiller, the faculty advisor for the Race-to-Zero team, served as coordinator of the Building Science program for many years as it developed a strong curriculum focusing on higher performance buildings. In particular, the App State students for the competition have all either taken TEC 3728 Building Science and/ or are currently taking TEC 5230 Advanced Building Science. Several also tuned into the Building Science Principles Webinars.

Signed Jeffrey S. Tiller, PE March 22, 2015

APPALACHIAN STATE UNIVERSITY

MOUNTAIN LAUREL HOME

Project Summary

Our design process started with an exciting partnership with Dan Ryan Homes, a national production homebuilder with regional headquarters in Raleigh. We wanted to design a single family residence that would not only be sustainable and zero-ready, but livable and marketable as well. Our goal was to find a balance between these three directions.

Relevance of Project to the Goals of the Competition

We want to inspire a progressive direction in production built homes. Using integrated design techniques we were able to unite students across disciplines and enhance the academic environment of Appalachian State University. Starting with currently marketable residential designs we were able to create a starting point that would merit feasibility in readiness of design for production residential application.

Design Strategy and Key Points

The Mountain Laurel House exceeds LEED Platinum certification by 7 ½ points, meets ENERGYSTAR v.3, DOE Zero Energy Ready Home National Program Requirements, EPA Indoor Air Quality Plus, and Water Sense standards, Passive House Standards, and has a HERS score of 41 before Photovoltaics are added. Advanced framing techniques along with an efficient layout reduced material requirements while increasing our mechanical systems' efficiencies. The Mountain Laurel design creates flexible and adaptable spaces within the home that grow and develop with its owner. The home is adaptable to many different climate zones without modification, and to more northern zones (6 and 7) with relatively minor changes in the HVAC system.

Project Data

- Mebane, North Carolina
- Climate Zone: 4
- 2,278 ft^2
- 5 Bedrooms, 2 ½ Bathrooms, 1 ½ Stories
- HERS Scores: 41 (Before PV), -3 (After PV)
- $83/Month

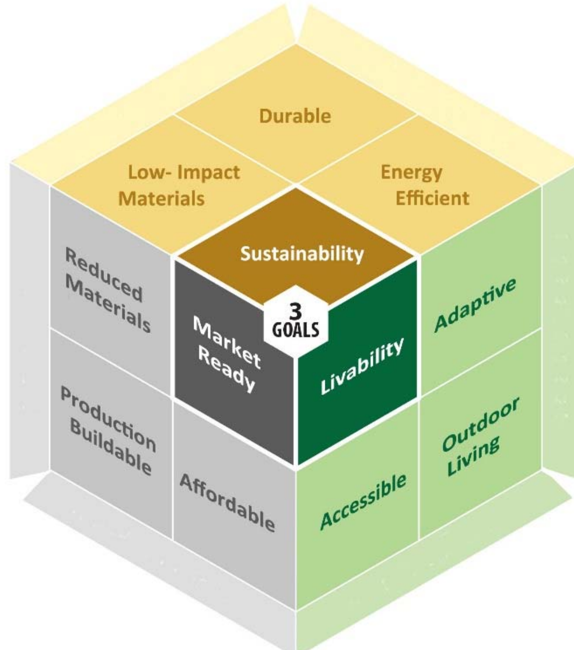
Technical Specifications

- Wall Insulation – Blown Cellulose, R-Value = 26.1 with R-10 exterior foam = R-37
- Foundation – Concrete Slab on Grade, R-Value = 15 perimeter
- Roof Insulation - Blown Cellulose, R-Value = 50/ Cathedral Ceiling – Blown Cellulose with 2" spray foam = 52.3
- Window Performance = U-Factor = 0.027, SHGC = 0.20
- HVAC specifications = Air Sourced Heat Pump, 16.0 SEER, 10 HSPF

DESIGN GOALS AND PROJECT CONTEXT

OUR MISSION

To create a sustainable, cost-effective design for single-family homes that production builders can use when reconsidering their current home designs in order to transform the marketplace for higher performance residential construction.



MOUNTAIN LAUREL

The Mountain Laurel is native to North Carolina as well as many other areas of North America. It is hardy, drought-tolerant, low maintenance, and suitable for any amount of sun exposure. This perennial evergreen shrub thrives in a wide range of climates and adapts well to urban environments. It is a compact plant, growing densely over its long lifespan. These characteristics of resiliency, adaptability, and longevity mirror the qualities of our home, making the Mountain Laurel a perfect name for our design.

"Because laurels are native to North America, they tend to blend and blur the boundaries between man-made and natural environments in this part of the world." *http://www.thegardenerseden.com/?p=1028*

OUR PHILOSOPHY

Our Project has focused on several interdependent attributes of house design. These attributes can be grouped into three fundamental themes.

Sustainability: This applied to both the construction and the operation of the house. For the construction phase, we gave great consideration to the recycled content, embodied energy and transportation of materials as well as reducing the amount of waste by opting for pre-finished materials and materials that could be recycled. By employing advanced framing techniques and designing an efficient layout with appropriately sized rooms, we also reduced our overall materials requirement. For the operation phase, we ensured that the design is not only energy efficient, but also durable and low maintenance, by choosing long-lasting materials and ensuring that the building assemblies are resists damage from pests, moisture, UV rays, and condensation within the assembly.

Livability: With an average length of home ownership of 5.9 years, or even less in production built single family homes, our team sought to create a home that can adapt to changing living situations in order to allow homeowners to live in a well-functioning home for much longer. Thus, our design incorporates flexible spaces for a variety of uses, and can be meet ADA accessibility specifications with only minor modifications. It is our intention that a family would live in this home for generations and throughout all stages of life.

Market-ready: For all the high performance and ultra-efficient advancements in the building industry, what is most important is that these advancements be used. It is not enough to develop incredible building materials that will only be used in the homes

of the rich and sustainably-minded. To make a significant change in the environmental impact of residential buildings, advancements must be feasible for the average home. This means not only affordable materials but also commonly available materials that do not require specialized installation equipment or customization. Using conventional building materials in innovative ways through improved building assemblies and special attention to continuous air, water, thermal, and vapor barriers, allows for production home builders to easily adopt improved building practices and deliver higher quality product with minimal (or no?) increase in cost.

OUR DESIGN PROCESS

Market Ready Design Parameters

The first step in our design process was to ask ourselves: who our customers are and how to best meet or exceed their expectations? There are two interrelated answers to this question. Our customers are production builders such as Dan Ryan Homes, who are looking for ways to offer sustainability upgrades while [staying with their general cost and consumer market]. Consequently, our customers are also the homebuyers in this market. Whether they are looking for sustainable features, a healthier indoor environment for their family, a durable home that can stay in the family for generations, or just minimizing the operating costs of utilities and maintenance, our design can provide these qualities and also fit the style, amenities, and price range that they expect.

The general project parameters are listed below, and are explored in detail in following sections.

House Type	**Single Family**
Location	Mebane, NC
Climate Zone	Zone 4, with adaptability to zones 2-7
Lot Size, Orientation	70' x 110'. Front facing East
Neighborhood	Arrowhead Community
Occupants	Adaptive for many possible occupant configurations. See section __
Sustainability	Low-impact materials, energy efficiency, durability, high indoor air quality, comfort
Project Type	Designed for future implementation by production builders
Programs and Standards	DOE Zero Energy Ready Home, Energy Star, LEED, ______

Integrated Design Process

DOE Recommended Quality Management Provisions #2 requires an integrated design process that includes meetings with HVAC, insulation, air sealing and framing trades. We have exceeded this requirement by meeting twice a week and involving not only the trades listed above, but also those responsible for plumbing, electrical, controls, IAQ, energy and moisture, architectural design, finance, and sustainable design. This integrated process is essential to a successful project. All too often, problems will arise in construction projects due to a lack of communication between the trades. These problems could be easily prevented, but a more difficult to fix afterward, increasing overall project cost and causing delays in schedule. The integrated design process allows us not only to avoid these problems, but also to optimize the way the house functions as a whole, and how the systems and the design complement each other.

The integrated design process hinges on clear communication and documentation of meeting outcomes. We have used cloud based storage to share our meeting notes, design goals and strategies, reference materials, plans, specs, and calculations. Every member of our team has access to these materials and can add their contributions in real-time.

Decision making

With a team of 18 students, plus faculty advisors and industry partners, it was important to identify a decision making process that would be based on qualitative and qualitative data and allow input from all team members. Thus, we employed a decision matrix approach in which each team member indicated the importance of factors such as cost, marketability, durability, energy use, and sustainability. With these weights and scores, our team was able to reach decisions on components such as comfort systems, flooring, finishes, and floor plans. Details of how incentives and tax credits informed our design can be found in Section G: Financial Analysis.

DESIGN STRATEGIES

We identified essential design strategies to meet our design goals. Although these architectural design strategies are often demonstrated in high-end custom homes, we have applied them to our project within the framework of a mass producible net-zero energy house that also meets customer and builder expectations in terms of style and cost. *(http://www1.eere.energy.gov/buildings/residential/pdfs/doe_challenge_home_provisions032812.pdf)*

Space and Flow

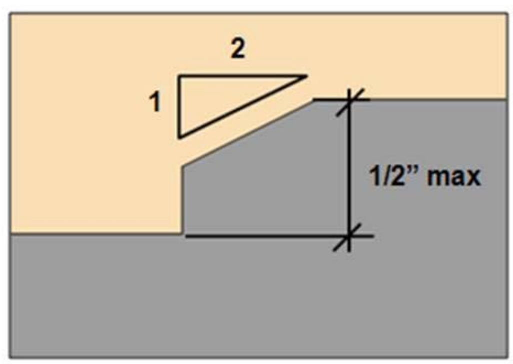
Considering the likely daily activities of the occupants, we created an arrangement of spaces that optimizes functionality and minimizes spaces that are only used as passageways from one area to another. Examples of this functional arrangement would include the proximity of garage and mudroom to the kitchen and pantry, simplifying the task of bringing in groceries. There is a clear alignment of the entryway, living room, dining room, and back [patio] that convenient and welcoming when entertaining guests. Building on this, our design addresses the need for a division of public and private spaces while

also encouraging family interaction. The master suite is comfortably separated from the main living areas.

Similarly, the other bedrooms are physically separated from the public living areas, however the balcony and vaulted ceiling visually connect the two areas, which provides a [good balance]. The upstairs bedrooms are sized to comfortably accommodate all of the typical furniture, but the rooms are not oversized in relation to their functions, as is typically seen in production built houses. Besides reducing energy use and materials, the bedroom sizes also encourage the family members to join together in the living areas rather than secluding in their bedrooms.

Aging in Place

The location of the master bedroom on the ground floor is essential for adaptability and long term home ownership. . The master bath and closet are designed so that the shared wall could be removed to have more room in the bath and retain the second closet on the adjacent wall. In preparation for any occupant or visitor with limited mobility, the first floor is designed with wide doorways and even transitions from hardwood to tile. There is a ½" beveled change in level from the porch and patio to the interior floor to provide accessibility while also managing bulk moisture issues.



Source: http://www.access-board.gov/guidelines-and-standards/buildings-and-sites/

Functionality

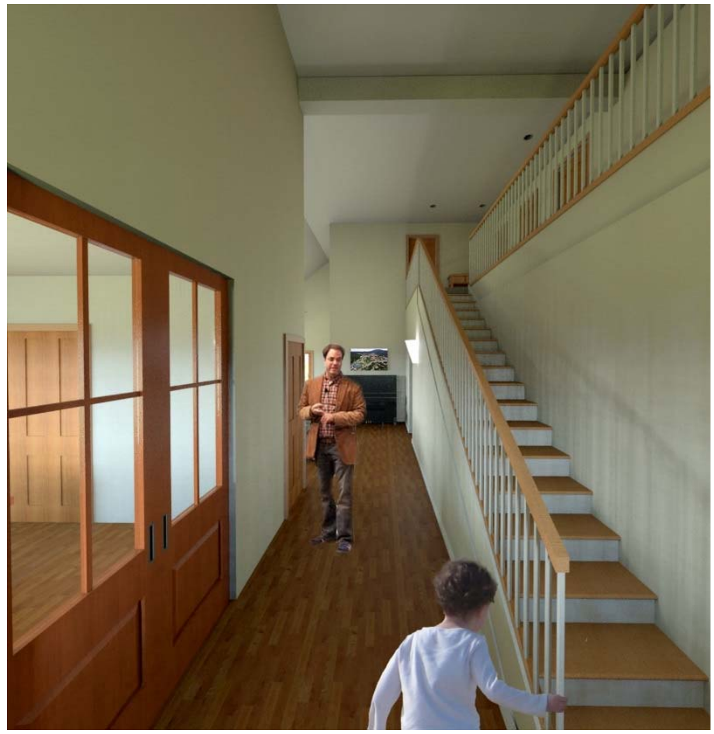
Throughout the design process, we sought to optimize the functionality of the house in order to reduce the conditioned area and better serve the needs or a range of homeowners. In 2,278 square feet, we have provided four reasonably sized bedrooms along with a flex room that can serve as a fifth bedroom. We have found that most production built homes include a formal dining room, formal living room, or both, although these rooms are the least used rooms in the house. Instead of dedicating space to rooms that would only be used a few times a year, our design offers a large open living and dining area along with an island for additional dining space. The flex room can easily be used as a formal living or dining room if desired.

The 1 ½ story floor plan makes use of the often wasted attic space. By using this design approach, we minimized wasted space, reduced the materials needed, and reduced the heating and cooling load (??). This design also created the opportunity for a vaulted ceiling over the entry, living, and dining areas and a balcony on the second floor. These elements help to open up the space, providing an elegant, inviting impression within an efficient layout.

Connection to Community and Outdoors

Designing a home for a production-built subdivision inspired the team to incorporate elements that promote outdoor activities and neighbor interaction. We created two designated outdoor living spaces, a deep covered porch, and a trellis-covered patio. The porch is more functional than the typical porch of similar homes. In effect, a functional porch moves some of the living space outside the conditioned envelope, decreasing the need for extra square footage inside. It also provides a connection to the neighborhood, encouraging interaction with the community. The back patio can serve as an additional dining space, resulting in a home with ample dining options without a formal dining room

The window design has been optimized to provide ample natural light and views with less total glazed area than a similar conventional house. Fenestration accounts for 7% of total wall area, with 35% South, 20% East, and 45% West. A portion of the glazing on the east and west are shaded by the



porch and trellis. There is no fenestration on the North wall. We designed the floorplan accordingly, with the living spaces on the south, the garage on the north, and bedrooms on the east and west.

Systems

The Mountain Laurel makes use of integrated systems, optimizing the performance of each system. Integration of the thermal barrier, air barrier, structure, and HVAC system allows for a design with the air handler, ERV, and ducts located in conditioned space. This strategy greatly reduces wasted energy caused by duct leakage to an unconditioned space, as well as heat loss through the ducts from the heated air to the unconditioned attic in the winter, and heat gain from the attic to the cooled air in the summer.

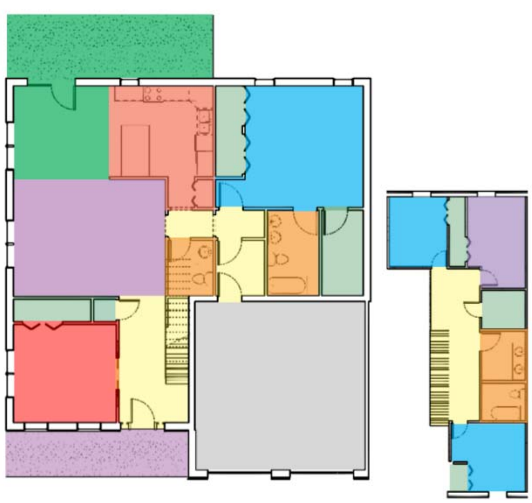
The heating and cooling loads are greatly reduced due to the orientation, compact layout, high R-value, and low air infiltration. As a result, the house is served by a 2 ton HVAC system, rather than the two to three-ton system of our comparison house. Similarly, the number of ducts runs is reduced (“cut in half”?) along with the diameter of ducts and the length of the duct runs. This not only leads to significant energy savings, but also reduced initial cost for the HVAC unit, materials, and labor as well as reduced cost for future maintenance.

The arrangement of wet areas in our compact layout allows for plumbing fixtures to be centralized. This compact distribution system reduces upfront material and labor costs and minimizes energy wasted from hot water lines. In accordance with DOE Zero Energy Ready Home National Program Requirements, the volume of water between the water heater and farthest hot water fixture is no more than .5 gallons.

There is also a whole house plumbing shut off conveniently located in the mudroom. This is a safety and durability strategy to minimize water damage from a leak or burst pipe by easily shutting off the water without having to search for the source and the appropriate branch shut off first?

Flexibility

Creating a production built home design for a wide range of occupants requires a great degree of flexibility in the functionality of the home. As part of our design goal of livability, optimizing the ways in which the home could be used was a priority throughout the design process. Below are just a few of the many functional ways the house could be used:



<u>3 Bedrooms with Home Office/ Exercise Room</u>

Designed for a family with two teenage children, there are two bedrooms upstairs with the third room being used as a media room for the family. The flex room downstairs can be used as either a home office

or exercise room.

<u>3 Bedrooms With Formal Dining Room</u>

Similar to the design above this house has 2 bedrooms upstairs with a family media room. The flex room in this design is used as a formal dining room allowing for large family and friend gatherings such as thanksgiving.

<u>4 Bedrooms: The Growing Family</u>

This layout is designed for an active family with multiple children. Three bedrooms are located upstairs for children and or guests. The downstairs flex room is used as a playroom for the family. The back patio extends the dining space outdoors encouraging the occupants to cook and eat outside on nice days.

Empty Nesters

One guest bedroom is located upstairs where the other two flex rooms can be used as a home gym, craft rooms, man cave, digital work space, or whatever meets the occupants' needs. The flex room downstairs becomes an extension of the living room for when grandchildren are visiting.

CERTIFICATIONS

The Mountain Laurel meets several recognized certifications including LEED for Homes Platinum, ENERGYSTAR v.3, DOE Zero Energy Ready Home National Program Requirements, EPA Indoor Air Plus, Water Sense, and Fortified. In addition, the design earned a HERS score of 41 without any renewable energy, and a HERS score of -3 with the addition of a 7.8 kW photovoltaic system. *****

DOE Zero Energy Ready Home

A DOE Zero Energy Ready Home is a home built to such a high standard of efficiency that it would require only modest amount of renewable energy installed to offset the annual energy use. The Mountain Laurel home meets the DOE Zero Energy Ready Home requirements through a tight envelope, superior insulation and efficient mechanical systems.

ENERGY STAR and Indoor airPLUS

A new home built to ENERGY STAR and Indoor airPLUS standards has gone through a thorough process of inspections and verification to meet the program requirements. Over one million homes throughout the United Sates are ENERGY STAR certified. ENERGY STAR and Indoor airPLUS are part of the requirements for meeting the DOE Zero Energy Ready Home program. The efforts undertaken to meet this program with energy efficiency, HVAC design, indoor air quality measures that have been planned for the Mountain Laurel allow the home to easily surpass the ENERGY STAR and Indoor airPLUS requirements.

Passive House

Passive House construction employs superior attention to the envelope tightness, insulation, and windows and doors, resulting in exceptionally low energy use. Passive standards for our area requires the annual heating demand of 3.7 kBtu/square footage of conditioned floor area per year (sf-iCFA.yr) and cooling demand of 5.7 kBtu/sf-iCFA.yr. The Mountain Laurel meets this standard with 3.2 kBtu/sf-iCFA.yr and cooling demand of 1.5 kBtu/sf-iCFA.yr.

Fortified

The Fortified rating is a program of DisasterSafety.org, a service of the Insurance Institute for Business & Home Safety. The goal is to identify and promote courses of actions to protect homes. The Fortified portal identifies risk specific to each region by zip code. Our home has met the requirements to increase our protection from flood, wind, hail, and wildfire. One added feature is the electrical storage system that is integrated with our proposed photovoltaic solar electric system, which will provide back-up power for vital electrical uses during power outages.

WaterSense

WaterSense is a voluntary labeling program sponsored by the U.S. Environmental Protection Agency that certifies water-efficient products and construction. Building to the WaterSense standard for new homes has the potential to save a family of four 50,000 gallons of water a year or more. The certification can be broken down into three categories that must be fulfilled: indoor water use, outdoor water use, and homeowner education. The Mountain Laurel easily meets the WaterSense standard through efficient fixtures and climate appropriate landscaping.

LEED

Leadership in Energy & Environmental Design (LEED) is a building certification focused on a broad array of elements. LEED bills itself as "the world's premier benchmark for high performance buildings." LEED has sets of prerequisites that must be met and offers points for performance within different categories. The steps we have taken to design and detail the Mountain Laurel to meet the preceding collection of certifications prepared us well for meeting the requirements of LEED. Our home exceeds the threshold for LEED's highest level, Platinum.

THE SITE

We embarked on our mission to create a market-ready net zero home by working directly with the builder Dan Ryan Homes to choose a site. They proposed a location in the Arrowhead Estates neighborhood, located in Mebane, North Carolina, approximately midway between Raleigh and Greensboro. Its proximity to a wide variety of employment centers within Chapel Hill, Research Triangle Park, Durham, Burlington, Raleigh, and Greensboro highlights the potential impact a replicable energy-efficient design may have on this region.

The development itself includes a swimming pool and a greenspace and is within walking distance of many community resources including:

- Daycare Center
- Fitness Center
- 2 Medical Offices
- 2 Pharmacies
- Several Restaurants
- Supermarket
- Many Retail Locations
- Major Employment Center

The lots in the neighborhood vary in width from 60 feet to 80 feet. The depths range from 120 feet to 150 feet. Each site is relatively flat and appropriate for slab-on-grade construction, which is the foundation of choice for all of the homes. The homes typically have short driveways and two-car garages. The driveways and walks are all built of concrete.

The lot we are using for our initial project faces due East, so the southern exposure is to the left when facing the front of the home. We have designed our home for flexibility in terms of site orientation, recognizing that in some locations, the roof that is to be used for solar equipment would not necessarily have the optimal setting.

One of the strategies that Dan Ryan Homes employs is to vary the fronts of their homes by adding dormers, bay windows, and other "bump outs" as well as changing the color schemes and finishes so that virtually identical floor plans have a different appearance. Our design can accommodate a similar approach to comply with their goal of minimizing the number of floor plans used in a given development.

Recognizing that the infrastructure cost of the neighborhood includes storm sewers, swales, and other features to control water flowing off of pavement and rooftops, we have adopted site strategies to help reduce storm water run-off. Our driveway utilizes a permeable surface using True Grid pavers, an open honeycomb design that will allow rain water to soak into the ground. These pavers also create a more appealing aesthetic than the solid concrete typically used. In addition, we enhanced the traditional approach to landscaping, which presently consists almost solely of adding a sod lawn with accompanying irrigation system, by installing the following:

1. During construction, straw bales in place of silt fences for much of the erosion control requirements. The bales can be reused on other lots and eventually serve as mulch in the landscapes of the homes.
2. A drought-tolerant turf without an irrigation system
3. Mulched beds around the house to aid in drainage away from the foundation and provide an additional amenity ready for installing flower, herb, or vegetable gardens.
4. Four to six drought-tolerant trees along with shrubberyfor future shading as well as control of ground water
5. Roof-water captured in a storage tank located on the side of the home to serve as a source of irrigation water as well as a buffer during high levels of rain

Site Plan Information

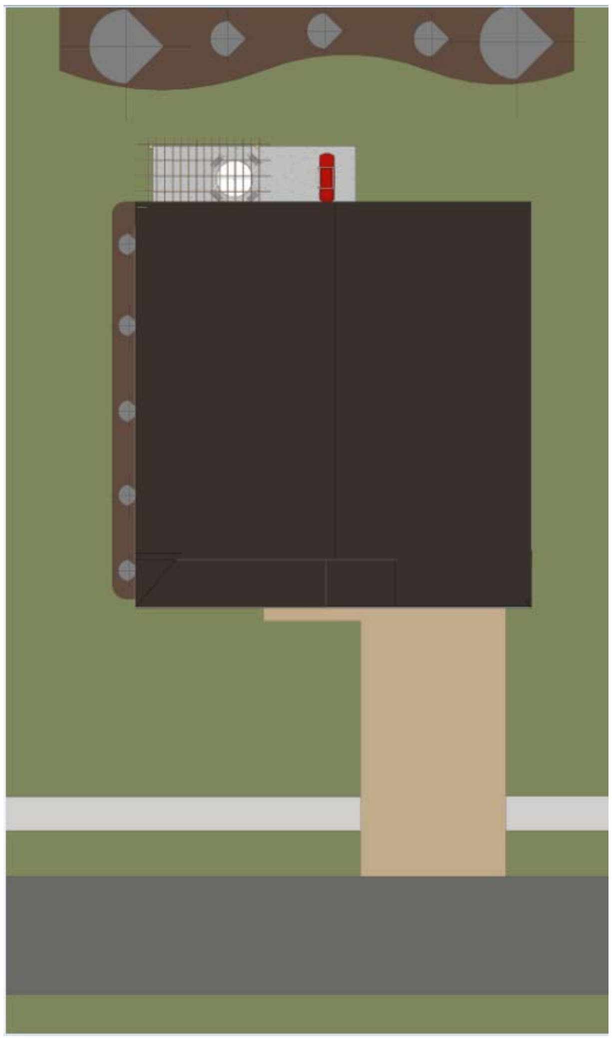
Landscaping Plan

Our main goals in developing the landscaping plan were to reduce the outdoor water demand, manage storm runoff from surrounding lots, and incorporate native plant species that will thrive in the local environment. We used the LEED for Homes water demand calculator to estimate that our landscape plan and irrigation system design was able to achieve a 70% reduction in outdoor water demand compared to the baseline water use.

The species of bushes, trees, and turf used in the landscaping plan were chosen for being noninvasive to the area and for their superior drought tolerance. Another consideration in the selection of these plant species is their ability to support and attract wildlife, such as birds, thus strengthening the local ecology.

Included in the landscape design is the native Mountain-Laurel bush, with which our team shares its name, and North Carolina's state tree, the Dogwood. These two species are well known and easily identified in the state and will bring beautiful colors tor our site from spring till winter. (http://treesandshrubs.about.com/od/selection/ss/Meet-12-Species-of-Dogwood-Trees-Shrubs-and-Subshrubs.htm)

The turf species used in our plan, Zoysia Grass, has an excellent drought tolerance and grows slowly. This reduces the required amount of time and energy needed for mowing and other maintenance and upkeep. (http://aggie-horticulture.tamu.edu/archives/parsons/turf/publications/zoysia.html)

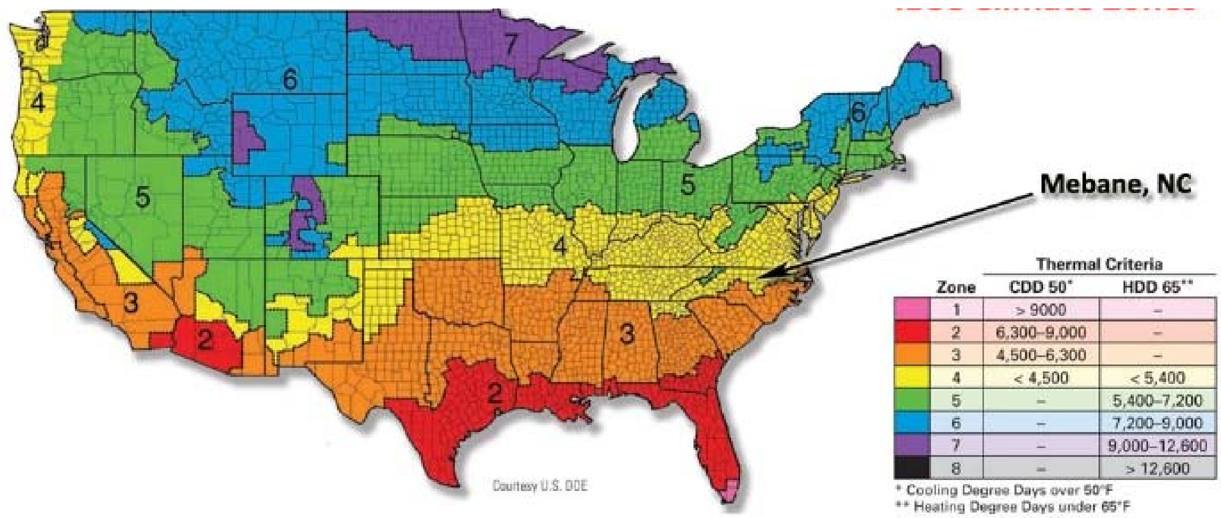


Irrigation/ site water management

The irrigation system for the trees and bushes is a high efficiency spot drip system from Rain Bird. The system will be connected to an inline programmable timer and the rain collection barrel. This system was chosen for its easy installation, high efficiency, and low cost. This system will not provide any irrigation to the turf.

The houses located behind our lot are slightly uphill, meaning that our lot would receive their runoff. The planting area in the back yard is designed to help direct this water runoff towards the swell of the yard. The plant bed along the north side of the house helps reduce the amount of runoff from the neighboring lot that reaches our foundation.

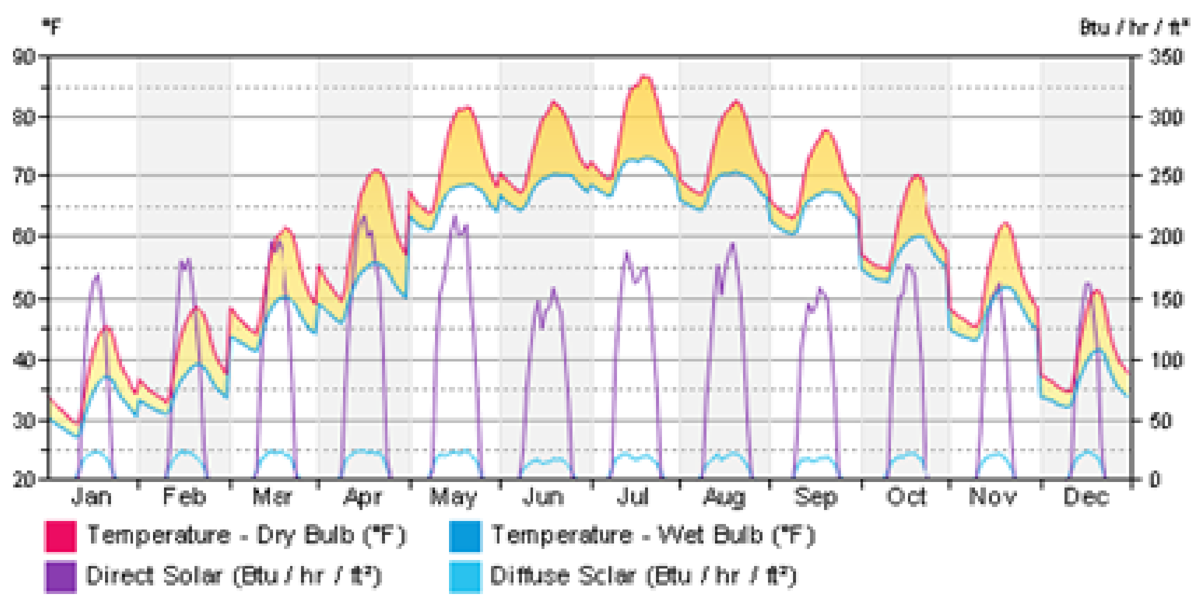
IECC Climate Zones *(from https://energycode.pnl.gov/EnergyCodeReqs/)*



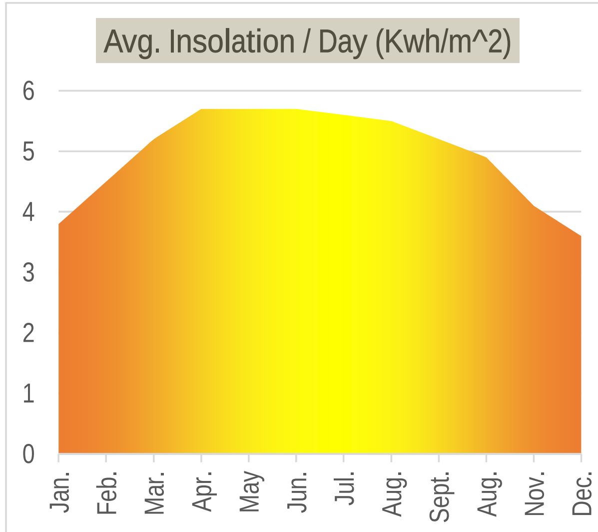
The Climate Zones

While our original site location is in Mebane, NC it is the intent of the house design to be relevant to multiple climates with only a few adjustments to foundation type, window specifications, mechanical systems and other heavily climate dependent design elements. The International Energy Conservation Code (IECC) climate zones are based on hygrothermal parameters, both temperature and humidity. These zones are then referenced to create energy code standards specific to each zone, mostly requiring minimum insulation values. Our original climate, being a humid temperate climate, falls within IECC climate zone 4A. This zone has a fairly balanced ratio between Heating Degree Days (HDD) and Cooling Degree Days (CDD).Another important climatic aspect of a region to research for the design of a net-zero home is solar exposure. A solar study was run in Autodesk Revit to ensure that the orientation and tilt of the proposed solar energy systems are optimally designed. The image below shows both the monthly average temperature range and the monthly average diurnal solar energy.

Diurnal Weather Averages



While there is a specific climate zone for the site we have selected, our design is adaptable to climate zones 2 through 7 in Moist, Dry and Marine regions. The insulation levels specified in our design far exceeds levels required by the 2015 International Energy Conservation Code-for all of these zones. In zones 6 and 7, higher levels of exterior foam insulation would be recommended to avoid potential condensation on the inside surface of the exterior sheathing during the winter months. Heating, cooling, and humidity control will be affected by the climate zone, and may require changes to the HVAC system. The zoned central HVAC system we have chosen is adaptable to a variety of climates. This would only require an alteration to the duct sizing and the capacity of the system, not a fundamental change in the type of comfort system.



The simplified roof design provides ample space for solar energy systems. Since many production builders would be resistant to solar systems facing the front of their homes, the solar oriented roof is on the side. There are no dormers or roof projections that would limit the size of a photovoltaic array or solar thermal system. The tilt angle of the roof is ideal at 38 degrees.

The total south-facing roof area is 1,450 square feet. We would leave 3-feet clear on the two sides of the roof, as well as a 3 foot strip along the bottom edge. The remaining roof area would be 1,145 square feet. The table below shows the monthly solar irradiance for south-facing surfaces tilted near the site's latitude.

ENVELOPE DURABILITY

From the ground up, every aspect of this home is designed is to maximize the longevity of both the structure and the occupants. Studying how each system individually, and the house as a whole, endures the constant environmental challenges of wind, water and temperature is key to our philosophy of sustainability and livability. Through the implementation of advanced framing methods, insulation, moisture control, and more sustainable materials, our team has designed a home that will withstand the passage of time.

GOALS

- Create a home that will last for generations
- Minimize thermal bridging of framing
- Minimize risk of air leaks
- Develop design strategies to better control moisture inside and out
- Create a healthy and comfortable environment for the occupants

ENVELOPE DESIGN PROCESS

Our team began by breaking down the building envelope into each of its systems (foundation, wall, and ceiling) and studied how each system interacts with environmental factors.

Focus then moved to how each system would connect with the others to create the building envelope. Careful consideration was given to this section of the design, as it is our goal that production builders are able to recreate this structure successfully time and time again.

The project team members assigned research topics and brought a wealth of information to the full class. To process this information and organize the results in a way that represented our philosophy and design goals, several different scoring systems were developed. Surveys were used to assign weights to several key aspects of the building envelope to assist in making decisions for durability, efficiency, cost and other factors for each possible system design. Following the DOE Zero Energy Ready Home Quality Management Provision #1, this process was documented to ensure all decisions were in accordance with ENERGY STAR as well as other performance goals described in section B.

Thermal Bridging

Heat can be transferred in three ways: Conduction, Convection and Radiation. In our attempt to reduce the amount of heat our envelope gains/losses due to conduction, our design utilizes advanced framing methods and materials that minimize the amount of heat the exterior sheathing transfers to interior finishes. Our framing design allows for insulation to be installed continuously on the exterior and without separation in the wall cavities, thus also reducing the heat gain due to convection associated with air leakage.

Air Leakage

Excessive air leakage in buildings is a major issue that too often is due to poor design and planning. Air leaks allow for the transfer of heat, moisture, reduce the indoor air quality (IAQ) of a building and the health of its occupants. For these reasons our team paid close attention to how layers of materials were connected together to remove the possibility of any air leaks. *(http://www.buildingscience.com/documents/reports/rr-1401-design-challenges-nist-net-zero-energy-residential-test-facility)*

Production Ready

As stated in the goals, we want production homebuilders to be able to successfully reproduce our design and use as a design option in future developments. Part of accomplishing this goal was to create an exterior that would tie into the rest of the neighborhood visually.

EXTERIOR WALL SYSTEM

The exterior wall system is one of the most important features that preserve the durability of the home. The Appalachian State team considered the information from the classes, the Webinars and other building science materials and readings in making a selection of a wall system.

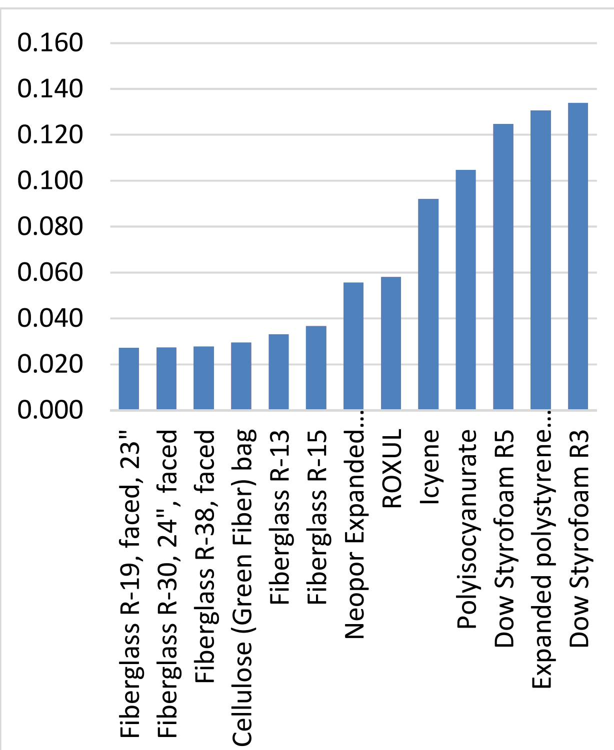
One of the primary considerations in the wall design was the cost, since we are seeking to move the production home market to offer extremely efficient homes. We investigated the cost of insulating materials as shown on the right. The costs are quite divergent, as insulation board products, such as extruded polystyrene, cost 4 to 5 times more than fiberglass and cellulose. We did identify one insulation board, an expanded polystyrene board which is actually widely used in North Carolina for perimeter slab insulation, which had a substantially lower price than other foam insulation boards.

The group decided to conduct a survey to determine the optimal wall system for the project. The criteria used, method of evaluation, and average weights as a result of the survey are shown in the bar chart.

We evaluated how well the different wall system options met each of the criteria using the measurement techniques shown previously. The wall systems evaluated, and the final evaluation scores for each are shown on the next page.

The option that received the highest score was a 2x8 wall with staggered 2x4 framing (turned 90 degrees on outside stud wall), blown cellulose insulation, and 2 ¼-inch expanded polystyrene. The second highest score was for a 2x6 wall with cellulose and 4 ½-inch expanded polystyrene. The schematic after the foundation section shows the components of the wall system selected.

Insulation Material Costs ($/sq ft - R-value)



Criteria for Scoring Alternative Wall Systems

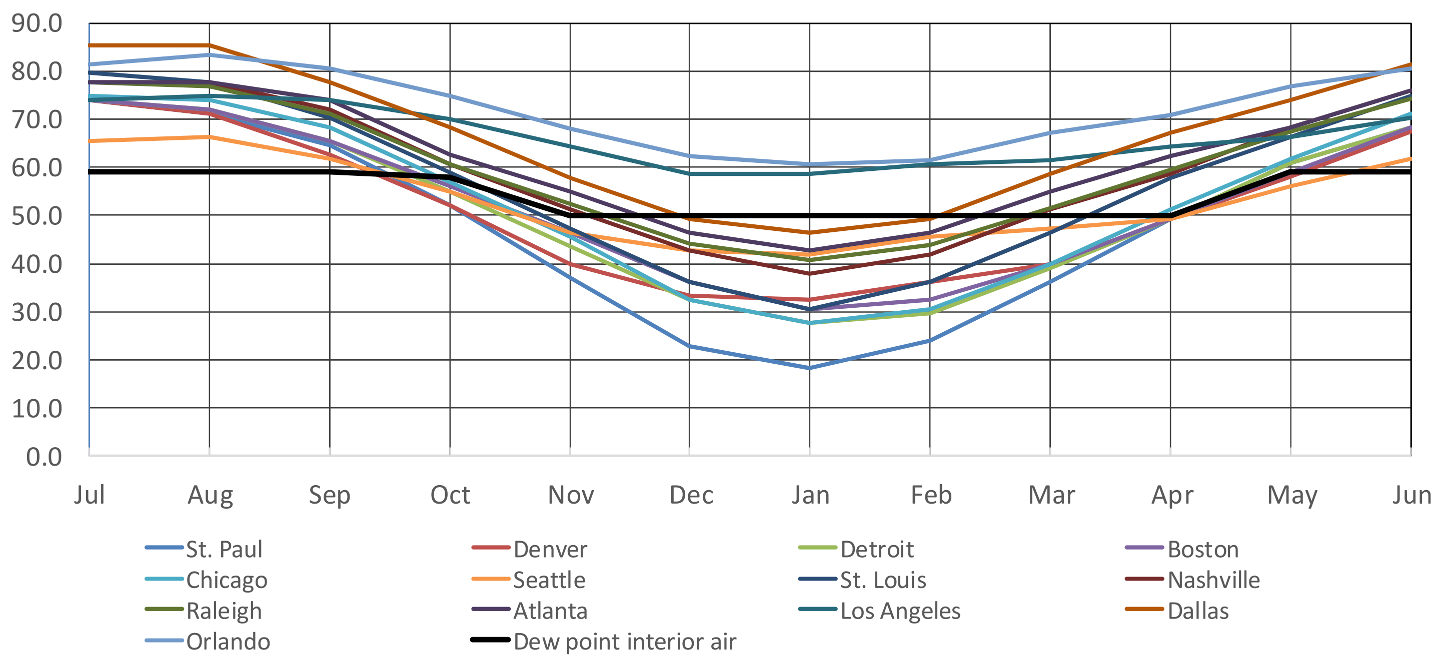
Criteria	Mode of Measurement	Weight from Survey
Cost/sq ft-R-value	Cost of wall system / R-value per sq ft	22.01
Exterior drainage?	Exterior vented rain screen?	13.69
% recycled products?	Cost of recycled product/ Total cost	10.76
Condensation potential?	Sum of differences between dew point temp and exterior sheathing temp in Dec, Jan and Feb	13.32
Annual energy savings?	Estimated annual energy savings from energy model	24.46
Financial analysis	Annual rate of return	15.77

Scoring Rubric for Wall Construction							
	Cost/sq ft-R-value	Drainage?	Recycled products	Condensation Potential?	Annual Energy Savings	Annual Rate of Return	Score
Weight	**22.01**	**13.69**	**10.76**	**13.32**	**24.46**	**15.77**	
2x4 Wall with R-15 Batt	1.00	1	0.0	1.1	1.00	1.00	0.9
2x6 Wall, Cellulose, 2" XPS	2.17	5	1.6	5.0	4.32	1.00	3.2
2x6 Wall, Cellulose, 3" XPS	1.91	5	1.3	4.4	4.65	1.00	3.1
2x6 Wall, Cellulose, 2 1/4" EPS	3.81	5	2.1	3.7	4.32	2.60	3.7
2x6 Wall, Cellulose, 4 1/2" EPS	4.38	5	1.7	5.0	5.00	1.35	3.9
2x6 Wall, Fiberglass, 2" XPS	3.03	5	0.0	3.7	4.32	1.00	3.1
2x6 Wall, Fiberglass, 3" XPS	2.64	5	0.0	4.4	4.65	1.00	3.1
2x6 Wall, Fiberglass, 2 1/4" EPS	4.65	5	0.0	3.7	4.32	5.00	4.0
2x6 Wall, Fiberglass, 4 1/2" EPS	5.00	5	0.0	5.0	5.00	2.73	4.1
2x10 wall with Cellulose	4.64	5	3.5	1.0	4.55	4.07	4.0
2x10 wall, Cellulose, 1" Spray Foam	4.26	5	2.7	2.4	4.65	2.37	3.7
2x8 wall, Cellulose, 2 1/4" EPS	4.85	5	2.6	3.2	4.79	3.46	4.2

Calculation of Condensation Potential

For the wall system we selected, the temperature of the interior of the wall sheathing remains above the dew point temperature of indoor air in Los Angeles and Orlando. In Dallas, Atlanta, Raleigh, and Seattle, the temperature of the sheathing stays above 40 degrees all winter. Since we have paid such careful attention to air leakage and have used moderate density cellulose in the wall cavity to limit air flow from the interior to the exterior of the wall cavity, we decided to stick with our proposed wall system. As a check on the condensation potential, we conducted several WUFI runs examining moisture flow and accumulation in buildings systems. The analysis showed our wall had one of the lowest moisture contents in proximity to the interior condensing surface of the exterior sheathing.

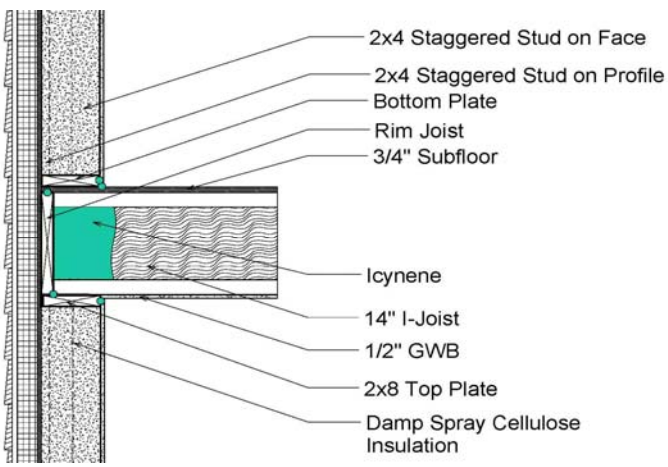
Condensation Potential of the 2 x 8 Wall with R-10 EPS Sheathing



SEALING THE BAND JOIST AREA

The next page shows a schematic of the wall system around the band joist between the first and second floor. This area commonly has insulation that is either poorly installed or becomes loose and out of position over time. It is also a zone that encounters substantial air leakage. We have used foam insulation, continuous housewrap, and sill sealer materials to minimize traditional issues.

Insulation and Air Sealing Band Joist Area



FOUNDATION SYSTEM

The foundation system for the slab-on-grade home has the following goals:

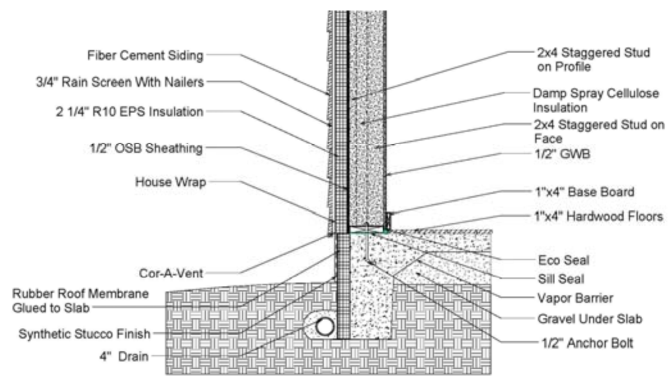
- Provide insulation with no thermal bridges
- Provide drainage to direct soil moisture away from the house
- Provide moisture protection against the concrete slab edge
- Provide protection against termite infestation

The North Carolina State Energy Code requires that the top edge of the insulation has a 2-inch gap to provide an inspection gap for termite treatment companies. The gap is obviously a major flaw in the insulation system.

The solution the Mountain Laurel Home uses is R-15 expanded polystyrene insulation (substantially less expensive than extruded polystyrene) covered with a rubber roofing membrane. The membrane would be sealed to the slab using mastic. Sill sealer would be installed over the membrane as an air sealant.

We have specified installation of a foundation drain embedded in gravel or a different aggregate, which would in turn be wrapped with a filter fabric, such as landscaping cloth. However, the typical approach for slab-on-grade construction in the production home market does not include foundation drains. The addition of the rubber membrane extending to the base of the foundation

Insulation and Air Sealing Slab-on-Grade



trench will resist surface moisture from the soil contacting the slab edge. The concrete can still drain to the gravel in the bottom of the trench if it absorbs moisture.

CEILING SYSTEM

Structure

Dan Ryan Homes currently uses roof trusses for the majority of their roof framing needs. Since our home is a 1 ½ story structure, roof trusses would be more challenging, but still potentially available. However, when considering the high levels of insulation our home requires, we decided that a simpler and more effective framing option would be to use 14" TJI's, which Dan Ryan Homes currently employs in the second floor structure.

The advantages of the TJI system are:

- They come in the necessary lengths for our home.
- They are straight and provide an excellent nailing surface for interior and exterior finishes.
- They have less thermal bridging than conventional 2x dimensional lumber.
- In the soffit area, the extensions from the full TJI rafter do not have the surface area of dimensional lumber and would thus draw less moisture into the interior of our home.
- They provide an excellent space to install a thick blanket of low-cost insulation material such as fiberglass or cellulose.
- They will provide more space in the knee wall area where the mechanical equipment will be than roof trusses.

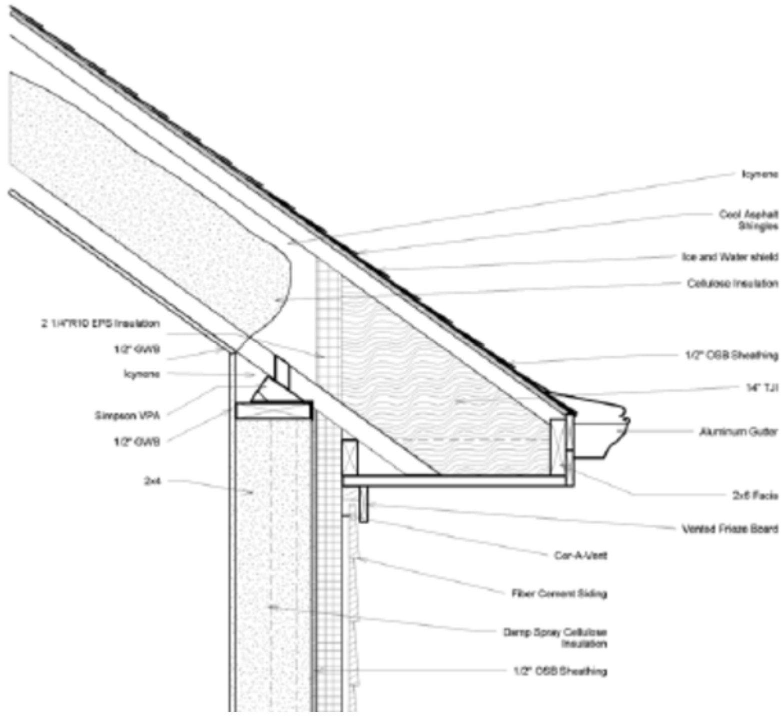
The TJI rafters will form the ceiling of the dining and living room. Horizontal 2x6's will connect the two rafters and support the flat 8-foot ceiling of the upstairs rooms. The ridge beam for the roof is structural.

Ceiling Insulation System

Cathedral Ceiling Insulation

The cathedral ceiling condition exists over the dining room, living room, and in the mechanical knee wall area. The insulation system begins with a 2" layer of Icynene insulation sprayed against the bottom of the roof deck. The Icynene will also fully enclose the junction between the rafter and the top plate of the wall system. In addition to providing an excellent air seal, the Icynene will serve to present a warmer condensing surface towards the interior of the house. One reason not to use high density foam is so that, in case of a roof leak, rainwater will travel through the Icynene more readily than high density foam and thus reveal the existence and approximate site of the leak more quickly. (http://www.buildingscience.com/documents/bareports/ba-1006-ba-high-r-roofs-case-study-analysis)

Insulation/ Air Sealing Ceiling Over Living Room



The remainder of the insulation will be provided by blown-in-place cellulose, selected by the team due to its recycled content. The 12" of cellulose will provide about R-42.

The schematic on the next page shows the ceiling in the mechanical attic. It is quite similar to the interior cathedral ceiling, except the finish material is a single layer of Thermoply.

Flat Attic Insulation

The flat attic will be air sealed with Icynene insulation for all penetrations, as well as at all construction joints, including the top plates of the wall systems. Afterward, R-50 cellulose insulation will be blown in place.

Attic Ventilation, Air Sealing and Insulation

The roof deck in the area of the house with an open attic will have an integrated radiant heat barrier. The barrier will reduce radiant heat gain into the attic in the summer months.

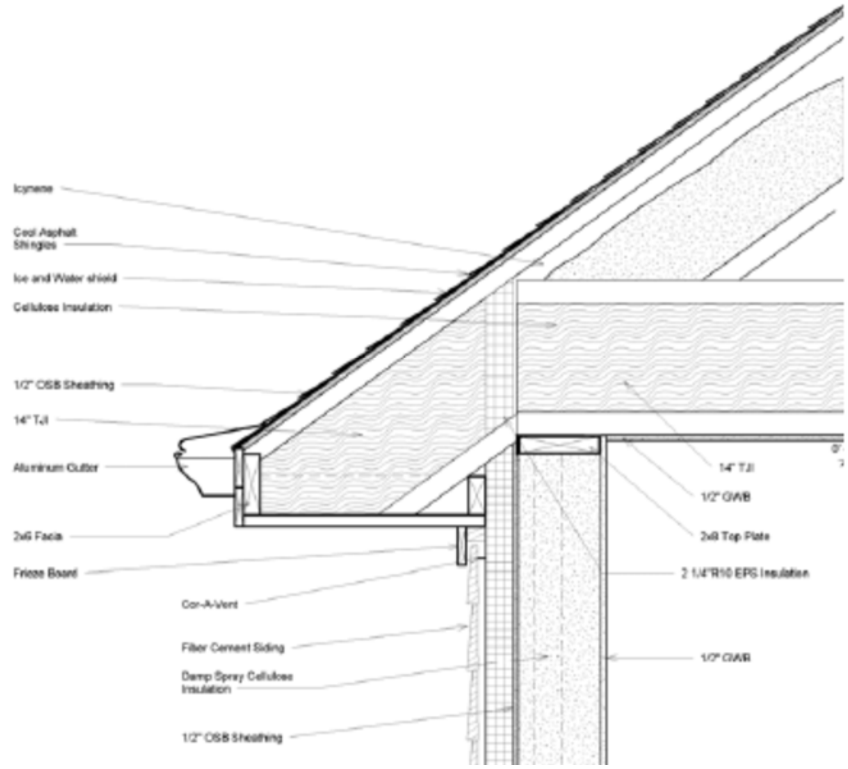
The attic floor will be air sealed with Icynene over all of the top plates and other air leakage locations. Attic rulers will be placed – at least one for every 300 square feet. Then, R-50 cellulose will be blown in place.

Since the cathedral ceiling portion of the attic is unvented, there is not a specific need to provide attic ventilation. However, it may help reduce higher temperature levels in the attic during the summer months and remove some moisture that may accumulate. Thus, we decided to install gable end vents.

WUFI analysis

Besides the thermal properties of a building component and their impact on heating losses, its hygric behavior has to be considered, as well. Permanently increased moisture content in the envelope may result in mold growth and/or moisture damage. In the Webinars and on-line publications, Joseph Lstiburek suggests, in order to reduce moisture build up within building components, that the exterior sheathing insulation R-value match the interior wall insulation's. However, current building practices do not require continuous insulation. Simulation was used to show how our wall section design successfully reduces moisture build-up compared with standard building practices by incorporating exterior continuous insulation.

Insulation and Air Sealing Ceiling Over Master Bedroom

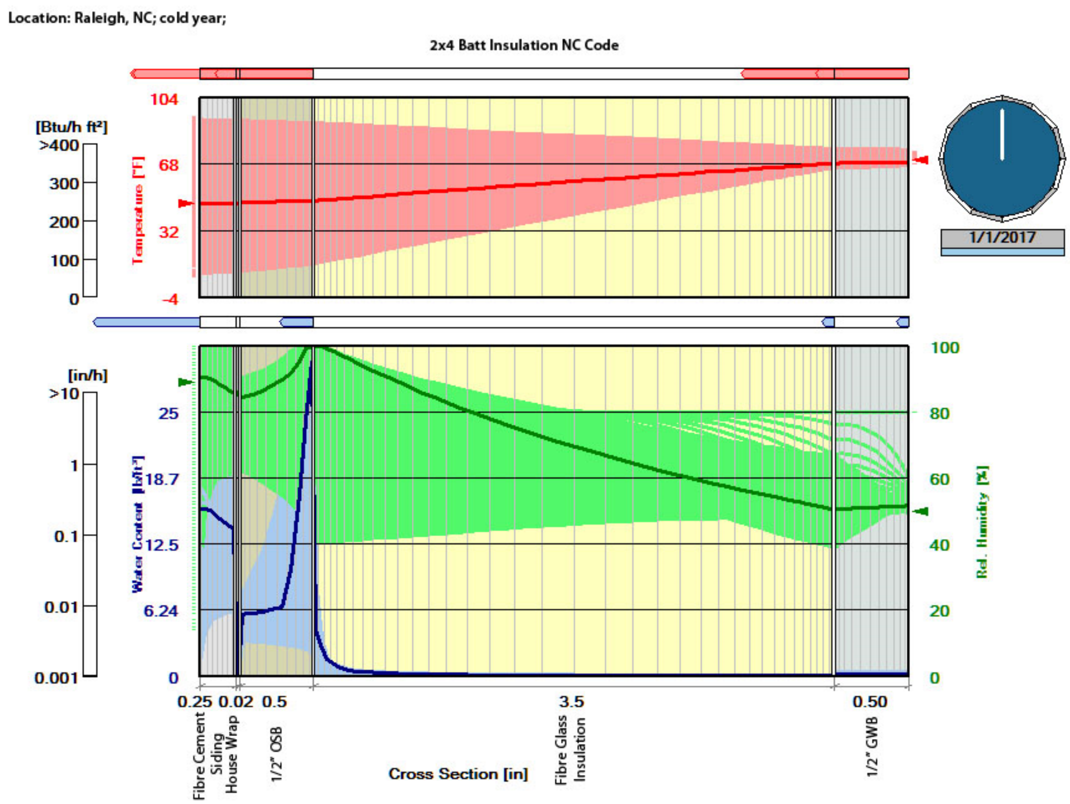


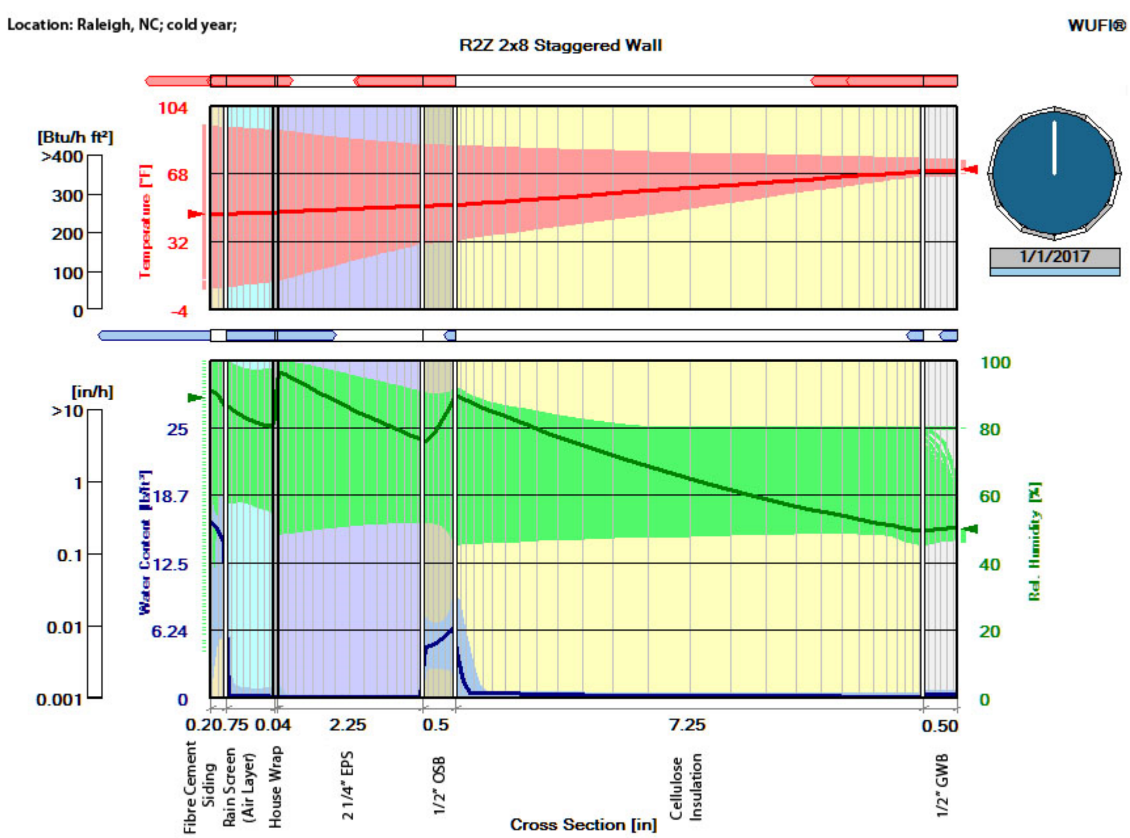
Progressions of a wall sections were tested for heat and moisture transfer using WUFI® 1-dimensional software. Four iterations of wall sections were tested using a year's worth of Raleigh, North Carolina TMY weather data. All wall sections have standard ½" gypsum wall board (GWB) on the interior and ¼" fiber cement siding on the exterior with ½" oriented strand board (OSB) between the stud wall and the additional sheathing or siding. For the purpose of simplification only the insulated portion of the wall systems were simulated. Elevated moisture content at the interior of the exterior sheathing has the potential of causing the most damage and was therefore was the primary focus of the WUFI simulation output.

The first iteration run through WUFI® was the minimum required by North Carolina building code standards (2x4 stud wall with R-15 fiberglass batt insulation). The next two iterations were 2x6 stud walls with R-21 insulation and show a progression from R5 exterior insulation to R10. The last iteration, the designed wall, was a 2x8 staggered stud wall with blown cellulose insulation and 2 ¼-inch

Wall system	Total R-value (h ft^2 °F/Btu)	Max. moisture content interior OSB surface (lb/ft^3)	Max. total moisture content (lb/ft^2)
2 x 4 wall with R-15 Batt	11.11	16.21	1.13
2 x 6 wall with R-21 Batt + R5 XPS	24.79	10.13	0.83
2 x 6 wall with R-21 Batt + R10 XPS	30.46	7.79	0.72
2 x 8 wall with Cellulose + R10 EPS	36.92	7.27	1

expanded polystyrene. The moisture content within the design wall compared to the NC building code standard is far less. The lower the moisture content at the cavity side of the vapor barrier the lower the risk for mold growth and material water damage.





IAQ EVALUATION

STRATEGIES FOR INDOOR AIR QUALITY

Indoor air quality will be managed through optimization of ventilation amounts, strategic floor plans that enhance airflow, eco-friendly material choices, and quality assurance inspections and certifications for relevant components to indoor air quality during the construction phase. Contaminants of concern were formaldehyde, NO2, radon, particulate matter, and volatile organic compounds. Concentrations of these contaminants and their off-gassing rates were one of the primary factors used in our decision matrix for material choice.

The IAQ strategies included in the Mountain Laurel Home are design to improve long term health of occupants, as well as provide an environment acceptable to asthmatic or allergenic occupants.

EPA airPLUS, LEED, and Other Certifications

This voluntary certification is to be conducted, see Appendix A-******___, with construction of the building to ensure high IAQ. EPA airPLUS certification reviews for proper moisture control, HVAC filtration, Environmental Tobacco Smoke mitigation, paint selection, and lumber selection and will be included with documentation provided to the buyer. The airPLUS certification requires that HVAC System Quality Installation Contractor and Rater, as well as Thermal Enclosure System Rater and Builder checklists are completed. Completion of these certifications along with an invested effort from the builder will help ensure thermal, moisture, and IAQ systems will work incoordination and components properly installed.

Material & Construction Choices for IAQ

Low-VOC, recycled materials (materials that have already off-gassed the majority of contaminants during their life), and/or non-off-gassing products were given selection priority to decrease the amount of contaminants being introduced into the house. These product choices include:

- Benjamin Moore Low VOC paints series
- Engineered Wood – "eco-timber?" - Hardwood Floors
- Low-VOC sealants and caulk

Wall construction, window components, roofing, slab system, and connections of these components were designed to reduce thermal bridging. Staggered stud framing was used in exterior walls to greatly reduce thermal bridging. Reduction of thermal bridging helps to minimize "cold-spots" where surface condensation can occur and create mold problems that affect both IAQ and durability.

A primary component of our HVAC system is our ERV's enthalpy wheel, which helps control humidity gains or losses from incoming ventilation air.

We chose to exclude carpets from our house. Although there are low-VOC recycled carpets available on the market, engineered wood appealed because of its low-VOC content and greater ease of maintenance/cleaning and greatly increased durability. Carpets are also large reservoirs for particulate matter and allergens which affect IAQ.

Off-Gassing Period

A full two-week off-gassing period will be taken after gaining the certificate of occupancy for the house. During this off-gassing period ventilation systems will be run but house will remain un-occupied. This allows for particulate matter created during construction and a large percentage of VOC's to be evacuated from the house and enhances health of buyers. (http://www.epa.gov/iaq/index.html)

Ventilation for Indoor Air Quality

The whole house ventilation system is discussed in detail in the Space Conditioning section, as it is integrated with the heating and cooling system. In summary, the house is continuously ventilated by an ERV. Exhaust air is drawn from the bathrooms, while fresh air is supplied to the house via the HVAC ductwork.

Indoor contaminants can be produced rapidly by cooking activities. A manually-operated kitchen fan exhausts air directly to the outside at 100 CFM, while a damper directly below the stove opens to bring in fresh make-up air.

SPACE CONDITIONING DESIGN

T he Appalachian State team had the following goals for the heating, ventilation and air conditioning system:

- Properly sized heating and cooling loads using Manual J procedures to take advantage of reduced loads due to efficiency, air sealing, interior HVAC location, and design
- Integration with ventilation system and house operation/ occupants' lifestyle
- Kitchen exhaust to exterior with make-up air
- Humidity control
- Automated control system

There are many cutting edge HVAC systems available on the market. However, it is important to choose a system that provides a reasonable financial return with a proven track record of performance, which is comfortable for builders to install and homeowners to operate. System types considered include:

- central air-air source heat pump
- central gas furnace with air conditioner
- mini-split heat pump
- ducted mini-split heat pump
- geothermal heat pump

After much discussion, we eliminated ductless mini-splits from consideration for the following reasons:

- High cost for sufficient units to deliver comfort for each room in the house
- Concerns about acceptability of the wall-mounted fan-coil units to the production home market

HVAC SYSTEM DESIGN

Sensible heating and cooling loads were minimized by optimizing the building envelope on a cost per R-value basis and effectively air sealing all sites of leakage. However, passive heat loss becomes insignificant in comparison to the volume of heat removed via mechanical fresh air ventilation according to the requirements of ASHRAE 62.2-2013. Therefore, it critical to use a high-efficiency energy recovery ventilator (ERV). Water heating makes up a significantly higher portion of total energy consumption than in a standard house, so it is important to consider how this might factor into HVAC system selection, in particular, with a heat pump water heater that communicates with interior air.

Manual J Calculations

In order to learn the logic behind ACCA's Manuals J and D, we developed a spreadsheet that followed the approved HVAC sizing procedures. The charts for the analysis are contained in the appendices. The table on the next page *** summarizes the analysis.

Manual J: HVAC Load Summary for Appalachian State Race-to-Zero House						
	Btuh	Cooling Load (Btuh)			Design	Adjusted
Rooms	Heating	Sensible	Latent	Total	CFM	CFM
Entry	1,808	868	153	1,021	39	55
Flex	1,504	684	218	901	35	48
Living + Bath	1,055	588	274	863	64	89
Kitchen	572	1,498	904	2,401	92	128
Dining	1,478	1,077	203	1,280	49	68
Master BR + Bath	3,402	834	433	1,267	81	112
Master BR Closet	1,959	270	33	303	40	56
Master Bath	shared	shared	shared	shared	shared	shared
Laundry	285	673	117	790	30	42
Bedrm 4 + Mech + Landin	1,389	1,279	303	1,583	54	75
Landing	shared	shared	shared	shared	shared	shared
Downstairs Bath	1,501	292	124	416	0	0
Bedrm 2 + Master Bath	1,748	812	254	1,066	50	70
Bedrm 3	405	788	250	1,038	40	55
Stair Bath	0	151	100	251	0	0
Mech	shared	shared	shared	shared	shared	shared
	0	0	0	0	0	0
Total	**17,105**	**9,813**	**3,366**	**13,180**	**574**	**800**

The house requires a two-ton HVAC system that will deliver at least 17,105 Btu/hour of space heating and 13,180 Btu/hour of cooling. The latent load represents about 25% of the cooling load. This load was derived from the Manual J procedures, but augmented by our assumptions about potential humidity gains through the building envelope and floor system. The air flow rates were adjusted for the actual air flow rate of a two-ton system, which is typically about 800 cfm.

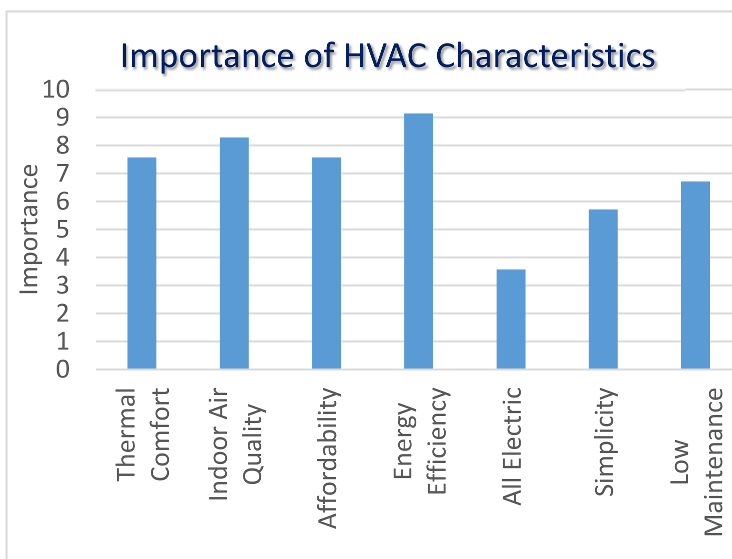
Design Selection

There is much more to an HVAC system than energy efficiency and cost performance; it should maintain good indoor air quality, provide a high level of thermal comfort, be acoustically and visually palatable, be simple enough to install and operate, and integrate well with renewable energy sources. The importance of various characteristics were rated in a voluntary survey among the Race to Zero team.

HVAC Survey

An HVAC team assembled to discuss and quantify the actual performance of different HVAC systems within each type of criteria. Many systems were informally ruled out in light of the advantages and greater market acceptance of similar technologies (for example, ducted mini-splits took precedence over ductless models). A radiant floor distribution system was also ruled out because of the potential for it to overheat in response to small loads, owing to its greater inertia over forced air systems, and its inability to provide cooling without courting dangers of condensation on the floor.

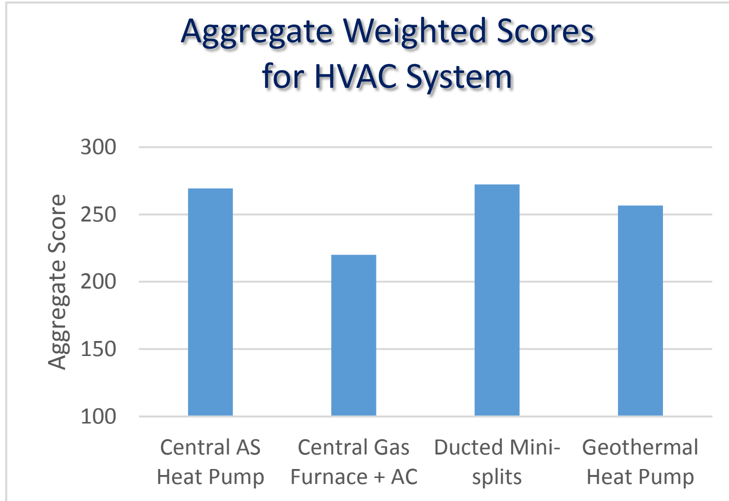
Geothermal was disadvantaged because of low affordability and higher complexity, while a natural gas furnace was inferior because of issues pertaining to the effects of combustion on IAQ and an obvious disconnect between natural gas and renewable



energy. The issues between ducted mini-split heat pumps and a central heat pump were so close for our particular floor plan that we decided to obtain actual cost estimates for various SEER ratings from an HVAC contractor before deciding between the two types of systems. We then developed a decision-making protocol for determining the optimal HVAC system using the following criteria:

The HVAC Team convened and developed a list of important HVAC characteristics. They developed a survey that was answered by the students on the team. Race to Zero team members voluntarily voted on the importance of each characteristic. The table to the right shows the average weights for each of the criteria.

The HVAC Team determined how well each of the system options met each criteria. They then multiplied the weights by the ratings for each characteristics and calculated the final score for each option. As shown in the tables to the right, the highest scores were for central air source heat pumps and ducted mini-split heat pumps.



Overlap with Water Heating

The HVAC system can interact with water heating in a few ways. Geothermal heat pumps that can supply both water heating and space conditioning. However, these systems were eliminated on the basis of affordability. Solar thermal panels can also be utilized for the combined functions of space heating and water heating. However, the performance of solar thermal panels is less effective in winter, when space heating is needed most, and they consume roof space that can otherwise be used for photovoltaics.

Analysis of a heat pump water heater with an energy factor of 2.75 showed that it had a net benefit on the combined cost of space conditioning and water heating. It is not ideal to place it within the conditioned space of the home in heating-dominated climates; however, the possibility of freezing precludes placing it outside of the building envelope. The reduced cost of space cooling together with the decreased cost of water heating more than offsets the increased cost of space heating.

We calculated that placing heat pump water heater within the conditioned space has a net savings approximately equal to a solar thermal water heating system that achieves 50% solar fraction.

Water Heater Controls

A caveat to using this method is that for heating-dominated climates, it can greatly increase the heating load for short periods of time. Disregarding the heat generated by compressor inefficiencies, the water tank heat pump can remove up to 6,500 Btuh from the indoor air. Sizing according to standard procedures would have us select a system large enough to meet this sporadic heating load in the coldest months, rendering the system oversized under the vast majority of conditions.

We overcame this issue by equipping the heat pump water heater with a controller that receives input from an outdoor temperature sensor. When the outdoor temperature drops below 40 °F, an internal electrical resistance heating element turns on, halting any additional load on the central HVAC. Although this controller cannot yet be purchased off-the-shelf, we believe it is a necessary solution that could eventually be integrated into many heat pump water heaters to solve an industry-wide problem for cold climates.

Distribution System Considerations

Air distribution systems can have drawbacks and benefits over radiant distribution. Commonly stated drawbacks include that it creates pressure differences within the envelope, driving a greater amount of air leakage, and that it is less comfortable than radiant heating systems. We are minimizing air leakage by ensuring a tight envelope rated at less than or equal to 0.6 ACH50 and balanced flow rates that do not create large pressure differences. The balanced distribution system, along with the tight, well-insulated building envelope, will also maximize thermal comfort.

Air distribution has other advantages in terms of our design goals. ASHRAE 62.2-2013 requires over 100 CFM of fresh air ventilation for our house. A ducted system allows for a balanced removal of this air from the home through an ERV. Conditioned air can be recirculated and filtered to remove dust, allergens, and particulates.

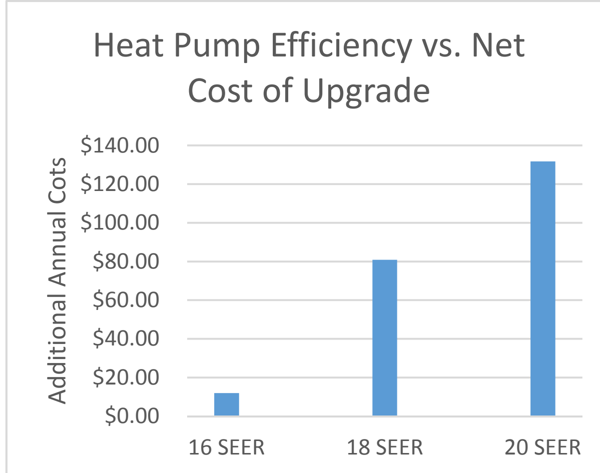
Final System Selection

The survey results favored either a ducted heat pump minisplit system or a central heat pump. After analyzing the plans and obtaining preliminary costs for the two options, the central system was selected. In addition to its lower cost, simpler integration with the ventilation system, potentially decreased maintenance costs due to fewer blowers and operating parts, and availability in very high efficiencies, central systems are most often used by the current residential HVAC industry, thus, a transition to Near-to-Zero housing would be easier and require less training.

Determination of Optimal Efficiency

We performed a cost payback analysis on the heat pumps with different SEER and corresponding HSPF ratings. Because our building envelope is much more efficient than that of an average house, the space conditioning loads are smaller and therefore have less of an impact on overall energy consumption when they are efficiently met.

Our analysis was performed on contractor cost estimates of different 2 ton central heat pumps* with three different SEER ratings: 16 SEER, 18 SEER, and 20 SEER. We adjusted the estimates by 15% to reflect the discount that a production builder would receive and further reduced the cost by $300 to reflect a Progress Energy discount for efficient systems. The net effect on annual payment was then compared to a baseline 13 SEER, 3.5 ton system that would likely be installed in a standard similarly sized house.



We used an adjustment factor to convert 2 ton units to expected 1.5 ton units, but ended up selecting a 2 ton system. This has a small effect on the calculations but the prioritization remains the same.

The cost of upgrading, defined as the annual increase in mortgage payment minus the annual energy cost savings, was negligible for the 16 SEER system, which only costs the homeowner $12 more per year than a 13 SEER system. The 18 SEER and 20 SEER systems cost much more and cannot be justified economically or environmentally, since the amount of energy saved could be more affordably produced with renewable energy systems.

Manual S and Manual HP Calculations

We considered the guidelines of Manual S and Manual HP in sizing our system. With our water heater controls implemented, the original heat load drops precipitously and the cooling load becomes the dominant concern.

A primary concern of Manual S is whether the system airflow is appropriate to the sensible heat ratio of the cooling load: airflow should be low when the latent heat load makes up a large percentage of the total heat load, and vice versa for low small latent heat loads.

Based on input from our industry partners concerning cost and reliability, we determined that an American Standard Silver 16 Heat Pump would be the best unit to fulfill Manual S requirements.

American Standard Silver 16 Heat Pump	
Outdoor Unit Model Number:	4A6H6024H1
Indoor Unit Model Number:	AM7A0B30H21
Heating and Cooling Capacity (Btuh):	24,400
AHRI Rated SEER:	16
AHRI Rated HSPF:	9.5

Duct Sizes to Each Room

Rooms	CFM	Duct Size (inches)
Entry	55	5
Flex	48	5
Living + Bath	89	6
Kitchen	128	7
Dining	68	5
Master BR + Bath	112	7
Master BR Closet	56	5
Master Bath	shared	n/a
Laundry	42	5
Bedrm 4 + Mech + Landing	75	5
Landing	shared	n/a
Downstairs Bath	shared	n/a
Bedrm 2 + Master Bath	70	5
Bedrm 3	55	5
Stair Bath	shared	n/a
Mech	shared	n/a

The best nominal capacity for our unit according to Manual S would be 1.5 tons, but this was not available in an acceptable SEER rating and HSPF. Because our system has multiple speeds and can therefore adjust to meet different sensible heat ratios, the 2 ton unit is expected to meet all comfort and humidity concerns.

DISTRIBUTION SYSTEM DESIGN

The project team used ACCA Manual D procedures to size the system ductwork. One advantage of the high efficiency envelope is the smaller HVAC system size and the resulting lower air flows and duct sizes required. We eliminated supplies that are typically installed to rooms such as bathrooms and the mudroom. Thus, our duct system should be much easier and cheaper to install than a typical system.

The most difficult challenge was finding an internal (inside the envelope) path for the ductwork to the flex room, front hallway, and living room. We decided to build a dropped soffit inside the second floor ceiling. The soffit also serves to divide the hallway from the living room area.

We laid out the duct system, initially on paper and afterward in Revit. The first step in Manual D is determining the Total Effective Length (TEL) of the longest supply and return runs, including all ducts, fittings, connections, and other features. The chart shown to the upper right summarizes this calculation. The TEL is 423 feet.

Supply Duct TEL	Effec Length	Number	Subtotal
Takeoff from supply plenum	35	1	35
Trunk with damper to box	6	1	6
Damper	done		
Junction box 1	30	1	30
Curved ducts "elbows"	10	5	50
Sheet metal elbows	25	1	25
Junction box 2	30	1	30
Run to front of house	18	1	18
Run across house	30	1	30
Run down to box 2	12	1	12
Boot	50	1	50
Subtotal (Equivalent Length in feet)			**286**
Return Duct TEL			
Takeoff from supply plenum	35	1	35
Trunk with damper to box	4	1	4
Damper	done		
Junction box 1	40	1	40
Curved ducts "elbows"	10	2	20
Sheet metal elbows	25	0	0
Junction box 2			
Run under floor	8	1	8
Other runs	0	1	0
Boot	30	1	30
Subtotal (Equivalent Length in feet)			**137**
Total Effective Length (feet)			**423**

The next series of steps is to find the friction loss in the ductwork:

1. External Static Pressure (ESP) from the manufacturer is 0.50 inches of water gauge (IWG) at a flow rate of 793 cfm
2. Total Component Losses are:
   - Already included in the ESP is the friction loss in the cooling coil, resistance heating coil, and regular filter
   - High efficiency filter = 0.07 IWG
   - Supply outlet = 0.03 IWG
   - Return outlet = 0.03 IWG
   - Balancing damper = 0.03 IWG
   - Total Component Losses = 0.16 IWG
3. Available Static Pressure = External Static Pressure – Component Losses = 0.5 – 0.16 = 0.34 inches water column (IWC)
4. Friction Rate = Available Static Pressure / TEL = 0.34 / 423 = 0.08 IWC/ 100 feet

The friction rate is used to size the ductwork based on the cfm flowing to each room. The table to the right summarizes the duct sizes required. Commonly only even sized ducts are used by most contractors.

VENTILATION SYSTEM

ASHRAE 62 and Design Considerations

Our team believes that every home needs a whole house ventilation system. In our case, due to the tightness of the structure, ventilation is even more critical. The latest version of ASHRAE 62.2 requires a cfm ventilation rate equal to:

7.5 * # occupants + 3% * conditioned floor area

In our case, the conditioned floor area is 2,278 square feet and there are potentially 5 bedrooms, which signifies 6 potential occupants. Thus, the ventilation rate would be 116 cfm. We selected a Zehnder Focus 200 ERV for the house with 91% efficient sensible sensible heat recovery. It would be operated at low speed, with the occupant's option of increasing the flow rate to the higher level of 118 cfm. The unit and its connecting ductwork would be located in the mechanical room in the conditioned attic space behind the upstairs bathroom. The small amount of flow from each bathroom, about 38 cfm, could be resupplied by undercutting the bathroom doors approximately one inch. Air would also flow into the bathrooms under the bottom plates and through the interior wall system, but if all of the air came from under the door, it would only depressurize the room by about 1 Pascal, which should not have any negative repercussions. Since the flooring is non-carpeted, the door undercut should not be compromised over time.

We considered installing a CO_2 sensor to lower the ERV fan speed when CO_2 levels in the home are below a reasonable threshold. However, the ventilation rate for the building occupants is only 45 cfm (6 occupants x 7.5 cfm each) of the total of 116 cfm. We did not think it was a worthwhile investment for the added sensors and control equipment to reduce the fan speed. Plus, it would reduce the ventilation rate in the bathrooms below the ASHRAE minimum of 20 cfm continuous.

Exhaust system

Bathroom Exhausts Tied to ERV

Our system uses the bathrooms as the location for the exhaust registers for the ERV as shown in the schematic. Because the house is so well insulated and airtight, the heating and cooling loads for the bathrooms are quite small. The three bathrooms combined only require a total of 55 cfm of air flow for their heating and cooling needs. Our design provides no supply ductwork to the bathrooms, but these rooms are connected to the exhaust side of the ERV and are under constant negative pressure. Thus, they are continually supplied with conditioned air from the house. The advantages of this design decision are:

- The homeowner does not have to remember to turn on the exhaust fan when using the shower/ tub.

- The rooms require no supply ductwork, which saves on the installed cost of the HVAC system.
- The rooms require no separate exhaust fans, thus saving on the cost of fans, controls, exhaust ductwork, and dampered exhaust ports. In typical homes, the ductwork for the exhaust fans is poorly installed with inadequate performance.
- Due to the constant negative pressure, any odors from the bathroom are exhausted to the exterior, rather than being pushed back into the home as in a typical home with bathroom supply ducts and no returns.

Kitchen Exhaust and Supply Air

In addition to the bathrooms, the kitchen requires local ventilation. We have specified a 100 cfm exhaust fan, with integrated microwave and high efficient lighting. The unit has tight damper which opens to a short duct to the exterior when the fan operates. In order to avoid high negative pressures inside the house when the fan operates, there is a make-up air duct in the base cabinet beside the stove. It has a damper that actuates when the fan turns on.

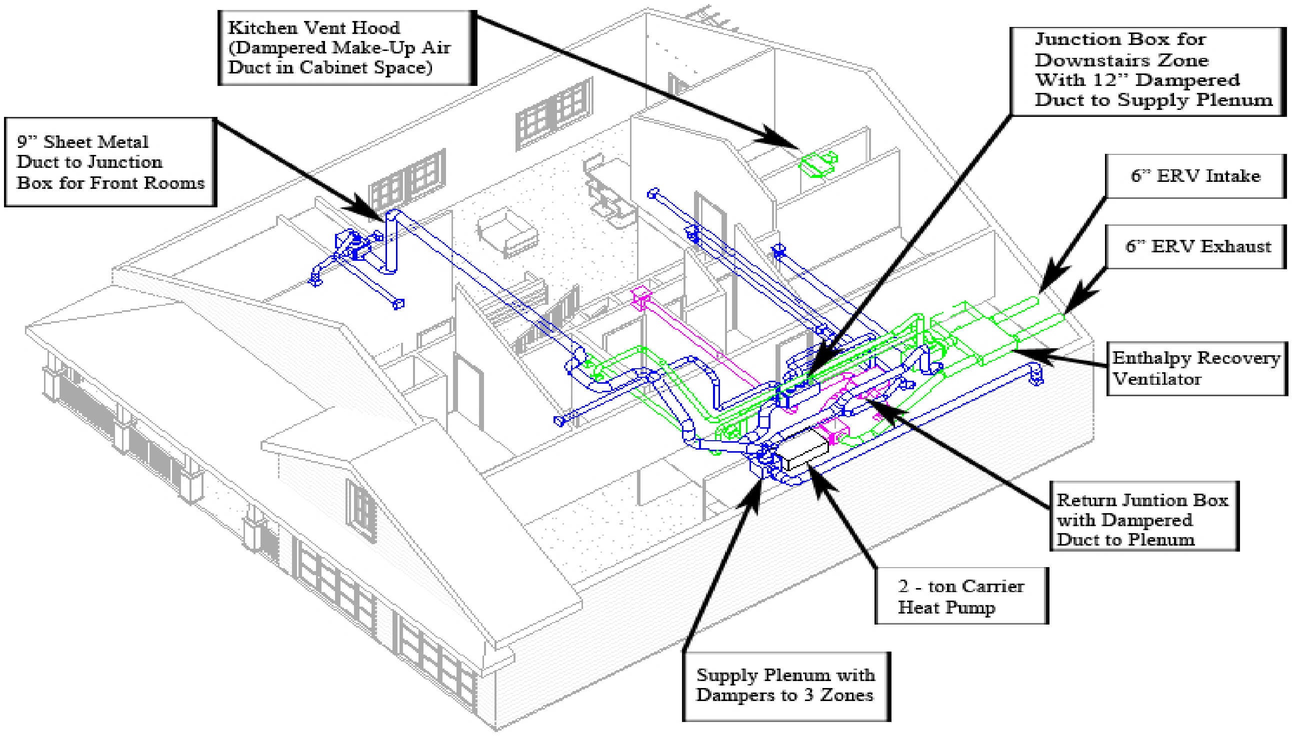
Fresh Air Supply

Fresh air from the ERV is pulled from outside and then delivered to the return plenum of the central air handler. In the common situation when the HVAC blower is not operating, the incoming fresh air could short circuit the house, flowing through the return ductwork and directly into the bathrooms. Thus, our system has a damper located in the main return trunk duct which is normally in a closed position. When the HVAC fan operates, it opens to all return air to flow into the house from both the return grilles and the ERV.

SUMMARY OF HVAC SYSTEM OPERATION

The house will use a simple control to provide comfort and help control indoor air quality in the home. The different functions of the control system are as follows:

1. Thermostatic control for the three comfort zones – upstairs rooms, master bedroom suite, downstairs rooms. Typically, a three-zone system requires a bypass duct with a barometric damper that connects the supply plenum to the return in order to provide pressure relief if only one zone is operating. However, since the system we selected has multiple speeds, it can operate at a lower speed with a single active operable zone and avoid overpressurization of the duct system.
2. When sensible cooling loads are low and latent loads are high, the controls will operate the system in elevated dehumidification mode.
3. Continuous operation of the Enthalpy Recovery Ventilation system with two operation options
   - When the HVAC blower is not operating, the damper to the return ductwork will remain closed.
   - When the HVAC blower operates, the damper will open.
4. When the kitchen exhaust fan operates, a make-up air damper will open.



Final HVAC System and Duct Design

HVAC System Commissioning

Many systems installed in homes operate at lower efficiencies and provide inferior comfort levels. ENERGY STAR version 3 has provisions to improve on the installation process via its inspection forms for both the HVAC contractor and the home energy rater. The project team feels that this process is adequate to ensure a high performance system. The completed inspection forms are included in the appendix.

Operation and Maintenance Schedule

Over the life of the home, the home occupant and/or owner must seek regular maintenance procedures for the HVAC system. The key steps include:

1. Install filters at the start of each heating and cooling system.
2. Once per year remove the registers and grilles located in floors and walls and vacuum out dust and debris.
3. Once per year, make sure that controls have the correct settings.
4. Make sure that the outdoor unit is kept clean of debris and that coils are not blocked.
5. Have the system serviced once per year, with the following measures:
    a. Check refrigerant charge correctly
    b. Check system operation in all cycles
    c. Measure for correct air flow and temperature conditions
    d. Ensure controls are working properly
    e. Clean coils

Control System

Programmable thermostats and building control systems can often provide the same energy savings as upgrading to more expensive HVAC systems or insulation measures. Additionally, they can enhance thermal comfort by automatically adjusting settings to occupant patterns.

Other than control over temperature, we decided the most important features in a control system are:

- Ability to manage zones independently
- Humidity control
- Remote access

Potential products analyzed include:

- Nest Thermostat
- Control4 Automation System
- Carrier Remote Access Touch Control

All control systems analyzed provide control over humidity and can be accessed remotely through smartphones, tablets, or computers. However, only the Carrier control system can manage multiple (i.e., up to 8) zones from a central interface. The Nest and Control4 solutions would need to be installed independently into each of the house's three zones.

The Carrier control system provides greater ease of control to the occupants, requires less installation work, and is more affordable overall than other options.

Infinity® Remote Access Touch Control SYSTXCCITC01-A

ENERGY ANALYSIS

Energy analysis has for years been used as a post-construction method of predicting energy cost. Recently, energy modeling and simulation software has also been utilized in the design phase to test and optimize building components. Our team utilized a combination of energy analysis software tools to test different building components as well as analyzing the whole building energy use in REMRate. The Home Energy Rating System (HERS) is used in REMrate to compare the energy performance of our design to a similar design with NC code compliant features. A home designed by Dan Ryan homes is also used as a comparison to show potential energy savings for production homes in similar climates.

Starting from the NC Code compliant home, with the same home layout as our design, improvements were simulated for energy savings and then compared with the cost to implement that improvement. The main improvements made were focused on ensuring the envelope was an efficient air, moisture, and thermal barrier to reduce the heating and cooling load. Once the envelope design was decided upon using Green Building Studio in Autodesk Revit along with Model J and Model D were used to simulate and size the HVAC equipment. The appliance and lighting efficiencies were the next area of focus which was decided based on EnergyStar v3 requirements. We were able to reach a HERS score of 41 with affordable envelope and appliance improvements based on current national energy code recommendations. The DOE Zero Energy Ready Home Target HERS rating using a size adjustment factor was 55. The active solar photovoltaic system was then designed to meet the 9735 kWh estimated annual energy use. With the addition of the PV system our home was able to achieve a HERS rating of -3.

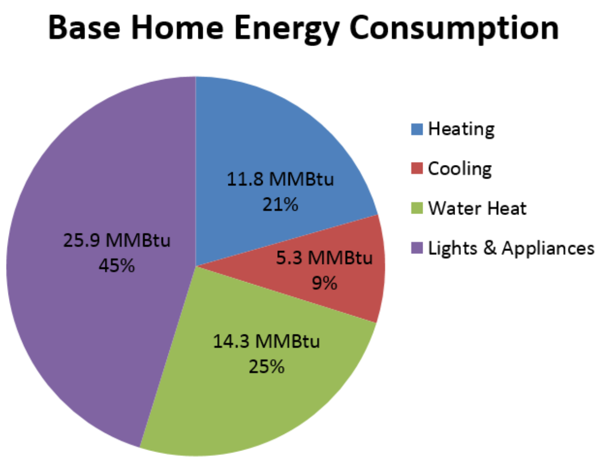
Some assumptions must be made when using an energy modeling software to predict energy usage instead of real building data. For example, the REMRate software did not have Mebane, NC specific climate data so our team used the closest city in proximity and in climate zone type which was Raleigh, NC. Another very important assumption made was the occupancy use. REMRate has preset conditions set for average residential occupancy schedules and appliance use but this average may not accurately reflect actual use. To combat this differentiation our team suggests a portion of the homebuilding process to include homeowner training to teach occupants how to use programmable thermostats effectively, the importance of turning lights and appliances off when not in use, and the importance of proper operable window operation.

REMRATE ITERATIONS

Before deciding on implementing certain building improvements these improvements modeled in REMRate and then priced. The base model mimicked the exact layout of the designed home with only the bare minimum building components and appliances to meet North Carolina 2012 Energy Code. The following table shows a breakdown of the base home components. All insulation was Grade II to represent an average installation method. The base model achieved a HERS score of 76, with a yearly energy consumption of 57.2 MMBtu (16,763 kWh), as our design layout had already been optimized to reduce square footage and take advantage of winter solar heat gain and summer shading.

Table 1 Base Home REMRate Inputs following NC Energy Code

Building Component	REMRate Input
Wall System	R-15/OSB Sheathing
Slab Insulation	R-10 with 2" gap at top
Windows	U-0.35/SHGC 0.30
Ceiling/Attic	R-30 attic
Infiltration	5.0 ACH50, 6% Duct Leakage
HVAC	SEER 13 / HSPF 7.8 Heat Pump
Water Heater	91% EF
Lighting	75% Fluorescent
Appliances	RESNET Defaults



The first improvements were made to the building design envelope. As it was our design to be appropriate in climate zones from 2-7 it was important that our building envelope be as air tight and thermally resistant as possible while still being affordable as a production built home. An envelope with reduced thermal conductance, water transfer, and air infiltration reduces the heating and cooling load which allows for a smaller and less energy intensive HVAC system. However, the trade-off for such a tight envelope is the requirement for mechanical ventilation when the ACH50 is less than a certain level. As HVAC type and sizing is very much dependent on the building envelope these improvements were not simulated until the building envelope had been decided upon. The lighting and appliance improvements were the last to be simulated and decided upon. The following improvements were added incrementally to the NC Energy Code base home to measure energy savings which were then compared with the price to implement such an improvement (shown in the Financial Analysis).

Envelope:

1. All insulation Grade 1/ R-50 attic/ceiling insulation / ACH50 from 5 to 4
2. 2x6 walls with R-5 continuous sheathing + ACH50 to 3.5
3. 2x6 walls with R-10 continuous sheathing + ACH50 to 3.25
4. 2x8 wall with R-10 continuous sheathing + ACH50 to 2.75
5. Windows to U-0.15 and SHGC-0.22 + addition of thermal mass area
6. R-15 rigid board insulation added to Slab Foundation
7. 0.6 ACH50 + Mechanical Ventilation (Balanced 100 CFM ERV)

HVAC:

8. SEER 14 a/c and 8.0 HSPF
9. SEER 16 a/c and 9.2 HSPF
10. SEER 18 a/c and 10 HSPF
11. SEER 20 a/c and 11.3 HSPF

Lighting & Appliances:

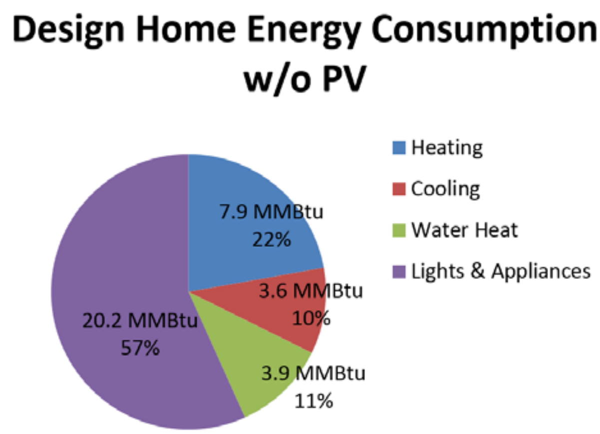
12. 75% Fluorescent to 100% Fluorescent
13. Energy Star rated Refrigerator, Dishwasher, Washing/Dryer, Oven
14. Water Heater from 0.91 EF to 2.75 EF electric heat pump with wrap insulation

Most of these improvements were accepted and implemented into the home design. Improvements that were considered too costly compared to energy savings include the window efficiencies and sizing and HVAC efficiency. The decided upon windows ended up being Plygem U-0.27/SHGC 0.20 as 10% of the floor area instead of Alpenglass U-0.15/SHGC 0.22 as 11% of floor area. The HVAC system is still an electric air side heat pump but with a SEER of 16 instead of 20 and HSPF of 10 instead of 11.3. These decisions resulted in a slightly increased energy use but reduced the initial building cost by a significant margin. The final REMRate results before the addition of the photovoltaic system was a HERS score of 41 with a yearly energy cost of 999 $/yr.

DOE HOME RATING SYSTEM:

DOE Zero Energy Ready Home National Program Requirements allow flexibility in selecting custom combination of measures as long as the HERS target home performance level is met or exceeded. This requires energy modeling using RESNET-accredited Home Energy Rating Software. Our team decided to use REM/Rate™ provided by Architectural Energy Corporation (AEC) which calculates energy loads, consumption, costs and code compliances. The target HERS score was decided upon using the DOE Target Home energy efficiency features and size modification. The formula for the size modification factor is $[CFA_{\text{Benchmark Home}} / CFA_{\text{Home To Be Built}}]^{0.25}$

Our design is composed of 4 bedrooms with a flex room that may be converted into an additional ground floor accessible bedroom if possible making the benchmark home size between 2,800 and 3,400 square feet. The square footage of conditioned and livable space within our design home is 2,200 square feet making the Size Modification Factor 1.00 as it cannot exceed 1. The other specifications listed in the DOE Zero Energy Ready Home National Requirements for mixed climate zone 4 were modeled and resulted in a target HERS rating of 55.



Building Component	DOE ZERH Target Home value	Mountain Laurel Home
HVAC Equipment	15 SEER/9HSPF	16 SEER/ 10 HSPF
Infiltration	2.5 ACH50	0.6 ACH50
Windows	0.27 SHGC/0.3 U-Value	0.20 SHGC/ 0.27 U-Value

Improvement	Heating (MMBtu/yr)	Cooling (MMBtu/yr)	Water Heating (MMBtu/yr)	Lights & Appliances (MMBtu/yr)	Total Annual Energy Cost ($)	HERS Rating
1	10.1	5.1	14.3	25.9	1519	74
2	7.9	4.9	14.3	25.9	1456	71
3	7.2	4.9	14.3	25.9	1439	70
4	6.5	4.8	14.3	25.9	1386	68
5	5	4.1	14.3	25.9	1360	64
6	4.9	4.1	14.3	25.9	1356	64
7	5.2	4.1	14.3	27	1382	60
8	5.4	3.8	14.3	27	1374	59
9	5.1	3.4	14.3	27	1371	57
10	4.9	3.1	14.3	27	1358	56
11	4.6	2.8	14.3	27	1341	55
12	4.8	2.7	14.3	25.6	1312	54
13	5	2.7	12.1	20.4	1118	47
14	5.1	2.8	3.9	20.4	909	40

HERS Ratings:

In order to gauge our home's competitiveness with current production homes we modeled a home designed by our industry partner, Dan Ryan Home Builders. They projected their HERS score to fall between 68 and 75. The Dan Ryan home we modeled was a 2,400 square foot 1.5 story home with 4 bedrooms and 2.5 baths in a similar neighborhood development and climate. This home resulted in a HERS score of 73 with an annual energy cost of 1446 $/yr. The HERS score of our home without the PV system is 41 with an annual energy cost of 999 $/yr. With the photovoltaic system the Mountain Laurel home energy generation exceeds its usage with a HERS score of -3, and an annual energy cost of 57 $/yr when factoring in a 60$ service charge.

CHOICE OF RENEWABLE ENERGY

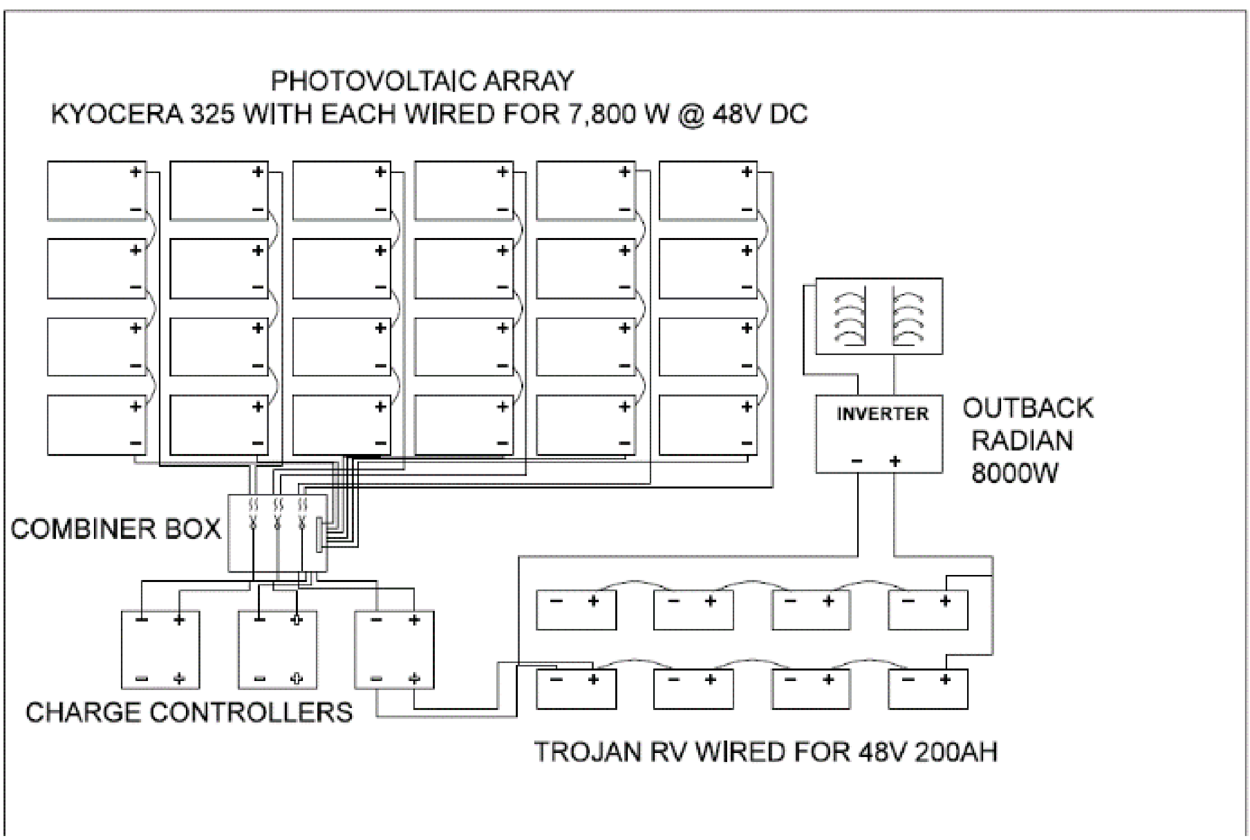
For an affordable net zero house, the cost of renewable energy is the metric by which all incremental improvements in energy efficiency should be measured. Our choice of renewable energy was therefore driven by the type of system that can produce a sufficiently high quantity of energy at a sufficiently low cost.

Many types of decentralized energy production, such as wind and hydraulic energy, are only suitable for niche locations and cannot act as a model for renewable energy production in most developments. Solar thermal water heating can be attractive in some circumstances, but in our design, a heat pump water heater with photovoltaic (PV) panels was simpler and at least as cost effective. The energy consumption of our design is thus intended to be offset exclusively by photovoltaics.

SYSTEM DESIGN

Panel Choice

The primary constraint in choosing a model of photovoltaic panel was whether the efficiency would be high enough to achieve net zero energy consumption while fitting on the available roof space. Products that meet this criteria must also have an attractive ratio of price to peak power production and fit well into the overall PV system design, which



integrates panels, charge controllers, batteries, and an inverter. The panel chosen was a Kyocera 325 Watt Polycrystalline module.

Size of Array

A feasibility assessment was performed by calculating the annual production of a 325 Watt panel in Raleigh, NC.

1) Average number of sun-hours (defined as 1 kWh/m²) in each month was obtained for Raleigh, NC from the NREL Renewable Resource Data Center. The tilt is assumed to be approximately equal to latitude.
2) Average panel output for each month was calculated from the rated panel output and the number of days in each month.
3) The outputs of the individual months were summed, and reduced by 10% to account for efficiency losses to get the annual production.

With an annual house load of 1,653 kWh/year, basic arithmetic shows that 23 of these panels are required to offset its consumption, requiring a gross area of 543 square feet. We increased this to 24 panels to create consistent voltages across each string of modules and to allow for a small margin of error. This easily fits onto the south face of our roof.

Storage:

The potential of batteries to improve the resilience and economics of a grid-tied system are often overlooked. We added eight Trojan 31-AGM 12V batteries with three Midnite Classic 250 charge controllers, comprising about 22% of the total system cost, to create a hybrid system. The battery bank can provide over 8.5 kWh of usable energy after being converted to AC power. Although the home uses more energy than this in a typical day, it is enough to provide continuous power during short power outages or perform select vital tasks during more prolonged outages. This functionality will attract homebuyers interested in having a backup generator.

Moreover, the batteries can offset their cost to the homeowner by allowing him to sell, rather than buy energy from the grid at peak times of demand when electricity is most expensive. Widespread adoption of this practice may increase the sustainability and profitability of the electrical grid by flattening out surges in demand, reducing the number of power plants that need to run intermittently. If net metering becomes unavailable, the homeowner will still need to purchase less power from utilities than if the PV system were to not have batteries.

Table #: PV Panel Specifications

Model Number:	KD325GX-LFB
Rated Max. Power:	325 W
Area:	23.6 square feet
Maximum Efficiency:	14.8%

Month	Days in Month	Avg. Insolation / Day (Kwh/m^2) (Reduced 10%)	PV Output per Day (kWh / Panel)	PV Output per Month (kWh / Panel)
Jan.	31	3.8	1.24	38.29
Feb.	28	4.5	1.46	40.95
Mar.	31	5.2	1.69	52.39
Apr.	30	5.7	1.85	55.58
May	31	5.7	1.85	57.43
Jun.	30	5.7	1.85	55.58
Jul.	31	5.6	1.82	56.42
Aug.	31	5.5	1.79	55.41
Sept.	30	5.2	1.69	50.70
Aug.	31	4.9	1.59	49.37
Nov.	30	4.1	1.33	39.98
Dec.	31	3.6	1.17	36.27
			System Efficiency:	90%
			Soiling Factor:	90%
Year:			Annual Production	**476.56**

FINANCIAL ANALYSIS

CONSTRUCTION COST ESTIMATE

Pricing Sources and Labor Estimation

The primary source of regional material and labor costs came of the online RS Means database. Special or unique material choice pricing came from information provided to use by our industry partner Dan Ryan Homes, and direct quotes from various local vendors. In our breakdown, labor was estimated with line item material prices. This allowed for our square footage method to incorporate both material and installation prices.

Square Footage Estimation Method

Exterior Wall, Interior Wall, Roof, and Flooring components were priced based on estimated cost per square foot that was extrapolated from the largest instance of said components in our design. For instance; the cost per square foot of exterior wall was derived from the east elevation's exterior wall, which was 44 feet long, an average 10 feet high, and contained the back sliding glass door and several windows. The square foot price derived was then multiplied by total calculated square footage of exteriors wall to come up with our total category price. This method allowed for overall cost changes from individual design choices to be compared quickly and easily.

Cost Summary

The Mountain Laurel Home's construction cost totaled $165,973, which was $35,000 more than a home of identical layout but with standard wall and roof systems and built using other standard methods. The Solar PV system accounted for $23,000 of the $35,000 increase in price, however the majority of the system's expense is recovered after both N.C. State and Federal rebates are collected. The large amounts of insulation required to reach desired R-values for the Mountain Laural home was another contributing factor to the cost increase. Construction Category totals can be compared in the chart below.

Mountain Laurel House			Standard House		
Category	Cost Estimate		Category	Cost Estimate	
Pre Construction & Site Prep	$	12,234.58	Pre Construction & Site Prep	$	12,234.58
Wall Systems	$	36,754.49	Wall Systems	$	34,473.32
Roof and Floor Systems	$	52,610.55	Roof and Floor Systems	$	38,649.73
Plumbing	$	9,523.45	Plumbing	$	9,522.78
Electrical	$	839.00	Electrical	$	7,034.26
Interior Packages	$	21,039.32	Interior Packages	$	19,236.00
HVAC	$	10,976.00	HVAC	$	8,925.00
Landscaping and Exterior	$	7,427.61	Landscaping and Exterior	$	6,670.34
Cleaning and Inspections	$	868.90	Cleaning and Inspections	$	868.90
Renewables	$	23,400.00	Renewables	$	-
Grand Total	$	165,973.90	Grand Total	$	130,010.57
Total + 40.6% Overhead	**$**	**233,359.30**	**Total + 40.6% Overhead**	**$**	**182,794.86**

FINANCIAL VALUATION

Mortgage and Cost of Living Overview

The overall cost including construction materials, labors, and overhead for the Mountain Laurel Home was $233,359, as compared to $200,459 for a house of comparable design but standard construction materials and methods. The difference in cost is due to the use of highly insulated walls, sustainable products, solar photovoltaic systems, high efficiency HVAC systems, high efficiency appliances, and moisture control systems. These systems achieve lower water, electricity, and maintenance bills as compared to the standard construction methods.

A thirty-year mortgage, at a 4.5% interest rate, is assumed and combined with calculated taxes, insurance, maintenance, energy, and cost of living expenses to estimate final sum of $494,685. This is actually $9,767 lower than the projected cost of home ownership for the standard construction home after the same 30 year mortgage! This lower cost is accredited to the PV offsets ($932.23 annually), one time incentives (totaling $4,650), renewable incentives (totaling $12,168), and superior durability of the materials chosen for the Mountain Laurel Home.

Mortgage Comparison

Mountain Laurel Home Mortgage		Mountain Laurel Home without PV Mortgage		Standard Construction Mortgage	
Construction Cost	$ 165,973.90	Construction Cost	$142,573.90	Construction Cost	$ 130,010.57
Construction + 40.6% Overhead	$ 233,359.30	Construction + 40.6% Overhead	$200,458.90	Construction + 40.6% Overhead	$ 182,794.86
Sales Price	$ 233,359.30	Sales Price	$ 200,458.90	Sales Price	$ 182,794.86
Downpayment	$46,671.86	Downpayment	$40,091.78	Downpayment	$36,558.97
Net Price After Downpayment	$ 186,687.44	Net Price After Downpayment	$ 160,367.12	Net Price After Downpayment	$ 146,235.89
Points	2.5	Points	2.5	Points	2.5
Principal	$191,354.63	Principal	$164,376.30	Principal	$149,891.79
Interest Rate	4.50%	Interest Rate	4.50%	Interest Rate	4.50%
Years	30	Years	30	Years	30
Monthly Mortgage Payment	$969.57	Monthly Mortgage Payment	$832.87	Monthly Mortgage Payment	$759.48

Mountain Laurel Cost of Home Ownership with PV

Loan Amortization and Cost of Homeownership								
	Escalator Factor	0.5%	0.5%	1.5%	1.5%	1.5%		
Year	Mortgage Payment	Taxes and Insurance	O&M Costs	Energy Cost	Water Cost	Solar PV System Offsets	Incentives	Cost of Home Ownership
0 (Downpayment + First Payment)	-$47,641.43					-$23,400.00		-$47,641.43
1	-$11,634.79	-$2,141.14	-$500.00	-$1,044.40	-$685.00	$932.2307	$16,818.00	$1,744.90
30	-$11,634.79	-$2,474.35	-$577.81	-$1,608.36	-$1,054.89	$1,461.5361		-$15,888.65
Totals						$11,956.57	$16,818.00	-$494,685.94

Mountain Laurel Cost of Home Ownership without PV

Loan Amortization and Cost of Homeownership								
	Escalator Factor	0.5%	0.5%	1.5%	1.5%	1.5%		
Year	Mortgage Payment	Taxes and Insurance	O&M Costs	Energy Cost	Water Cost	Solar PV System Offsets	Incentives	Cost of Home Ownership
0 (Downpayment + First Payment)	-$42,864.20							-$42,864.20
1	-$10,468.12	-$2,016.18	-$500.00	-$1,090.27	-$685.00	$0.00	$4,650.00	-$10,109.57
30	-$10,468.12	-$2,329.94	-$577.81	-$1,678.99	-$1,054.89	$0.00		-$16,109.75
Totals						$0.00	$4,650.00	-$500,121.39

Standard Construction Cost of Home Ownership

Loan Amortization and Cost of Homeownership								
	Escalator Factor	0.5%	0.5%	1.5%	1.5%	1.5%		
Year	Mortgage Payment	Taxes and Insurance	O&M Costs	Energy Cost	Water Cost	Solar PV System Offsets	Incentives	Cost of Home Ownership
0 (Downpayment + First Payment)	-$37,318.45					$0.00		-$37,318.45
1	-$9,113.76	-$1,871.12	-$500.00	-$2,162.65	-$959.00	$0.00	$0.00	-$14,606.53
30	-$9,113.76	-$2,162.31	-$577.81	-$3,330.45	-$1,476.84	$0.00		-$16,661.17
Totals						$0.00	$0.00	-$504,453.86

Client Profile

Based on criteria set by the Race to Zero competition and an assumed debt to income ratio of .28, the minimum income require for a family to live would be $62,057. This can be lowered with the annually energy offsets and incentives from the Mountain Laurel Home to give us an adjusted minimum income of $60,325. Monthly cost of home ownership of the Mountain Laurel Home is estimated to be $1,242 relative to a $3,619 estimated monthly cost of living of our client.

The median family annual income in Alamance County, the proposed site of the Mountain Laurel House, was $49,028. This translates to a monthly affordability of $1,552 for homeownership and other living expenses. Families living in the Mountain Laurel Home would need to have an annual income $13,028 more than the median family in Alamance County.

Client Income and Expenses

Financial Valuation	
Mountain Laurel Home - Client Profile (Family with 2 children)	
Minimum Adjusted Annual Income	$60,324.66
Debt to Income Ratio	0.28
Monthly Cost of Living	-$3,619.48
Monthly Cost of Home Ownership	-$1,241.79
Other monthly debt	-$300.00
Monthly PV Offset	$91.39
Mountain Laurel Home - Mortgage Summary	
Annual Principal + Interest	-$11,634.79
Annual Taxes + Interest	-$2,141.14
Annual PITI	-$13,775.93
Debt and Savings Adjustments	
Minimum Income For HomeOwnership	$62,056.89
Other annual debt	-$3,600.00
Total annual debt	-$17,375.93
Annual Energy Savings	$932.23
Annual Water Savings	$800.00
Minimum Adjusted Income	$60,324.66

Median Family Description

Median Family Income in Alamance		Difference between Client and Median Family
Annual Income	$49,028.00	$11,296.66
Monthly Affordability	-$1,552.55	$2,066.93
Monthly Cost of Home Ownership	-$434.71	$807.08
Monthly Debt	-$245.14	$54.86

Upgrade Packages and Offsets

We designed the Mountain Laurel Home so that different energy upgrade packages and sustainability upgrade packages can be bought to optimize customer budget and environmental impact. These packages, their expenses, and their potential annual energy savings are listed in table below. This lends the Mountain Laurel Home to a wider range of the market, while staying within methods accepted by typical production builders.

Upgrade Packages

Energy Efficiency Upgrade Packages vs. Standard Construction Packages					
Package	Standard Construction	Upgrades	Cost Increase	Unit	Annual Utilities Savings
Attic	6% duct leakage 90% ductwork in the attic All insulation Grade 2 R - 30	0% duct leakage No ductwork in attic All insulation Grade 1 R - 50	$8.59	Sq. Ft.	$49.00
Window & Doors	U-0.35 SHGC .30 window area to 11% of the floor area	U-0.27 SHGC .20 optimized	$338.58	All Windows	$208.00
Wall Construction and Insulation	R-15 walls/ OSB sheathing Grade 2 Insulation	2x8 staggard stud wall with R-10 Grade 1 Insulation	$1.92	Sq. Ft.	$182.00
Slab	R-10 slab with 2" gap at top	Slab to R-15	$0.96	Sq. Ft.	$212.00
HVAC	SEER 13 a/c HSPF 7.8 heat pump	SEER 16 a/c 9.2 HSPF	$2,051.00	Entire System	$197.00
Lighting	75% Florescent	High Efficency Lighting	-$1,783.26	Entire System	$256.00
Appliances	Standard	Energy Star, Water Sense	$1,395.00	Entire System	$450.00
Hot Water Heater	Resistance electric water heater at 0.91 EF	2.75EF Heat pump water heater	$337.00	Entire System	$659.00

Sustainability Upgrade Packages vs. Standard Construction Packages				
Package	Standard Construction	Upgrades	Const Increase	Unit
Exterior Walls	Typicall Framing and Insulation Unvented Rain Screen	Moisture Control Design based off outside drainage Vented Rain Screen	$1.92	Sq. Ft.
Finishes	Paint Carpets	Low VOC Paint Engineered Wood and Marmoleum	$12,468.39	Enitre System
PV System	None	10 Kilowatt system	$23,400.00	Entire System
Driveway	Concrete Gravel Underbed	Grass Pavers Dirt Fill	$2,427.28	Entire System
Landscaping	Unacclimated Plants Water Intensive Plants and Sprinkler System Drains Flow to Street and Storm Drains	Native/Non-Invasion Plants Xeriscaping Strategic Drainage	$2,553.58	Entire System

PV System

The Solar PV system's rate of return was 52%, mainly due to the tax rebate received the second year. Annually it offset energy cost by $933. Which was actually 105% of the energy bill, helping to further lower costs of homeownership. This was a driving factor behind the lower final cost between the standard house the Mountain Laurel Home.

Other Assumptions

Assumptions							
Property Tax	0.53%	Water Rate per gal	$0.00304	Sewer Rates per gal	$0.00381	PV System Annual Offset in kWh	10966.2
Alamance County MFI	$49,028.00	Annual Water Usage	100000	Sewer Use	100000	Duke Progress Energy HERO Incentive	$4,000.00
Monthly Debt (0.005 MFI)	$245.14	kWh Rate	$0.10	Solar PV System Cost	$ 23,400.00	HeatPump Water Heater Incentive	$350.00
Insurane Premium Annually	$895.00	kWh used	10444	Solar PV System Federal + NC Rebate	$12,168.00	High Efficency HVAC	$300.00
						Net PV Buyback Rate	$0.09

PV Costs and Offsets		
Solar PV System Cost	$	23,400.00
Solar PV System Federal + NC Rebate	$	12,168.00
Rate of Return	52%	
Annual Cost of Sign-Up	$	48.00
On-Peak	$	0.055
Off-Peak	$	0.0469
Average	$	0.0509
Green Power Rate (5 kW out of 7.8 kW)	$	0.06
Green Power Rate (adjusted)	$	0.0385
Net Total Rate	$	0.089
PV System Annual Offset in kWh	10966.2	
PV System Annual Offset	$	932.23

DOMESTIC HOT WATER, LIGHTING AND APPLIANCES

RESEARCH AND SELECTION PROCESS

After consideration of cost, energy use, and embodied energy of materials, we chose the following appliances for the Mountain Laurel:

- Whirlpool dishwasher at $299, consuming 260 kWh/year
- Frigidaire 22.1 cubic foot refrigerator at $989, consuming 549 kWh/year
- Whirlpool Duet 4.2 cubic foot clothes washer at $719, consuming 145 kWh/year
- Whirlpool 7.3 cubic foot heat pump dryer at $1599, consuming 531 kWh/year
- Whirlpool 50-gallon heat pump water heater at $1092, consuming 1,597 kWh/year

Ceiling fans will be installed in all of the bedrooms and the kitchen. All fans are Energy Star certified and will incorporate LED lighting in place of CFLs. While CFL lighting is less expensive than LED in upfront costs, LED lighting will last longer and use less energy than CFLs. LED bulbs will also be used in all light fixtures in the home to minimize consumption.

More information on the decision process for these appliances can be found in the Appendix.

EPA WATER SENSE

Water efficient fixtures are just as important to our home design as energy efficient appliances and building techniques. In order to ensure our home uses water in a sustainable manner, we have sourced products that conform to the EPA's Watersense guidelines for efficient water usage. In our showers, we have opted for High Sierra Watersense certified 1.5 GPM showerhead. For our toilets, we have chosen the American Standard H2Option dual flush 1.6/1.0 GPF toilet. In our kitchen sink, we will use the MOEN Finley Single-Handle Side Sprayer Kitchen that is rated at 1.5GPM flow. The bathroom sinks will use Glacier Bay Builders 4 in. 2-Handle Faucet rated at 1.5GPM flow. (http://www.epa.gov/watersense/new_homes/saving_inside_and_out.html#tabs-1)

Hot Water Wait Times

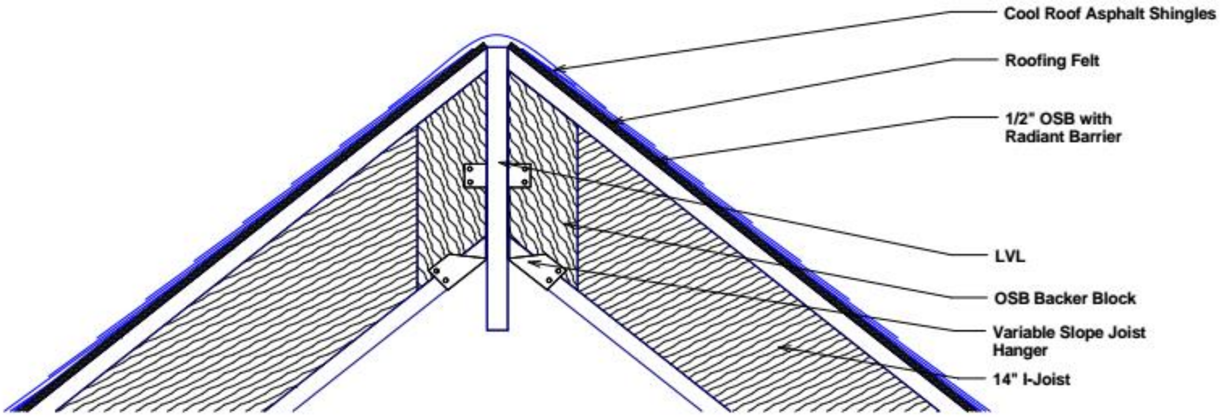
WaterSense is a voluntary labeling program sponsored by the U.S. Environmental Protection Agency that certifies water-efficient products and construction. Building to the WaterSense for new homes standard has the potential to save a family of four 50,000 gallons of water a year or more. The certification can be broken down into three categories that must be fulfilled. These are categories are indoor water use, outdoor water use, and homeowner education.

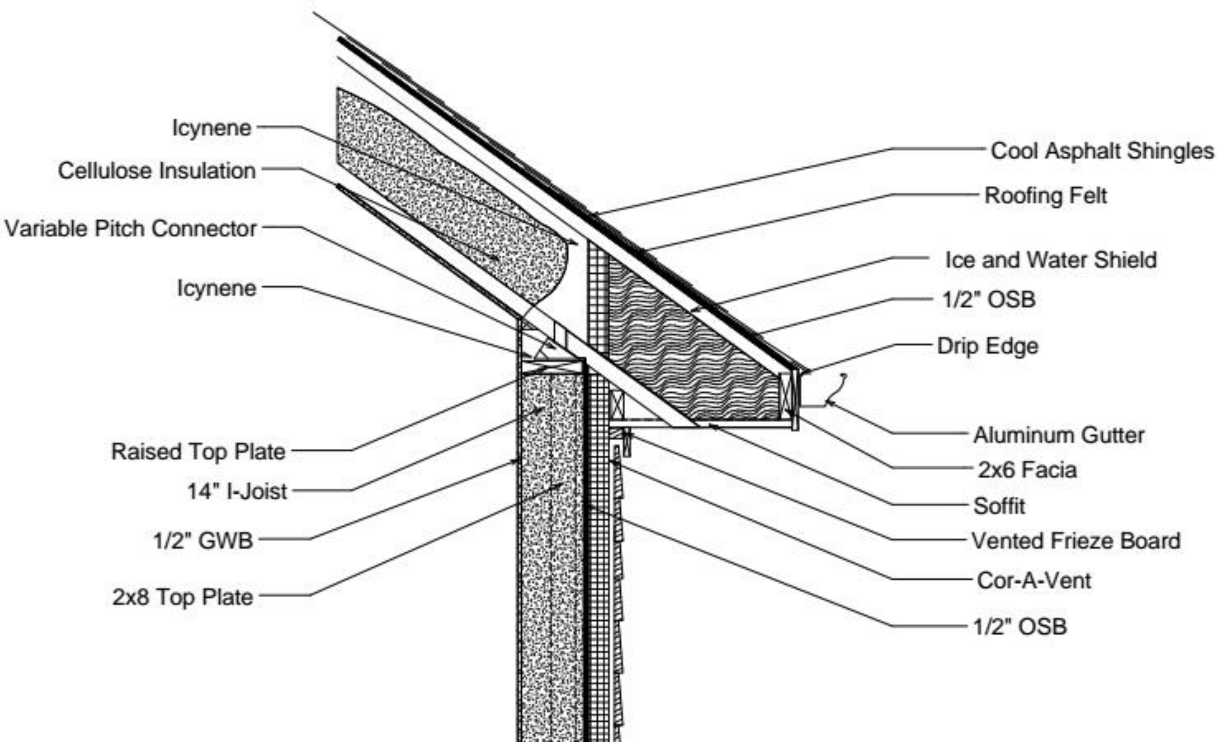
Hot water consumption is more important than overall water consumption for achieving net zero energy efficiency, so strong emphasis was placed on low flow fixtures that use the largest amount of hot water (i.e. mainly showerheads).

For indoor water usage the hot water delivery system is targeted for maximum efficiency. All hot water plumbing between fixtures and the hot water source were designed to be under 0.5 gallons. Our longest run of PEX plumbing is 45.2 ft. and has a capacity of .42 gallons.

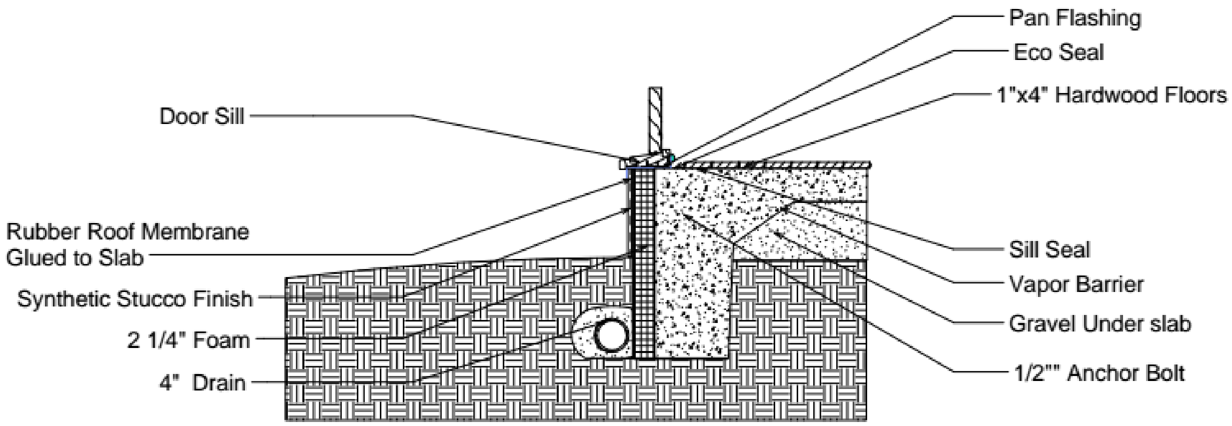
CONSTRUCTION DOCUMENTATION

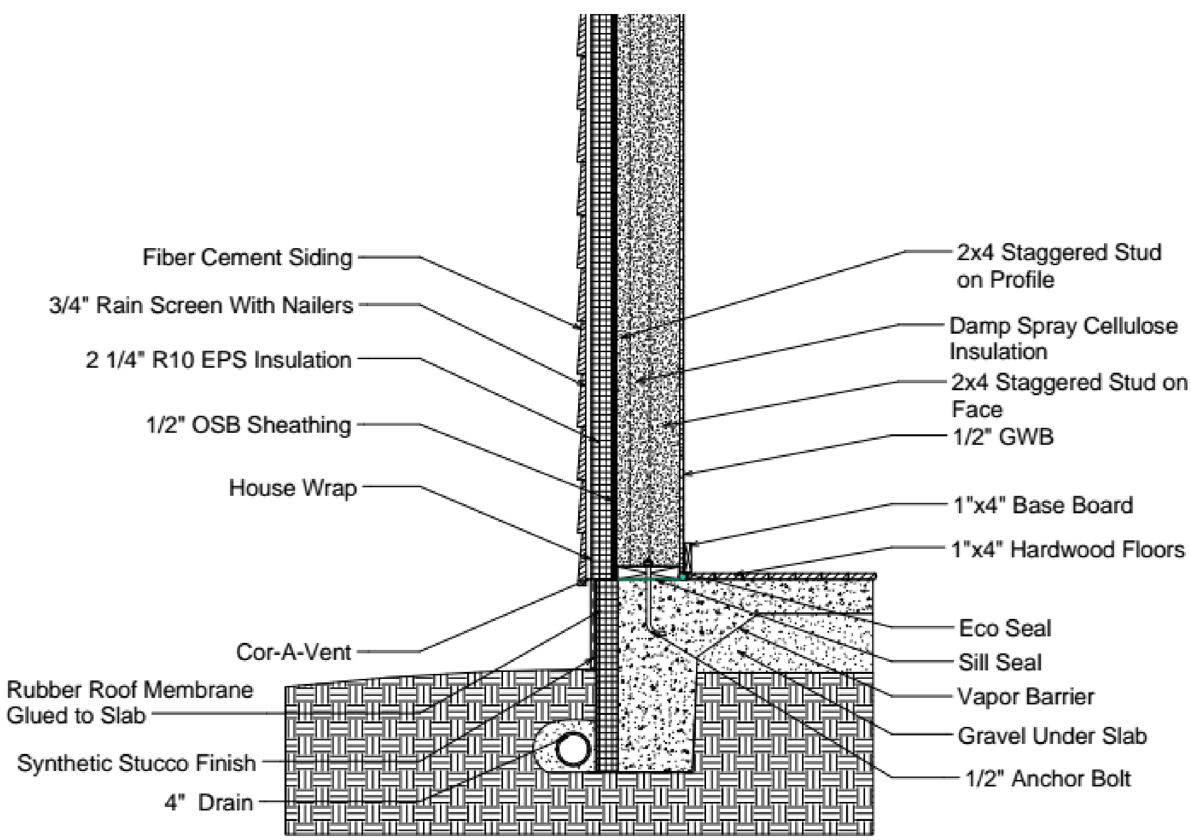
PLEASE SEE THE APPENDIX FOR A COMPLETE SET



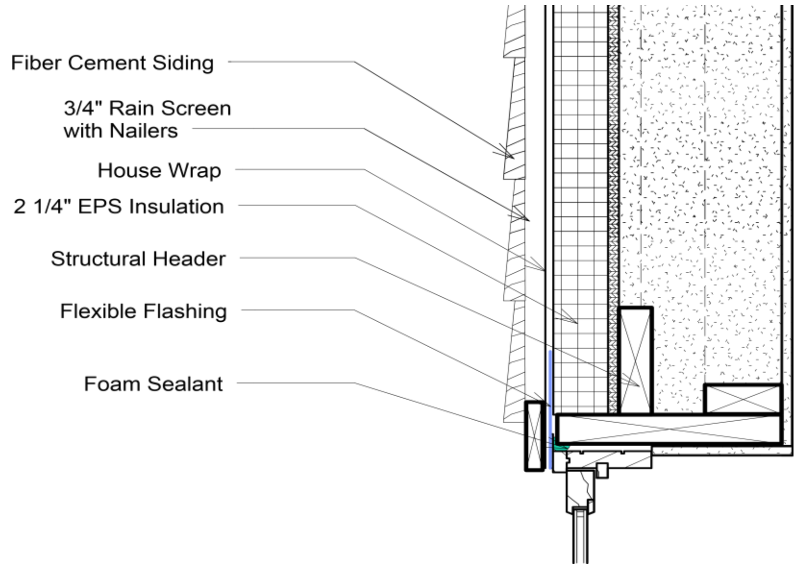


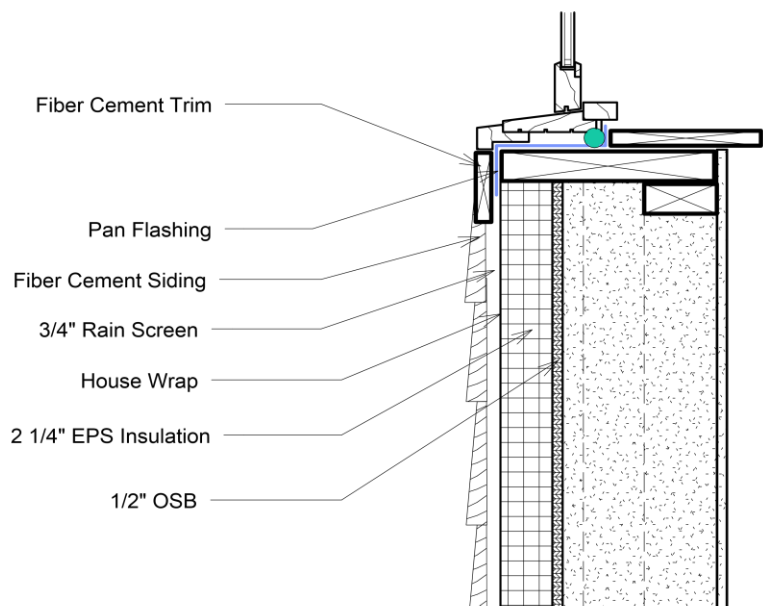
ROOF DETAILS (NTS)



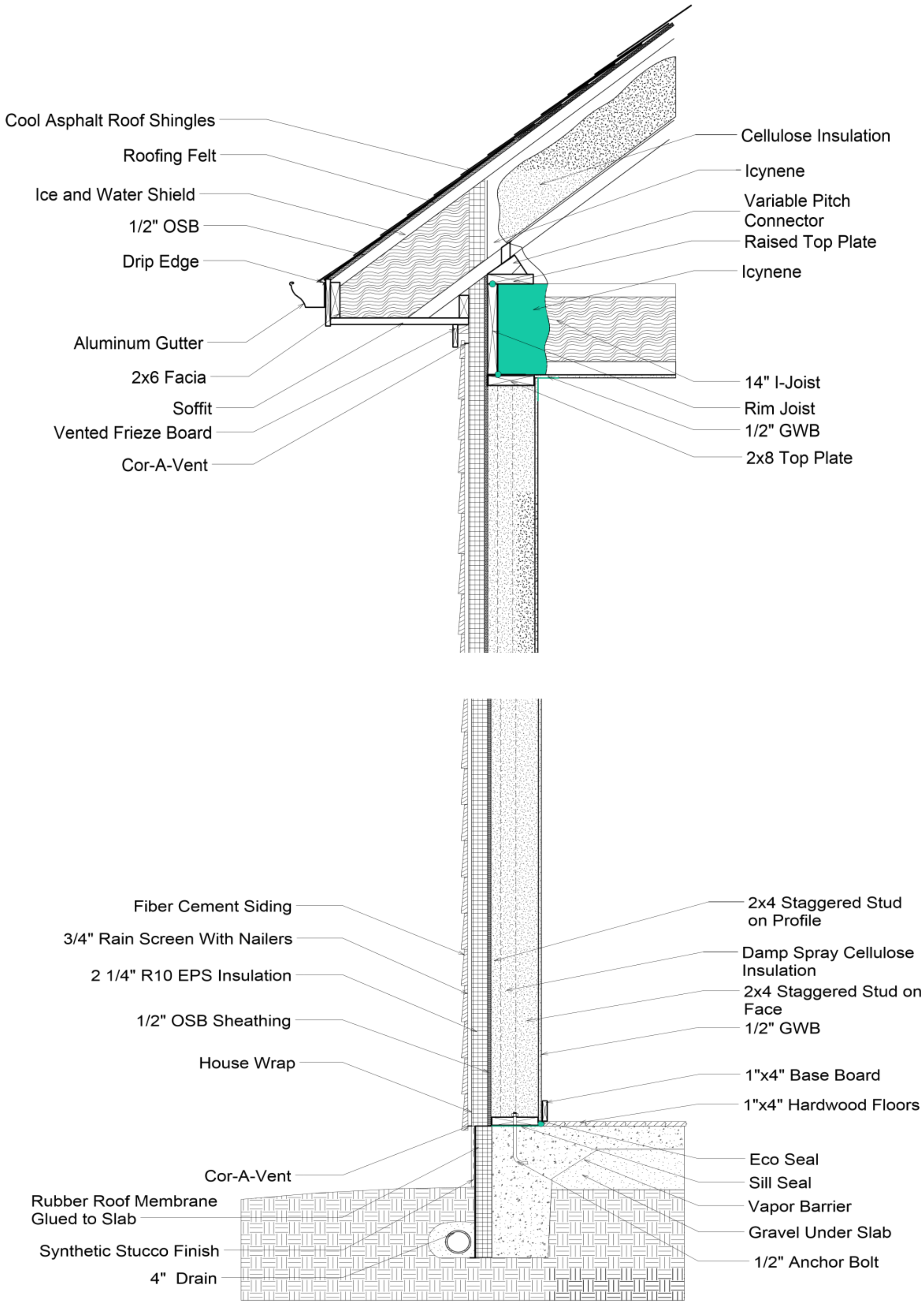


SLAB & SILL DETAILS (NTS)

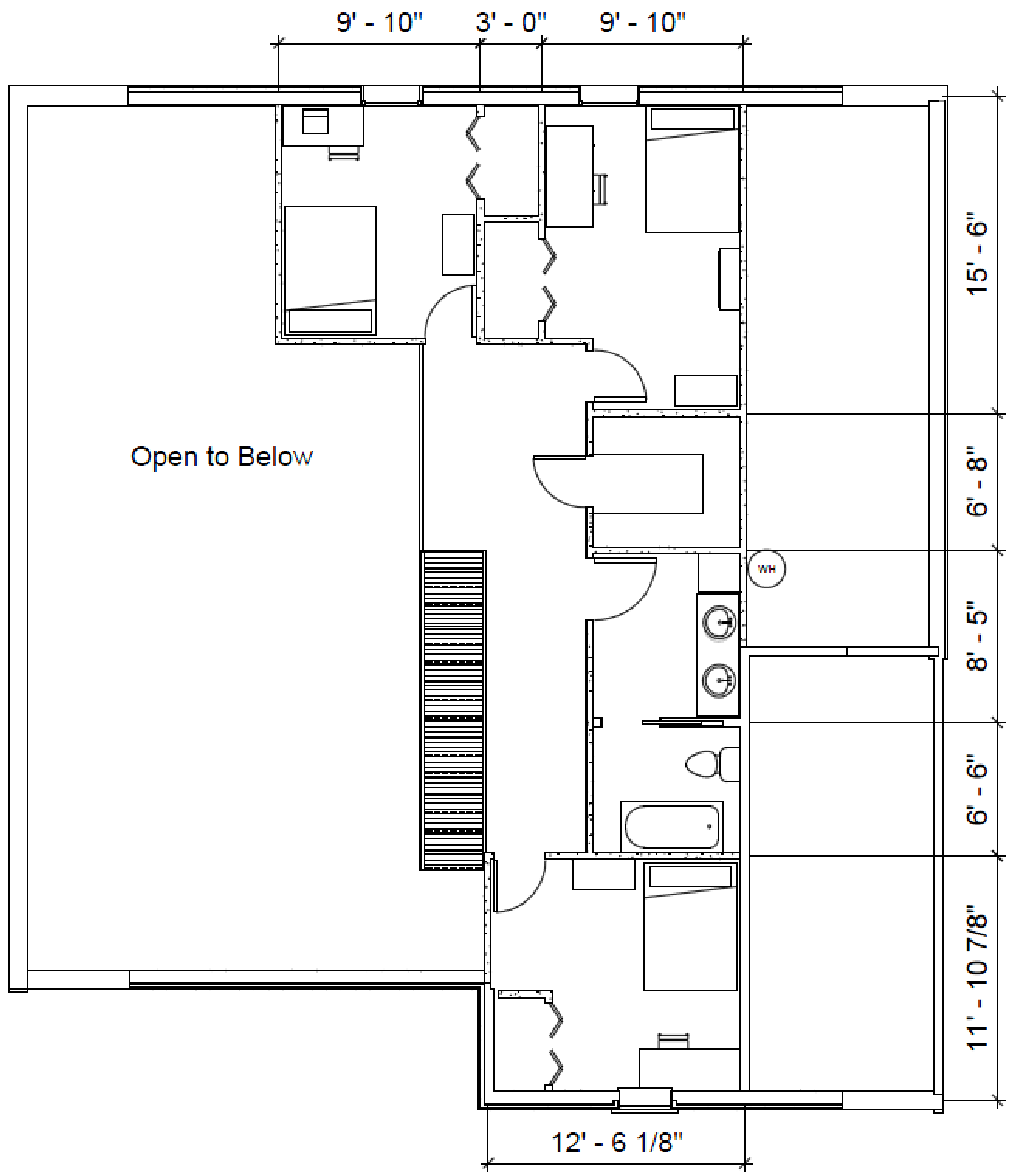




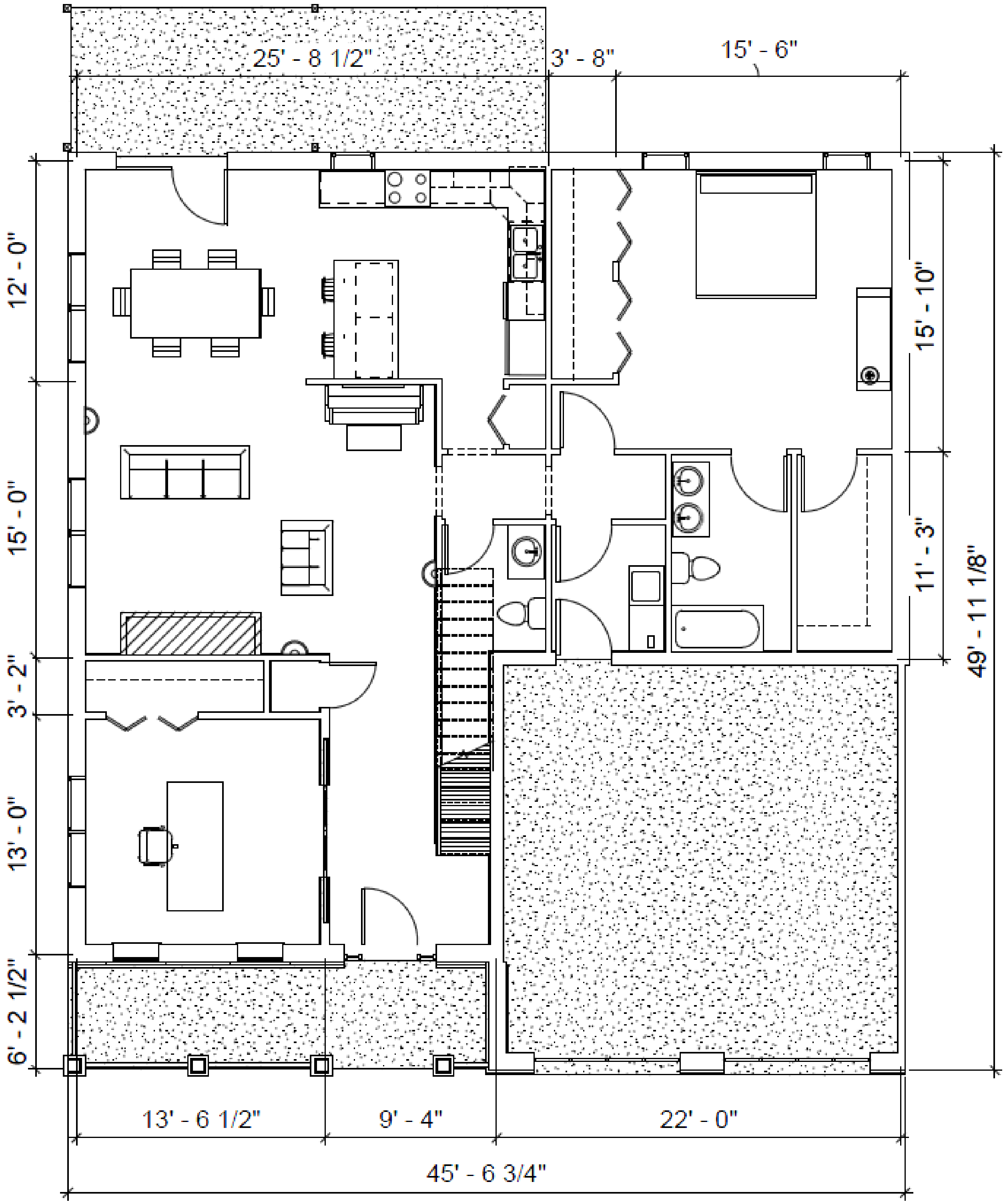
WINDOW DETAILS (NTS)



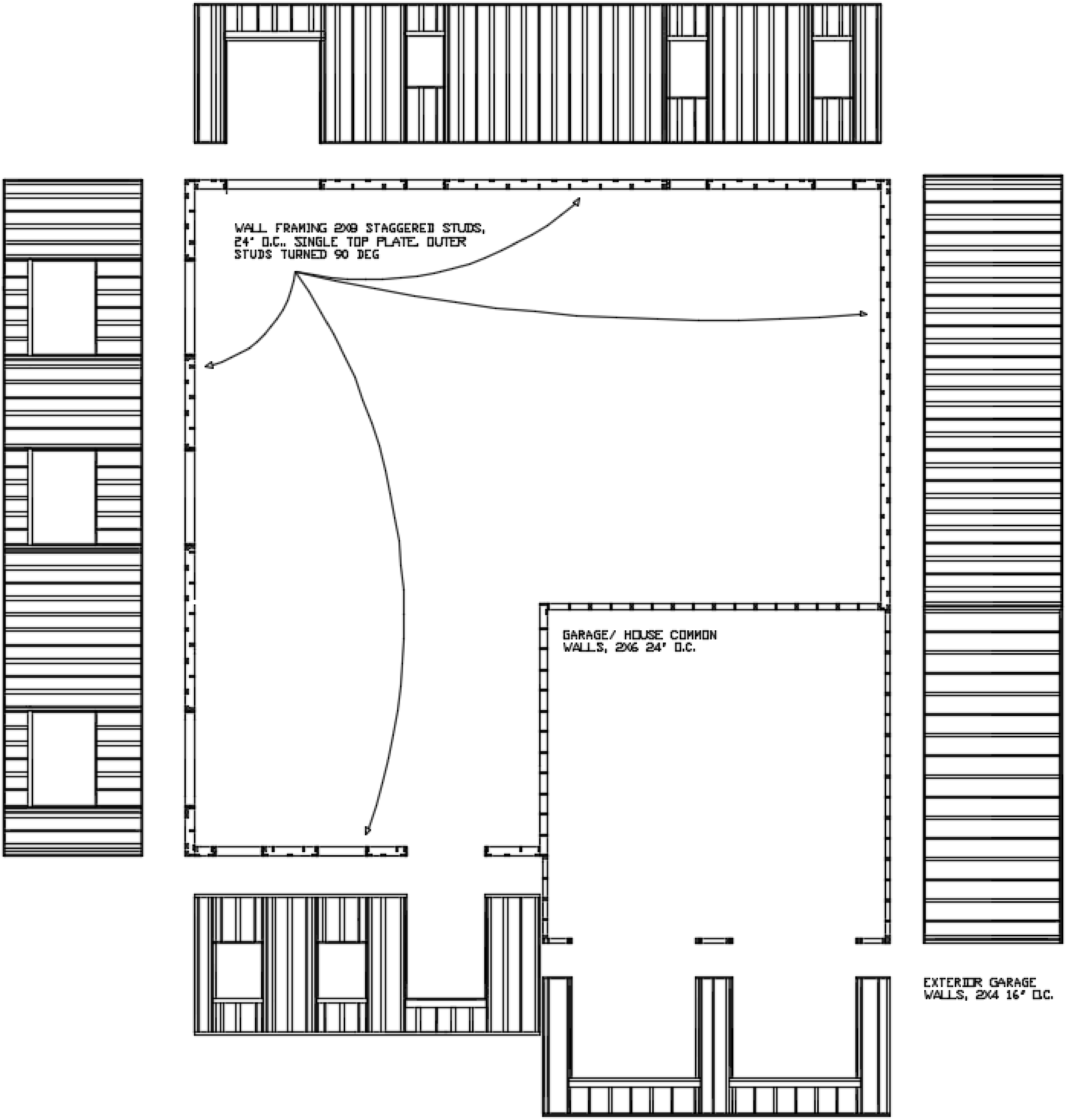
WALL DETAILS (NTS)



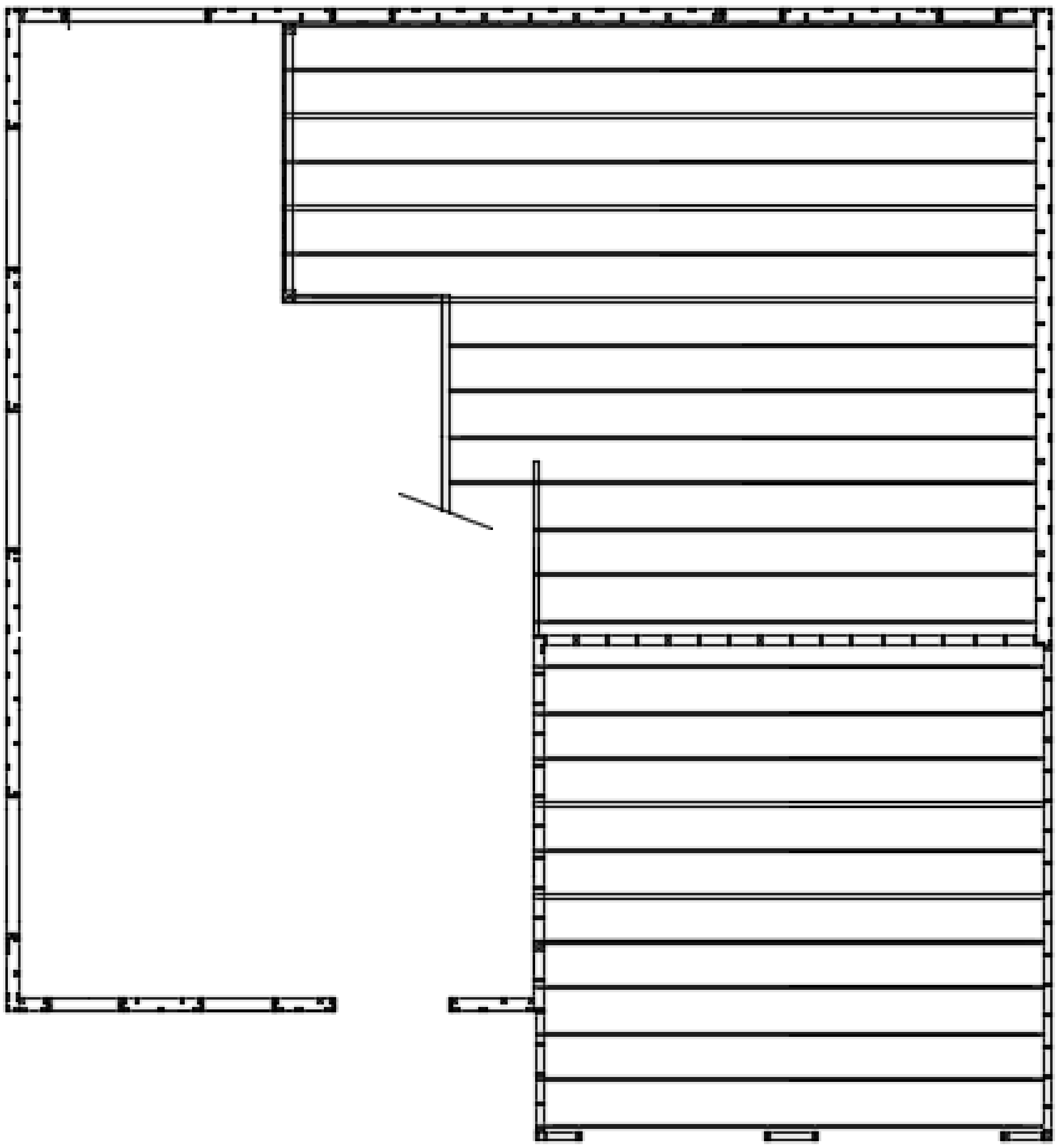
SECOND FLOOR PLAN



FIRST FLOOR PLAN



WALL FRAMING DETAILS (NTS)



SECOND FLOOR FRAMING DETAILS (NTS)

INDUSTRY PARTNERSHIPS

Appalachian State's Race-to-Zero team had excellent industry support during the course of the project. Our primary builder partner was Dan Ryan Homes, although we consulted with other builders as well. Dan Ryan Homes' Raleigh branch builds 400 to 600 homes per year and is a major player in the ever expanding central North Carolina homebuilding market.

We met with Dan Ryan Homes at their Raleigh headquarters and visited the project site. Our main contact is the President of the regional office, Edwin Woods. Throughout the design process, their leadership team provided excellent support and documentation, including home plans, estimates, and construction schedules. We will consolidate our report into a set of upgrade packages that they could offer to their customers. They are excited to see our recommendations.

PlyGem was also an active partner. This major material supplier to the construction industry provided recommendations for a variety of products, including windows, doors, exterior finishes, interior finishes, and paving materials. They also provided feedback on the details of the construction systems. Our main contact is the Innovation Director for the company, Lee Clark-Sellers. As shown with two of her colleagues at PlyGem to the right, she participated actively in the Solar Decathlon Europe project and is always looking for new ideas to explore and bring to the market place.

Duke Energy provided input as well. Mark Tabert, of their residential programs, gave input on our design features, as well as potential incentives that Duke Energy might provide.

We also presented our ideas to the following individuals and received their feedback:

- Rob Howard, Director of Sustainability for Habitat for Humanity
- Chuck Perry, builder and director of the North Carolina Energy Efficiency Alliance (headquartered at Appalachian State)
- Liz Riddick, real estate broker
- Matt Vincent, real estate broker and builder
- Greg Reese, HVAC technician for the Appalachian State University Physical Plant
- John Edmisten, Edmisten Heating and Air