Dollars and Carbon:

Effectiveness of Sustainable Construction Methods in the Roaring Fork Valley of Colorado

August 18, 2014

Mark McLain, Angela Loughry, Steve Eichhorst, Chase Anderson

Study made possible by a
Design Assistance Grant
From CORE – the Community Office for Resource Efficiency

INDEX

I - EXECUTIVE SUMMARY

Habitat for Humanity of the Roaring Fork Valley has built 19 homes in the Roaring Fork Valley region of Colorado since its inception in 2000. Since 2007, Habitat has attempted various sustainability upgrades to homes in an ad hoc manner based on volunteer interests or material donations. In an effort to be more methodical about their investment in sustainability, Habitat for Humanity in partnership with area architects, Confluence Architecture, received a design assistance grant from CORE (Community Office for Resource Efficiency) to study a "typical" Habitat home and find the most cost effective sustainable practices. The following report is the result of the research afforded by the CORE grant.

This study seeks to answer a subjective question: **How best can additional money and carbon be invested in the construction of an affordable home in the Roaring Fork Valley to minimize lifetime utility and carbon[1] costs?**

This question is investigated through the lens of a Habitat for Humanity home currently under construction in Carbondale, Colorado. While not changing the physical design of the home (shape, footprint, floor plan, windows, area etc.) 100+ home configurations are studied through LCA (life cycle analysis), energy modeling and construction cost estimates. The configurations focus on practical construction choices made every day such as wall assemblies, insulation levels, treatment of crawl spaces, attics and mechanical systems.

The study finds, unsurprisingly, that the most expensive home configuration to build saves the most carbon and has the lowest annual energy costs. The perfect mix between initial construction costs and carbon and energy savings is dependent on the values of the investor. In order to illustrate several successful investments, this report contains an in-depth analysis of 8 benchmark home configurations that illustrate practical construction combinations over a range of investment and performance levels. Following is a list of notable trends distilled from the data:

1. **The best way to reduce the carbon footprint of a home is to reduce operational energy consumption, even if it raises the initial construction carbon footprint.** The carbon footprint for materials, transportation, and construction of the home is exceeded by the carbon footprint of the annual energy usage in 3 years for a typical code home and 5 years for a high performing home. Construction carbon becomes important only as homes begin to reach net-zero and in some key carbon-rich construction materials.
2. **The largest factor in fuel consumption and construction cost is the mechanical system.** Avoid electric heating of any kind. Ducted furnace air systems are the lowest monetary cost path to efficient building heat. Hydronic systems provide

[1] For the purposes of this report, carbon refers to Imperial tons CO2 equivalent, Specific components included in this metric are available it the Methods section (Section IV) of this report.

the best comfort and have an overall lower carbon footprint- with an added monetary investment.

3. **Avoid active cooling.** While air-conditioning use is increasing in the Roaring Fork Valley, energy modeling reveals it to be unnecessary for a well-designed and built home in our heating dominated climate. The cooling load is only 3% of the heating needed. Active cooling systems have the potential to use excessive electricity in an area where there is little need, especially if it is used in lieu of passive strategies (like appropriate clothing, opening windows at night, and proper shading of glazing).

4. **Insulation continues to be a cost effective way to increase building performance.** The type and location of insulation matter. This study found continuous exterior insulation to be more effective than added cavity insulation. SPF (Spray Polyurethane Foam) insulation[2] proved not to be as cost effective as other insulation types, going against an emerging trend for spray foam insulation in the Roaring Fork Valley. Beyond the cost and performance balance, insulation has the single largest impact on initial material carbon of any building component. The carbon footprint of like performing insulations types can vary 500-fold. The lowest carbon insulation option is blown cellulose while carbon intensive insulations are XPS[3] (Extruded Polystyrene) and SPF.

5. **Air Sealing is on par with insulation in its cost effectiveness in increasing building performance.** If careful air barrier control becomes a part of standard construction techniques the energy savings reward is significant relative to cost.

6. **Volume is a luxury**. Two homes that are identical on the exterior and have the same mechanical systems, windows, and shell construction can vary in energy performance by 5 - 15% due to the inclusion of vaulted interior spaces and conditioned crawl spaces. It is notable that this is one of the few areas where carbon and money are not at odds. More compact interior spaces are cheaper to build, require less initial construction carbon and are more efficient to run.

7. **Photovoltaics are becoming a key component to include in any home shell beyond the basic code minimum.** This came as a surprise to the study authors, questioning a rule of thumb where shell upgrades are better done prior to the addition of renewables. Due to continued price declines, PV is proving to be more economical than many shell upgrades such as high performing windows or super insulation.[4]

8. **Net-zero is not out of reach**. This study finds several home configurations that can be made net-zero in a construction price range ($200-225/sf) that is in keeping with market rate construction and home sales costs in the Roaring Fork Valley. These homes use typical construction techniques and materials.

---

[2] Closed Cell Spray polyurethane foam with HFC (hydrofluorocarbon) blowing agents

[3] Extruded Polystyrene, sometimes known as "blueboard". Not to be confused with EPS (Expanded polystyrene) which is typically white.

[4] Note: This is true only for the higher than construction costs in the Roaring Fork Valley region. Regions with lower labor/construction costs may still benefit from more labor intensive shell upgrades compared to the purchase of PV systems.

II- STUDY HISTORY AND GOALS

This study uses a real Habitat for Humanity home currently under construction in Carbondale, Colorado. While not changing the physical design of the home (shape, footprint, floor plan, windows, etc.) 117 home configurations are studied by varying construction elements such as wall assemblies, insulation levels, treatment of crawl space and attic and mechanical systems. All of the home configurations look almost identical from the exterior and interior, just their performance varies widely. The configurations tested range from a code minimum home to a net-zero home.

This study's goal is to use hybrid LCA and energy modeling to produce a regional guide that ranks energy efficiency construction assemblies and systems by their cost-effectiveness with respect to energy savings and carbon reduction. Building configurations are analyzed by two ratios:

1. Construction and Operational cost trough time
2. Carbon accumulation over time

From the analysis of the original 117 models, benchmark home configurations are highlighted that illustrate practical construction combination over a range of investment and performance levels. The goal is that these template home configurations can be widely used by agencies and builders to inform construction in the Roaring Fork Valley.

III- MODEL HOME

In 2012 Habitat obtained 12 single-family home lots in the Keator Grove subdivision of Carbondale, Colorado. One home is complete, two homes are currently under construction; leaving nine additional lots to build out. Given the lot sizes and covenants of Keator Grove, these homes are very similar in size and design but can utilize a wide variety of building shell and mechanical configurations. In an effort be more systematic on the build out of the remaining nine lots, a design that is currently under construction (the Davis Residence) is analyzed here. The Davis Residence design is directly applicable to nine future Habitat Homes at Keator grove, but its design and size are also applicable to a number of low and middle income homes across the Roaring Fork Valley.

Figure 1- Rendering of Model Home by Scott McHale

The Davis Home is a two-story home built on a relatively flat site. It has 1770 sf of conditioned living space. In addition, it has an attached single-car unconditioned garage occupying 264 sf. It has 3 bedrooms and 2.5 baths. Building plans are available in the appendix B. The compact size and footprint give this home a sustainable leg up on larger or more sprawling home. The compact home size is in keeping with area affordable housing guidelines, which require single family homes between 1100 and 2200 sf.[5] The price of various home configurations in this study range from $295,000-$395,000 without land costs.[6] This is a construction per square foot livable space cost of $166/sf -$223/sf. For reference, the median home price including land in Carbondale based on 2014 sales is $475,000. Average price per square foot for homes sales in Carbondale is $256. [7]

[5] Aspen/Pitkin County Affordable Housing Guideline, Jan. 2014, Part VII Section 7 set maximum unit size at 2,220 sf with an additional garage at 500 sf and basement at 800 sf. Section 8 places minimum home size for 3 bedroom single family at 1100 sf-1900 sf depending on category, Carbondale Community Housing Guidelines from 2014 place the minimum single-family home livable area at 1100 sf – 1200 sf. Glenwood Springs Community Housing guidelines from 2001 place the minimum livable area at 1200 sf (not including garages and unfinished basements). Garfield County Affordable Housing Guidelines from 2008 place minimum home size at 1400.

[6] These costs are based on one General Contractor's cost estimate from plans and specs for the model home in Carbondale, CO in 2014. They do not include land costs and do not reflect actual Habitat for Humanity costs.

[7] Trulia.com Based on 3 bedroom home sales in Carbondale, CO for May-August of 2014. Note this price includes land while the construction cost estimates on home configurations does not.

IV - METHODS

The study starts with the geometry of the Davis home, then modifies the components of the shell and mechanical systems and compares the resulting data. From that model house a matrix is created with different mechanical systems running in the X direction (horizontally) and different shell, or envelope, packages running in the Y direction (vertically). See appendix C.

Ten different mechanical systems are compared, ranging from simple electric baseboard heaters with tank-less hot water systems to complex natural gas hydronic solar integrated systems. Assumptions that guide the modeling of mechanical systems include:

- Gas-fired machines are always high-efficiency, sealed-combustion units
- Equipment and ductwork are always located in conditioned space
- Ventilation for the health of the occupants was added to any home configuration with a shell package with an air infiltration rate of 3 ACH50[8] or less
- Heat pumps and propane were not included in the study

More details on the mechanical systems are available in appendix C.

Twenty-five different shell packages are investigated, ranging from the minimum insulation levels allowed by building codes to super-insulated versions with low air infiltration rates. Other variations that are investigated in the shell packages include: ventilated roofs and attics verses conditioned attics, ventilated crawlspaces verses conditioned crawlspaces, exterior insulation versus cavity insulation, different types of cavity insulation, and varying window performance. The shells are limited to types of construction that are typical used in the area- wood framed construction and SIPs (Structural Insulated Panels) construction. More shell details are available in appendix C.

Assumptions that guide the modeling of shell package include:

- The laws of thermodynamics tell us that it is most effective to distribute insulation evenly around a house, therefore the insulation values of different assemblies are balanced with one another.
- Air infiltration rates are estimated based the number of ventilated assemblies, on surface area and the areas sealed with SPF insulation.
- Insulation installation is presumed to be grade 1(the highest quality installation).

The combination of 10 mechanical systems and 25 different building shells yields 250 possible combinations, referred to as home configurations. To simplify the range of

[8] Air Changes per Hour when home is pressurized to 50 Pascale by use of a blower door. An air change is when a volume of air equal to the volume of the house exchanges with outside air. 1 ACH 50, then, means all the air in the house exchanges once per hour under 50 pascale fan pressure.

data, 133 configurations are deleted based on practical assumptions. Some configurations are impractical; i.e. ductwork would not be installed in a house without either an attic and/or a crawlspace. Some configurations are deleted based on the economics of construction. Money tends to be spent on different parts of a house evenly; i.e. code minimum windows would not be installed in a wall with double the code minimum insulation values. A photovoltaic solar system would not be installed on house without also installing high-efficacy lighting and ENERGY STAR certified appliances.

It is important to note that many factors influencing the performance of house in real-world conditions are beyond the scope of this study. The study does not consider occupant behaviors, abnormal weather, maintenance costs or finance costs. There are conservation design strategies that could be applied to these case studies to improve performance that are beyond the scope of this study. These strategies include passive solar design, passive cooling, envelope sharing, non-standard building assemblies and mechanical system minimization.

The resulting 117 home configurations are construction cost estimated, modeled for energy use and carbon footprint. The data from the three different sources is graphed over a twenty year period to evaluate the performance of each home configuration over time. See figure 4 on p. 14. A detailed discussion of each of the three study methods follows:

A. Energy Simulation

Energy modeling or energy consumption simulation is a process which predicts the energy consumption of house that has yet to be built. For this study a HERS (Home Energy Rating Score) modeling protocol is used. A HERS model is an energy modeling protocol for residential structures that rates energy performance of the home relative to a typical code constructed home. Roughly, a score of 100 is equal to minimal code construction while a score of 0 equals a net-zero home. The HERS index was developed by RESNET (Residential Energy Services Network)[9]. The specific software used is REM/Rate V.14.4.1 which is developed to meet the RESNET standards.[10]

Typically a custom model is created for each house to be studied. This study starts with a single energy model based on the geometry of the model house, then modifies the components of the shell and mechanical systems and compares the resulting data.

[9] RESNET is a not-for-profit membership corporation that is a recognized national standard making body for building energy efficiency rating and certification standards.

[10] More information about REM/Rate can be found at the Architectural Energy Corporation website. http://www.archenergy.com/products/remrate . More information about the RESNET standards can be found at the RESNET website http://www.resnet.us/about/resnet-standards .

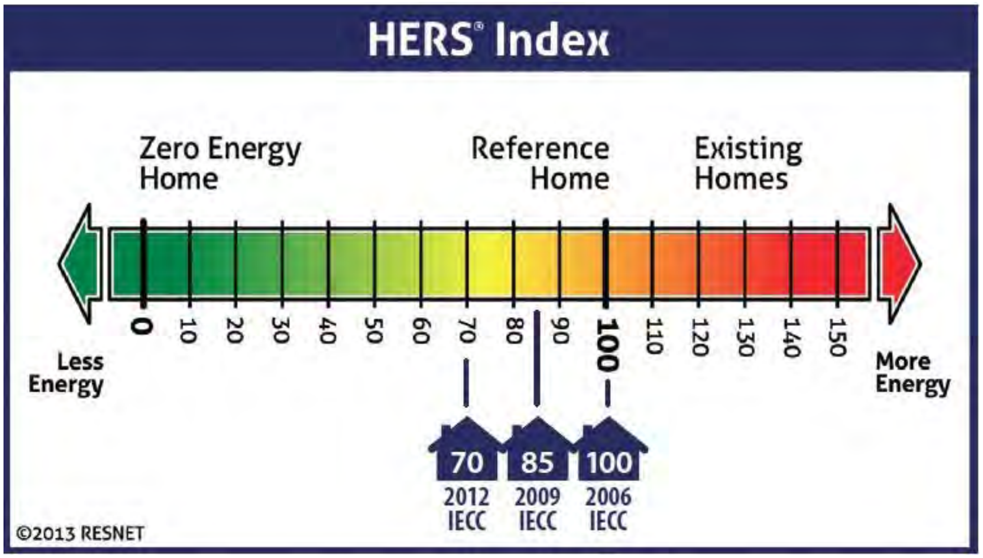


Figure 2- HERS Index and IECC code minimums

Note that a 100 score is based on a code minimum home built to the 2006 IECC.[11] While all local jurisdictions have adopted the 2006 IRC and IECC, many have adopted newer versions or measures in addition to the codes that would make that jurisdiction's code minimum different from the national standard. Specifically, a code minimum home of 2000 sf in Carbondale will score a maximum 75 HERS rating.[12] Also note that the code minimum rating is decreasing with new code adoptions as show in figure 2 above.

In addition to an energy performance score, REM/Rate also reports annual energy usage for electricity (KwH) and gas (therms). The study translated these values using the EPA Greenhouse Gas Equivalencies Calculator[13] to tons CO_2 equivalent[14] in order to be able to compare home energy usage to embodied construction energy (found via the LCA) in the home. Energy costs in today's dollars are generated by the software from databases of local utility companies. This cost of energy is raised by an annual inflation rate of 4% for modeling purposes.

Mark McLain of Confluence Architecture executed the HERS models. You can find more information about Mark and Confluence Architecture in the Biography section, appendix A.

---

[11] International Energy Conservation Code for Residences

[12] Per Town of Carbondale Residential Efficient building Program, Ordinance No. 8, series of 2011.

[13] http://www.epa.gov/cleanenergy/energy-resources/calculator.html#results

[14] CO_2 (Carbon Dioxide) Equivalent is a metric measure used to compare the emission from various greenhouse gases based upon their global warming potential (GWP). The greenhouse gases included in the equivalent calculation are CO2, methane, nitrous oxide and sometimes cholorofluorocarbons, hydrochlorofluorocarbons, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. $C0_2$ is the largest component accounting for an average of 82% of all US greenhouse gas emissions.

B. Life Cycle Assessment

A LCA (Life Cycle Assessment) is a “cradle-to-grave” approach for assessing products. “Cradle-to-grave” indicates that the entire life of the product is taken into account starting with the gathering of raw materials to create the product and continuing through manufacturing, installing, and service to the end of life when the product material parts are returned to the earth.

In the early 1990s an international standard for LCA was developed by the ISO[15] (International Organization for Standardization). These ISO standards are used by many LCA tools. As noted by the Athena Sustainable Materials Institute “The ISO standards mentioned . . . can be interpreted in various ways, which makes compliance with the standard difficult to gauge. In fact, there is a rather wide set of alternatives for completing an LCA.”[16] It is not unusual to get differing results from LCA tools even if they are based on the same ISO standards. As such, the LCA is most powerful as a comparison tool when the same tool examines many possibilities. The relative differences in the environmental impacts of design iterations are a more powerful measure than any one numerical output.

The whole building LCA tool used in this research is called *Athena Impact Estimator for Buildings*. The LCA covers five life stages and examines seven environmental impact categories.

Life Cycle Stages	**Environmental Impact Categories**
-Cradle- 1. Manufacturing 2. Construction **-Gate-** 3. Maintenance 4. End of Life 5. Operating Energy **-Grave-**	1. Fossil Fuel Consumption: Embodied energy required to transform or transport raw materials into products and buildings including (MJ) 2. Global Warming Potential: A reference measure for measuring greenhouse gases including CO_2, CH_4, N_2O, HFC-23, CF4, and SF_6 translated into CO_2 equivalent units[17] 3. Acidification Potential: regional image of high concentrations of NO_x and SO_2 (H^+ eq) 4. Human Health Criteria: Particulates that affect health due to impact on human respiratory system. (PM10 eq) 5. Aquatic Eurtrophication Potential: fertilization of surface waters (N eq) 6. Ozone Depletion Potential: Measurement of ozone depleting substances includes CFCs, HFCs and Halons. (CFC-11 eq) 7. Photochemical Ozone Formation (Smog) Potential: Measure of smog as caused by interaction of VOCs and NO_x (O_3 eq)

Figure 3. LCA Life Cycles Stages and Impact Categories

[15] ISO 14040:2006 Environmental Management – Life Cycle Assessment – Principles and Framework and ISO 14044:2006 Environmental Management – Life Cycle Assessment – Requirements and Guidelines
[16] Athena

In order to keep the data comparable with data from the REM/Rate software, only a small portion of the data generated was used; specifically Global Warming Potential measured in tons (imperial) of CO_2 equivalent for the homes at the time of completion of construction (cradle-to-gate) and at the end of a 60 year life (cradle-to-grave).

Also, only elements of the home that changed in the home configurations were modeled. This includes the structural system and entire exterior envelope of the home including the garage and enclosures between the garage and the home. Interior walls, interior finishes, cabinetry, electrical wiring, and plumbing fixtures were not modeled as all configurations examined assumed that these were the same. Given these limits, the reader is cautioned against taking the final carbon number as the total carbon footprint of the home and to look at the differences between the configurations for accuracy.

The Athena Impact Estimator for Buildings did not have the ability to model a few key components that were critical to this study. The table in appendix D lists the components and the source of LCA data that was used.

Angela Loughry of Confluence Architecture did the LCA modeling. You can find more information about Angela and Confluence Architecture in the Biography section, appendix A.

C. Costing

Homes built by Habitat for Humanity have a different costing model than typical market rate homes. Volunteer labor, donated materials, home owner “sweat equity”, and financing structure change the cost of a Habitat Home compared to a typical home. In order for this study data to be useful to those outside of the Habitat model, this study uses market rate pricing. The estimating was done on plans for the Davis Home by a professional estimator. He priced a base model (code minimum) and then gave an a la cart price for each sustainability upgrade.

It is important to note that this pricing was done with a whole home price emphasis. Individual component prices should not be examined too carefully as their price was derived as part of a whole. The pricing is targeted at accurately finding general trends such as: the portion of construction cost that is part of the mechanical system, comparison costs between mechanical systems, and comparison costs between shell systems. This pricing was also done on a specific design in a specific location. It may seem obvious, but it is worth stating, that a home of the same size and features could well have a very different cost based on location or complexity of design. The exact same home cost will vary depending on the location in the Roaring Fork Valley by as much as 10%. Also, no rebates or other incentives were applied into the cost model such as: CORE rebates for appliances or Federal Tax Credits for PV, as these rebates vary by location and date.

Steve Eichhorst of Evaluation Services performed the estimating. You can find more information about Steve and Evaluation Services in the Biography section.

V - RESULTS

Unsurprisingly, the most expensive home configuration to build saves the most carbon and has the lowest annual energy costs. Also, unsurprisingly, the least expensive home configurations proved to have the highest overall carbon costs and the highest annual energy costs. The perfect balance between initial construction costs and carbon and energy savings is a more difficult question. The answer depends on value the questioner puts on certain factors such as the importance of initial cost versus annual cost. What is the value of carbon? How important is durability and quality? What is the expected lifespan of the home?

The following graphs show all 117 models in one location. The lines that are more horizontal indicate a better rate of return in annual operation costs use per dollar of initial construction and carbon use per initial construction carbon. You will note that the lowest carbon home (configuration 250 in pink) is the highest cost home on the graph. If the graph were extrapolated beyond 20 years, this would no longer be true, quickly begging the question of time in the effort to construct the best home. A home with a 10 year lifespan will have different needs than a 100 year home.

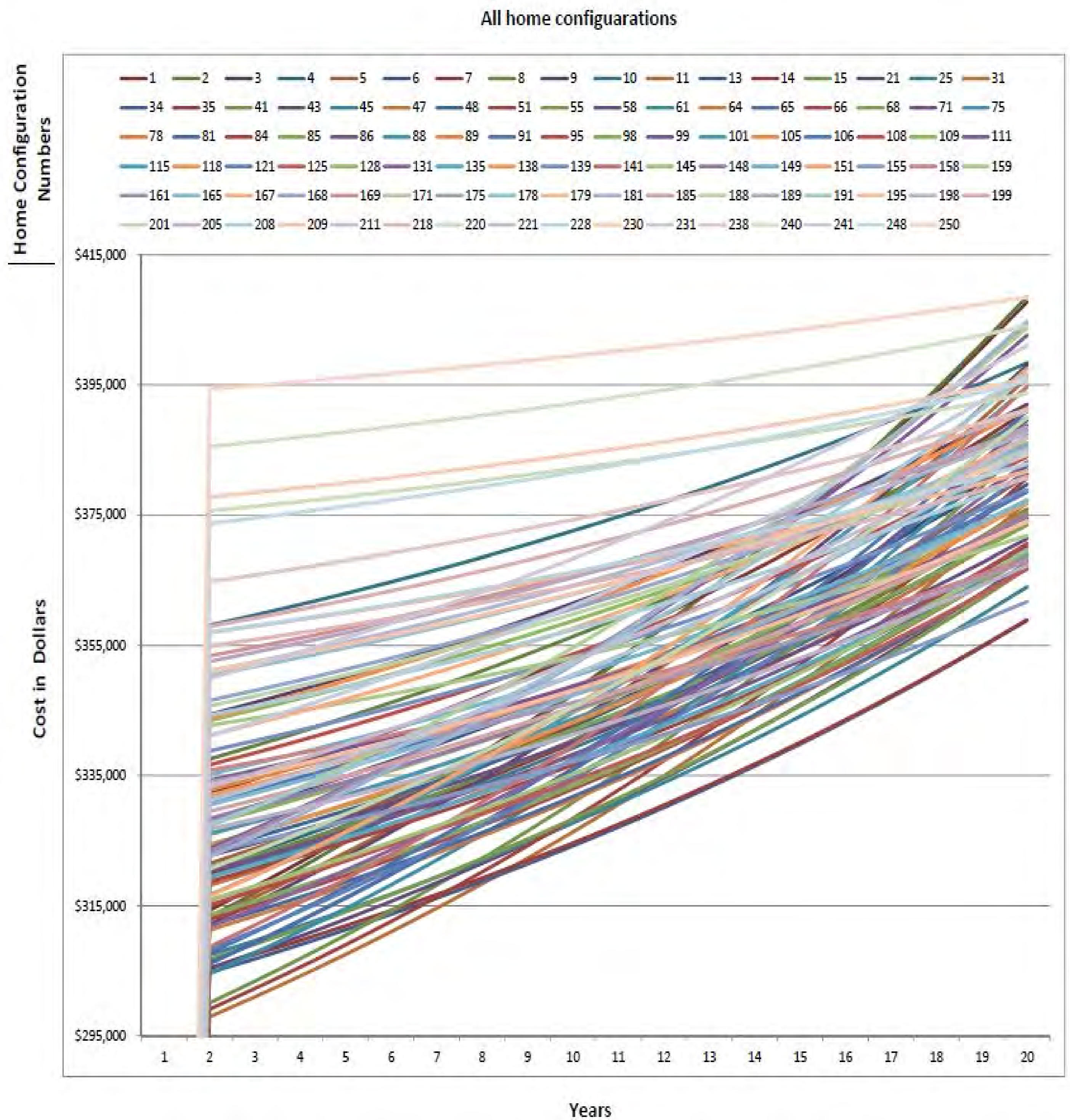
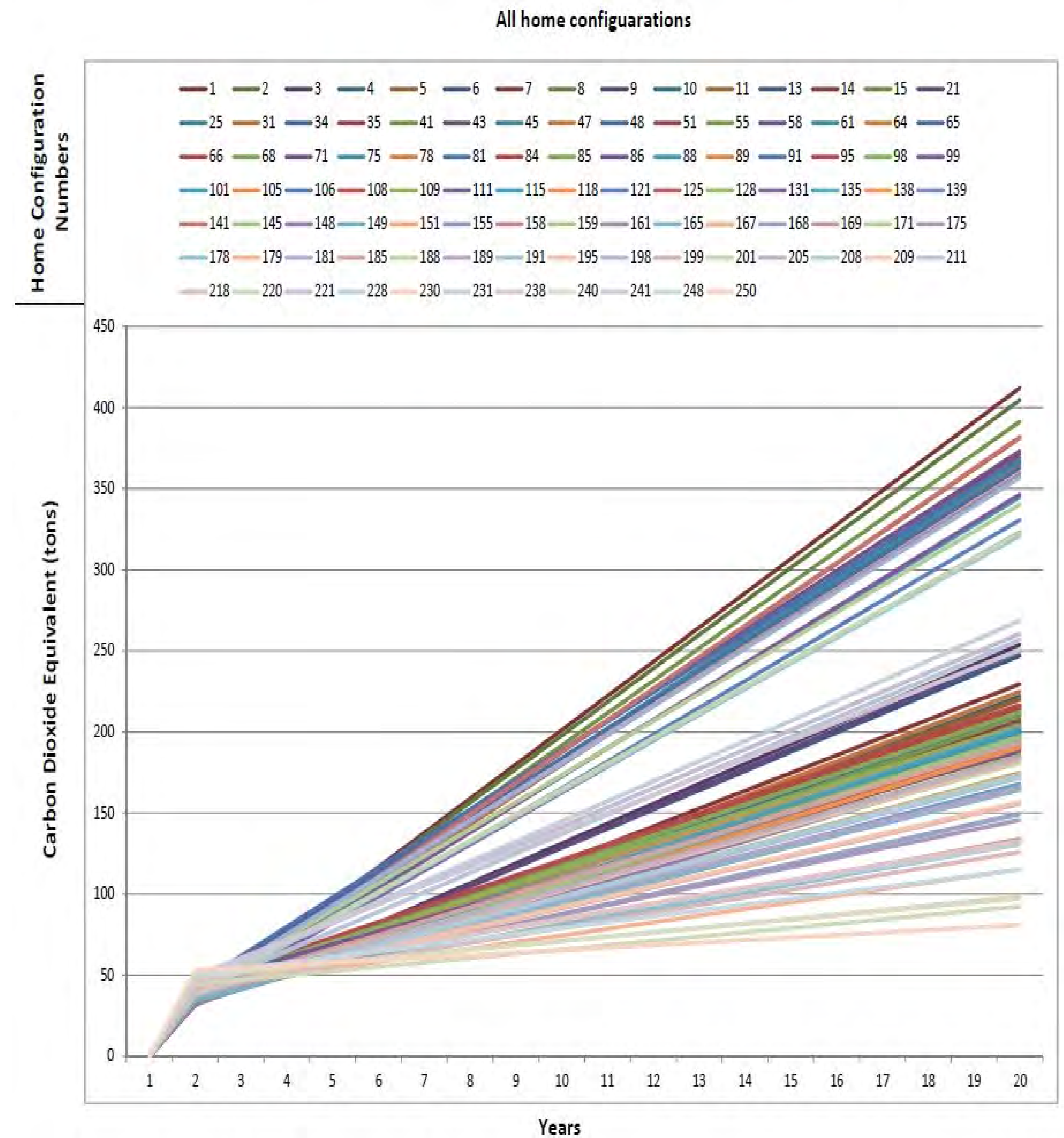


Figure 4. Cost of Home Configuration + Energy over 20 years for all configurations



Carbon over 20 years for all home confifuations

A. Mechanical

In order to understand the vast amount of data, it is beneficial to look at simplified graphs. The mechanical system has a large impact on the annual energy and carbon usage. A graph that shows each of the 10 types of mechanical systems on a single shell type (shell type 1); one can see the install costs and operational costs of each mechanical system. One can see the more efficient systems represented by more horizontal lines.

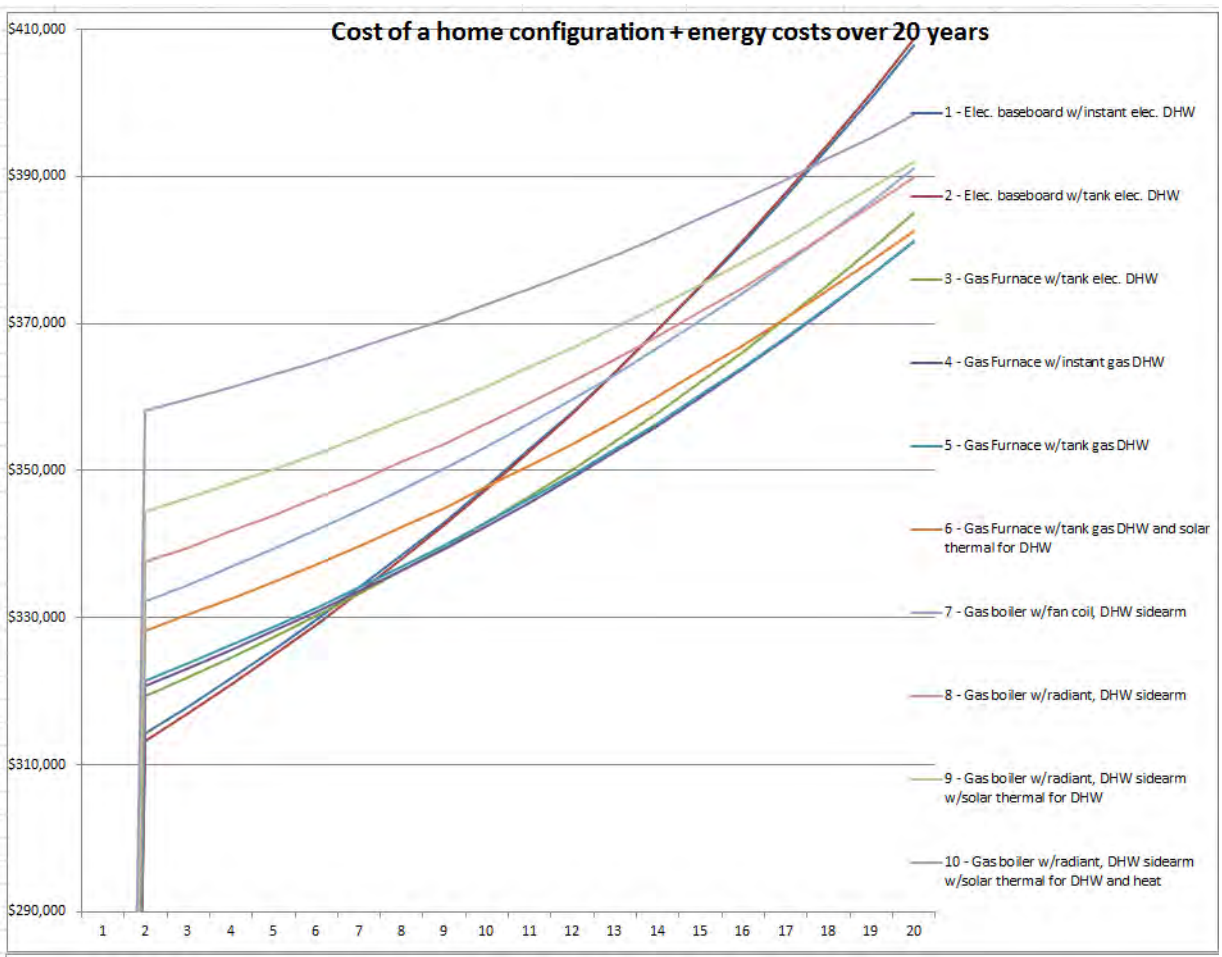


Figure 5. Cost of Home Configuration + Energy over 20 years for 10 mechanical systems using shell type 1

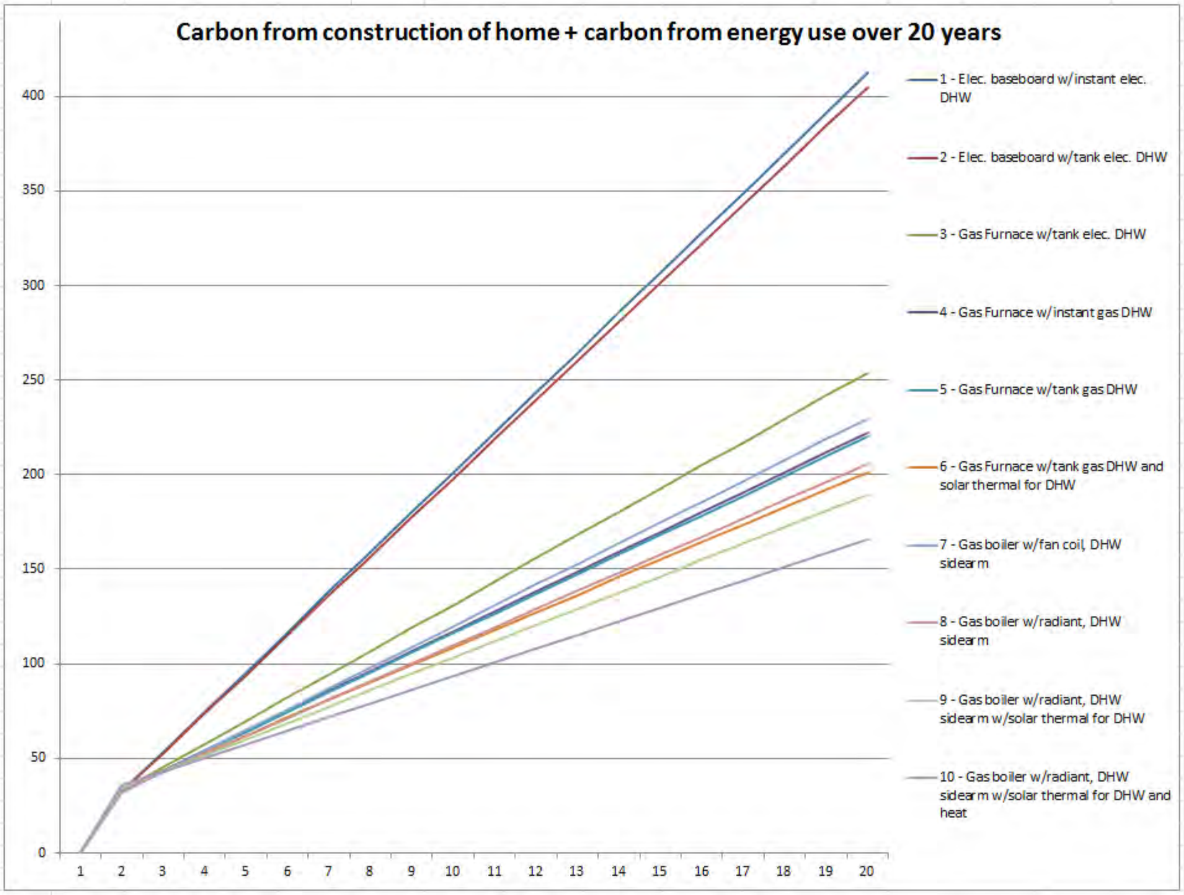


Figure 6. Construction Carbon + Energy Carbon over 20 years for 10 mechanical systems using shell type 1

From the previous graphs the following mechanical system conclusions emerge:

- The initial dollar cost of the systems is significant relative to their operational costs while the initial carbon footprint of the systems is insignificant relative to their operational carbon.
- All electric mechanical systems are inexpensive to install (about $8000 less than a furnace and $21,000 less than a boiler) but highly expensive annually in dollars and carbon (as shown by the more vertical curves for 1,2, and 3 in figures 5 and 6). The cheaper electric systems begin to cost more dollars in 7 years and more carbon in 1-2 years. All electric heating systems do not make sense by any measure.
- A furnace system is significantly cheaper to install than a hydronic heating system (about $13,000). The performance of a hydronic system is better (10%-15%) but that performance is difficult to justify based purely on dollars as it takes 50 years to get a return on investment. If you look at the carbon picture, the choice of the more efficient hydronic system is easier. It takes 4.5 years to get a return on carbon investment. It should be noted that the forced air and radiant heating systems are not necessarily equal. Due to the large cost

implications, furnace systems make sense in housing driven by shorter term economic concerns, but the hydronic system has the potential to provide better comfort, carbon footprint and integrates better with hydronic renewable energy sources. Rebates or other incentives for these systems could help the market make carbon-wise and comfort-wise decisions.

- It does not make sense to combine a boiler and a forced air system. The system studied was a gas boiler feeding a fan coil (system 7). It results in the poor comfort of the furnace and efficiencies that are worse than either a furnace or a hydronic system. This system does allow for the use of solar thermal, but even that addition does not make up for efficiency losses.
- Renewables in the form of solar thermal panels have a noticeable result on operational and carbon performance. A more horizontal (efficient) curve results when a solar thermal solar system is added to the mechanical system (systems 6, 9, 10) in figure 5 an 6. A solar thermal system sufficient to supply DHW (domestic hot water) costs about $7000 and can save approximately 10% in annual energy costs. Similar to the boiler system the dollar return on investment is disappointing at 30-35 years. While the carbon return is much more impressive at 2 years. Please note that current rebates were not figured into the cost. Rebates and incentives help the market use solar thermal systems.
- If the solar thermal effort is increased to cover both DHW and heating loads (system 10) the efficiency is increased resulting in a 25% savings in annual energy costs. This system has a similar return as a DHW solar system, struggling to make up for the initial added cost. This system is highly recommended for a net-zero home.

None of the mechanical systems studied include active cooling in any form. The cooling load in the Roaring Fork Valley is on average only 3% of the heating load.[18] The cost of mechanical cooling system ranges from $4000 for an evaporative cooler to $7250 for a small, direct expansion air conditioning system that uses forced air ductwork. If an air conditioner is added to hydronic system requiring standalone ductwork the cost is even more. This raises the total mechanical system cost by a minimum of 50%. The 50% added cost does not seem warranted for a 3% need while the load can be mitigated in other ways. Adding an active cooling system to the energy model has little effect because the model does not see a need to activate the cooling system; comfortable temperatures and humidity levels can be maintained without it. While there is a perceived need for cooling, the data analysis doesn’t support that perception. Of course, modeled energy usage may not reflect reality. The existence of active cooling in the home sets it up to be used excessively or uneconomically,

[18] This figure is arrived at by comparing the heating degree days with the cooling degree days in various locations. Data obtained from BizEE degree days based on weather station at corner of 10th and Colorado in Carbondale and at airports in Rifle and Aspen.

such as when the windows are open or a fireplace is running, this creates the potential for large energy usage where there is not a large comfort need.

Overwhelmingly comfort issues are more economically addressed by other means that benefit the home for more than relatively few hours of actual cooling need. Better insulation, windows, ventilation, home orientation, window coverings, and window shading benefit the home on multiple fronts making those items better investments than an active cooling system.

B. Building Shell

If we isolate the data to see differences in shell systems related to a single mechanical package, we can understand the shell of the home in isolation. The following graphs look at all 25 shell types with one mechanical system (furnace system 5).

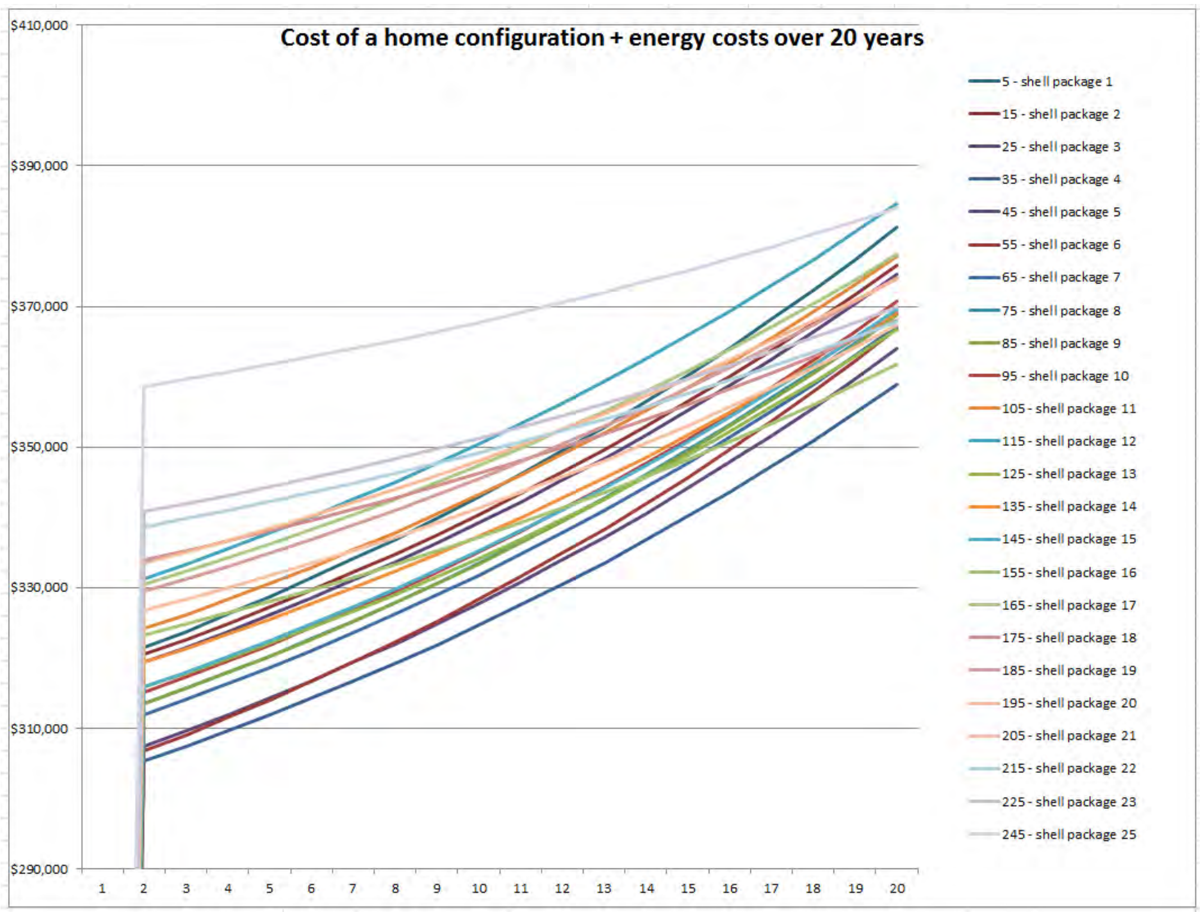


Figure 7. Cost of Home Configuration + Energy over 20 years for 25 building shells using mechanical system type 5 (high efficiency furnace with no renewables)

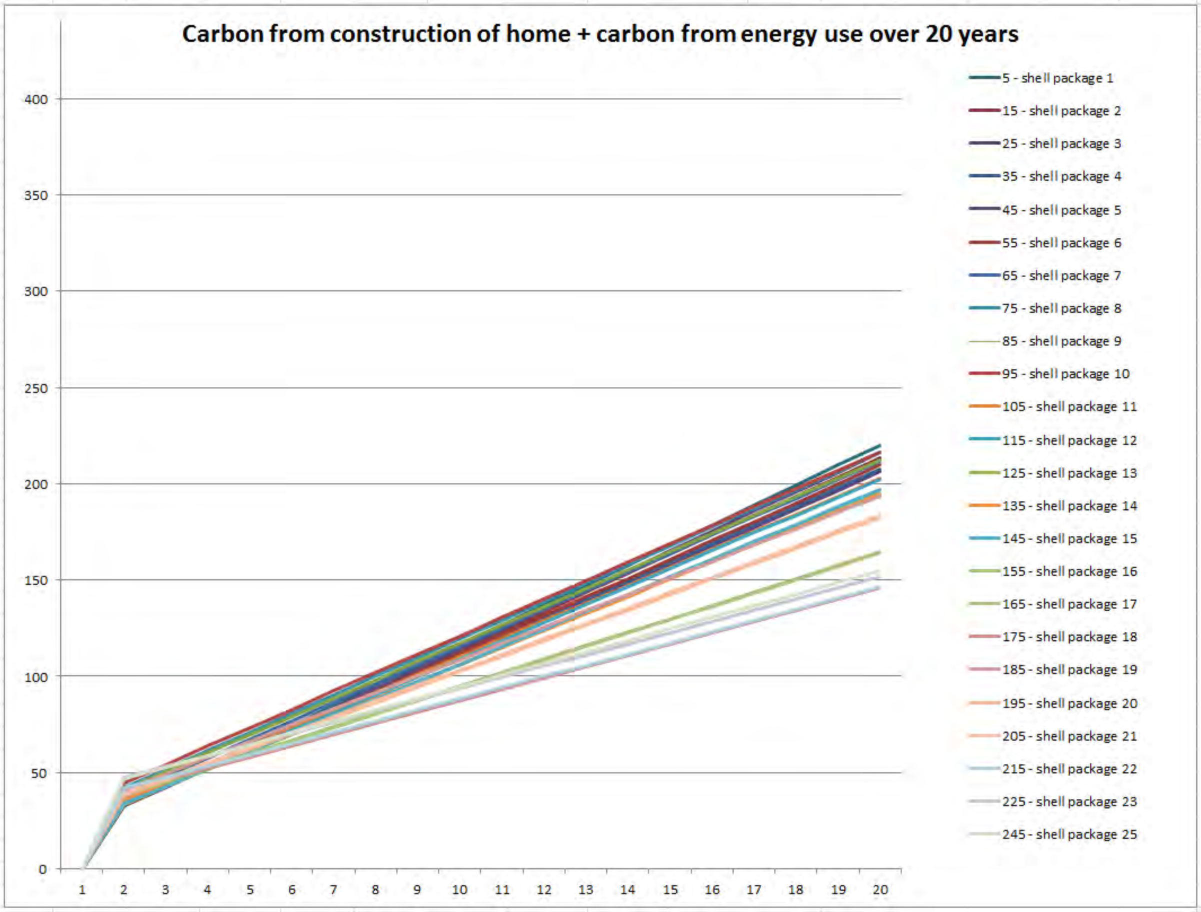


Figure 8. Construction Carbon + Energy Carbon over 20 years for 25 building shells using mechanical system type 5 (high efficiency furnace with no renewables)

From these graphs the following conclusions emerge.

Insulation:

- More insulation is better up to a point of diminishing returns. The most horizontal lines (205, 185, and 195) distinguish themselves by exceeding code insulation levels by 30-50%. See more information on diminishing returns of insulation in the LCA discussion on p. 23-25.
- The type of insulation matters. Continuous exterior insulation is particularly effective in money and carbon[19] as it prevents thermal bridging. A framed wall with only cavity insulation compared with a framed wall with a combination of cavity and exterior polyisocyanurate insulation will cost 5% more energy per year even though the total R-value of the insulation is

[19] As noted in further LCA discussion below, the type of insulation will have a huge initial carbon impact but will have very little performance impact.

the same. The added cost of exterior wall insulation is relatively small and results in a typical dollar return of investment of 10 years.

- There are two ways roof insulation can prevent thermal bridging. First, provide continuous exterior insulation. Second, create a vented attic assembly. Unlike walls, continuous exterior insulation on the roof did not prove to be cost effective. The performance of a continuous insulation assembly to an equal R-value cavity insulation assembly is only better by .001%. A vented attic assembly, is however, less expensive and performs 1% better than an unvented assembly of the same R-value.
- SPF insulation assists with air sealing and allows a high R-value in a limited space, but its high initial dollar and carbon cost are not worth the small increase in energy performance. For example a wall with combination of spray foam and batt insulation compared with an equal R value wall with batt will only save .1% energy annually and take 500+ years to pay back the initial investment.

Air Sealing:

- Increasing air sealing by 1 ACH 50 decreases energy costs by 4%. The current code standard is 7 ACH 50. If that home were sealed to the point of needing mechanical ventilation, an HRV (Heat Recovery Ventilator) is added to the system for mechanical ventilation needs. Homes sealed to 3 ACH 50 could see cumulative savings of 16%, paying off the HRV in eight years of energy savings. Air sealing is probably the easiest, least expensive way to skew these findings in favor of sustainable construction.

Volume:

- Increased volume is a luxury. A vaulted ceiling adds volume that must be conditioned. It also limits insulation assemblies to more expensive options. If all factors are the same (insulation level, windows, mechanical, exterior shell) the change from a flat to a vaulted ceiling will add 3-5% to the annual energy costs and $8000 to construction costs.
- Similarly, a conditioned crawlspace that adds volume to the home will increase annual energy costs by 5-10% over a vented crawlspace or slab on grade. The cost to build a conditioned crawlspace adds $1000 to the cost of a vented crawl space or $2000 to the cost of a slab. Note: there may be other reasons that a conditioned crawl space is desired, most notably if a space is needed for mechanical equipment or ductwork.

Also, many building scientists advocate for conditioned crawlspaces over vented crawlspaces for moisture control and overall performance.[20]

Windows:

- Increasing window performance from a U-factor of .35 to a U-factor of .31 or from a U-factor of .31 to U-factor of .25 saves 2%-3% on annual energy. Unfortunately, that upgrade is costly resulting in a 50+ year return on investment. To build a truly high-performance home, at some point, one must install high-performance windows but that choice would be lower on this list on a home driven by econonmics.

SIPs:

- While SIP construction may be useful for speed of construction, this study did not show that the other potential advantages of SIP construction are worth the added cost. A SIP roof and wall compared with an equal R-value cavity insulated roof and wall saves 3-5% on annual energy costs, but the cost of the initial investment requires more than 250 years to pay back. SIPs look better from a purely carbon standpoint. The SIP panels save four tons of initial construction carbon and .3 tons of operational carbon every year. A better solution seems to be continuous exterior insulation to achieve thermal bridging prevention. A SIP home compared with a framed home with exterior wall and roof insulation assemblies of the same R-value uses 8% more energy and costs $15,000 more to build. The SIP home also requires one more ton of carbon to build.

Double walls:

- Gaining wall insulation by creating an extra wide double framed wall did not prove to be a space effective solution. A double framed wall compared to a similar R-value 2x6 cavity wall with exterior insulation only performs .1% better and costs 75% of the exterior insulation wall. Unfortunately, the floor space lost to double framing is 125 sf. If you presume that that interior space is worth $200/sf that equals $25,000 of floor area occupied by thickened walls instead of people.

Lights and Appliances:

- Upgrading all appliances to ENERGY STAR certified and all lighting from 50% high efficacy to 100% LED saves 2.5% on annual energy. $1500 was added to the home cost for this upgrade (this cost does not include available rebates).

[20] Building Science Corporation has several excellent white papers on this topic. See BSI-009 New Light in Crawlspaces, by Joseph Lstiburek, 10/16/2008. See also BA-0401: Conditioned Crawlspace Construction, Performance and Codes by Joseph Lstiburek,, 11/27/2006.

C. Photovoltaics

The increasing cost competitiveness of PV (Photovoltaic Solar) relative to other construction techniques to save energy was a surprise to the report authors. PV has become so cost competitive that, from a purely economic standpoint, it often provides more return in energy savings per dollar than other shell upgrades. Adding 2kW PV will save 29% of annual energy and have a 13 year payback. The initial carbon hit of a PV system is 5 tons. This carbon is recovered in 2.3 years of use. In terms of return on investment, PV systems are second only to insulation and air sealing.

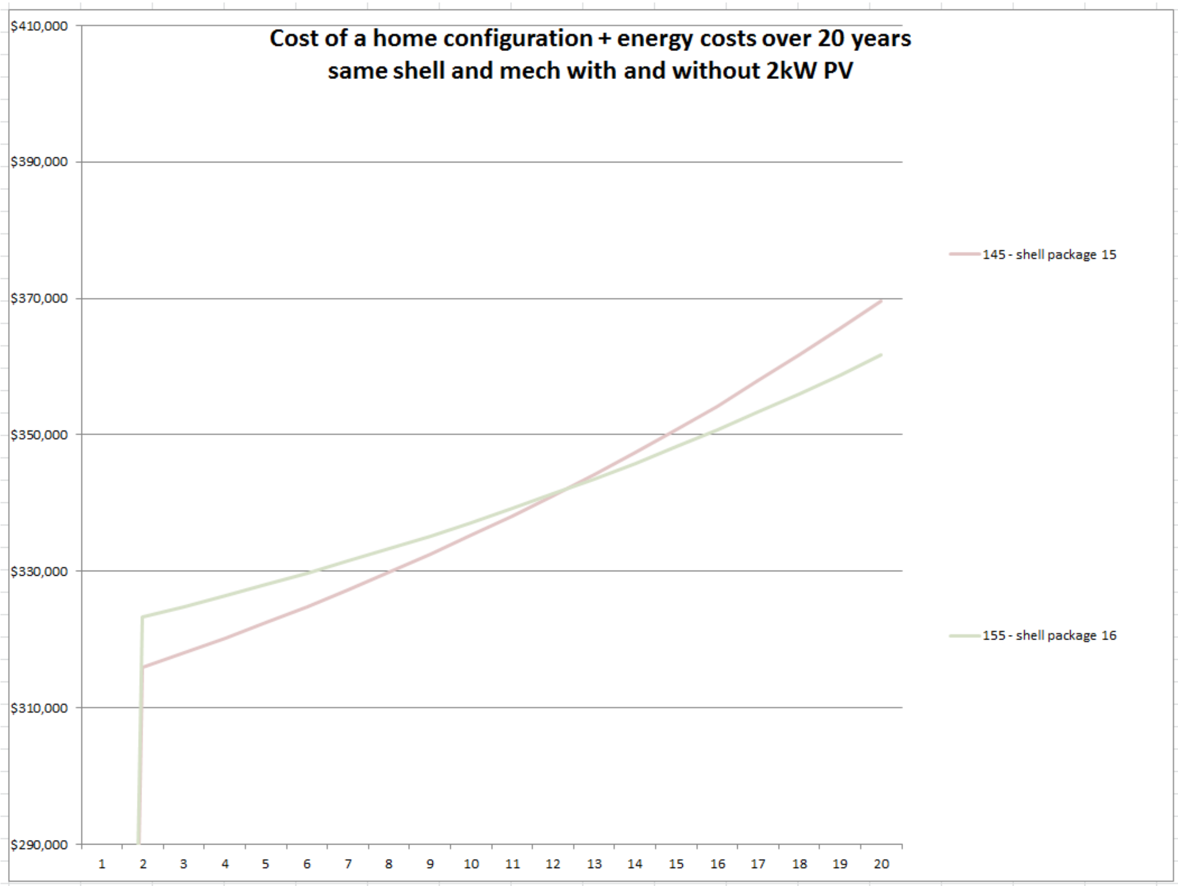


Figure 9. Construction Carbon + Energy Carbon over 20 years for the same building with and without PV

In the baseline and benchmark home configurations in section VI, PV is used as a metric. Each configuration has the amount of PV needed to create a "hypothetical" net-zero home. The roof of the subject house can carry 10 kW of PV[21]. While offsite PV is always a possibility, site specific net-zero homes are only possible on home configurations requiring 10 kW or less of PV.

[21] This is based on the available area on east and west roofs and the estimated output of a 230 sf system placed in 2014 on a neighboring Habit For Humanity home (the Lavender home) by Sunsense.

D. Life Cycle Assessment

Looking at the LCA data independent of cost and usage energy data, a few key trends are worth noting.

Insulation: The widest swings in carbon impacts between the shell packages are the result of the choice of insulation. These swings exceed those demonstrated by extra framing needed for double walls or crawl space floors, extra concrete in the slab packages, or the choice of a mechanical package. They have a similar carbon impact as the addition of PV or solar thermal systems. To minimize the carbon footprint of a typical stick framed home prior to building usage, insulation type is the single most impactful decision. (Note this statement would vary for different construction techniques – for example an ICF (Insulated Concrete Form) home with full-height concrete walls, a straw bale home with low lumber usage, or a home requiring significance hot rolled steel elements would skew this truism.)

Not all insulations are the same in regards to carbon. Insulations that require HFC (hydrofluorocarbon) blowing agents (XPS and SPF) have carbon footprints that are high in relation to the carbon they can save through energy conservation resulting from high insulation values. All insulations have a point of diminishing returns where there is less benefit for adding an R-value the more total R-value you have. Insulations with blowing agents (XPS and SPF) have a high lifetime carbon footprint due to the release of the blowing agents. At some point, the addition of these high carbon footprint insulations would actually counteract the benefit of energy savings. The graph below (figure 10) illustrates this phenomenon. You see the fiberglass batt (yellow) and EPS (black) returning carbon benefits (if ever diminishing) with increasing R-value, while XPS (blue) and SPF (green) at some point produce more carbon than they save (at around R21 and R30 respectively).[22] It is important to note that new XPS and SPF insulations are currently under development with much less impactful blowing agents, but these are not yet widely available on the market.[23]

Both XPS and SPF insulations are used in various home configurations in this study. The amount used did not exceed the point where the insulation actually started to add carbon.

[22] This graph is from an excel calculator developed by David White a Passive House consultant from Brooklyn.

[23] See Avoiding the Global Warming Impact of Insulation by Alex Wilson on BuildingGreen.com for an excellent discussion of carbon of various insulations.

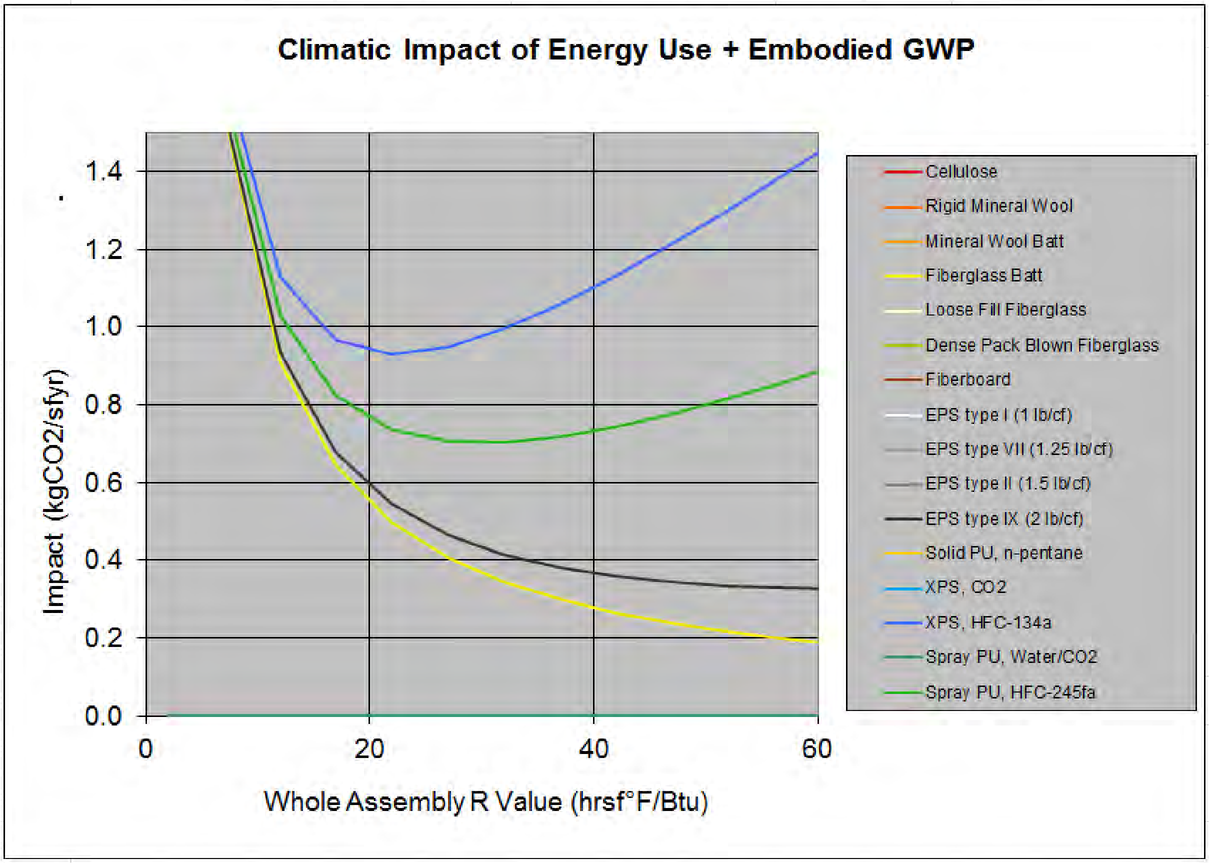


Figure 10. Climatic Impact of Energy Use + Embodied GWP (Global Warming Potential)

Beyond XPS and SPF there are marked differences between other insulations. The chart below shows the carbon footprints of widely used insulations. Notably, there is a large difference between cellulose dense pack and fiberglass batt. If a dense pack cellulose is substituted for fiberglass in a code minimum cavity wall and ceiling insulation the construction carbon savings is 4.5 tons; that is the approximate carbon foot print of a 2 kW PV system.

Insulation Material	R-value R/inch	Density lb/ft^3	Emb. E MJ/kg	Emb. Carbon $kgCO_2$/kg	Emb. Carbon $kgCO_2$/ft^2•R	Blowing Agent (GWP)	Bl. Agent kg/kg foam	Blowing Agent GWP/ bd-ft	Lifetime GWP/ ft^2•R
Cellulose (dense-pack)	3.7	3.0	2.1	0.106	0.0033	None	0	N/A	0.0033
Fiberglass batt	3.3	1.0	28	1.44	0.0165	None	0	N/A	0.0165
Rigid mineral wool	4.0	4.0	17	1.2	0.0455	None	0	N/A	0.0455
Polyisocyanurate	6.0	1.5	72	3.0	0.0284	Pentane (GWP=7)	0.05	0.02	0.0317
Spray polyurethane foam (SPF) – closed-cell (HFC-blown)	6.0	2.0	72	3.0	0.0379	HFC-245fa (GWP=1,030)	0.11	8.68	1.48
SPF – closed-cell (water-blown)	5.0	2.0	72	3.0	0.0455	Water (CO_2) (GWP=1)	0	0	0.0455
SPF – open-cell (water-blown)	3.7	0.5	72	3.0	0.0154	Water (CO_2) (GWP=1)	0	0	0.0154
Expanded polystyrene (EPS)	3.9	1.0	89	2.5	0.0307	Pentane (GWP=7)	0.06	0.02	0.036
Extruded polystyrene (XPS)	5.0	2.0	89	2.5	0.0379	HFC-134a[1] (GWP=1,430)	0.08	8.67	1.77

1. XPS manufacturers have not divulged their post-HCFC blowing agent, and MSDS data have not been updated. The blowing agent is assumed here to be HFC-134a.

Figure 11. GWP of various insulations[24]

Concrete: Shell packages that included more concrete (slab on grade rather than crawl space) have a greater carbon footprint. A concrete slab over 2" XPS insulation has 160% of the carbon of an 11 7/8" TJI (Trussed Joist) framed floor with batt insulation. It is important to note here that we choose to do a typical stem wall construction requiring a stem wall to frost depth under the bearing walls (3' deep min.). As such, the slab on grade options only adds concrete at the main floor slab and does not have concrete savings from a reduced stem wall. If a building includes a shallow frost-protected foundation, the carbon impact of a slab on grade can be fully offset. Alternatively, full ICF wall construction will have a carbon footprint 166% of typical 2x6 framed walls with fiberglass batt cavity insulation.

Renewables: Solar thermal and PV systems have large construction carbon footprints. A typical 2 kW PV system has a 5 ton carbon footprint (cradle-to-gate). A two panel flat panel solar system has a 1.3 ton carbon footprint. In comparison, a typical mechanical system is 2-3 tons and the carbon footprint of a whole home runs between 25-31 tons. The addition of renewables doubles (or more) the mechanical system footprint and less than 10% of the total home footprint.

Volume of shell: While it was demonstrated that the choice of a crawl space versus slab, or the choice of flat versus vaulted ceiling could have noticeable

[24] From Wilson, Alex. Avoiding Global Warming Impacts of Insulation. Environmental Building News.

energy usage and cost impacts, the embodied carbon of these changes through the LCA lens was negligible.

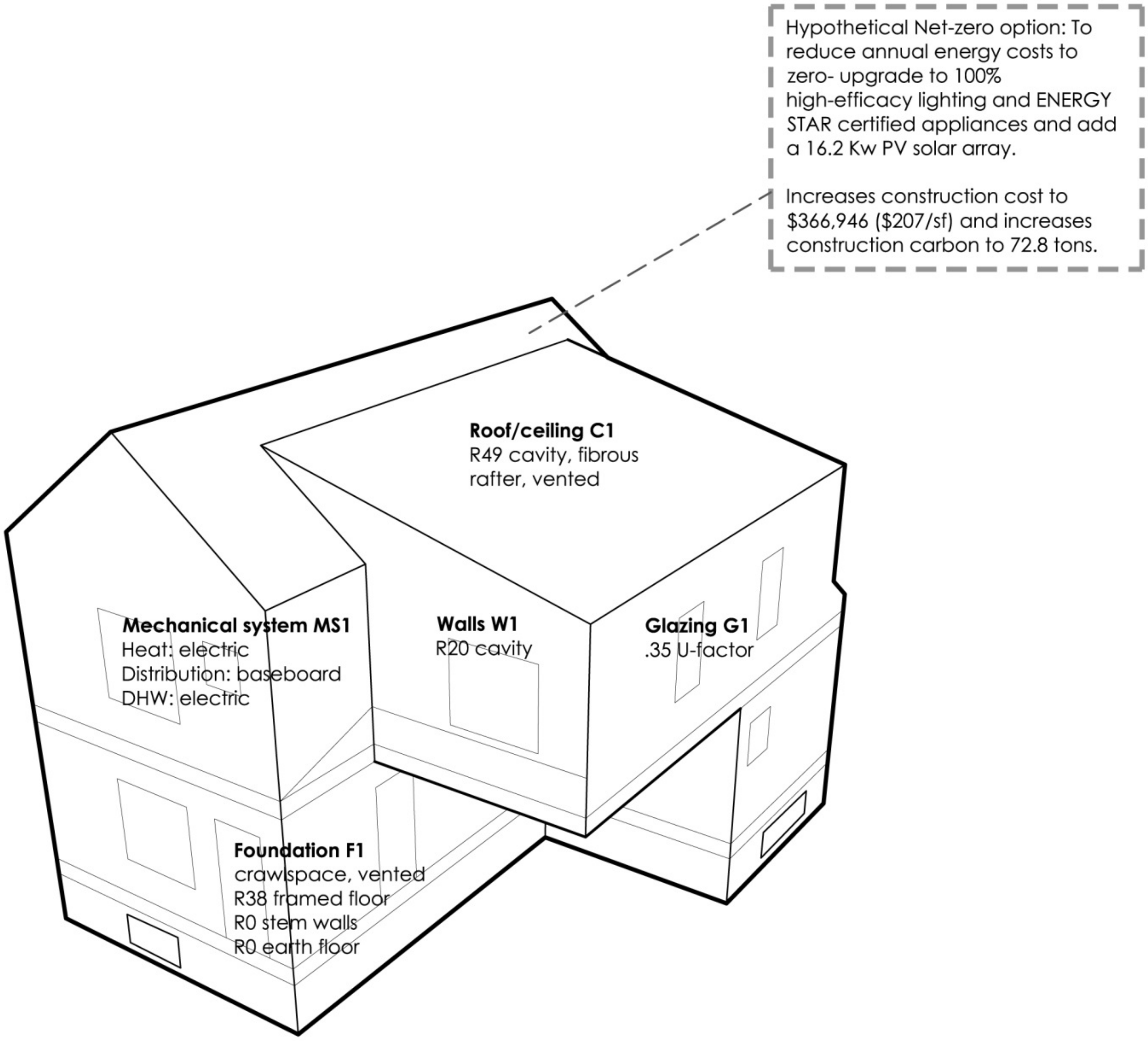
Time: To have an equal metric between cost, building energy usage, and embodied carbon footprint, we choose to not include the entire material lifespan (cradle-to-grave) in the carbon number of some of the data. As was mentioned in the insulation section above, this choice does have a large impact on the data. It was found that insulations with blowing agents and less durable materials (wood siding versus brick siding) have a larger carbon footprint over their life span. The shell packages end of construction carbon ranges between 50 and 65% of the total life cycle carbon. In other words almost ½ of all building material carbon is generated during the lifetime of the building (presumed to be 60 years for this study). This "maintenance and end of life" carbon foot print included greenhouse gas off-gassing by materials, necessary maintenance (painting and repairs), replacement of elements (assuming the asphalt shingle roof is replaced every 15 years) and the final deconstruction and recycling of the home at the end of its life.

VI – BASELINE AND WINNING BENCHMARK CONFIGURATIONS

In order to better understand the data from the 117 models, selected home configurations are examined more closely in this section. These configurations package the data into real, buildable home models. The three baseline configurations look at a code minimum home and two basic production homes. The numbers and graphs pointed to a few benchmark home configurations that are noteworthy due to excelling in a category of performance, or by virtue of being a balanced combination of energy, carbon and money savings. The benchmark configurations step through various upgrades from a basic production home to a final net-zero home.

A Home Configuration Baseline

Baseline configuration: this configuration is the starting point for comparisons. It is built to minimum code standards. It has the lowest construction cost and the highest annual energy costs.



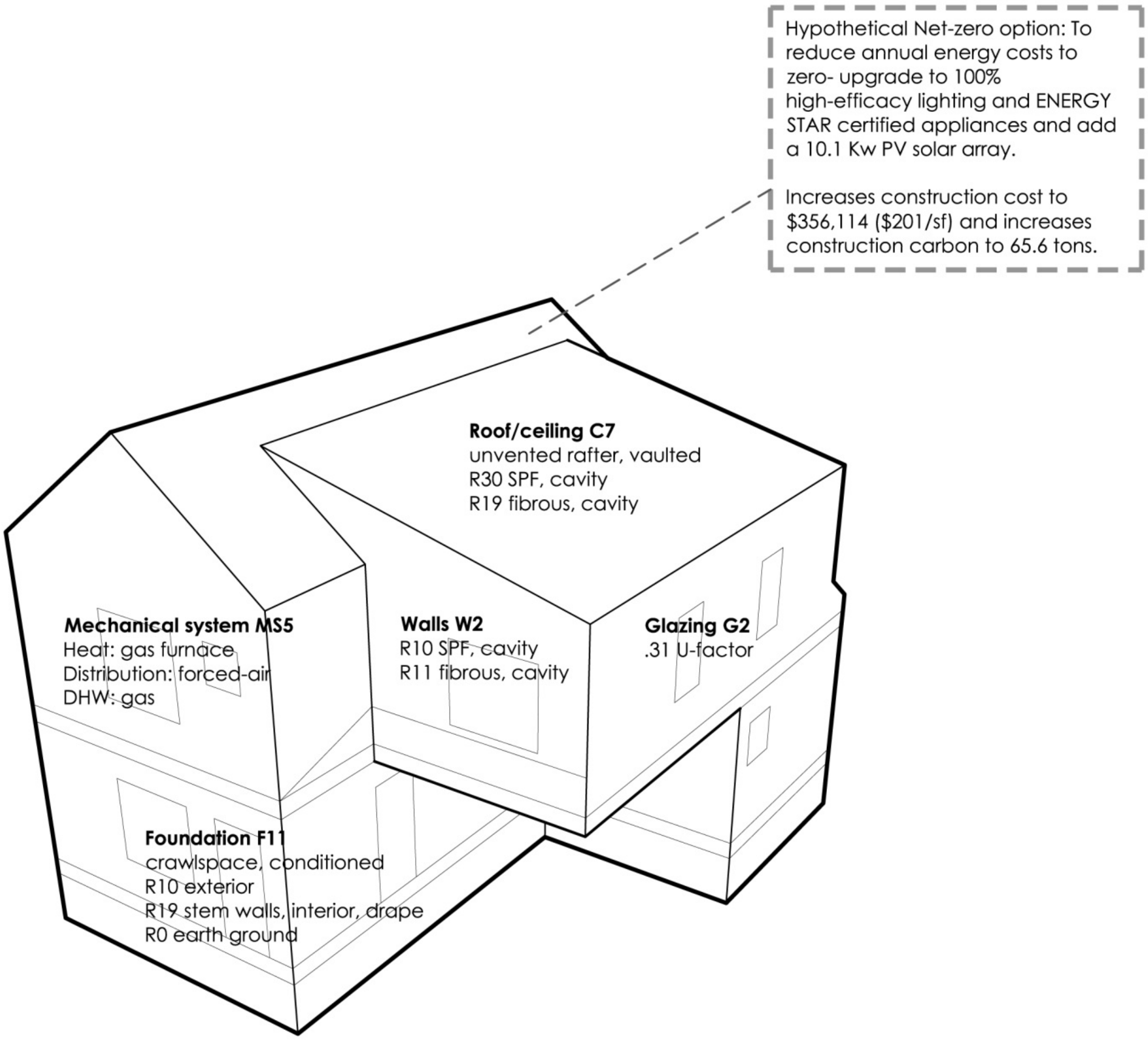
Construction cost: **$302,146 ($171/sf)**
Construction carbon: **32.2 tons**
Annual energy cost: **$3,141 & 22.7 tons of CO_2**

Home Energy Rating Score: **100**
Tons of carbon after 60 years: **1411.7 tons**
Quality, Comfort & Durability: **D-**

For better performance - go to home configuration B

B Home Configuration

This configuration utilizes a flash & batt technique

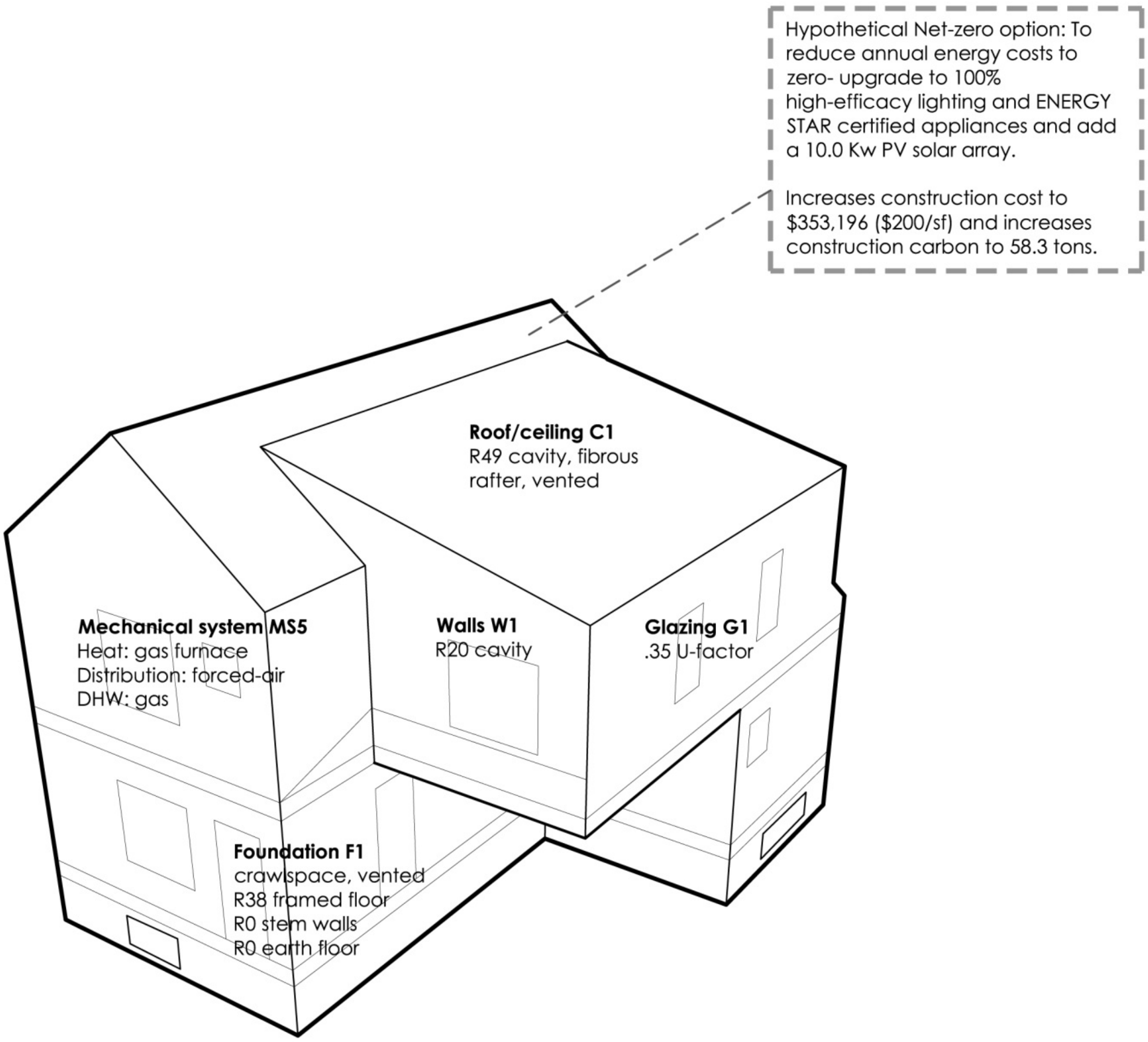


Construction cost:	**$314,214 ($178/sf)**
Construction carbon:	**40.1 tons**
Annual energy cost:	**$1,823 & 11.1 tons of CO2**
Home Energy Rating Score:	**69**
Tons of carbon after 60 years:	**763.0 tons**
Quality, Comfort & Durability:	**C-**

For better performance - go to home configuration C

C Home Configuration

This configuration replaces electricity with gas for heating and water heating fuel.



Construction cost: **$311,696 ($176/sf)**
Construction carbon: **33.1 tons**
Annual energy cost: **$1,780 & 10.9 tons of CO2**

Home Energy Rating Score: **67**
Tons of carbon after 60 years: **704.6 tons**
Quality, Comfort & Durability: **C-**

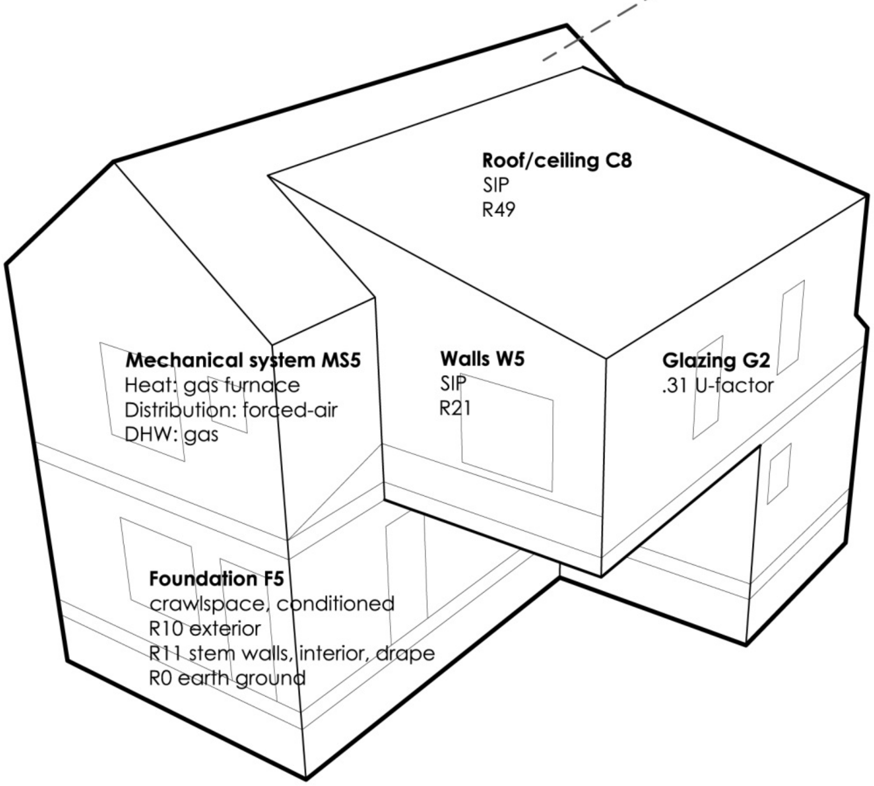
For better performance - go to home configuration D

D Home Configuration

This configuration upgrades the envelope to SIPs for the roof and walls.

Net-zero option: To reduce annual energy costs to zero- upgrade to 100% high-efficacy lighting and ENERGY STAR certified appliances and add a 9.9 Kw PV solar array.

Increases construction cost to $374,681 ($212/sf) and increases construction carbon to 59.8 tons.



Construction cost:	**$333,581 ($188/sf)**
Construction carbon:	**35.0 tons**
Annual energy cost:	**$1,773 & 10.8 tons of CO2**
Home Energy Rating Score:	**67**
Tons of carbon after 60 years:	**699.3 tons**
Quality, Comfort & Durability:	**C-**

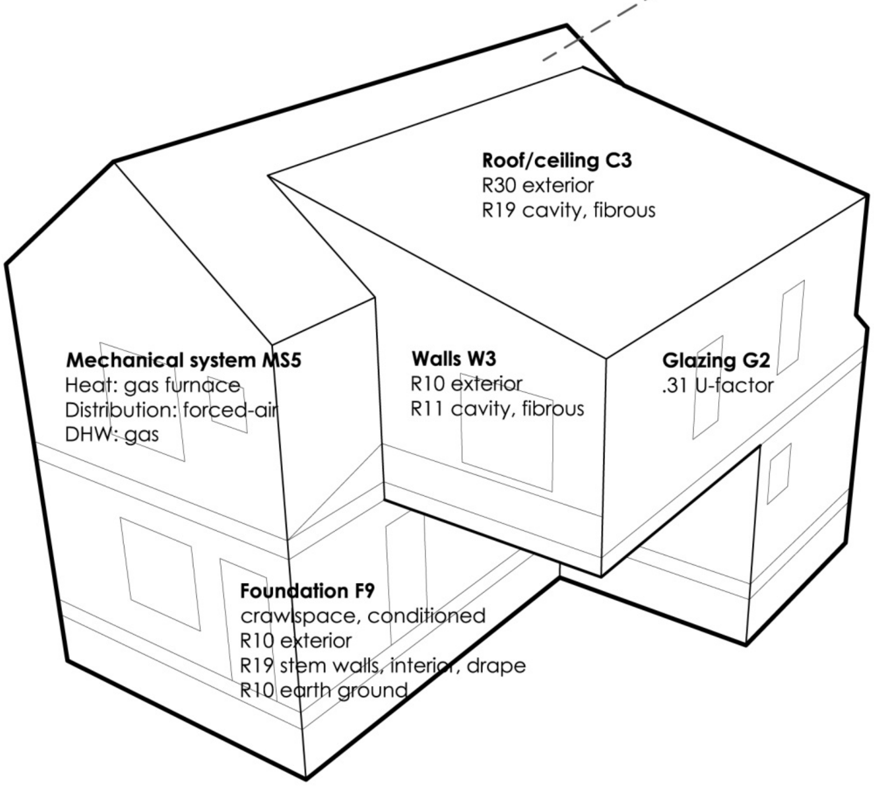
For better performance - go to home configuration E

E Home Configuration

This configuration uses exterior insulation.

Net-zero option: To reduce annual energy costs to zero- upgrade to 100% high-efficacy lighting and ENERGY STAR certified appliances and add a 9.7 Kw PV solar array.

Increases construction cost to $372,670 ($211/sf) and increases construction carbon to 58.5 tons.

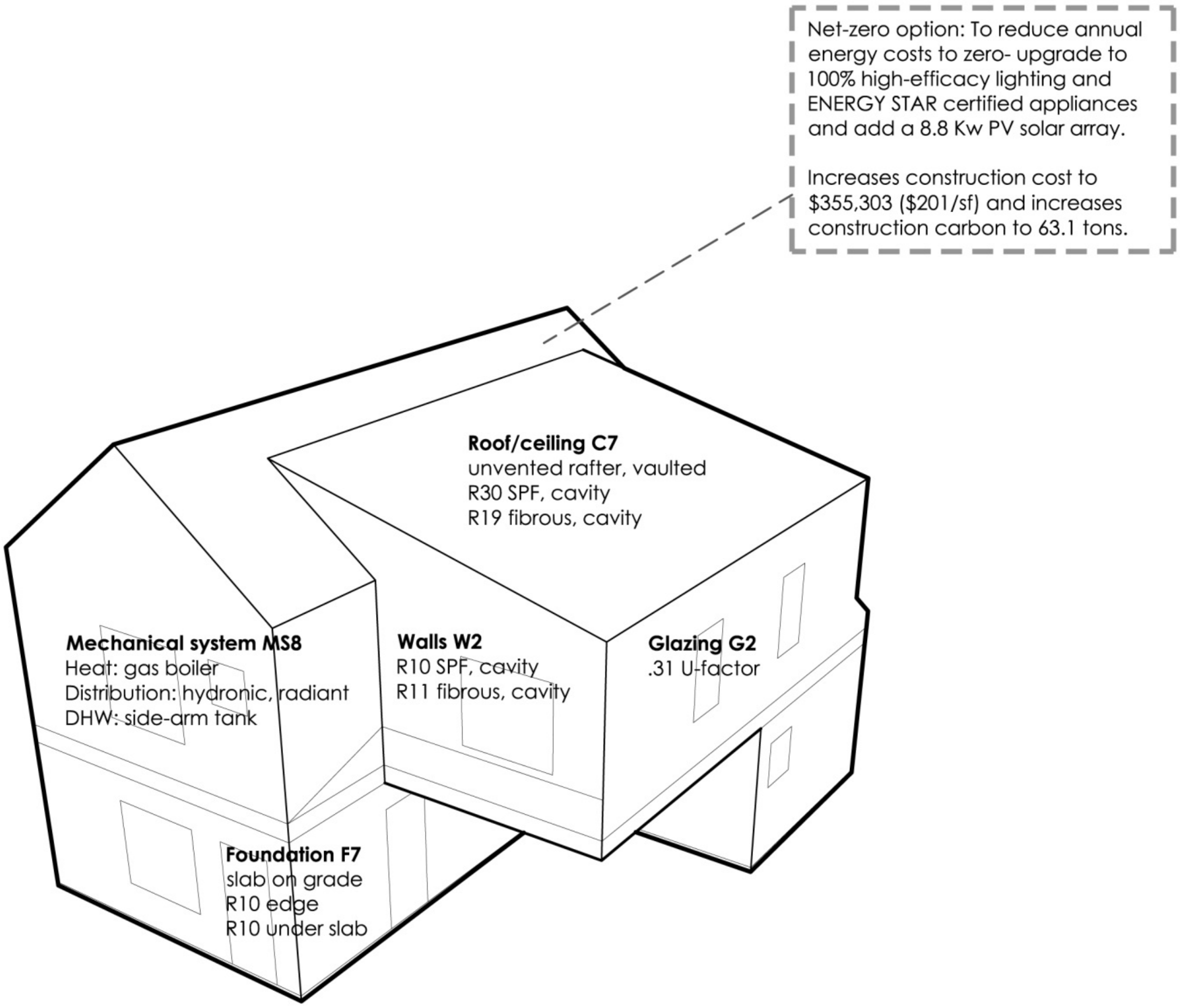


Construction cost:	**$332,370 ($188/sf)**
Construction carbon:	**34.0 tons**
Annual energy cost:	**$1,740 & 10.5 tons of CO2**
Home Energy Rating Score:	**64**
Tons of carbon after 60 years:	**680.5 tons**
Quality, Comfort & Durability:	**C**

For better performance - go to home configuration F

F Home Configuration

Hydronic distribution and a gas-fired boiler with side-arm water heating. This configuration has flash & batt insulation.

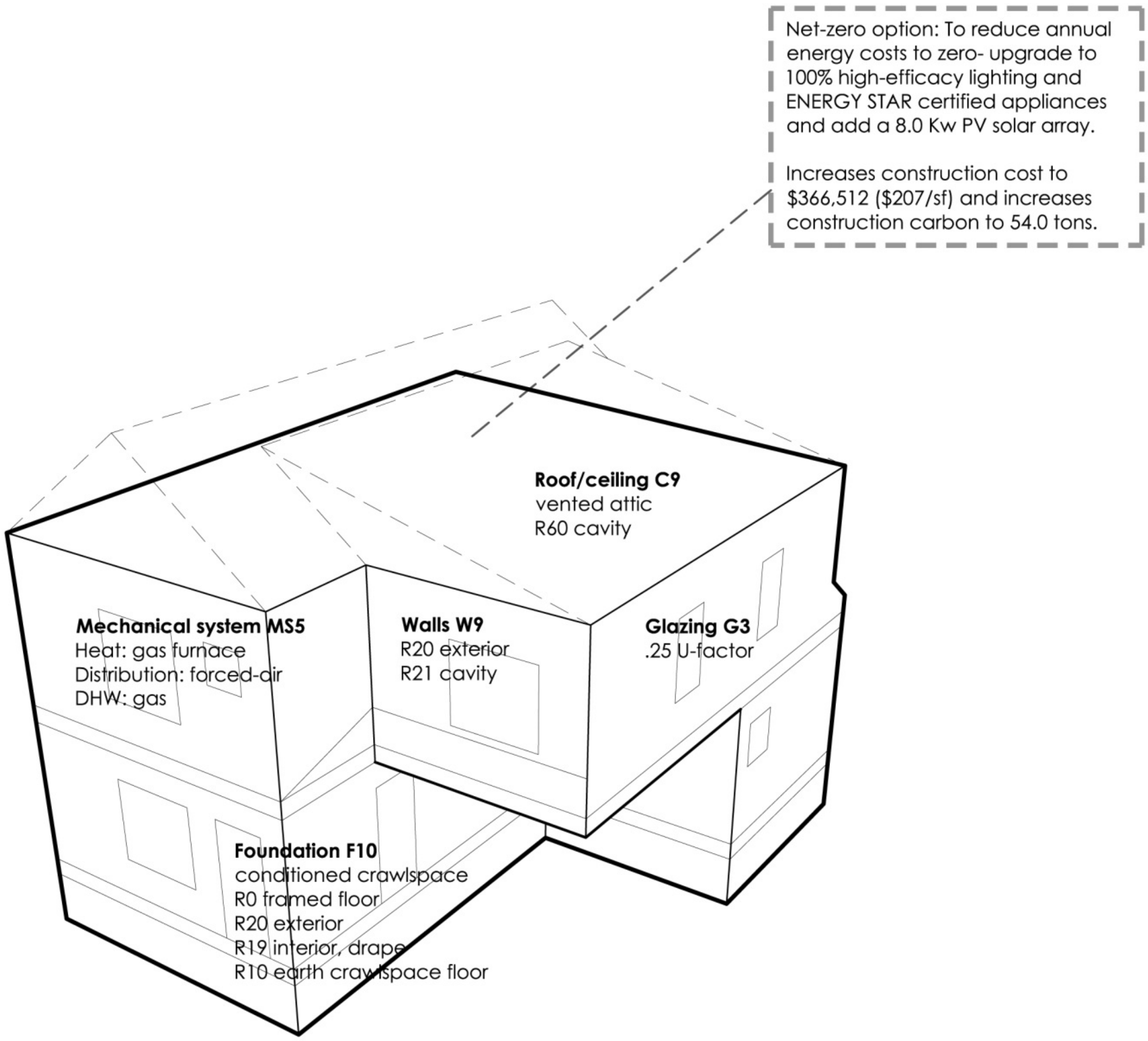


Construction cost:	**$318,603 ($201/sf)**
Construction carbon:	**40.9 tons**
Annual energy cost:	**$1,541 & 9.7 tons of CO2**
Home Energy Rating Score:	**62**
Tons of carbon after 60 years:	**659.9 tons**
Quality, Comfort & Durability:	**B**

For better performance - go to home configuration G

G Home Configuration

This configuration is heavily insulated.



Construction cost:	**$333,012 ($188/sf)**
Construction carbon:	**33.8 tons**
Annual energy cost:	**$1,506 & 9.2 tons of CO_2**
Home Energy Rating Score:	**47**
Tons of carbon after 60 years:	**608.7 tons**
Quality, Comfort & Durability:	**A-**

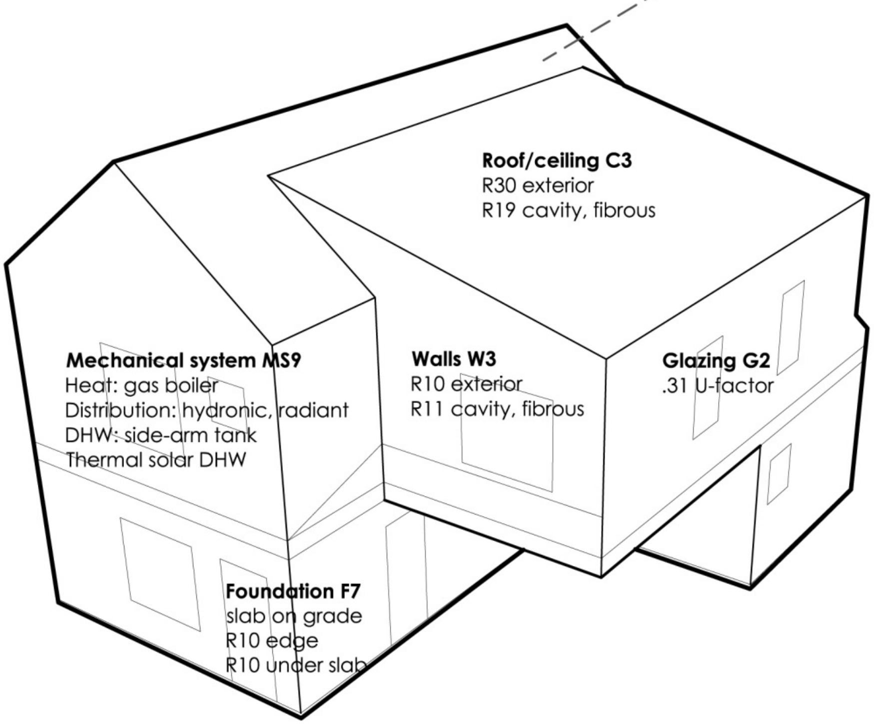
For better performance - go to home configuration H

H Home Configuration

This configuration is exterior insulation.

Net-zero option: To reduce annual energy costs to zero- upgrade to 100% high-efficacy lighting and ENERGY STAR certified appliances and add a 7.0 Kw PV solar array.

Increases construction cost to $382,284 ($216/sf) and increases construction carbon to 52.5 tons.

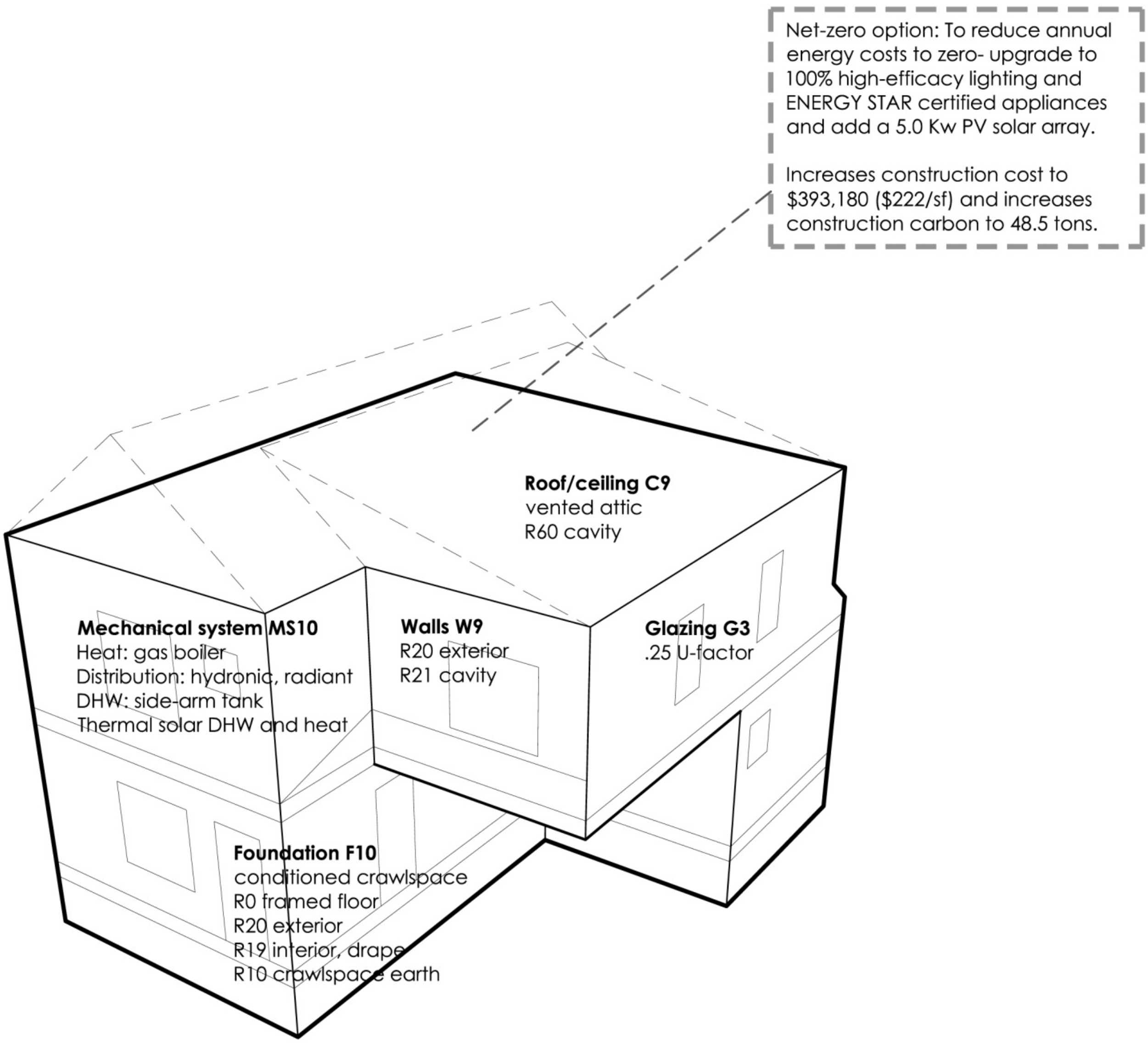


Construction cost:	**$352,784 ($199/sf)**
Construction carbon:	**34.8 tons**
Annual energy cost:	**$1,359 & 8.3 tons of CO2**
Home Energy Rating Score:	**50**
Tons of carbon after 60 years:	**549.9 tons**
Quality, Comfort & Durability:	**B**

For better performance - go to home configuration I

I Home Configuration

This configuration is heavily insulated.



Construction cost:	**$371,680 ($210/sf)**
Construction carbon:	**35.8 tons**
Annual energy cost:	**$1,134 & 6.9 tons of CO2**
Home Energy Rating Score:	**30**
Tons of carbon after 60 years:	**472.6 tons**
Quality, Comfort & Durability:	**A**

APPENDIX

Appendix A

BIOGRAPHIES

Confluence Architecture
0515 Crystal Circle
Carbondale, CO 81623
970.963.9720
www.confluencearchitecture.com

Confluence Architecture performed the HERS and LCA component analysis. Confluence Architecture is a small multi-discipline firm. Confluence specializes in using the latest techniques to optimize the efficiency, comfort and durability of a building with the greatest economy of means. Indoor air quality, sound control and day-lighting are all intimately connected to the performance of the shell and the mechanical systems of a building. Confluence Architecture is uniquely equipped to maximize this balance to favor the highest quality building possible with the lowest possible operational, maintenance and construction costs.

Mark McLain is a registered architect and certified Home Energy Rater. He has performed over 25 HERS ratings in the Valley and most recently worked with Habitat for Humanity on the Lavender Home.

Angela Loughry, LEED AP BD+C is a registered architect who has assisted Habitat for Humanity with LEED certification as well has LEED analysis for the Third Street Center and Living Building Analysis for Solar Energy International's Paonia Campus and the Third Street Center.

Evaluation Services, LLC
2695 Patterson Road
Suite 2, #124
Grand Junction, CO 81560

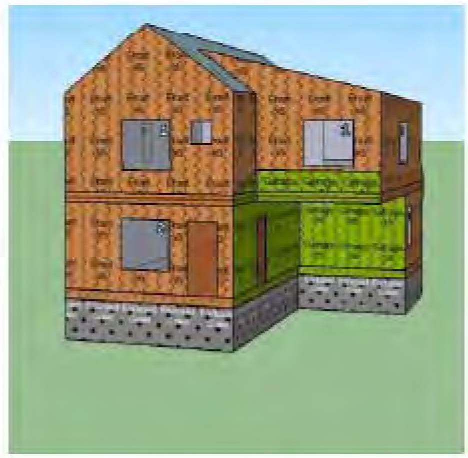
Steve Eichhorst of Evaluation Services and Sopris General Contractors has worked in the Roaring Fork Valley for many years on a wide range of projects and provided the relative market rate cost of each of the different construction and HVAC packages.

Appendix B

MODEL HOME DRAWINGS

Habitat for Humanity
Roaring Fork Valley

Model home



Energy simulation

These conditions and assumptions were constant in all of the energy and LCA models:

Location:	Aspen climate data region
Climate Zone:	7
Conditioned Area:	1770 sf
Type:	single-family detached
Shelter class:	3
Number of floors:	2
Number of bedrooms:	3
Window to floor ratio:	0.18
Mechanical location:	conditioned space
Thermostats:	programmable
Setpoints:	68 heat 78 cool
Insulation:	insulation is always installed at grade 1
Ductwork:	conditioned space
Garage:	outside; not included in energy model

DAVIS RESIDENCE

HABITAT FOR HUMANITY

LOT 16, KEATOR GROVE
CARBONDALE, COLORADO

PROJECT INFORMATION

PROJECT DESCRIPTION

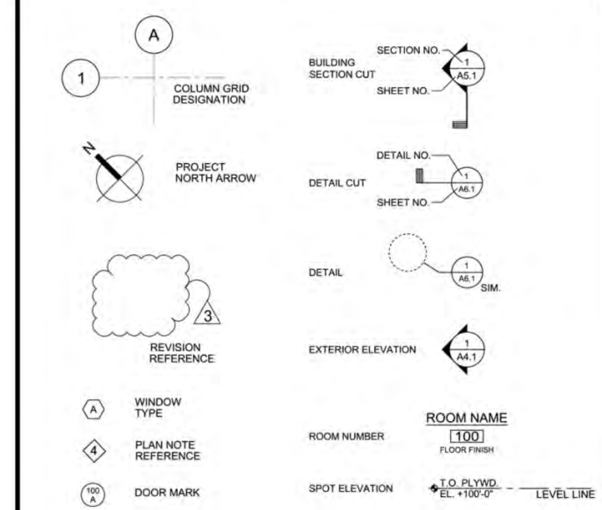
THE SCOPE OF THIS PROJECT INCLUDES THE CONSTRUCTION OF A SINGLE FAMILY HOME IN THE KEATOR GROVE SUBDIVISION.

PHYSICAL ADDRESS:
KEATOR GROVE, LOT 16
CARBONDALE, CO

CODE & ZONING INFORMATION:

OCCUPANCY:	R-3 RESIDENTIAL
TYPE OF CONSTRUCTION:	TYPE VB
BUILDING GROSS AREA	1,985 S.F
BUILDING CODE USED:	2009 IRC

ARCHITECTURAL SYMBOLS



PROJECT DIRECTORY

OWNER

HABITAT FOR HUMANITY
970-948-8264
CONTACT: SCOTT GILBERT

CONTRACTOR

HABITAT FOR HUMANITY
970-379-8883
CONTACT: RICK FARR

ARCHITECTURAL DESIGNER

E. SCOTT McHALE
DESIGN & CONSULTING
246 SOPRIS AVE
CARBONDALE, CO 81623
T 970-708-5035

CONTACT: SCOTT MCHALE

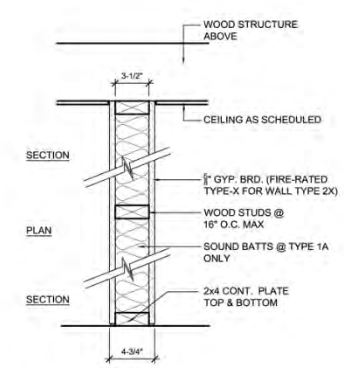
STRUCTURAL ENGINEER

ALBRIGHT & ASSOCIATES
402 PARK AVE, UNIT E
BASALT, CO 81621
T 970-927-4363

CONTACT: JACK ALBRIGHT

SHEET INDEX

WALL TYPES



1 — 2X4 STUD WALL

1A — SAME AS ABOVE, WITH SOUND BATTS

E. Scott McHale, LEED AP
Design & Consulting
246 Sopris Ave
Carbondale, CO 81623
970-708-5035

mchalescott@gmail.com

DAVIS RESIDENCE
HABITAT FOR HUMANITY
KEATOR GROVE LOT 16
CARBONDALE, COLORADO

ISSUE:
HOA SUBMITTAL

REVISIONS:

DATE:
FEB 03, 2014

DRAWN BY: ESM

CHECKED BY: ESM

PROJ #: File Name.dwg

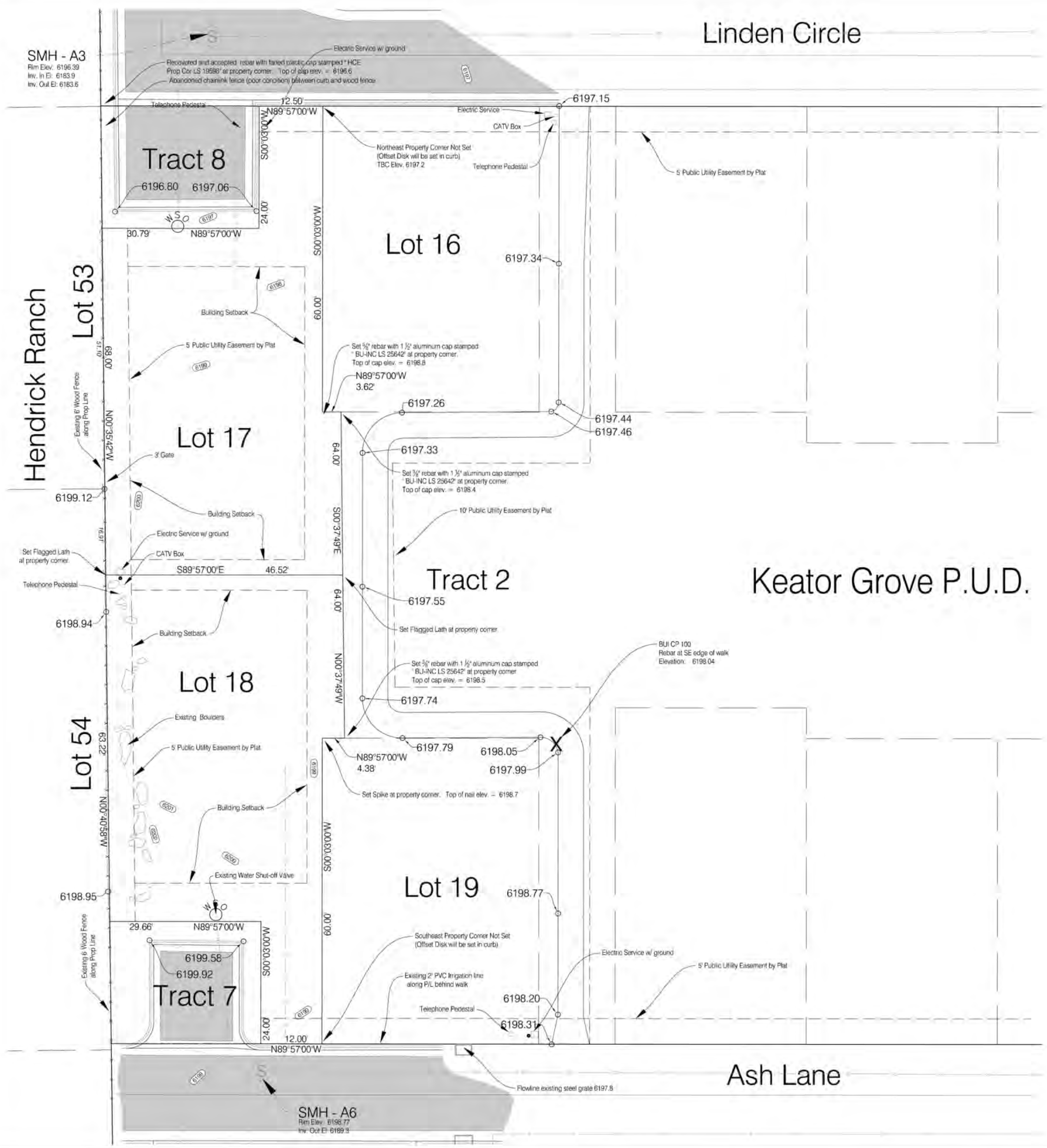
COVER SHEET

SHEET TITLE:

SCALE:

A1.0

SHEET:



SURVEY NOTES:

1) No title policy was supplied for this survey. This survey does not constitute a title search by Boundaries Unlimited Inc. to determine ownership of this tract or to verify the description shown; the compatibility of this description with that of adjacent tracts; nor easements of record.
2) Basis of Bearings: A bearing of S 89°57'00" E along the North line of Lots 25 through 29 as monumented by nail and shiners stamped "LS 28643"
3) Date of Survey was June 15, 2013.
4) Property description: Lot 17 and 18, First Lot Line Adjustment Plat of Keator Grove, A Planned Unit Development as recorded in Garfield County, Colorado.
5) Bench Mark: Top of rebar with Orange Plastic Cap stamped "LS 28643" at the NE Corner of Lot 1A. Elevation: 6194.40
6) Underground utility as-builts are as shown on Keator Grove As-Builts by Sopris Engineering dated September 2009. There are no as-builts for electric, telephone, cable, gas or irrigation known to exist by this surveyor.

IMPROVEMENT SURVEY STATEMENT

I hereby state that this Improvement Survey Plat was prepared by Boundaries Unlimited, Inc for Habitat for Humanity.
I further state that the improvements on the above described parcel on this date, June 19, 2013, except utility connections are entirely within the boundaries of the parcel, except as shown. That there are no encroachments upon the described premises by improvements on any adjoining premises, except as indicated, and that there is no apparent evidence or sign of any easement or sign of easement crossing or burdening any part of said parcel, except as noted, are shown hereon to the best of my knowledge and belief. I further state that this property may subject to reservations, restrictions, covenants and easements of record or in place.

Steven L. Smith, PLS 25642 Date

Boundaries Unlimited Inc.
Civil Engineering Surveying & Beyond
923 Cooper Avenue
Suite 201
Glenwood Springs, CO 81601
tele: 970.945.5252
fax: 970.384.2833

Engineer or Surveyor Seal

Client Information:
Habitat for Humanity
0062 CR 113, Warehouse-G
Carbondale, Colorado 81623
970-309-8179

NORTH

Scale: 1" = 10'

811 Know what's below. Call before you dig.

Carbondale, Colorado

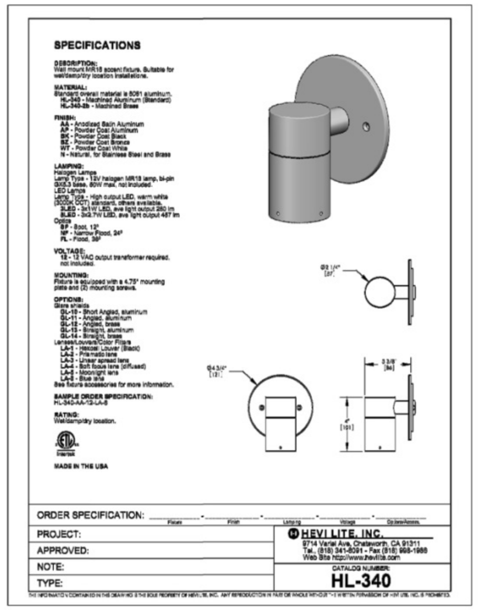
Improvement Survey Plat

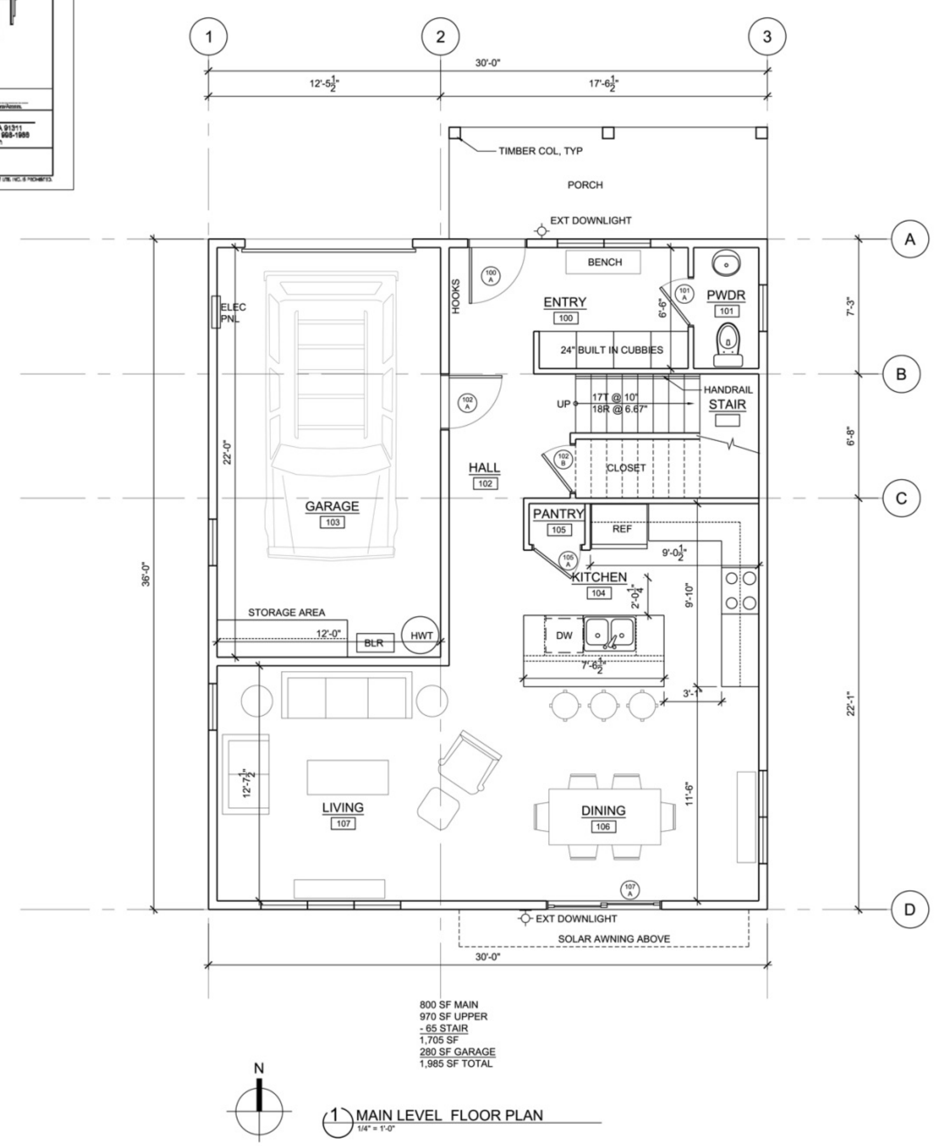
First Lot Line Adjustment Plat of Lots 17 $ 18

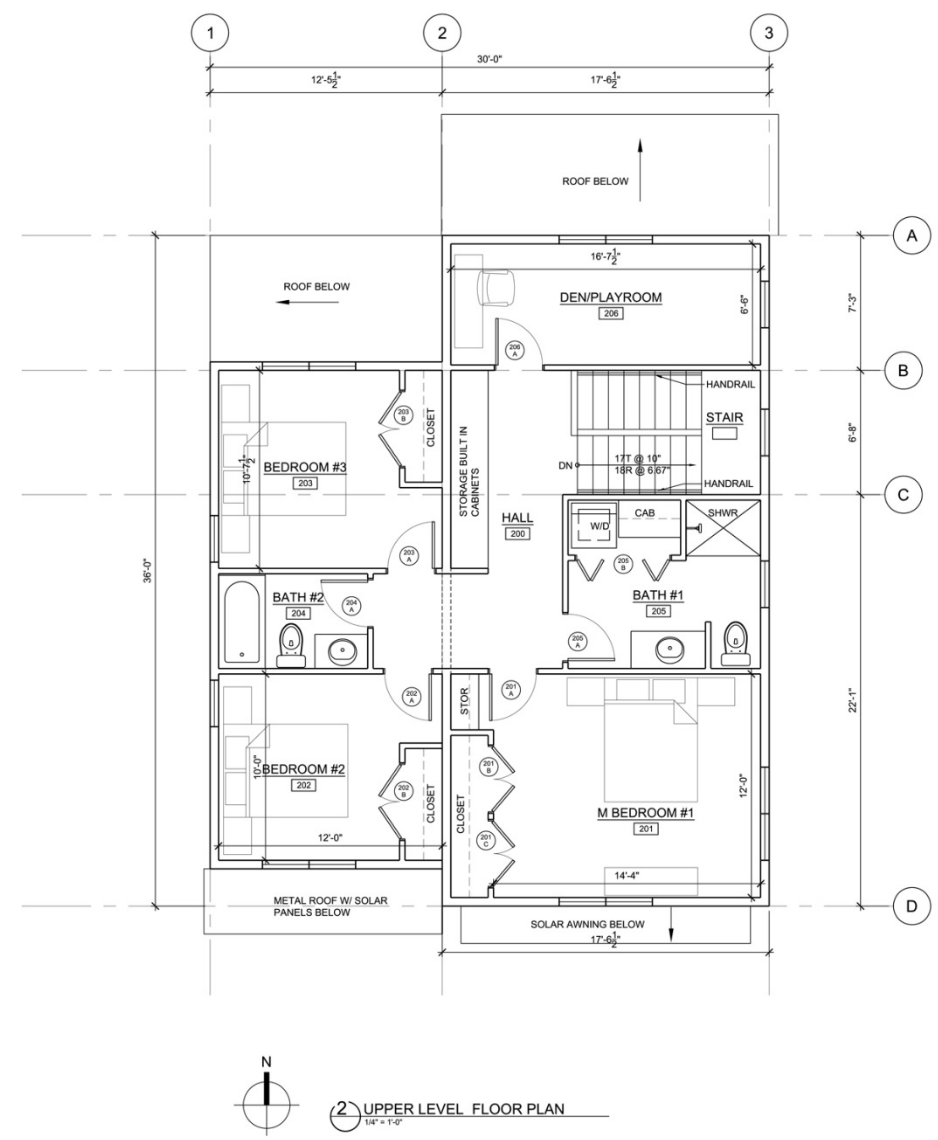
Keator Grove P.U.D.

By | Revision | Date | No.

Sheet C1







E. Scott McHale, LEED AP
Design & Consulting
246 Sopris Ave
Carbondale, CO 81623
970-708-5035
mchalescott@gmail.com

DAVIS RESIDENCE

HABITAT FOR HUMANITY
KEATOR GROVE LOT 16
CARBONDALE, COLORADO

ISSUE:
HOA SUBMITTAL

REVISIONS:

DATE:
FEB 03, 2014

DRAWN BY: ESM

CHECKED BY: ESM

PROJ #: File Name.dwg

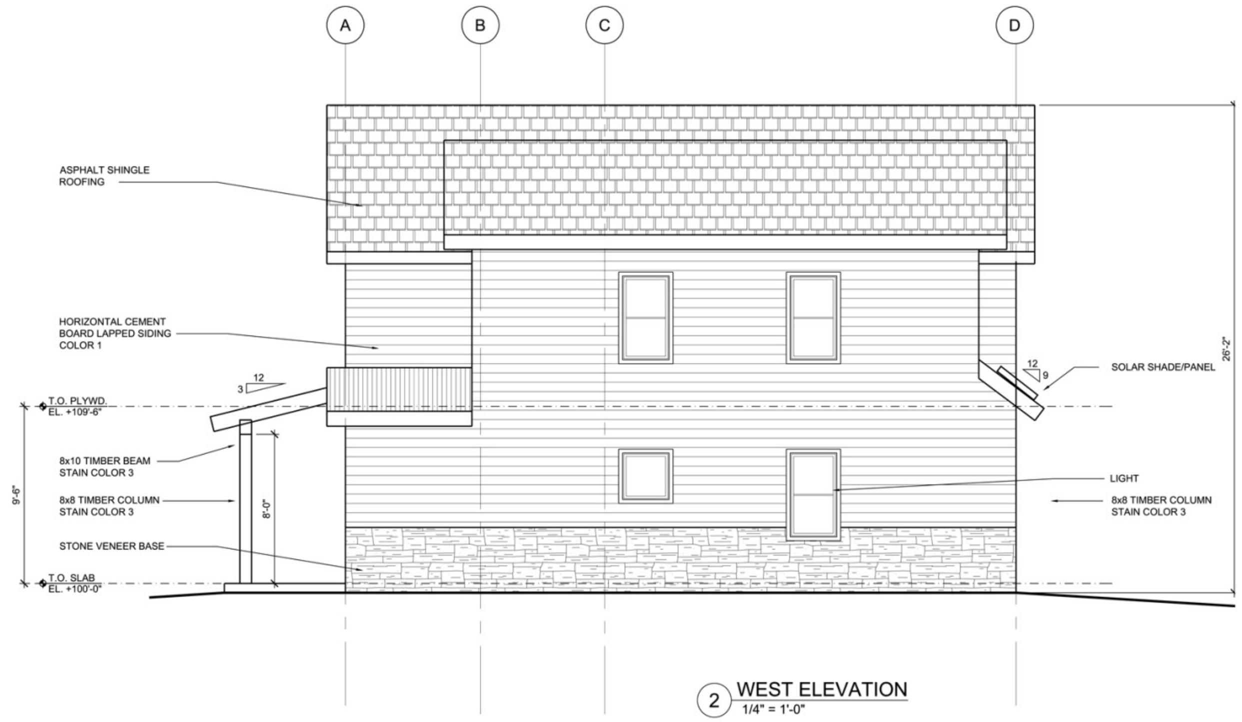
FLOOR PLANS

SHEET TITLE:

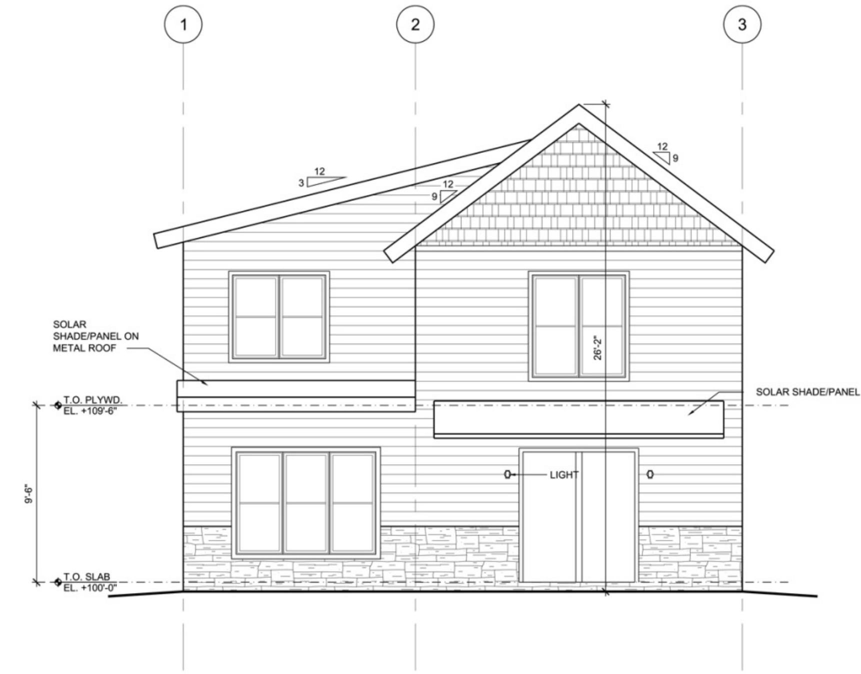
SCALE: 1/4" = 1'-0"

A2.1

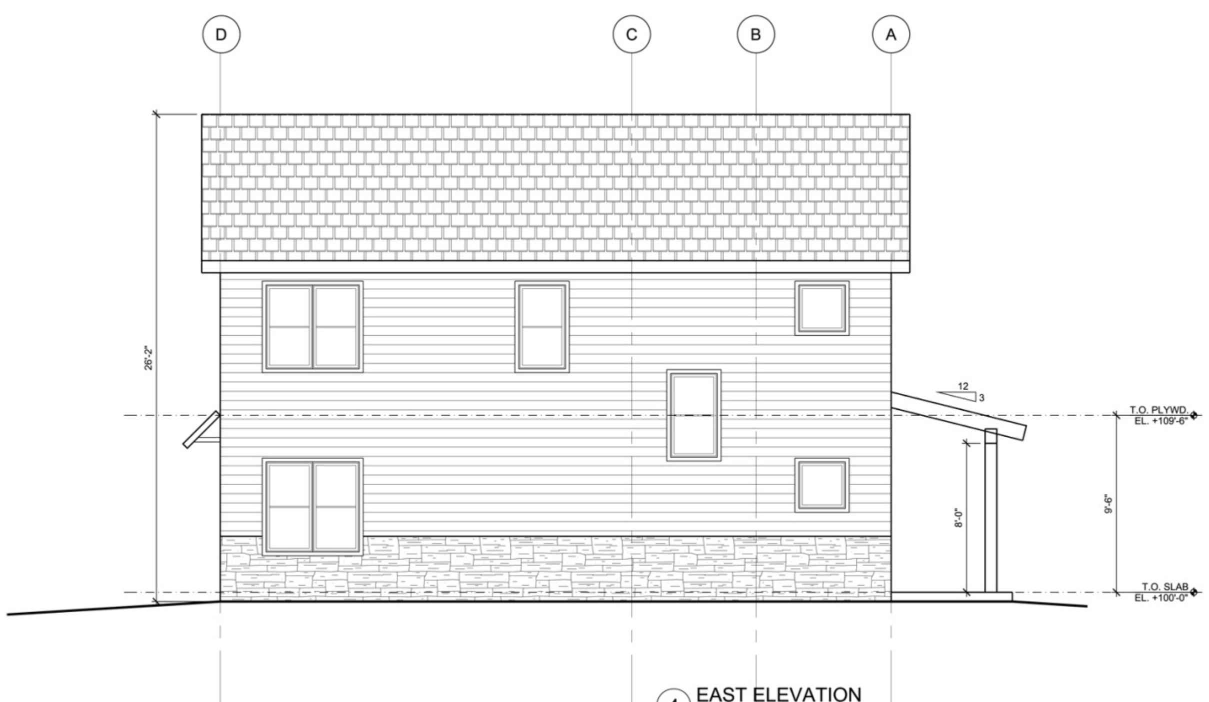
SHEET:



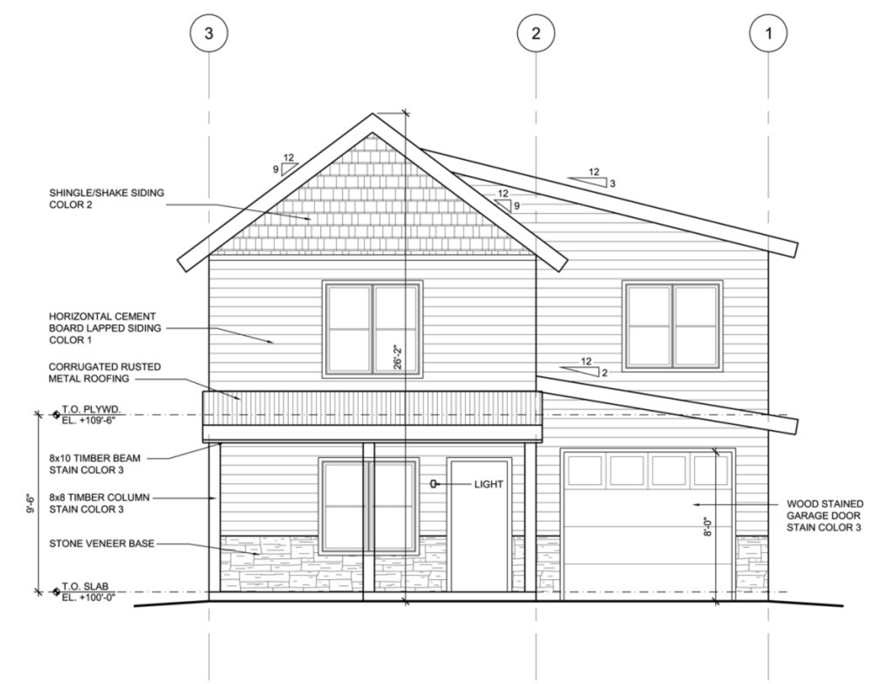
2 WEST ELEVATION
1/4" = 1'-0"



1 SOUTH ELEVATION
1/4" = 1'-0"



4 EAST ELEVATION
1/4" = 1'-0"



3 NORTH ELEVATION
1/4" = 1'-0"

E. Scott McHale, LEED AP
Design & Consulting
246 Sopris Ave
Carbondale, CO 81623
970-708-5035
mchalescott@gmail.com

DAVIS RESIDENCE
HABITAT FOR HUMANITY
KEATOR GROVE LOT 16
CARBONDALE, COLORADO

ISSUE:
HOA SUBMITTAL

REVISIONS:

DATE:
FEB 03, 2014
DRAWN BY: ESM
CHECKED BY: ESM
PROJ #: File Name.dwg

ELEVATIONS
SHEET TITLE:

SCALE: 1/4" = 1'-0"

A4.1
SHEET:

E. Scott McHale, LEED AP
Design & Consulting
246 Sopris Ave
Carbondale, CO 81623
970-708-5035
mchalescott@gmail.com

DAVIS RESIDENCE

HABITAT FOR HUMANITY
KEATOR GROVE LOT 16
CARBONDALE, COLORADO

ISSUE:
HOA SUBMITTAL

REVISIONS:

DATE:
FEB 03, 2014

DRAWN BY: ESM

CHECKED BY: ESM

PROJ #: File Name.dwg

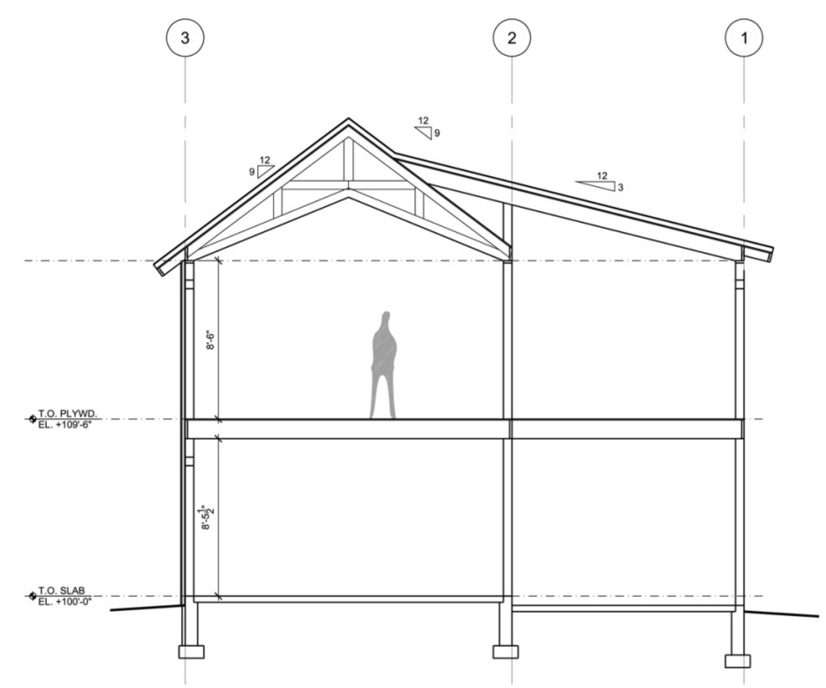
MATERIALS & MODEL VIEWS

SHEET TITLE:

SCALE: NTS

A4.0

SHEET:



1 SECTION
1/4" = 1'-0"

E. Scott McHale, LEED AP
Design & Consulting
246 Sopris Ave
Carbondale, CO 81623
970-708-5035

mchalescott@gmail.com

DAVIS RESIDENCE

HABITAT FOR HUMANITY
KEATOR GROVE LOT 16
CARBONDALE, COLORADO

ISSUE:
HOA SUBMITTAL

REVISIONS:

DATE:
FEB 03, 2014

DRAWN BY: ESM

CHECKED BY: ESM

PROJ #: File Name.dwg

SECTIONS

SHEET TITLE:

SCALE: 1/4" = 1'-0"

A5.1

SHEET:

Appendix C

HOME CONFIGURATION RECIPES

configuration name	MS1	MS2	MS3	MS4	MS5	MS6	MS7	MS8	MS9	MS10
SP1	1	2	3	4	5	6	7	8	9	10
SP2	11	12	13	14	15	16	17	18	19	20
SP3	21	22	23	24	25	26	27	28	29	30
SP4	31	32	33	34	35	36	37	38	39	40
SP5	41	42	43	44	45	46	47	48	49	50
SP6	51	52	53	54	55	56	57	58	59	60
SP7	61	62	63	64	65	66	67	68	69	70
SP8	71	72	73	74	75	76	77	78	79	80
SP9	81	82	83	84	85	86	87	88	89	90
SP10	91	92	93	94	95	96	97	98	99	100
SP11	101	102	103	104	105	106	107	108	109	110
SP12	111	112	113	114	115	116	117	118	119	120
SP13	121	122	123	124	125	126	127	128	129	130
SP14	131	132	133	134	135	136	137	138	139	140
SP15	141	142	143	144	145	146	147	148	149	150
SP16	151	152	153	154	155	156	157	158	159	160
SP17	161	162	163	164	165	166	167	168	169	170
SP18	171	172	173	174	175	176	177	178	179	180
SP19	181	182	183	184	185	186	187	188	189	190
SP20	191	192	193	194	195	196	197	198	199	200
SP21	201	202	203	204	205	206	207	208	209	210
SP22	211	212	213	214	215	216	217	218	219	220
SP23	221	222	223	224	225	226	227	228	229	230
SP24	231	232	233	234	235	236	237	238	239	240
SP25	241	242	243	244	245	246	247	248	249	250

Mechanical Systems

MS1	$6,300	MS6	$21,750
heat	electric	heat	gas, furnace
distribution	radiant	distribution	forced air
DHW	electric, instant	DHW	gas, tank
supplementary ventilation	none	supplementary ventilation	none
thermal solar	none	thermal solar	yes, DHW

MS2	$5,200	MS7	
heat	electric	heat	**$25,500**
distribution	radiant	distribution	gas, boiler
DHW	electric, tank	DHW	fan coil
supplementary ventilation	none	supplementary ventilation	side-arm tank
thermal solar	none	thermal solar	none
			none

MS3	$12,450	MS8	$20,150
heat	gas, furnace	heat	gas, boiler
distribution	forced air	distribution	radiant
DHW	electric, tank	DHW	side-arm tank
supplementary ventilation	none	supplementary ventilation	none
thermal solar	none	thermal solar	none

MS4	$14,050	MS9	$27,150
heat	gas, furnace	heat	gas, boiler
distribution	forced air	distribution	radiant
DHW	gas, instant	DHW	side-arm tank
supplementary ventilation	none	supplementary ventilation	none
thermal solar	none	thermal solar	DHW

MS5	$14,750	MS10	$41,150
heat	gas, furnace	heat	gas, boiler
distribution	forced air	distribution	radiant
DHW	gas, tank	DHW	side-arm tank
supplementary ventilation	none	supplementary ventilation	none
thermal solar	none	thermal solar	DHW & heat assist

Shell Packages

SP1									up charge
ceiling	C3	unvented	rafter or attic	continuous exterior insulation	R30	poly-iso	4.3"		$15,008
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F2	unvented	crawlspace	framed floor	R0				$10,352
				crawlspace walls	R11	interior	fiberous	drape	
				earth floor	R10		XPS	2"	
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$47,325

SP2								up charge
ceiling	C3	unvented	rafter or attic	continuous exterior insulation	R30	poly-iso	4.3"	$15,008
				cavity insulation	R19	fiberous	5.5"	
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"	$2,944
foundation	F1	vented	crawlspace	framed floor	R38	cavity	fiberous	$9,544
				crawlspace walls	R0			
				earth floor	R0			
floor over garage	U1			framed floor	R38	cavity	fiberous	$411
glazing	G1	U-factor .35 (.35 SHGC)						$18,610
air exchange, ACH50		6.0						
cooling		none						
lighting efficacy		code minimum						
appliances		no ENERGY STAR						
PV		none						
								$46,517

SP3									up charge
ceiling	C3	unvented	rafter or attic	continuous exterior insulation	R30	poly-iso	4.3"		$15,008
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$45,433

SP4									up charge
ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		6.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$31,495

SP5		up charge

ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F2	unvented	crawlspace	framed floor	R0				$10,352
				crawlspace walls	R11	interior	fiberous	drape	
				earth floor	R10		XPS	2"	
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		6.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$33,387

SP6									up charge
ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F1	vented	crawlspace	framed floor	R38	cavity	fiberous		$9,544
				crawlspace walls	R0				
				earth floor	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		6.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$32,579

SP7									up charge
ceiling	C7	unvented	rafter or attic	cavity insulation	R30	SPF 2#	5"		$5,949
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	

				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.5							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$37,964

SP8									up charge
ceiling	C6	unvented	rafter or attic	cavity insulation	R49	SPF 2#	8.2"		$7,505
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.5							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$39,520

SP9									up charge
ceiling	C7	unvented	rafter or attic	cavity insulation	R30	SPF 2#	5"		$5,949
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W2	SPF	framed	cavity insulation	R10	SPF 2#	1.7"		$4,562
				cavity insulation	R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411

									up charge
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$39,582

SP10									up charge
ceiling	C6	unvented	rafter or attic	cavity insulation	R49	SPF 2#	8.2"		$7,505
above grade walls	W2	SPF	framed	cavity insulation	R10	SPF 2#	1.7"		$4,562
				cavity insulation	R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$41,138

SP11									up charge
ceiling	C4	unvented	rafter or attic	continuous exterior insulation	R10	poly-iso	2"		$9,246
				cavity insulation	R20	SPF 2#	3.3"		
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W3	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$11,939
					R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411

glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.5							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$50,256

SP12									up charge
ceiling	C8	unvented	SIP	SIP	R49	EPS	12"		$11,390
above grade walls	W5	SIP	SIP	SIP	R21	EPS	6"		$16,900
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.5							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$57,361

SP13									up charge
ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W3	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$11,939
					R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		5.0							

cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$42,080

SP14									up charge
ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W3	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$11,939
					R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G3	U-factor .25 (.25 SHGC)							$23,787
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		code minimum							
appliances		no ENERGY STAR							
PV		none							
									$45,667

SP15									up charge
ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W3	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$11,939
					R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		LED							$1,000

appliances		ENERGY STAR							$500
PV		none							
									$41,990

SP16									up charge
ceiling	C2	vented	attic	blown/batt	R49	fiberous	14"		$1,070
above grade walls	W3	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$11,939
					R11	fiberous	3.5"		
foundation	F6	unvented	slab on grade	framed floor	NA				$8,460
				stem walls	R10	exterior	XPS	2"	
				under slab	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		2 Kw							$8,000
									$49,990

SP17									up charge
ceiling	C3	unvented	rafter or attic	continuous exterior insulation	R30	poly-iso	4.3"		$15,008
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F2	unvented	crawlspace	framed floor	R0				$10,352
				crawlspace walls	R11	interior	fiberous	drape	
				earth floor	R10		XPS	2"	
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		2 Kw							$8,000
									$56,825

SP18									up charge
ceiling	C3	unvented	rafter or attic	continuous exterior insulation	R30	poly-iso	4.3"		$15,008
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W1		framed	cavity insulation	R21	fiberous	5.5"		$2,944
foundation	F2	unvented	crawlspace	framed floor	R0				$10,352
				crawlspace walls	R11	interior	fiberous	drape	
				earth floor	R10		XPS	2"	
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G1	U-factor .35 (.35 SHGC)							$18,610
air exchange, ACH50		5.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		3 Kw							$12,000
									$60,825

SP19									
ceiling	C5	unvented	rafter or attic	continuous exterior insulation	R20	XPS	4"		$13,534
				cavity insulation	R29	SPF 2#	4.8"		
above grade walls	W6	cont	framed	continuous exterior insulation	R7.5	XPS	1.5"		$9,818
					R19	fiberous	5.5"		
foundation	F3	unvented	crawlspace	framed floor	R0				$10,484
				crawlspace walls	R19	interior	fiberous	drape	
				earth floor	R0				
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		4.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		none							
									$55,947

SP20									up charge
ceiling	C4	unvented	rafter or attic	continuous exterior insulation	R10	poly-iso	2"		$9,246
				cavity insulation	R20	SPF 2#	3.3"		
				cavity insulation	R19	fiberous	5.5"		
above grade walls	W8	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$13,656
					R21	fiberous	5.5"		
foundation	F9	unvented	crawlspace	framed floor	R0				$12,911
				crawlspace walls	R10	exterior	XPS	2"	
					R19	interior	fiberous	drape	
				earth floor	R10		XPS	2"	$411
floor over garage	U1			framed floor	R38	cavity	fiberous		
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		3.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		none							
mech ventilation		HRV						(add $1300 if no forced air present)	$2,200
									$60,124

SP21									up charge
ceiling	C9	vented	attic	blown/batt	R60	fiberous	17"		$1,916
above grade walls	W7		double-frame	cavity insulation	R40	fiberous	11.25"		$14,187
foundation	F9	unvented	crawlspace	framed floor	R0				$12,911
				crawlspace walls	R10	exterior	XPS	2"	
					R19	interior	fiberous	drape	
				earth floor	R10		XPS	2"	$411
floor over garage	U1			framed floor	R38	cavity	fiberous		
glazing	G2	U-factor .31 (.31 SHGC)							$20,200
air exchange, ACH50		3.0							
cooling		none							
lighting efficacy		LED							$1,000

appliances		ENERGY STAR							$500
PV		none							
mech ventilation		HRV						(add $1300 if no forced air present)	$2,200
									$53,325

SP22									up charge
ceiling	C10	vented	attic	cavity insulation	R9	SPF 2#	1.5"		$1,916
				blown/batt	R40	fiberous	12"		
above grade walls	W8	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"		$13,656
					R21	fiberous	5.5"		
foundation	F9	unvented	crawlspace	framed floor	R0				$12,911
				crawlspace walls	R10	exterior	XPS	2"	
					R19	interior	fiberous	drape	
				earth floor	R10		XPS	2"	$411
floor over garage	U1			framed floor	R38	cavity	fiberous		
glazing	G3	U-factor .25 (.25 SHGC)							$23,787
air exchange, ACH50		2.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		2 Kw							$8,000
mech ventilation		HRV						(add $1300 if no forced air present)	$2,200
									$64,381

SP23									up charge
ceiling	C11	vented	attic	cavity insulation	R9	SPF 2#	1.5"		$3,503
				blown/batt	R51	fiberous	14.6"		
above grade walls	W7		double-frame	cavity insulation	R40	fiberous	11.25"		$14,187
foundation	F9	unvented	crawlspace	framed floor	R0				$12,911
				crawlspace walls	R10	exterior	XPS	2"	
					R19	interior	fiberous	drape	

				earth floor	R10		XPS	2"		$411
floor over garage	U1			framed floor	R38	cavity	fiberous			
glazing	G3	U-factor .25 (.25 SHGC)								$23,787
air exchange, ACH50		2.0								
cooling		none								
lighting efficacy		LED								$1,000
appliances		ENERGY STAR								$500
PV		2 Kw								$8,000
mech ventilation		HRV							(add $1300 if no forced air present)	$2,200
										$66,499

SP24										up charge
ceiling	C12	unvented	rafter or attic	continuous exterior insulation	R20	SPF 3#	3"			$11,786
				cavity insulation	R38	fiberous	10"			
above grade walls	W8	cont	framed	continuous exterior insulation	R10	poly-iso	1.5"			$13,656
					R21	fiberous	5.5"			
foundation	F9	unvented	crawlspace	framed floor	R0					$12,911
				crawlspace walls	R10	exterior	XPS	2"		
					R19	interior	fiberous	drape		
				earth floor	R10		XPS	2"		$411
floor over garage	U1			framed floor	R38	cavity	fiberous			
glazing	G3	U-factor .25 (.25 SHGC)								$23,787
air exchange, ACH50		2.0								
cooling		none								
lighting efficacy		LED								$1,000
appliances		ENERGY STAR								$500
PV		2 Kw								$8,000
mech ventilation		HRV							(add $1300 if no forced air present)	$2,200
										$74,251

SP25									up charge
ceiling	C12	unvented	rafter or attic	continuous exterior insulation	R20	SPF 3#	3"		$11,786
				cavity insulation	R38	fiberous	10"		
above grade walls	W9	cont	framed	continuous exterior insulation	R20	poly-iso	3"		$18,486
					R21	fiberous	5.5"		
foundation	F10	unvented	crawlspace	framed floor	R0				$14,311
				crawlspace walls	R20	exterior	XPS	4"	
					R19	interior	fiberous	drape	
				earth floor	R10		XPS	2"	
floor over garage	U1			framed floor	R38	cavity	fiberous		$411
glazing	G3	U-factor .25 (.25 SHGC)							$23,787
air exchange, ACH50		2.0							
cooling		none							
lighting efficacy		LED							$1,000
appliances		ENERGY STAR							$500
PV		3 Kw							$12,000
mech ventilation		HRV						(add $1300 if no forced air present)	$2,200
									$84,481

Appendix D

LCA Data Sources

Medium Density (2#) Spray Foam Insulation	Spray Polyurethane Foam Alliance. Life Cycle Assessment of Spray Polyurethane Foam Insulation. Spray Polyurethane Foam Alliance. Fairfax, VA: SPFA, 2012.
Residential boilers and furnaces and associated equipment	Yang, Zmeureanu, Rivard. Comparison of Environmental Impacts of two Residential Heating Systems. Building and Environment. Elseiver.2007. Shah, Debella, Ries. Life Cycle Assessment of residential Heating and Cooling Systems in Four regions in the United States. Energy and Buildings.
Tank and tankless hot water heaters	Lu, McMahon, Masanet, Lutz. Our Environment in Hot Water: Comparing Water Heaters, A Life Cycle Approach Comparing Tank and Tankless Water Heaters in California. Lawrence Berkeley National Laboratory. Berkeley, CA: 2008.
LED, CFL, and Incandescent lighting	Gonzales, Chase. What We Know and Don't Know about embodied Energy and Greenhouse Gases for Electronics, Appliances, and Light Bulbs. Natural Resources Defense Council. ACEEE: 2012. Navigant Consulting, Inc.. Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products. Part 1. U.S. Department of Energy. 2012
PV systems	Fthenakis, V.M. and Kim, H.C. Photovoltaics: Lie-cycle Analyses. Solar Energy 85. Elsevier. Online. February 23, 2010 NREL. Life Cycle Greenhouse Gas Emissions for Solar Photovoltaics. NREL. Denver, CO: NREL 2012. Fthenakis, V.M., Kim, H.C., Fischknecht, R., Raugei, M., Sinha, P., Stucki, M. Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems. International Energy Agency. October 2011.
Flat Plate Solar Hot water systems	Martinopoulos, G., Tsilingiridis, G., Kyriankis, N. Three Eco-tool Comparison with the Example of the Environmental Performance of Domestic Solar FlatePlate Hot Water Systems. Global NEST Jornal, Vol 9, No. 2 pp 174-181, Greece. 2007. Laborderie., Puech, Adra, Blanc, Beloin-Saint_Pierre, Padey, Payer, Sie, Jacquin. Environmental Impacts of Solar Thermal Systems with Life Cycle Assessment. World Renewable Energy Congress. Sweden, 2011.