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What is the Best Residential Roof Assembly for the U.S. Desert Southwest, with Respect to Cost, Energy Efficiency and Embodied Energy Concerns

John Joseph Carroll
University of Nevada, Las Vegas

WHAT IS THE BEST RESIDENTIAL ROOF ASSEMBLY FOR THE U.S. DESERT SOUTHWEST, WITH RESPECT TO COST, ENERGY EFFICIENCY AND EMBODIED ENERGY CONCERNS

By

John Joseph Carroll, Jr.

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University of Nevada, Las Vegas
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John Joseph Carroll, Jr.

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Alfredo Fernandez-Gonzalez, M.Arch
Examination Committee Chair

Eric Weber, M.Arch.
Examination Committee Member

Joshua Vermillion, M.Arch.
Examination Committee Member

David E. James, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D
Graduate College Interim Dean

ABSTRACT

The climate is continually changing for the worse as there are poor decisions being made in the rapidly constructed built environment. In an effort to reduce the impact on the built environment, the typical residential roof assemblies that are currently being used in the U.S. desert southwest are not the best for the environment. Through research and simulations, this paper compares several residential roof assemblies to the standard code compliant construction and provides cost breakdowns of simple payback and cost of save energy for each of the simulated systems. A case study was also designed for the U.S. Department of Energy, Race to Zero Student Design Competition using the information of this paper. The case study verified that the results work for the climate and demonstrate that low energy use residential buildings in the U.S. Desert Southwest are possible. The results of this paper will allow designers to work toward the goal of creating net-zero energy housing.

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I would also like to thank my team members for being around to keep the focus on the end goal, no matter how little sleep we got.

DEDICATION

I dedicate my thesis work to my family, loved ones and many friends. To my parents who have always showed that I have the potential to succeed and keep reminding me of it every day. To my sisters and their families for their support and helping however they could.

I also dedicate this work to the love of my life Andrea. Without her support and care, I would not be as strong as I am today and I hope that I can repay her and give her the same back in our lives.

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The largest consumer of energy in the United States is the building sector consuming 47.6% of the total energy used (Fig. 1.1), with 5.9% of the total energy consumed by building construction and materials alone (Fig. 1.2) (Why the Building Sector).

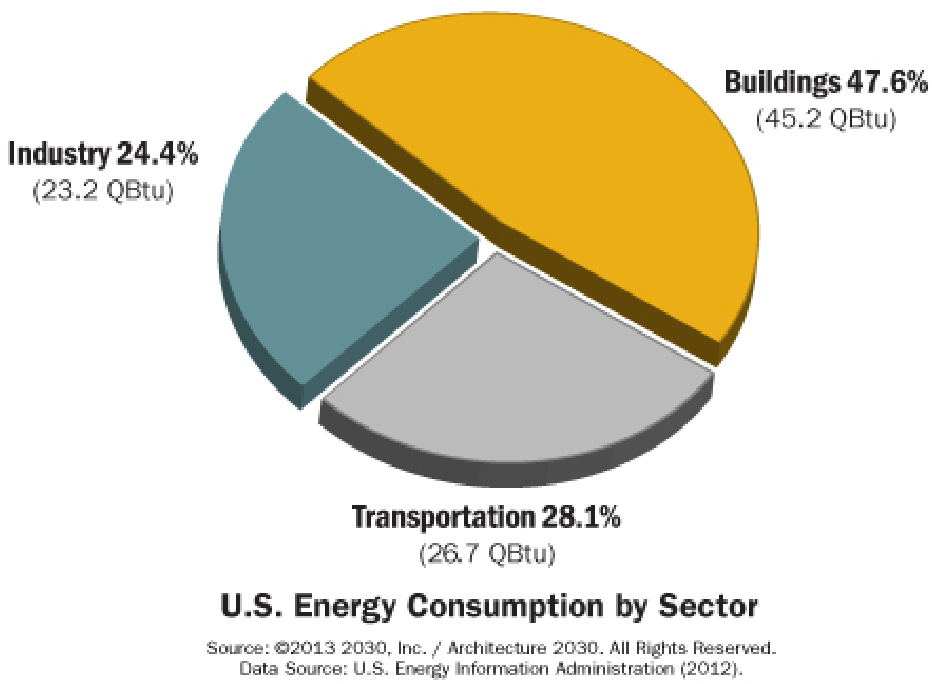


Figure 1.1 U.S. Energy Consumption by Sector (Why the Building Sector)

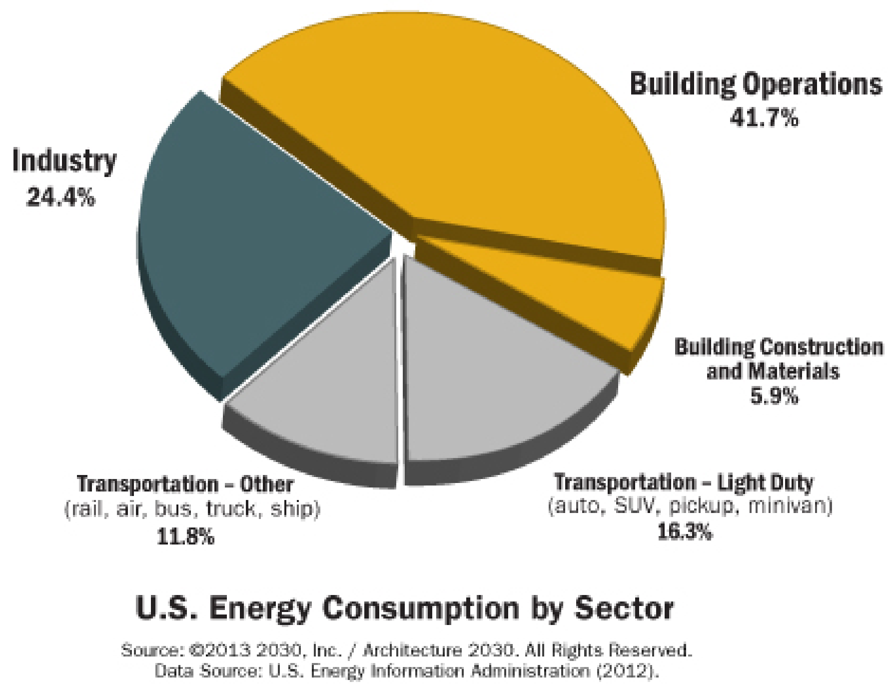
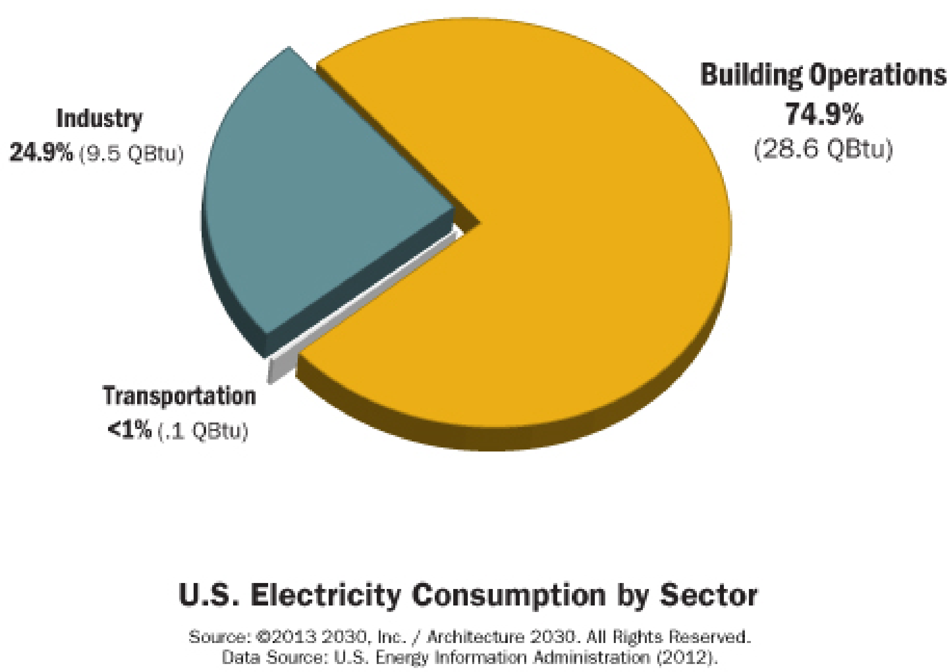


Figure 1.2 U.S. Energy Consumption by Sector (Why the Building Sector)



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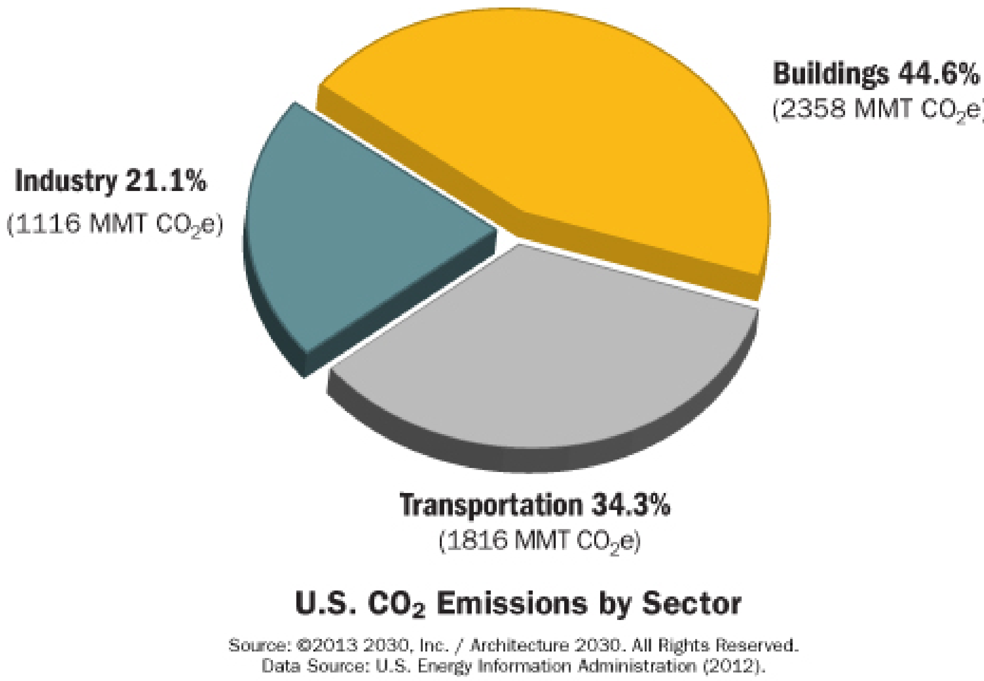


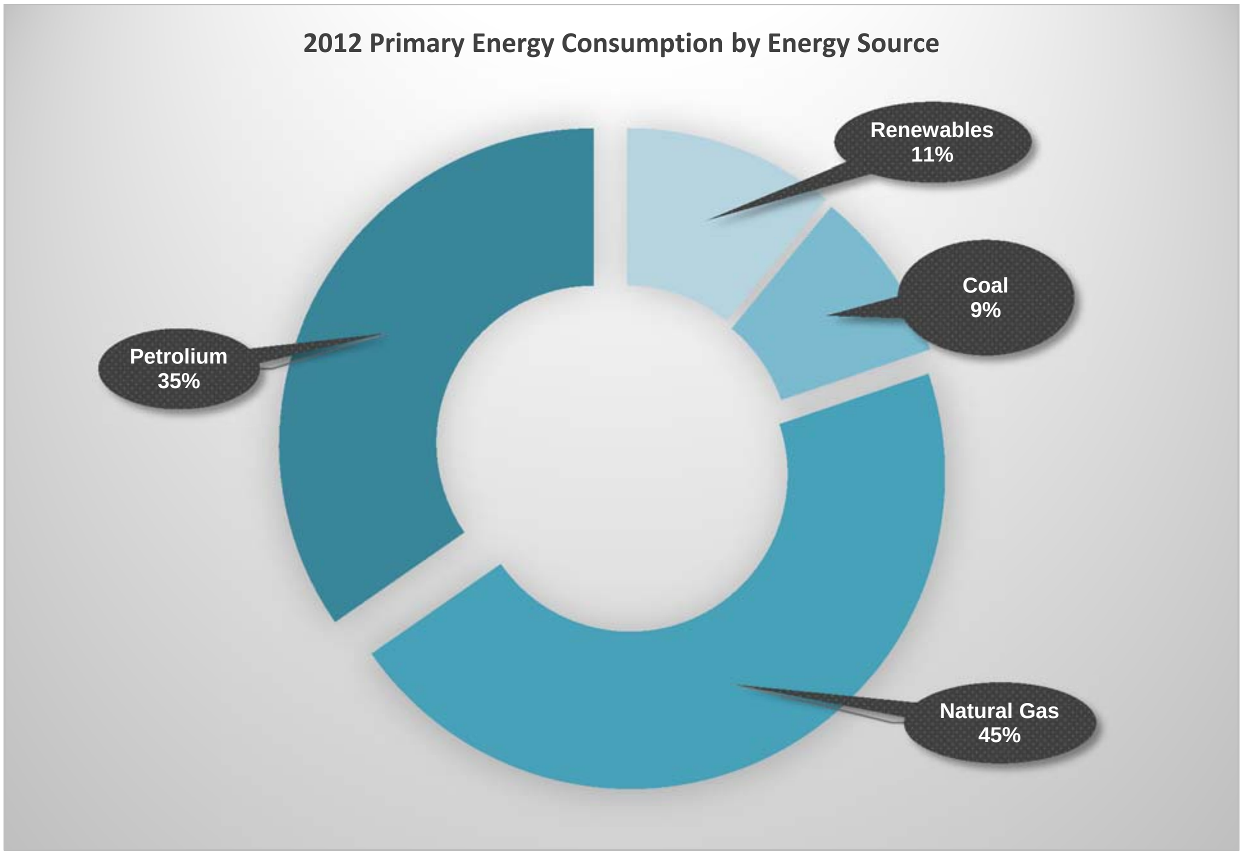
Figure 1.4 U.S. CO2 Emissions by Sector (Why the Building Sector)

Of the all electricity consumed in the U.S., building operations consume 74.9% while industry consumes 24.9% and transportation follows with the remaining 0.2% (Fig 1.3). Additionally, buildings emit the highest amount of CO2 at 44.6% compared to the industry and transportation at 21.1% and 34.3% respectively (Fig 1.4).

According to the Buildings Data Book on the US Department of Energy's website, the construction statistics show that the average size of single-family residences was 1,740 square feet in 1980 and has grown to 2,392 square feet in 2010. With the continual increase of the average square footage, it has become particularly important to dissect and understand the materials used for construction and the impacts they will have on the environment in the future. The materials used need to outlast the energy used to manufacture the raw materials over the life expectancy of the residence.

1.2 Population

The state of Nevada experienced a 1% growth in population per year between 2005 and 2013, resulting in a population of 2,791,494 and 999,016 households in 2013 (Nevada Energy Fact Sheet, 2015). The population is projected to continue to rise in Nevada and with the rise in population comes additional energy usage. Logically, if energy use is reduced there will be cost savings for consumers, a reduction in the creation of new power plants, reduced demand applied to the ever-aging power infrastructure, and will consequently lower greenhouse gas emissions. For primary energy consumption per capita, Nevada ranks 41st and 38th in total energy consumption (Nevada Energy Fact Sheet, 2015). Natural gas is the leading source for electricity generation at 73% of the total, followed by coal at 16% and renewables at 11% (Fig 1.5). This amounts to the electric utilities using 68% of the total amount of natural gas with the residential sector using 15%, followed by commercial sector at 12% and the industrial sector using 5% (Fig 1.6).



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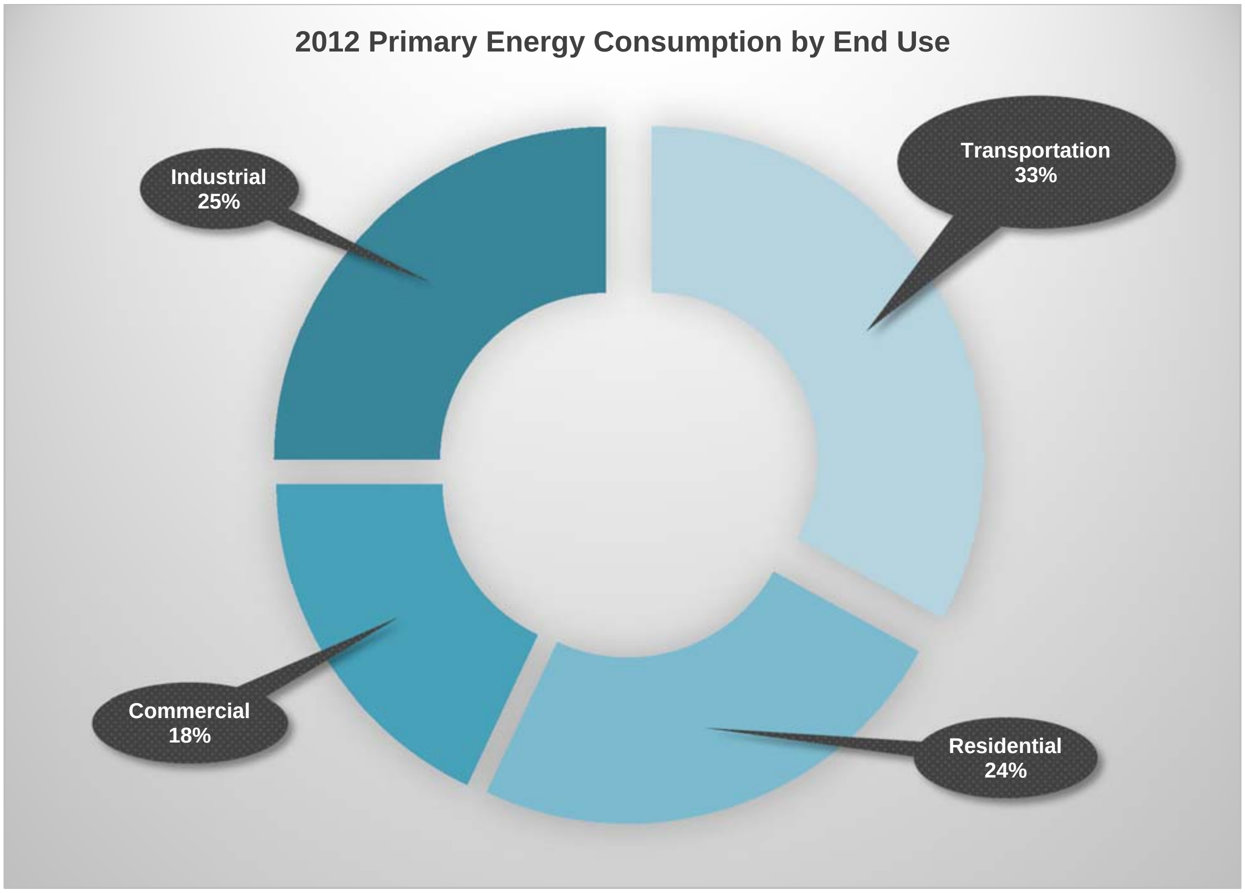


Figure 1.6 Primary Energy Consumption by End Use (Nevada Energy Fact Sheet, 2015)

1.3 Climate

Southern Nevada is located in the arid desert southwest, which is heavily reliant on active systems to condition the indoor spaces, but there is still potential for the reduction of energy use by using passive systems and properly designed building envelopes. There are many benefits to proper design of the envelope of the building. Some of the benefits are that the buildings systems work in there intended ways, and the envelope will last in the climate it was designed for.

The annual temperature range for Nevada is wide spread, with the design highs and lows falling far outside the typical comfort zone; this results in the usage of mechanical heating and cooling for much of the year. The only times of the year that the weather has average highs that fall within the comfort zone and would support natural ventilation are March, April and October (Fig 1.7).

The dry bulb temperature for Las Vegas is shown in Figure 1.8; for most times of the year that the temperature is above the comfort zone or below the comfort zone during the day and at night. Thus, there are only a few hours per day when the temperatures are considered comfortable which results in the high use of mechanical conditioning of the indoor spaces.

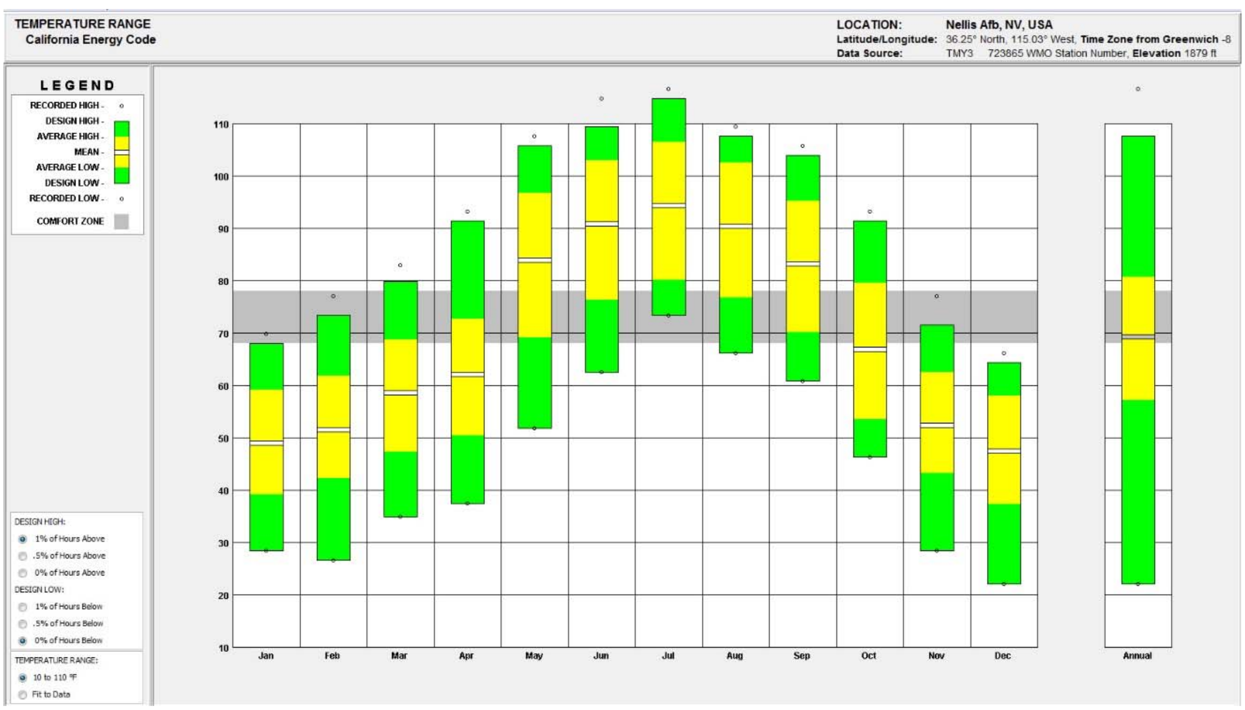


Figure 1.7 Temperature Range for Las Vegas from Climate Consultant Software

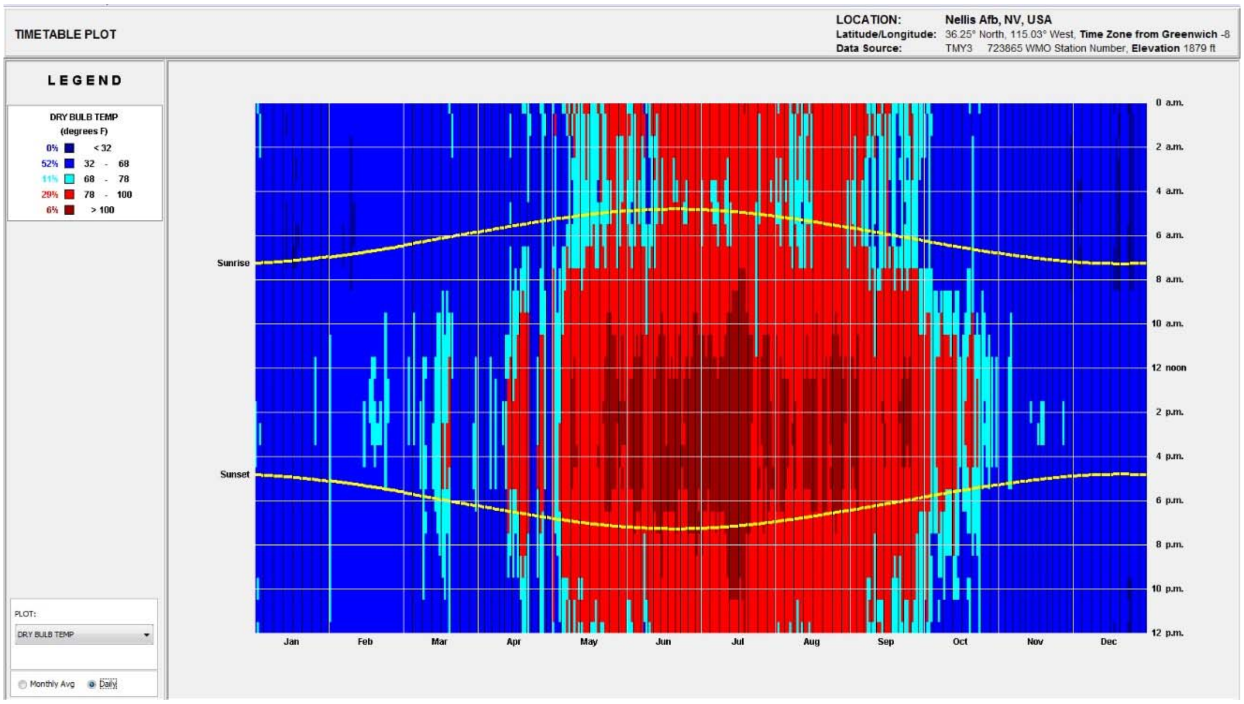


Figure 1.8 Dry Bulb Temperature Range for Las Vegas from Climate Consultant Software

1.4 Roofs

Roofs are a very important part of the building envelope and are ever more important as todays cities are becoming more dense and compact. “Roof surfaces are key interfaces in the volumetric exchange of energy because they constitute a large fraction of urban surface areas, and due to their exposure, they receive considerable solar radiation” (Meyn, 2009). If residential roof systems with higher R-values are constructed, then the demand created by the houses for heating and cooling will be reduced.

1.5 Design Profession

It is up to the design professionals to make a change in how the built environment consumes energy. Architecture 2030 points out some optimal opportunities where designers can assist homeowners with residential buildings to ensure energy efficiency. Designers may intervene and provide design efficiency guidance in the early stages of the design phase of new construction, existing home purchases, home mortgage refinancing and rebuilding after natural disasters (Effective Intervention Points for the Building Sector, 2010). The first intervention point is the design phase, which is considered the ideal time to create a better performing residence; there are many opportunities to design efficiently and to provide construction administration to verify that the structure is built as the plans detailed. Design professionals may also provide guidance during existing home purchases and home mortgage refinances. The opportunities of increasing the energy efficiency and thus lowering the carbon footprint of the residence are harder to achieve. The costs of retrofitting existing structures may add significant costs that the occupant might not be able to afford. Furthermore, retrofitting homes so they are more energy efficient may result in a loss of net square footage, if for instance walls need to be furred out for more insulation.

The last intervention point of repairing after natural disasters is similar to the first point but has additional needs. Measures should be taken to prevent similar disasters and the fate of the natural disaster on the new structure. This paper focuses on the initial design of residential structures.

CHAPTER 2: LITERATURE REVIEW

2.1 Energy Use

"Climate change and global warming have been of major concern to the public because of the potential threat to the ecosystem and living environment" (Wang and Chen, 2014, 428). Wang and Chen studied the effects that climate change has on all seven climatic regions of the U.S. on different types of residential and commercial buildings (2014). The results were that there would be more energy used in the future with occupants of zones 1-4 and there would be decreased energy usage in zones 6-7 (Wang and Chen, 2014). One suggestion from their findings is that code officials could require higher insulation for envelopes and with higher performing glazing to help reduce the effects of global warming (Wang and Chen, 2014).

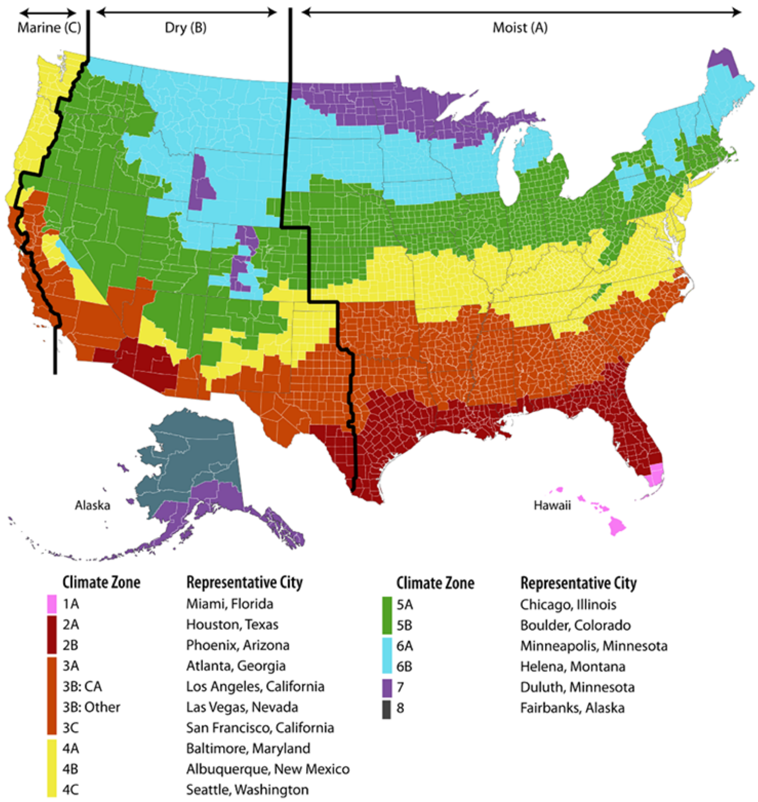


Figure 2.1 ASHRAE Climate Zones (Climate Zones, 2015)

Roofs make up a large percentage of the urban surface area and are major influences in the exchange of energy due to the amount of solar radiation received by the roof surface (Meyn and Oke, 2009). Meyn and Oke suggest that studying the heat absorbed by different roof systems is complex because roofs are comprised of multiple layers, each with their own thermal properties, and this complicates the modeling of heat fluxes and measurements through roofs (2009). Meyn and Oke state the indexing of urban heat storage could be vastly improved with increased interest and better studies of how roofs store versus radiate heat in suburban settings (2009).

With the recent understanding of the need to reduce buildings' negative impacts on the environment; there has been a rise in rating systems to help develop green buildings (Kallaos

and Bohne, 2012). Kallaos and Bohne (2012) say that the common goals of most of these rating systems are to reduce the impact on the environment while increasing the overall use of resources efficiently. The green building rating systems originated for commercial building purposes, and when the popularity for residential ratings started, some of the design methods were transferred to this sector. These methods included using the floor area to calculate energy efficiency, which is not useful in the residential sector, as it allows for a false sense of the increase in energy efficiency by increasing the size of the building all while hiding the increase of material use. This results in more embodied energy used, increased greenhouse gases and use-phase energy (Kallaos and Bohne, 2012).

With continual population increase and growth of the residential market comes the construction industries' higher energy use. The energy used is higher than the amount of energy used in the existing buildings when embodied energy is accounted for (Treloar et al., 2001). Treloar et al. suggest, that the use of a hybrid input-output (I-O) analysis method is needed; this method shows the energy paths of the residential construction sector (2001). In the study by Treloar et al., a medium-density residential subject was analyzed using the hybrid I-O method for determining data about the embodied energy of the building that were not so commonly known, such as the services sector, by modifying the known information, with none of the materials accounted for in more than one category (Treloar et al., 2001). The conclusions of the author's study showed that 48% of the embodied energy of the residence comprised I-O data that would have gone unused which suggests that the I-O data needs to be included for completeness and reliability of determining the energy efficiency of a residence (Treloar et al., 2001).

2.2 Simulation and Modeling

There are many options when it comes to residential building energy simulation software. The various software options permit the designer to review the energy usage and overall efficiency of simulated home modeled projects and allow for predictions of various potential energy savings, which may be implemented early on in the design phases (Valovcin et al., 2014). These programs are not perfect, as they make assumptions that can cause biased results in areas such as actual versus assumed behaviors of occupants. Also, because they are physics based, they could be inaccurate if there are errors in date inputs (Valovcin et al., 2014). Nevertheless, the information is useful and allows for the information to be understood prior to construction.

2.3 Cost Analysis

A study by Ferrara et al. (2014) was conducted to find the best cost for the return using the regulations of the Energy Performance of Buildings Directive (EPDR) and also to effectively provide a way to model a large number of options and configurations of buildings for a typical french residence. Ferrara et al. states that in Europe, according to the Buildings Performance Institute Europe, 40% of the energy used is currently from the building sector, along with 36% of carbon emissions, and that the EPDR would require all new construction to be nearly net zero energy buildings by 2020 as one of the main objectives (2014). To achieve the reduction of energy and increased sustainability required by the EPDR, there would have to be analyses of the financial impacts in order to verify the feasibility and profit potential for developers (Ferrara et al., 2014). The results of the authors' study was a ranking of the twelve models tested including envelope options, energy systems and costs of the various combinations.

With commercial buildings, the improvement of energy efficiency is one of the most economical options even with the added initial costs for the building owner, The building owner would significantly lower the building's energy usage, operating costs and carbon footprint over the life of the building (Kneifel, 2010). Joshua Kneifel's study researched new commercial buildings that utilized an integrated design approach for conventional energy efficiency through an analysis of life-cycle energy savings, reduction of carbon emissions and cost feasibility (2010). During the course of this study, Kneifel researched the original building cost, the maintenance or repairs required, the annual energy costs and the building's residual value at the end of the study for four different lengths of time and for each of the commercial building types studied (2010).

2.4 Standard Building Practices

The standard constructions of roofs in the Las Vegas valley are currently based on the 2012 International Residential Code (2012 IRC) requirements and the 2009 International Energy Conservation Code (2009 IECC). Concrete roofing tiles are the most commonly used roofing material for the Las Vegas valley; section R-905.3 of the 2012 IRC states that the construction is to be installed over solid sheathing or spaced structural sheathing boards with an underlayment that meets ASTM D226 Type II; ASTM D 2626 Type I; or ASTM D 6380 Class M mineral surfaced roll roofing. The roof tiles themselves shall adhere to ASTM C 1492 for concrete roof tiles (2012 IRC, 442-443). The 2009 IECC requires for the region of Clark County (3B) that the ceiling has an R-value of R-30 minimum with an equivalent U-factor of 0.035 or less (2009 IECC, 27-28).

2.5 Best Building Practices

Local production builder Pulte Homes, designed a community in which all homes were built to LEED (Leadership in Energy and Environmental Design) Platinum certification standards with a HERS (Home Energy Rating System) that is greater than 50% more efficient than similarly sized homes built with standard building practices (France, 2009). In the Las Vegas valley, Pulte Homes in conjunction with UNLV designed a community that would represent high performing residential houses that featured solar panels, continuous insulation at the exterior layer of the building envelope and technological features to help the homeowner see how well the house performs and what they can do to continue to improve the performance. The roof construction was R-30 spray insulation at the roof with an unvented attic.

2.6 Roof Ponds

Roof ponds can serve multiple duties besides simply being a roof; they can aide in passive heating and cooling. Roof ponds aid in cooling during the summer months by being covered with insulated panels during the day and exposed to the night air to radiate the built up heat from the daytime (Brown and Dekay, 2001, 176). The roof ponds use the metal deck that they are resting on to aid in becoming sponges of the thermal build-up in the spaces below them during the day, which is released at night through natural convection to the black body of the clear night skies (AZ Solar Center). Roof ponds aid in heating in the winter by being exposed to the sun during the day and covered during the night to allow the heat to radiate into the home during the night (Brown and Dekay, 2001, 176). “They should have an unobstructed path toward the zenith (directly overhead). Adjacent trees, walls and other buildings can impact the cooling rate by reducing radiation to the night sky. Trees and walls also absorb solar heat by day and

radiate this energy into the ponds at night. Cloud cover can interfere with the cooling performance of a roof pond system." (AZ Solar Center)

"For best cooling results, ponds can range from 6-12 inches deep, depending on location and local conditions, and should cover as much of the roof as possible. An average tract home in the southwest, with good heat gain control, can easily gain 200,000 to 400,000 BTU's on a hot July day. A 6-inch-deep roof pond covering the entire roof, will rise in temperature by only 4-8°F from this heat gain, and with nighttime cooling rates of 25-30 BTU/hr/ft', all this excess heat can be released to the outside by daybreak" (AZ Solar Center).

The most exposed element of the building is the roof, which would allow for a wide range of options to dissipate heat for cooling purposes (Spanaki et al., 2011). Roof ponds have the potential to be very cost effective, simply "by enclosing water in plastic bags, metal or fiberglass tanks with rigid transparent plastic covers" (Spanaki et al., 2011, 3524). In Spanaki et al.'s 2001 study, the authors test twelve different options for roof ponds ranging from the traditional uncovered variation with and without water spraying overtop, to more recently developed ventilated roof ponds to allow for parameters to demonstrate which system to use for the various construction types and climate zones (Spanaki et al., 2011). The seven parameters that were used by the authors were: "cooling more than one floor, application in uninsulated concrete roof, absence of demand for daily attention, walkability of the roof, low contamination, winter function, easy to construct (availability of materials and devices), low initial costs, null maintenance and function cost, and widespread know how" (Spanaki et al., 2011, 3531). The authors concluded that roof ponds are very popular to be used for passive cooling in the climates that favor evaporative and/or radiative cooling. This is due in part to the fact that the only construction requirements are that the roof is watertight, can support the dead load of the water, and also that they have low initial installation and implementation costs (Spanaki et al., 2011). Furthermore, the authors also state that if roof ponds are used as a passive solar

technique, then they have a good chance to reduce the energy required by the building sector (Spanaki et al., 2011).

One of the newer techniques being used for roof ponds is a ventilated roof pond with a reflective layer that is suspended above the water to allow air to circulate between the two layers (Spanaki et al., 2014). The roof pond tested in Spanaki et al.'s study is mostly for cooling purposes and might require that the water is drained during the winter and replaced with insulation to meet the insulation required for the heating months (Spanaki et al., 2014). The roof proposed in this study is similar to the vented roof pond with a secondary roof proposed by Baruch Giovani, which would use an aluminum cover to reflect solar radiation during the day and act as a radiator during the night (Spanaki et al., 2014). During the 35 day testing period of a small building in Crete, Greece, the minimum temperature of the water was close to the ambient air temperature, while the highest temperature was 8-13ºC (46.4-55.4ºF) lower than the highest ambient air temperature (Spanaki et al., 2014).

In a 2003 study, Tang et al. (2003) studied the effects of a roof pond with a floating wetted cloth (pond 1) and how it compared to five other cooling techniques. For this study, two test cells were built and placed on a roof just outside of Negev, Israel, during the hot and dry season to test the techniques which are: comparing pond 1 and open pond, comparing pond 1 and a covered pond, comparing pond 1 to a pond with moveable insulation, comparing pond 1 with a shaded roof pond, and comparing the shaded pond to the open pond (Tang et al., 2003). The results showed that when compared to the covered pond (highest performing of the comparative ponds and was claimed to be the preferred evaporative cooling roof) the floating wetted cloth model performed better by having more heat flux from the building and by keeping the temperature of the bottom of pond cooler (Tang et al., 2003). One observation of the authors was that in order to prevent stratification of temperatures that occur during the night readings of pond 1, the mesh holding the cloth needed to be as open as possible to allow the cold water from the cloth to mix with the warm water of the pond (Tang et al., 2003). This version of pond

does not require the user to cover the pond in the morning and uncover it at night, which eases the operation of this roof pond (Tang et al., 2003).

In a 2004 study, Tang and Etzion researched the effects of a roof pond that used gunny bags on the surface of the water through simulations (2004). Using information from an earlier study by Tang et al., the authors discuss how the evaporation rate of a wetted surface is different from a free water surface (Tang and Etzion, 2004). In the study, they collected data from three types of buildings with different roof types: a well-insulated concrete roof with mass walls, a poorly insulated with metal deck roof and light walls, and a well-insulated metal deck roofed mass wall building; and with all data, they simulated the wetted gunny bags and roof pond with gunny bags (Tang and Etzion, 2004). The authors concluded that the roof pond with gunny bags provided a more even temperature range and higher heat flux out of the buildings than the wetted gunny bags, which were previously thought to be the best performing (Tang and Etzion, 2004).

2.7 Double-Skin Roofs

Double roof systems consist of two separate roof systems that are separated by either a ventilated or unventilated air cavity that allows for the thermal gains of the outermost roof to not affect the inner roof.

In a study by Biwole, Woloszyn and Pompeo, the effects of ventilated and reflective double-skin roofs were analyzed to see if they would assist in the reduction of cooling needs during the summer in France by recording the systems potential to reflect solar radiation that is absorbed by traditional roofs (2008). In this study, the authors looked at the spacing required between the metal roof layer and the metal screen layer as well as the performance of the roof at different angles (Biwole et al., 2008). The results showed that as the angle increase, the temperature went down and the velocity of the interstitial air went up which aided in the

reduction of the solar radiation that actually reached the interior of the structure (Biwole et al., 2008). The conclusions of this study were that the emissivity of the roof and screen need to be as low as possible, the insulation value as high as possible, and between 6-10 cm (2.3-3.9 in.) of separation between outer screen and roof; the optimal option tested was spaced at 10 cm apart, with 5 cm of insulation below the roof and set at a 30º angle (Biwole et al., 2008).

A study done in Taiwan by Lai, Huang and Chiou looked into the use of double-skin roofs to replace the traditional low-cost metal sheet roofs of the area, which would allow for the reduction of greenhouse gas emissions from space conditioning (2007). Lai et al. study focuses on the optimal spacing between the different planes of the roof as their research showed there was a lack of research in this area (2008). The authors created an experimental mock-up to be able to test the different spacing and the angle to find the optimal setup (Lai et al., 2008). The results of this study concluded similar results to the Biwole et al. study that a 30º angle is the optimal angle to extract the most amount of thermal radiation.

“The ventilation of a roof or attic has become one of the greatest interests for building researchers in the last several decades” (Susanti and Matsumoto, 2011, 211). Sustani and Matsumoto did a study of the implementation of double-skin roofs as a potential energy saver and as increasing thermal comfort in a factory setting (2011). The location of this study was in Toyohashi City, Japan, and the model was based on a one-story factory building, with the thermal comfort to be recorded for both naturally ventilated and air conditioned modes (Susanti and Matsumoto, 2011). The double-skin model showed a reduction in energy required for cooling ranging from 47-52% over the traditional single roof model (Susanti and Matsumoto, 2011). Other notable conclusions were that when openings were at a ratio of 50% of the cavity space at both the top and bottom, the double skin roof performed the best. Also, the air velocity increased as the solar radiation became stronger such as would happen during the summer. Finally, during the air conditioning tests the thermostat could be raised 7.6ºC (45.68ºF) higher than that of the single roof model (Susanti and Matsumoto, 2011).

2.8 Green Roofs

Another potential way roofs can contribute to the energy reduction of a building is to incorporate a green roof (La Roche and Berardi, 2014). In this study by La Roche and Berardi, a more intelligent green roof system is investigated in three different climate zones that allows for the level of insulation to be modified through the use of a plenum space located below the roof and above the ceiling (2014). Using Sailors simulation that is included in EnergyPlus, buildings were simulated to test the effects of different aspects of green roofs along with the base case which was a cool roof (which is the requirement in California) for their energy efficiency (La Roche and Berardi, 2014). The authors also used test cells with varying types of vegetation that were observed for seven years with the only varying item being the roofs systems (La Roche and Berardi, 2014). The results of the testing were that even though the standard green roofs with high mass and night ventilation often kept the space cooler than the control cell, some overheating was observed; this is why the assembly with variable insulation was tested. The model with the variable insulation had the lowest temperatures during the summer cooling months when a ventilation fan was running and reversed roles during the winter when the fan was shut and insulation was added to perform better (La Roche and Beradi, 2014).

David J. Sailor developed a module for EnergyPlus that allows designers to test green roofs (or ecoroofs) using more reliable data that was physically based on the energy balance of the systems and components (2008). In the module, various options can be modified by the designer that include the “growing media depth, thermal properties, plant canopy density, plant height, stomatal conductance (ability to transpire moisture), and soil moisture conditions (including irrigation and precipitation)” (Sailor, 2008, 1467-1468). To test the validity of the ecoroof module, Sailor replicated a project located at the University of Central Florida’s student union building, which has sensors that monitor performance, in the EnergyPlus software, which showed predictions similar to the recorded data from the test roof (Sailor, 2008). With the

implementation of this software module, designers have a method to test various ecoroof options, which will help establish qualitative estimates of green roof systems and the potential of energy use reduction and ultimately result in data for the analyses of life-cycle costs (Sailor, 2008).

Sailor and Hagos, expanded on the earlier study by Sailor (2008) that included analysis of materials mostly found in western U.S. locations, researched soil compaction and a wider library of growing media for different regions of the U.S. (Sailor and Hagos, 2011). The compaction of the growing media happens naturally over time, which affects the amount of oxygen that is available for the plants to grow and also the thermal conductivity of the roof (Sailor and Hagos, 2009). With the results of this study, the authors were able to create useful information that the building information modeling users can utilize when analyzing the various green roof design options. The resulting data will illustrate the reduction of urban heat island effects and increase of energy efficiency (Sailor and Hagos, 2011).

A further area of green roof modeling that needed to be researched according to Moody and Sailor is how to integrate thermal performance values into energy calculations (Moody and Sailor, 2013). The thermal characteristics of green roofs cannot be classified as one R-value as it is variable depending on the time of year and it needs a way in which the true performance can be analyzed in energy modeling software (Moody and Sailor, 2013). With the EnergyPlus ecoroof module, the authors tested different green roof options, which were then compared to physical results of the green roof test modules located on the Portland State University campus in order to validate the method (Moody and Sailor, 2013). The authors then used the information to test in four cities (Chicago, Houston, Atlanta and Portland) using different ecoroof options and options for thermal connectivity to the building to compile data that shows how the systems would perform based on climate and season (Moody and Sailor, 2013).

2.9 Cool Roofs

Cool roofs are composed of high albedo roof components to help to reflect as much of the suns radiation back into the atmosphere. Cool roofing materials are another option to be investigated to help lower the effects of the urban heat island effects. The heat island effect is often a result of cities not having open green spaces and using dark materials on the rooftops, which absorb thermal radiation and raise the internal temperatures of structures, the temperature of surrounding areas and raise building operating costs (Santamouris et al., 2011). The materials that are used in cool roofs have high solar reflectivity and infrared emittance which help to keep the surface of the buildings envelope cooler, which will then reduce the urban heat island effect as well as reduce the energy consumption required to condition the building (Santamouris et al., 2011). There are cool roof options for nearly every type of roofing used in both commercial and residential construction industries, as well as for both low and steep sloped roofs (Santamoures et al., 2011). The authors conclude that the use of cool roofs reduce the cooling load, but can increase the heating load required and can also lose performance characteristics as the products age and become discolored (Santamoures et al., 2011).

2.10 Structural Insulated Panels

Structural Insulated Panels (SIP) are composed of a rigid insulation core usually either extruded polystyrene insulation (XPS) or expanded polystyrene insulation (EPS) sandwiched between Oriented Strand Board (OSB) or Metal. James M Tracy describes the uses of SIPs are primarily for walls and roofs but can be used for floors also (2000). One good thing about SIPs over conventional framing is the R-value of the system is higher as there is no framing in the middle of the panels to create thermal bridges that are averaged in the calculation and lower the

intended total insulation. Mullens and Mohammed say a SIP panel with a 3.5” core would have a continuous R-value of R-14 as compared to a traditionally framed wall that would have an R-value of only R-9.8 that had R-11 in the cavities. (2006)

Another important factor of SIP panels are that they are manufactured in controlled factory settings. Having the panels manufactured in factories allows for the products to be flatter requiring less shimming for finish products and also require less skilled labor as the SIP panels interlock with each other and take out the interpretations of drawings. (Mullens and Mohammed, 2006)

CHAPTER 3: RESEARCH QUESTION

3.1 Purpose

Residential buildings provide comfort, shelter, and many other benefits to the occupants that inhabit them, but also account for a majority of the negative energy consumption impacts that face the global environment (Kallaos and Bohne, 2013). Energy efficiency is a very important element to think about when designing in the U.S. desert southwest. However, most builders would rather take higher profits, use the most economical building materials and forego looking at the embodied energy or energy efficiency of the products to help the end user with lower energy bills or a lower impact on the environment. Some of the possible solutions that have been investigated to help reduce the cooling load in hot climates are shading, earth shelters, plant protection of buildings, roof cooling using roof ponds and water sprays, double skin walls and ventilation (Kharrufa and Adil, 2012). Some of these same strategies can be used in the U.S. desert southwest to reduce the demand for energy intense air conditioning.

Armed with the proper knowledge, design professionals and contractors will be more apt to construct the most efficient roof assemblies, as they have economic advantage over competitors. Designing and building more efficiently will help the consumer save over time the money that they invested as a premium upon the initial purchase. Then, as more and more designers, contractors and owners improve over their neighbors and competitors, the consumers and planet will benefit.

3.2 Research Question

This research project aims to answer the main question “Which residential roof assembly is the best for the U.S. desert southwest using studies and simulations for the three sub-

problems?” The sub problems to be researched are (1) the cost associated with different roof assemblies, (2) energy efficiency of the options, and (3) any possible embodied energy factors accounted for. The article “Beyond the code: Energy, carbon and cost savings using conventional technologies” by Joshua Kneifel (2010) looks at the different strategies that can be used in commercial buildings to reduce energy consumption and costs while also looking at life-cycle assessments. Similar to this article, the researcher would like to study energy efficiency, cost comparisons and life-cycle assessments in the residential sector of the U.S. desert southwest to be able to determine the best roof assembly for this region.

3.3 Roof Assembly Evaluation

There are many roof assembly options to be tested. Of the many roof assemblies that are available, several are better suited for the U.S. desert southwest climate. This research focused on comparing a typical code compliant traditionally framed house with a roof that has R-30 batt insulation at the ceiling and vented attic to several options. The options of the roof assemblies that were researched include:

1. Sip Panel with R-27.5,
2. Sip Panel with R-37.5
3. Sip Panel with R47.5
4. Spray insulation with R-30 sprayed on underside of roof (Best Practice of the Area)
5. Spray insulation with R-38 sprayed on underside of roof
6. Spray Insulation with R-49 sprayed on underside of roof
7. Spray Insulation with R-60 sprayed on underside of roof
8. 7” Roof Pond
9. Green Roof with R-30 insulation at ceiling
10. Spray insulation with R-30 sprayed on ceiling

11. Spray insulation with R-38 sprayed on ceiling
12. Spray insulation with R-49 sprayed on ceiling

The roof assemblies that this research evaluated are compared and tested in four different orientations (north, south, east and west) and with three different roof pitches (1:12, 3:12 and 6:12) which are commonly seen in the U.S. Desert Southwest. The most common roof pitch to the mission style house traditionally built in the U.S. desert southwest is mid slope roof with a pitch of between 2:12 and 4:12. With the exception of the green roof and roof pond, the roof finishes of the tested roof assemblies remained the same as the control of the typically used concrete tile of the region. All other components of the house remained as the code compliant base case with the exception of the HVAC ducting that would either be in the unconditioned attic space or the conditioned envelope of the house.

3.4 Case Study

The Department of Energy (DOE) Race to Zero Student Design Competition has the same intent as the effort to generate this research thesis. The information from that competition can be used to help developers create Net Zero Energy Ready homes. The Race to Zero Student Deign Competition is an annual competition to help students create houses that can fall under one of two paths:

1) Redesign an existing builder design to be a high-performance house.
2) Develop a completely new house design that is high-performance.

The team from UNLV for the 2015 Race to Zero Student Design Competition decided to generate a design using the second option. The team of students would each research different components required prior to any design of the competition house. The areas researched included orientation, wall construction, roof construction, openings, and mechanical systems &

Indoor Air Quality. All of the students' research was combined to create the design of the house that would allow for the greatest energy efficiency and ultimately be Net-Zero Energy Ready.

The team used software provided by the National Renewable Energy Laboratory (NREL), BEopt, to run the simulations for their research. The data that was obtained from the BEopt simulations allowed the students to establish which of the tested systems or assemblies would be the optimal system to be used for the competition house.

Once all of the optimal systems were decided, a model using these systems was created in BEopt to simulate how well the house performed for several categories of data. These categories that were obtained were site energy used, cost of systems and efficiency measurements.

CHAPTER 4: METHODS

4.1 Context

The purpose of this research project is to model several roof assemblies and see how they compare in terms of cost and energy for ASHRAE zone 3B. From the results of the simulations, a ranking of the best roof assembly for the U.S. desert southwest is chosen to answer the research questions. The results of this research will be implemented as part of the Department of Energy Race to Zero Student Competition. Each student researched a different building subject area to provide design input for the design of a Net Zero Energy Ready Home. All the input from the various research areas conducted was combined to create the basis for the residence for the competition.

4.2 Approach

Modeling packages were evaluated to determine which can perform simulations of building systems. These programs were Autodesk Revit, Green Building Studio, DOE2, EnergyPlus, BEopt and HEED. Revit and the Green Building Studio were tested for creating the base model control system to compare the roof assemblies, but they did not allow for the full control of all systems of the building. This would have not shown the performance differences that the roof assemblies would have compared to the control and thus were not used. HEED was tested also, along with BEopt (Building Energy Optimization), and while both programs allowed for the most control of the building systems, BEopt was ultimately chosen to do the simulations. BEopt uses data from either the Department of Energy's EnergyPlus database or Lawrence Berkley National Laboratory's DOE2 database. The EnergyPlus database was ultimately chosen as it includes the 'ecoroof' analysis created by David Sailor that enables the

user to add green roofs to their modelled buildings and simulate their effects (Castleton et al., 2010).

The different roof assemblies that were studied were compiled into matrices showing how they perform at different roof pitches and orientations. In BEopt, the test model was built to simulate a standard 1800 square foot, standard control one-story home typically found in the U.S. desert southwest. The standard control model built consists of Las Vegas Valley code compliant construction. The standard model serves as a control that allows the roof assembly to be changed while all the other data remains constant to show the full effects of the roof assembly changes on the energy efficiency of the residential structure.

"The BEopt software is a computer program designed to find optimal building designs along the path to ZNE and to accelerate the process of developing high-performance building designs. In addition to an optimization search, the BEopt software includes (1) a main input screen that allows the user to select, from many predefined options, those to be used in the optimization, (2) an output screen that allows the user to display detailed results for many optimal and near-optimal building designs, and (3) an options library spreadsheet that allows a user to review and modify detailed information on all available options." (Christensen et al., 2006, 4)

4.3 Roof Pond Calculations:

Roof ponds are not an integral part of the simulation software BEopt. The simulation software allows custom roof types to be created if all of the parameters of the system are entered. To obtain the information required for testing roof ponds, the calculation in Appendix A utilizes climatic information for the U.S. desert southwest to find the delta change to be entered in BEopt. The equation and data in Appendix A are from Stein and Reynolds Mechanical and Electrical Equipment for Buildings, 9th Edition. (2000)

4.4 Green Roofs

The components that create a green roof system come in a wide variety of products. This can make for simulating the green roof a challenge. Fortunately, green roof information is available in EnergyPlus, which is a database that BEopt utilizes for running the simulations. For the green roof simulation, a soil thickness of 6” was assumed with desert landscape cover. There was also R-30 spray insulation added under the roof deck to help with the prevention of thermal heat transfer.

4.5 Assemblies Tested

The standard code compliant base case of the region consists of 2x wood framing for the roof and ceiling structure spaced. It consists of insulation added on top of the ceiling assembly and a vented attic space. Figure 4.1 shows the construction of components of the standard code compliant roof assembly.

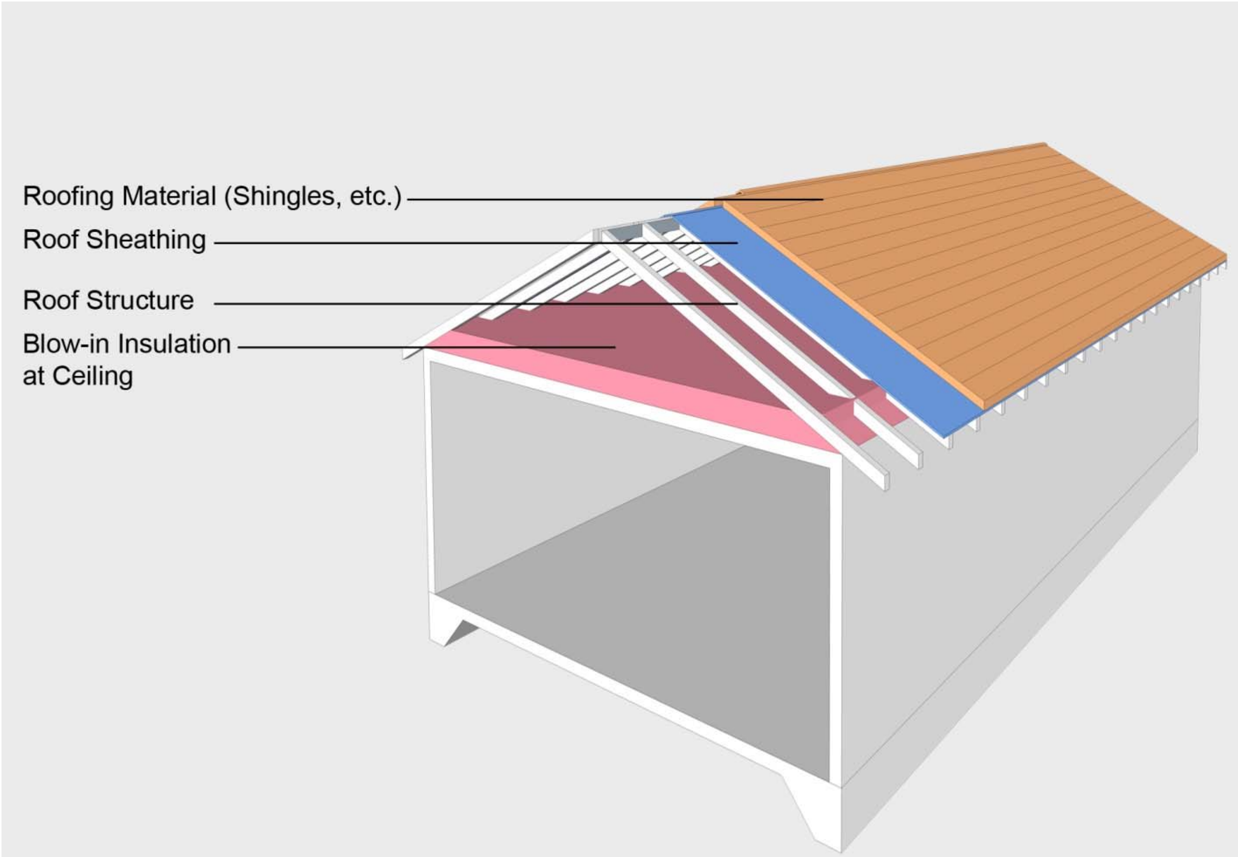


Figure 4.1 Standard Code Compliant Assembly

The best practices of the area consists of 2x wood framing for the roof and ceiling structure. It consists of insulation added on the underside of the roof assembly and an un-vented attic space. Figure 4.2 shows the construction of components of the spray insulation on underside of the roof.

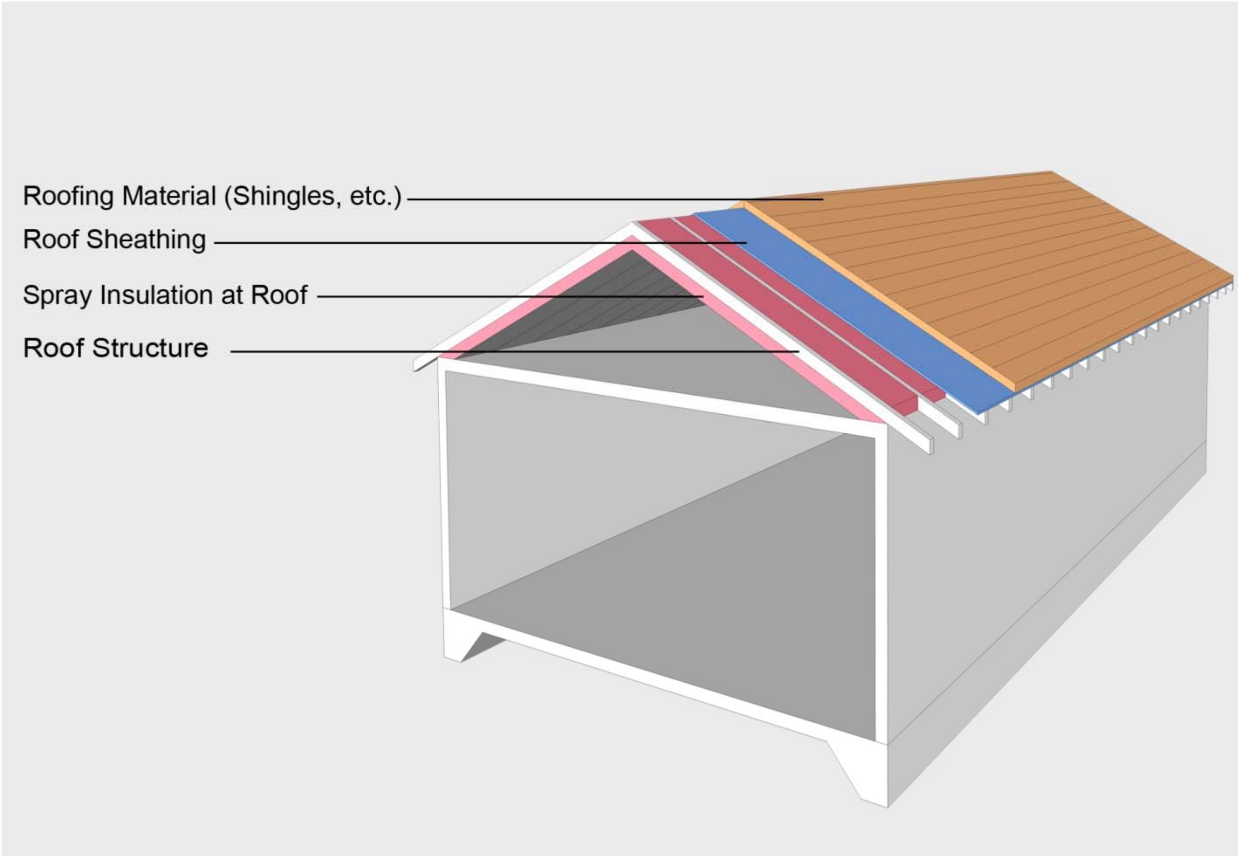


Figure 4.2 Spray Insulation at Roof Assembly

The roof assembly of spray insulation applied to the ceiling consists of 2x wood framing for the roof and ceiling structure. It consists of spray insulation added on top of the ceiling assembly and a vented attic space. Figure 4.3 shows the construction of components of the standard code compliant roof assembly.

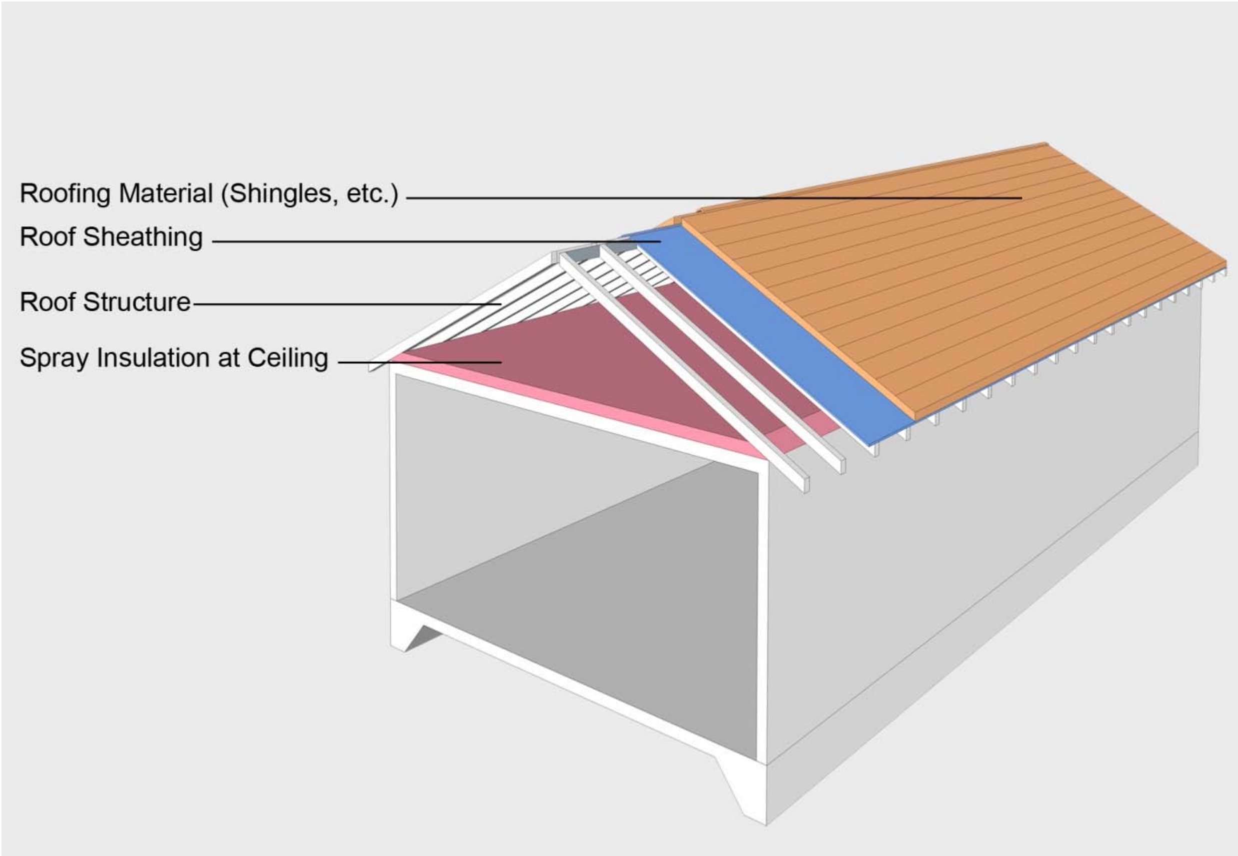


Figure 4.3 Spray Insulation at the Ceiling Assembly

The roof assembly of structural insulated (SIP) panels consists of rigid insulation sandwiched between oriented strand board (osb) that make up the structure of the roof with no attic. Figure 4.4 shows the construction of components of the SIP panel roof assembly.

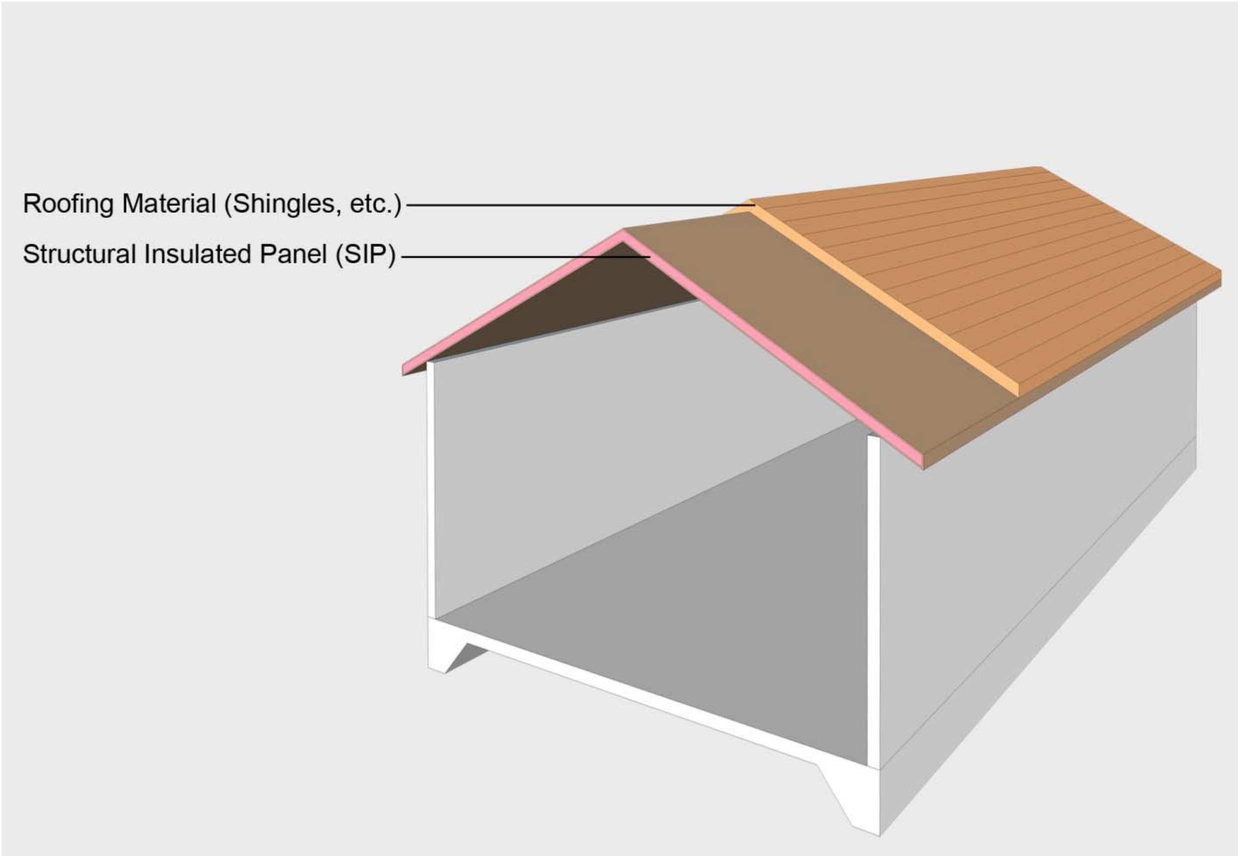


Figure 4.4 Structural Insulated Panel Assembly

The roof assembly of a roof pond consists of bags of water on top of metal deck over framing structure. The water acts as the insulation and radiates heat from the space at night during the summer and into the space during the daytime hours of winter. In order to control unwanted gains or losses, movable insulation is installed over the water bags. Figure 4.5 shows the construction of components of the roof pond assembly.

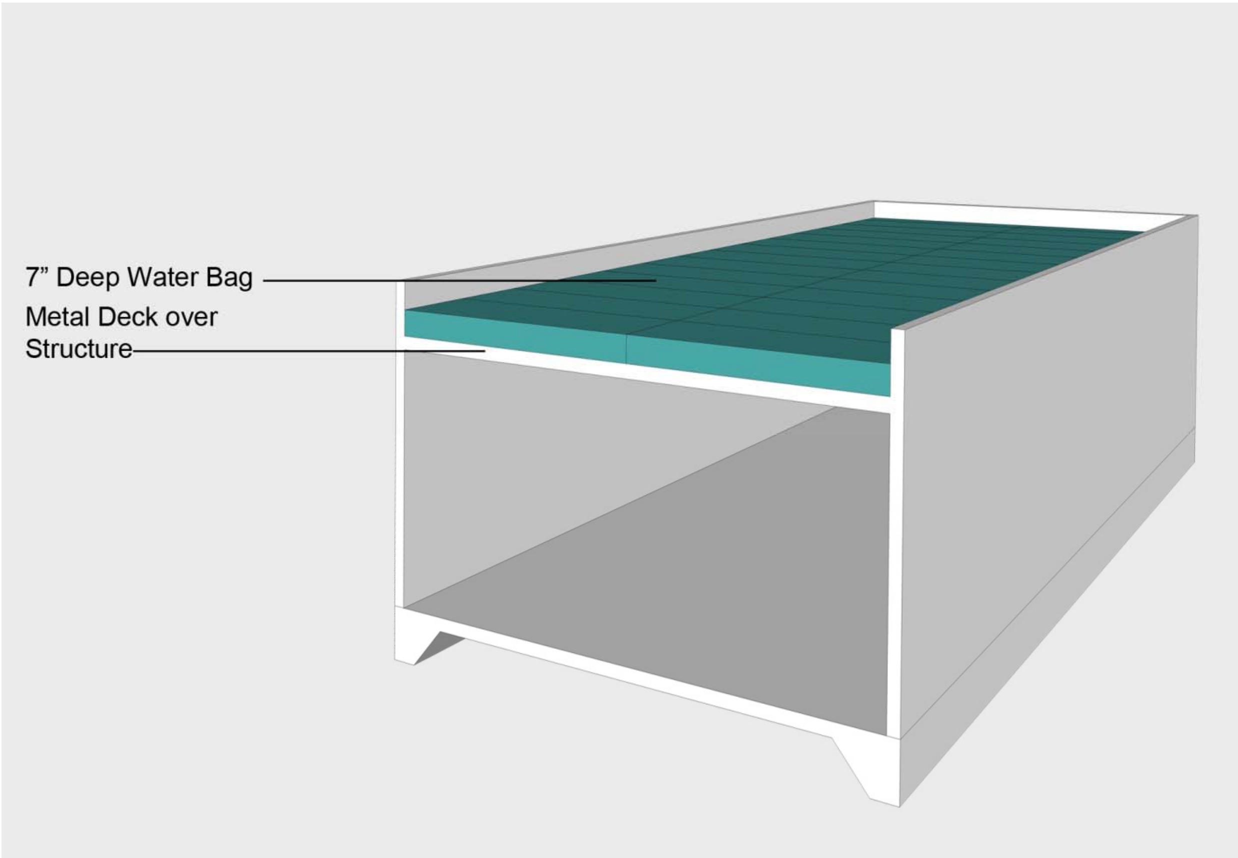


Figure 4.5 Roof Pond Assembly

The green roof consists of vegetation planted in a soil media with drainage and waterproofing measures over metal deck and building structure. The simulated system also includes R-30 spray insulation on the underside of the building structure. Figure 4.6 shows the construction of components of the green roof assembly.

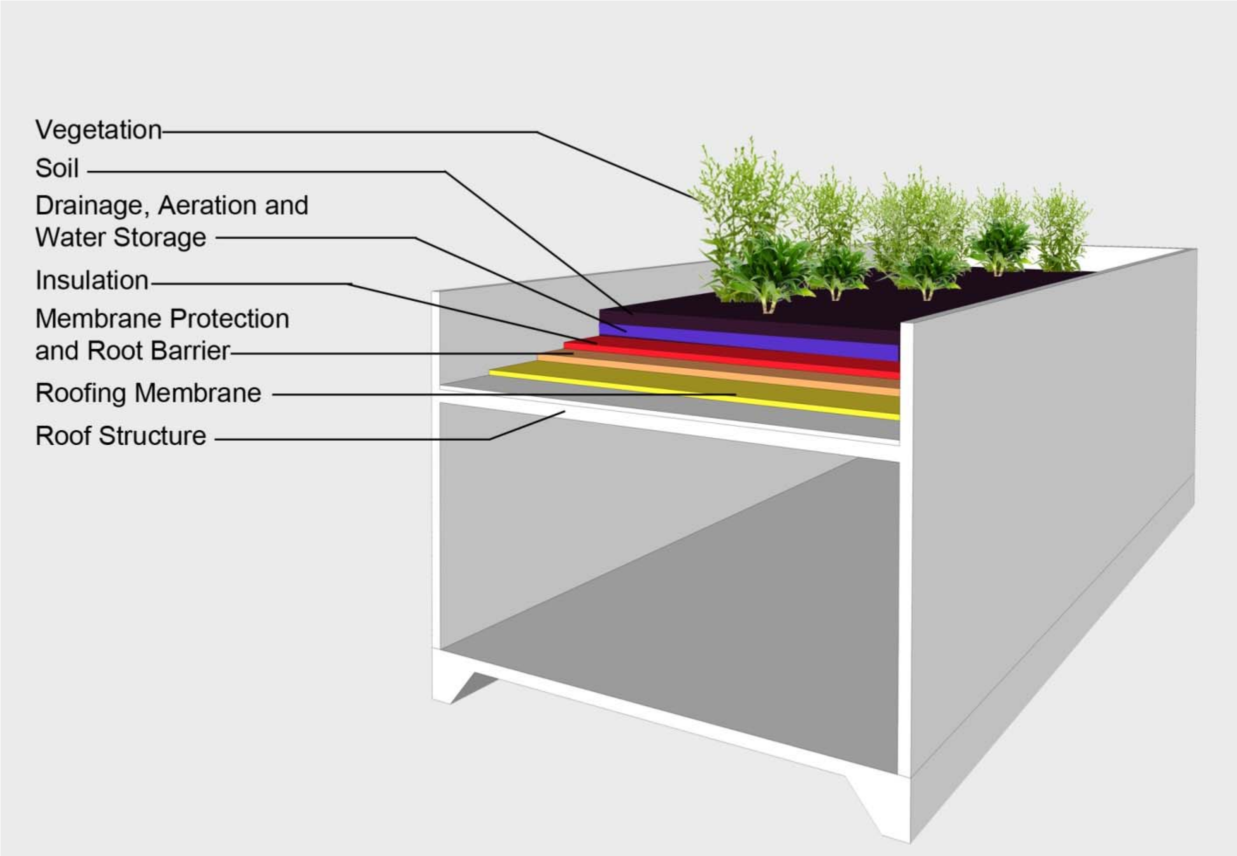


Figure 4.6 Green Roof Assembly

The roof pitch chosen for the design is an important decision. For this research three roof pitches were simulated – 1:12 low slope roof, 3:12 mid slope roof and 6:12 steep slope roof. The 1:12 roof slopes are considered a flat roof. The dominant roof pitches of the U.S. desert southwest are the 1:12 and 3:12. Figure 4.7 shows the different roof pitches of the research.

Figure 4.8 shows how the construction of the sloped roof pond and green roof assemblies were assumed in the simulations.

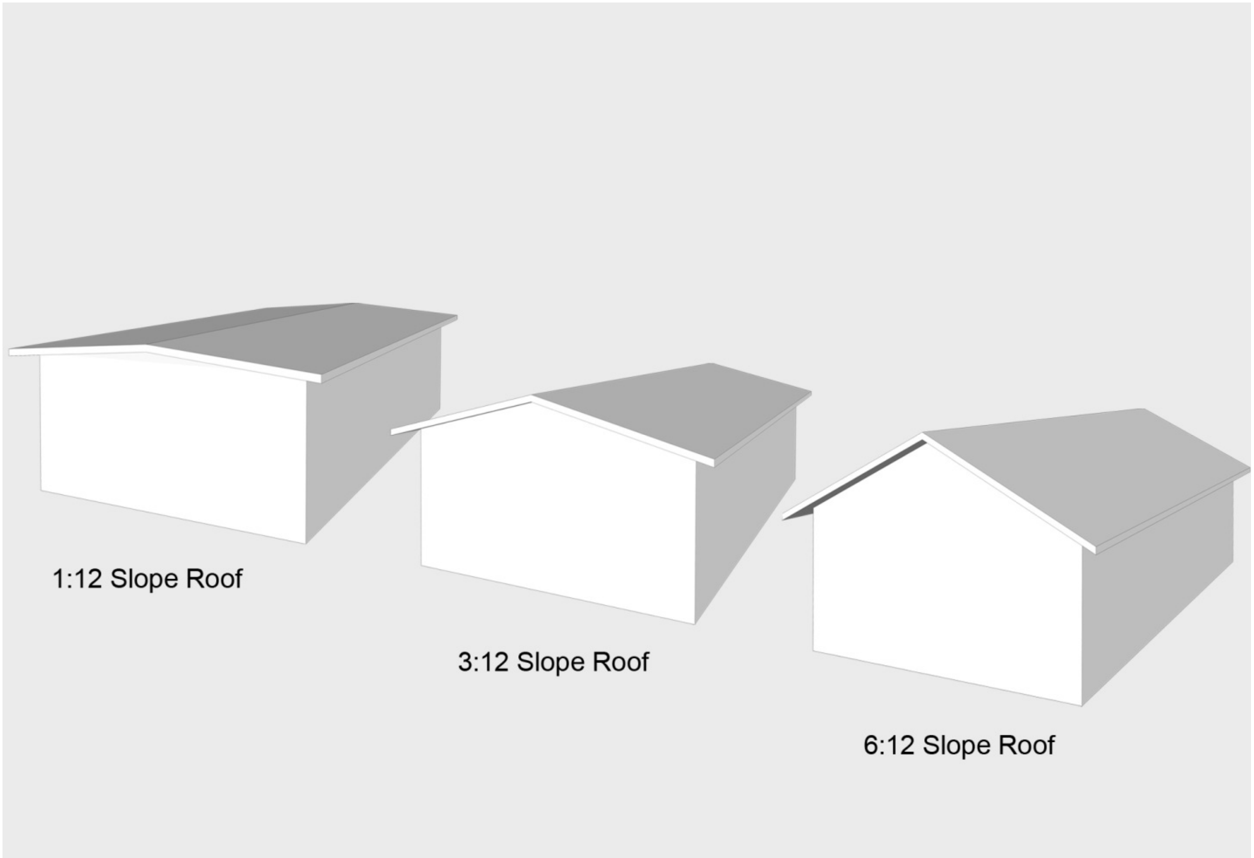


Figure 4.7 Roof Pitch Diagram

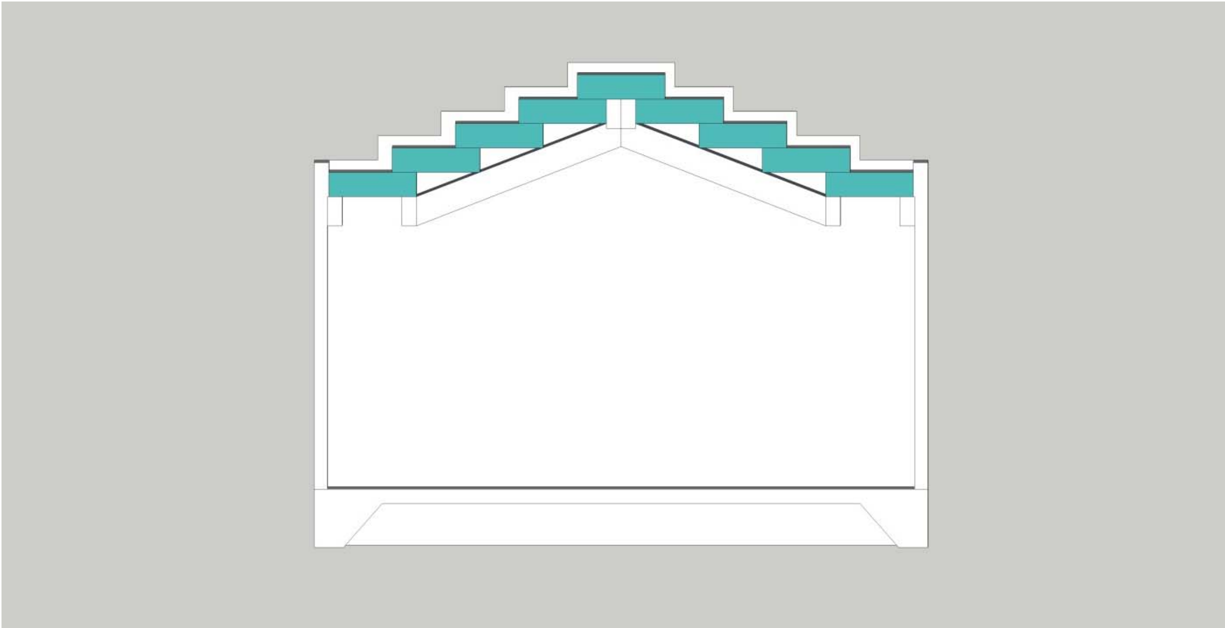
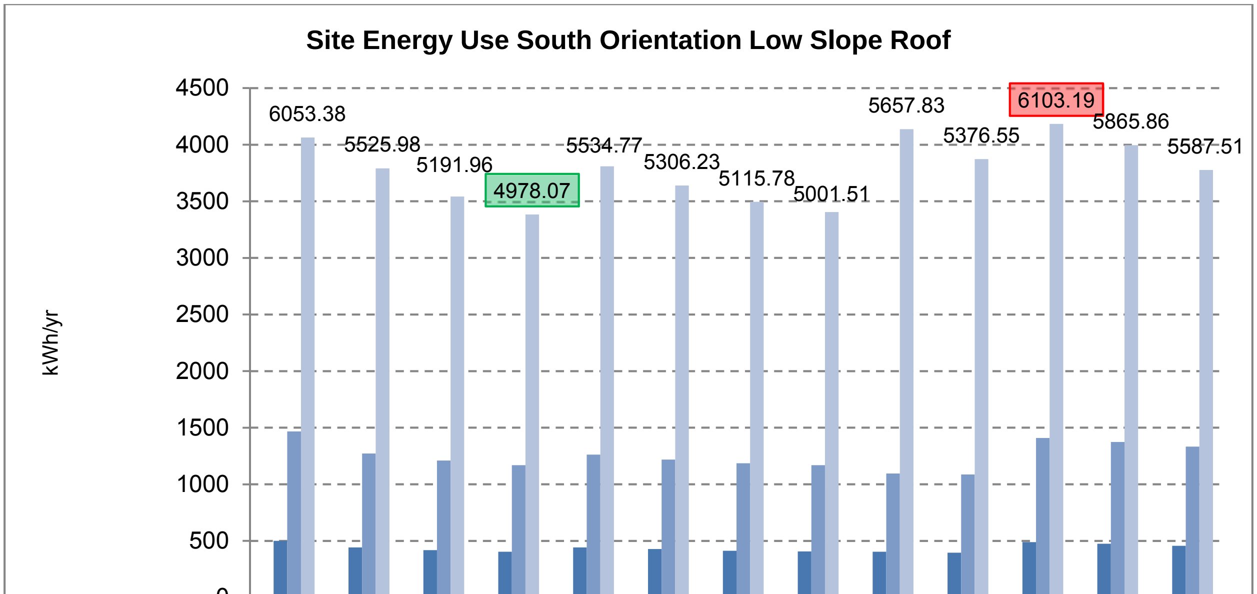


Figure 4.8 Sloped Green Roof and Roof Pond Construction Diagram

CHAPTER 5: RESULTS

5.1 Simulation Outputs for Site Energy Use

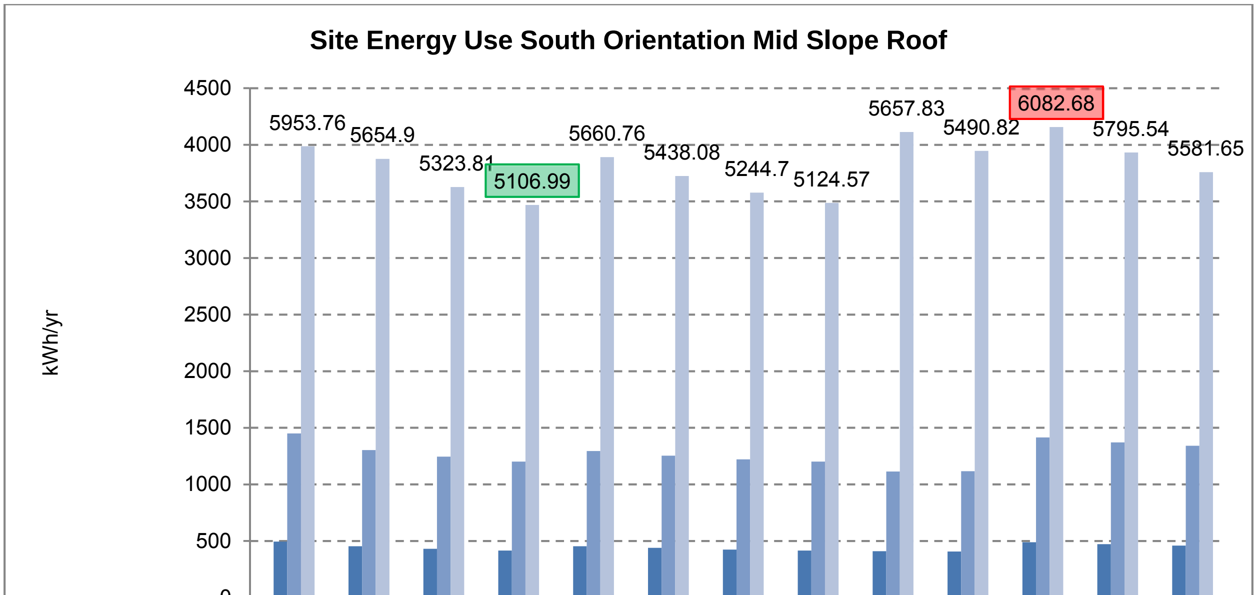
The outputs of site energy use from the BEopt simulations are below. The first twelve simulations (Tables 5.1-5.12) show the comparison of the thirteen tested roof systems for each of the four orientations as well as for the three distinct roof pitches. The total site energy use for each system is listed above the bar graphs.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	501.03	442.43	418.99	404.34	442.43	427.78	413.13	407.27	404.34	395.55	489.31	474.66	457.08
Cooling (E)	1467.93	1271.62	1210.09	1169.07	1262.83	1218.88	1186.65	1169.07	1095.82	1087.03	1409.33	1374.17	1333.15
Heating (G)	4063.91	3791.42	3542.37	3384.15	3809	3639.06	3495.49	3404.66	4137.16	3873.46	4184.04	3996.52	3776.77

Table 5.1 Site Energy Use South Orientation 1:12 Roof Pitch

The results of the simulations for the orientation of the building facing south with a low pitch roof, table 5.1, shows that the base case roof was the second worst performer with a total site energy use of 6,053.38 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,103.19 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 4,978.07 kWh/yr.

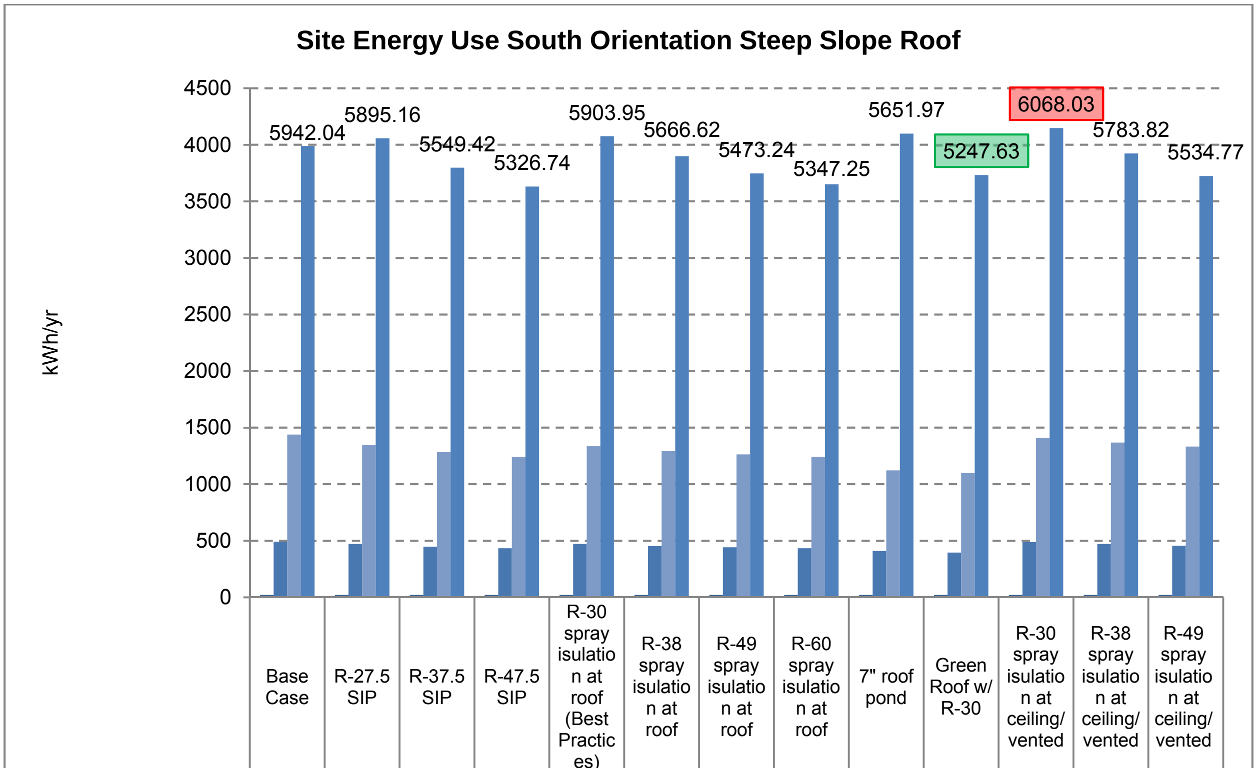


	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	495.17	454.15	430.71	416.06	454.15	439.5	424.85	416.06	410.2	407.27	489.31	471.73	460.01
Cooling (E)	1450.35	1303.85	1245.25	1201.3	1295.06	1254.04	1221.81	1201.3	1113.4	1116.33	1415.19	1371.24	1341.94
Heating (G)	3987.73	3876.39	3627.34	3469.12	3891.04	3724.03	3577.53	3486.7	4113.72	3946.71	4157.67	3932.06	3759.19

Table 5.2 Site Energy Use South Orientation 3:12 Roof Pitch

The results of the simulations for the orientation of the building facing south with a mid slope roof, table 5.2, shows that the base case roof was the second worst performer with a total

site energy use of 5,953.76 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,082.68 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,106.99 kWh/yr.

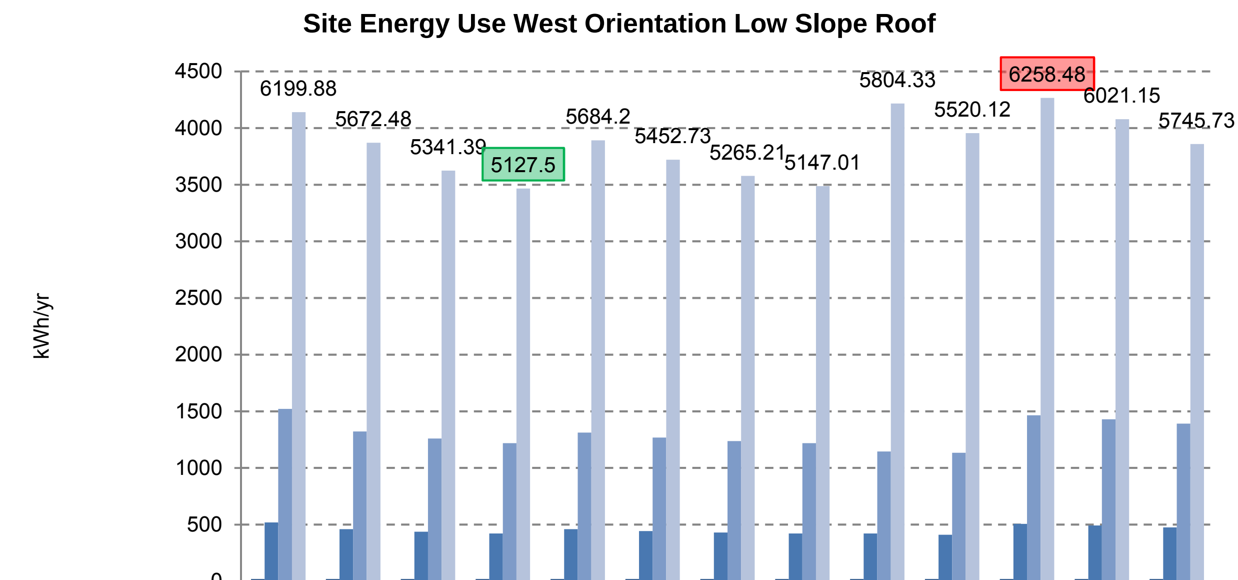


	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	492.24	471.73	448.29	433.64	471.73	454.15	442.43	433.64	410.2	395.55	489.31	471.73	457.08
Cooling (E)	1438.63	1344.87	1283.34	1242.32	1336.08	1292.13	1262.83	1242.32	1122.19	1098.75	1409.33	1368.31	1333.15
Heating (G)	3990.66	4058.05	3797.28	3630.27	4075.63	3899.83	3747.47	3650.78	4099.07	3732.82	4148.88	3923.27	3724.03

Table 5.3 Site Energy Use South Orientation 6:12 Roof Pitch

The results of the simulations for the orientation of the building facing south with a steep slope roof, table 5.3, shows that the base case roof was the second worst performer with a total site energy use of 5,942.04 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,068.03 kWh/yr. The best performing

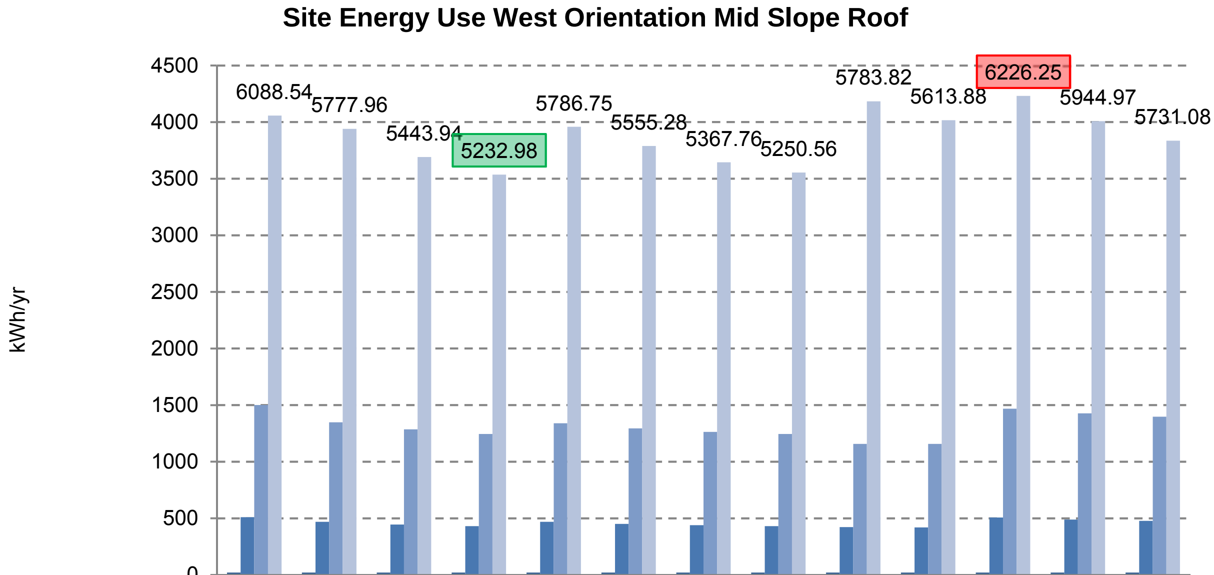
roof assembly is the green roof with R-30 insulation with a total site energy use of 5,247.63 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	518.61	460.01	436.57	421.92	460.01	442.43	430.71	421.92	421.92	410.2	506.89	492.24	474.66
Cooling (E)	1520.67	1321.43	1259.9	1218.88	1312.64	1268.69	1236.46	1218.88	1145.63	1133.91	1465	1429.84	1391.75
Heating (G)	4140.09	3870.53	3624.41	3466.19	3891.04	3721.1	3577.53	3486.7	4216.27	3955.5	4266.08	4078.56	3858.81

Table 5.4 Site Energy Use West Orientation 1:12 Roof Pitch

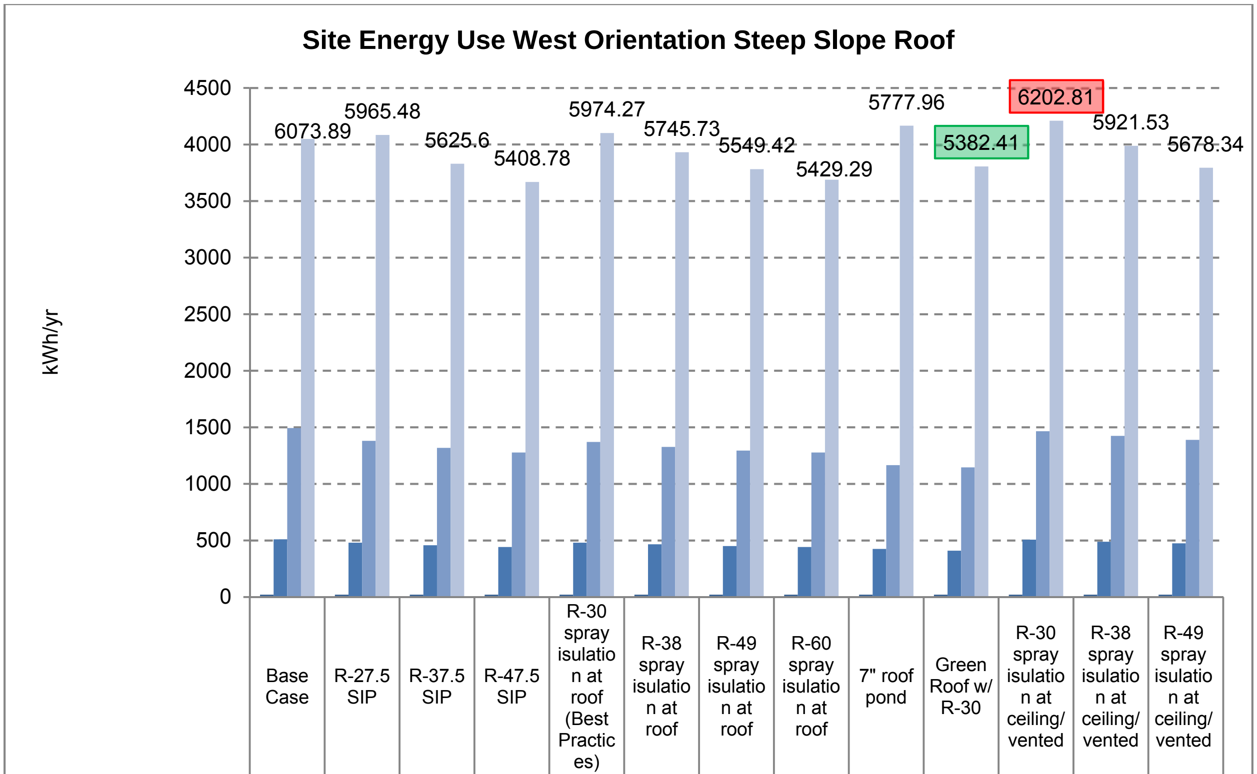
The results of the simulations for the orientation of the building facing west with a low slope roof, table 5.4, shows that the base case roof was the second worst performer with a total site energy use of 6,199.88 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,258.48 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,127.5 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	509.82	468.8	445.36	430.71	468.8	451.22	439.5	430.71	421.92	418.99	506.89	489.31	477.59
Cooling (E)	1500.16	1347.8	1286.27	1245.25	1339.01	1295.06	1262.83	1245.25	1157.35	1157.35	1467.93	1426.91	1397.61
Heating (G)	4058.05	3940.85	3691.8	3536.51	3958.43	3788.49	3644.92	3554.09	4184.04	4017.03	4230.92	4008.24	3835.37

Table 5.5 Site Energy Use West Orientation 3:12 Roof Pitch

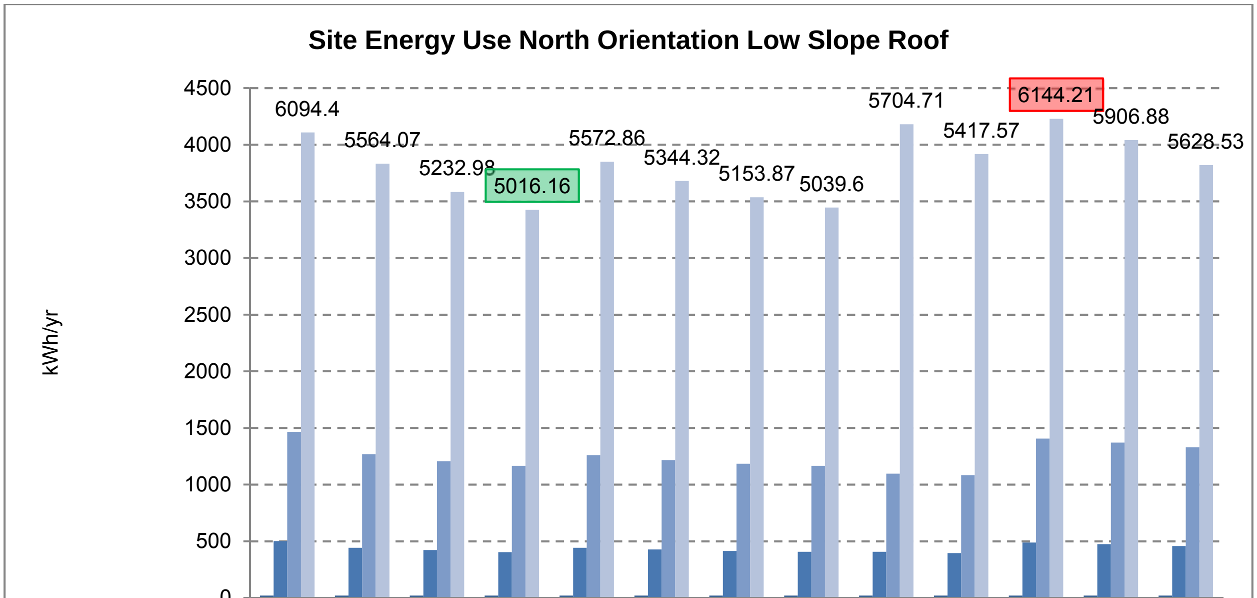
The results of the simulations for the orientation of the building facing west with a mid slope roof, table 5.5, shows that the base case roof was the second worst performer with a total site energy use of 6,088.54 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,226.25 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,232.98 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	509.82	480.52	457.08	442.43	480.52	465.87	451.22	442.43	424.85	410.2	506.89	489.31	474.66
Cooling (E)	1494.3	1380.03	1318.5	1277.48	1371.24	1327.29	1295.06	1277.48	1166.14	1145.63	1465	1423.98	1388.82
Heating (G)	4049.26	4084.42	3829.51	3668.36	4102	3932.06	3782.63	3688.87	4166.46	3806.07	4210.41	3987.73	3794.35

Table 5.6 Site Energy Use West Orientation 6:12 Roof Pitch

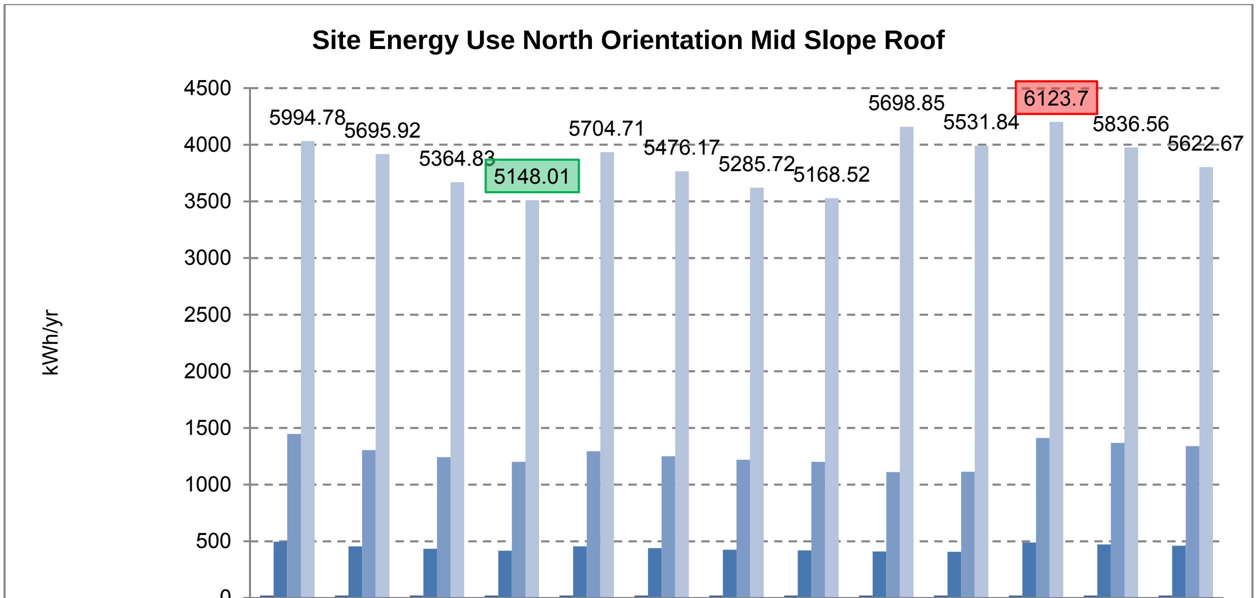
The results of the simulations for the orientation of the building facing west with a steep slope roof, table 5.6, shows that the base case roof was the second worst performer with a total site energy use of 6,073.89 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,202.81 kWh/yr. The best performing roof assembly is the green roof with R-30 insulation with a total site energy use of 5,382.41 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	501.03	442.43	421.92	404.34	442.43	427.78	413.13	407.27	407.27	395.55	489.31	474.66	457.08
Cooling (E)	1465	1268.69	1207.16	1166.14	1259.9	1215.95	1183.72	1166.14	1095.82	1084.1	1406.4	1371.24	1330.22
Heating (G)	4107.86	3832.44	3583.39	3425.17	3850.02	3680.08	3536.51	3445.68	4181.11	3917.41	4227.99	4040.47	3820.72

Table 5.7 Site Energy Use North Orientation 1:12 Roof Pitch

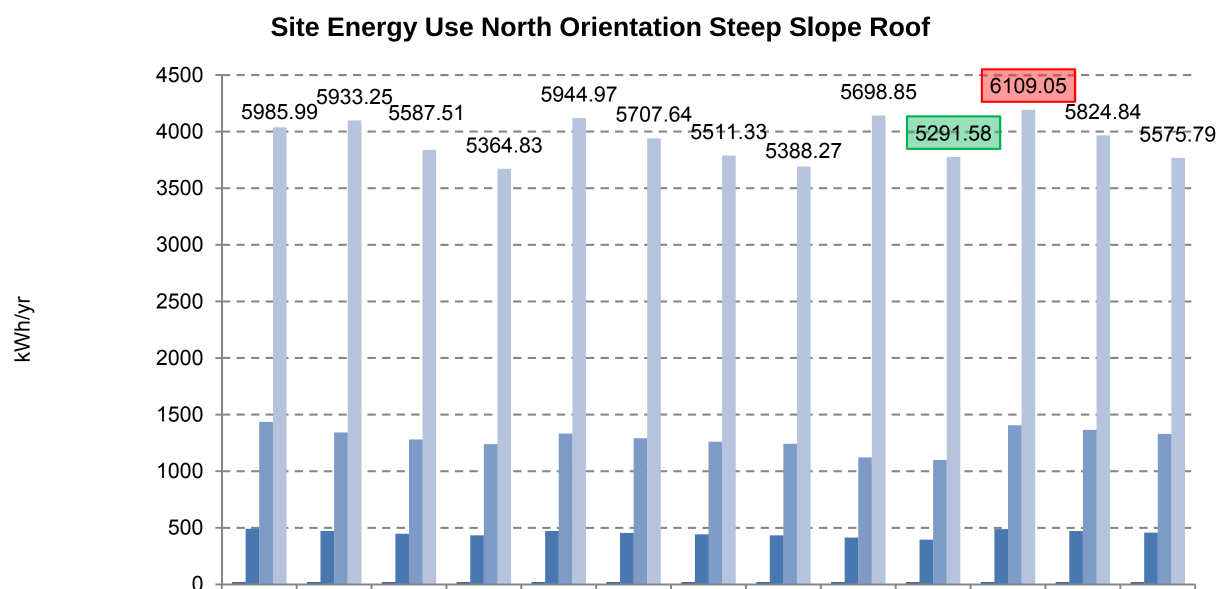
The results of the simulations for the orientation of the building facing north with a low slope roof, table 5.7, shows that the base case roof was the second worst performer with a total site energy use of 6,094.4 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,144.21 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,016.16 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	495.17	454.15	433.64	416.06	454.15	439.5	424.85	418.99	410.2	407.27	489.31	471.73	460.01
Cooling (E)	1447.42	1303.85	1242.32	1201.3	1295.06	1251.11	1218.88	1201.3	1110.47	1113.4	1412.26	1368.31	1339.01
Heating (G)	4031.68	3917.41	3668.36	3510.14	3934.99	3765.05	3621.48	3527.72	4157.67	3990.66	4201.62	3976.01	3803.14

Table 5.8 Site Energy Use North Orientation 3:12 Roof Pitch

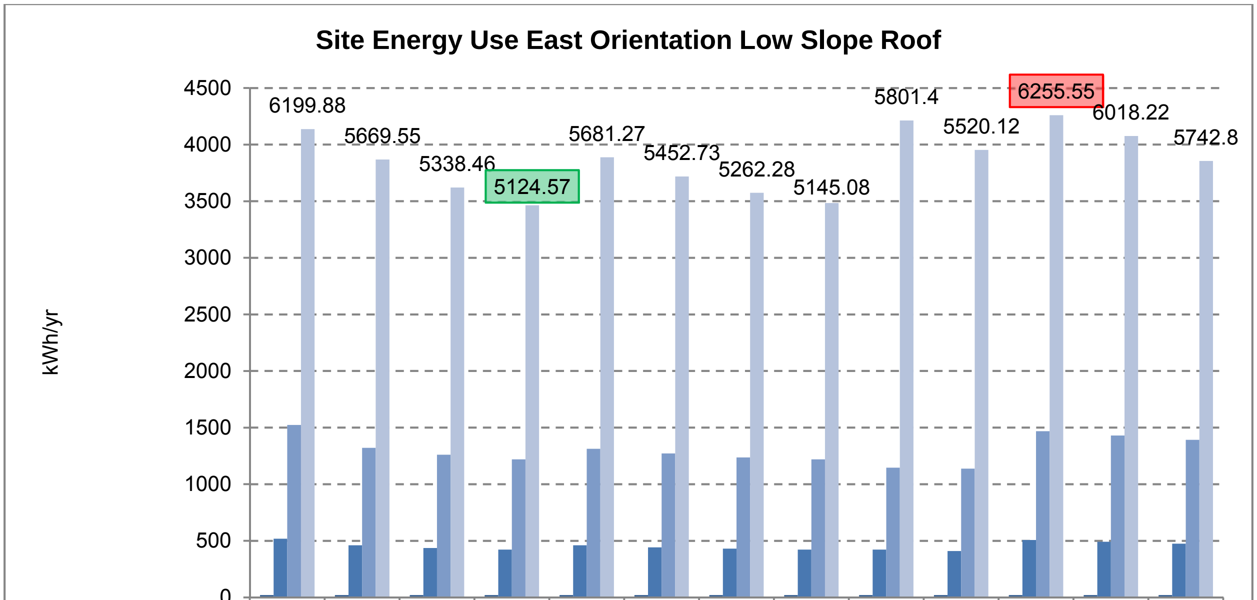
The results of the simulations for the orientation of the building facing north with a mid slope roof, table 5.8, shows that the base case roof was the second worst performer with a total site energy use of 5,994.78 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,123.7 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,148.01 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	492.24	471.73	448.29	433.64	471.73	454.15	442.43	433.64	413.13	395.55	489.31	471.73	457.08
Cooling (E)	1435.7	1341.94	1280.41	1239.39	1333.15	1292.13	1259.9	1242.32	1122.19	1098.75	1406.4	1365.38	1330.22
Heating (G)	4037.54	4099.07	3838.3	3671.29	4119.58	3940.85	3788.49	3691.8	4143.02	3776.77	4192.83	3967.22	3767.98

Table 5.9 Site Energy Use North Orientation 6:12 Roof Pitch

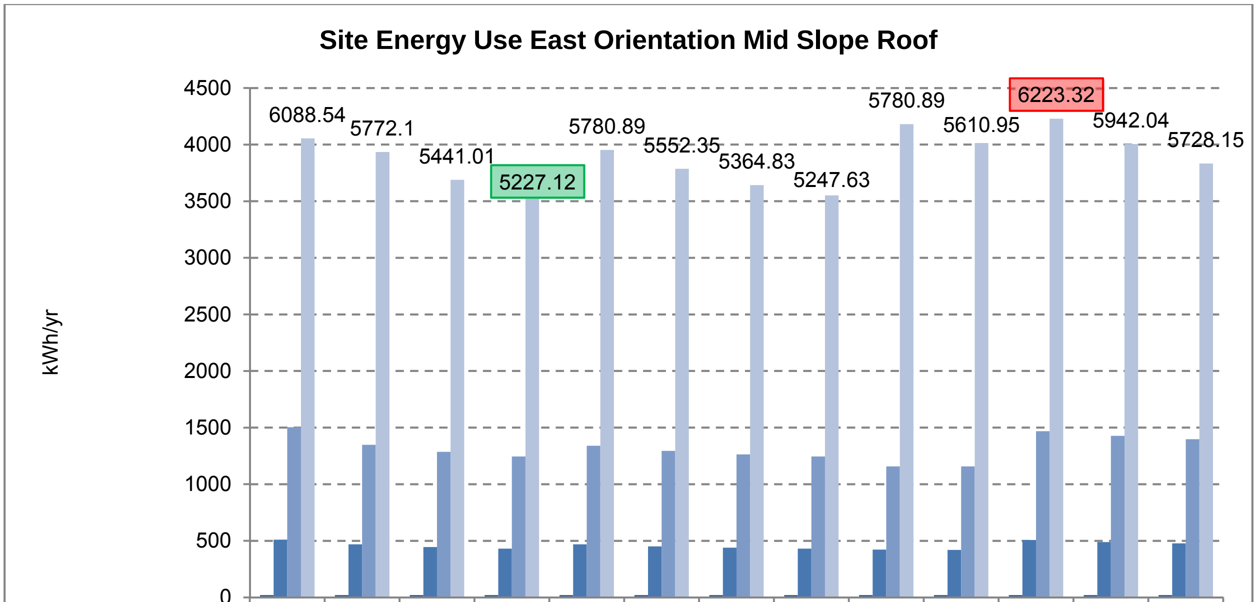
The results of the simulations for the orientation of the building facing north with a steep slope roof, table 5.9, shows that the base case roof was the second worst performer with a total site energy use of 5,985.99 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,109.05 kWh/yr. The best performing roof assembly is the green roof with R-30 insulation with a total site energy use of 5,291.58 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	518.61	460.01	436.57	421.92	460.01	442.43	430.71	421.92	421.92	410.2	506.89	492.24	474.66
Cooling (E)	1523.6	1321.43	1259.9	1218.88	1312.64	1271.62	1236.46	1218.88	1145.63	1136.84	1467.93	1429.84	1391.75
Heating (G)	4137.16	3867.6	3621.48	3463.26	3888.11	3718.17	3574.6	3483.77	4213.34	3952.57	4260.22	4075.63	3855.88

Table 5.10 Site Energy Use East Orientation 1:12 Roof Pitch

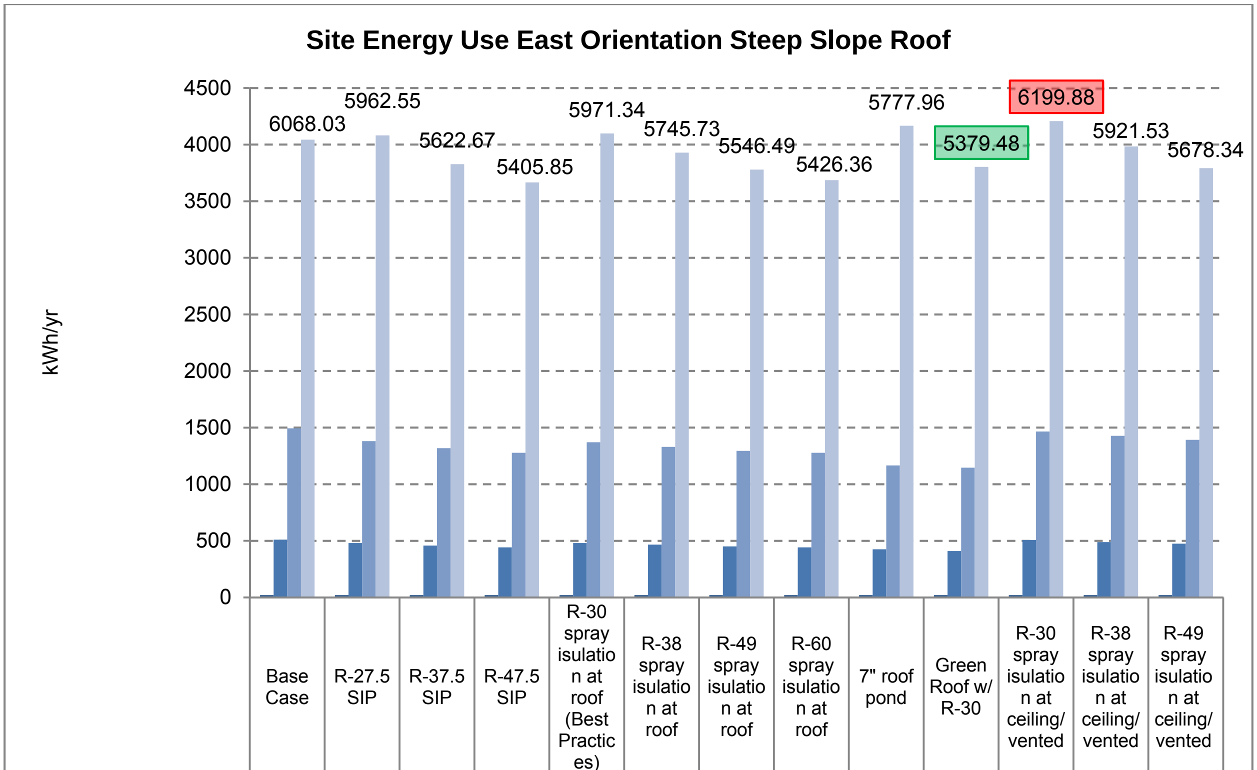
The results of the simulations for the orientation of the building facing east with a low slope roof, table 5.10, shows that the base case roof was the second worst performer with a total site energy use of 6,199.88 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,255.55 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,124.57 kWh/yr.



	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	509.82	468.8	445.36	430.71	468.8	451.22	439.5	430.71	421.92	418.99	506.89	489.31	477.59
Cooling (E)	1503.09	1347.8	1286.27	1245.25	1339.01	1295.06	1262.83	1245.25	1157.35	1157.35	1467.93	1426.91	1397.61
Heating (G)	4055.12	3934.99	3688.87	3530.65	3952.57	3785.56	3641.99	3551.16	4181.11	4014.1	4227.99	4005.31	3832.44

Table 5.11 Site Energy Use East Orientation 3:12 Roof Pitch

The results of the simulations for the orientation of the building facing east with a mid slope roof, table 5.11, shows that the base case roof was the second worst performer with a total site energy use of 5,227.12 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,223.32 kWh/yr. The best performing roof assembly is the R-47.5 SIP with a total site energy use of 5,227.12 kWh/yr.



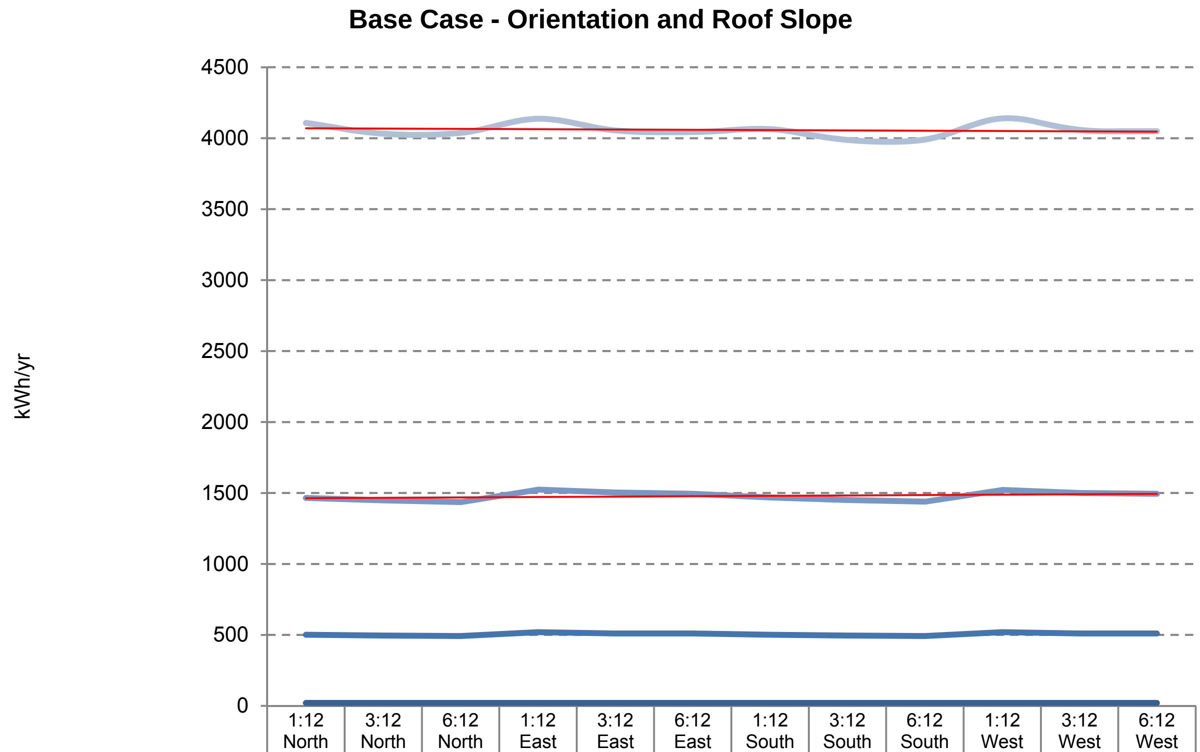
	Base Case	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 spray isulation at roof (Best Practices)	R-38 spray isulation at roof	R-49 spray isulation at roof	R-60 spray isulation at roof	7" roof pond	Green Roof w/ R-30	R-30 spray isulation at ceiling/ vented	R-38 spray isulation at ceiling/ vented	R-49 spray isulation at ceiling/ vented
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	509.82	480.52	457.08	442.43	480.52	465.87	451.22	442.43	424.85	410.2	506.89	489.31	474.66
Cooling (E)	1494.3	1380.03	1318.5	1277.48	1371.24	1330.22	1295.06	1277.48	1166.14	1145.63	1465	1426.91	1391.75
Heating (G)	4043.4	4081.49	3826.58	3665.43	4099.07	3929.13	3779.7	3685.94	4166.46	3803.14	4207.48	3984.8	3791.42

Table 5.12 Site Energy Use East Orientation 6:12 Roof Pitch

The results of the simulations for the orientation of the building facing north with a steep slope roof, table 5.12, shows that the base case roof was the second worst performer with a total site energy use of 6,068.03 kWh/yr. The worst performer was the R-30 spray insulation at the ceiling with the vented attic with a total site energy use of 6,199.88 kWh/yr. The best performing roof assembly is the green roof with R-30 insulation with a total site energy use of 5,379.48 kWh/yr.

The results below are the thirteen roof systems compared to each other for the four orientations simulated as well as for the three roof pitches simulated (Tables 5.13-5.25). These results show how the different systems perform side by side for the different orientations and

pitches so that the highest performing orientations and pitches are able to be chosen for a particular roof assembly. These results will allow for further analysis of the roof assemblies to see if orientation and roof slope have effects on the overall performance of the energy consumption of the residential structure.

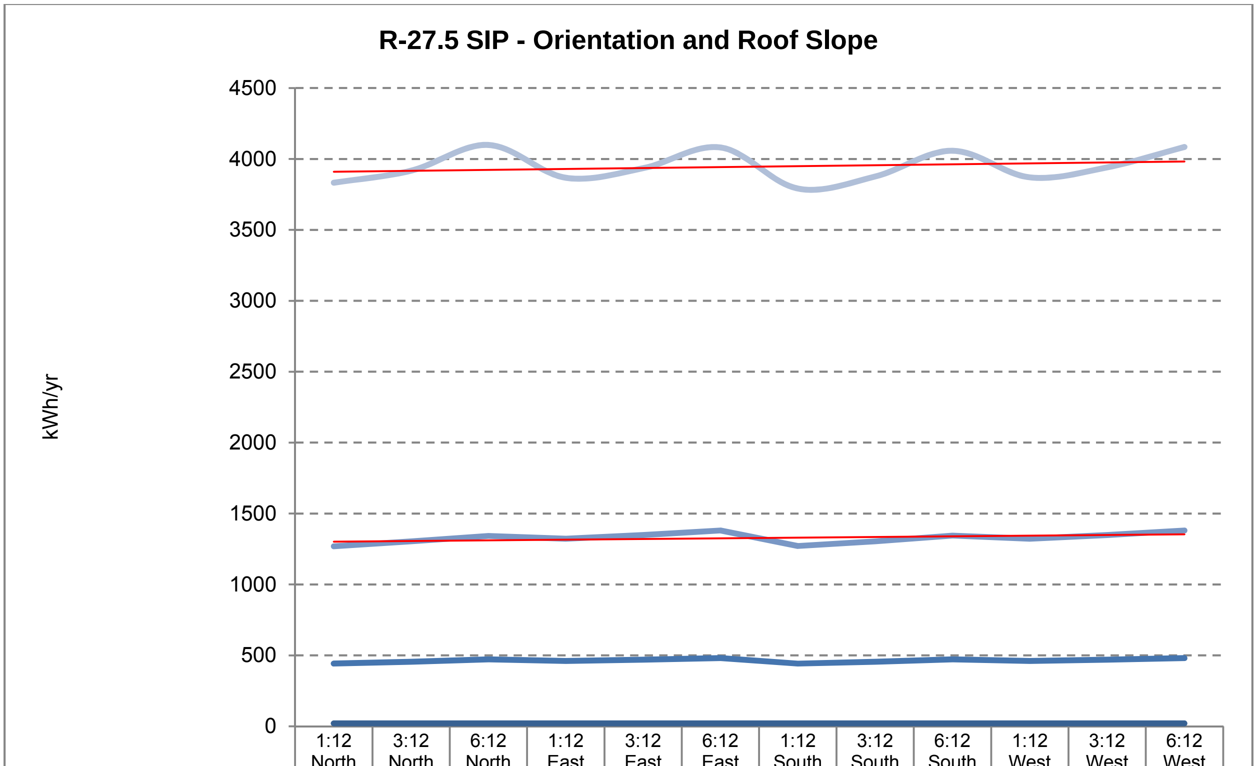


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	501.03	495.17	492.24	518.61	509.82	509.82	501.03	495.17	492.24	518.61	509.82	509.82
Cooling (E)	1465	1447.42	1435.7	1523.6	1503.09	1494.3	1467.93	1450.35	1438.63	1520.67	1500.16	1494.3
Heating (G)	4107.86	4031.68	4037.54	4137.16	4055.12	4043.4	4063.91	3987.73	3990.66	4140.09	4058.05	4049.26

Table 5.13 Site Energy Use Base Case - Orientation & Roof Slope

When comparing the results of simulating the base case roof assembly for all orientations and roof pitches Table 5.13, the site energy used for heating varies between 3987.73 kWh/yr with a south orientation with a mid slope pitch to 4,140.09 kWh/yr with an east

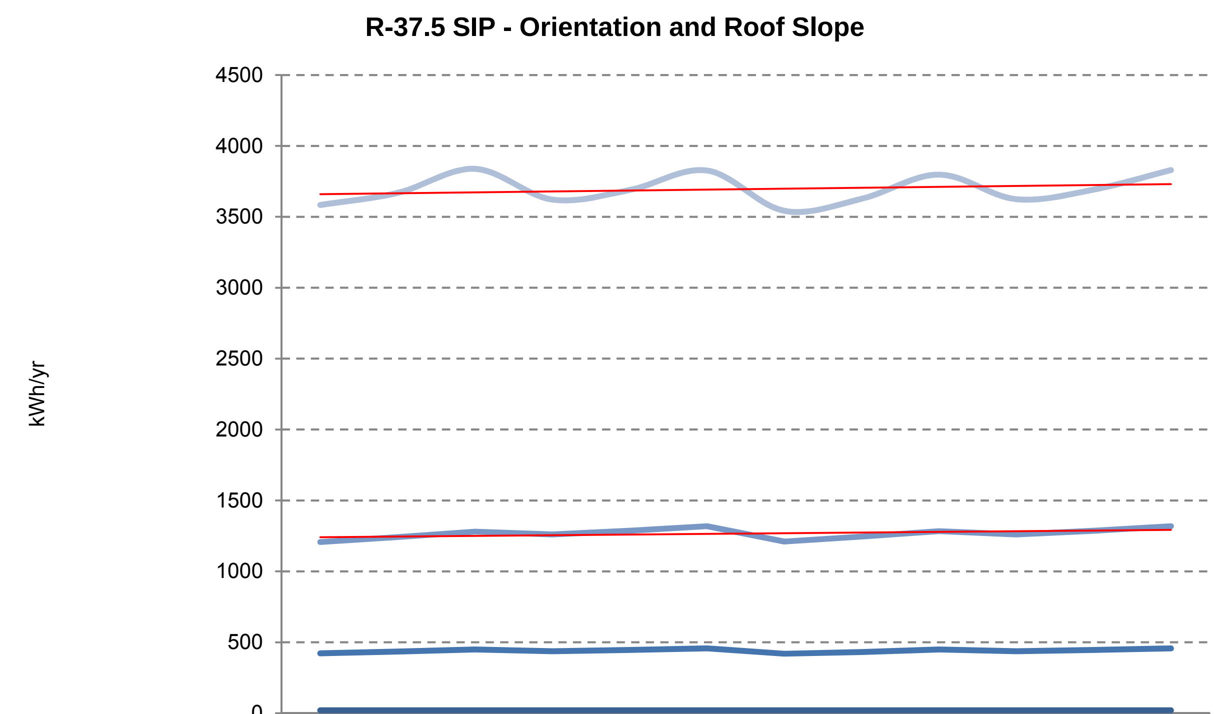
orientation and low slope pitch. The site energy used for cooling varies from 1,435.7 kWh/yr with a north orientation and steep slope pitch to 1,523.6 kWh/yr with an east orientation and low slope pitch. The site energy used for the HVAC fan/pump varies from 492.24 kWh/yr with either a south or north orientation and steep slope to 518.61 kWh/yr with either an east or west orientation and low slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The base case assembly performs better for heating with a mid slope for north and south orientations, and performs better with a steep slope for east and west orientations. The base case also performs better for cooling with a steep slope, for HVAC fan/pump with a steep slope, and for vent fan, all slopes were the same.



	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	442.43	454.15	471.73	460.01	468.8	480.52	442.43	454.15	471.73	460.01	468.8	480.52
Cooling (E)	1268.69	1303.85	1341.94	1321.43	1347.8	1380.03	1271.62	1303.85	1344.87	1321.43	1347.8	1380.03
Heating (G)	3832.44	3917.41	4099.07	3867.6	3934.99	4081.49	3791.42	3876.39	4058.05	3870.53	3940.85	4084.42

Table 5.14 Site Energy Use R-27.5 SIP - Orientation & Roof Slope

When comparing the results of simulating the R-27.5 SIP roof assembly for all orientations and roof pitches Table 5.14, the site energy used for heating varies between 3,791.42 kWh/yr with a south orientation with a low slope pitch to 4,099.07 kWh/yr with a north orientation and steep slope pitch. The site energy used for cooling varies from 1,268.69 kWh/yr with a north orientation and low slope pitch to 1380.03 kWh/yr with either an east orientation or west orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 442.43 kWh/yr with either a south or north orientation and low slope to 480.52 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-27.5 SIP assembly performs better for heating with a low slope, for cooling with a low slope, for HVAC Fan/Pump with a low slope, and for vent fan, all slopes were the same.

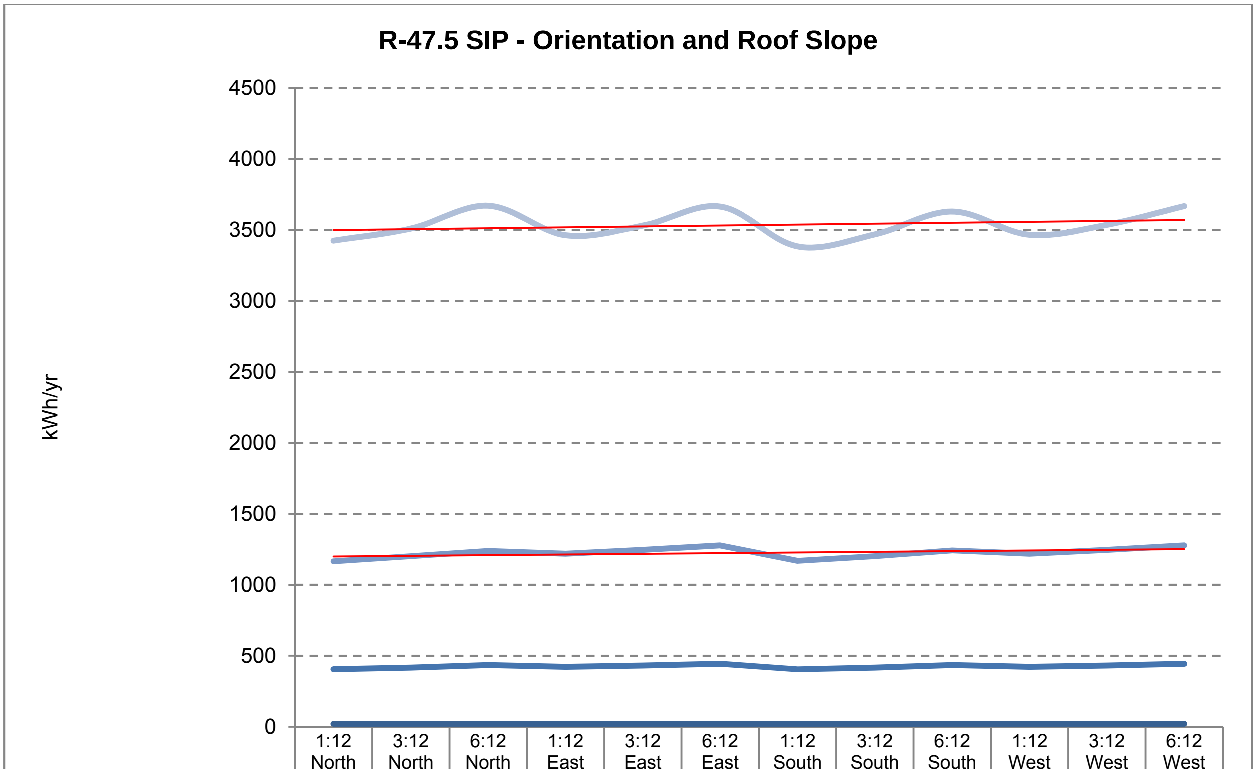


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	421.92	433.64	448.29	436.57	445.36	457.08	418.99	430.71	448.29	436.57	445.36	457.08
Cooling (E)	1207.16	1242.32	1280.41	1259.9	1286.27	1318.5	1210.09	1245.25	1283.34	1259.9	1286.27	1318.5
Heating (G)	3583.39	3668.36	3838.3	3621.48	3688.87	3826.58	3542.37	3627.34	3797.28	3624.41	3691.8	3829.51

Table 5.15 Site Energy Use R-37.5 SIP - Orientation & Roof Slope

When comparing the results of simulating the R-37.5 SIP roof assembly for all orientations and roof pitches Table 5.15, the site energy used for heating varies between 3,542.37 kWh/yr with a south orientation with a low slope pitch to 3,829.51 kWh/yr with west orientation and steep slope pitch. The site energy used for cooling varies from 1,207.16 kWh/yr with a north orientation and low slope pitch to 1,318.5 kWh/yr with either an east or west orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 418.99 kWh/yr with a south orientation and low slope to 448.29 kWh/yr with either a north or south orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-37.5 SIP assembly

performs better for heating with a low slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan, all slopes were the same.

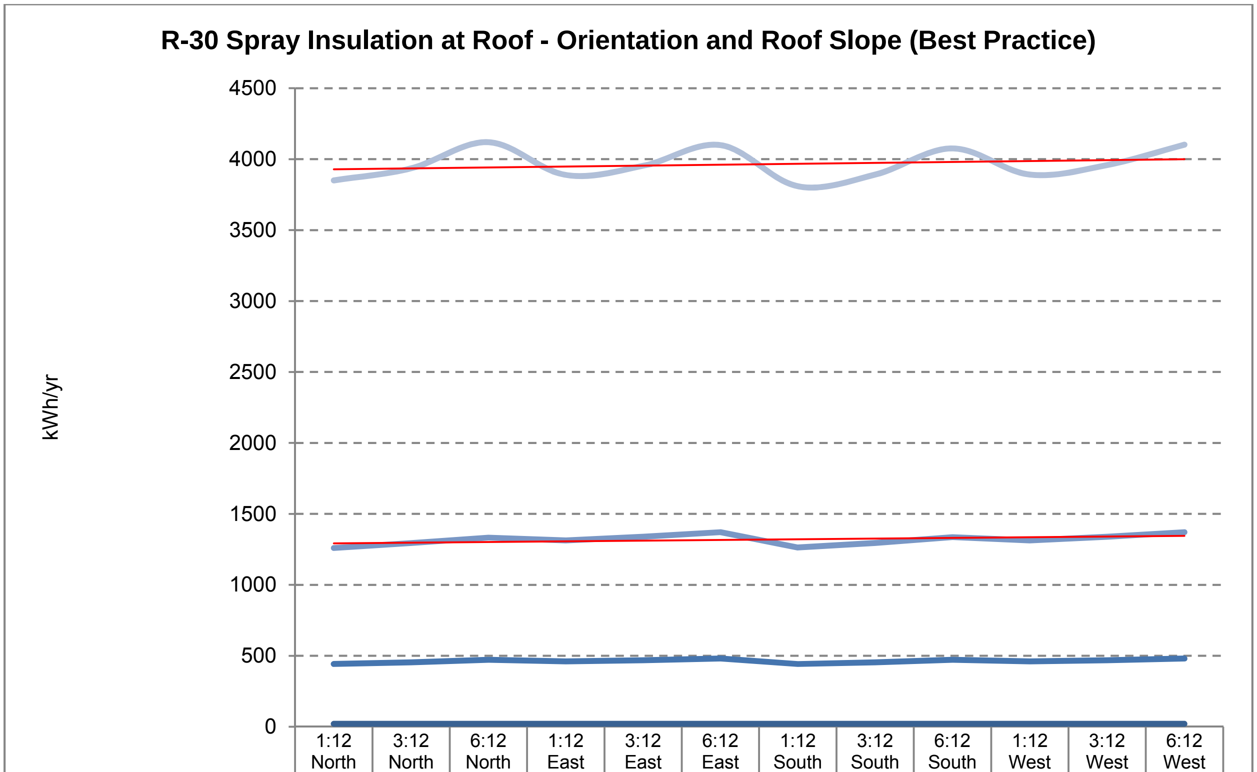


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	404.34	416.06	433.64	421.92	430.71	442.43	404.34	416.06	433.64	421.92	430.71	442.43
Cooling (E)	1166.14	1201.3	1239.39	1218.88	1245.25	1277.48	1169.07	1201.3	1242.32	1218.88	1245.25	1277.48
Heating (G)	3425.17	3510.14	3671.29	3463.26	3530.65	3665.43	3384.15	3469.12	3630.27	3466.19	3536.51	3668.36

Table 5.16 Site Energy Use R-47.5 SIP - Orientation & Roof Slope

When comparing the results of simulating the R-47.5 SIP roof assembly for all orientations and roof pitches Table 5.16, the site energy used for heating varies between 3,384.15 kWh/yr with a south orientation with a low slope pitch to 3,668.36 kWh/yr with west orientation and steep slope pitch. The site energy used for cooling varies from 1,166.14 kWh/yr with a north orientation and low slope pitch to 1,277.48 kWh/yr with either an east or west

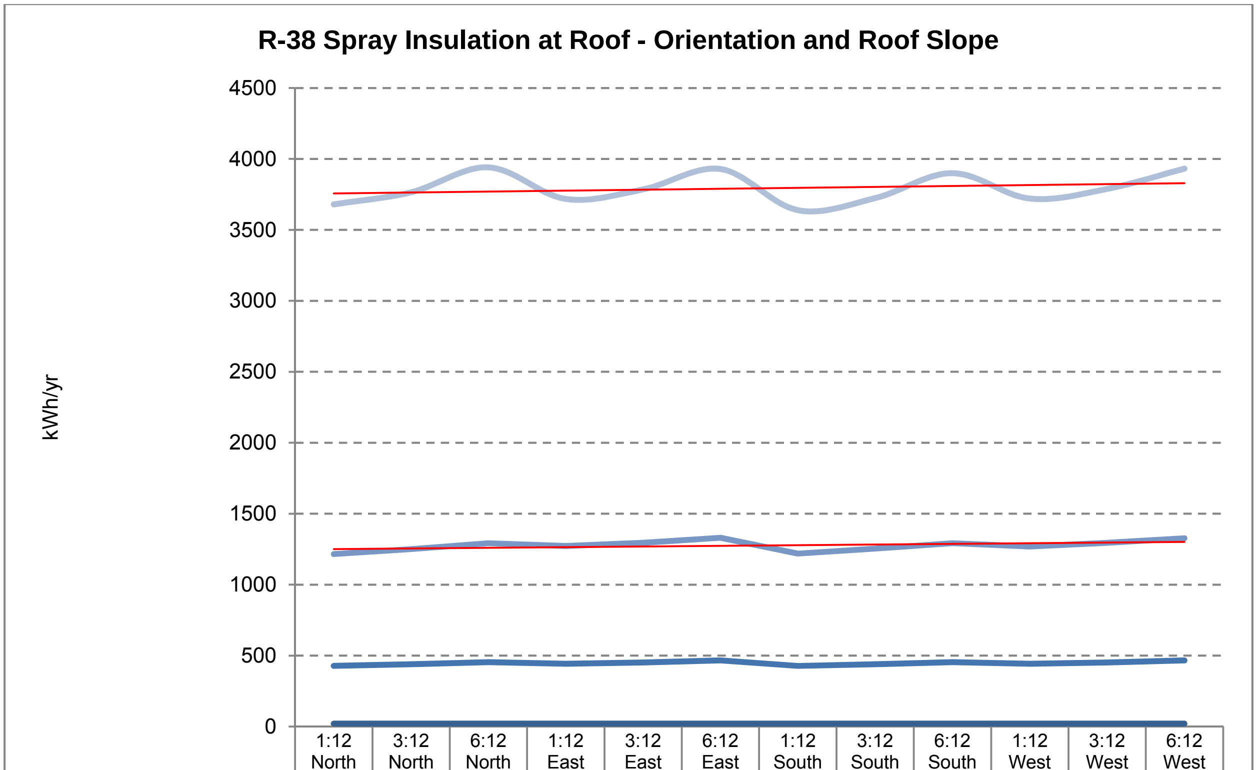
orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 404.34 kWh/yr with either a north or south orientation and low slope to 442.43 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-47.5 SIP assembly performs better for heating with a low slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan all, slopes were the same.



	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	442.43	454.15	471.73	460.01	468.8	480.52	442.43	454.15	471.73	460.01	468.8	480.52
Cooling (E)	1259.9	1295.06	1333.15	1312.64	1339.01	1371.24	1262.83	1295.06	1336.08	1312.64	1339.01	1371.24
Heating (G)	3850.02	3934.99	4119.58	3888.11	3952.57	4099.07	3809	3891.04	4075.63	3891.04	3958.43	4102

Table 5.17 Site Energy Use R-30 Spray Insulation at Roof - Orientation & Roof Slope (Best Practice)

When comparing the results of simulating the R-30 Spray insulation at roof assembly for all orientations and roof pitches Table 5.17, the site energy used for heating varies between 3,809 kWh/yr with a south orientation with a low slope pitch to 4,119.58 kWh/yr with north orientation and steep slope pitch. The site energy used for cooling varies from 1,259.9 kWh/yr with a north orientation and low slope pitch to 1,371.24 kWh/yr with either an east or west orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 442.43 kWh/yr with either a north or south orientation and low slope to 480.52 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-30 Spray insulation at roof assembly performs better for heating with a low slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan, all slopes were the same.

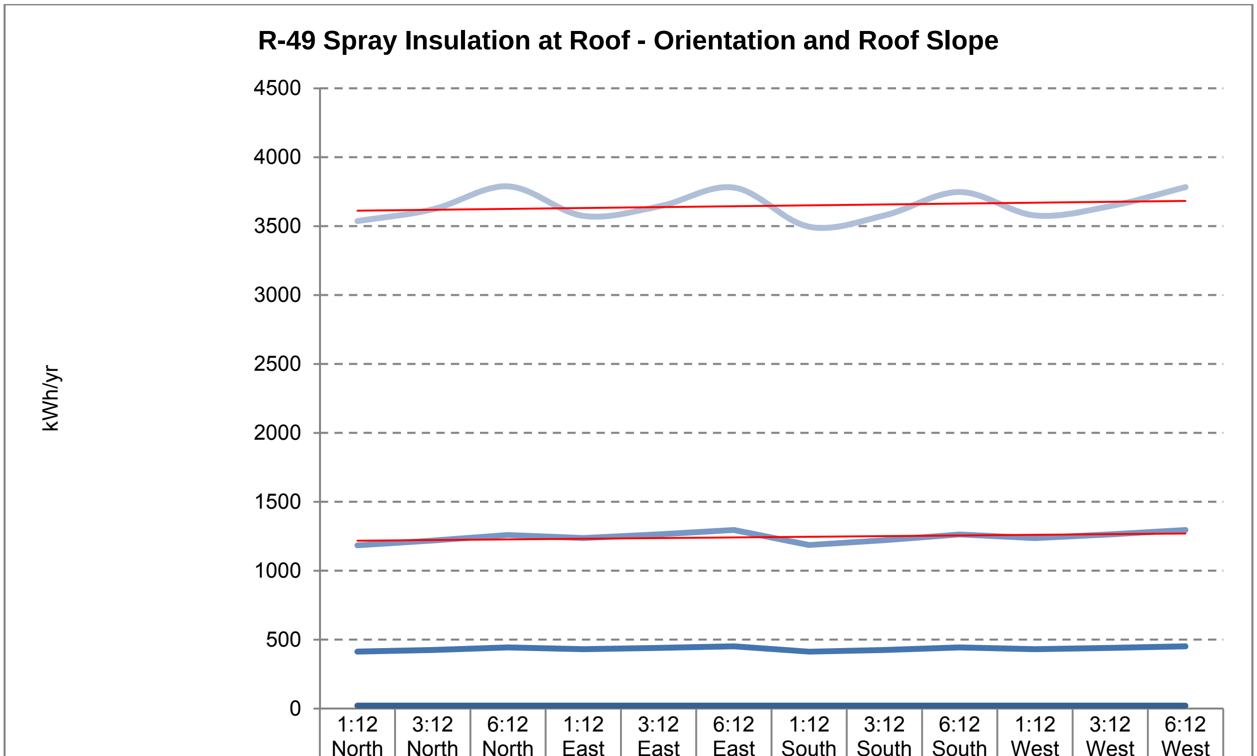


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	427.78	439.5	454.15	442.43	451.22	465.87	427.78	439.5	454.15	442.43	451.22	465.87
Cooling (E)	1215.95	1251.11	1292.13	1271.62	1295.06	1330.22	1218.88	1254.04	1292.13	1268.69	1295.06	1327.29
Heating (G)	3680.08	3765.05	3940.85	3718.17	3785.56	3929.13	3639.06	3724.03	3899.83	3721.1	3788.49	3932.06

Table 5.18 Site Energy Use R-38 Spray Insulation at Roof - Orientation & Roof Slope

When comparing the results of simulating the R-38 Spray insulation at roof assembly for all orientations and roof pitches Table 5.18, the site energy used for heating varies between 3,639.06 kWh/yr with a south orientation with a low slope pitch to 3,940.85 kWh/yr with north orientation and steep slope pitch. The site energy used for cooling varies from 1,215.95 kWh/yr with a north orientation and low slope pitch to 1,330.22 kWh/yr with an east orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 427.78 kWh/yr with either a north or south orientation and low slope to 465.87 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-38 Spray insulation at roof assembly

performs better for heating with a low slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan, all slopes were the same.

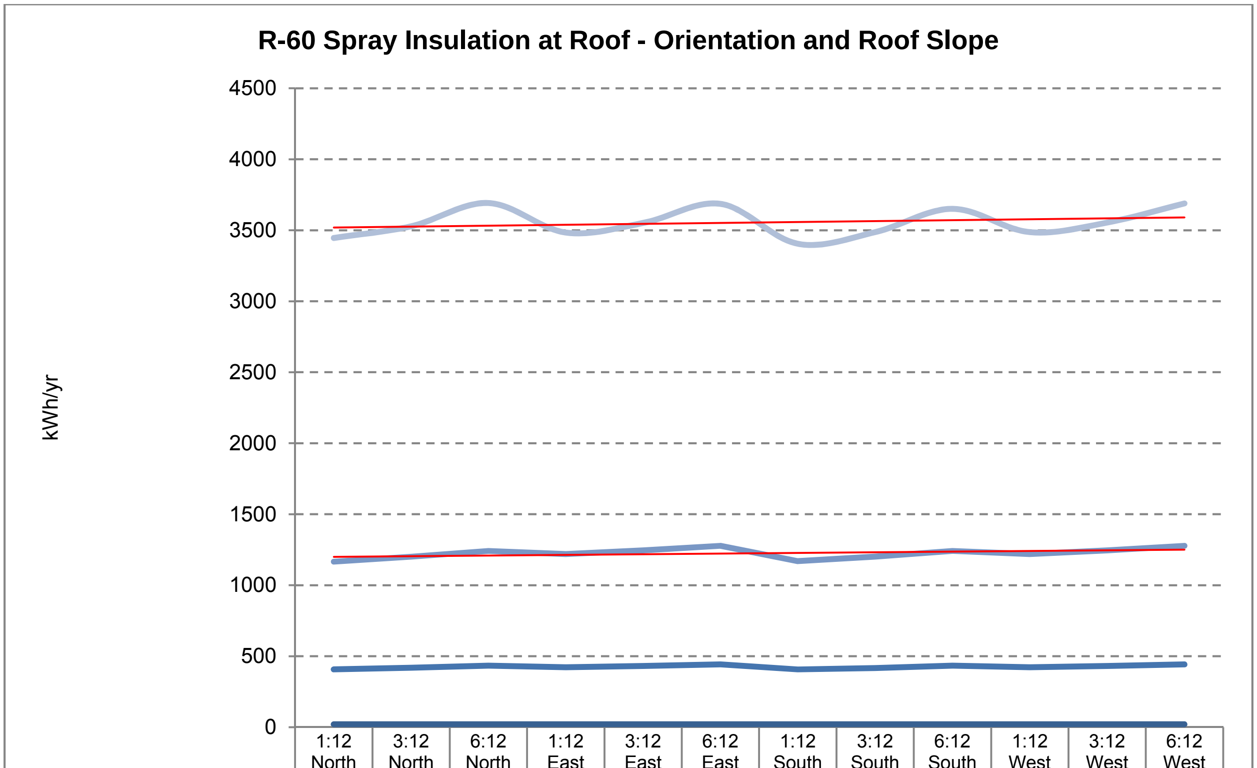


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	413.13	424.85	442.43	430.71	439.5	451.22	413.13	424.85	442.43	430.71	439.5	451.22
Cooling (E)	1183.72	1218.88	1259.9	1236.46	1262.83	1295.06	1186.65	1221.81	1262.83	1236.46	1262.83	1295.06
Heating (G)	3536.51	3621.48	3788.49	3574.6	3641.99	3779.7	3495.49	3577.53	3747.47	3577.53	3644.92	3782.63

Table 5.19 Site Energy Use R-49 Spray Insulation at Roof - Orientation & Roof Slope

When comparing the results of simulating the R-49 Spray insulation at roof assembly for all orientations and roof pitches Table 5.19, the site energy used for heating varies between 3,495.49 kWh/yr with a south orientation with a low slope pitch to 3,788.49 kWh/yr with north orientation and steep slope pitch. The site energy used for cooling varies from 1,183.72 kWh/yr with a north orientation and low slope pitch to 1,295.06 kWh/yr with either an east or west

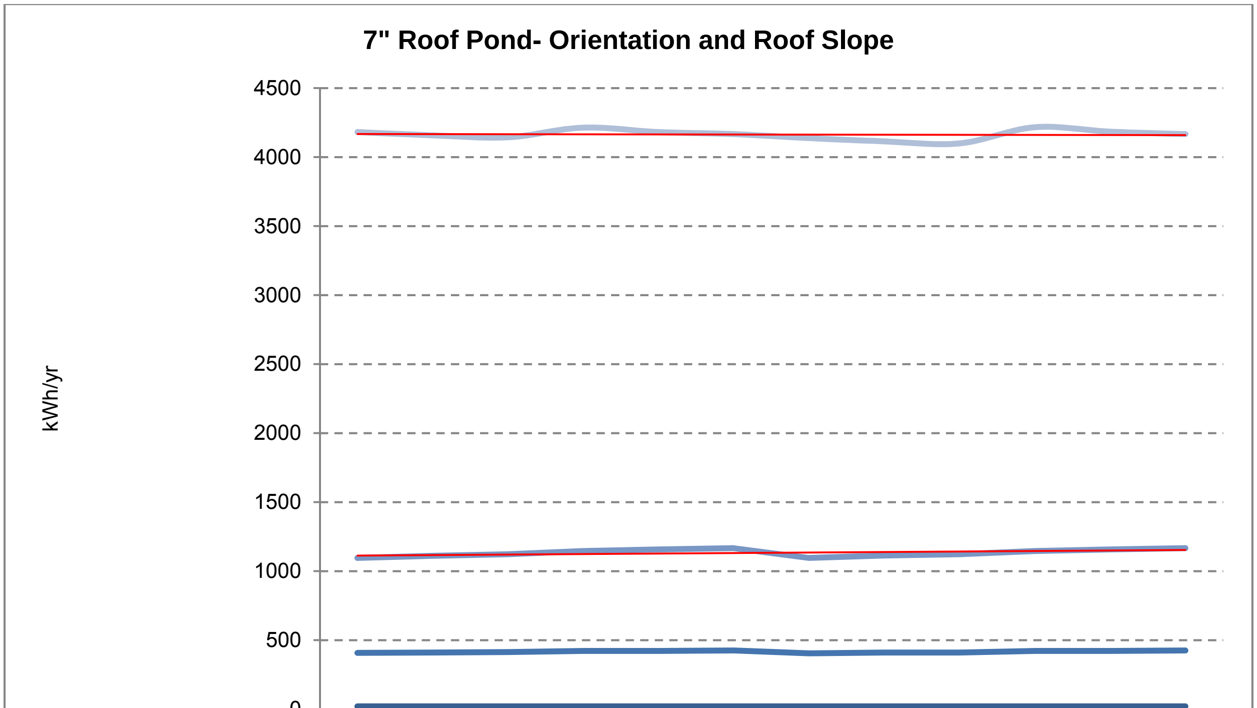
orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 413.13 kWh/yr with either a north or south orientation and low slope to 451.22 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-49 Spray insulation at roof assembly performs better for heating with a low slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan, all slopes were the same.



	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	407.27	418.99	433.64	421.92	430.71	442.43	407.27	416.06	433.64	421.92	430.71	442.43
Cooling (E)	1166.14	1201.3	1242.32	1218.88	1245.25	1277.48	1169.07	1201.3	1242.32	1218.88	1245.25	1277.48
Heating (G)	3445.68	3527.72	3691.8	3483.77	3551.16	3685.94	3404.66	3486.7	3650.78	3486.7	3554.09	3688.87

Table 5.20 Site Energy Use R-60 Spray Insulation at Roof - Orientation & Roof Slope

When comparing the results of simulating the R-60 Spray insulation at roof assembly for all orientations and roof pitches Table 5.20, the site energy used for heating varies between 3,404.66 kWh/yr with a south orientation with a low slope pitch to 3,691.8 kWh/yr with north orientation and steep slope pitch. The site energy used for cooling varies from 1,166.14 kWh/yr with a north orientation and low slope pitch to 1,277.48 kWh/yr with either an east or west orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 407.27 kWh/yr with either a north or south orientation and low slope to 442.43 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-60 Spray insulation at roof assembly performs better for heating with a low slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan, all slopes were the same.

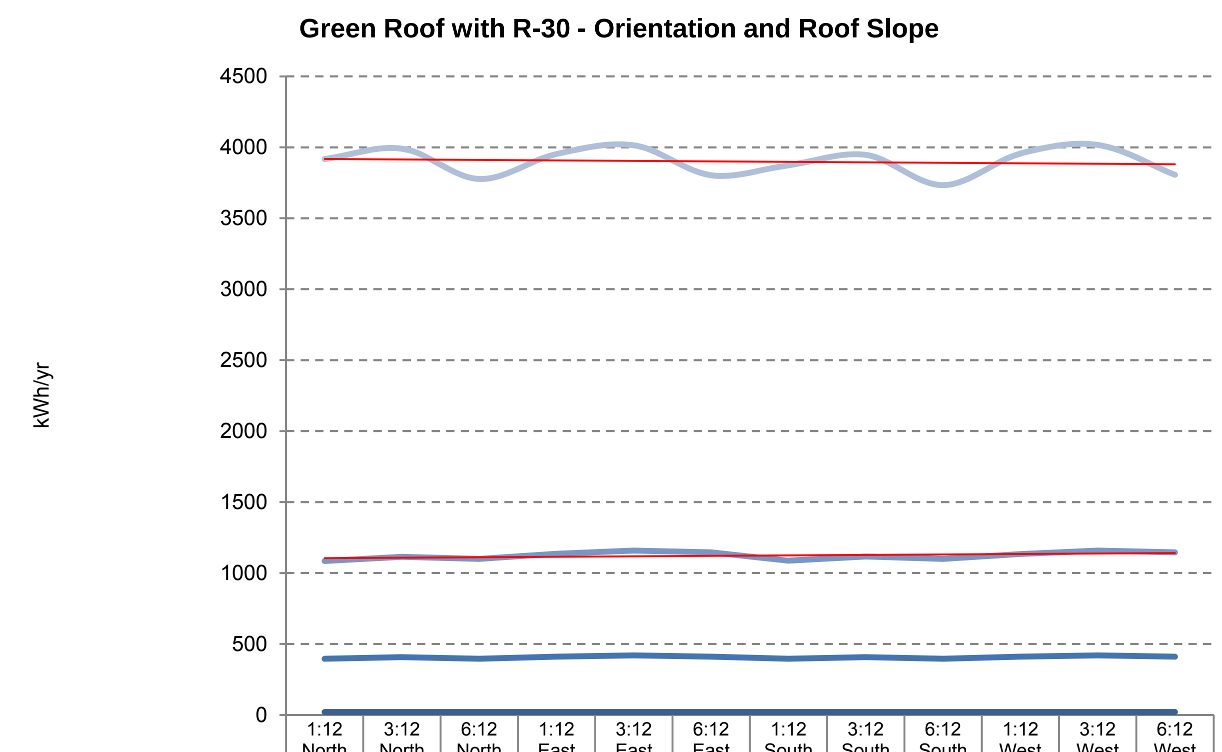


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	407.27	410.2	413.13	421.92	421.92	424.85	404.34	410.2	410.2	421.92	421.92	424.85
Cooling (E)	1095.82	1110.47	1122.19	1145.63	1157.35	1166.14	1095.82	1113.4	1122.19	1145.63	1157.35	1166.14
Heating (G)	4181.11	4157.67	4143.02	4213.34	4181.11	4166.46	4137.16	4113.72	4099.07	4216.27	4184.04	4166.46

Table 5.21 Site Energy Use 7” Roof Pond - Orientation & Roof Slope

When comparing the results of simulating the roof pond assembly for all orientations and roof pitches Table 5.21, the site energy used for heating varies between 4,099.07 kWh/yr with a south orientation with a steep slope pitch to 4,216.27 kWh/yr with west orientation and low slope pitch. The site energy used for cooling varies from 1,095.82 kWh/yr with either a north or south orientation and low slope roof to 1,166.14 kWh/yr with either an east or west orientation and steep slope pitch. The site energy used for the HVAC fan/pump varies from 404.34 kWh/yr with a south orientation and low slope to 424.85 kWh/yr with either an east or west orientation and steep slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The roof pond performs better for heating with a steep

slope, for cooling with a low slope, for HVAC fan/pump with a low slope, and for vent fan, all slopes were the same.

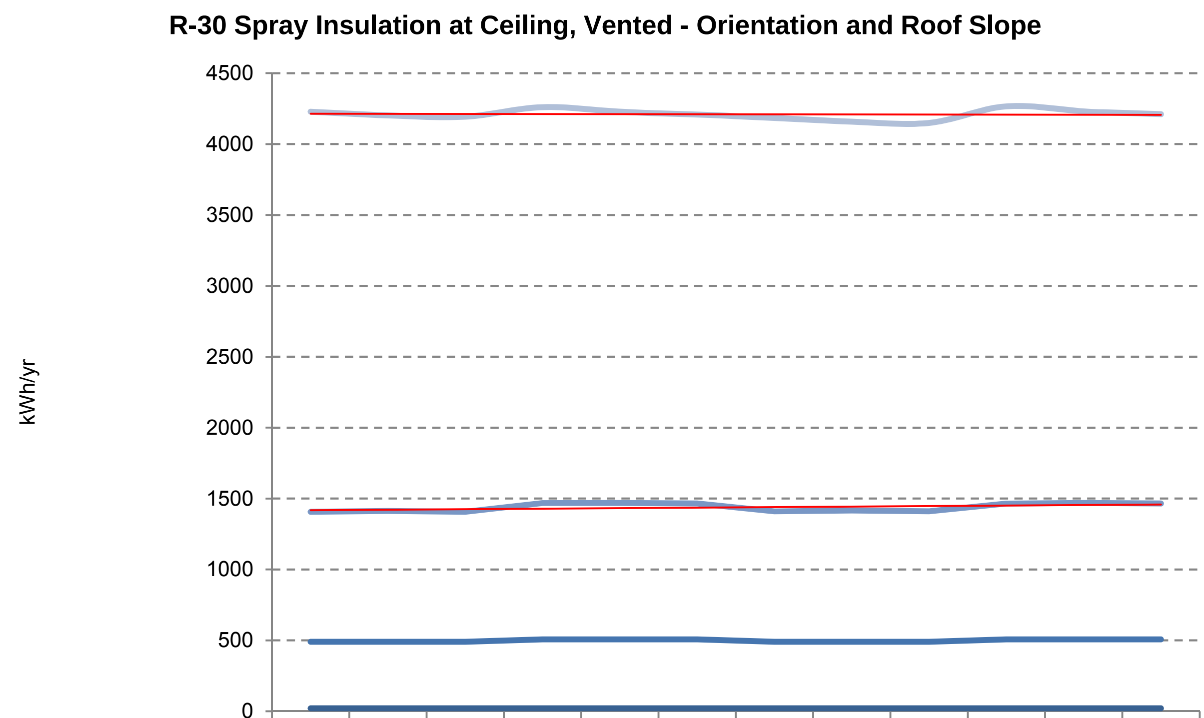


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	395.55	407.27	395.55	410.2	418.99	410.2	395.55	407.27	395.55	410.2	418.99	410.2
Cooling (E)	1084.1	1113.4	1098.75	1136.84	1157.35	1145.63	1087.03	1116.33	1098.75	1133.91	1157.35	1145.63
Heating (G)	3917.41	3990.66	3776.77	3952.57	4014.1	3803.14	3873.46	3946.71	3732.82	3955.5	4017.03	3806.07

Table 5.22 Site Energy Use Green Roof with R-30 - Orientation & Roof Slope

When comparing the results of simulating the green roof with R-30 insulation assembly for all orientations and roof pitches Table 5.22, the site energy used for heating varies between 3,803.14 kWh/yr with an east orientation with a steep slope pitch to 4,017.03 kWh/yr with west orientation and mid slope pitch. The site energy used for cooling varies from 1,084.1 kWh/yr with a north orientation and low slope roof to 1,157.35kWh/yr with either an east or west

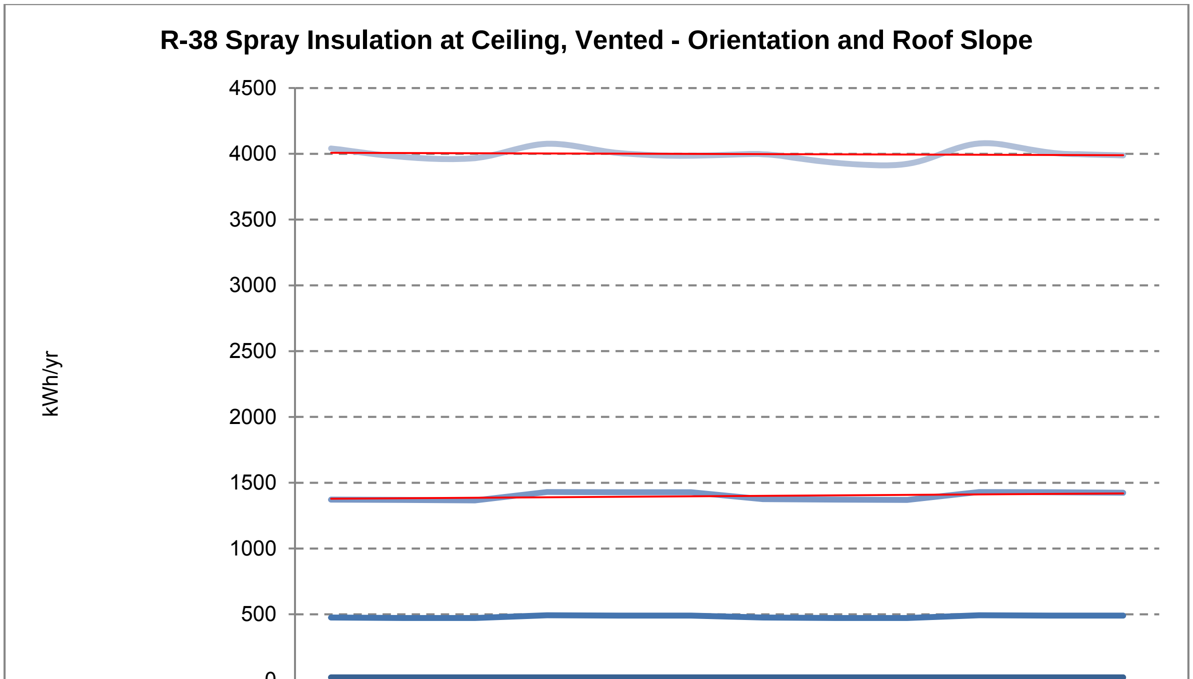
orientation and mid slope roof. The site energy used for the HVAC fan/pump varies from 395.55 kWh/yr with either a south or north orientation and either a low or steep slope to 418.99 kWh/yr with an east orientation and mid slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The green roof performs better for heating with a steep slope, for cooling with a low slope, for HVAC fan/pump with either a low slope or steep slope, and for vent fan, all slopes were the same.



	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	489.31	489.31	489.31	506.89	506.89	506.89	489.31	489.31	489.31	506.89	506.89	506.89
Cooling (E)	1406.4	1412.26	1406.4	1467.93	1467.93	1465	1409.33	1415.19	1409.33	1465	1467.93	1465
Heating (G)	4227.99	4201.62	4192.83	4260.22	4227.99	4207.48	4184.04	4157.67	4148.88	4266.08	4230.92	4210.41

Table 5.23 Site Energy Use R-30 Spray Insulation at Ceiling, Vented - Orientation & Roof Slope

When comparing the results of simulating the R-30 Spray insulation at ceiling with vented attic assembly for all orientations and roof pitches Table 5.23, the site energy used for heating varies between 4,148.88 kWh/yr with a south orientation with a steep slope pitch to 4,266.08 kWh/yr with west orientation and low slope pitch. The site energy used for cooling varies from 1,406.4 kWh/yr with a north orientation and either a low or steep slope roof to 1,467.93 kWh/yr with either an east or west orientation and either a low or mid slope roof. The site energy used for the HVAC fan/pump varies from 489.31 kWh/yr with either a north or south orientation and any slope to 506.89 kWh/yr with either an east or west orientation and any slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-30 Spray insulation at ceiling with vented attic assembly performs better for heating with a steep slope, for cooling with either a low or steep slope, for HVAC fan/pump with any slope, and for vent fan all slopes were the same.

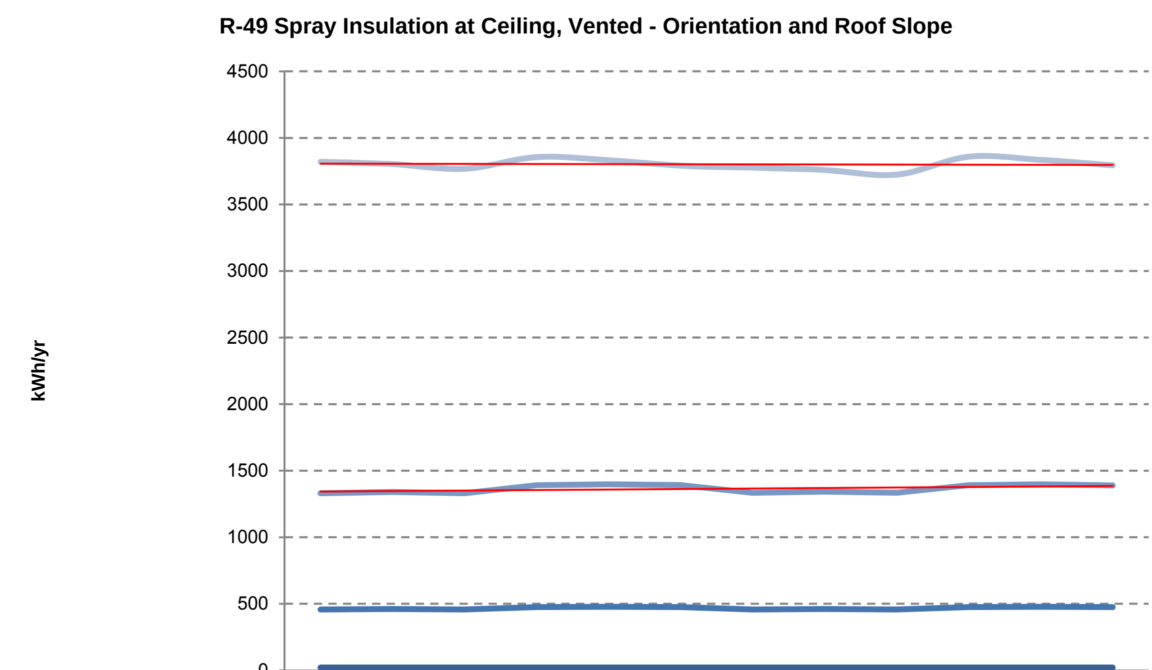


	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	474.66	471.73	471.73	492.24	489.31	489.31	474.66	471.73	471.73	492.24	489.31	489.31
Cooling (E)	1371.24	1368.31	1365.38	1429.84	1426.91	1426.91	1374.17	1371.24	1368.31	1429.84	1426.91	1423.98
Heating (G)	4040.47	3976.01	3967.22	4075.63	4005.31	3984.8	3996.52	3932.06	3923.27	4078.56	4008.24	3987.73

Table 5.24 Site Energy Use R-38 Spray Insulation at Ceiling, Vented - Orientation & Roof Slope

When comparing the results of simulating the R-38 Spray insulation at ceiling with vented attic assembly for all orientations and roof pitches Table 5.24, the site energy used for heating varies between 3,923.27 kWh/yr with a south orientation with a steep slope pitch to 4,078.56 kWh/yr with west orientation and low slope pitch. The site energy used for cooling varies from 1,365.38 kWh/yr with a north orientation and a steep slope pitch to 1,429.84 kWh/yr with either an east or west orientation and a low slope pitch. The site energy used for the HVAC fan/pump varies from 471.73 kWh/yr with either a north or south orientation and either a mid or steep slope pitch to 492.24 kWh/yr with either an east or west orientation and a low slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-38 Spray insulation at ceiling with vented attic assembly performs better

for heating with a steep slope, for cooling with a steep slope, for HVAC fan/pump with either a mid or steep, and for vent fan, all slopes were the same.



	1:12 North	3:12 North	6:12 North	1:12 East	3:12 East	6:12 East	1:12 South	3:12 South	6:12 South	1:12 West	3:12 West	6:12 West
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	457.08	460.01	457.08	474.66	477.59	474.66	457.08	460.01	457.08	474.66	477.59	474.66
Cooling (E)	1330.22	1339.01	1330.22	1391.75	1397.61	1391.75	1333.15	1341.94	1333.15	1391.75	1397.61	1388.82
Heating (G)	3820.72	3803.14	3767.98	3855.88	3832.44	3791.42	3776.77	3759.19	3724.03	3858.81	3835.37	3794.35

Table 5.25 Site Energy Use R-49 Spray Insulation at Ceiling, Vented - Orientation & Roof Slope

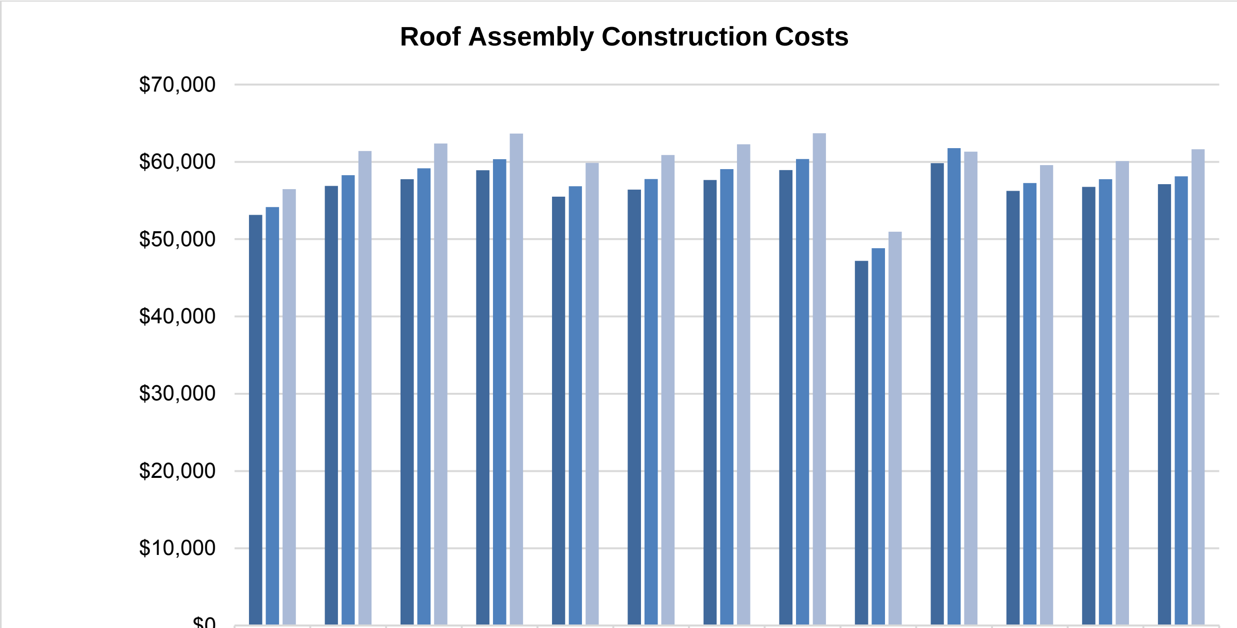
When comparing the results of simulating the R-49 Spray insulation at ceiling with vented attic assembly for all orientations and roof pitches Table 5.25, the site energy used for heating varies between 3,724.03 kWh/yr with a south orientation with a steep slope pitch to 3,858.81 kWh/yr with west orientation and low slope pitch. The site energy used for cooling varies from 1,330.22 kWh/yr with a north orientation and either a low or steep slope pitch to 1,397.61 kWh/yr with either an east or west orientation and a mid slope pitch. The site energy

used for the HVAC fan/pump varies from 457.08 kWh/yr, with either a north or south orientation and with either a low or steep slope pitch to 477.59 kWh/yr with either an east or west orientation and a mid slope pitch. The vent fan site energy use was unaffected by orientation or roof slope and remained constant at 20.51 kWh/yr. The R-49 Spray insulation at ceiling with vented attic assembly performs better for heating with a steep slope, for cooling with either a low or steep slope, for HVAC fan/pump with either a low or steep slope, and for vent fan, all slopes were the same.

5.2 Costs of Systems

The cost of the roof systems are important to review. Along with seeing how well a system performs in different orientations and pitches, the cost of the overall system to achieve those results weighs in heavily. There needs to be a good return for the investment for the system selected and if there is a system that performs as well and lowers the cost it would be worth looking at further.

To help in the analysis of the roof systems, construction cost data was compiled from the tests performed in BEopt. The construction costs of the different roof systems including costs for the three tested roof slopes are below.



	Standard Practice	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 Spray insulation at Roof	R-38 Spray insulation at Roof (Best Practice)	R-49 Spray insulation at Roof	R-60 Spray insulation at Roof	7" Roof Pond*	Green Roof w/ R-30	R-30 Spray insulation at ceiling	R-38 Spray insulation at ceiling	R-49 Spray insulation at ceiling
Low-Sloped Roof	$53,142	$56,887	$57,758	$58,916	$55,496	$56,410	$57,663	$58,937	$47,201	$59,821	$56,244	$56,758	$57,115
Mid-Sloped Roof	$54,147	$58,266	$59,160	$60,350	$56,837	$57,775	$59,062	$60,371	$48,833	$61,772	$57,249	$57,763	$58,120
Steep_Sloped Roof	$56,477	$61,411	$62,381	$63,671	$59,879	$60,878	$62,274	$63,694	$50,971	$61,318	$59,580	$60,094	$61,628

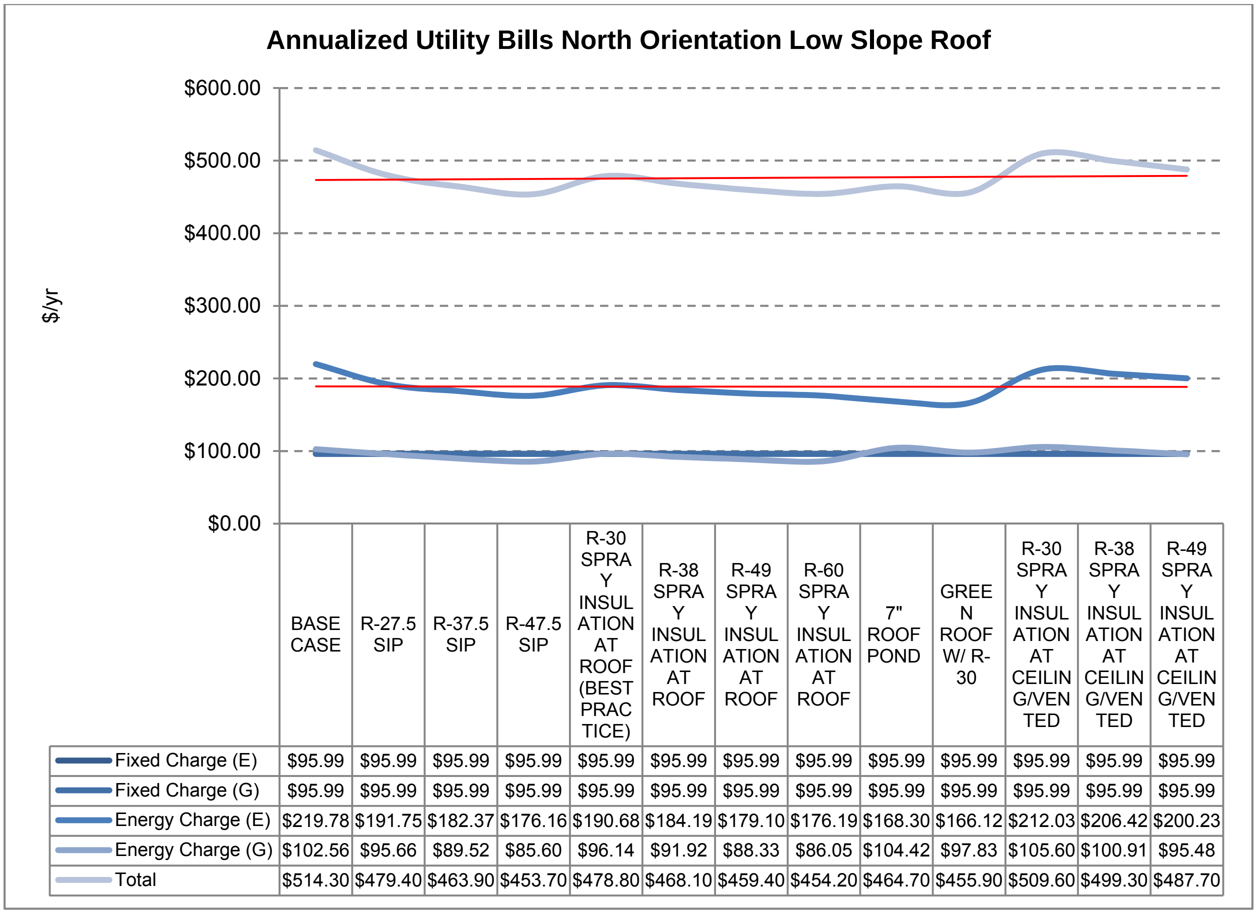
Table 5.26 Roof Assembly Construction Costs

The results in Table 5.26, show that the standard practice roof types are the most economical for the three roof pitches of traditional roofs. The roof pond is more economical with up-front costs by a few thousand dollars but the cost does not include the replacement of the water holding media that would need to be replaced. “Given that the bags are only exposed to solar radiation during the heating season, the lifespan of the water bags is somewhere between two and four times the stated duration of the UV protection (which assumes daily exposure to solar radiation). Most UV protected polyethylene plastics are guaranteed for four years, and therefore their expected lifespan in a roofpond building would be anywhere from eight to sixteen

years.” (Fernandez-Gonzalez, 2014) The other systems are using the concrete tile in the simulations with the exception of the green roof.

5.3 Annual Utility Costs

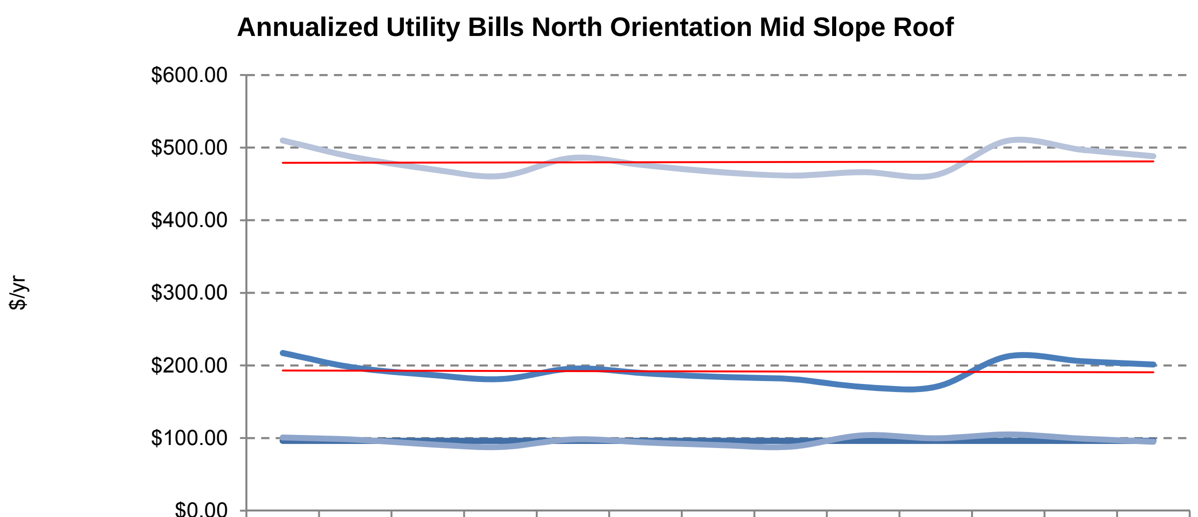
The energy usage of the different roofing systems are important to analyze as it will show how efficient the roofing system is. During the testing, the loads that analyzed were the heating and cooling loads as they would show the most information and are what all of occupants of the U.S. Desert Southwest would use. The results below show the annual utility costs for the different roof systems at four cardinal orientations (North, East, South and West) as well as three different pitches (1:12, 3:12 and 6:12). The different orientations and pitches show the information on how well the roof systems continue to perform when applied to different orientations and designs of houses in the U.S. Desert Southwest. The assumed costs for the utilities are .11 $/kWh for electricity and .73 $/therm for gas.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$219.78	$191.75	$182.37	$176.16	$190.68	$184.19	$179.10	$176.19	$168.30	$166.12	$212.03	$206.42	$200.23
Energy Charge (G)	$102.56	$95.66	$89.52	$85.60	$96.14	$91.92	$88.33	$86.05	$104.42	$97.83	$105.60	$100.91	$95.48
Total	$514.30	$479.40	$463.90	$453.70	$478.80	$468.10	$459.40	$454.20	$464.70	$455.90	$509.60	$499.30	$487.70

Table 5.27 Annual Utility Bills North Orientation 1:12 Roof Pitch

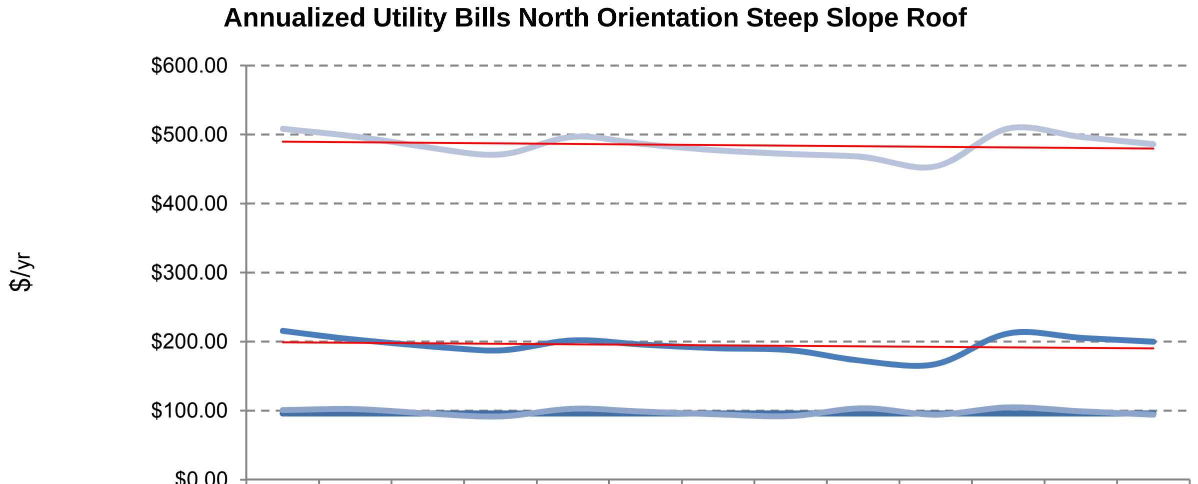
The utility cost associated with the north orientation and low slope roof Table 5.27, show that the base case costs $514.30 for the year for heating and cooling. This is the lowest performing system. The best practice of the area, the R-30 spray insulations at roof, uses $478.80 for the year. If you compare the similar R- values the R-27.5 Sip panel cost is similar to the R-30 spray insulation at the roof uses $479.40 even though it has less insulation. The systems that cost the least for energy usage are the roof pond and the green roof with R-30 insulation at $464.70 and $455.70 respectfully. The other SIP panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$217.13	$196.83	$187.47	$181.16	$195.69	$189.25	$184.19	$181.32	$170.40	$170.49	$212.63	$206.02	$201.27
Energy Charge (G)	$100.71	$97.78	$91.59	$87.65	$98.22	$94.04	$90.40	$88.07	$103.83	$99.65	$104.95	$99.31	$94.94
Total	$509.80	$486.60	$471.00	$460.80	$485.90	$475.30	$466.60	$461.40	$466.20	$462.10	$509.60	$497.30	$488.20

Table 5.28 Annual Utility Bills North Orientation 3:12 Roof Pitch

The utility cost associated with the north orientation and mid-slope roof Table 5.28, show that the base case costs $509.80 for the year of heating and cooling. This is the lowest performing system. The best practice of the area, the R-30 spray insulations at roof, uses $485.90 for the year. If you compare the similar R- values the R-27.5 Sip panel cost is similar to the R-30 spray insulation at the roof uses $486.60 even though it has less insulation. The systems that cost the least for energy usage are the roof pond and the green roof with R-30 insulation at $464.20 and $462.10 respectfully. The other SIP panels tested have less utility costs than the spray insulation equivalents.

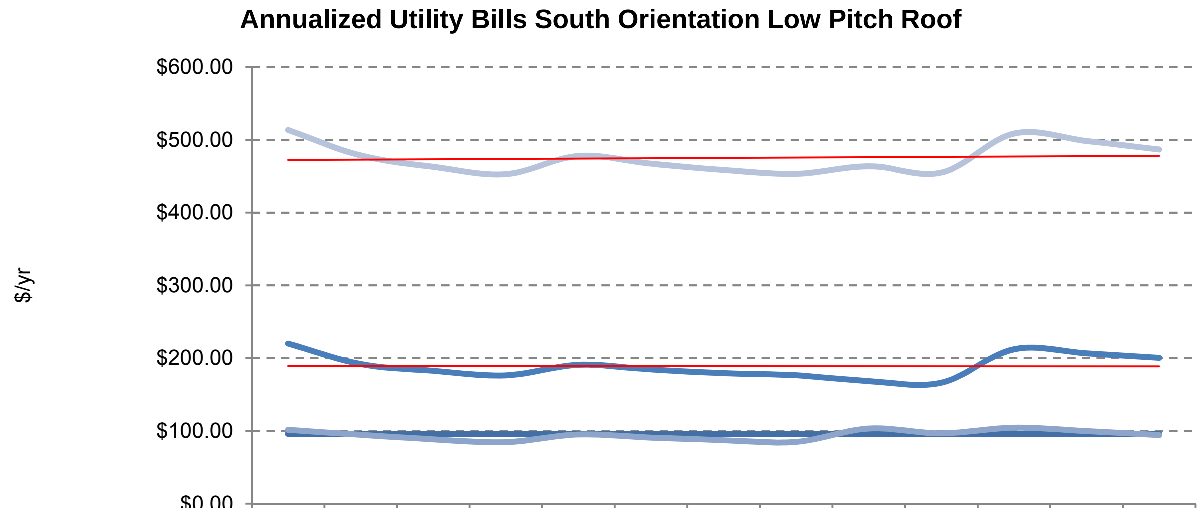


	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICES)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$215.54	$202.85	$193.59	$187.38	$201.78	$195.41	$190.42	$187.54	$171.94	$167.48	$211.98	$205.53	$199.89
Energy Charge (G)	$100.81	$102.35	$95.88	$91.70	$102.83	$98.42	$94.65	$92.22	$103.50	$94.29	$104.76	$99.08	$94.11
Total	$508.30	$497.20	$481.50	$471.10	$496.60	$485.80	$477.10	$471.70	$467.40	$453.80	$508.70	$496.60	$486.00

Table 5.29 Annual Utility Bills North Orientation 6:12 Roof Pitch

The utility cost associated with the north orientation and steep slope roof Table 5.29, show that the base case costs $508.30 for the year of heating and cooling. This is the second lowest performing system tested. The R-30 spray insulation at the ceiling with vented attic at $508.70 per year costs the most of all systems. The best practice of the area, the R-30 spray insulations at roof, uses $496.60 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $497.20 is similar to the R-30 spray insulation at the roof with utility cost of $496.60, even though it has less insulation. The systems that cost the least for energy usage are the roof pond and the green roof with R-30 insulation at $467.40 and $453.80

respectfully. The other SIP panels tested have less utility costs than the spray insulation equivalents.

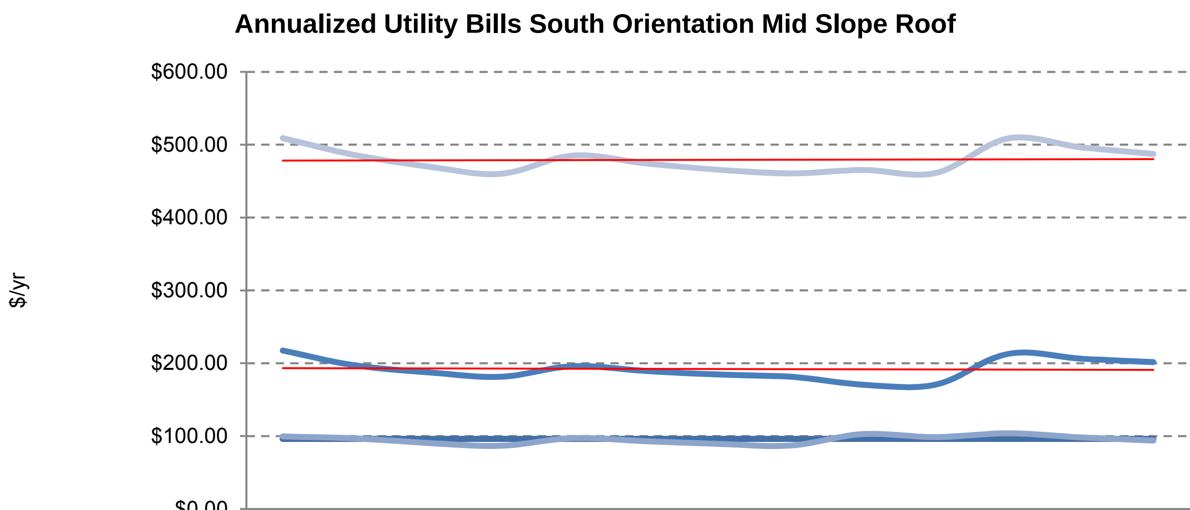


	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$220.09	$191.93	$182.58	$176.36	$190.82	$184.40	$179.31	$176.42	$168.48	$166.27	$212.27	$206.68	$200.44
Energy Charge (G)	$101.48	$94.68	$88.46	$84.57	$95.11	$90.88	$87.27	$84.98	$103.33	$96.75	$104.49	$99.79	$94.33
Total	$513.60	$478.60	$463.00	$452.90	$477.90	$467.30	$458.60	$453.40	$463.80	$455.00	$508.70	$498.50	$486.80

Table 5.30 Annual Utility Bills South Orientation 1:12 Roof Pitch

The utility cost associated with the South orientation and low slope roof Table 5.30, show that the base case costs $513.60 for the year of heating and cooling. This is the most costly roof system tested. The best practice of the area, the R-30 spray insulations at roof, uses $477.90 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $478.60 is similar to the R-30 spray insulation at the roof with utility cost of $477.90, even

though it has less insulation. The system that cost the least for energy usage was the R-47.5 SIP at $452.90 per year. The other SIP panels tested have less utility costs than the spray insulation equivalents.

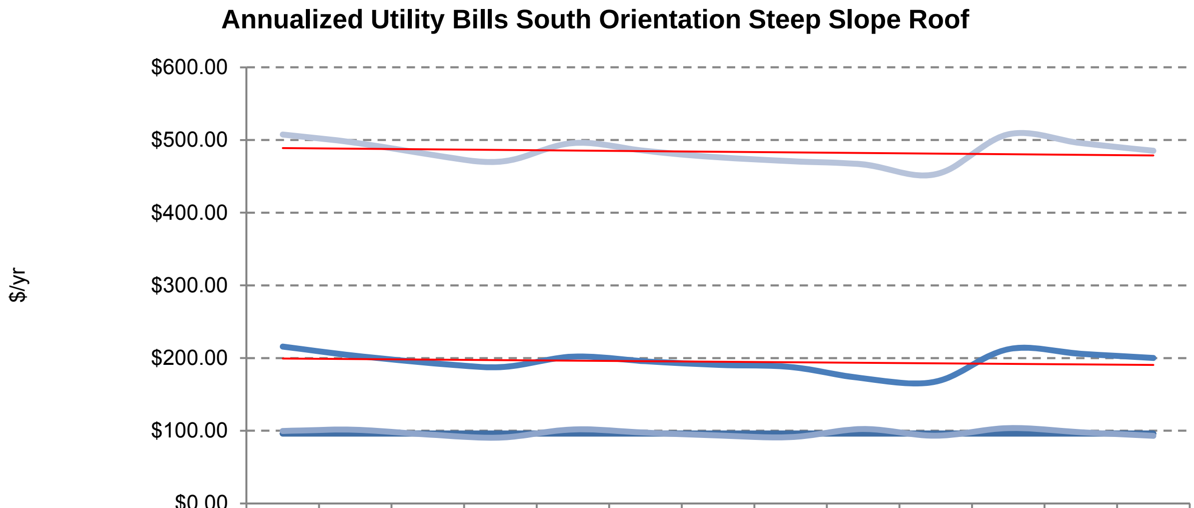


	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$217.43	$196.99	$187.64	$181.38	$195.91	$189.43	$184.43	$181.51	$170.59	$170.67	$212.91	$206.31	$201.54
Energy Charge (G)	$99.56	$96.76	$90.58	$86.61	$97.19	$92.99	$89.34	$87.07	$102.76	$98.52	$103.83	$98.17	$93.84
Total	$509.00	$485.70	$470.20	$460.00	$485.10	$474.40	$465.80	$460.60	$465.30	$461.20	$508.70	$496.50	$487.40

Table 5.31 Annual Utility Bills South Orientation 3:12 Roof Pitch

The utility cost associated with the south orientation and mid slope roof Table 5.32, show that the base case costs $509.00 for the year of heating and cooling. This is the most costly of systems for annual utility costs. The best practice of the area, the R-30 spray insulations at roof, uses $485.10 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility

cost of $485.70 is similar to the R-30 spray insulation at the roof with utility cost of $485.10, even though it has less insulation. The system that cost the least for energy usage was the R-47.5 SIP at $460.00 annually. The other SIP panels tested have less utility costs than the spray insulation equivalents.

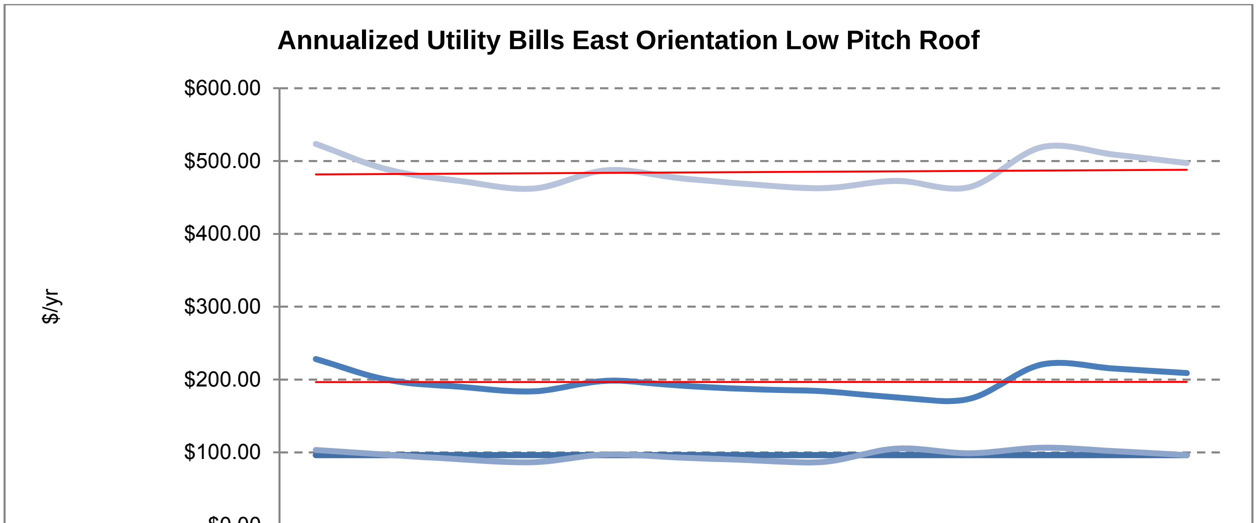


	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICES)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$215.83	$203.10	$193.77	$187.58	$201.97	$195.63	$190.64	$187.74	$172.08	$167.61	$212.23	$205.79	$200.14
Energy Charge (G)	$99.74	$101.33	$94.80	$90.64	$101.80	$97.37	$93.59	$91.18	$102.37	$93.19	$103.63	$97.96	$93.03
Total	$507.60	$496.40	$480.60	$470.20	$495.80	$485.00	$476.20	$470.90	$466.40	$452.80	$507.80	$495.70	$485.20

Table 5.32 Annual Utility Bills South Orientation 6:12 Roof Pitch

The utility cost associated with the south orientation and steep slope roof Table 5.32, show that the base case costs $507.60 for the year of heating and cooling. This is the second lowest performing system tested. The R-30 spray insulation at the ceiling with vented attic at

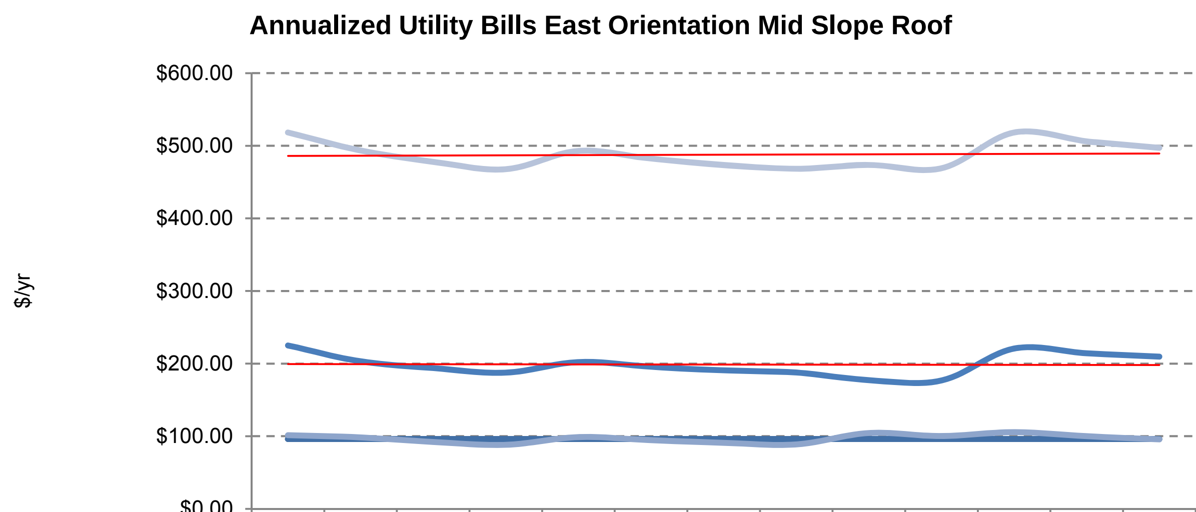
$507.80 per year costs the most of all systems. The best practice of the area, the R-30 spray insulations at roof, uses $495.80 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $496.40 is similar to the best practice of the area, even though it has less insulation. The systems that cost the least for energy usage are the roof pond and the green roof with R-30 insulation at $466.40 and $452.80 respectfully. The other SIP panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$228.11	$199.36	$189.97	$183.77	$198.24	$191.81	$186.75	$183.81	$175.59	$173.42	$220.60	$215.05	$208.91
Energy Charge (G)	$103.33	$96.62	$90.42	$86.49	$97.07	$92.86	$89.24	$86.97	$105.17	$98.73	$106.40	$101.73	$96.31
Total	$523.40	$488.00	$472.40	$462.20	$487.30	$476.70	$468.00	$462.80	$472.70	$464.10	$519.00	$508.80	$497.20

Table 5.33 Annual Utility Bills East Orientation 1:12 Roof Pitch

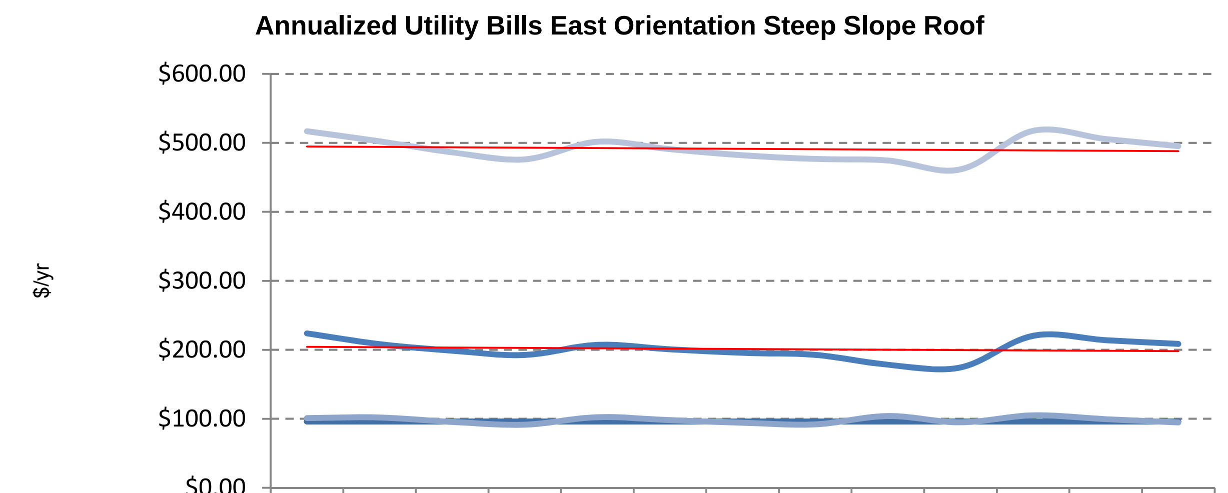
The utility cost associated with the east orientation and low slope roof Table 5.33, show that the base case costs $523.40 for the year of heating and cooling. This is the most costly of systems for annual utility costs. The best practice of the area, the R-30 spray insulations at roof, uses $487.30 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $488.00 is similar to the best practice of the area, even though it has less insulation. The system that cost the least for energy usage was the R-47.5 SIP at $462.20 annually. The other SIP panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$224.98	$203.18	$193.83	$187.54	$202.14	$195.66	$190.62	$187.68	$177.18	$176.76	$220.72	$214.19	$209.55
Energy Charge (G)	$101.31	$98.35	$92.12	$88.20	$98.77	$94.54	$90.95	$88.68	$104.40	$100.21	$105.60	$100.00	$95.65
Total	$518.30	$493.50	$477.90	$467.70	$492.90	$482.20	$473.60	$468.30	$473.60	$469.00	$518.30	$506.20	$497.20

Table 5.34 Annual Utility Bills East Orientation 3:12 Roof Pitch

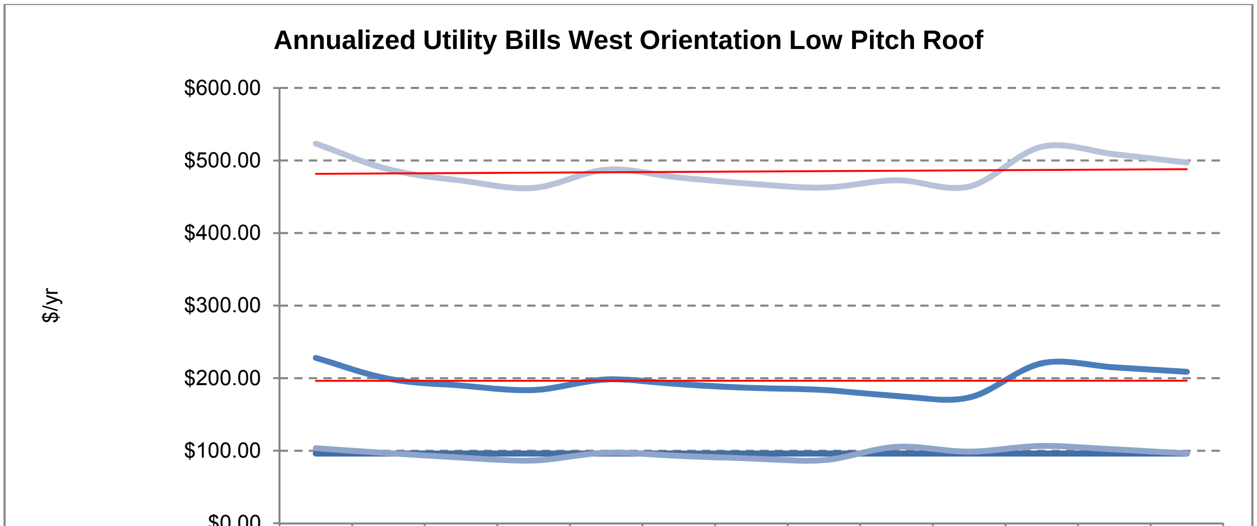
The utility cost associated with the east orientation and mid slope roof Table 5.34, show that the base case costs $518.30 for the year of heating and cooling. This is the most costly of systems for annual utility costs, along with the R-30 spray insulation at ceiling and vented attic at the same cost. The best practice of the area, the R-30 spray insulations at roof, uses $492.90 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $493.50 is similar to the best practices of the area, even though it has less insulation. The system that cost the least for energy usage was the R-47.5 SIP at $467.70 annually. The other SIP panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICES)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$223.85	$208.30	$198.80	$192.53	$207.29	$200.76	$195.67	$192.69	$178.48	$174.45	$220.40	$214.08	$208.53
Energy Charge (G)	$101.02	$101.93	$95.56	$91.54	$102.37	$98.10	$94.37	$92.02	$104.03	$94.96	$105.08	$99.53	$94.71
Total	$516.90	$502.20	$486.30	$476.10	$501.60	$490.80	$482.00	$476.70	$474.50	$461.40	$517.50	$505.60	$495.20

Table 5.35 Annual Utility Bills East Orientation 6:12 Roof Pitch

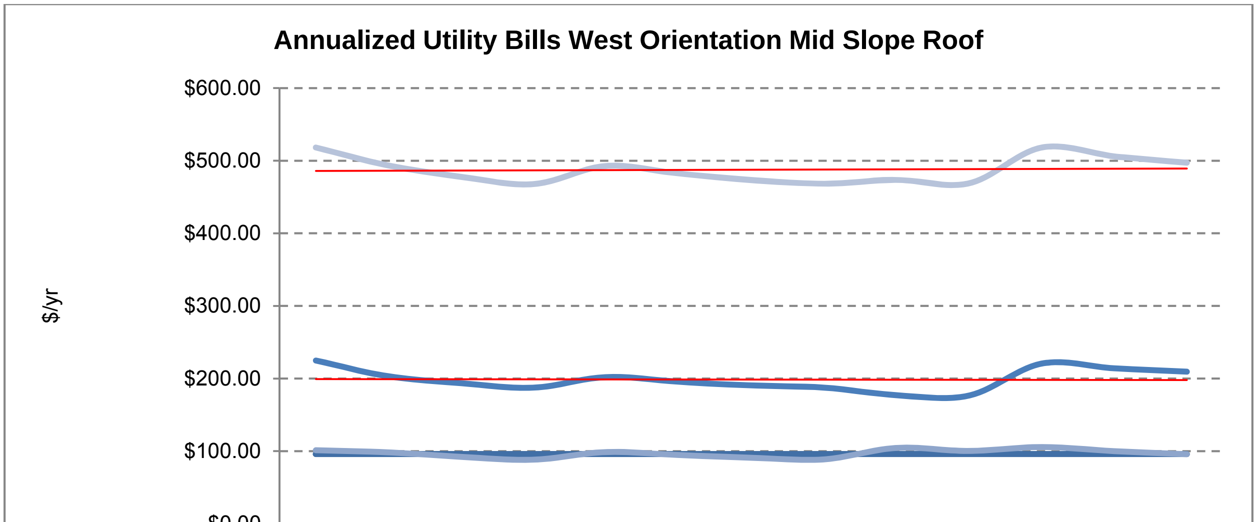
The utility cost associated with the east orientation and steep slope roof Table 5.35, show that the base case costs $516.90 for the year of heating and cooling. This is the second lowest performing system tested. The R-30 spray insulation at the ceiling with vented attic at $517.50 per year costs the most of all systems. The best practice of the area, the R-30 spray insulations at roof, uses $501.60 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $502.20 is similar to the best practice of the area, even though it has less insulation. The systems that cost the least for energy usage are the roof pond and the green roof with R-30 insulation at $474.50 and $461.40 respectfully. The other SIP panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$227.94	$199.22	$189.89	$183.65	$198.15	$191.72	$186.61	$183.73	$175.49	$173.32	$220.48	$214.91	$208.80
Energy Charge (G)	$103.42	$96.66	$90.49	$86.54	$97.15	$92.90	$89.32	$87.04	$105.29	$98.77	$106.52	$101.81	$96.37
Total	$523.30	$487.90	$472.40	$462.20	$487.30	$476.60	$467.90	$462.80	$472.80	$464.10	$519.00	$508.70	$497.20

Table 5.36 Annual Utility Bills West Orientation 1:12 Roof Pitch

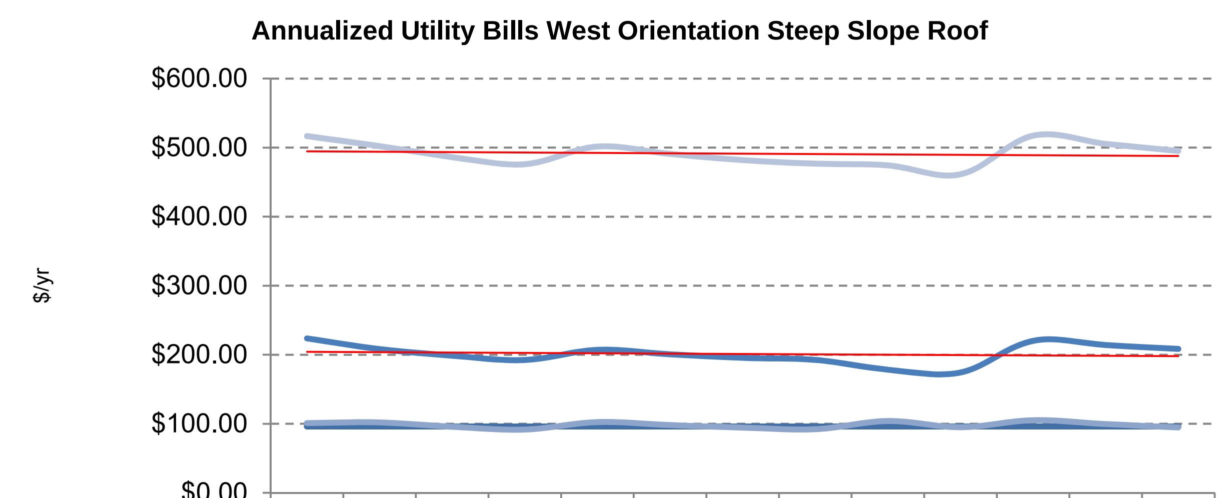
The utility cost associated with the west orientation and low slope roof Table 5.36, show that the base case costs $523.30 for the year of heating and cooling. This is the highest costing system tested. The best practice of the area, the R-30 spray insulations at roof, uses $487.30 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $487.90 is similar to the best practice of the area, even though it has less insulation. The system that costs the least for energy usage is the R-47.5 SIP at $462.20 annually. The other SIP panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICE)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$224.86	$203.15	$193.68	$187.50	$202.04	$195.56	$190.49	$187.54	$177.08	$176.63	$220.60	$214.06	$209.42
Energy Charge (G)	$101.34	$98.38	$92.22	$88.27	$98.80	$94.66	$91.04	$88.74	$104.49	$100.29	$105.64	$100.08	$95.81
Total	$518.20	$493.50	$477.90	$467.80	$492.80	$482.20	$473.50	$468.30	$473.60	$468.90	$518.20	$506.10	$497.20

Table 5.37 Annual Utility Bills West Orientation 3:12 Roof Pitch

The utility cost associated with the west orientation and low slope roof Table 5.37, show that the base case costs $518.20 for the year of heating and cooling. This is the most costly of systems for annual utility costs, along with the R-30 spray insulation at ceiling and vented attic at the same cost. The best practice of the area, the R-30 spray insulations at roof, uses $492.80 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $493.50 is similar to the best practice of the area, even though it has less insulation. The system that costs the least for energy usage is the R-47.5 SIP at $467.80 annually. The other Sip Panels tested have less utility costs than the spray insulation equivalents.



	BASE CASE	R-27.5 SIP	R-37.5 SIP	R-47.5 SIP	R-30 SPRAY INSULATION AT ROOF (BEST PRACTICES)	R-38 SPRAY INSULATION AT ROOF	R-49 SPRAY INSULATION AT ROOF	R-60 SPRAY INSULATION AT ROOF	7" ROOF POND	GREEN ROOF W/ R-30	R-30 SPRAY INSULATION AT CEILING/VENTED	R-38 SPRAY INSULATION AT CEILING/VENTED	R-49 SPRAY INSULATION AT CEILING/VENTED
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$223.66	$208.20	$198.68	$192.37	$207.16	$200.66	$195.56	$192.57	$178.40	$174.29	$220.27	$213.97	$208.43
Energy Charge (G)	$101.07	$102.00	$95.65	$91.62	$102.48	$98.13	$94.49	$92.10	$104.03	$95.04	$105.17	$99.57	$94.78
Total	$516.70	$502.20	$486.30	$476.00	$501.60	$490.80	$482.00	$476.70	$474.40	$461.30	$517.40	$505.50	$495.20

Table 5.38 Annual Utility Bills West Orientation 6:12 Roof Pitch

The utility cost associated with the east orientation and steep slope roof Table 5.38, show that the base case costs $516.70 for the year of heating and cooling. This is the second lowest performing system tested. The R-30 spray insulation at the ceiling with vented attic at $517.40 per year costs the most of all systems. The best practice of the area, the R-30 spray insulations at roof, uses $501.60 for the year. If you compare the similar R- values, the R-27.5 Sip panel with utility cost of $502.20 is similar to the best practice of the area, even though it has less insulation. The systems that cost the least for energy usage are the roof pond and the green roof with R-30 insulation at $474.40 and $461.30 respectfully. The other SIP panels tested have less utility costs than the spray insulation equivalents.

5.4 Embodied Energy

Embodied energy is the calculation of all products from their extraction to the final material product that is installed by the end user. Embodied energy information for products in the United States is not as readily available as it is in other countries. The distance from the supplier also has great effects on how much embodied energy a certain product has.

Companies are starting to release their product information in Environmental Product Declarations (EPD) mostly from countries located within the European Union (EU). The EPD's show what standards are used in the manufacturing process, products that go into the final product, technical properties of the final products, the manufacturing process and the environmental, health and safety required during production stage. The EPD's also show the life cycle analysis of the product.

Being as these items are not the same as the products from manufacturers in the United States, embodied energy is not factored.

CHAPTER 6: CONCLUSION

6.1 Competition

For the competition, several students on the team from UNLV, Desert Sunrise collaborated to produce a design that would meet the competition requirements of being a Net Zero Energy Ready Home. The students involved also wanted to incorporate requirements and design elements into the house that could be potentially used by the Paiute Indians of the Las Vegas Valley as they had recently experienced damaging flooding. Upon further research, the team discovered that Paiutes had not had any new housing built on their reservation since the mid 1970’s. The designed house had 1,387 square feet with two bedrooms and one bathroom. The ultimate design that resulted was a house that was oriented with the long axis of the house having a south/north orientation. This allowed for a large open gathering space that the Paiute Indians had said was a requirement, as they are always having large groups at their houses. The group analyzed the research compiled for the roofs as well as other components and created the envelope of the building.

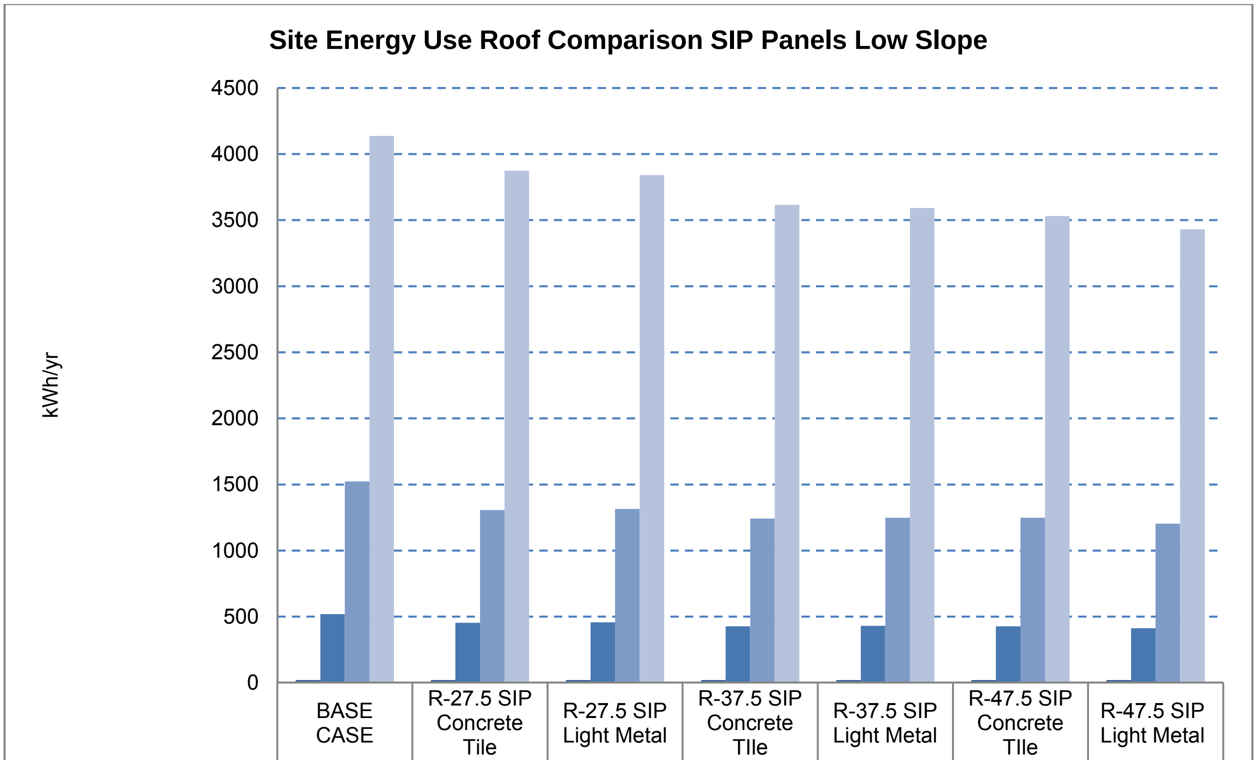
6.2 Roof Analysis

From the research, simulations conducted and the requirements of the competition, the roofs assemblies were analyzed. The Structural Insulated Panels were consistently performing as the assembly with the least site energy use for low and mid slope pitches. The R-27, R-37.5 and R-47.5 SIP assemblies also had lower R-values than did the other simulated assemblies. The green roof outperformed the SIP panel assemblies for all orientations for the steep slope pitch with as little as 25kWH/yr less and as much as 650kWh/yr more. Overall, the SIP panel assemblies performed the best with a southern orientation.

Based on the research outcomes, simulations conducted for costs, the requirements of the competition and the Paiute Tribe requests, the SIP Panel assemblies were not the most economical. However, SIP panel assemblies do have many benefits over traditional framing. These include being manufactured off-site in controlled environments, which not only saves time during framing but also all the way to finishing with truer surfaces resulting in less shimming and shaving. In addition, since the panels are manufactured off site, the panels can be pre-cut to the design requirements, allowing for faster install times. One other benefit to having the panels manufactured off-site is that there is a higher probability that the waste will be recycled and not contribute to landfills.

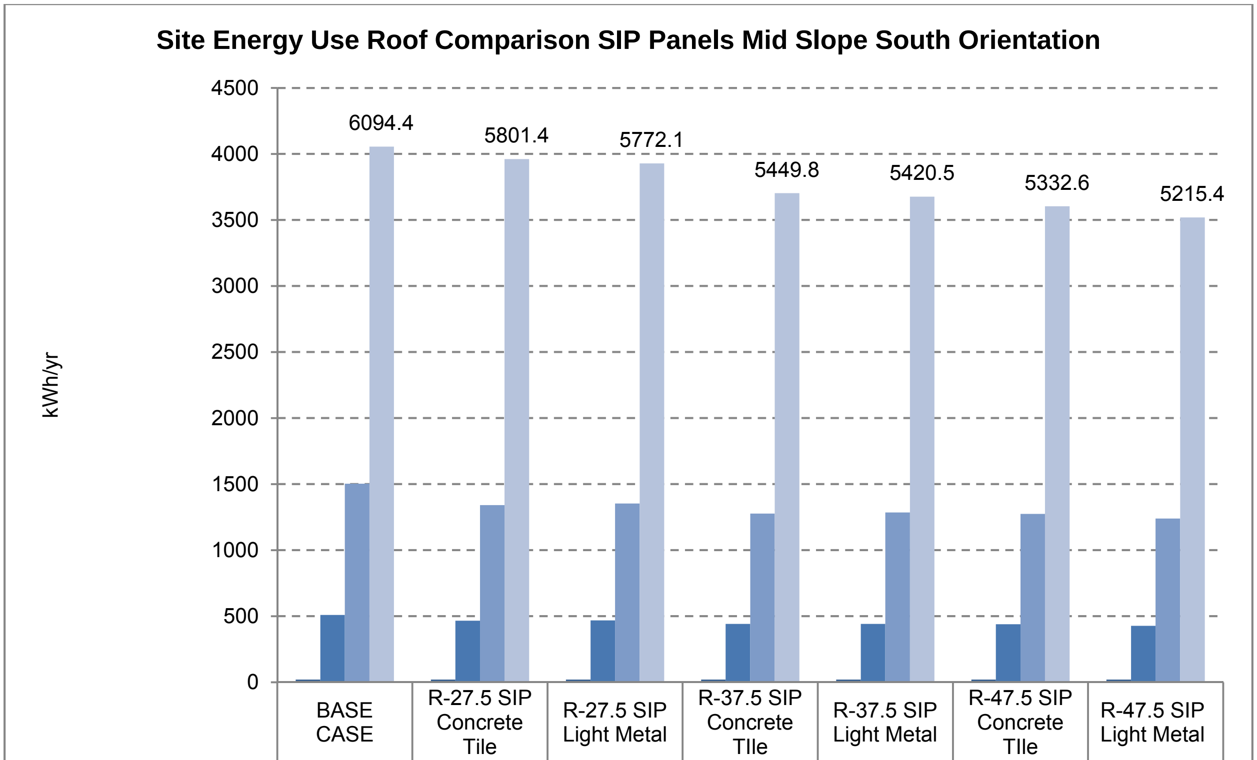
During the design phase of the competition, the SIP panel assembly was chosen to take advantage of the aforementioned benefits as well as to work with the wall assemblies, which were also SIP panels. This allowed the whole house to be designed on a grid to save in materials and labor.

The design of the roof was ultimately decided to be south facing residence with a mid slope reverse pitch butterfly roof to allow for both the catchment of rain water, and also allow for more daylighting in the residence. When considering the rain catchment from the roof, there came a need to examine different roof finishes beyond the simulated concrete tile roof of the tested assemblies. To better allow for the catchment of rainwater, a metal roof with a high albedo finish was simulated for the three different SIP assemblies and a mid slope pitch. The results of the comparison of roof finishes are found in table 6.1. Site energy was reduced by 30-117 kWh/yr by changing out the roof finish to metal with a high albedo coating. The R-37.5 SIP panel were chosen with the metal roof as it had lower energy costs and also was in the budget of the project.



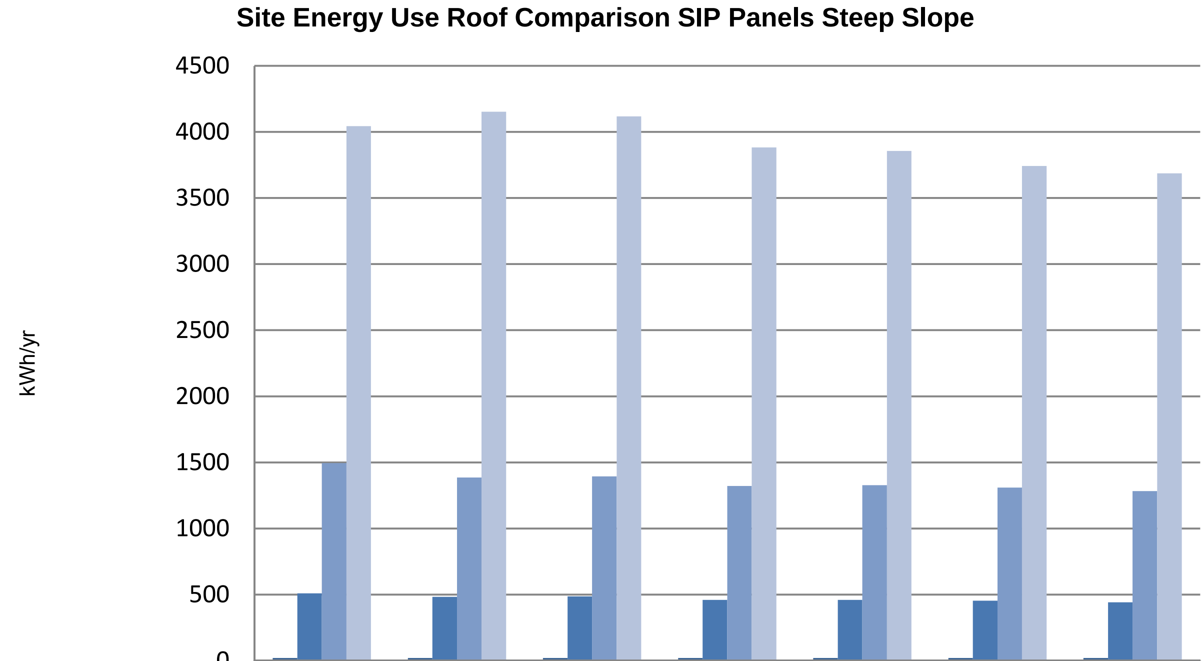
	BASE CASE	R-27.5 SIP Concrete Tile	R-27.5 SIP Light Metal	R-37.5 SIP Concrete TIle	R-37.5 SIP Light Metal	R-47.5 SIP Concrete TIle	R-47.5 SIP Light Metal
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	518.61	454.15	457.08	427.78	430.71	427.78	413.13
Cooling (E)	1523.6	1306.78	1315.57	1242.32	1248.18	1248.18	1204.23
Heating (G)	4137.16	3873.46	3841.23	3615.62	3592.18	3530.65	3431.03

Table 6.1 Site Energy Use Roof Comparison SIP 1:12 Roof Pitch South Orientation



	BASE CASE	R-27.5 SIP Concrete Tile	R-27.5 SIP Light Metal	R-37.5 SIP Concrete TIle	R-37.5 SIP Light Metal	R-47.5 SIP Concrete TIle	R-47.5 SIP Light Metal
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	509.82	465.87	468.8	442.43	442.43	439.5	427.78
Cooling (E)	1503.09	1341.94	1353.66	1277.48	1286.27	1274.55	1239.39
Heating (G)	4055.12	3961.36	3929.13	3703.52	3677.15	3603.9	3518.93

Table 6.2 Site Energy Use Roof Comparison SIP 3:12 Roof Pitch South Orientation



	BASE CASE	R-27.5 SIP Concrete Tile	R-27.5 SIP Light Metal	R-37.5 SIP Concrete TIle	R-37.5 SIP Light Metal	R-47.5 SIP Concrete TIle	R-47.5 SIP Light Metal
Vent Fan (E)	20.51	20.51	20.51	20.51	20.51	20.51	20.51
HVAC Fan/Pump (E)	509.82	483.45	486.38	460.01	460.01	454.15	442.43
Cooling (E)	1494.3	1385.89	1394.68	1321.43	1327.29	1309.71	1283.34
Heating (G)	4043.4	4151.81	4116.65	3882.25	3855.88	3741.61	3685.94

Table 6.3 Site Energy Use Roof Comparison SIP 6:12 Roof Pitch South Orientation

Another deciding factor for the metal roof change was to allow for the installation of solar panels either during or after construction. With the use of corrugated metal roofing, attachment blocks, these can be added at the high points of the roof profile that the solar panels can attach to. These blocks can either be added during initial construction or as an easy retrofit later.

Once the roof analysis was completed to compare the change in the use of metal with a high albedo finish, the cost was re-analyzed utilizing the database of costs from BEopt. With the change of the roof material from concrete tile to metal, the cost dropped just under $10,000 for construction costs as shown in Table 6.4. This brought the cost to below the base case of the standard home being built in the Las Vegas Valley.

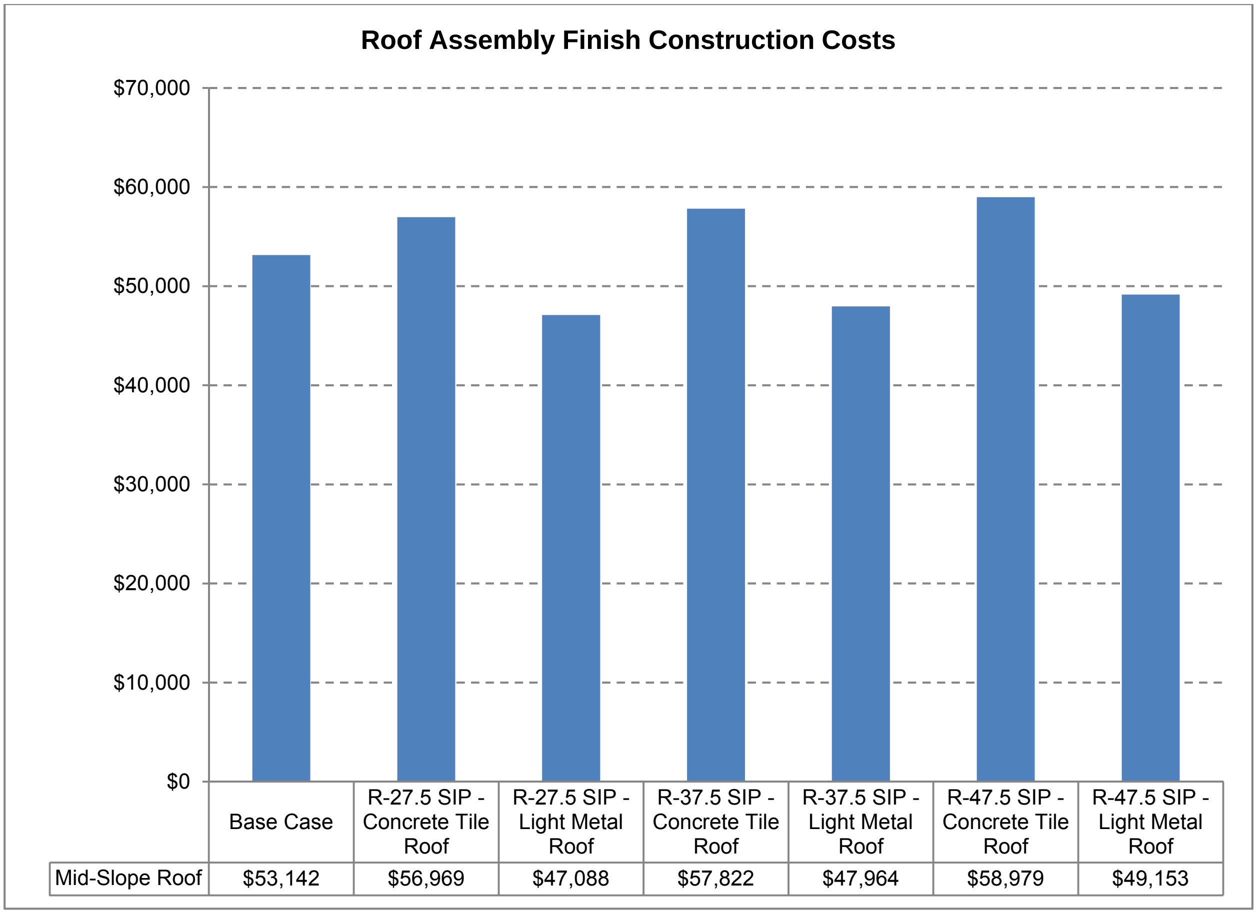


Table 6.4 Roof Assembly Finish Construction Costs Mid Slope

6.3 Methods

It is evident that change needs to happen in the way that the built environment is constructed and maintained. Design professionals have a monumental role, as they need to conduct the proper research on products prior to ever putting their ideas on paper. Contractors also have an important role; they need to build to the design intents of the professional and monitor where construction waste ends up. The consumer has the largest role in the whole process as they are the ones paying for the design professional and contractor to allow their dreams to become reality. They need to know all the repercussions of the products being used

in their houses. They need to know that the product will perform as intended and not be harmful to the environment, not only during manufacturing processes, but also during its entire life cycle.

The research conducted for this paper and for the competition was based on the climate and design characteristics of the U.S. desert southwest. By simulating the roof assembly typically used in the region, as well as twelve additional options, values are seen in the different roof assemblies, next to each other representing how well they perform in the four different orientations as well as in the three different roof slopes.

The assessment of the results showed that the structural insulated panels (SIP) were the most desirable assembly option for the desert southwest, as they performed best in the low and mid slope simulations for all orientations. The desert southwest has a majority of the roofs being mid slope which would allow the SIPs to perform optimally.

When the costs are factored in, the SIPs do cost more initially, but with a lower amount of thermal breaks per panel over the other assemblies, there will be less energy wasted in the overall roof assembly. The other added benefits of the SIPs are available as a manufactured, precut product to the design needs, thus eliminating a majority of the opportunity for errors and wasted materials in the field.

Referring to the 2010 research by Joshua Kniefel, the results of the roof assemblies simulations were analyzed for an assumed 30-year life span. The results below in tables 6.5 through 6.16 show the energy use break down of each roof assembly in kBTU per square foot per year, the system cost per square foot, the utility cost in dollars per square foot per year, the cost of saved energy (CSE) per square foot and the simple payback per square foot in years. The base case of the standard code compliant house is used as a comparison to the other assemblies that were tested for that orientation and roof pitch to see how long before the initial investment is paid back. As many of these assemblies last longer than the payback it would be up to the budget of the client to see if increasing the insulation or changing to more of an untraditional construction would be beneficial to them.

1:12 Slope East	Energy Use (kBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWH)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.84	2.89	$29.52	$0.00	$0.00914	$0.01463	Base	Base
R-27.5 SIP	7.33	2.51	$31.60	$2.08	$0.00883	$0.01333	$0.36	68.4
R-37.5 SIP	6.87	2.39	$32.09	$2.57	$0.00854	$0.01290	$0.27	52.1
R-47.5 SIP	6.57	2.31	$32.73	$3.21	$0.00836	$0.01261	$0.27	52.1
R-30 Spray insulation at Roof	7.37	2.49	$30.83	$1.31	$0.00885	$0.01328	$0.23	44.1
R-38 Spray insulation at Roof	7.05	2.41	$31.34	$1.82	$0.00865	$0.01298	$0.22	42.5
R-49 Spray insulation at Roof	6.78	2.34	$32.04	$2.52	$0.00848	$0.01275	$0.25	46.9
R-60 Spray insulation at Roof	6.61	2.31	$32.74	$3.22	$0.00838	$0.01261	$0.28	53.3
7" Roof Pond*	7.99	2.17	$26.22	-$3.30	$0.00923	$0.01224	-$0.76	0
Green Roof w/ R-30	7.49	2.16	$33.23	$3.71	$0.00892	$0.01214	$0.50	95.2
R-30 Spray insulation at ceiling	8.08	2.78	$31.25	$1.73	$0.00928	$0.01427	$2.85	542.2
R-38 Spray insulation at ceiling	7.73	2.71	$31.53	$2.01	$0.00906	$0.01401	$1.02	193.1
R-49 Spray insulation at ceiling	7.31	2.64	$31.73	$2.21	$0.00881	$0.01372	$0.44	84.4

Table 6.5 Simple Payback Costs Low Slope East Orientation

3:12 Slope East	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWh)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.69	2.85	$30.08	$0.00	$0.00913	$0.01486	Base	Base
R-27.5 SIP	7.46	2.56	$32.37	$2.29	$0.00900	$0.01385	$0.66	126.3
R-37.5 SIP	6.99	2.44	$32.87	$2.79	$0.00871	$0.01342	$0.40	75.2
R-47.5 SIP	6.69	2.36	$33.53	$3.45	$0.00853	$0.01313	$0.37	69.9
R-30 Spray insulation at Roof	7.49	2.54	$31.58	$1.50	$0.00902	$0.01380	$0.45	85.1
R-38 Spray insulation at Roof	7.18	2.46	$32.10	$2.02	$0.00882	$0.01350	$0.35	65.7
R-49 Spray insulation at Roof	6.91	2.39	$32.81	$2.73	$0.00865	$0.01327	$0.35	65.8
R-60 Spray insulation at Roof	6.73	2.36	$33.54	$3.46	$0.00855	$0.01313	$0.38	71.8
7" Roof Pond*	7.93	2.19	$27.16	-$2.92	$0.00928	$0.01265	-$0.87	0
Green Roof w/ R-30	7.61	2.19	$34.32	$4.24	$0.00908	$0.01263	$0.82	154.9
R-30 Spray insulation at ceiling	8.02	2.78	$31.81	$1.73	$0.00933	$0.01466	$1.18	224
R-38 Spray insulation at ceiling	7.59	2.71	$32.09	$2.01	$0.00907	$0.01436	$1.26	239.4
R-49 Spray insulation at ceiling	7.27	2.65	$32.29	$2.21	$0.00887	$0.01415	$0.56	107

Table 6.6 Simple Payback Costs Mid Slope East Orientation

6:12 Slope East	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($)		CSE ($/sf/yr)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.67	2.83	$31.38	$0.00	$0.00912	$0.01481	Base	Base
R-27.5 SIP	7.74	2.62	$34.12	$2.74	$0.00916	$0.01409	$2.39	453.3
R-37.5 SIP	7.26	2.50	$34.66	$3.28	$0.00887	$0.01365	$0.68	128.5
R-47.5 SIP	6.95	2.42	$35.37	$3.99	$0.00868	$0.01336	$0.55	105.1
R-30 Spray insulation at Roof	7.77	2.60	$33.27	$1.89	$0.00918	$0.01404	$1.80	341.1
R-38 Spray insulation at Roof	7.45	2.52	$33.82	$2.44	$0.00899	$0.01374	$0.70	132.1
R-49 Spray insulation at Roof	7.17	2.46	$34.60	$3.22	$0.00881	$0.01350	$0.57	107.7
R-60 Spray insulation at Roof	6.99	2.42	$35.39	$4.01	$0.00870	$0.01336	$0.57	109
7" Roof Pond*	7.90	2.21	$28.32	-$3.06	$0.00926	$0.01271	-$0.97	0
Green Roof w/ R-30	7.21	2.17	$34.07	$2.69	$0.00884	$0.01252	$0.36	68.2
R-30 Spray insulation at ceiling	7.98	2.78	$33.10	$1.72	$0.00931	$0.01465	$1.20	227.6
R-38 Spray insulation at ceiling	7.56	2.71	$33.39	$2.01	$0.00905	$0.01436	$1.26	239.4
R-49 Spray insulation at ceiling	7.19	2.64	$34.24	$2.86	$0.00883	$0.01410	$0.67	128.1

Table 6.7 Simple Payback Costs Steep Slope East Orientation

1:12 Slope North	Energy Use (kBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWH)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.79	2.78	$29.52	$0.00	$0.00919	$0.01462	Base	Base
R-27.5 SIP	7.27	2.41	$31.60	$2.08	$0.00887	$0.01332	$0.36	68.4
R-37.5 SIP	6.79	2.29	$32.09	$2.57	$0.00859	$0.01289	$0.27	52.1
R-47.5 SIP	6.49	2.21	$32.73	$3.21	$0.00841	$0.01260	$0.27	51.9
R-30 Spray insulation at Roof	7.30	2.39	$30.83	$1.31	$0.00889	$0.01327	$0.23	43.8
R-38 Spray insulation at Roof	6.98	2.31	$31.34	$1.82	$0.00870	$0.01297	$0.22	42.3
R-49 Spray insulation at Roof	6.71	2.24	$32.04	$2.52	$0.00853	$0.01274	$0.25	46.8
R-60 Spray insulation at Roof	6.53	2.21	$32.74	$3.22	$0.00843	$0.01260	$0.28	53.3
7" Roof Pond*	7.93	2.08	$26.22	-$3.30	$0.00928	$0.01224	-$0.78	0
Green Roof w/ R-30	7.43	2.06	$33.23	$3.71	$0.00897	$0.01213	$0.50	95.6
R-30 Spray insulation at ceiling	8.02	2.67	$31.25	$1.73	$0.00933	$0.01426	$3.19	606.1
R-38 Spray insulation at ceiling	7.66	2.60	$31.53	$2.01	$0.00912	$0.01400	$0.98	187
R-49 Spray insulation at ceiling	7.24	2.52	$31.73	$2.21	$0.00886	$0.01371	$0.44	82.8

Table 6.8 Simple Payback Costs Low Slope North Orientation

3:12 Slope North	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWh)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.64	2.74	$30.08	$0.00	$0.00911	$0.01450	Base	Base
R-27.5 SIP	7.43	2.47	$32.37	$2.29	$0.00897	$0.01356	$0.70	133.7
R-37.5 SIP	6.96	2.36	$32.87	$2.79	$0.00868	$0.01312	$0.41	77.3
R-47.5 SIP	6.66	2.28	$33.53	$3.45	$0.00850	$0.01283	$0.37	71.1
R-30 Spray insulation at Roof	7.46	2.46	$31.58	$1.50	$0.00899	$0.01350	$0.47	90.2
R-38 Spray insulation at Roof	7.14	2.37	$32.10	$2.02	$0.00880	$0.01321	$0.36	68
R-49 Spray insulation at Roof	6.87	2.31	$32.81	$2.73	$0.00863	$0.01297	$0.35	67.2
R-60 Spray insulation at Roof	6.69	2.28	$33.54	$3.46	$0.00852	$0.01284	$0.38	73.1
7" Roof Pond*	7.88	2.11	$27.16	-$2.92	$0.00925	$0.01233	-$0.91	0
Green Roof w/ R-30	7.57	2.11	$34.32	$4.24	$0.00906	$0.01234	$0.84	159.8
R-30 Spray insulation at ceiling	7.97	2.68	$31.81	$1.73	$0.00930	$0.01429	$1.23	234.2
R-38 Spray insulation at ceiling	7.54	2.59	$32.09	$2.01	$0.00904	$0.01398	$1.17	221.7
R-49 Spray insulation at ceiling	7.21	2.54	$32.29	$2.21	$0.00884	$0.01376	$0.55	103.6

Table 6.9 Simple Payback Costs Mid Slope North Orientation

6:12 Slope North	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($)		CSE ($/sf/yr)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.66	2.72	$31.38	$0.00	$0.00911	$0.01442	Base	Base
R-27.5 SIP	7.77	2.54	$34.12	$2.74	$0.00918	$0.01384	$4.77	906.5
R-37.5 SIP	7.28	2.43	$34.66	$3.28	$0.00888	$0.01341	$0.76	143.6
R-47.5 SIP	6.96	2.35	$35.37	$3.99	$0.00869	$0.01312	$0.59	112.1
R-30 Spray insulation at Roof	7.81	2.53	$33.27	$1.89	$0.00920	$0.01379	$4.23	803.9
R-38 Spray insulation at Roof	7.47	2.45	$33.82	$2.44	$0.00900	$0.01349	$0.81	153
R-49 Spray insulation at Roof	7.18	2.39	$34.60	$3.22	$0.00883	$0.01326	$0.62	118.4
R-60 Spray insulation at Roof	7.00	2.36	$35.39	$4.01	$0.00871	$0.01313	$0.62	117.1
7" Roof Pond*	7.86	2.13	$28.32	-$3.06	$0.00924	$0.01240	-$0.98	0
Green Roof w/ R-30	7.16	2.08	$34.07	$2.69	$0.00881	$0.01220	$0.36	67.6
R-30 Spray insulation at ceiling	7.95	2.67	$33.10	$1.72	$0.00929	$0.01426	$1.28	243.9
R-38 Spray insulation at ceiling	7.52	2.59	$33.39	$2.01	$0.00903	$0.01396	$1.15	2.176
R-49 Spray insulation at ceiling	7.14	2.52	$34.24	$2.86	$0.00880	$0.01370	$0.64	121.7

Table 6.10 Simple Payback Costs Steep Slope North Orientation

1:12 Slope South	Energy Use (kBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWH)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.71	2.78	$29.52	$0.00	$0.00914	$0.01463	Base	Base
R-27.5 SIP	7.19	2.41	$31.60	$2.08	$0.00883	$0.01333	$0.36	68.8
R-37.5 SIP	6.72	2.29	$32.09	$2.57	$0.00854	$0.01290	$0.27	52.1
R-47.5 SIP	6.42	2.22	$32.73	$3.21	$0.00836	$0.01261	$0.27	52.1
R-30 Spray insulation at Roof	7.22	2.39	$30.83	$1.31	$0.00885	$0.01328	$0.23	44.1
R-38 Spray insulation at Roof	6.90	2.31	$31.34	$1.82	$0.00865	$0.01298	$0.22	42.5
R-49 Spray insulation at Roof	6.63	2.25	$32.04	$2.52	$0.00848	$0.01275	$0.25	46.9
R-60 Spray insulation at Roof	6.46	2.22	$32.74	$3.22	$0.00838	$0.01261	$0.28	53.4
7" Roof Pond*	7.84	2.08	$26.22	-$3.30	$0.00923	$0.01224	-$0.77	0
Green Roof w/ R-30	7.34	2.06	$33.23	$3.71	$0.00892	$0.01214	$0.50	95.6
R-30 Spray insulation at ceiling	7.93	2.67	$31.25	$1.73	$0.00928	$0.01427	$3.19	606.1
R-38 Spray insulation at ceiling	7.58	2.61	$31.53	$2.01	$0.00906	$0.01401	$0.98	187
R-49 Spray insulation at ceiling	7.16	2.53	$31.73	$2.21	$0.00881	$0.01372	$0.44	82.8

Table 6.11 Simple Payback Costs Low Slope South Orientation

3:12 Slope South	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWh)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.56	2.75	$30.08	$0.00	$0.00905	$0.01451	Base	Base
R-27.5 SIP	7.35	2.47	$32.37	$2.29	$0.00892	$0.01356	$0.70	133.7
R-37.5 SIP	6.88	2.36	$32.87	$2.79	$0.00864	$0.01313	$0.41	77.3
R-47.5 SIP	6.58	2.28	$33.53	$3.45	$0.00845	$0.01284	$0.37	71.1
R-30 Spray insulation at Roof	7.38	2.46	$31.58	$1.50	$0.00894	$0.01351	$0.47	89.3
R-38 Spray insulation at Roof	7.06	2.38	$32.10	$2.02	$0.00875	$0.01321	$0.36	68.3
R-49 Spray insulation at Roof	6.78	2.32	$32.81	$2.73	$0.00858	$0.01298	$0.35	67.2
R-60 Spray insulation at Roof	6.61	2.28	$33.54	$3.46	$0.00848	$0.01285	$0.38	72.8
7" Roof Pond*	7.80	2.11	$27.16	-$2.92	$0.00920	$0.01234	-$0.91	0
Green Roof w/ R-30	7.48	2.12	$34.32	$4.24	$0.00901	$0.01235	$0.84	159.8
R-30 Spray insulation at ceiling	7.88	2.68	$31.81	$1.73	$0.00925	$0.01430	$1.23	234.2
R-38 Spray insulation at ceiling	7.46	2.60	$32.09	$2.01	$0.00899	$0.01400	$1.17	221.7
R-49 Spray insulation at ceiling	7.13	2.54	$32.29	$2.21	$0.00879	$0.01377	$0.55	103.6

Table 6.12 Simple Payback Costs Mid Slope South Orientation

6:12 Slope South	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($)		CSE ($/sf/yr)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.57	2.73	$31.38	$0.00	$0.00906	$0.01444	Base	Base
R-27.5 SIP	7.69	2.55	$34.12	$2.74	$0.00914	$0.01385	$5.37	1019.8
R-37.5 SIP	7.20	2.43	$34.66	$3.28	$0.00883	$0.01341	$0.77	145.8
R-47.5 SIP	6.88	2.36	$35.37	$3.99	$0.00864	$0.01313	$0.93	177.3
R-30 Spray insulation at Roof	7.73	2.53	$33.27	$1.89	$0.00916	$0.01379	$4.56	865.8
R-38 Spray insulation at Roof	7.39	2.45	$33.82	$2.44	$0.00895	$0.01350	$0.81	154.6
R-49 Spray insulation at Roof	7.11	2.39	$34.60	$3.22	$0.00878	$0.01327	$0.63	119.8
R-60 Spray insulation at Roof	6.92	2.36	$35.39	$4.01	$0.00867	$0.01314	$0.62	117.6
7" Roof Pond*	7.77	2.13	$28.32	-$3.06	$0.00918	$0.01241	-$0.97	0
Green Roof w/ R-30	7.08	2.08	$34.07	$2.69	$0.00876	$0.01220	$0.36	67.6
R-30 Spray insulation at ceiling	7.87	2.67	$33.10	$1.72	$0.00924	$0.01427	$1.25	238.2
R-38 Spray insulation at ceiling	7.44	2.59	$33.39	$2.01	$0.00898	$0.01397	$1.17	221.7
R-49 Spray insulation at ceiling	7.06	2.53	$34.24	$2.86	$0.00875	$0.01371	$0.64	122.5

Table 6.13 Simple Payback Costs Steep Slope South Orientation

1:12 Slope West	Energy Use (kBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWH)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.85	2.88	$29.52	$0.00	$0.00923	$0.01500	Base	Base
R-27.5 SIP	7.34	2.51	$31.60	$2.08	$0.00892	$0.01367	$0.36	68.8
R-37.5 SIP	6.87	2.39	$32.09	$2.57	$0.00863	$0.01324	$0.27	52.2
R-47.5 SIP	6.57	2.31	$32.73	$3.21	$0.00845	$0.01295	$0.27	52.2
R-30 Spray insulation at Roof	7.38	2.49	$30.83	$1.31	$0.00894	$0.01362	$0.23	44.3
R-38 Spray insulation at Roof	7.06	2.41	$31.34	$1.82	$0.00874	$0.01332	$0.22	42.5
R-49 Spray insulation at Roof	6.78	2.34	$32.04	$2.52	$0.00858	$0.01308	$0.25	47
R-60 Spray insulation at Roof	6.61	2.31	$32.74	$3.22	$0.00847	$0.01295	$0.28	53.4
7" Roof Pond*	7.99	2.17	$26.22	-$3.30	$0.00932	$0.01257	-$0.77	0
Green Roof w/ R-30	7.50	2.15	$33.23	$3.71	$0.00902	$0.01247	$0.50	95.2
R-30 Spray insulation at ceiling	8.09	2.78	$31.25	$1.73	$0.00938	$0.01465	$2.71	515.1
R-38 Spray insulation at ceiling	7.73	2.71	$31.53	$2.01	$0.00916	$0.01439	$1.03	196.2
R-49 Spray insulation at ceiling	7.32	2.64	$31.73	$2.21	$0.00891	$0.01411	$0.45	84.9

Table 6.14 Simple Payback Costs Low Slope North Orientation

3:12 Slope West	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/kWh)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.69	2.84	$30.08	$0.00	$0.00914	$0.01485	Base	Base
R-27.5 SIP	7.47	2.56	$32.37	$2.29	$0.00900	$0.01385	$0.68	128.7
R-37.5 SIP	7.00	2.44	$32.87	$2.79	$0.00871	$0.01341	$0.40	75.5
R-47.5 SIP	6.71	2.36	$33.53	$3.45	$0.00853	$0.01312	$0.37	70.4
R-30 Spray insulation at Roof	7.51	2.54	$31.58	$1.50	$0.00902	$0.01380	$0.46	86.7
R-38 Spray insulation at Roof	7.18	2.46	$32.10	$2.02	$0.00883	$0.01350	$0.35	66.1
R-49 Spray insulation at Roof	6.91	2.39	$32.81	$2.73	$0.00866	$0.01326	$0.35	66.1
R-60 Spray insulation at Roof	6.74	2.36	$33.54	$3.46	$0.00855	$0.01313	$0.38	72
7" Roof Pond*	7.93	2.19	$27.16	-$2.92	$0.00928	$0.01264	$(0.88)	0
Green Roof w/ R-30	7.62	2.19	$34.32	$4.24	$0.00909	$0.01262	$0.82	155.9
R-30 Spray insulation at ceiling	8.02	2.78	$31.81	$1.73	$0.00933	$0.01466	$1.15	219.2
R-38 Spray insulation at ceiling	7.60	2.71	$32.09	$2.01	$0.00908	$0.01435	$1.29	244.3
R-49 Spray insulation at ceiling	7.27	2.65	$32.29	$2.21	$0.00888	$0.01414	$0.57	107.9

Table 6.15 Simple Payback Costs Mid Slope North Orientation

6:12 Slope West	Energy Use For (MMBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($)		CSE ($/sf/yr)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base Case	7.68	2.83	$31.38	$0.00	$0.00912	$0.01480	Base	Base
R-27.5 SIP	7.74	2.62	$34.12	$2.74	$0.00917	$0.01408	$2.32	441
R-37.5 SIP	7.26	2.50	$34.66	$3.28	$0.00887	$0.01364	$0.67	127.7
R-47.5 SIP	6.96	2.42	$35.37	$3.99	$0.00869	$0.01335	$0.55	104.7
R-30 Spray insulation at Roof	7.78	2.60	$33.27	$1.89	$0.00919	$0.01403	$1.74	331
R-38 Spray insulation at Roof	7.46	2.52	$33.82	$2.44	$0.00899	$0.01373	$0.68	129.7
R-49 Spray insulation at Roof	7.17	2.46	$34.60	$3.22	$0.00882	$0.01350	$0.56	107.1
R-60 Spray insulation at Roof	6.99	2.42	$35.39	$4.01	$0.00871	$0.01336	$0.57	108.5
7" Roof Pond*	7.90	2.21	$28.32	-$3.06	$0.00926	$0.01270	-$0.95	0
Green Roof w/ R-30	7.03	2.17	$34.07	$2.69	$0.00884	$0.01251	$0.36	67.9
R-30 Spray insulation at ceiling	7.98	2.78	$33.10	$1.72	$0.00931	$0.01464	$1.23	232.8
R-38 Spray insulation at ceiling	7.56	2.70	$33.39	$2.01	$0.00905	$0.01435	$1.21	230.2
R-49 Spray insulation at ceiling	7.19	2.63	$34.24	$2.86	$0.00883	$0.01409	$0.66	126.2

Table 6.16 Simple Payback Costs Steep Slope North Orientation

6.4 Future Steps

With this research conducted, there are a few paths of expansion. One step could be taken to researching other roof finishes to see how they affects the energy efficiency of the roof assembly. One could also build test modules to simulate the effects of the different roof assemblies with affects of weather and site conditions.

APPENDIX A: ROOF POND CALCULATION

STEP 1	106	maximum dry bulb (temperature ºF)
	30	mean daily range
	76	minimum db temperature (ºF)
	70	design wet bulb (2.5%)
	19	average maximum rh for July
	90	July Average Temperature (ºF)
	53	minimum wet bulb temperature (ºF)
	340	average July operating hours for residential AC
STEP 2	q=	U x A x DETD
	q=	.66 X 1800 SF x 49
	q=	58212
STEP 3	230	Btu/h heat gain per person
	Qe=	(Btu/h, peak hourly gain) X (N, hours for July)
		31, days in July
	Qe=	(920 Btu/h, peak hourly gain) X (340)
		31
	Qe=	(920 Btu/h, peak hourly gain) X (340)
		31
	Qe=	10090.3
STEP 4	1200	btu/h internal gain
STEP 5	Qi=	internal gains/h x daily hours of building occupancy
	Qi=	1600 x 24
	Qi=	28800
STEP 6	Qp=	.4(Ac)(4 x DB max - DB min - 200)

	Qp=	.4(1800)(4 x 106- 76 - 200)	
	Qp=	106560	
STEP 7	1.25	*h*	
STEP 8	80	*Top*	
STEP 9	*Timax*=	*Top* + F	
	Timax=	80 + 4	
	Timax=	84	
STEP 10.a	max. pond T=	Timax -	(peak total hourly gain, including internal gains, Btu/h) / *h*(Ac)
	max. pond T=	84 -	38890.3 / 1.25 (1800)
	max. pond T=	66.7	
STEP 10.b.1	water depth (dry)		2"
	min. pond Tdry=	DBmin + 1.5°F ± corrections °F	
	min. pond Tdry=	76 + 1.5°F - 1.5	
	min. pond Tdry=	76°F	
	water depth (dry)		4"
	min. pond Tdry=	DBmin + 1.5°F ± corrections °F	
	min. pond Tdry=	76 + 1.5°F + 0	

	min. pond Tdry=	77.5°F	
	water depth (dry)		6"
	min. pond Tdry=	DBmin + 1.5°F ± corrections °F	
	min. pond Tdry=	76 + 1.5°F + .7	
	min. pond Tdry=	78.2°F	
	water depth (dry)		10"
	min. pond Tdry=	DBmin + 1.5°F ± corrections °F	
	min. pond Tdry=	76 + 1.5°F + 1	
	min. pond Tdry=	78.5°F	
STEP 10.b.2	min. pond Twet=	DBmin -	Dbmin -WBmin / 2
	min. pond Twet=	76 -	76 - 53 / 2
	min. pond Twet=	64.5°F	
STEP 10.c	water depth (dry)		2"
	ΔTpdry=	max. pond T - min. pond Tdry	
	ΔTpdry=	66.7-76	
	ΔTpdry=	-9.3	
	water depth (dry)		4"

	ΔTpdry=	max. pond T - min. pond Tdry
	ΔTpdry=	66.7-77.5
	ΔTpdry=	-10.8
	water depth (dry)	6"
	ΔTpdry=	max. pond T - min. pond Tdry
	ΔTpdry=	66.7-78.2
	ΔTpdry=	-11.5
	water depth (dry)	10"
	ΔTpdry=	max. pond T - min. pond Tdry
	ΔTpdry=	66.7-78.5
	ΔTpdry=	-11.8
	ΔTpwet=	max. pond T - min. pond Twet
	ΔTpdry=	66.7-64.5
	ΔTpdry=	2.2
STEP 11	D =	$\frac{(0.19)(Qe + Qi + Qp)}{(\Delta Tp)(Ac)}$
	D =	$\frac{(0.19)(10090.3 + 28800 + 106650)}{(2.2)(1800)}$

	D =	6.98 inches

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CURRICULUM VITAE

John Joseph Carroll, Jr.

About

I am a problem solver and an observer; I like to learn from my surroundings, catalog good ideas and imagine more creative and sustainable solutions for our environment. I am self-driven and propelled by the positive impact architects and designers have on the lives of others.

Education

University of Nevada, Las Vegas - Las Vegas, NV
Master of Architecture (in progress)
Projected graduation date, December 2015

University of Nevada, Las Vegas - Las Vegas, NV
Bachelor of Science, Architecture, May 2007

College of Southern Nevada - Las Vegas, NV
Associate of Arts, May 2005

Durango High School - Las Vegas, NV
High School Diploma, May 2001

Academic Experiences and Awards

U.S. Department of Energy Race to Zero Student Design Competition
Design Excellence Award
Using the research from this project, was responsible for choosing the roof assembly for project and developed design drawings, renderings and details.

National Organization of Minority Architecture Students (NOMAS) Competition UNLV
Best Design, Best Concept, Best Presentation and Best Overall Project

Professional Accreditation

Leadership in Energy & Environmental Design, Accredited Professional (LEED AP)

Interests and Activities

Architectural photography, furniture building, sports recreation

Work Experience

March 2013 - Present: Gary Guy Wilson Architects – Senior Job Captain
Assist with all aspects of design including conceptual design, schematic renderings & drawings, construction drawings and specifications, bidding administration, and construction administration. Types of projects consist of tenant improvements, custom residential and ground up construction.

April 2011 - March 2013: MGM Resorts International – Accounts Receivable Specialist
Had communication with the many visitors of various MGM Resorts International properties consisting of hotel guests, restaurant patrons, retail shoppers, and convention groups. Collected past due bills and resolved disputed charges of the guests, and worked with various large groups and companies to collect deposits required for upcoming events at the properties.

May 2006 - April 2009: Bergman Walls and Associates – Architectural Drafter and 3D Designer
Gained experience by working on the different design stages for various hospitality projects including the creation of 3D conceptual renderings & videos and construction documents.

Software Knowledge

Autodesk Suite (AutoCAD 2d and 3d, Revit, 3DS Max); Microsoft Office (Word, Excel, PowerPoint, Outlook, Publisher); Adobe Suite (Photoshop, Illustrator, InDesign, Lightroom, After Effects, Premier); SketchUp; BEopt; HEED; EnergyPlus