UNLV | UNIVERSITY LIBRARIES

UNLV Theses, Dissertations, Professional Papers, and Capstones

December 2015

Architectural form, orientation, and energy for residential design in the Southern Nevada region.

Ludwing Vaca
University of Nevada, Las Vegas

Follow this and additional works at: https://digitalscholarship.unlv.edu/thesesdissertations

Part of the Architecture Commons, and the Oil, Gas, and Energy Commons

Repository Citation

Vaca, Ludwing, "Architectural form, orientation, and energy for residential design in the Southern Nevada region." (2015). *UNLV Theses, Dissertations, Professional Papers, and Capstones*. 2591.
http://dx.doi.org/10.34917/8220172

This Thesis is protected by copyright and/or related rights. It has been brought to you by Digital Scholarship@UNLV with permission from the rights-holder(s). You are free to use this Thesis in any way that is permitted by the copyright and related rights legislation that applies to your use. For other uses you need to obtain permission from the rights-holder(s) directly, unless additional rights are indicated by a Creative Commons license in the record and/or on the work itself.

This Thesis has been accepted for inclusion in UNLV Theses, Dissertations, Professional Papers, and Capstones by an authorized administrator of Digital Scholarship@UNLV. For more information, please contact digitalscholarship@unlv.edu.

ARCHITECTURAL FORM, ORIENTATION, AND ENERGY FOR RESIDENTIAL DESIGN IN THE SOUTHERN NEVADA REGION.

By

Ludwing Hernan Vaca

Bachelor of Architecture

University of Southern California

1999

A thesis submitted in partial fulfillment

of the requirements for the

Master of Architecture

School of Architecture

College of Fine Arts

The Graduate College

University of Nevada, Las Vegas

December 2015

Copyright© 2015 by Ludwing Hernan Vaca,
All Rights Reserved

UNLV | GRADUATE COLLEGE

Thesis Approval

The Graduate College
The University of Nevada, Las Vegas

November 5, 2015

This thesis prepared by

Ludwing Vaca

entitled

Architectural Form, Orientation, and Energy for Residential Design in the Southern Nevada Region

is approved in partial fulfillment of the requirements for the degree of

Master of Architecture
School of Architecture

Alfredo Fernandez-Gonzalez, M.Arch
Examination Committee Chair

Glenn N.P. Nowak, M.Arch.
Examination Committee Member

Joshua Vermillion, M.Arch.
Examination Committee Member

David James, Ph.D.
Graduate College Faculty Representative

Kathryn Hausbeck Korgan, Ph.D
Graduate College Interim Dean

ABSTRACT

With the population increase, the high demand of energy from the residential sector, as well as the harsh weather conditions of the Las Vegas region, there needs to be careful consideration in the design of new homes. Energy efficiency in a single family residential building can be augmented early in the design process by careful consideration of the building form and orientation. A systematic investigation and analysis was taken to study the effects of five building forms and different orientations along the cardinal points using the software BEopt version 2.4.0.1. To connect the study to real world circumstances, a residential development in the Las Vegas region was modified using the information found in this study to see how residential developers can design these communities and their buildings with optimized orientations for potential energy savings.

The cooling study gave the most diverse results for the different shapes analyzed, with some of the shapes outperforming others in different orientations. Even though the rectangular and square shapes have less surface areas, the L, U and courtyard shapes seemed to have benefited from self shading to reduce the cooling loads. The L and courtyard shapes in particular performed the best, with the U shape not far behind them. The square and rectangular shapes used more energy to cool the homes, specially the square shape. As an average between 3-5% more energy was spent in space conditioning in the square and rectangular shapes than the courtyard shape. Moreover, the rectangular shape showed the largest delta change and was more sensitive to an orientation change. The largest variation was as much as a 5% increase from south to south west.

The results for all of the shapes show that the greatest energy use is spent in heating the homes, as an average 3.08 to 4.05 more times than cooling, or 69.3% to 74.2%. of the total energy spent in space conditioning. The total heating results were more predictable and not as varied as the total cooling loads from the previous analysis. The smaller and more compact

homes responded better and used less energy for space heating, with the square shape outperforming the other shapes in all orientations and the rectangle coming a close second. The courtyard shape behaved the opposite as it had for cooling, performing the worst of all the shapes studied.

The two shapes that performed the best for combined cooling and heating loads were the square and rectangle shapes, followed closely to the L-shape. Though the rectangular shape performed better in north and south orientations, from WSW 67.5° to NW 157.5° and from ENE 247.5° to SSE 337.5°, the square shape actually performed better than the rectangular shape along these orientations. Moreover, the L-shape was not far in performance to these two shapes, considering it had two more additional surfaces. As an average, it used 1.1% more energy than the rectangle and 1.7% more than the square. While the courtyard shape, as an average, used about 14.6% more energy than the rectangle and 15.3% more than the square shape. It is also important to note, that the square shape performed the best in all orientations, with the rectangular shape using 0.6% and the L-shape 1.7% more energy.

If a developer would like to repeat a unit type and mass produce it for subdivision, the rectangle form actually performs the worst to orientation changes. Instead the analysis performed on this paper would recommend the use of a square plan, as it performs overall better around the different orientations.

Current energy prices in electricity and gas utility charges are affordable to homeowners. The study showed an increase of only 1% to 2% between orientations or no more than $15 in yearly costs for space conditioning. Similarly between the different shapes there was an average increase of $122 in utility costs for space conditioning, which is an increase of only $10 per month. However, a more significant finding was the annual savings that could be done on the layout of residences in larger subdivision developments that are present in the Las Vegas region. A more meaningful impact was seen by simply orienting the variety on units to the more optimal south facing direction, about nine households in Nevada could be given free

electricity yearly. As the Nevada population increases and the demand for single family detached residences continues, the design and construction industry need to have a more careful examination of the layout of these communities to reduce their energy demands.

ACKNOWLEGEMENTS

My sincere gratitude to the graduate committee for taking the time to help me with this work. Specifically I would like to thank Professor Fernández-Gonzáles for pushing us into doing the U.S. Department of Energy, Race to Zero Student Design Competition and have us produce a cohesive and commendable project for the Moapa Pauite.

Johny, John, Nick, and David, thank you for your committed loyalty even at the toughest of times. Thank you for helping an old student keep learning throughout this process.

DEDICATION

For my mother Lily Vaca who help me become the person I am today. Thank you for all your love and support.

For my uncles Richard, Hugo, and Wilfredo, thank you for all the help you gave me throughout my childhood.

For my brother Herbert who always pushed me to become a better person.

This work is specially dedicated to my wife Sylvie and my sons Gael and Robin. Thank you for giving me the opportunity to better myself as person. Thank you for all the love and support you have giving me throughout these years. My love will always be with you.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1: INTRODUCTION

1.1 Background.

Over the last decade Nevada has grown in population by almost 40% from 1,998,257 to 2,790,136 inhabitants (Selected Housing Characteristics). The Nevada Energy Fact Sheet shows that Nevada has seen a population growth rate from 2005-2012 by about 1.8% per year. Moreover, the total number of residential households in 2010 was 1.14 million, while in 2013 this figure grew to 1.18 million, a 3.26% increase in three years. Over 360,000 residential units were built between the years of 2000-2009 (Figure 1.2.) . As seen in Figures 1.1. and 1.3., about 60% of these housing types were single family detached homes.

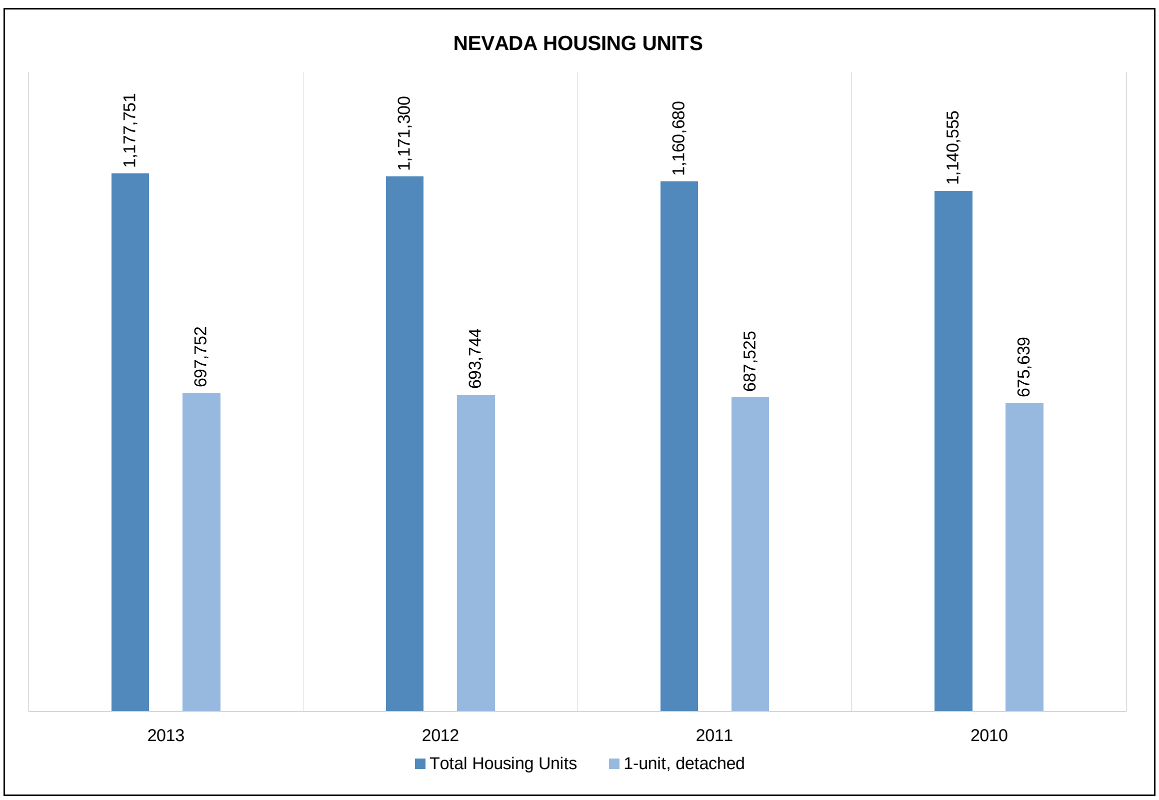


Figure 1.1. Nevada housing units 2010-2013, from U.S. Census Bureau 2013.

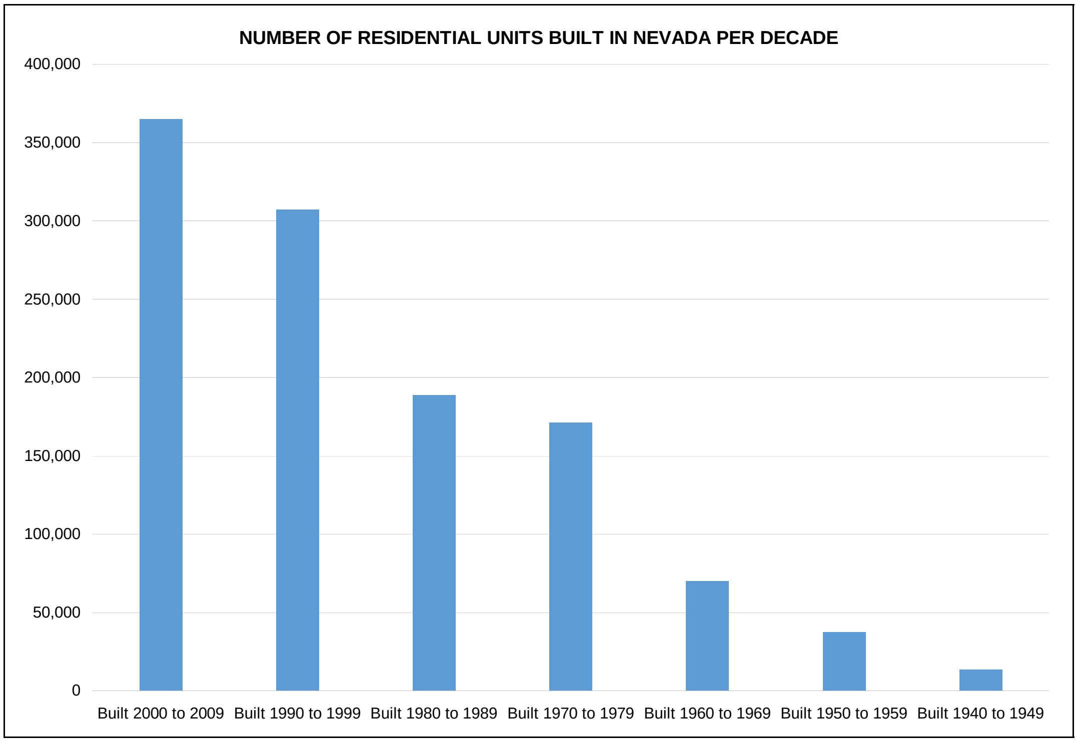


Figure 1.2. Nevada housing units 1940-2009, from U.S. Census Bureau 2013.

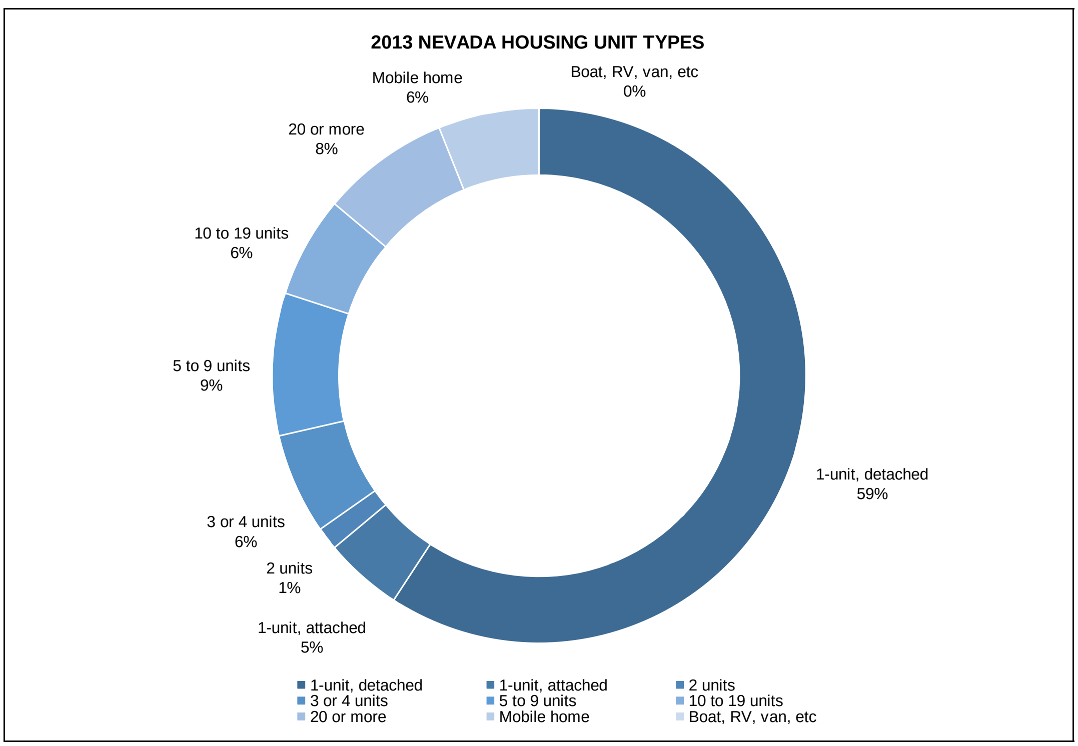


Figure 1.3. 2013 Nevada housing units types, from U.S. Census Bureau 2013.

Residences consume about 24% of the total energy the state of Nevada uses, utilizing more than the commercial sector and just below the transportation industry, as seen in Figure 1.4. (Nevada Energy Fact Sheet, 2). This same source lists the average electrical energy consumption of a Nevada residence at 12,154 kWh a year, while the residential gas use per household at 313.5 therms (2). Only 11% of the 2012 energy consumption in the state came from renewable energy, with the rest being produced from natural resources in the form of coal, natural gas, and petroleum (1) as illustrated in Figure 1.4.

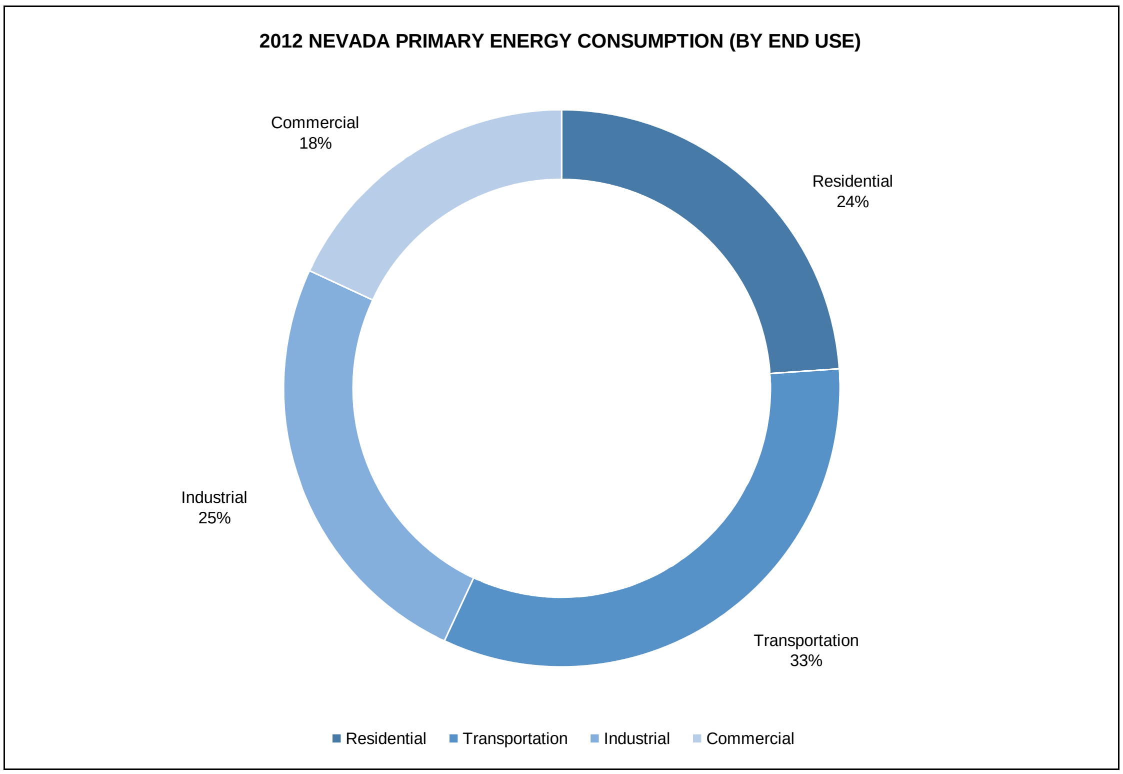


Figure 1.4. 2012 Nevada primary energy consumption by end use, from Nevada Energy Fact Sheet 2015.

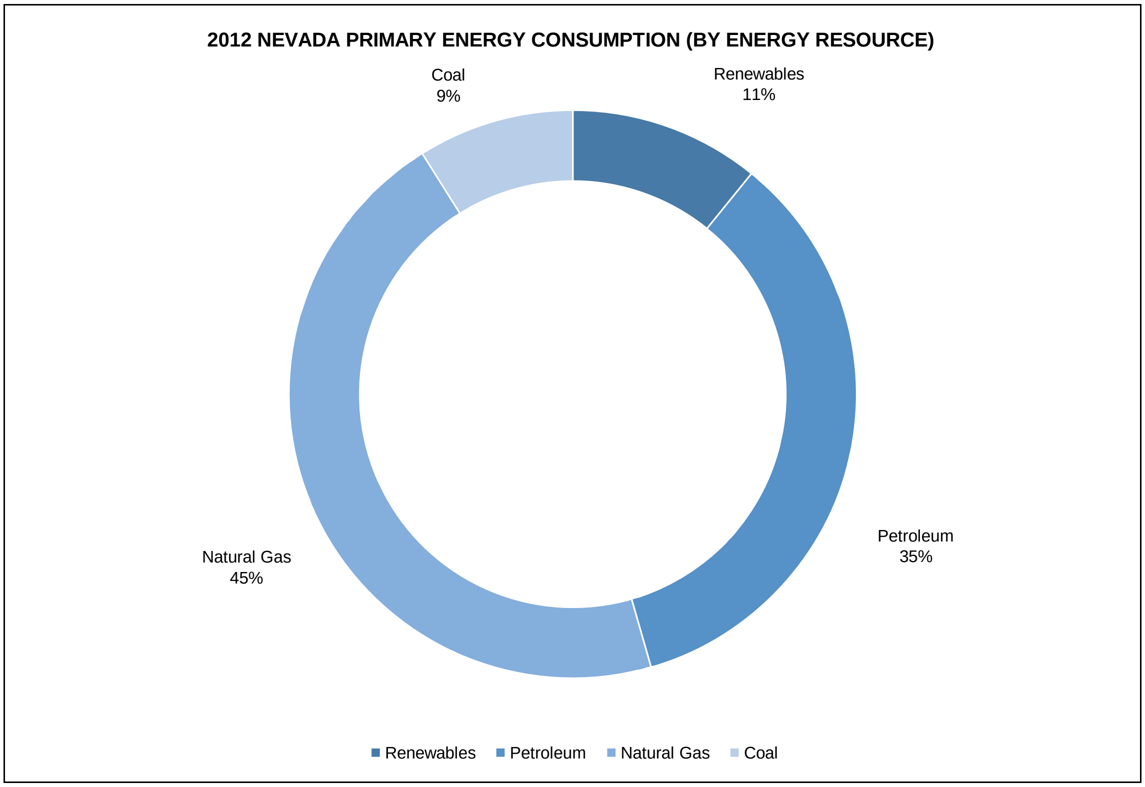


Figure 1.5. 2012 Nevada primary energy consumption by energy resource, from Nevada Energy Fact Sheet 2015.

As shown in Figure 1.6., residential homes in the Mountain South region, which include the states of Nevada, Arizona, and New Mexico, use about 42% of its energy in air conditioning in the hot summer months or in space heating in the winter season (Residential Energy Consumption Survey). In the Figure 1.7. we can see that for air conditioning purposes, this region uses almost three times more energy than the national average to cool the homes.

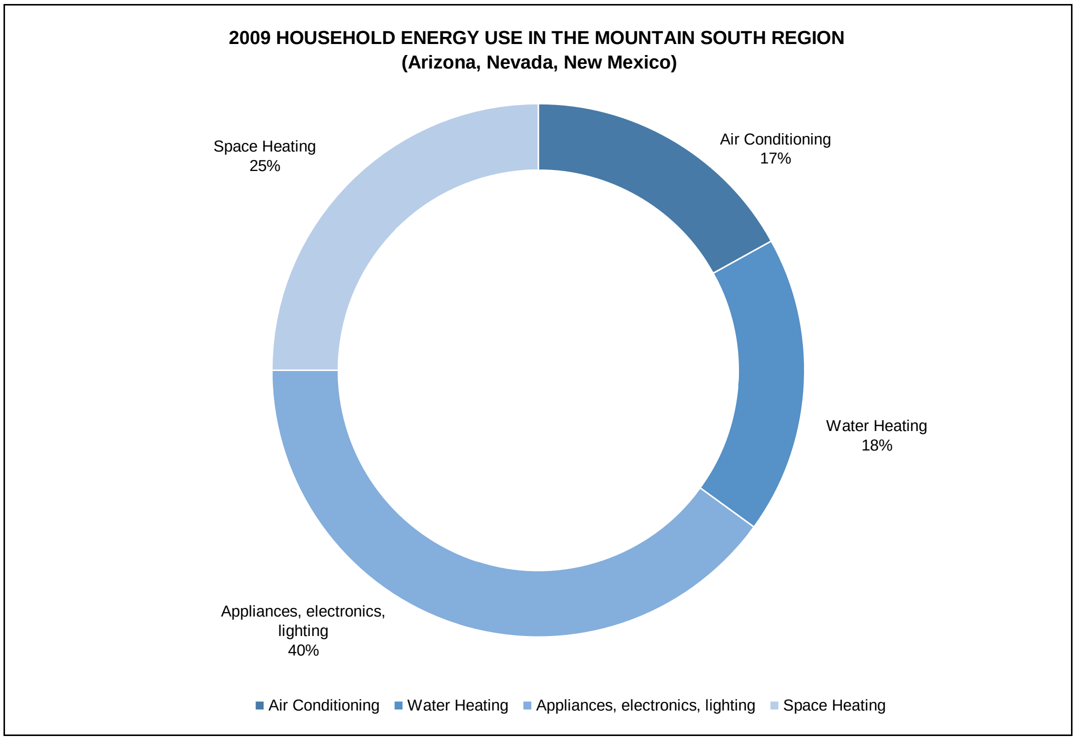


Figure 1.6. 2009 Household energy use in the Mountain South Region (AZ, NV, NM), from EIA Residential Energy Consumption Survey, 2009.

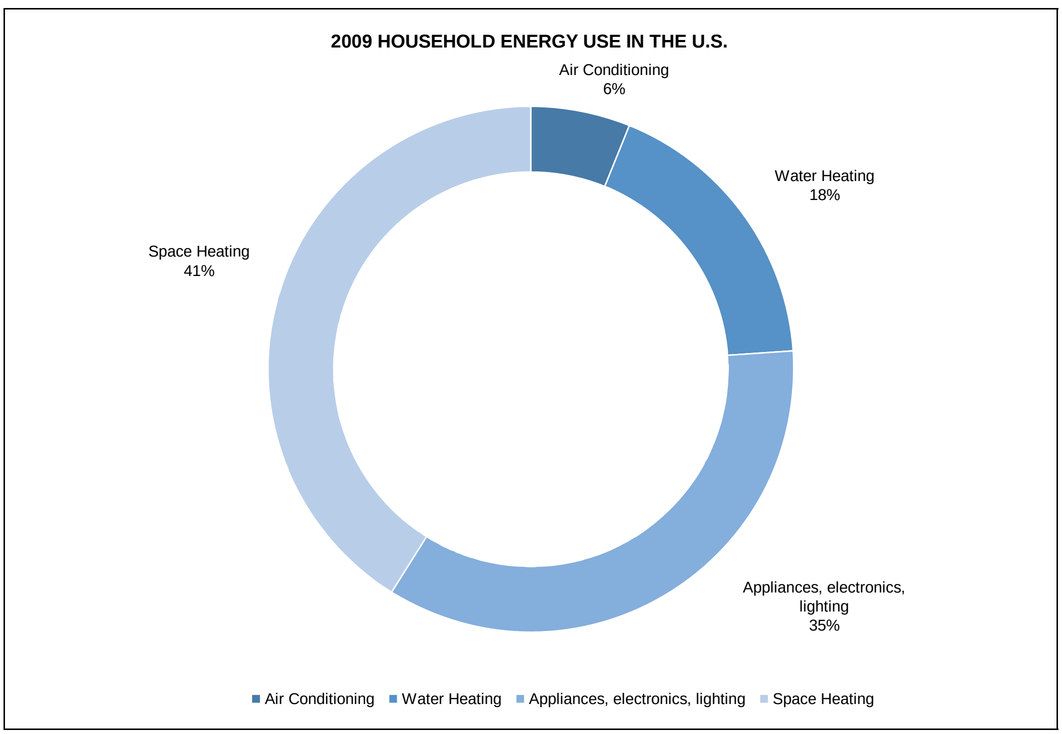


Figure 1.7. 2009 Household energy use in the US., from EIA Residential Energy Consumption Survey, 2009.

This same survey shows that for cooling purposes, about 82% of residences rely on central air conditioning or window units, while for space heating 90% of households use natural gas or electricity to keep their homes warm (Figure 1.8 and 1.9.). Only a minority of Mountain South households do not use any energy to condition their homes.

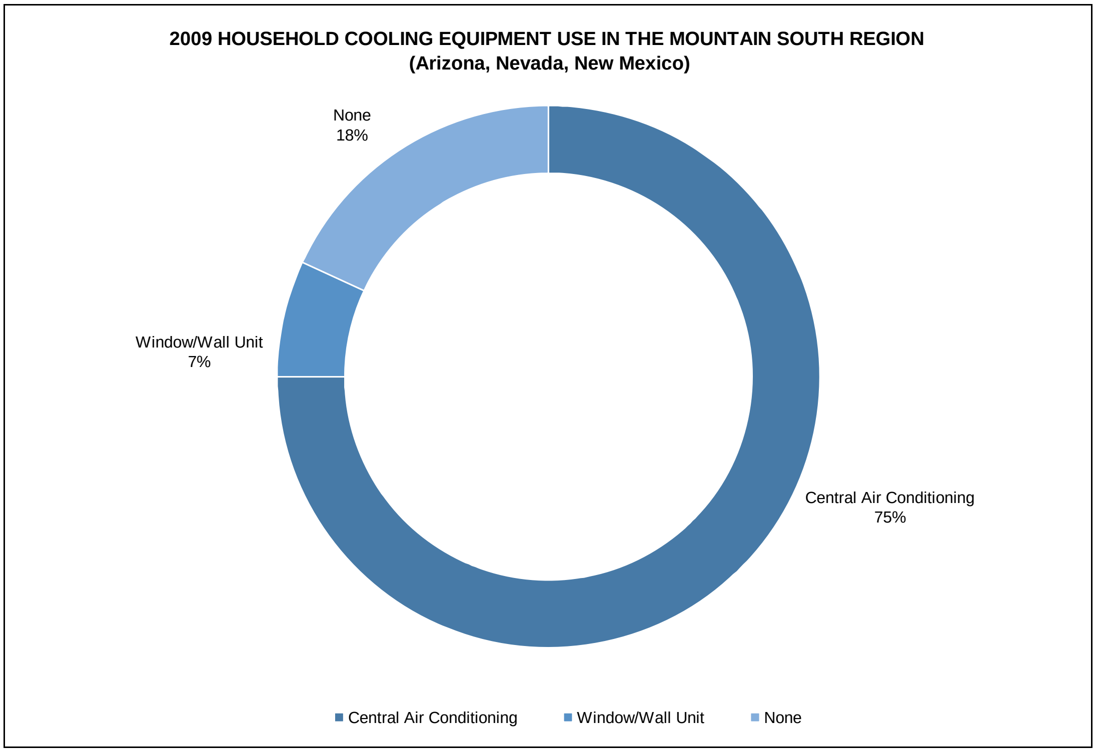


Figure 1.8. 2009 Household cooling equipment use in the Mountain South Region, from EIA Residential Energy Consumption Survey, 2009.

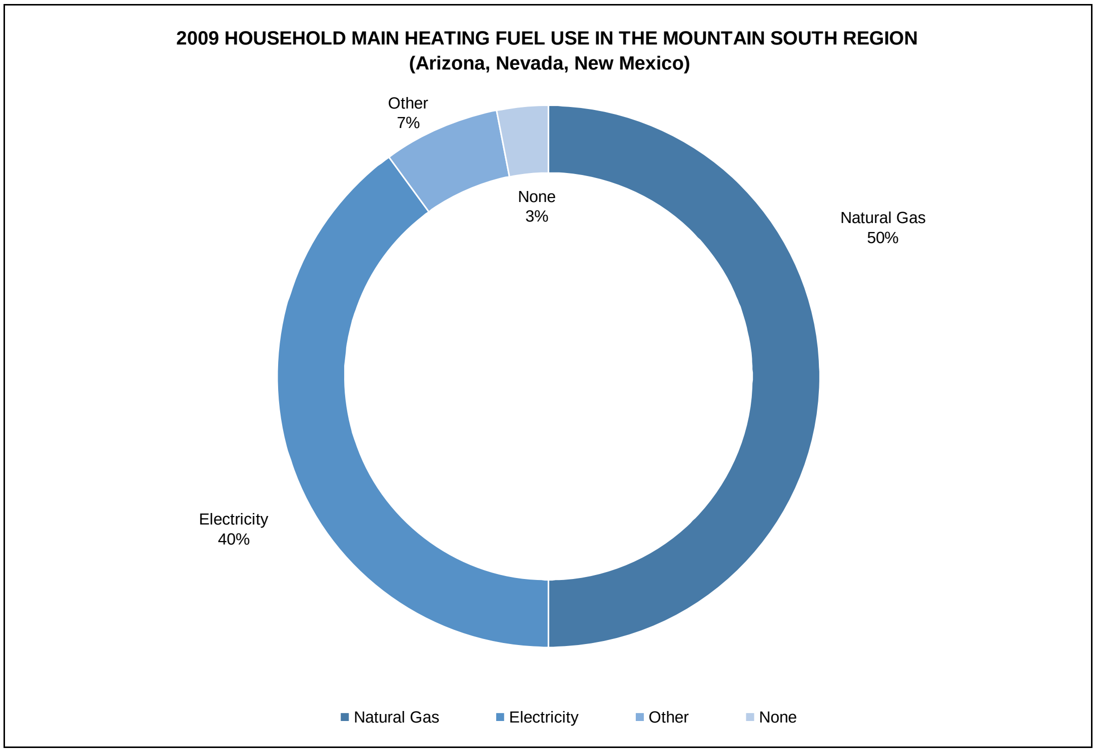


Figure 1.9. 2009 Household main heating fuel use in the Mountain South Region, from EIA Residential Energy Consumption Survey, 2009.

1.2 Climate Conditions.

Keplinger's article *Designing New Buildings of Optimum Shape and Orientation,* suggests that the initial consideration in planning for energy efficient buildings is that of climate. He lists southern Nevada as a hot arid region, with clear skies, dry atmosphere, extended periods of overheating and large daytime temperature ranges (578).

Weather conditions in Las Vegas are normally hot throughout most of the year during the daytime, while night temperatures are cooler, especially during the winter months. Temperatures drastically increase during the summer season, the city's location in the middle of the desert brings high temperatures, typically lasting from May to September. Temperatures during this season range from 81°F to 106°F, but sometimes exceeding 115°F, which present a higher demand in energy to cool residences. For this reason cooling in buildings has become

one of the most important design considerations in this part of the country. During the winter months of November to March temperatures average between 58°F to 38°F but can drop to freezing temperatures, with the lowest recorded temperatures on the 20°F range. As seen from the temperature range diagram in Figure 1.10., recorded extremes for the region for a typical year can range between 106°F to 22°F. Another important aspect to note is the prolonged heat during summer days that residences are exposed to. For example, in 2014 the longest day during the Las Vegas summer was from 5:23 am until 8:01 pm, with the total exposure to the sun being 14 hours and 37 minutes long.

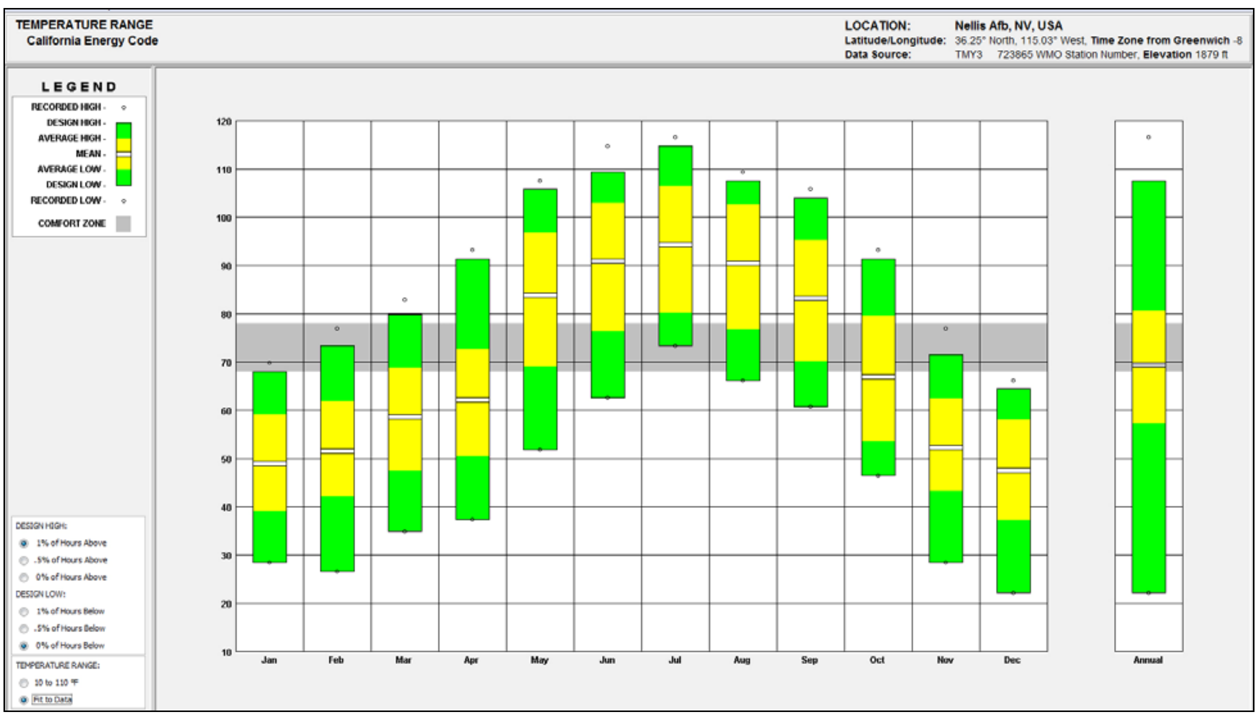


Figure 1.10. Temperature Range for Las Vegas region. Climate Control Software.

It is also important to note that during the summer months of June through August the time table plot on Figure 1.11. for the region shows that the temperature is usually above the comfort zone in a 24 hour period, meaning that even during the night time the temperature is

above 78°F. Similarly the chart shows that during the winter months of December through February, the temperature almost never goes above 68°F.

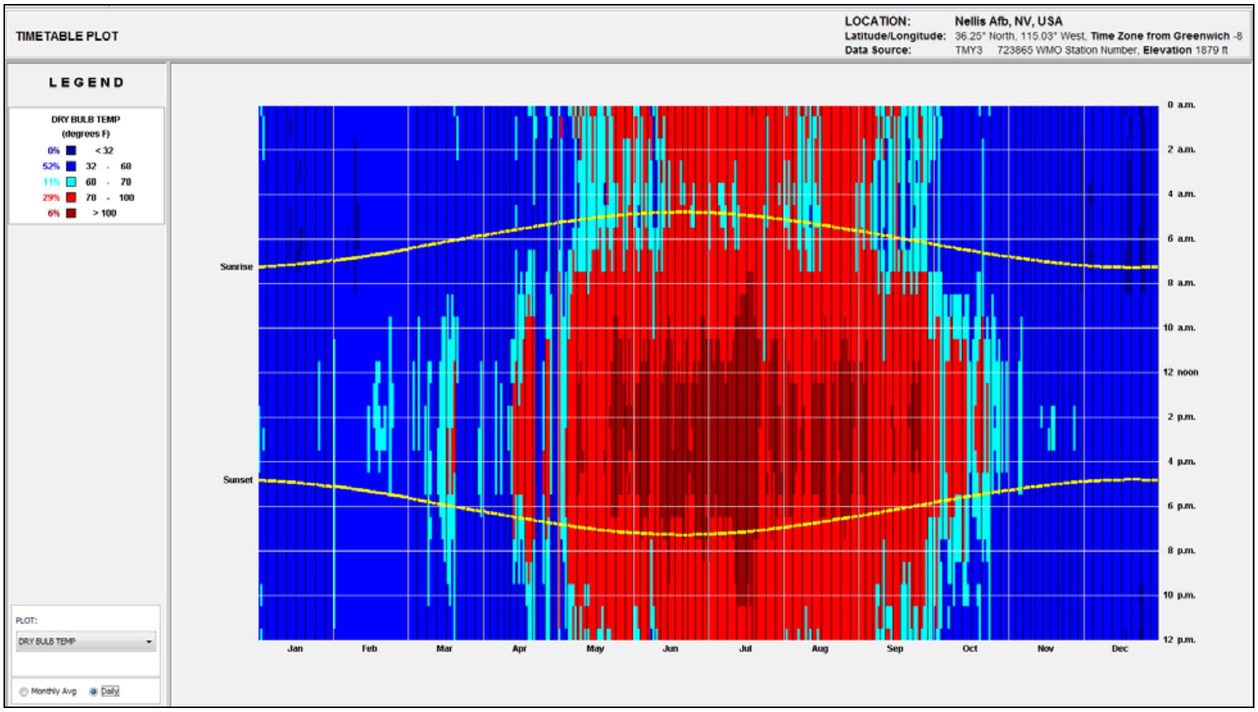


Figure 1.11. Time Table Plot for Las Vegas region. Climate Control Software.

The sun chart in Figure 1.12. for the Las Vegas region illustrates that during the summer months the southern façade would benefit greatly from shading devices to block solar gain.

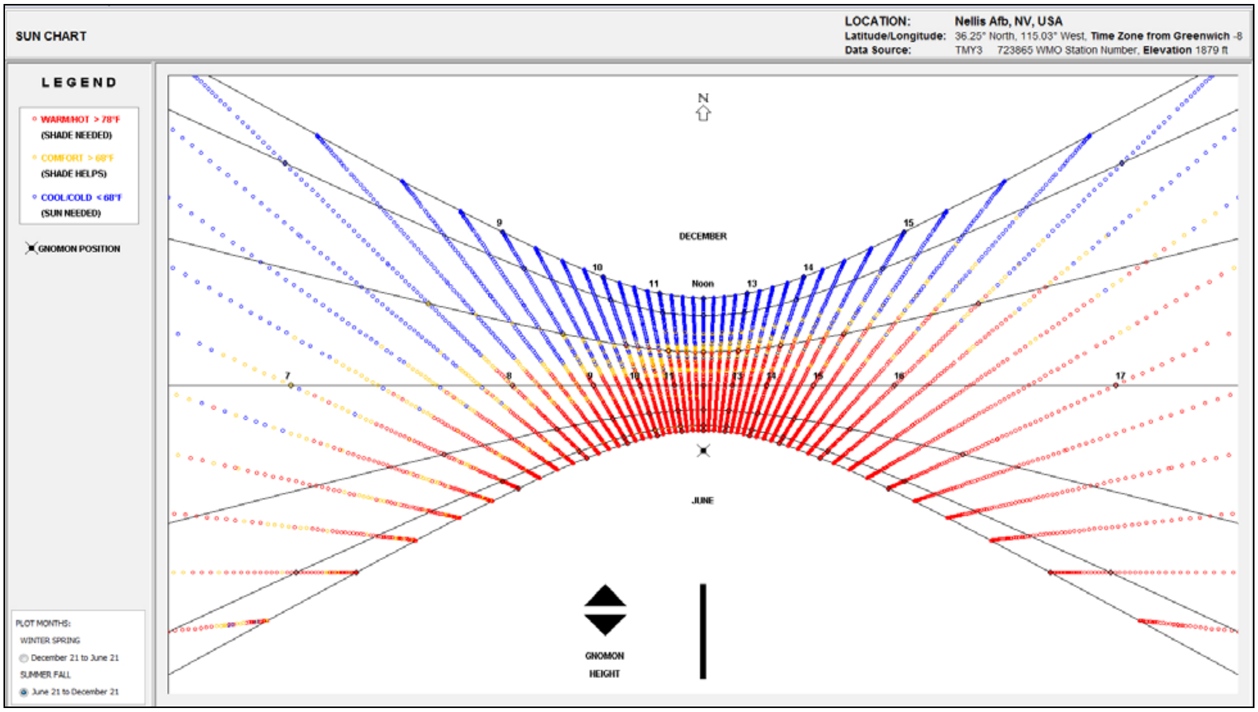


Figure 1.12. Sun Chart (June 21-December 21) for Las Vegas region. Climate Control Software.

Wind direction varies in the Las Vegas region throughout the year, with typical wind speeds ranging from 0 mph to 18 mph, with high winds recorded rarely going over 30 mph. As shown on the wind velocity range diagram in Figure 1.13., the average wind speed for the year is about 9 mph.

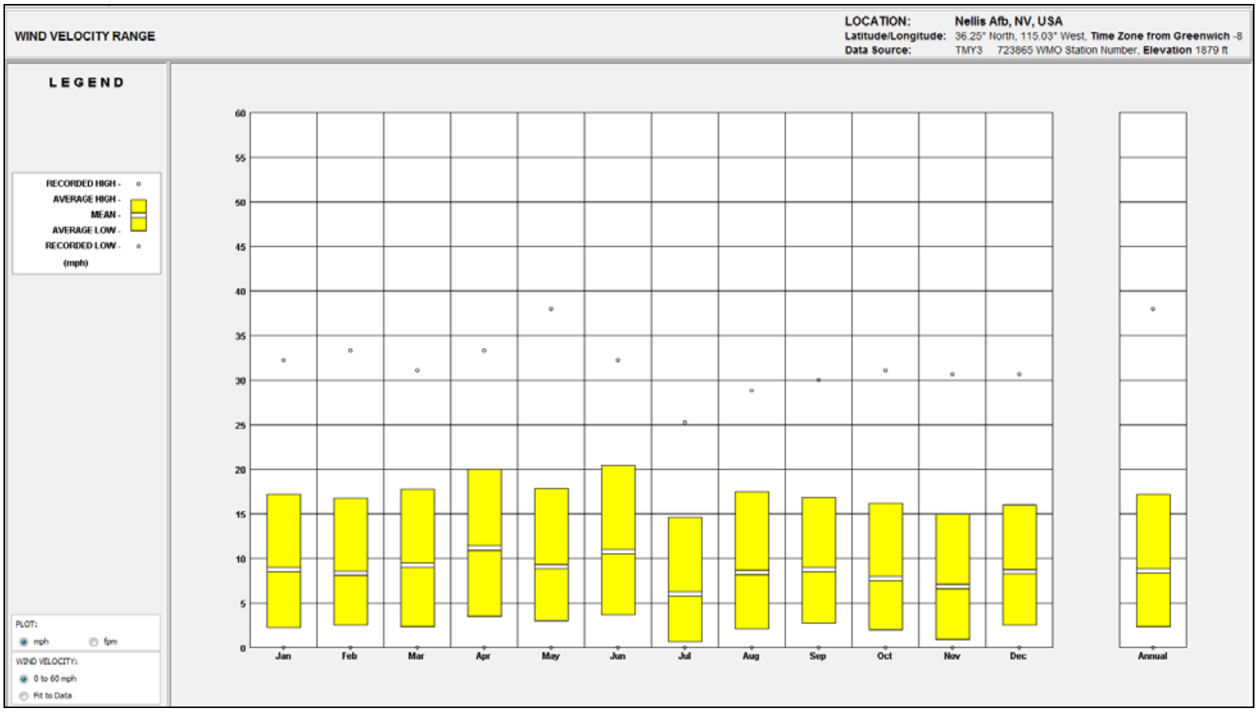


Figure 1.13. Wind Velocity Range for Las Vegas region. Climate Control Software.

The wind wheel analysis for the Las Vegas region in Figure 1.14. shows that there is no prominent wind direction throughout the year. However, during the winter months of December (Figure 1.15.) through February the wind appears to come from the north and north-east. In the summer months wind is prominent from the north west direction as seen from the wind wheel diagram from June in Figure 1.16.

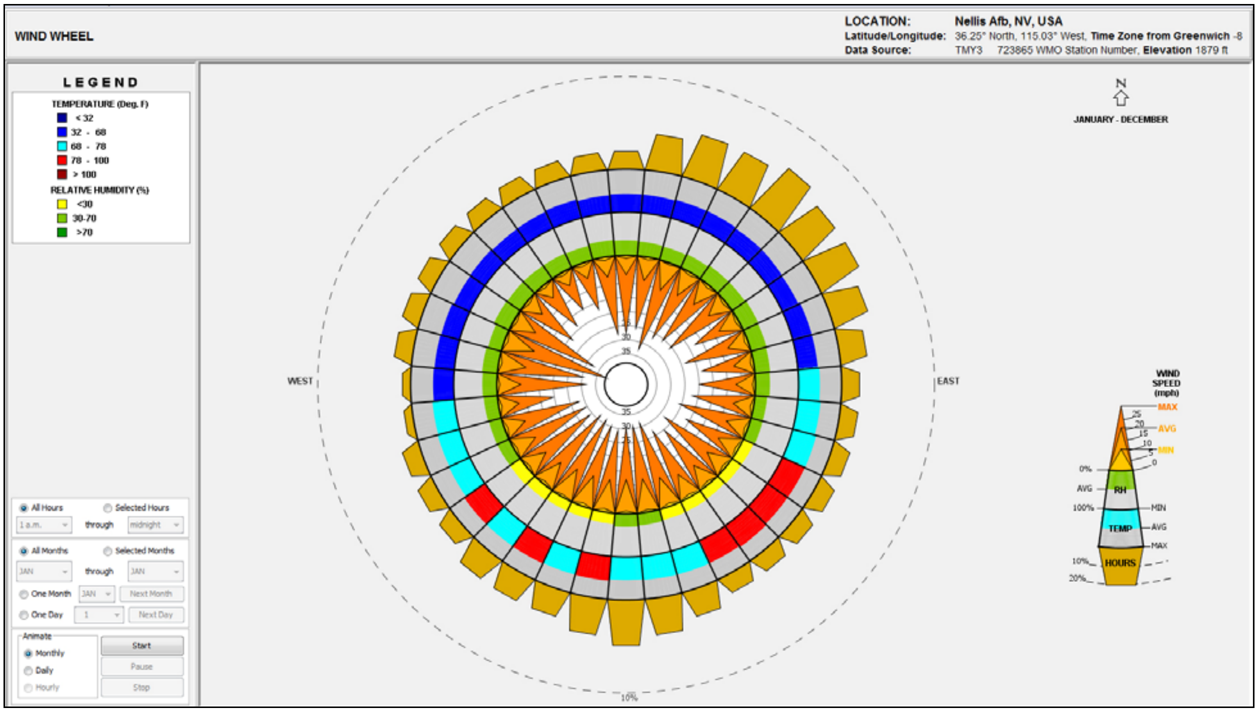


Figure 1.14. Wind Wheel (January-December) for Las Vegas region. Climate Control Software.

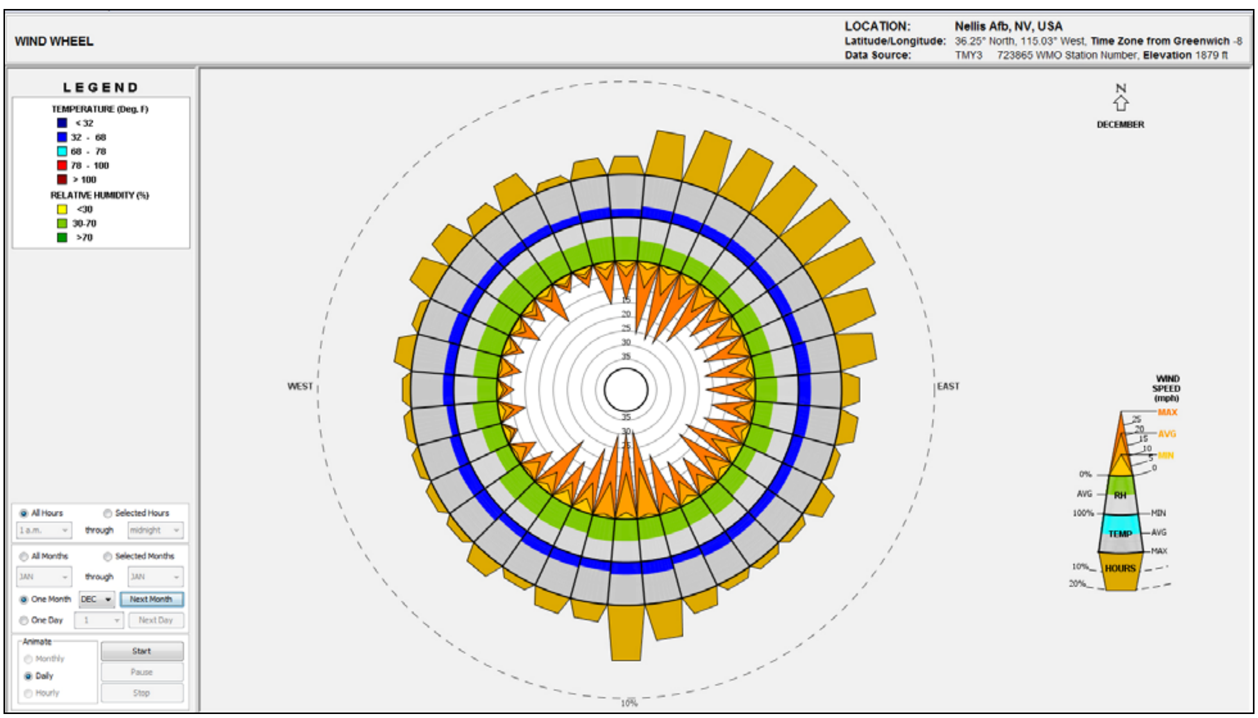


Figure 1.15. Wind Wheel (December) for Las Vegas region. Climate Control Software.

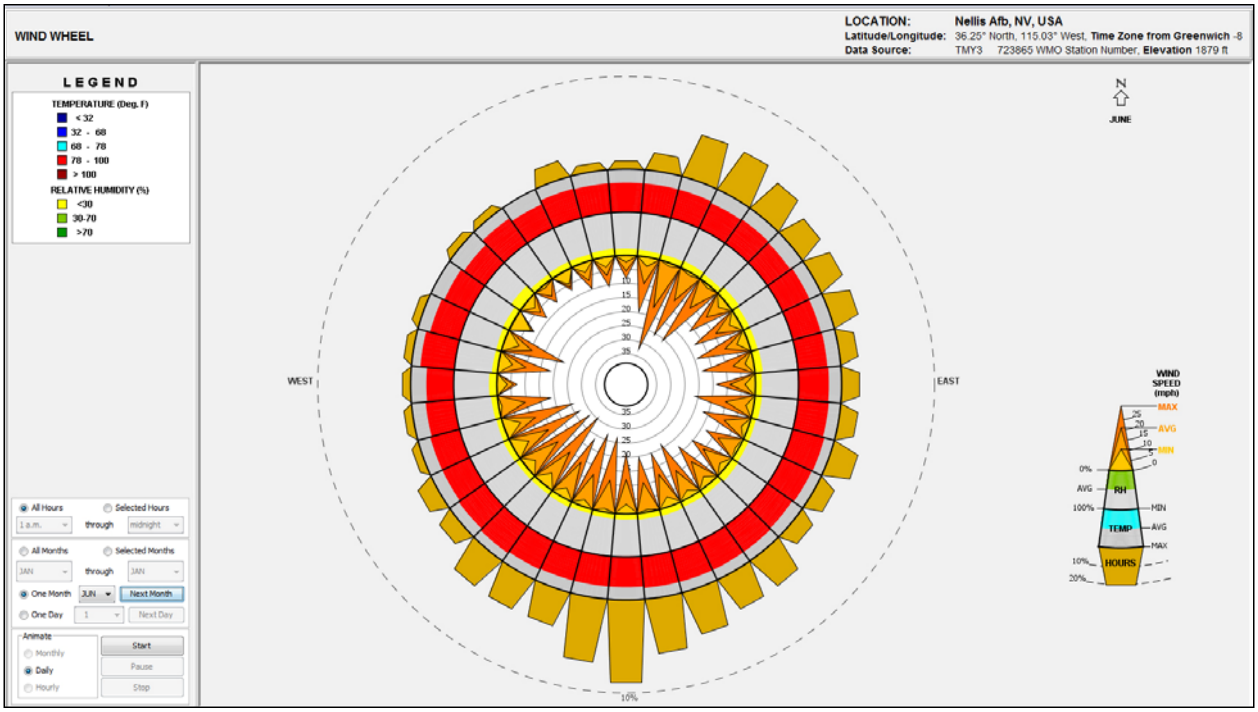


Figure 1.16. Wind Wheel (June) for Las Vegas region. Climate Control Software.

1.3 Building form and orientation.

With the population increase, the high demand of energy from the residential sector, as well as the harsh weather conditions of the Las Vegas region, there needs to be careful consideration in the design of new homes. Improving the building envelope, that is the walls, glazing, roof, foundations, thermal insulation, thermal mass, or movable shading devices can help achieve less energy use in cooling or heating a building. However, many of these techniques are only applicable in the later stages of schematic design, or throughout the design development and construction documentation phases. Energy efficiency in a single family residential building can be augmented early in the design process by careful consideration of the building form and orientation. This in turn can help reduce energy demand from the grid, by using less electrical lighting, as well as mechanical systems to cool or heat a home.

1.4 Purpose of research.

Buildings have long-term consequences, including the energy spent in space conditioning. The design and construction industries have the opportunity to create buildings that enable them to have improved energy efficiency during the lifetime of their use (Morrissey, 568). There has been little incentive by builders to think about the long-term energy costs associated with cooling, heating, and lighting buildings. Instead there has been an emphasis of building fast and moving to the next project or as author Ralph Knowles describes " grow cheap and maintain expensive" (15). In Figure 1.7., an aerial image from photographer Christoph Gielen shows an example of this occurring in the Southern Nevada region. Here residential unit types are built in identical fashion and rotated around with little regard to sun orientation and potential energy benefits.

Figure 1.17. Untitled IV : Residential development in the Las Vegas region. Photography by Christoph Gielen, Nevada 2010.

Building orientation can have a substantial influence on the end use energy consumption of a building so it may maximize passive solar benefits. Properly orienting a residential building early in design process can be an excellent way to reduce energy use instead of relying on the latter phases of the design process that may include more costly mechanical and renewable energy systems. In the paper *Affordable Passive Solar Design in a Temperate Climate: An Experiment in Residential Building Orientation,* note that the important decisions concerning the sustainability of a building can be made in the early design stages with appropriate orientations potentially reducing energy requirements on a residence by about 20 percent (Morrisey et al. 568).

Keplinger's article *Designing New Buildings of Optimum Shape and Orientation,* points out significant aspects on the costs of these systems and that of orientation and shape. He describes that optimum geometric shape of buildings have difficulty in measuring tangible benefits. Contrasting cost of insulation, solar collectors, or other systems can be estimated along with their potential energy savings (581). However, unless an analysis of optimal shapes and orientations is done, as this paper aims to do, it is difficult to access a monetary value or energy savings to this preliminary design effort.

He adds that current studies in the field of energy conservation concentrate on the building envelope, transmission of heat through various material assemblies, or window treatment. Knowles expands on this by arguing that architects and designers do not have to wait until the advanced stage of planning to evaluate the energy usage of a building. Simulations or calculations can be done easily on initial massing forms early in the design concept phases (21).

The purpose of this research is to study which are the most beneficial shapes, forms, and orientations that help reduce building energy loads for single family residences in the hot arid climate of Southern Nevada. This methodology can hopefully aid residential designers, developers, and builders early in the design process to make building shape and orientation decisions in order to have high energy performance residential buildings. A systematic investigation and analysis will be taken to study the effects of five building forms and different orientations along the cardinal points using the software BEopt version 2.4.0.1. Using the software, simulations of these base case residential buildings will be performed and test the performance of the buildings. A matrix of these findings will be generated to inform the design and construction industry on how shape and orientation affects energy consumption, but also help educate homebuyers on how different residences behave depending on their shape and placement on a lot.

Moreover, to connect the study to real world circumstances, a residential development in the Las Vegas region will be analyzed and modified using the information found in this study to see how residential developers can design these communities and their buildings with optimized orientations for energy savings. The study hopes to find which strategies can help reduce energy consumption, minimize annual energy costs, and improve the thermal performance of residential buildings and detached single family home communities in the Southern Nevada region.

CHAPTER 2: LITERATURE REVIEW

The literature review for this research project consisted of becoming familiarized with architectural geometries, forms, and orientations that are used for single residential homes and understand their relationships to reduce energy consumption. It was also important to see how other researchers evaluated and performed simulations on residential buildings and analyzed architectural form, orientation, and energy. Understanding their process and methods became a significant tool in order to perform a similar analysis and study for single family residences in the Southern Nevada region.

2.1 Building Shape and Orientation.

Morrissey et al. in their paper *Affordable Passive Solar Design in a Temperate Climate: An Experiment in Residential Building Orientation*, encourage passive solar design strategies such as building orientation, plan proportion and shape, and window placement. Of these parameters, they see appropriate building orientation as the most fundamental aspect for passive solar design, which can be an effective way to lower energy use. They also see this technique as simple and inexpensive in the design process (569).

The studies performed by Morrissey et al. included the simulation of a total of 81 plans conducted for eight orientations (NE, E, SE, S, SW, W, NW and N). An important aspect of their simulations to note is that in rotating the base building model to the eight different proposed orientations, the glazing areas were not adjusted, reflecting that volume builders would make very few adjustments to their stock plans for construction (572). Their results showed that floor area was the most important factor in terms of adaptability to orientation change. This means that smaller footprint dwellings had smaller energy loads across eight orientations, compared to larger houses.

Keplinger's article *Designing New Buildings of Optimum Shape and Orientation*, promotes that a building that is properly oriented can greatly reduce the demands of cooling or heating systems, or it can scale down the area and cost of expensive solar collectors. Moreover, once a building is poorly oriented, the opportunity for correction may be lost forever or be too cost prohibitive. He describes the most optimum shape for economic design is also the same as optimum shape to help reduce heat loss or heat gain, which is a compact plan with the least amount of envelope surface exposed to the elements (577).

Keplinger adds that for the hot arid areas in the southwest of the country, concerns of orientation are as important than the shape of the building. He favors the most efficient shape as one that is compact in plan, multi-level, and with small openings. The main objective, he adds, is to minimize the amount of external surfaces in order to reduce heat gain. He favors buildings in this region to exhibit a south orientation (585).

Different studies have shown that orientation can significantly influence energy loads on a residential building. The journal article by Hemsath et al., *Sensitivity Analysis Evaluating Basic Building's Geometry Effect on Energy Use*, suggest that greater surface-to-volume ratios increase heat transfer through the building envelope. The balance between form, shape, volume, daylight, and envelope become crucial for the design of low-energy architecture. Hemsath et al. put an emphasis on a building's geometry in the early design phase, instead of later design stage applications like mechanical or renewable energy systems (526). One strategy discussed is building compactness as an effective way to reduce energy for cooling or heating.

Orientation studies on a rectangular building by Anderson et al. in the southwest city of Albuquerque have noted that a south orientation produced the lowest total loads for this climate (216). In the paper *The Impact of Building Orientation on Residential Heating and Cooling*, building simulations show the importance of mixed heating and cooling requirements the southwest high desert region climate has, with a heating load that was 61% of the total (216).

The authors point out that these qualities have an excellent match of seasonal heating and cooling loads and the high yearly solar resource (216). The figure below (Figure 2.1.) illustrates how departing from the south orientation results in a major change in total load building consumption. It is important to note that the heating load increases rapidly as the building is turned away from south, the highest difference at the NE and NW directions. East and west orientations produced a higher total load, they attribute these results to the climate's extensive solar exposure and clear sky hours. For cooling purposes, only the north or south orientation had nearly equal loads. Anderson et al. conclude that with appropriate overhangs, north orientations can perform as well as south in the hottest U.S. climates.

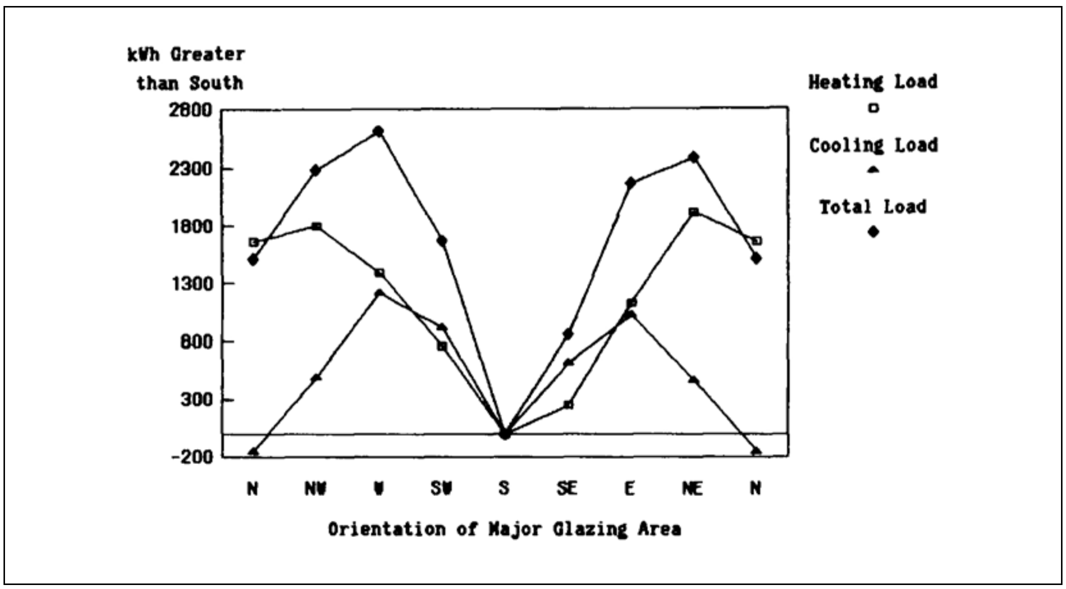


Figure 2.1. Albuquerque: Orientation sensitivity studies show that a south orientation is best in this passive solar climate.

A study performed by Hemsath et al. in their paper *Sensitivity Analysis Evaluating Basic Building's Geometry Effect on Energy Use*, showed the importance of energy performance evaluation of building form is to help in the decision making process for architects to achieve

high performance buildings. Their simulations tested twenty different roof type variations to a square mass measuring 100'x100'x30' while maintaining the interior condition volume and constraining the buildings overall volume and surface area (527-528). The building and the roof variations were then tested at different orientations in multiples of 45°. This study presented an excellent precedent for the type of simulation and analysis that could be tested in the southern Nevada region for building shapes and orientations. Some of the conclusions of their study revealed that energy modeling tools can help designers evaluate early design decisions about a building's geometric characteristics (537). In addition, building geometry in some cases, depending on the location, became more important than the materials used for the building envelope (537). It is important to note that in this study, the authors decided to eliminate windows from their base buildings to understand fully geometric factors related to energy performance (529)

On journal article, *Effect of Building Shape on a Residential Building's Construction, Energy and Life Cycle Costs* by Bostancioglu, simulations were performed on square, rectangular, H- and star-shaped residential buildings in Turkey. In all cases, the buildings share the same properties, such as area, wall and windows, with the only variable being the external wall area of the building. Annual heating energy loads, the most prominent in the region that the analysis was performed, were calculated based on these shapes on eight different orientations (446). The results of this study demonstrated that a square plan had the lowest heating energy costs in the different orientation alternatives (448).

A rectangular shape is regarded as an optimal shape for energy efficiency according to the authors of the book *Sun, Wind & Light,* as well as the authors of the web resource the 2030 Palette. Brown et al., the authors of the book *Sun, Wind & Light,* recommend to elongate buildings in the east-west direction, since it exposes mostly the shorter east and west facades to the prolonged heat gain and high afternoon temperatures of the summer months (63) . At the

same time, the east-west floor plan increases the southern winter facing facade in order to collect solar radiation during this season (85).

Caroline Hachem's article *Using Passive Design* points out that the aspect ratio (AR) for rectangular shapes between the south facing facade and the perpendicular facade should have a ratio of 1.2 to 1.3 to offer a good balance between heating and cooling loads (72). Another technique on a rectangular form that the 2030 Palette recommends is to keep a narrow floor plate or thin organization in order to incorporate cross or stack ventilation to cool the interior of the building (Form for cooling).

Non-rectangular shapes that are self-shading, like an L or U shape, can offer solar advantages that can be evaluated. For self-shading geometries the depth ratio (DR) between shaded facade to facade lengths becomes important (Hachem 74). Hachem points out that a building with an L-shape configuration with a depth ratio that is one half will require 9% less heating than an L-shape with a depth ratio of 1 (73-74). Moreover, the shading created by L or U-shapes will reduce heat gain due to self-shading from the building wings (74).

For roof design it is recommended that the roof geometry be designed for potential solar photovoltaic or other solar collectors. The tilt angle for these collectors has the rule of thumb to be the latitude of the location. For the Las Vegas region this would be 36.125°N. Hachem's studies on orientation at mid-latitude locations point out that a 45° tilt angle by 45° relative to the south, can provide up to 5% reduction of electricity, while a rotation by 60° to the west or east of the south can result in an energy reduction of 12% (74).

On the book *Energy, Environment and Building*, Philip Steadman discusses the use of minimum surface area in energy efficient buildings (27) and that the wall that receives the most amount of solar radiation is the west side (38). He discusses studies done by Victor Olgyay on optimum shapes for buildings, which take into account heat loss in the winter and heat gain in the summer months, where rectangular plans that are elongated east and west become effective shapes to use (38). East and west façades receive the most amount of summer

radiation, therefore their surface area should be reduced. During the winter months the south elevation receives radiation and its area can be larger in size (38). As shown in the figure below (Figure 2.2.), he recommends a rectangular plan with the proportions of 1:1.3 in a hot arid region. This ratio gives a reduced amount of heat gain during the summer and heat losses in the winter (37).

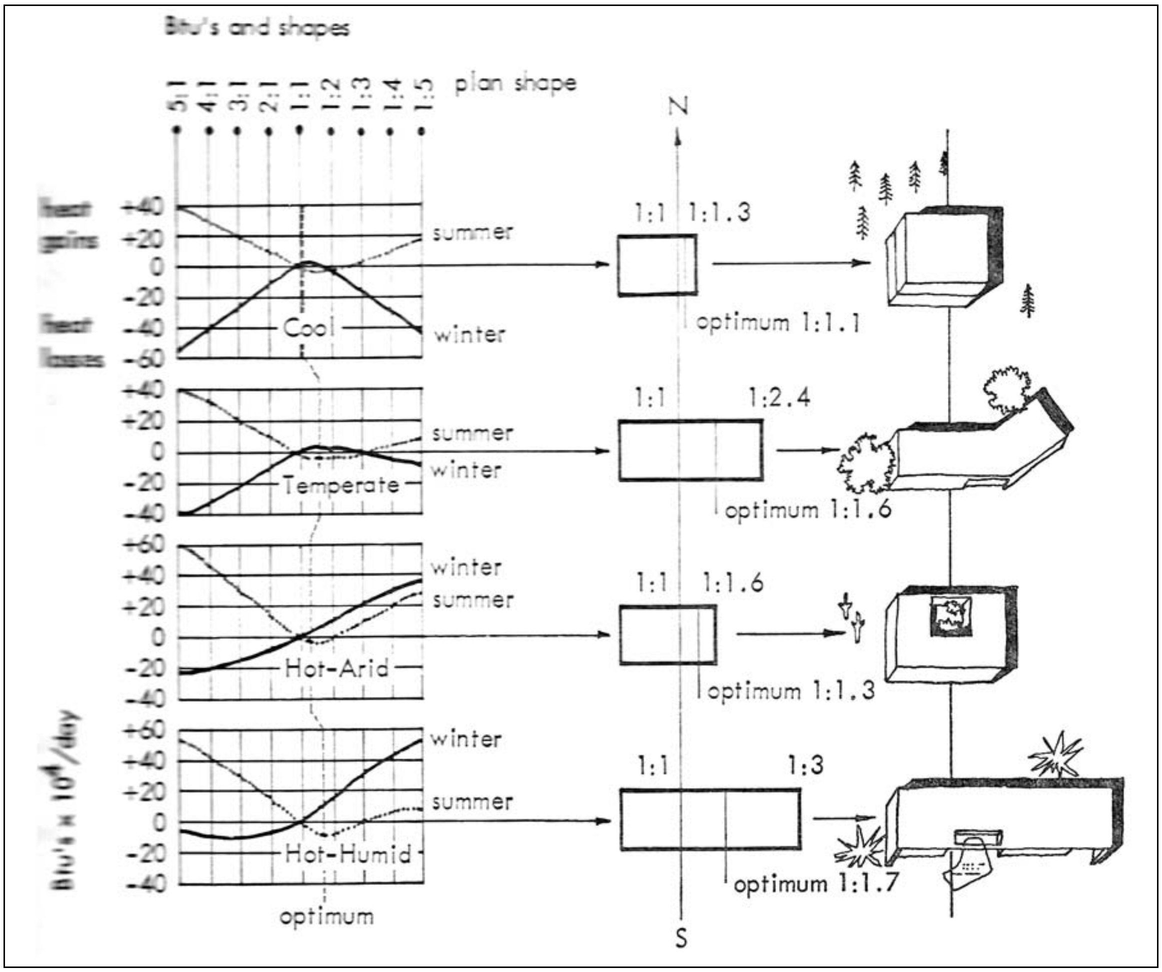


Figure 2.2. 'Basic forms and building shapes in different regions,' from Victor G. Olgyay.

Steadman expands on the advantages on reduction of openings on the west facade while adding them in the south side with studies done on the orientation and planning of house done by Henry Nicholas Wright (41). His study placed the most important rooms with large opening on the south and south west to benefit from the winter sun, while minimizing openings in the west and northwest sides because of the excessive solar radiation during the summer months (39-41). His analysis of the plan turned in perpendicular orientations is shown on the figure below (Figure 2.3.).

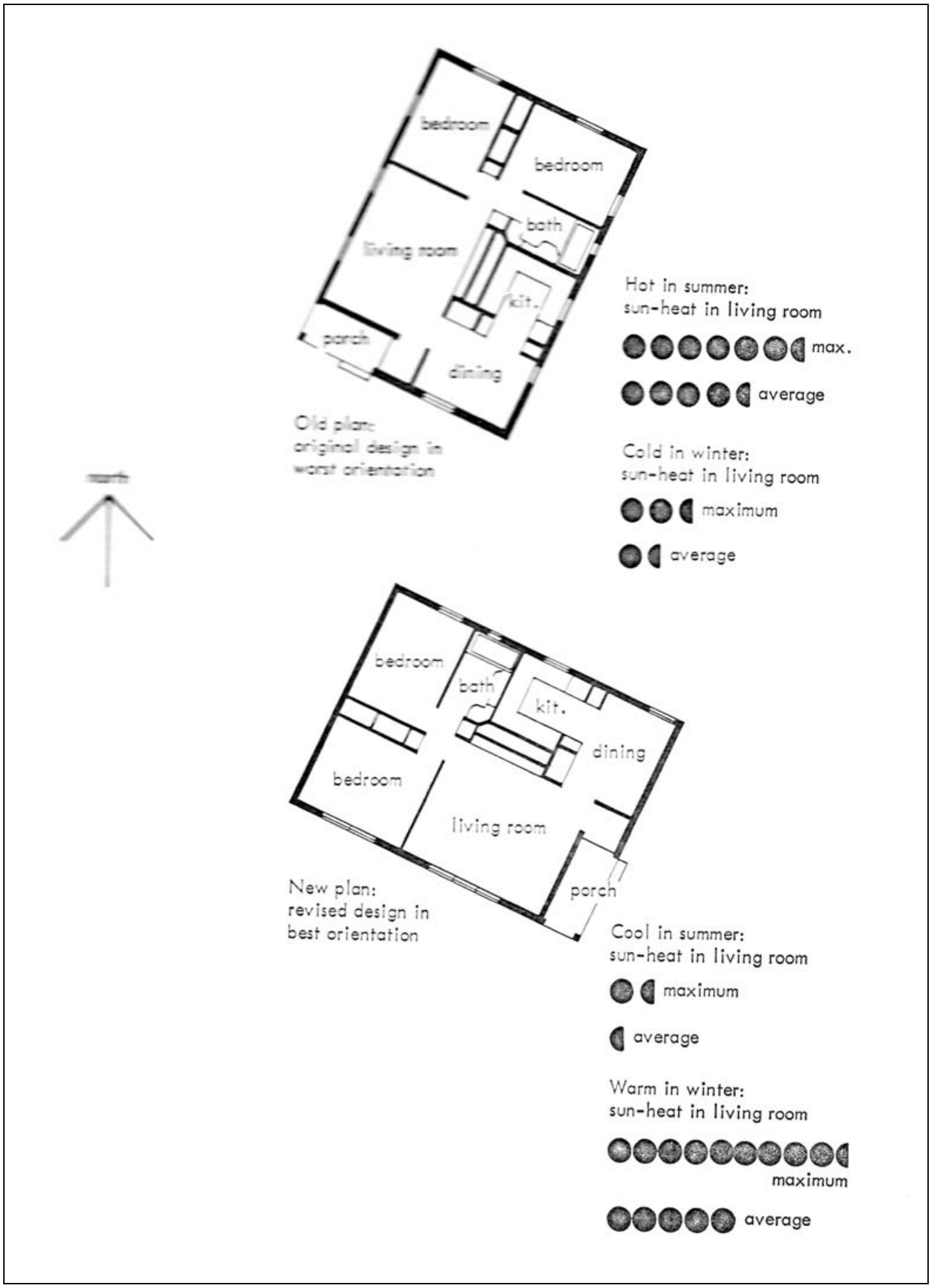


Figure 2.3. Comparison of effects of solar radiation on a solar house in New York area in two perpendicular orientations. Illustration by Henry Niccols Wright.

Many of the writings that author Ralph Knowles focuses on are on the solar envelope, which is defined as the physical boundaries of surrounding properties and the period of assured

access to sunshine. It is important to note that in these studies, the ratio between the building volume and the surface area (V/S) become an important. This ratio helps become an energy-based descriptor, where in small buildings with low V/S use energy to overcome skin loads and have an architectural connection with the sun. In the other hand, larger buildings with high V/S will require additional energy to compensate overheating (18).

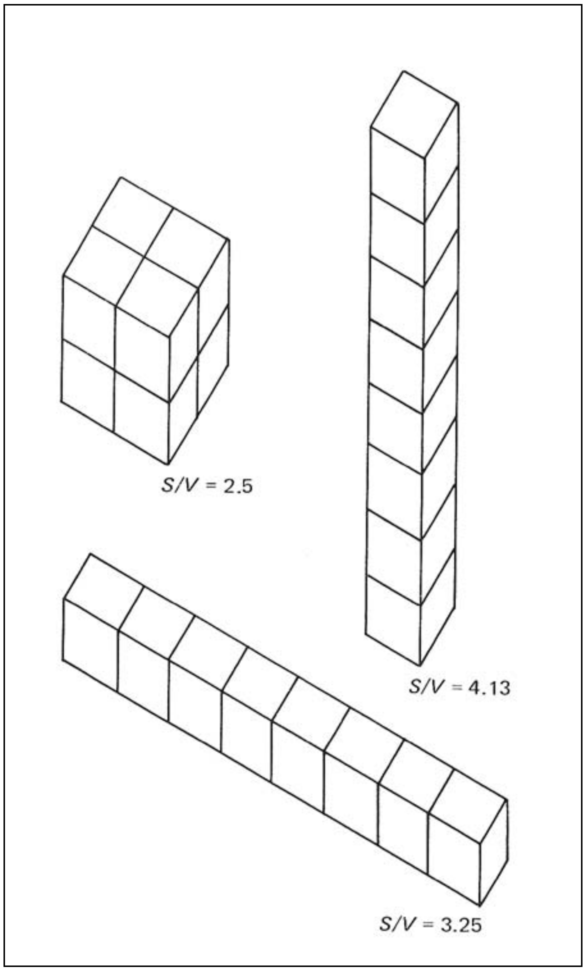


Figure 2.4. The shape of the form has an effect on its surface to volume ratio. Illustration by Ralph Knowles.

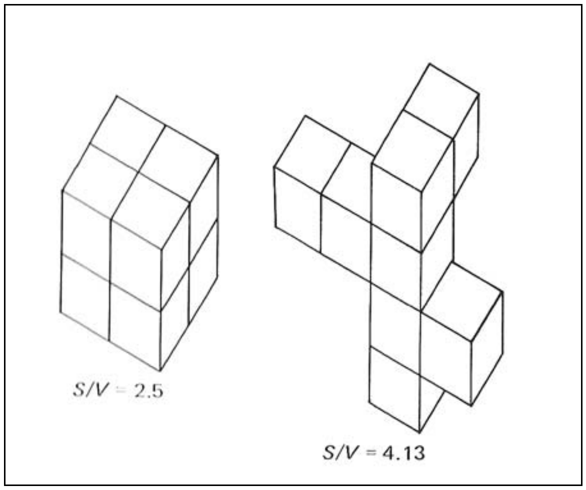


Figure. 2.5. Simpler shapes generally have a lower surface to volume ratio than complex shapes of the same volume. Illustration by Ralph Knowles.

After becoming familiarized with many of the concepts and studies done on geometry, orientation, and energy the next step was to set up the methods in which this analysis was going to be performed for the Southern Nevada region.

CHAPTER 3: RESEARCH METHODS

3.1 Race to Zero Student 2015 Competition.

This study and thesis was done in conjunction with the Race to Zero Student 2015 Competition sponsored by the U.S. Department of Energy. Some of the analyses performed on the base building models were performed respecting some of the rules and guidelines that the competition established. In particular these included the use of the energy simulation software BEopt, as well square footage areas set for the homes. Some of the competition parameters are discussed below.

The goal of the competition was to design a high performance home that was net zero energy ready and to equip the next generation of architects and engineers with creative solutions in the design and construction of single family homes. The guidelines required homes to a minimum design target of the DOE Zero Energy Ready Home Rev.04 (4-10). This included a benchmark home size of no less than 1,600 square feet for a two bedroom home and 2,200 for a three bedroom residence. This floor area represented only the conditioned space for the residence (Student Design Competition Guide to Project Preparation and Submittal, 3). More on the square footage and number of bedrooms of the homes in Section 3.2.

For the energy analysis part of the competition, the guidelines suggested and encouraged students to use NREL's own BEopt software as a supporting resource to help simulate the energy efficiency of the home (Student Design Competition Guide to Project Preparation and Submittal 4-10). A brief description of the BEopt software program used follows.

3.2 BEopt.

In order to evaluate the different shapes and orientation strategies base models were created using BEopt version 2.4.0.1 and different simulations were tested. Having worked with other energy modeling programs like RemRate version 14.6.1. Equest version 3.65, and Revit Green Building Studio version 2014, the use of the BEopt platform was an appropriate tool to evaluate conceptual ideas, as the other programs became more useful for the later stages of the design process.

The BEopt (Building Energy Optimization) software is developed by the National Renewal Energy Laboratory to evaluate residential building designs and find energy saving strategies along the path to zero net energy. BEopt can be used in new construction or existing residential retrofits with simulation based analysis on different type of characteristics, like size, building construction materials, location, equipment, and utility costs. BEopt uses existing, established simulation engines (currently DOE-2.2 and EnergyPlus). A particular benefit for this study is the ability that BEopt has to quickly generate full 3D geometry of residential homes and rotate them around the different cardinal points to do a comparative analysis on the energy performance of each.

3.2 Building envelope to volume ratios.

The first task performed before simulating the different shapes and orientations was create base building models with the same characteristics of current homes in the Southern Nevada area. An analysis of surface to volume ratios was performed on four typical single family residences in the Las Vegas region. Two to three bedroom homes are the most common type of residence in Nevada, as seen in Figure 3.1. (Selected Housing Characteristics), so these were target examples to be analyzed.

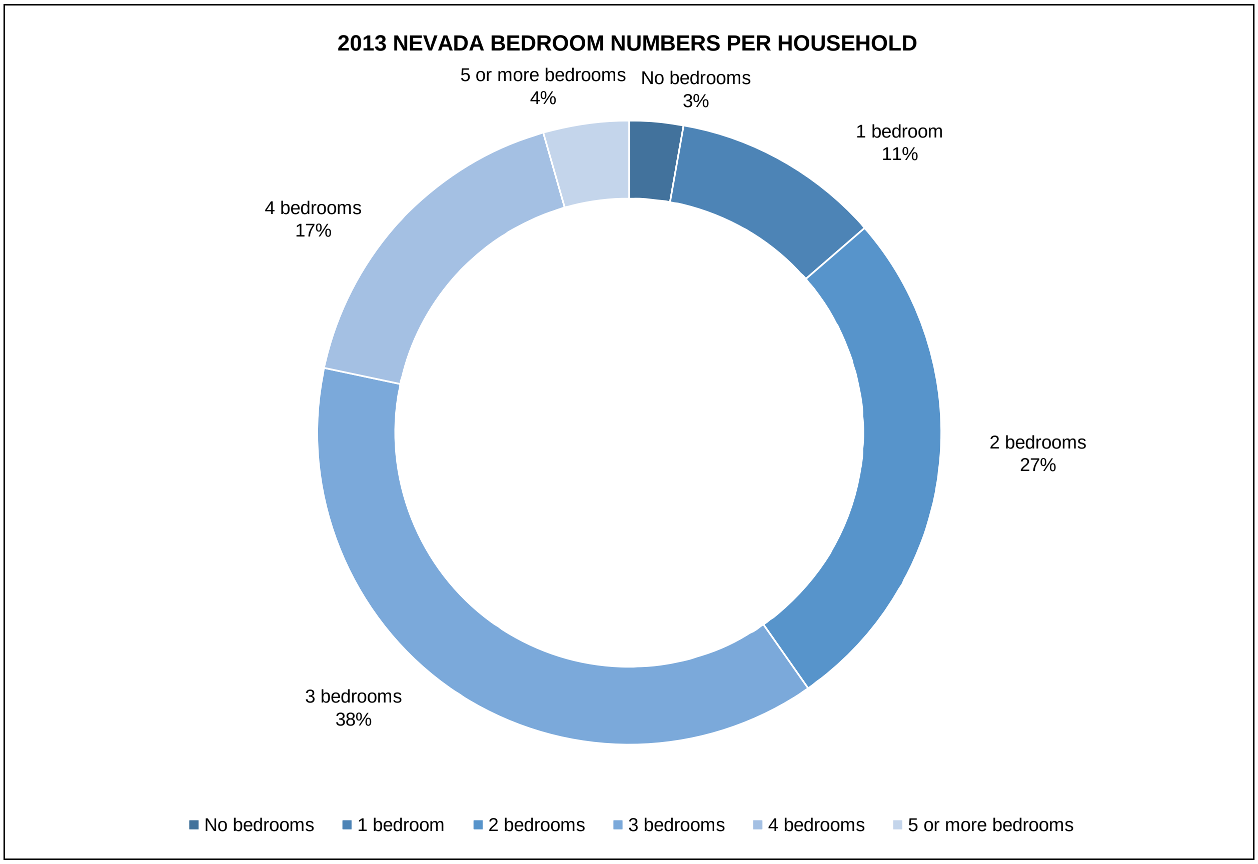


Figure 3.1. 2013 Nevada bedroom numbers per household, from U.S. Census Bureau 2013.

Five students from the School of Architecture at the University of Las Vegas, Nevada, drew the floor plans of these residences, taking into account wall and window areas per facade, floor and roof areas, as well as the volume of the conditioned space. Therefore spaces like garages were omitted from the calculations. The preliminary data that were captured are summarized in Table 3.1. along with the corresponding drawings of each residence in Figures 3.1.-3.4. It is important to note that all the residences surveyed were single story homes, as the simulations and study done on this paper aimed at this typology.

HOUSE 1		HOUSE 2		HOUSE 3		HOUSE 4	
Conditioned Volume:		Conditioned Volume:		Conditioned Volume:		Conditioned Volume:	
	15,000 cu.ft.		18,240 cu.ft.		15,102 cu.ft.		14,449 cu.ft.
Surface areas:		Surface areas:		Surface areas:		Surface areas:	
North:	240 sq.ft.	North:	240 sq.ft.	North:	333 sq.ft.	North:	293 sq.ft.
East:	220 sq.ft.	East:	384 sq.ft.	East:	724 sq.ft.	East:	446 sq.ft.
South:	240 sq.ft.	South:	128 sq.ft.	South:	153 sq.ft.	South:	104 sq.ft.
West:	360 sq.ft.	West:	608 sq.ft.	West:	360 sq.ft.	West:	689 sq.ft.
Roof:	1,239 sq.ft.	Roof:	1,767 sq.ft.	Roof:	1,693 sq.ft.	Roof:	1,588 sq.ft.
Floor:	1,239 sq.ft.	Floor:	1,767 sq.ft.	Floor:	1,693 sq.ft.	Floor:	1,588 sq.ft.
Windows areas:		Windows areas:		Windows areas:		Windows areas:	
North:	18 sq.ft.	North:	30 sq.ft.	North:	76 sq.ft.	North:	91 sq.ft.
East:	60 sq.ft.	East:	27 sq.ft.	East:	53 sq.ft.	East:	46 sq.ft.
South:	4 sq.ft.	South:	12 sq.ft.	South:	20 sq.ft.	South:	17 sq.ft.
West:	117 sq.ft.	West:	54 sq.ft.	West:	8 sq.ft.	West:	56 sq.ft.
Roof:	0 sq.ft.	Roof:	0 sq.ft.	Roof:	0 sq.ft.	Roof:	0 sq.ft.
% of floor area	16%	% of floor area	7%	% of floor area	9%	% of floor area	13%

Table 3.1. Data collected on surfaces and conditioned volume on four residences in the Las Vegas region. Data collected by Johny Corona, John Carroll, David McCredo, Nick Inouye, and Ludwing Vaca.

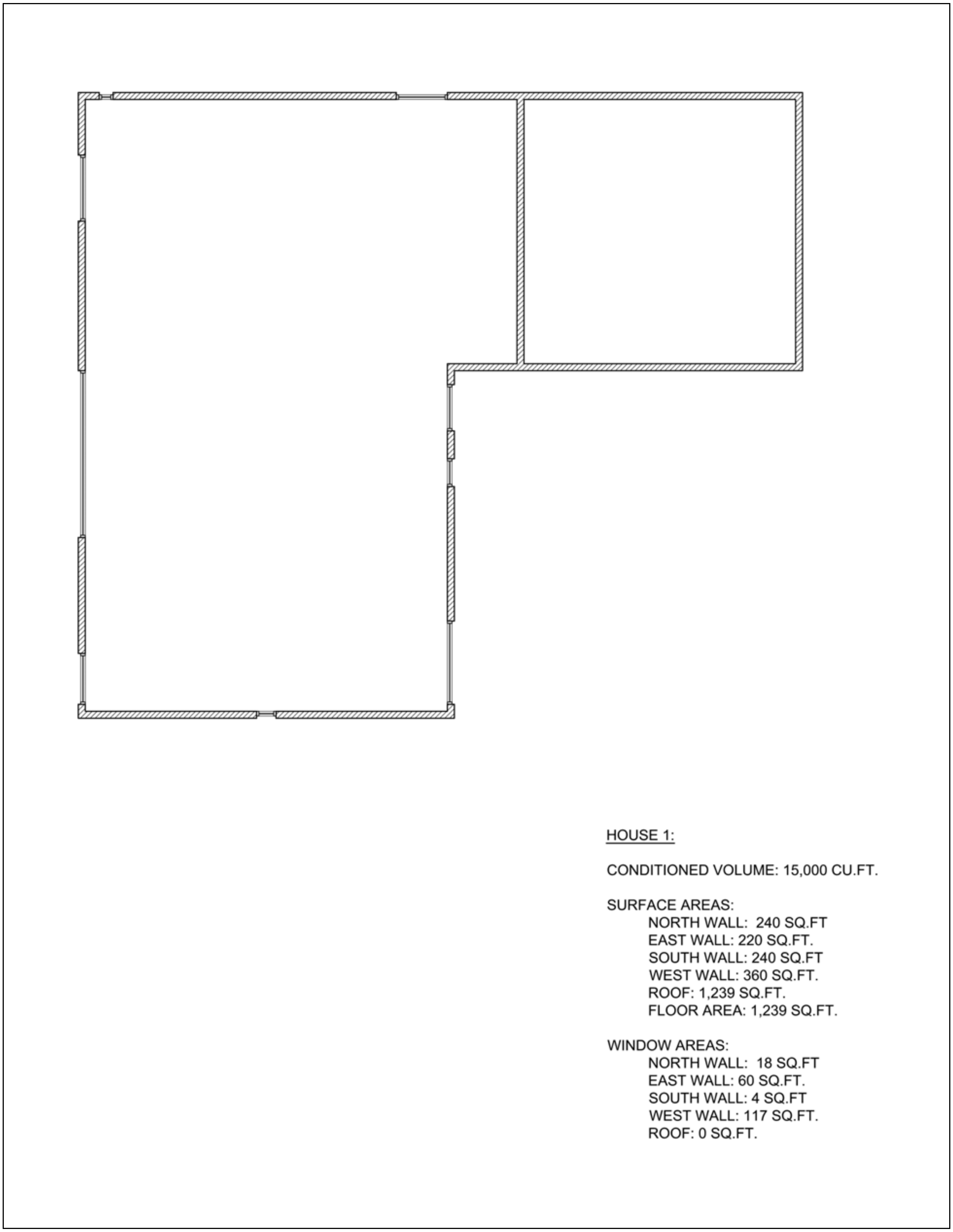


Figure 3.2. House 1 Floor Plan.

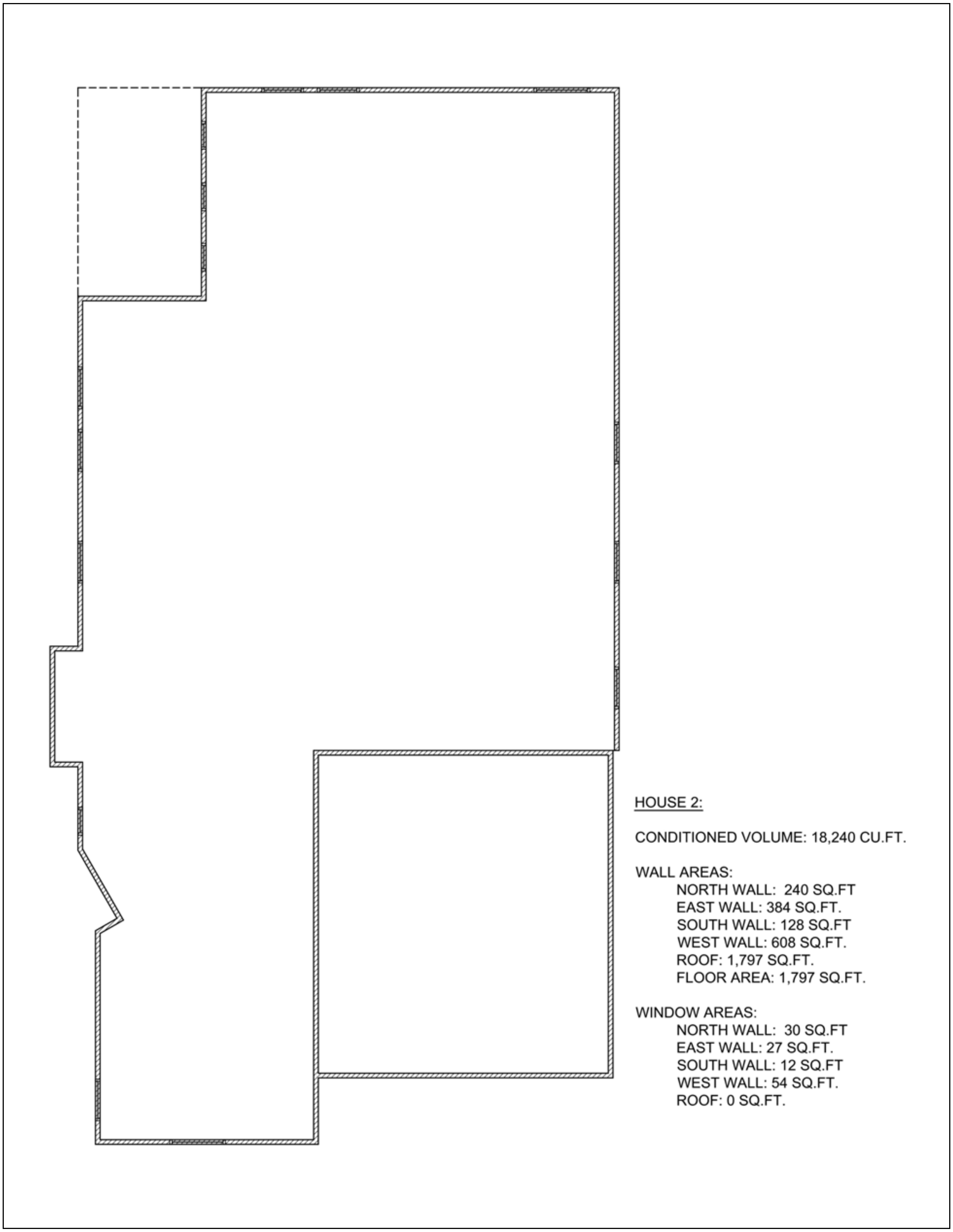
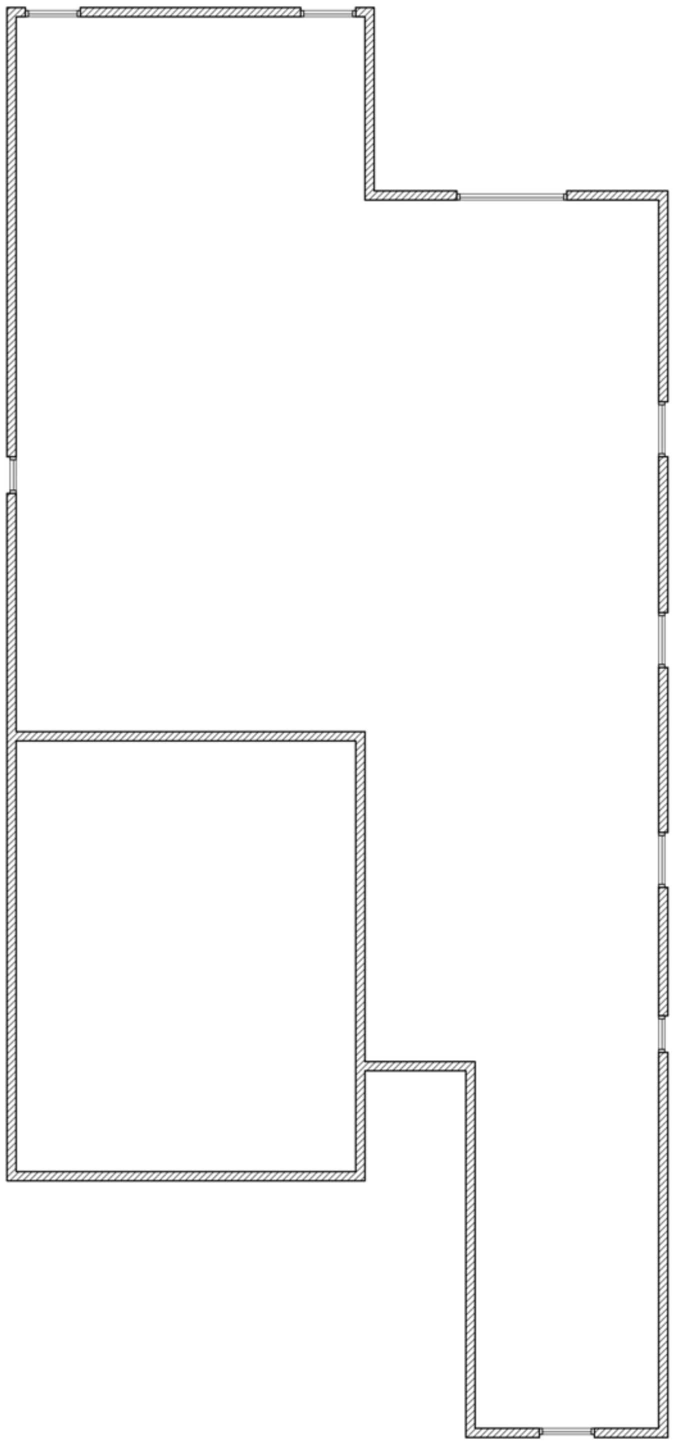


Figure 3.3. House 2 Floor Plan.



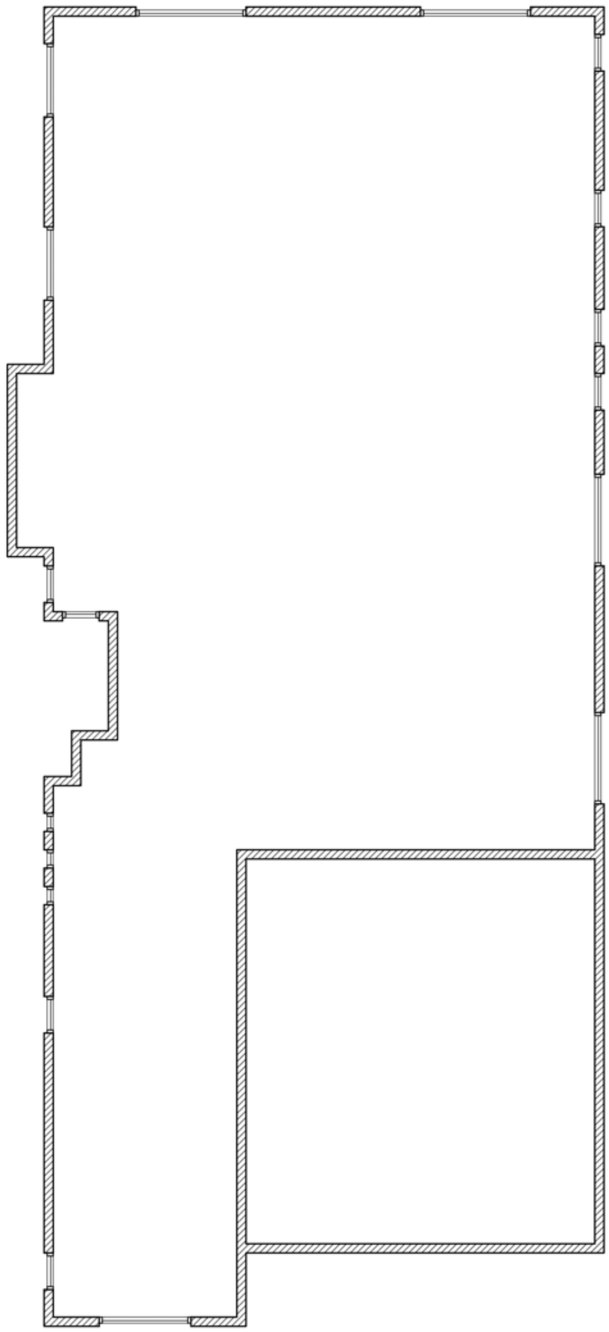
HOUSE 3:

CONDITIONED VOLUME: 15,102 CB.FT.

WALL AREAS:
NORTH WALL: 333 SQ.FT
EAST WALL: 724 SQ.FT.
SOUTH WALL: 153 SQ.FT
WEST WALL: 360 SQ.FT.
ROOF: 1,693 SQ.FT.
FLOOR AREA: 1,693 SQ.FT.

WINDOW AREAS:
NORTH WALL: 76 SQ.FT
EAST WALL: 53 SQ.FT.
SOUTH WALL: 20 SQ.FT
WEST WALL: 8 SQ.FT.
ROOF: 0 SQ.FT.

Figure 3.4. House 3 Floor Plan.



HOUSE 4:

CONDITIONED VOLUME: 14,499 CB.FT.

WALL AREAS:
- NORTH WALL: 293 SQ.FT
- EAST WALL: 446 SQ.FT.
- SOUTH WALL: 104 SQ.FT
- WEST WALL: 689 SQ.FT.
- ROOF: 1,588 SQ.FT.
- FLOOR AREA: 1,588 SQ.FT.

WINDOW AREAS:
- NORTH WALL: 91 SQ.FT
- EAST WALL: 46 SQ.FT.
- SOUTH WALL: 17 SQ.FT
- WEST WALL: 56 SQ.FT.
- ROOF: 0 SQ.FT.

Figure 3.5. House 4 Floor Plan.

After gathering these data, the next step was to get the envelope to volume ratios of each home and then average these out to get a figure that could be used for the building of the base models. Table 3.2. below summarizes the calculations taken to find the envelope to volume ratios of each residence surveyed.

	HOUSE 1	HOUSE 2	HOUSE 3	HOUSE 4
Surface Areas Total	3,198 sf	3,250 sf	3,420 sf	3,330 sf
Conditioned Volume	15,000 cf	18,240 cf	15,102 cf	14,449 cf
S/V	0.21	0.18	0.23	0.23
1/(S/V)	**4.69**	**5.61**	**4.42**	**4.34**

Table 3.2. Envelope to volume ratios for the four homes surveyed for the Las Vegas region.

Taking an average of the for the final 1/(S/V) figures above, an envelope to volume ratio of 1:4.76 would be used for all base models, as seen in Table 3.3. below.

	(4.69 +5.61 + 4.42 +4.34)/4
Average for the four houses surveyed	4.76
Final envelope to volume ratio	**1:4.76**

Table 3.3. Final envelope to volume ratio for base models to be simulated in BEopt.

3.3 Shapes.

Based on the surface to volume ratio that was studied on the previous analysis, five different floor plans were drawn respecting this ratio of 1:4.76 as close as possible. These homes and shapes included a rectangle and square, as well as self shading plans comprising of L-shape, U-shape , and a courtyard buildings. When creating the shapes and volumes for the

base building models and maintaining the ratio above, the goal was to create floor plans and volumes that had good architectural proportions and making sure their square footages were in line with typical two to three bedroom homes that are common of single family residences in the Las Vegas market as well as the benchmark home sizes described in the Department of Energy Zero Energy Ready Home National Program Requirements. Through trial and error, the five final building floor plans to be modeled were developed with building heights set to be nine feet tall. The square and rectangle shapes were drawn to be 1,600 square feet and 1800 square feet respectively. The other plans required more floor area due to their shape, which was about 2,400 square feet. A summary of these floor areas and conditioned volume is shown in table 3.4.

3.4 Orientations.

After the shapes of the buildings to be analyzed were determined, the next step was to determine the different angles around the cardinal points these buildings would be orientated for energy simulation. Each of the building models was to be rotated at 22.5 degrees in plan, with some of the shapes only rotated a few times because of the symmetrical nature of th shapes. This angle was a constant, as it was one of the set parameters that the software BEopt allowed the user to change. A list of the angles of simulation for each shape can be seen in Table 3.4. as well as a graphic matrix of these simulation in Figure 3.6.

3.5 Base building model properties.

In order to compare the five different models equally, except for their shape and orientation, all the characteristics in construction and materiality were to be the same. Just as we had previously surveyed current Las Vegas residences to figure out a constant building envelope to volume ratio, we took the current building standards and codes to which residences are required to be built in the region as the rules to follow to build the base models for the

simulation. Table 3.5. shows all the values that meet 2009 IECC code standards that include envelope materials for roof, walls and glass. Also included in the table are typical space conditioning systems that are used in the region. Water heater, lighting, plug loads, and appliances like refrigerator, dishwasher, clothes washer, or dryer were set to zero for the simulation. Therefore only space conditioning energy use was the data to be extracted from the simulations.

Glazing areas were determined according to ASHRAE 189.1-2004 in order to achieve an average daylight factor of 4%. The daylight factor formula is $DF_{avg} = (0.2) \times [(window\ area)/(floor\ area)]$ and if we would like to achieve the 4% average daylight factor, the formula turns into $0.04 = (0.2) \times [(window\ area)/(floor\ area)]$. Solving for the window area we find out that it equals to 20% of the floor area for each home as seen below.

$$DF_{avg} = (0.2) \times [(window\ area)/(floor\ area)]$$

$$0.04 = (0.2) \times [(window\ area)/(floor\ area)]$$

$$window\ area = (floor\ area) \times (0.2)$$

This figure is represented in Table 3.4. according to the different floor areas for the five different base buildings to be simulated. Note that the glazing was distributed evenly around the four façades in order to have a fair analysis of each building shape and orientation.

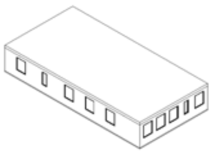
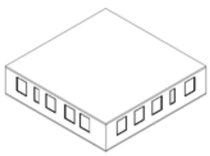
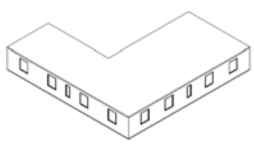
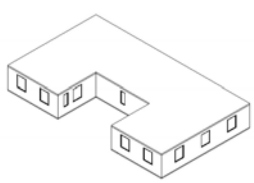
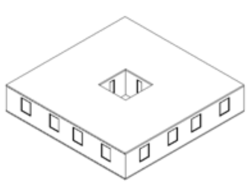
BUILDING SHAPE	CHARACTERISTICS	SIMULATION (AZIMUTH DEGREES)	
	Floor Area: 1,800 sf Volume: 16,200 cf Window area: 360sf. Envelope to Volume Ratio: 1:4.74	South: 0.0° SSW: 22.5° South West: 45.0° WSW: 67.5° West: 90° WNW: 112.5° Northwest: 135° NNW: 157.5°	North: 180° NNE: 202.5° Northeast: 225.0° ENE: 247.5° East: 270.0° ESE: 292.5° Southeast: 315° SSE: 337.5°
	Floor Area: 1,600 sf Volume: 14,400 cf Window area: 320 sf. Envelope to Volume Ratio: 1:4.74	South: 0.0° SSW: 22.5° South West: 45.0° WSW: 67.5° West: 90° WNW: 112.5° Northwest: 135° NNW: 157.5°	North: 180° NNE: 202.5° Northeast: 225.0° ENE: 247.5° East: 270.0° ESE: 292.5° Southeast: 315° SSE: 337.5°
	Floor Area: 2,400 sf Volume: 21,600 cf Window area: 480 sf Envelope to Volume Ratio: 1:4.7	South: 0.0° SSW: 22.5° South West: 45.0° WSW: 67.5° West: 90° WNW: 112.5° Northwest: 135° NNW: 157.5°	North: 180° NNE: 202.5° Northeast: 225.0° ENE: 247.5° East: 270.0° ESE: 292.5° Southeast: 315° SSE: 337.5°
	Floor Area: 2,363 sf Volume: 21,267 cf Window area: 480 sf Envelope to Volume Ratio: 1:4.6	South: 0.0° SSW: 22.5° South West: 45.0° WSW: 67.5° West: 90° WNW: 112.5° Northwest: 135° NNW: 157.5°	North: 180° NNE: 202.5° Northeast: 225.0° ENE: 247.5° East: 270.0° ESE: 292.5° Southeast: 315° SSE: 337.5°
	Floor Area: 2,356 sf Volume: 21,204 cf Window area: 480 sf Envelope to Volume Ratio: 1:4.6	South: 0.0° SSW: 22.5° South West: 45.0° WSW: 67.5° West: 90° WNW: 112.5° Northwest: 135° NNW: 157.5°	North: 180° NNE: 202.5° Northeast: 225.0° ENE: 247.5° East: 270.0° ESE: 292.5° Southeast: 315° SSE: 337.5°

Table 3.4. Building shapes, characteristics, and orientation azimuth degrees to be simulated using BEopt.

SIMULATION PARAMETERS	DESCRIPTION
EPW Location	Las Vegas, McCarran International Airport.
Neighbors	None.
Walls	R-13 Fiberglass batt insulation with 2x4 studs 16 inches on center with 1/2" gypsum board.
Exterior Finish	Stucco with a medium dark paint.
Roof	R-30 Fiberglass batt insulation vented roof with terra cotta tiles.
Ceiling	5/8" gypsum board.
Foundation	Whole slab R-10 with R-5 XPS insulation.
Window Areas	Achieve daylight factor of 4% per ASHRAE 189.1-2014. Glazing area equal to 20% of the total floor area.
Windows	Double-pane, high-gain low-E, non-mental frame, argon filled (U-value 0.37, solar heat gain coefficient 0.53), with no overhangs on windows.
Space Conditioning	Central air conditioning SEER 13.
	Gas furnace 78% AFUE.
	Ducts: 8 CFM25 per 100 sf, R-8 in unconditioned space.
Space Conditioning Schedules	Cooling set point 78F.
	Heating set point: 68F.
	Humidity set point: 60% relative humidity.
Utility Rates	Electricity: Fixed: $8/month. $0.1189 $/kWh
	Natural Gas: Fixed: $8/month. $0.9155 $/therm

Table 3.5. Building simulation parameters entered into BEopt.

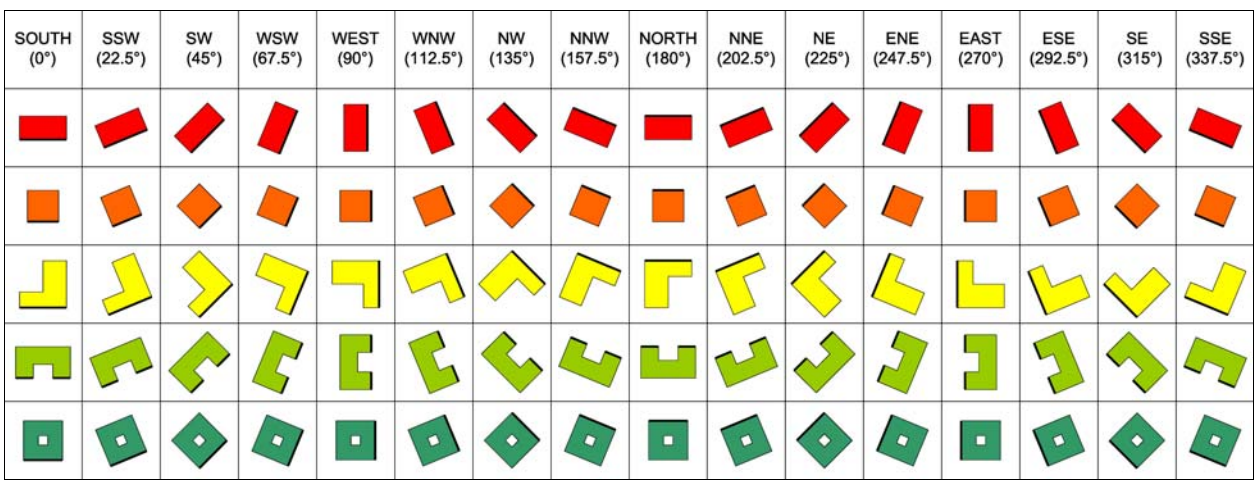


Figure 3.6. Matrix of base building model shapes and orientation azimuth degrees to be simulated using BEopt.

3.6 Energy and utility cost for space conditioning matrix generation.

After running all the simulations using BEopt, a matrix was created outlining how each shape behaves along the different orientations and the amount of energy and utility costs being spent on each residence. The utility costs will be broken down on electrical charges in kWh spent for the central air conditioning unit and natural gas used on the heating system in therms. Table 3.5. shows the current utility rate averages for the state of Nevada for electricity and natural gas.

The final goal of the matrix would be for residential developers and builders to start generating useful data like this for their customers. Much like when buying a new appliance a customer can see on the product description the annual energy consumption and the cost of the product before they buy it, a potential home buyer should have this information provided by the developers and builders of a residence. This information becomes even more relevant as many of these homes are similar in nature as their layouts and plans get repeated throughout a community as shown in the following section and in Figures 3.7. and 3.8.

3.7 Residential development space conditioning energy analysis.

The next analysis will involve evaluating a residential development in the region to see how the different single family units that were simulated can behave in terms of orientation and energy. The subdivision development of Central Park Estates is located in southern part of the city of Las Vegas, on the intersection of Gillespie Street and Agate Avenue. It is a 39 acre site that contains a total of 262 single family residences with seven different types of unit types ranging between 1,322 sq.ft. to 2,211 sq.ft. each. All homes are mostly three bedrooms, except for a total of 8 units that are two bedroom residences. Also, all the unit types are one story except for one that is two stories in height. Most streets on the subdivision run east west and

191 of the lots where the homes are built have longest property line running north south, as seen from the aerial photograph in Figure 3.7. This data and information was collected and drawn using the Clark County Assessor and Maps office as well as the website zillow.com.

Instead of modeling and simulating these existing residences we will use the base models from our initial investigation and match them as closely as possible to the unit types in Central Park Estates which are listed and keyed in plan in Figure 3.8. The goal of this exercise would be to simulate how developers would create different types of unit types for the Las Vegas market and lay them out in a site like Central Park Estates. Then one can compare the energy use of this original layout as a community with another layout where the homes are optimally orientated, to see if energy may be saved in a residential development of this type.

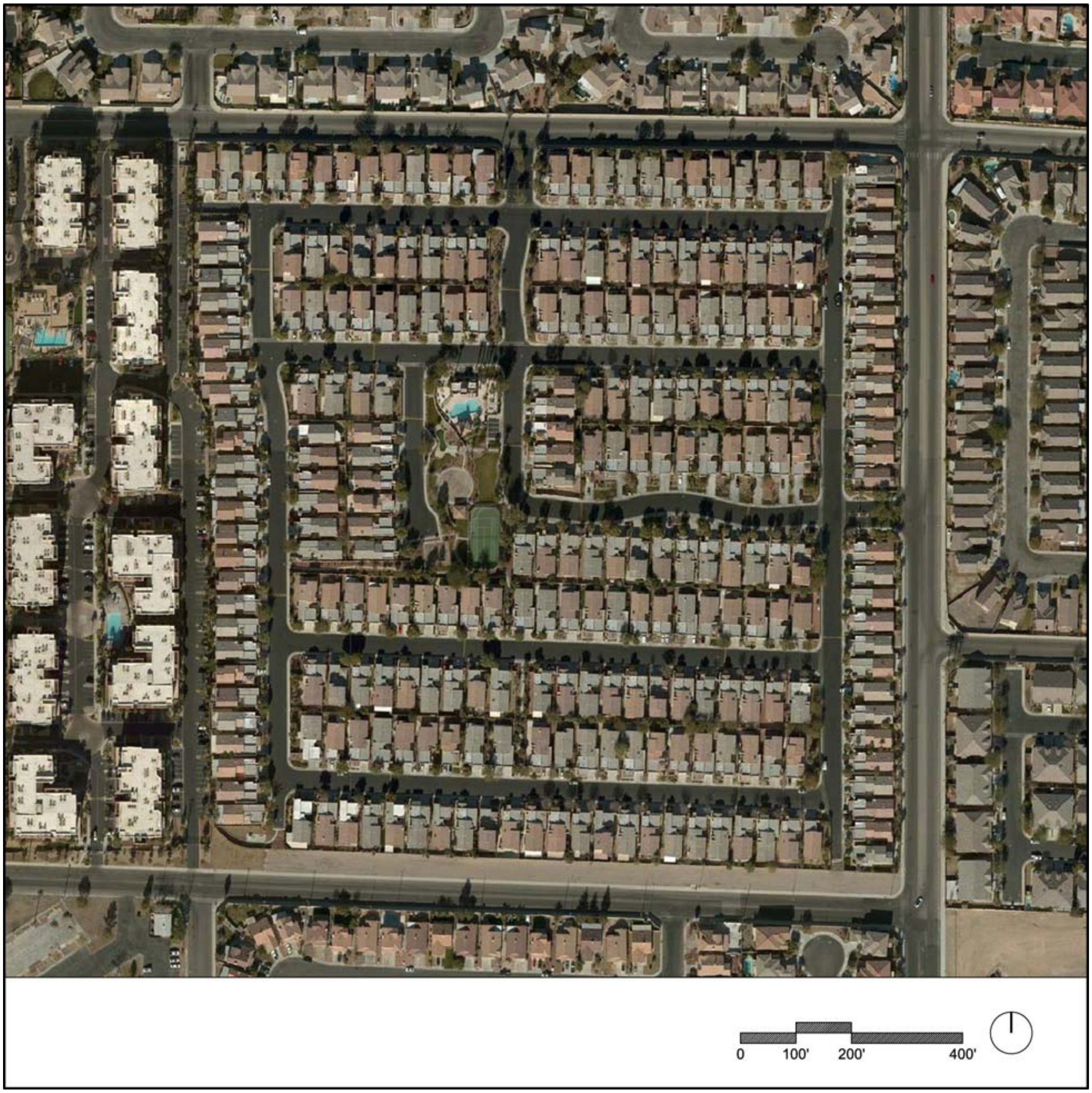
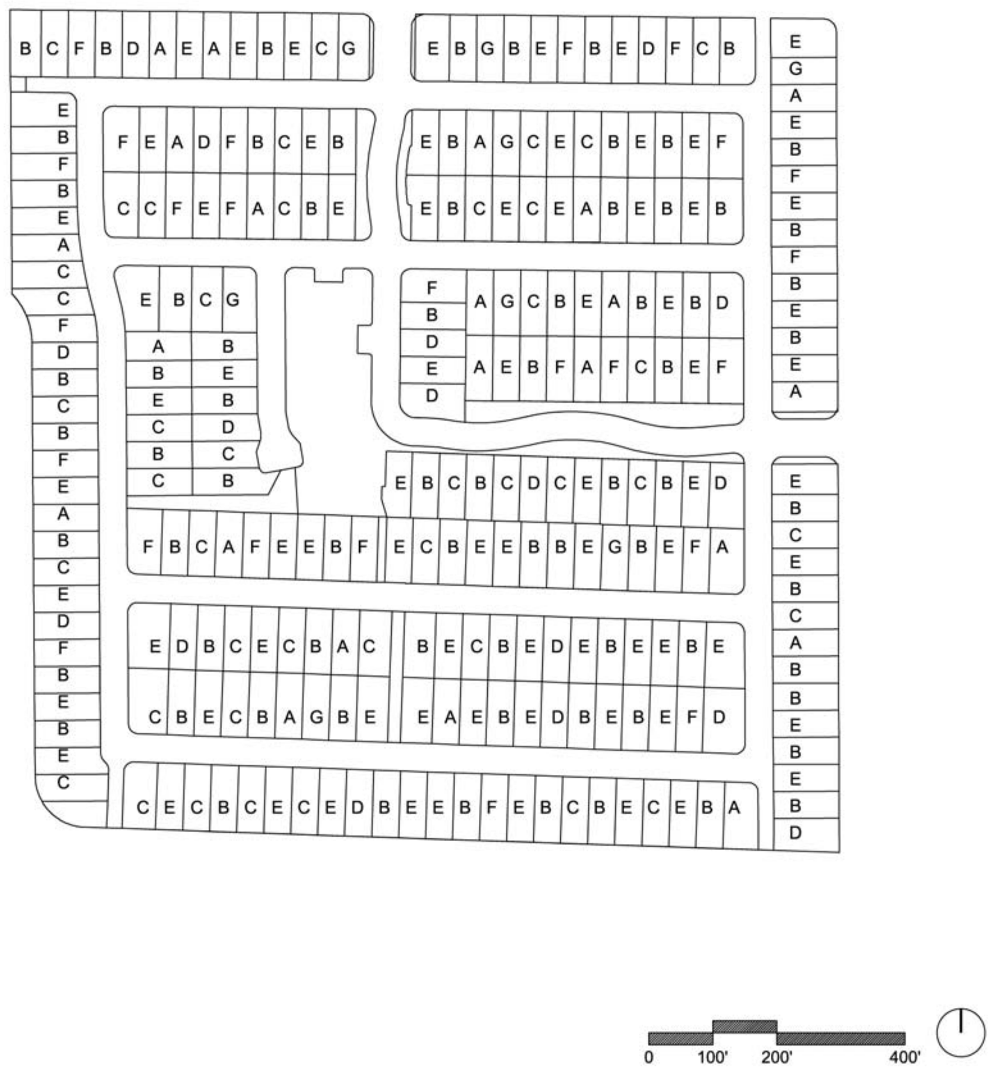


Figure 3.7. Aerial photograph of Central Park Estates, Las Vegas, Nevada. U.S. Geological Survey, Map data 2015.



UNIT TYPE	# OF UNITS	SQ.FT.	SQ.FT. TOTAL	BEDROOMS	STORIES
Type A	22	1,322	29,084	3	1
Type B	74	1,593	117,882	3	1
Type C	42	1,784	74,928	3	1
Type D	17	1,893	32,181	3	1
Type E	75	1,977	148,275	3	1
Type F	24	2,211	53,064	3	2
Type G	8	1,457	11,656	2	1
Total	**262**		**467,070**		

Figure 3.8. Central Park Estates unit types plan and characteristics.

CHAPTER 4: RESEARCH DATA AND PARAMETRIC SIMULATION RESULTS

With all five base buildings modeled in BEopt, the results were divided into several categories. First, the energy loads for space conditioning were calculated for the five prototype buildings set in the Las Vegas region along sixteen different orientations. These orientations included the four cardinal points with eight intermediate directions that are referred with the following nomenclature in all the data and graphs: S 0°, SSW 22.5°, SW 45, WSW 67.5°, W 90°, NNW 112.5°, NW 135°, NNW 157.5°, N 180°, NNE 202.5°, NE 225°, ENE 247.5°, E 270°, ESE 292.5°, SE 315°, and SSE 337.5°.

The software produced site energy usage in MMBtu/yr recorded for the vent fan, HVAC fan/pump, cooling, heating and total. These are shown in bar graphs that follow (Figures 4.1., 4.3., 4.5., 4.7.,and 4.9.) with the site energy on the vertical axis and the different orientations along the horizontal one. A sensitivity analysis is also on cooling, heating, and total site energy usage as compared to the south orientation. These are seen in the figures that follow (Figures 4.2., 4.4., 4.6., 4.8., 4.10.) with the site energy as compared to the south on the vertical axis and once again orientations of the base buildings on the horizontal axis.

The second category of analysis was a comparison of the different shapes among each other. In order to do this comparison, the site energy use was divided by the square footage of each of the five different residences to normalize the results. The units for this analysis were recorded in EUI's (energy use intensity), which is KBtu's per square feet a year. This allowed each design parameter, shape and orientation, to be compared in an equal fashion. These results are given for cooling, heating, and the total site usage. The data results of this analysis can be seen in the tables and figures below (Figures 4.11. - 4.16., Tables 4.6. - 4.8.), where the vertical access shows the difference in energy load in KBtu's/ sq.ft a year and the horizontal

axis represent the sixteen different orientations. Five different colors are assigned to represent the different building shapes analyzed.

The other categories of analysis consisted on a cost analysis of each shape and orientation as well as the creating of a matrix of this information as well as energy usage for builders and home owners to use. Utility costs were calculated in dollars per year, while energy was divided into kWh used for electrical charges and therms for the natural gas.

Last, using the base building models an analysis was done in total energy use on a subdivision in the Las Vegas region. These results were done in total kWh consumed per year for 262 homes.

4.1 Rectangle shape results.

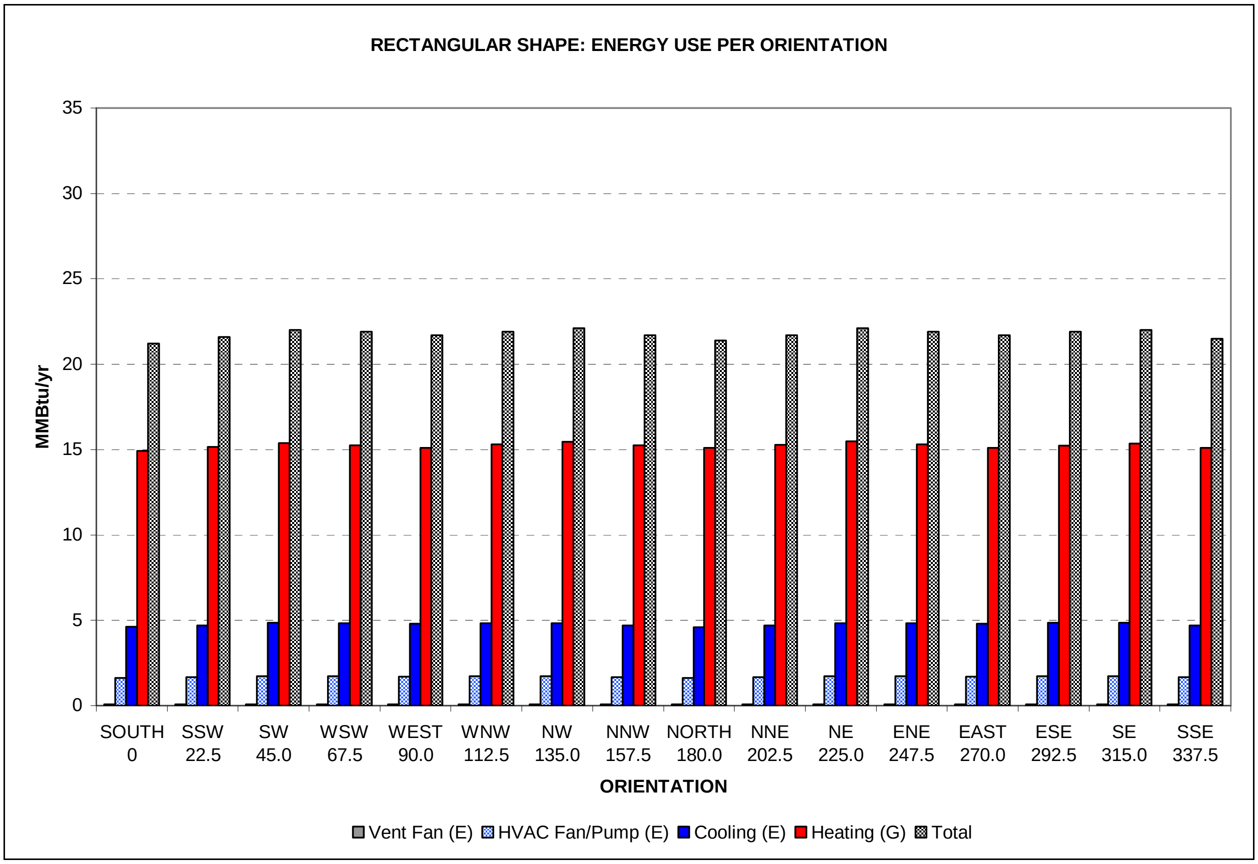


Figure 4.1. Rectangle shape site energy use (MMBtu/yr).

	S 0º	**SSW 22.5º**	**SW 45º**	**WSW 67.5º**	**W 90º**	**WNW 112.5º**	**NW 135º**	**NNW 157.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	1.63	1.66	1.71	1.71	1.69	1.71	1.71	1.66
Cooling (E)	4.61	4.7	4.85	4.84	4.8	4.84	4.84	4.69
Heating (G)	14.92	15.14	15.38	15.25	15.11	15.31	15.47	15.26
Total	**21.2**	**21.6**	**22**	**21.9**	**21.7**	**21.9**	**22.1**	**21.7**
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	1.63	1.67	1.71	1.71	1.69	1.71	1.71	1.66
Cooling (E)	4.6	4.69	4.84	4.84	4.81	4.85	4.86	4.7
Heating (G)	15.09	15.29	15.49	15.3	15.1	15.24	15.35	15.1
Total	**21.4**	**21.7**	**22.1**	**21.9**	**21.7**	**21.9**	**22**	**21.5**

Table 4.1. Rectangle shape site energy use (MMBtu/yr).

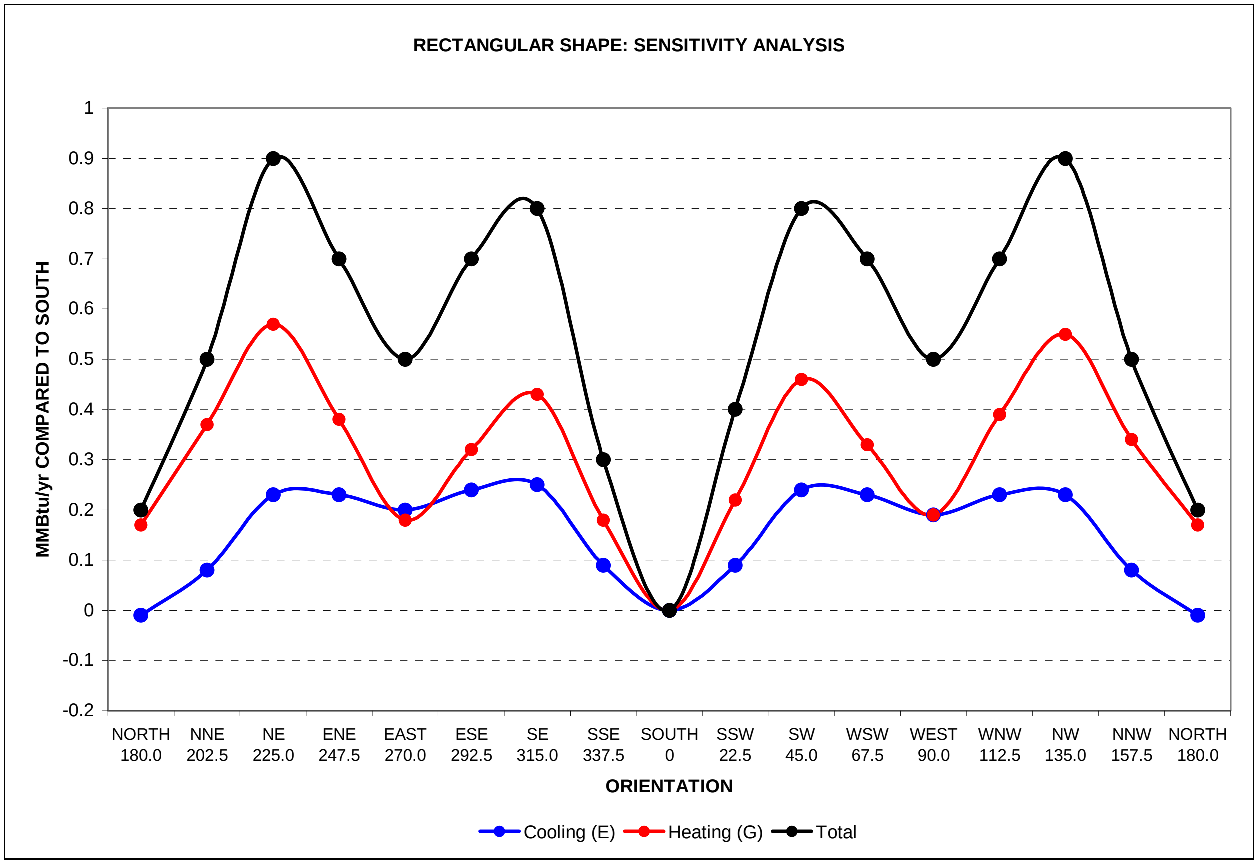


Figure 4.2. Rectangle shape sensitivity analysis site energy use (MMBtu/yr).

The rectangular shape showed the most variations in energy consumption as the shape was rotated along the different orientations. Large differences resulted at NE 225°, SE 315°, SW 45°, and NW 135° compared to north or south orientations with an increase of almost 3-4% percent in total energy consumption. The NW 135° and SE 135° orientation had the biggest deltas over all with a total energy increase compared to south or north by 4.25%.

As an average 3.2 times more energy, or 70% of the total energy, was consumed in heating for the home than cooling. This will be a repeating characteristic among all the shapes, where most of the energy being consumed for all the homes is for heating purposes.

4.2 Square shape results.

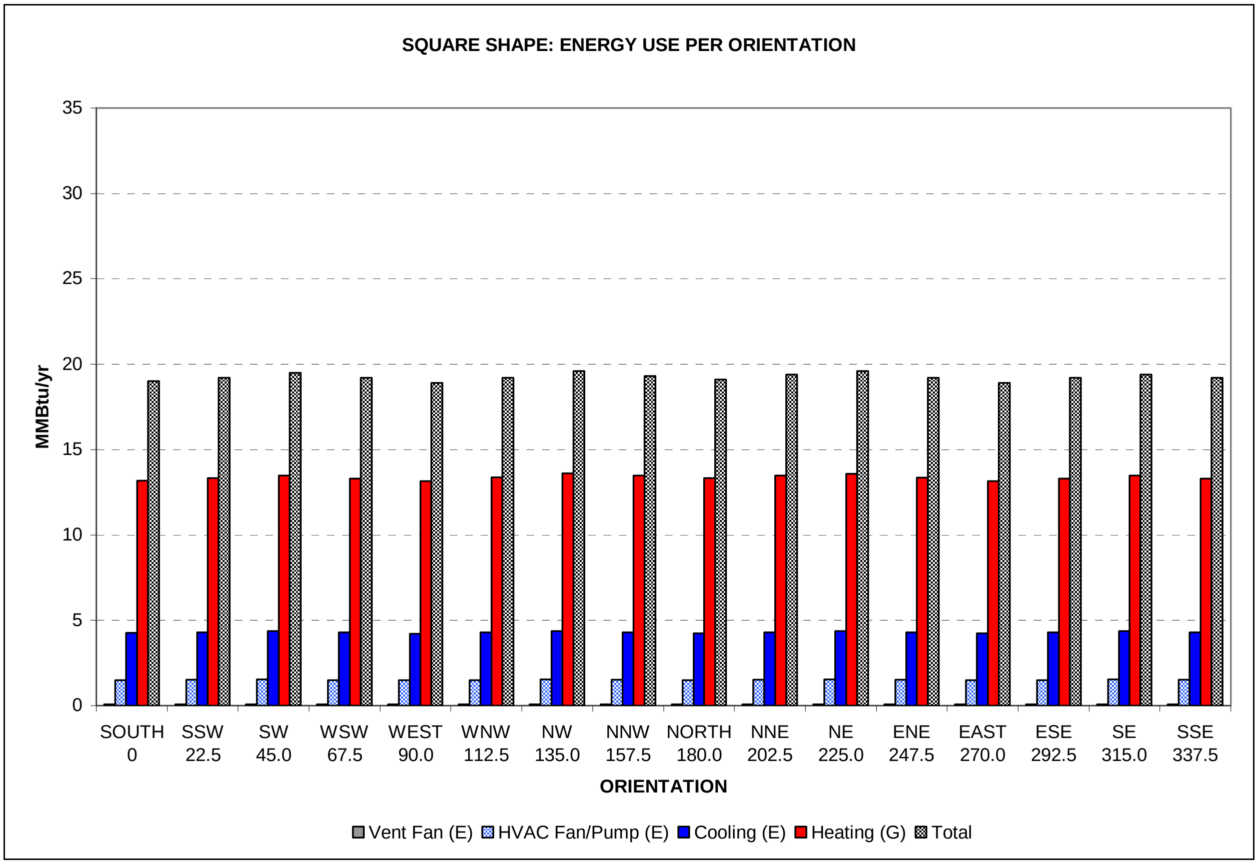


Figure 4.3. Square shape sensitivity analysis site energy use (MMBtu/yr).

	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	1.49	1.51	1.53	1.5	1.48	1.5	1.53	1.51
Cooling (E)	4.25	4.3	4.37	4.3	4.22	4.29	4.36	4.29
Heating (G)	13.17	13.33	13.48	13.3	13.15	13.38	13.6	13.47
Total	**19.0**	**19.2**	**19.5**	**19.2**	**18.9**	**19.2**	**19.6**	**19.3**
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	1.49	1.51	1.53	1.51	1.48	1.5	1.53	1.51
Cooling (E)	4.24	4.29	4.36	4.29	4.23	4.3	4.37	4.3
Heating (G)	13.34	13.48	13.59	13.35	13.14	13.3	13.47	13.31
Total	**19.1**	**19.4**	**19.6**	**19.2**	**18.9**	**19.2**	**19.4**	**19.2**

Table 4.2. Square shape site energy use (MMBtu/yr).

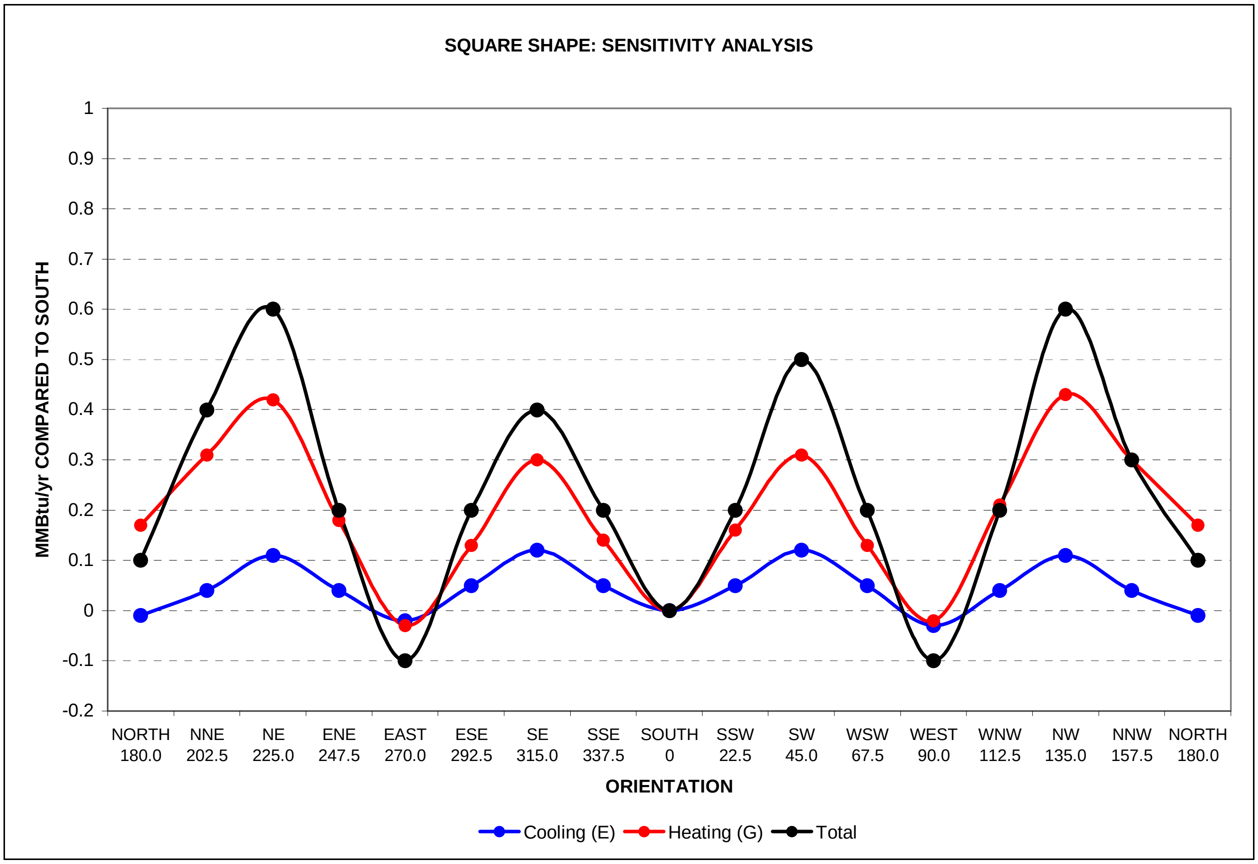


Figure 4.4. Square shape sensitivity analysis site energy use (MMBtu/yr).

Because of the purity of the shape, the square base model showed the least amount of variation in energy consumption even in directions where the highest deltas were recorded for all the other shapes, those being the NE 225°, SE 315°, SW 45°, and NW 135° orientations. Along these orientations an increase of 2.1-3.2% or 0.4-0.6 MMBtu/yr of energy use occurred, nearly half that of the rectangular shape. Also note that E 270° and W 90°performed slightly better than south orientation.

Once again heating was the biggest contributor in energy consumption, this time 3.1 times higher than cooling, which as an average, was the lowest ratio between these two values among the five different shapes.

4.3 L-shape results.

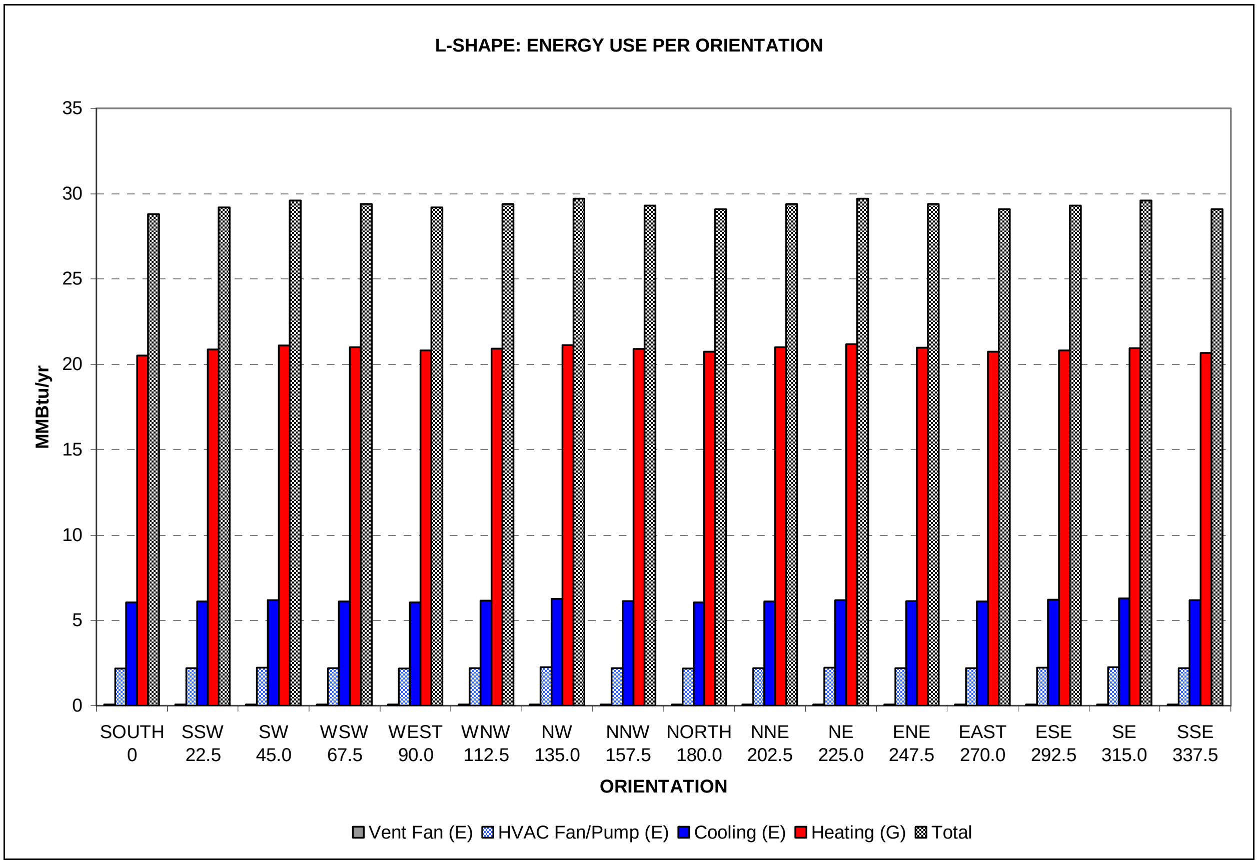


Figure 4.5. L-shape sensitivity analysis site energy use (MMBtu/yr).

	S 0º	**SSW 22.5º**	**SW 45º**	**WSW 67.5º**	**W 90º**	**WNW 112.5º**	**NW 135º**	**NNW 157.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	2.18	2.2	2.23	2.2	2.19	2.22	2.25	2.21
Cooling (E)	6.06	6.1	6.19	6.11	6.07	6.17	6.26	6.15
Heating (G)	20.53	20.87	21.12	21	20.82	20.93	21.14	20.91
Total	**28.8**	**29.2**	**29.6**	**29.4**	**29.2**	**29.4**	**29.7**	**29.3**
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	2.18	2.2	2.23	2.21	2.2	2.23	2.26	2.21
Cooling (E)	6.05	6.1	6.19	6.13	6.11	6.21	6.3	6.18
Heating (G)	20.76	21.01	21.19	20.97	20.74	20.83	20.95	20.67
Total	**29.1**	**29.4**	**29.7**	**29.4**	**29.1**	**29.3**	**29.6**	**29.1**

Table 4.3. L- shape site energy use (MMBtu/yr).

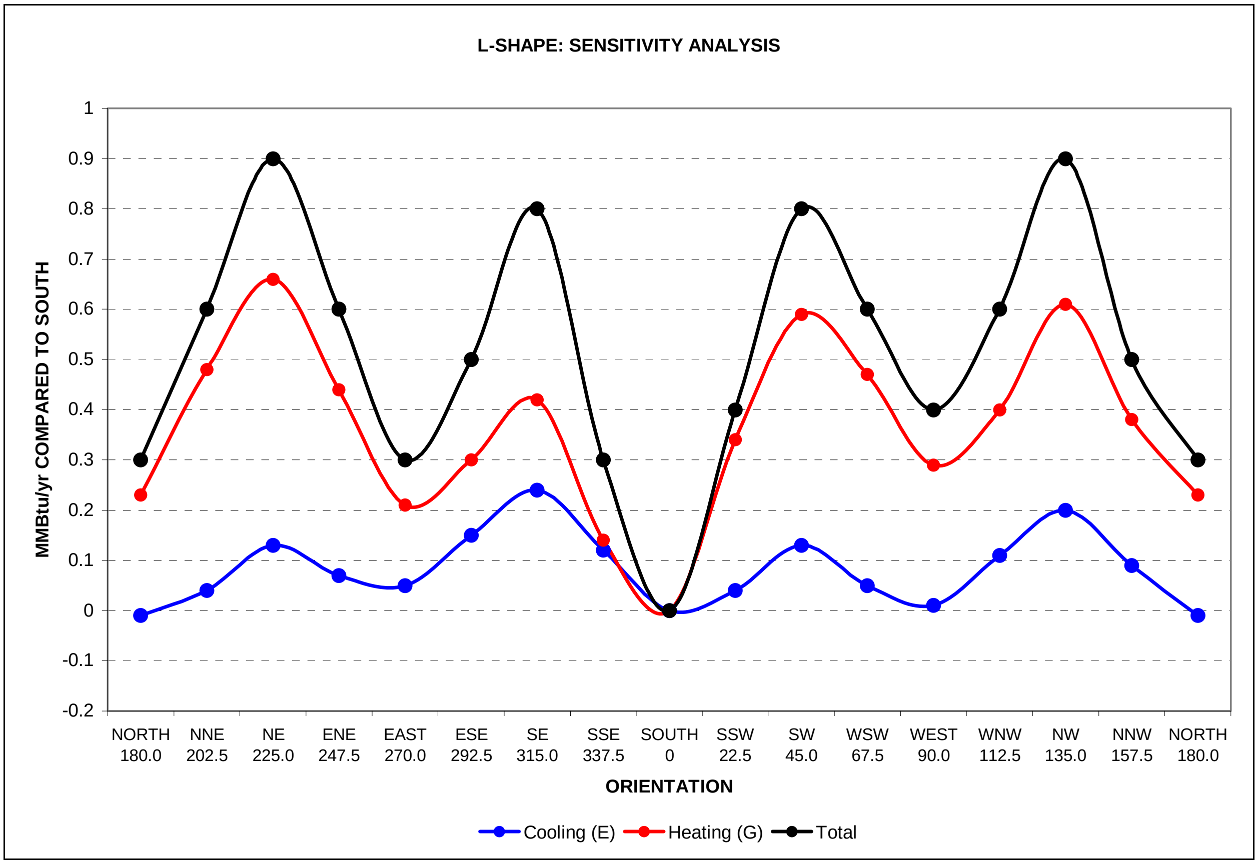


Figure 4.6. L-shape sensitivity analysis site energy use (MMBtu/yr).

The L-shape also showed great variations when shifting from the south. NE 225° and NW 135° orientations showed the greatest total discrepancy with an increase of about 3% or 0.9 MMBtu/yr compared to the south.

The cooling load had the least amount of delta compared to all the other shapes. With an the an average increase of 1.5% to south orientation. This is also the first result that showed that for the cooling load, the north orientation performed slightly better than the south. This was most likely caused by some self shading that occurred from the extended wing of the home.

Moreover, 3.4 times more energy was spent in heating for the home than for cooling, or about 71.3% of the total energy.

4.4 U-shape results.

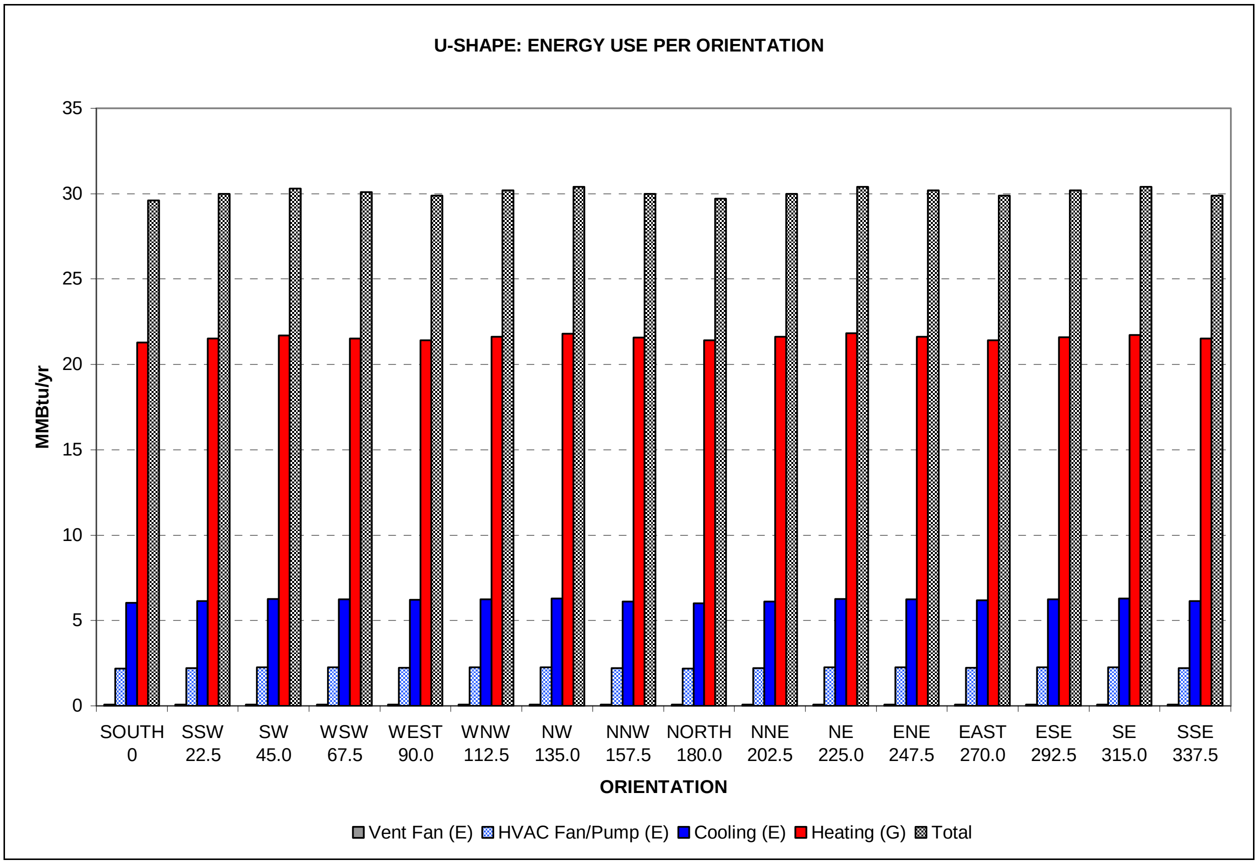


Figure 4.7. U-shape sensitivity analysis site energy use (MMBtu/yr).

	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	2.19	2.22	2.27	2.25	2.24	2.26	2.27	2.22
Cooling (E)	6.03	6.13	6.27	6.24	6.21	6.25	6.28	6.12
Heating (G)	21.29	21.53	21.71	21.53	21.42	21.61	21.8	21.58
Total	**29.6**	**30.0**	**30.3**	**30.1**	**29.9**	**30.2**	**30.4**	**30.0**
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	2.19	2.22	2.27	2.25	2.24	2.26	2.27	2.22
Cooling (E)	6.01	6.12	6.27	6.23	6.2	6.25	6.28	6.13
Heating (G)	21.41	21.61	21.82	21.61	21.42	21.59	21.73	21.52
Total	**29.7**	**30.0**	**30.4**	**30.2**	**29.9**	**30.2**	**30.4**	**29.9**

Table 4.4. U- shape site energy use (MMBtu/yr).

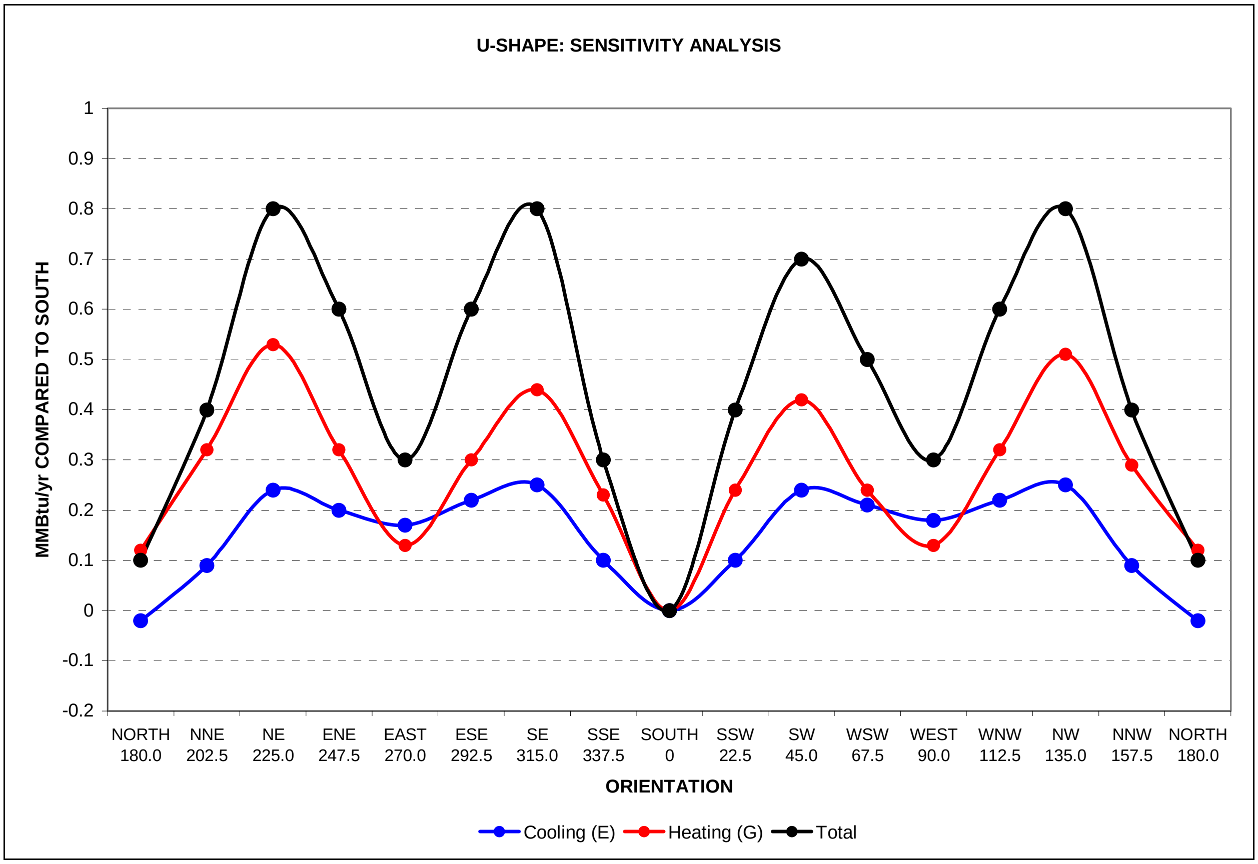


Figure 4.8. U-shape sensitivity analysis site energy use (MMBtu/yr).

One of the most interesting results from the U-shape was that at E 270 and W 90.0 orientations the heating load performed quite well compared to south, with an increase of 0.6% or 0.3 MMBtu/yr compared to this orientation.

Another aspect of this shape that is important to note is that in the north orientation the cooling load used slightly lower than the south, similar to the L-shape. If the two wings on the U-shape are pointing north, they helped create shading for the surfaces that were exposed in between, causing this small reduction in energy consumption.

About 3.5 times more energy is spent in heating than in cooling for the home, or 71.7% of the total energy.

4.5 Courtyard shape results.

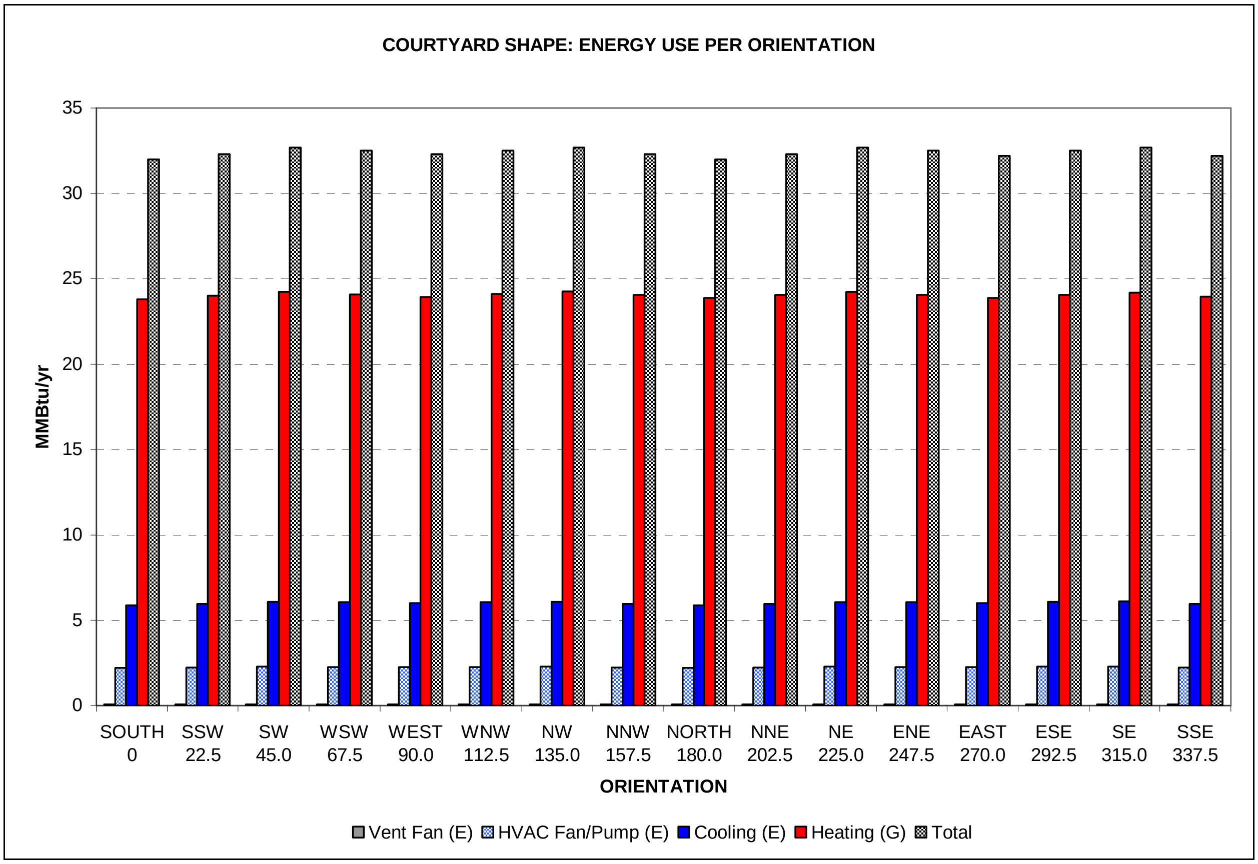


Figure 4.9. Courtyard shape sensitivity analysis site energy use (MMBtu/yr).

	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	2.21	2.24	2.28	2.27	2.25	2.27	2.28	2.24
Cooling (E)	5.88	5.96	6.08	6.06	6.01	6.06	6.08	5.95
Heating (G)	23.8	24	24.24	24.08	23.93	24.12	24.27	24.05
Total	**32.0**	**32.3**	**32.7**	**32.5**	**32.3**	**32.5**	**32.7**	**32.3**
	N 180º	**NNE 202. 5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
Vent Fan (E)	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Fan/Pump (E)	2.21	2.24	2.28	2.27	2.25	2.28	2.28	2.24
Cooling (E)	5.87	5.95	6.07	6.06	6.02	6.08	6.1	5.96
Heating (G)	23.87	24.07	24.25	24.06	23.88	24.06	24.2	23.95
Total	**32.0**	**32.3**	**32.7**	**32.5**	**32.2**	**32.5**	**32.7**	**32.2**

Table 4.5. Courtyard shape site energy use (MMBtu/yr).

COURTYARD SHAPE: SENSITIVITY ANALYSIS

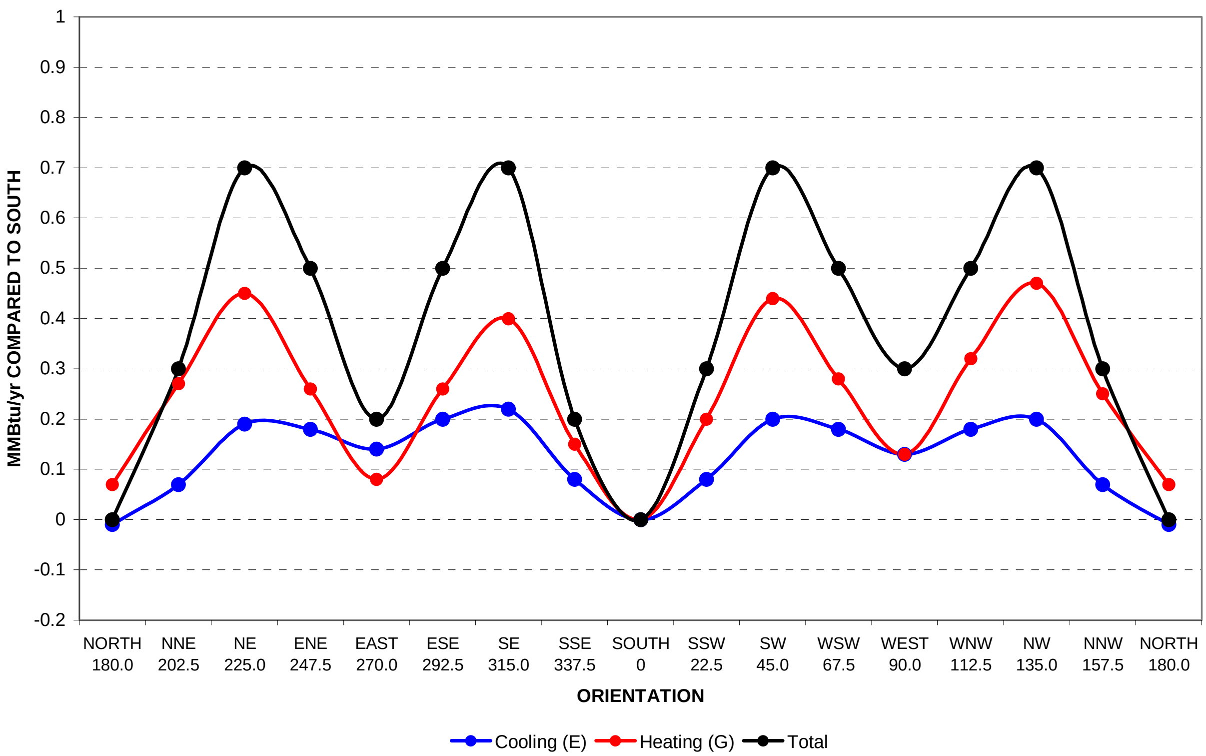


Figure 4.10. Courtyard shape sensitivity analysis site energy use (MMBtu/yr).

Because of its symmetric form, the courtyard shape showed similar results as the square shape, though with much higher energy consumption. For the NE 225°, SE 315°, SW 45°, and NW 135° orientations an increase of 2.2% or 0.7 MMBtu/yr in the total energy consumption occurred compared to south, east, west or north orientations.

As an average 4.0 times more energy is spent in heating the courtyard shape than in cooling it, or 74.2% of the total energy spent in space conditioning. This was the highest ratio between these two values among the five different shapes.

4.6 Combined results for cooling in EUI.

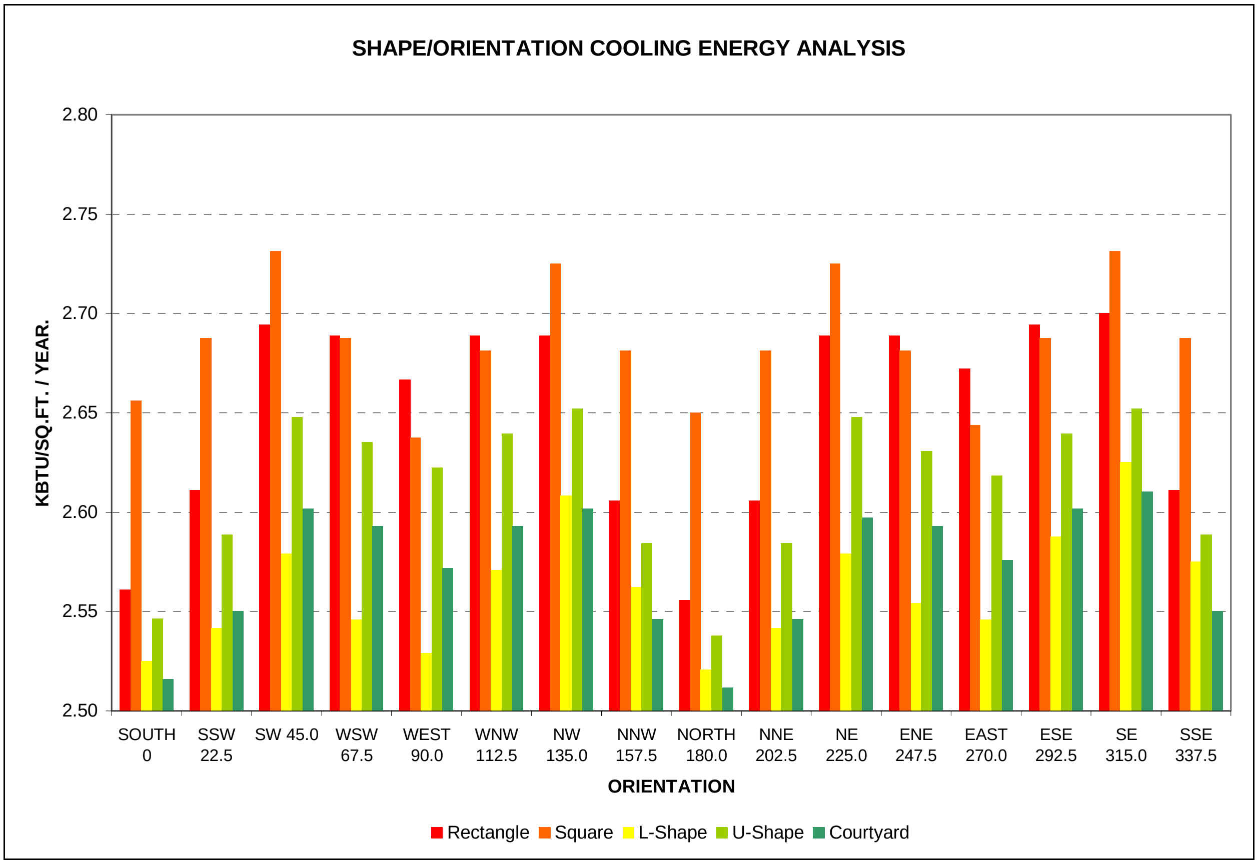


Figure 4.11. Total cooling site energy use (KBtu/sq.ft. / Year).

SHAPE	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Rectangle	2.56	2.61	2.69	2.69	2.67	2.69	2.69	2.61
Square	2.66	2.69	2.73	2.69	2.64	2.68	2.73	2.68
L-Shape	2.53	2.54	2.58	2.55	2.53	2.57	2.61	2.56
U-Shape	2.55	2.59	2.65	2.64	2.62	2.64	2.65	2.58
Courtyard	2.52	2.55	2.60	2.59	2.57	2.59	2.60	2.55
	N 180º	NNE 202.5º	NE 225º	ENE 247.5º	E 270º	ESE 292.5º	SE 315º	SSE 337.5º
Rectangle	2.56	2.61	2.69	2.69	2.67	2.69	2.70	2.61
Square	2.65	2.68	2.73	2.68	2.64	2.69	2.73	2.69
L-Shape	2.52	2.54	2.58	2.55	2.55	2.59	2.63	2.58
U-Shape	2.54	2.58	2.65	2.63	2.62	2.64	2.65	2.59
Courtyard	2.51	2.55	2.60	2.59	2.58	2.60	2.61	2.55

Table 4.6. Total cooling site energy use (KBtu/sq.ft. / Year).

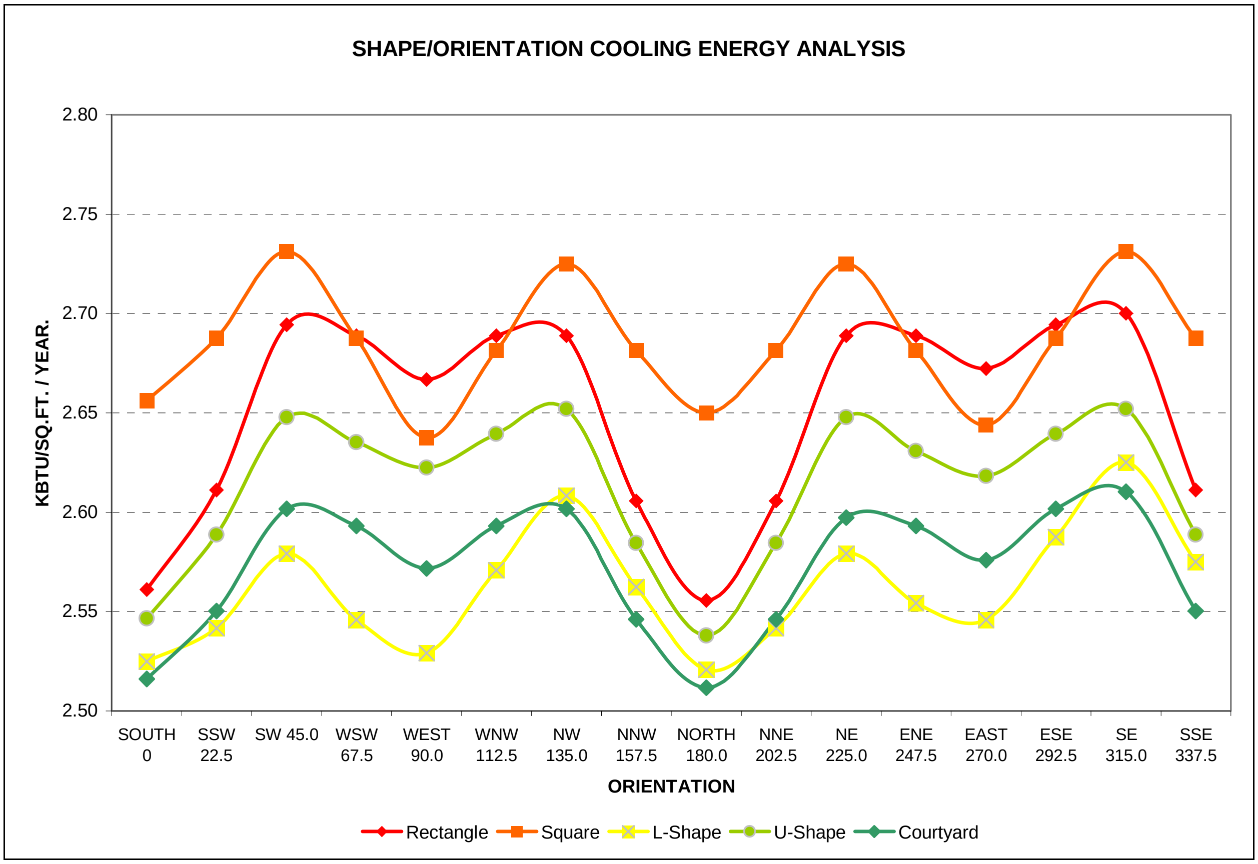


Figure 4.12. Total cooling site energy use (KBtu/sq.ft. / Year).

Cooling load peaks were the highest for the SW 45°, NW 135°, NE 225°, and SE 315° orientations, lower in the west and east exposures, while the lowest were found in the south and north orientations.

The cooling study gave the most diverse results for the different shapes analyzed with some of the shapes outperforming others in different orientations. Even though the rectangular and square shapes have less surface area, the L, U and courtyard shapes seemed to have benefited from self shading to reduce the cooling loads. The L and courtyard shapes in particular performed the best, with the U shape not far behind them. The L-shape even performed well against the main cardinal points of north, south, east, and west even though it is not symmetrical in nature. For traditional south orientation, the courtyard shape surprisingly outdid both the more compact square and rectangular shapes, these two producing higher loads in all directions, specially the square shape.

It came as a surprise that the more compact shapes that had less surfaces, the square and rectangular shapes, used more energy to cool the homes, specially the square shape. As an average between 3-5% more energy was spent in space conditioning than the courtyard shape. Moreover, the rectangular shape showed the largest delta change and was more sensitive to an orientation change. The largest variation was as much as a 5% increase from south to south west.

The study also showed how there is an extensive solar gain from the east and west sides that can produce over heating. In all cases, when the orientation of each of the building exposed more wall surface area to these two cardinal points, such as SW 45°, NW 135°, NE 225°, or SE 315°; there was an extensive amount of cooling loads created. As an average, these orientations had a 3-4% increase in energy loads versus north and south orientations. The long summer season that can sometimes extend into the winter season, gave a distinct advantage for north orientation for all building shapes. This was expected as solar gain

increases cooling loads and in all cases the north orientation exposed less wall surface area to the prolonged summer sun.

4.7 Combined results for heating in EUI.

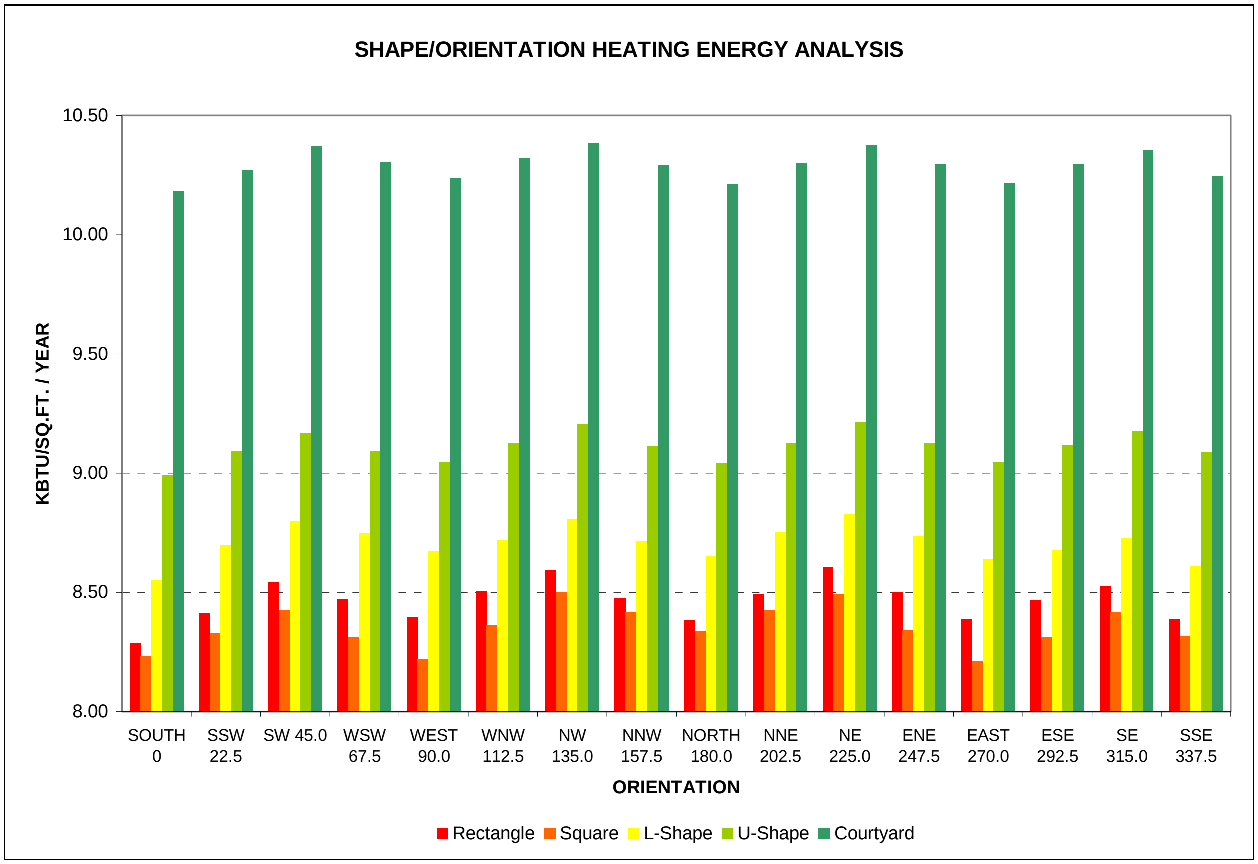


Figure 4.13. Total heating site energy use (KBtu/sq.ft. / Year).

SHAPE	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Rectangle	8.29	8.41	8.54	8.47	8.39	8.51	8.59	8.48
Square	8.23	8.33	8.43	8.31	8.22	8.36	8.50	8.42
L-Shape	8.55	8.70	8.80	8.75	8.68	8.72	8.81	8.71
U-Shape	8.99	9.09	9.17	9.09	9.05	9.13	9.21	9.11
Courtyard	10.18	10.27	10.37	10.30	10.24	10.32	10.39	10.29
	N 180º	NNE 202.5º	NE 225º	ENE 247.5º	E 270º	ESE 292.5º	SE 315º	SSE 337.5º
Rectangle	8.38	8.49	8.61	8.50	8.39	8.47	8.53	8.39
Square	8.34	8.43	8.49	8.34	8.21	8.31	8.42	8.32
L-Shape	8.65	8.75	8.83	8.74	8.64	8.68	8.73	8.61
U-Shape	9.04	9.13	9.21	9.13	9.05	9.12	9.18	9.09
Courtyard	10.21	10.30	10.38	10.30	10.22	10.30	10.36	10.25

Table 4.7. Total heating site energy use (KBtu/sq.ft. / Year).

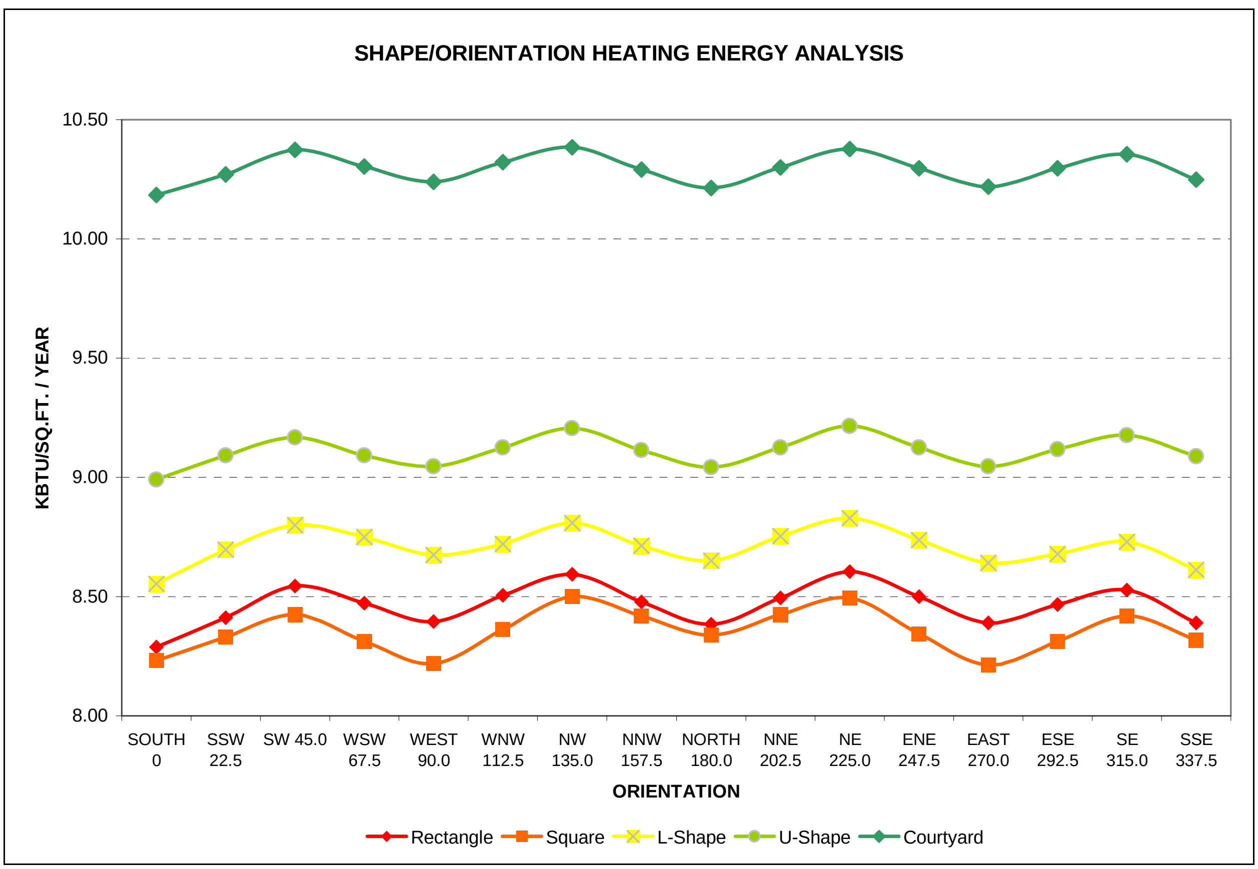


Figure 4.14. Total heating site energy use (KBtu/sq.ft. / Year).

The results for all of the shapes show that the greatest energy use is spent in heating the homes, as an average 3.08 to 4.05 more times than cooling, or 69.3% to 74.2%. of the total energy spent in space conditioning. The total heating results were more predictable and not as varied as the total cooling loads from the previous analysis. The smaller and more compact homes responded better and used less energy for space heating, with the square shape outperforming the other shapes in all orientations and the rectangle coming a close second. The courtyard shape behaved the opposite as it had for cooling, performing the worst of all the shapes studied. As an average it needed 24% more energy to heat the home more than the square shape and 22% more than a rectangular base model.

In general, where the shapes were oriented to the main cardinal points, that is the south, north, east, and west, all shapes saw only a slight increase in energy use compared to south orientation.   In the square and courtyard shapes, east, west, and north orientations were equal to the south because of their symmetrical form. While in the rectangular shape there was only an increase of 1.3% from east and west orientations to that of north of south. Similarly for the L and U shapes, there was increase of 1-1.4% or less in energy use in the east and west orientation compared to south. It can be interpreted that when any of these shapes vary in orientation to the main cardinal points, less window surface areas in the facade receive solar exposure, causing this slight variation in more energy use to heat the homes.

4.8 Total combined results in EUI.

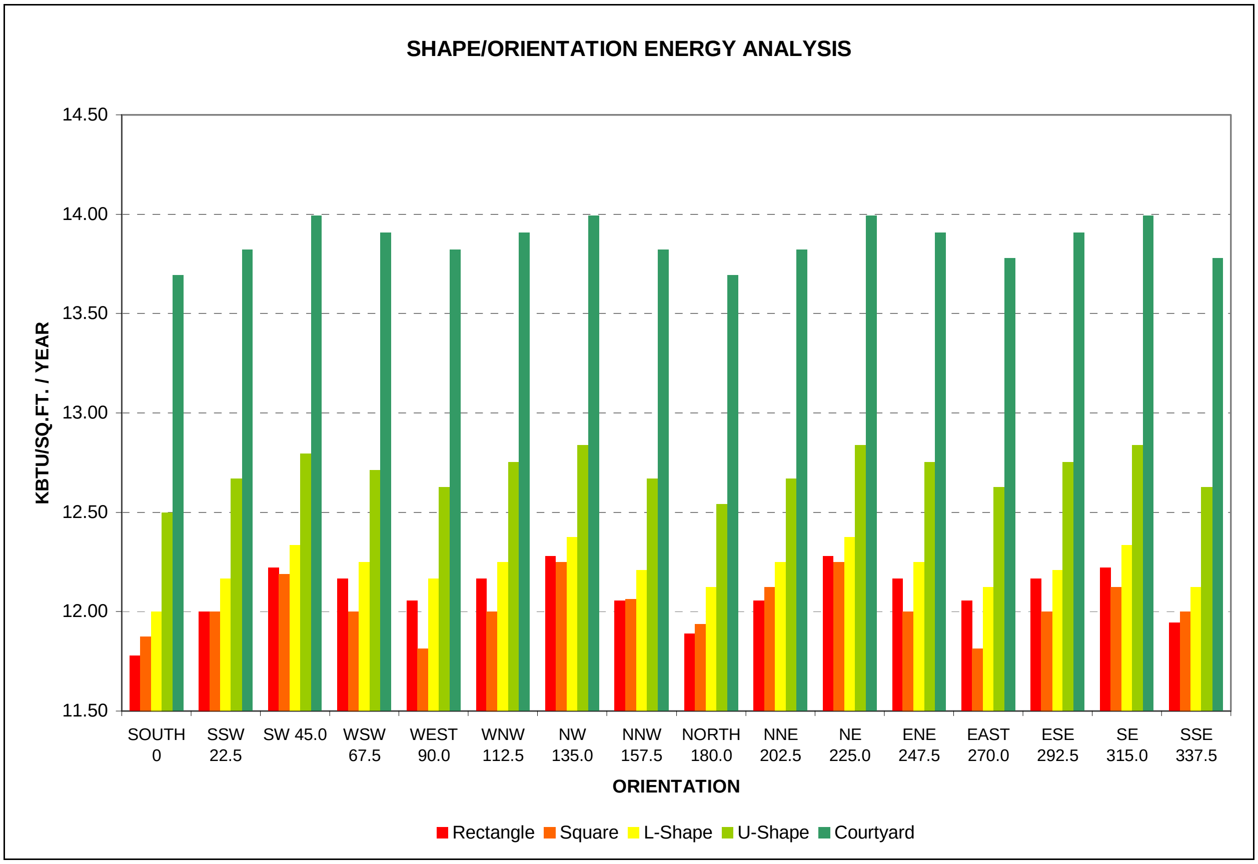


Figure 4.15. Shape and orientation energy analysis (KBtu/sq.ft. / Year).

SHAPE	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Rectangle	11.78	12.00	12.22	12.17	12.06	12.17	12.28	12.06
Square	11.88	12.00	12.19	12.00	11.81	12.00	12.25	12.06
L-Shape	12.00	12.17	12.33	12.25	12.17	12.25	12.38	12.21
U-Shape	12.50	12.67	12.80	12.71	12.63	12.75	12.84	12.67
Courtyard	13.69	13.82	13.99	13.91	13.82	13.91	13.99	13.82
	N 180º	NNE 202.5º	NE 225º	ENE 247.5º	E 270º	ESE 292.5º	SE 315º	SSE 337.5º
Rectangle	11.89	12.06	12.28	12.17	12.06	12.17	12.22	11.94
Square	11.94	12.13	12.25	12.00	11.81	12.00	12.13	12.00
L-Shape	12.13	12.25	12.38	12.25	12.13	12.21	12.33	12.13
U-Shape	12.54	12.67	12.84	12.75	12.63	12.75	12.84	12.63
Courtyard	13.69	13.82	13.99	13.91	13.78	13.91	13.99	13.78

Table 4.8. Shape and orientation energy analysis (KBtu/sq.ft. / Year).

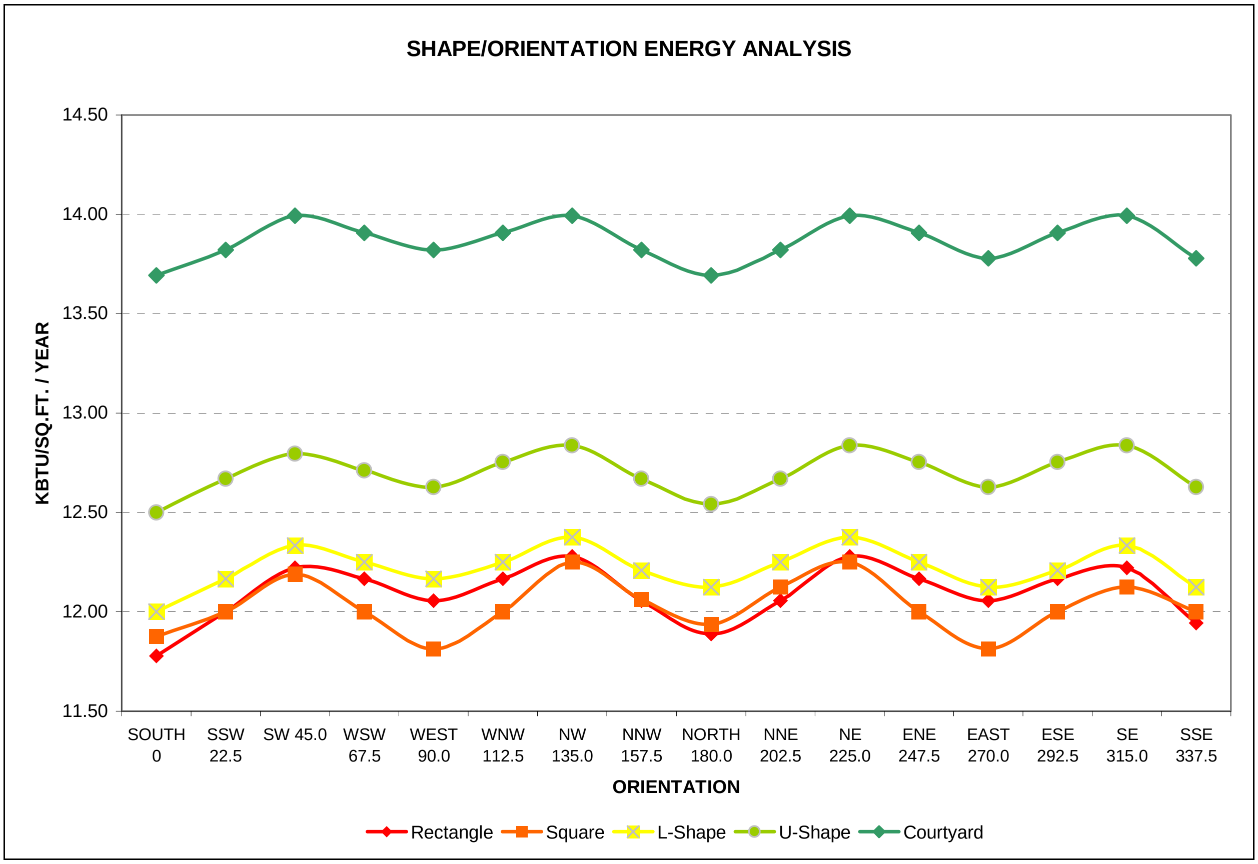


Figure 4.16. Shape and orientation energy comparison analysis (KBtu/sq.ft. / Year).

South and north orientations had the lowest cooling and heating loads for all five building forms, except for the square and courtyard shapes that had equal loads on the N 90°, W 180°, and E 270°, as the exposed surfaces for this study were equal in these directions. The two shapes that performed the best for combined cooling and heating loads were the square and rectangle shapes, followed closely to the L-shape. Though the rectangle shape performed better in north and south orientations, from WSW 67.5° to NW 157.5° and from ENE 247.5° to SSE 337.5° the square shape actually performed better than the rectangular shape along these orientations. Moreover, as mentioned earlier, the L-shape was not far in performance to these two shapes, considering it had two more additional surfaces. As an average, it used 1.1% more energy than the rectangle and 1.7% more than the square. The courtyard shape, as an average, used about 14.6% more energy than the rectangle and 15.3% more than the square shape.

It is also important to note, that the square shape performed the best in all orientations, with the rectangular shape using 0.6% and the L-shape 1.7% more energy. The U-shape fell somewhere in between these three shapes, while the courtyard shape showed an increase of 5.2% more than the square shape.

SW 45°, NW 135°, NE 225°, and SE 315° orientations produced the higher total loads, heating and cooling, for all of the shapes. This most likely due that during the winter not enough window surfaces received solar gain because less surface area was exposed to the sun. In the summer, more surface areas were exposed to the long solar radiation that is typical of the Southern Nevada region.

4.9 Total utility cost for space conditioning results.

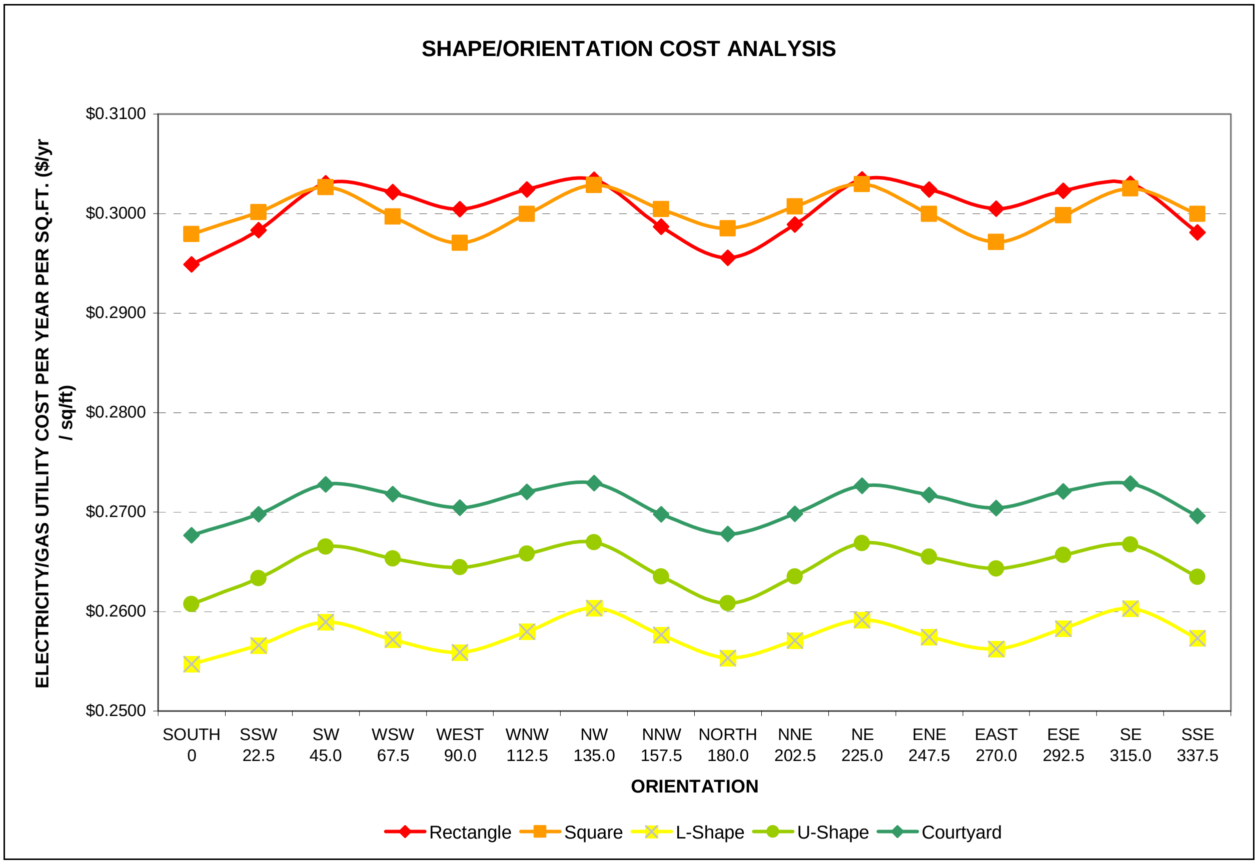


Figure 4.17. Shape and orientation total utility cost for space conditioning analysis ($/yr per sq.ft.).

SHAPE	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
Rectangle	$0.2949	$0.2983	$0.3031	$0.3022	$0.3004	$0.3024	$0.3034	$0.2987
Square	$0.2979	$0.3001	$0.3026	$0.2997	$0.2971	$0.2999	$0.3029	$0.3004
L-Shape	$0.2547	$0.2566	$0.2590	$0.2572	$0.2559	$0.2580	$0.2603	$0.2577
U-Shape	$0.2608	$0.2634	$0.2665	$0.2653	$0.2645	$0.2658	$0.2669	$0.2635
Courtyard	$0.2677	$0.2698	$0.2728	$0.2718	$0.2705	$0.2720	$0.2729	$0.2698
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
Rectangle	$0.2956	$0.2989	$0.3034	$0.3024	$0.3005	$0.3023	$0.3030	$0.2981
Square	$0.2985	$0.3007	$0.3029	$0.2999	$0.2971	$0.2998	$0.3025	$0.2999
L-Shape	$0.2553	$0.2571	$0.2592	$0.2575	$0.2563	$0.2583	$0.2603	$0.2573
U-Shape	$0.2609	$0.2635	$0.2669	$0.2655	$0.2643	$0.2657	$0.2667	$0.2635
Courtyard	$0.2678	$0.2698	$0.2726	$0.2717	$0.2704	$0.2721	$0.2729	$0.2696

Table 4.9. Shape and orientation utility cost for space conditioning analysis ($/yr per sq.ft.).

Comparing the total utility cost for space conditioning among the different shapes, the results showed that the L-shape, U-shape, and courtyard shapes had the lowest utility costs per square feet, around or below $0.27 a year. The more compact shapes, the rectangle and square, see an average increase of about 10-11% to about $0.30 annually per square feet for the use of the central air conditioning and gas furnace systems.

The following section creates a matrix for potential homeowners on total costs, as well as the energy used on these systems.

4.10 Energy and utility cost for space conditioning matrix.

Tables 4.10. through 4.14. in this section show each shape along the 16 different orientations with the corresponding utility costs and the amount of energy used on each per year. These are subdivided into electrical and gas sub categories. Using this data a potential homebuyer can have a clear understanding on how much money he or she would need to spend on space conditioning costs based on the type of shape and orientation a residence has.

As mentioned in the introduction the 2015 Nevada Energy Fact Sheet lists the average electrical energy consumption of a Nevada residence at 12,154 kWh a year, while the residential gas use per household at 313.5 therms. This information is used to identify the percentage of energy used on space conditioning compared to the total amount of energy an average household uses in the state of Nevada. As an example the square base model orientated south uses 14% of the total annual electricity that a normal household of Nevada uses to run its air conditioning system. A more evident and greater impact is seen on how much natural gas is spent in heating compared to the total residential Nevada gas use of 313.5 therms. The base mode courtyard units use about 76-78% of this total on space heating during the winter months.

The goal of the matrix is to have developers come up with similar information when they advertise residential units for sale. Potential homebuyers can in turn become aware of the annual energy spent and utility costs on cooling and heating a residence, therefore making a more informed decision on which residence or unit type to buy.

	S 0º	**SSW 22.5º**	**SW 45º**	**WSW 67.5º**	**W 90º**	**WNW 112.5º**	**NW 135º**	**NNW 157.5º**
								
(E) $/yr	$304.16	$308.34	$314.83	$314.38	$312.54	$314.30	$314.59	$308.01
(G) $/yr	$226.65	$228.63	$230.66	$229.52	$228.28	$230.07	$231.49	$229.59
Total $/yr	$530.80	$537.00	$545.50	$543.90	$540.80	$544.40	$546.10	$537.60
kWh/yr	1,849	1,885	1,943	1,940	1,923	1,940	1,940	1,882
% of NV total kWh use	15.2%	15.5%	16.0%	16.0%	15.8%	16.0%	16.0%	15.5%
therms/yr	149.2	151.4	153.8	152.5	151.1	153.1	154.7	152.6
% of NV total therm/yr use	47.6%	48.3%	49.1%	48.6%	48.2%	48.8%	49.3%	48.7%
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
								
(E) $/yr	$303.88	$308.08	$314.63	$314.41	$312.73	$314.63	$315.00	$308.41
(G) $/yr	$228.16	$229.90	$231.59	$229.98	$228.19	$229.42	$230.38	$228.19
Total $/yr	$532.00	$538.00	$546.20	$544.40	$540.90	$544.10	$545.40	$536.60
kWh/yr	1,846	1,885	1,940	1,940	1,926	1,943	1,946	1,885
% of NV total kWh use	15.2%	15.5%	16.0%	16.0%	15.8%	16.0%	16.0%	15.5%
therms/yr	150.9	152.9	154.9	153	151	152.4	153.5	151
% of NV total therm/yr use	48.1%	48.8%	49.4%	48.8%	48.2%	48.6%	49.0%	48.2%

Table 4.10. Rectangular shape builder/homebuyer space conditioning cost and energy use matrix.

	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
								
(E) $/yr	$284.29	$286.63	$289.55	$286.23	$283.07	$285.96	$289.07	$286.15
(G) $/yr	$192.36	$193.54	$194.64	$193.31	$192.23	$193.89	$195.51	$194.51
Total $/yr	$476.70	$480.20	$484.20	$479.50	$475.30	$479.90	$484.60	$480.70
kWh/yr	1,703	1,723	1,750	1,720	1,691	1,717	1,747	1,720
% of NV total kWh use	14.0%	14.2%	14.4%	14.2%	13.9%	14.1%	14.4%	14.2%
therms/yr	131.7	133.3	134.8	133	131.5	133.8	136	134.7
% of NV total therm/yr use	42.0%	42.5%	43.0%	42.4%	41.9%	42.7%	43.4%	43.0%
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
								
(E) $/yr	$283.99	$286.41	$289.34	$286.22	$283.24	$286.32	$289.49	$286.54
(G) $/yr	$193.57	$194.68	$195.40	$193.67	$192.13	$193.34	$194.52	$193.36
Total $/yr	$477.60	$481.10	$484.70	$479.90	$475.40	$479.70	$484.00	$479.90
kWh/yr	1,700	1,720	1,747	1,720	1,700	1,720	1,747	1,720
% of NV total kWh use	14.0%	14.2%	14.4%	14.2%	14.0%	14.2%	14.4%	14.2%
therms/yr	133.4	134.8	135.9	133.5	133.4	134.8	135.9	133.5
% of NV total therm/yr use	42.6%	43.0%	43.3%	42.6%	42.6%	43.0%	43.3%	42.6%

Table 4.11. Square shape builder/homebuyer space conditioning cost and energy use matrix.

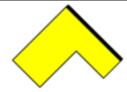
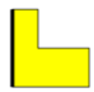
	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
								
(E) $/yr	$365.10	$367.19	$370.99	$367.55	$365.90	$369.91	$374.16	$369.41
(G) $/yr	$246.20	$248.71	$250.51	$249.65	$248.34	$249.19	$250.67	$249.00
Total $/yr	$611.30	$615.90	$621.50	$617.20	$614.20	$619.10	$624.80	$618.40
kWh/yr	2,436	2,453	2,488	2,456	2,441	2,479	2,515	2,471
% of NV total kWh use	20.0%	20.2%	20.5%	20.2%	20.1%	20.4%	20.7%	20.3%
therms/yr	205.3	208.7	211.2	210	208.2	209.3	211.4	209.1
% of NV total therm/yr use	65.5%	66.6%	67.4%	67.0%	66.4%	66.8%	67.4%	66.7%
	N 180º	NNE 202.5º	NE 225º	ENE 247.5º	E 270º	ESE 292.5º	SE 315º	SSE 337.5º
								
(E) $/yr	$364.87	$367.26	$370.96	$368.47	$367.23	$371.54	$375.42	$370.24
(G) $/yr	$247.90	$249.76	$251.05	$249.46	$247.78	$248.40	$249.28	$247.21
Total $/yr	$612.80	$617.00	$622.00	$617.90	$615.00	$619.90	$624.70	$617.50
kWh/yr	2,433	2,453	2,488	2,465	2,456	2,494	2,529	2,479
% of NV total kWh use	20.0%	20.2%	20.5%	20.3%	20.2%	20.5%	20.8%	20.4%
therms/yr	207.6	210.1	211.9	209.7	207.4	208.3	209.5	206.7
% of NV total therm/yr use	66.2%	67.0%	67.6%	66.9%	66.2%	66.4%	66.8%	65.9%

Table 4.12. L-shape builder/homebuyer space conditioning cost and energy use matrix.

	S 0º	SSW 22.5º	SW 45º	WSW 67.5º	W 90º	WNW 112.5º	NW 135º	NNW 157.5º
								
(E) $/yr	$364.43	$368.81	$374.93	$373.53	$372.13	$373.96	$375.34	$368.77
(G) $/yr	$251.75	$253.51	$254.87	$253.51	$252.74	$254.12	$255.47	$253.88
Total $/yr	$616.20	$622.30	$629.80	$627.00	$624.90	$628.10	$630.80	$622.70
kWh/yr	2,430	2,468	2,523	2,509	2,497	2,515	2,526	2,465
% of NV total kWh use	20.0%	20.3%	20.8%	20.6%	20.5%	20.7%	20.8%	20.3%
therms/yr	212.9	215.3	217.1	215.3	214.2	216.1	218	215.8
% of NV total therm/yr use	67.9%	68.7%	69.3%	68.7%	68.3%	68.9%	69.5%	68.8%
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
								
(E) $/yr	$363.68	$368.60	$374.93	$373.23	$371.92	$373.85	$375.40	$369.12
(G) $/yr	$252.71	$254.12	$255.69	$254.12	$252.71	$253.94	$254.93	$253.47
Total $/yr	$616.40	$622.70	$630.60	$627.40	$624.60	$627.80	$630.30	$622.60
kWh/yr	2,424	2,465	2,523	2,506	2,494	2,515	2,526	2,468
% of NV total kWh use	19.9%	20.3%	20.8%	20.6%	20.5%	20.7%	20.8%	20.3%
therms/yr	214.1	216.1	218.2	216.1	214.2	215.9	217.3	215.2
% of NV total therm/yr use	67.9%	68.7%	69.3%	68.7%	68.3%	68.9%	69.5%	68.8%

Table 4.13. U-shape builder/homebuyer space conditioning cost and energy use matrix.

	S 0º	**SSW 22.5º**	**SW 45º**	**WSW 67.5º**	**W 90º**	**WNW 112.5º**	**NW 135º**	**NNW 157.5º**
								
(E) $/yr	$360.50	$363.98	$369.32	$368.17	$366.05	$368.41	$369.37	$363.65
(G) $/yr	$270.11	$271.58	$273.39	$272.23	$271.13	$272.44	$273.59	$271.97
Total $/yr	$630.60	$635.60	$642.70	$640.40	$637.20	$640.90	$643.00	$635.60
kWh/yr	2,392	2,424	2,471	2,462	2,441	2,462	2,471	2,421
% of NV total kWh use	19.7%	19.9%	20.3%	20.3%	20.1%	20.3%	20.3%	19.9%
therms/yr	238	240	242.4	240.8	239.3	241.2	242.7	240.5
% of NV total therm/yr use	75.9%	76.6%	77.3%	76.8%	76.3%	76.9%	77.4%	76.7%
	N 180º	**NNE 202.5º**	**NE 225º**	**ENE 247.5º**	**E 270º**	**ESE 292.5º**	**SE 315º**	**SSE 337.5º**
								
(E) $/yr	$360.29	$363.60	$368.88	$368.11	$366.41	$368.94	$369.85	$363.99
(G) $/yr	$270.65	$272.07	$273.42	$272.04	$270.72	$272.03	$273.08	$271.24
Total $/yr	$630.90	$635.70	$642.30	$640.20	$637.10	$641.00	$642.90	$635.20
kWh/yr	2,389	2,421	2,468	2,462	2,444	2,471	2,477	2,424
% of NV total kWh use	19.7%	19.9%	20.3%	20.3%	20.1%	20.3%	20.4%	19.9%
therms/yr	238.7	240.7	242.5	240.6	238.8	240.6	242	239.5
% of NV total therm/yr use	76.1%	76.8%	77.4%	76.7%	76.2%	76.7%	77.2%	76.4%

Table 4.14. Courtyard shape builder/homebuyer space conditioning cost and energy use matrix.

4.11 Subdivision community space conditioning energy analysis.

The first step in analyzing the energy spent on space conditioning by a subdivision community was to try to match the existing unit types to the base models simulated in BEopt in the previous sections. As seen in Table 4.15., the square unit was used to represent unit types A and G, while the rectangle one represented unit types B, C, D, and E, last the U-shape base model represented the largest floor plan unit in Central Park Estates.

Next, these base models were placed in orientations that matched the original layout done by the developers of the community, with Figure 4.17. showing which units had a 0° south orientation in light gray and which had a 180° west facing one. The majority of the units, 192 of them, had the latter west orientation.

After doing a walk though the neighborhood and measuring the proximity of each residence to one another, there was a distance of about ten feet between each one. Therefore a separate simulation was done on the three shapes along the south 0° and west 180° orientations to reflect this change as the original simulation had no surrounding neighbors in this input parameter. These results are seen on tables 4.16., 4.17., and 4.18.

Multiplying the total kWh/yr of each unit by the number of units represented in the site plan layout of Figure 4.17., a total of 1,703,853.6 kWh/yr were used as a community, as shown in Tables 4.19. and 4.20. All 192 units that had a west orientation were then flipped to face south and the totals were added once again, shown in Tables 4.21. and 4.22. Finally the difference between these two was calculated, with a potential savings of 108,058.4 kWh yearly by properly orienting the west facing homes or about a 7% savings from the original layout. Another way to look at it is that just about nine Nevada households could get free electricity each year if a community like Central Park Estates would optimally orient their residences to save energy in space conditioning.

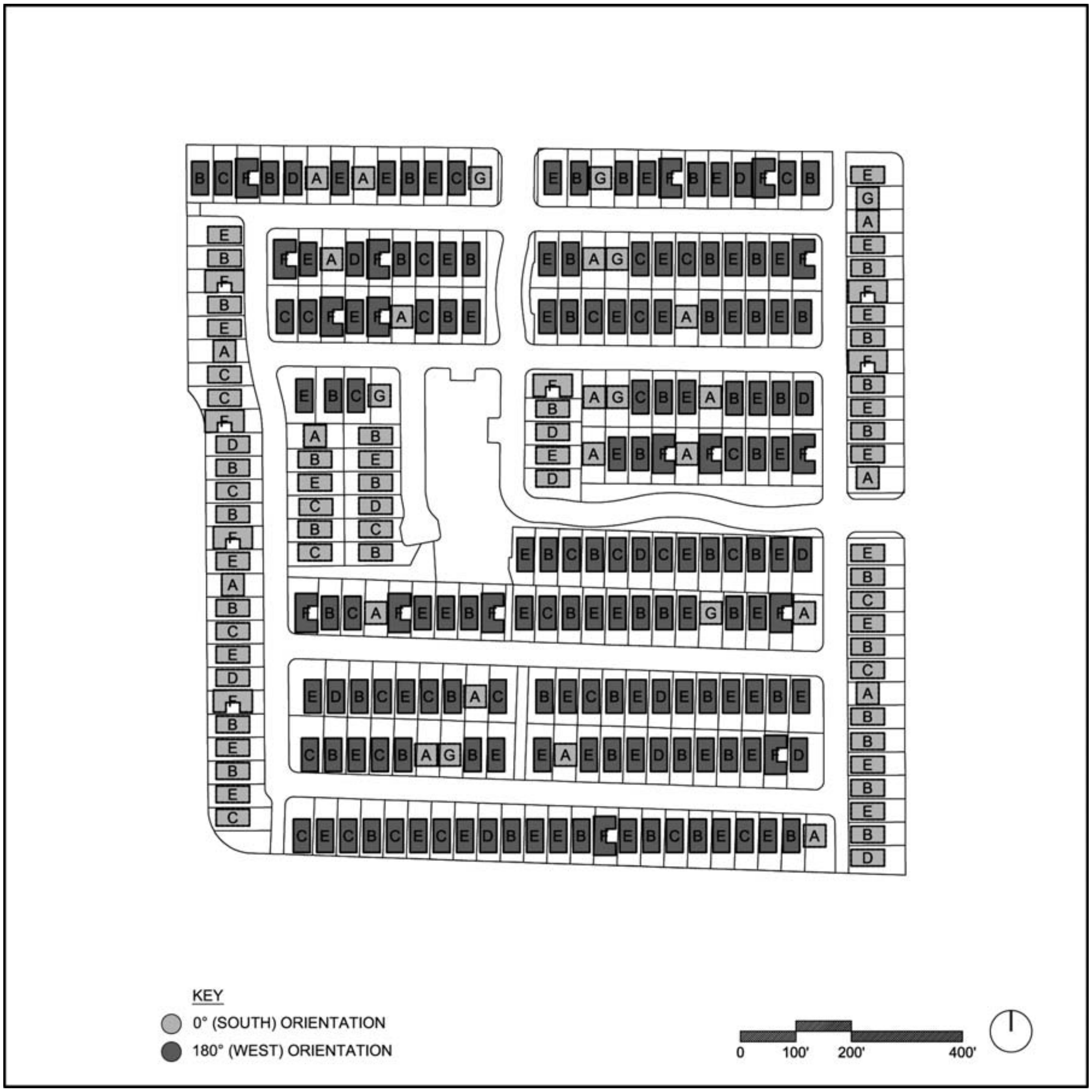


Figure 4.18. Central Park Estates unit layout based on residence size and residences orientation.

SHAPE	SQ.FT.	UNIT TYPE TO REPRESENT	SQ.FT.OF ORIG INAL UNITS	# OF UNITS	TOTAL SQ.FT.
Squre	1,600	A,G	1,322/1,457	30	48,000
Rectangle	1,800	B,C,D,E	1,593/1,784/1,893/1,977	208	374,400
U-shape	2,363	F	2,211	24	56,712
Total				**262**	**479,112**

Table 4.15. Central Park Estates unit types based on original residence size and orientation.

Rectangle Site Energy Use (kWh/yr)	S 0º	W 90º	Rectangle Annualized Utility Bills ($/yr)	S 0º	W 90º
					
Vent Fan (E)	20.5	20.5	Fixed Charge (E)	$95.99	$95.99
HVAC Fan (E)	407.3	492.2	Fixed Charge (G)	$95.99	$95.99
Cooling (E)	1,078.2	1,359.5	Energy Charge (E)	$169.64	$210.78
Heating (G)	4,439.0	4,688.0	Energy Charge (G)	$132.66	$140.10
Total	5,947.9	6,563.2	Total	$494.30	$542.90

Table 4.16. Space conditioning energy use and utility cost adjusted for neighbors at a 10' offset for rectangular shape.

Square Site Energy Use (kWh/yr)	S 0º	W 90º	Square Annualized Utility Bills ($/yr)	S 0º	W 90º
					
Vent Fan (E)	20.5	20.5	Fixed Charge (E)	$95.99	$95.99
HVAC Fan (E)	363.3	430.7	Fixed Charge (G)	$95.99	$95.99
Cooling (E)	955.2	1,186.7	Energy Charge (E)	$148.06	$181.19
Heating (G)	4,049.3	4,266.1	Energy Charge (G)	$101.07	$106.53
Total	5,391.2	5,918.6	Total	$441.10	$479.70

Table 4.17. Space conditioning energy use and utility cost adjusted for neighbors at a 10' offset for square shape.

U-shape Site Energy Use (kWh/yr)	S 0º	W 90º	U-shape Annualized Utility Bills ($/yr)	S 0º	W 90º
					
Vent Fan (E)	20.5	20.5	Fixed Charge (E)	$95.99	$95.99
HVAC Fan (E)	588.9	635.8	Fixed Charge (G)	$95.99	$95.99
Cooling (E)	1,599.8	1,769.7	Energy Charge (E)	$244.51	$268.31
Heating (G)	5,986.0	5,927.4	Energy Charge (G)	$149.46	$148.02
Total	8,204.0	8,350.5	Total	$586.00	$608.30

Table 4.18. Space conditioning energy use and utility cost adjusted for neighbors at a 10' offset for U- shape.

		S 0º	W 90º	Total
Rectangle	#units	57	151	208
	kWh/yr	339,030.3	991,043.2	1,330,073.5
Square	#units	6	24	30
	kWh/yr	32,347.2	142,046.4	174,393.6
U-shape	#units	7	17	24
	kWh/yr	57,428.0	141,958.5	199,386.5

Table 4.19. Space conditioning energy use results for 3 distinct unity types on the Central Park Estates site.

Totals	
kWh/yr	1,703,853.6

Table 4.20. Total space conditioning energy use results on 262 residences in the Central Park Estates site.

		S 0º	W 90º	Total
Rectangle	#units	208	0	208
	kWh/yr	1,237,163.2	0	1,237,163.2
Square	#units	30	0	30
	kWh/yr	161,736.0	0	161,736.0
U-shape	#units	24	0	24
	kWh/yr	196,896.0	0	196,896.0

Table 4.21. Space conditioning energy use results for 3 distinct unity types optimized for orientation on the Central Park Estates site.

Totals	
kWh/yr	1,595,795.2

Table 4.22. Total space conditioning energy use results for 262 residences with optimized orientation on Central Park Estates site.

Totals	
kWh/yr	1,703,853.6 - 1,595,795.2
	108,058.4

Table 4.23. Total potential space conditioning energy use savings from optimized residences on Central Park Estates site.

CONCLUSION

At the early design stage, appropriate orientation and shape considerations can be studied, analyzed and implemented quite easily. They are also a low cost energy efficiency technique that can be used before more complex active techniques and systems may be implemented. This paper's aim was to simulate and model the impact of building shape and orientation for new residences in the southern Nevada region and to provide evidence and support for earlier decisions in the design process. The results can be used to provide more sustainable approach in creating low-energy residential buildings as well as larger community developments and see how much energy may be saved at a larger scale.

A brief comparison is also provided in Table 4.24. comparing the characteristics and results of this study with ones done by Bostancloglu and Morrisset el al. It is significant to note that shape changes have more impact in energy than orientation in all three research paper. Moreover, all studies have in common finding solutions to how adapt plans for single family residences for volume builders.

As discussed earlier, overall building orientation of the shapes resulted on energy savings of up to 4%, while the savings in energy between the shapes themselves could be of up to 15% Therefore selecting the appropriate shape for a residence becomes a significant decision early in the design process and fine tuning its orientation a good next step.

Most of the energy that was spent in space conditioning came from heating the base model homes, with most requiring between 70% to 75% of the total to power the gas furnace. For heating purposes the more compact the shape was, the better it performed, though still requiring a great percentage of the total energy in space conditioning. It would seem appropriate that to offset the larger heating needs perhaps different passive or active strategies can be used to lower this energy demand.

More variation existed in shape and orientation for the cooling loads and were not as static as the heating analysis performed. Interestingly, some shapes performed better at different orientations than others. A designer can look at opportunities here if other angles are required because of site constraints like city girds, natural formations, setbacks, or views to see which shapes may behave better at these orientations, in turn select one that responds well to cooling loads and decide to offset the higher heating loads by other means. The data and matrices generated can hopefully encourage designers to use a similar process as an affordable passive solar design technique.

Moreover, an interesting finding was that even though the literature review and basic passive design rules of thumb have always pointed to rectangular buildings in an east and west direction as best practice in the region, a square and L-shape could also be used with minimal increase in energy use. A difference of only 1-2% more energy use resulted among these two shapes along the different orientations compared to the rectangle. The square shape even performed better over all in the east and west orientations.

If a developer would like to repeat a unit type and mass produce it for subdivision, the rectangle form actually performs the worst in orientation changes. Instead, the analysis performed on this paper would recommend the use of a square plan, as it performs better overall around the different orientations.

Another significant finding was that for space conditioning utility cost per square foot, the L-shape also performed better than the compact square and rectangle shape. It is important to note that current energy prices in electricity and gas utility charges are affordable to homeowners. The study showed an increase of only 1% to 2% between orientations or no more than $15 in yearly costs for space conditioning. Similarly between the different shapes there was an average increase of $122 in utility costs for space conditioning, which is an increase of only $10 per month. However, a more significant finding was the annual savings that could be obtained on the layout of residences in larger subdivision developments that are present in the

Las Vegas region. A more meaningful impact was seen by simply orienting the variety of units to the more optimal south facing direction, about nine households in Nevada could be given free electricity yearly.

As the Nevada population increases and the demand for single family detached residences continues, the design and construction industry needs to take a more careful look in the layout of these communities to reduce their energy demands. The lesson learned here is that having residential designers, builders, and developers become more aware of studies like this one and can help them to see how low cost initial design decisions on shape and orientation can have a significant impact in energy savings for single homes and community developments. Additional research and analysis can be performed using designs of multiple unit types and floor plans of single family homes that are mass produced for communities in the Southern Nevada region. Additionally, if these industries start providing energy and cost data to potential homebuyers, similar to the matrices produced on this paper, as a standard practice there will be an added awareness by consumers.

	This paper (2015)	Bostancioglu (2010)	Morrisset et al. (2011)
Location	Las Vegas	Istanbul	Melbourne
Climate	Hot Arid	Warm temperate dry	Temperate, Mild Climate
Latitude	36º 10' N	40º 58' N	37° 48' S
Shape/plans studied	5	4	81
Areas (sq.ft.) range	1,600-2400	4305-4478	947-3681
Type of residence	Detached	Attached	Detached
Typical Wall R-value	R-13	Detailed material list provided in paper.	R-11.3 (brick wall)
Typical Roof R-value	R-30	Detailed material list provided in paper.	R-20
Glazing Specs	Double Glazing	Detailed material list provided in paper.	Double Glazing
Energy simulation software	BEopt	-	AccuRate
Orientation Conclusions	Square plan performs better around different orientations. 4% difference along orientations.	0.86% difference due to orientation changes.	Floor area most significant factor in terms of adaptability to orientation change.
Shape Conclusion	L-shape & square shape can perform almost as good as the rectangular shape.	Increase change in shape (exterior wall area/floor area increase) will cause energy cost, construction cost and life cycle costs to increase. Building shape changes can increase up to 26.92% in energy cost.	-
Volume Building	Square plan will perform better for larger residential developments		More energy efficient built homes are better suited for volume building construction,

Table 4.24. Orientation and shape studies summaries.

APPENDIX A: DEFINITION OF TERMS

Active Solar System - A system that uses mechanical devices and an external energy source in addition to solar energy, to collect, store, and distribute thermal (heat) energy.

Azimuth - Angle between the north vector and the perpendicular projection of the star down onto the horizon. Azimuth is usually measured in degrees (°)

Building Envelope - the physical separator between the exterior and interior of a building. The included walls, foundations, roofs, glazing, thermal insulation, thermal mass, shading devices, and doors.

Construction Documents - Next phase after design development, the construction document phase produces drawings in greater detail. These include specifications for construction details and materials.

Direct Solar Gain - Direct gain is the collection and containment of radiant solar energy within the occupied space.

Design Development - Referred as DD, design development takes the initial design documents from the schematic design laying out mechanical, structural, and architectural details. The level of detail is determined by the project requirements and owners request.

Killowatt Hour (kWh) - a kilowatt-hour is a unit of energy equivalent to one kilowatt (1 kW) of power sustained for one hour.

Passive Solar Design - The use of the energy from the sun for heating and cooling of living spaces.

Schematic Design - first phase of services provided by an architect where project goals and requirements are determined with the owner. Typical deliverables in this phase include site plan, floor plans, sections, and elevations.

Space Conditioning - Space conditioning nvolves providing heating or cooling to an area and controlling the interior temperature.

Solar Gain - the increase in temperature in space as a result of solar radiation.

Thermal comfort - thermal comfort is the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.

Therms - The therm (symbol thm) is a non-SI unit of heat energy equal to 100,000 British thermal units (BTU). It is approximately the energy equivalent of burning 100 cubic feet (often referred to as 1 CCF) of natural gas.

APPENDIX B: IECC 2009

CHAPTER 3
CLIMATE ZONES

SECTION 301
CLIMATE ZONES

301.1 General. Climate *zones* from Figure 301.1 or Table 301.1 shall be used in determining the applicable requirements from Chapters 4 and 5. Locations not in Table 301.1 (outside the United States) shall be assigned a climate *zone* based on Section 301.3.

301.2 Warm humid counties. Warm humid counties are identified in Table 301.1 by an asterisk.

301.3 International climate zones. The climate *zone* for any location outside the United States shall be determined by applying Table 301.3(1) and then Table 301.3(2).

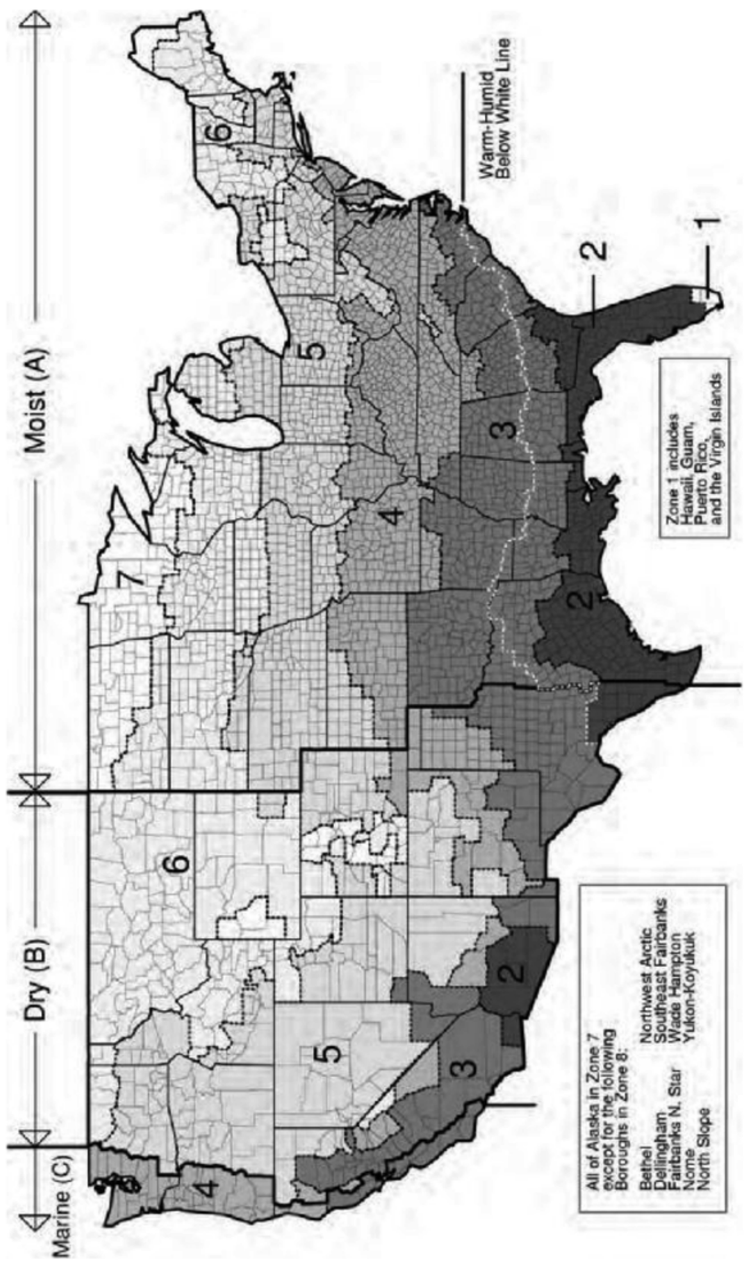


FIGURE 301.1
CLIMATE ZONES

TABLE 301.1
CLIMATE IONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

Note: Table 301.1 in the 2006 edition has been replaced in its entirety. Margin lines are omitted for clarity.

Key: A - Moist, B - Dry, C - Marine. Absence of moisture designation indicates moisture regime is irrelevant. Asterisk (*) indicates a warm-humid location.

US STATES

ALABAMA
3A Autauga*
2A Baldwin*
3A Barbour*
3A Bibb
3A Blount
3A Bullock*
3A Butler*
3A Calhoun
3A Chambers
3A Cherokee
3A Chilton
3A Choctaw*
3A Clarke*
3A Clay
3A Cleburne
3A Coffee*
3A Colbert
3A Conecuh*
3A Coosa
3A Covington*
3A Crenshaw*
3A Cullman
3A Dale*
3A Dallas*
3A DeKalb
3A Elmore*
3A Escambia*
3A Etowah
3A Fayette
3A Franklin
3A Geneva*
3A Greene
3A Hale
3A Henry*
3A Houston*
3AJackson
3A Jefferson
3A Lamar
3A Lauderdale
3A Lawrence
3A Lee
3A Limestone
3A Lowndes*
3A Macon*
3A Madison
3A Marengo*
3A Marion
3A Marshall
2A Mobile*
3A Monroe*
3A Montgomery*
3A Morgan
3A Perry*
3A Pickens
3A Pike*
3A Randolph
3A Russell*
3A Shelby
3A St. Clair
3A Sumter
3A Talladega
3A Tallapoosa
3A Tuscaloosa
3A Walker
3A Washington*
3A Wilcox*
3A Winston

ALASKA
7 Aleutians East
7 Aleutians West
7 Anchorage
8 Bethel
7 Bristol Bay
7 Denali
8 Dillingham
8 Fairbanks North Star
7 Haines
7 Juneau
7 Kenai Peninsula
7 Ketchikan Gateway
7 Kodiak Island
7 Lake and Peninsula
7 Matanuska-Susitna
8 Nome
8 North Slope
8 Northwest Arctic
7 Prince of Wales-Outer Ketchikan
7 Sitka
7 Skagway-Hoonah-Angoon
8 Southeast Fairbanks
7 Valdez-Cordova
8 Wade Hampton
7 Wrangell-Petersburg
7 Yakutat
8 Yukon-Koyukuk

ARIZONA
SB Apache
3B Cochise
SB Coconino
4B Gila
3B Graham
3B Greenlee
2B La Paz
2B Maricopa
3B Mohave
SB Navajo
2B Pima
2B Pinal
3B Santa Cruz
4B Yavapai
2B Yuma

ARKANSAS
3A Arkansas
3A Ashley
4A Baxter
4A Benton
4A Boone
3A Bradley
3A Calhoun
4A Carroll
3A Chicot
3A Clark
3A Clay
3A Cleburne
3A Cleveland
3A Columbia*
3A Conway
3A Craighead
3A Crawford
3A Crittenden
3A Cross
3A Dallas
3A Desha
3A Drew
3A Faulkner
3A Franklin
4A Fulton
3A Garland
3A Grant
3A Greene
3A Hempstead*
3A Hot Spring
3A Howard
3A Independence
4A Izard
3A Jackson
3A Jefferson
3AJohnson
3A Lafayette*
3A Lawrence
3ALee
3A Lincoln
3A Little River*
3A Logan
3A Lonoke
4A Madison
4A Marion
3A Miller*
3A Mississippi
3A Monroe
3A Montgomery
3A Nevada
4A Newton
3A Ouachita
3A Perry
3A Phillips

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

3A Pike
3A Poinsett
3A Polk
3A Pope
3A Prairie
3A Pulaski
3A Randolph
3A Saline
3A Scott
4A Searcy
3A Sebastian
3A Sevier*
3A Sharp
3A St. Francis
4A Stone
3A Union*
3A Van Buren
4A Washington
3A White
3A Woodruff
3A Yell

CALIFORNIA

3C Alameda
6B Alpine
4B Amador
3B Butte
4B Calaveras
3B Colusa
3B Contra Costa
4C Del Norte
4B El Dorado
3B Fresno
3B Glenn
4C Humboldt
2B Imperial
4B Inyo
3B Kern
3B Kings
4B Lake
5B Lassen
3B Los Angeles
3B Madera
3C Marin
4B Mariposa
3C Mendocino
3B Merced
5B Modoc
6B Mono
3C Monterey
3C Napa
5B Nevada
3B Orange
3B Placer
5B Plumas
3B Riverside
3B Sacramento
3C San Benito
3B San Bernardino
3B San Diego
3C San Francisco
3B San Joaquin
3C San Luis Obispo
3C San Mateo
3C Santa Barbara
3C Santa Clara
3C Santa Cruz
3B Shasta
5B Sierra
5B Siskiyou
3B Solano
3C Sonoma
3B Stanislaus
3B Sutter
3B Tehama
4B Trinity
3B Tulare
4B Tuolumne
3C Ventura
3B Yolo
3B Yuba

COLORADO

5B Adams
6B Alamosa
5B Arapahoe
6B Archuleta
4B Baca
5B Bent
5B Boulder
6B Chaffee
5B Cheyenne
7 Clear Creek
6B Conejos
6B Costilla
5B Crowley
6B Custer
5B Delta
5B Denver
6B Dolores
5B Douglas
6B Eagle
5B Elbert
5B El Paso
5B Fremont
5B Garfield
5B Gilpin
7 Grand
7 Gunnison
7 Hinsdale
5B Huerfano
7 Jackson
5B Jefferson
5B Kiowa
5B Kit Carson
7 Lake
5B La Plata
5B Larimer
4B Las Animas
5B Lincoln
5B Logan
5B Mesa
7 Mineral
6B Moffat
5B Montezuma
5B Montrose
5B Morgan
4B Otero
6B Ouray
7 Park
5B Phillips
7 Pitkin
5B Prowers
5B Pueblo
6B Rio Blanco
7 Rio Grande
7 Routt
6B Saguache
7 San Juan
6B San Miguel
5B Sedgwick
7 Summit
5B Teller
5B Washington
5B Weld
5B Yuma

CONNECTICUT

5A (all)

DELAWARE

4A (all)

DISTRICT OF COLUMBIA

4A (all)

FLORIDA

2A Alachua*
2A Baker*
2A Bay*
2A Bradford*
2A Brevard*
1A Broward*
2A Calhoun*
2A Charlotte*
2A Citrus*
2A Clay*
2A Collier*
2A Columbia*
2A DeSoto*
2A Dixie*
2A Duval*
2A Escambia*
2A Flagler*
2A Franklin*
2A Gadsden*
2A Gilchrist*
2A Glades*
2A Gulf*
2A Hamilton*
2A Hardee*
2A Hendry*
2A Hernando*
2A Highlands*
2A Hillsborough*
2A Holmes*
2A Indian River*
2A Jackson*
2A Jefferson*
2A Lafayette*
2A Lake*
2A Lee*
2A Leon*
2A Levy*
2A Liberty*
2A Madison*
2A Manatee*
2A Marion*
2A Martin*
1A Miami-Dade*
1A Monroe*
2A Nassau*
2A Okaloosa*
2A Okeechobee*

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

2A Orange*
2A Osceola*
2A Palm Beach*
2A Pasco*
2A Pinellas*
2A Polk*
2A Putnam*
2A Santa Rosa*
2A Sarasota*
2A Seminole*
2A St. johns*
2A St. Lucie*
2A Sumter*
2A Suwannee*
2A Taylor*
2A Union*
2A Volusia*
2A Wakulla*
2A Walton*
2A Washington*

GEORGIA

2A Appling*
2A Atkinson*
2A Bacon*
2A Baker*
3A Baldwin
4A Banks
3A Barrow
3A Bartow
3A Ben Hill*
2A Berrien*
3A Bibb
3A Bleckley*
2A Brantley*
2A Brooks*
2A Bryan*
3A Bulloch*
3A Burke
3A Butts
3A Calhoun*
2A Camden*
3A Candler*
3A Carroll
4A Catoosa
2A Charlton*
2A Chatham*
3A Chattahoochee*
4A Chattooga
3A Cherokee
3A Clarke
3A Clay*
3A Clayton
2A Clinch*
3A Cobb
3A Coffee*
2A Colquitt*
3A Columbia
2A Cook*
3A Coweta
3A Crawford
3A Crisp*
4A Dade
4A Dawson
2A Decatur*
3A DeKalb
3A Dodge*
3A Dooly*
3A Dougherty*
3A Douglas
3A Early*
2A Echols*
2A Effingham*
3A Elbert
3A Emanuel*
2A Evans*
4A Fannin
3A Fayette
4A Floyd
3A Forsyth
4A Franklin
3A Fulton
4A Gilmer
3A Glascock
2A Glynn*
4A Gordon
2A Grady*
3A Greene
3A Gwinnett
4A Habersham
4A Hall
3A Hancock
3A Haralson
3A Harris
3A Hart
3A Heard
3A Henry
3A Houston*
3A Irwin*
3Ajackson
3A jasper
2A jeff Davis*
3A jefferson
3A jenkins*
3Ajohnson*
3Ajones
3A Lamar
2A Lanier*
3A Laurens*
3A Lee*
2A Liberty*
3A Lincoln
2A Long*
2A Lowndes*
4A Lumpkin
3A Macon*
3A Madison
3A Marion*
3A McDuffie
2A McIntosh*
3A Meriwether
2A Miller*
2A Mitchell*
3A Monroe
3A Montgomery*
3A Morgan
4A Murray
3A Muscogee
3A Newton
3A Oconee
3A Oglethorpe
3A Paulding
3A Peach*
4A Pickens
2A Pierce*
3A Pike
3A Polk
3A Pulaski*
3A Putnam
3A Quitman*
4A Rabun
3A Randolph*
3A Richmond
3A Rockdale
3A Schley*
3A Screven*
2A Seminole*
3A Spalding
4A Stephens
3A Stewart*
3A Sumter*
3A Talbot
3A Taliaferro
2A Tattnall*
3A Taylor*
3A Telfair*
3A Terrell*
2A Thomas*
3A Tift*
2A Toombs*
4A Towns
3A Treutlen*
3A Troup
3A Turner*
3A Twiggs*
4A Union
3A Upson
4A Walker
3A Walton
2A Ware*
3A Warren
3A Washington
2A Wayne*
3A Webster*
3A Wheeler*
4A White
4A Whitfield
3A Wilcox*
3A Wilkes
3A Wilkinson
3A Worth*

HAWAII

1A (all)*

IDAHO

5B Ada
6B Adams
6B Bannock
6B Bear Lake
5B Benewah
6B Bingham
6B Blaine
6B Boise
6B Bonner
6B Bonneville
6B Boundary
6B Butte
6B Camas
5B Canyon
6B Caribou
5B Cassia
6B Clark
5B Clearwater
6B Custer
5B Elmore

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

6B Franklin
6B Fremont
SBGem
SB Gooding
SB Idaho
6B jefferson
SB jerome
SB Kootenai
SB Latah
6B Lemhi
SB Lewis
SB Lincoln
6B Madison
SB Minidoka
SB Nez Perce
6B Oneida
SB Owyhee
SB Payette
SB Power
SB Shoshone
6B Teton
SB Twin Falls
6B Valley
SB Washington

ILLINOIS

SA Adams
4A Alexander
4A Bond
SA Boone
SA Brown
SA Bureau
SA Calhoun
SA Carroll
SA Cass
SA Champaign
4A Christian
SA Clark
4A Clay
4A Clinton
SA Coles
SA Cook
4A Crawford
SA Cumberland
SA DeKalb
SA De Witt
SA Douglas
SA DuPage
SA Edgar
4A Edwards
4A Effingham
4A Fayette
SA Ford
4A Franklin
SA Fulton
4A Gallatin
SA Greene
SA Grundy
4A Hamilton
SA Hancock
4A Hardin
SA Henderson
SA Henry
SA Iroquois
4Ajackson
4A jasper
4A jefferson
SA jersey
SA jo Daviess
4Ajohnson
SA Kane
SA Kankakee
SA Kendall
SA Knox
SA Lake
SA La Salle
4A Lawrence
SA Lee
SA Livingston
SA Logan
SA Macon
4A Macoupin
4A Madison
4A Marion
SA Marshall
SA Mason
4A Massac
SA McDonough
SA McHenry
SA McLean
SA Menard
SA Mercer
4A Monroe
4A Montgomery
SA Morgan
SA Moultrie
SA Ogle
SA Peoria
4A Perry
SA Piatt
SA Pike
4A Pope
4A Pulaski
SA Putnam
4A Randolph
4A Richland
SA Rock Island
4A Saline
SA Sangamon
SA Schuyler
SA Scott
4A Shelby
SA Stark
4A St. Clair
SA Stephenson
SA Tazewell
4A Union
SA Vermilion
4A Wabash
SA Warren
4A Washington
4A Wayne
4A White
SA Whiteside
SA Will
4A Williamson
SA Winnebago
SA Woodford

INDIANA

SA Adams
SA Allen
SA Bartholomew
SA Benton
SA Blackford
SA Boone
4A Brown
SA Carroll
SA Cass
4A Clark
SA Clay
SA Clinton
4A Crawford
4A Daviess
4A Dearborn
SA Decatur
SA De Kalb
SA Delaware
4A Dubois
SA Elkhart
SA Fayette
4A Floyd
SA Fountain
SA Franklin
SA Fulton
4A Gibson
SA Grant
4A Greene
SA Hamilton
SA Hancock
4A Harrison
SA Hendricks
SA Henry
SA Howard
SA Huntington
4Ajackson
SA jasper
SA jay
4A jefferson
4A jennings
SA johnson
4A Knox
SA Kosciusko
SA Lagrange
SA Lake
SA La Porte
4A Lawrence
SA Madison
SA Marion
SA Marshall
4A Martin
SA Miami
4A Monroe
SA Montgomery
SA Morgan
SA Newton
SA Noble
4A Ohio
4A Orange
SA Owen
SA Parke
4A Perry
4A Pike
SA Porter
4A Posey
SA Pulaski
SA Putnam
SA Randolph
4A Ripley
SA Rush
4A Scott
SA Shelby

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

4A Spencer
SA Starke
SA Steuben
SA St. joseph
4A Sullivan
4A Switzerland
SA Tippecanoe
SA Tipton
SA Union
4A Vanderburgh
SA Vermillion
SA Vigo
SA Wabash
SA Warren
4A Warrick
4A Washington
SA Wayne
SA Wells
SA White
SA Whitley

IOWA

SA Adair
SA Adams
6A Allamakee
SA Appanoose
SA Audubon
SA Benton
6A Black Hawk
SA Boone
6A Bremer
6A Buchanan
6A Buena Vista
6A Butler
6A Calhoun
SA Carroll
SA Cass
SA Cedar
6A Cerro Gordo
6A Cherokee
6A Chickasaw
SA Clarke
6A Clay
6A Clayton
SA Clinton
SA Crawford
SA Dallas
SA Davis
SA Decatur
6A Delaware
SA Des Moines
6A Dickinson
SA Dubuque
6A Emmet
6A Fayette
6A Floyd
6A Franklin
SA Fremont
SA Greene
6A Grundy
SA Guthrie
6A Hamilton
6A Hancock
6A Hardin
SA Harrison
SA Henry
6A Howard
6A Humboldt
6A Ida
SA Iowa
SA jackson
SA jasper
SA jefferson
SA johnson
SA jones
SA Keokuk
6A Kossuth
SA Lee
SA Linn
SA Louisa
SA Lucas
6A Lyon
SA Madison
SA Mahaska
SA Marion
SA Marshall
SA Mills
6A Mitchell
SA Monona
SA Monroe
SA Montgomery
SA Muscatine
6A O'Brien
6A Osceola
SA Page
6A Palo Alto
6A Plymouth
6A Pocahontas
SA Polk
SA Pottawattamie
SA Poweshiek
SA Ringgold
6ASac
SA Scott
SA Shelby
6A Sioux
SA Story
SA Tama
SA Taylor
SA Union
SA Van Buren
SA Wapello
SA Warren
SA Washington
SA Wayne
6A Webster
6A Winnebago
6A Winneshiek
SA Woodbury
6A Worth
6A Wright

KANSAS

4A Allen
4A Anderson
4A Atchison
4A Barber
4A Barton
4A Bourbon
4A Brown
4A Butler
4A Chase
4A Chautauqua
4A Cherokee
SA Cheyenne
4A Clark
4A Clay
SA Cloud
4A Coffey
4A Comanche
4A Cowley
4A Crawford
SA Decatur
4A Dickinson
4A Doniphan
4A Douglas
4A Edwards
4A Elk
SA Ellis
4A Ellsworth
4A Finney
4A Ford
4A Franklin
4A Geary
SA Gove
SA Graham
4A Grant
4A Gray
SA Greeley
4A Greenwood
SA Hamilton
4A Harper
4A Harvey
SA Haskell
4A Hodgeman
4Ajackson
4A jefferson
SA jewell
4A johnson
4A Kearny
4A Kingman
4A Kiowa
4A Labette
SA Lane
4A Leavenworth
4A Lincoln
4A Linn
SA Logan
4A Lyon
4A Marion
4A Marshall
4A McPherson
4A Meade
4A Miami
SA Mitchell
4A Montgomery
4A Morris
4A Morton
4A Nemaha
4A Neosho
SA Ness
SA Norton
4A Osage
SA Osborne
4A Ottawa
4A Pawnee
SA Phillips
4A Pottawatomie
4A Pratt
SA Rawlins
4A Reno
SA Republic

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

4A Rice
4A Riley
SA Rooks
4A Rush
4A Russell
4A Saline
SA Scott
4A Sedgwick
4A Seward
4A Shawnee
SA Sheridan
SA Sherman
SA Smith
4A Stafford
4A Stanton
4A Stevens
4A Sumner
SA Thomas
SA Trego
4A Wabaunsee
SA Wallace
4A Washington
SA Wichita
4A Wilson
4A Woodson
4A Wyandotte

KENTUCKY

4A (all)

LOUISIANA

2A Acadia*
2A Allen*
2A Ascension*
2A Assumption*
2A Avoyelles*
2A Beauregard*
3A Bienville*
3A Bossier*
3A Caddo*
2A Calcasieu*
3A Caldwell*
2A Cameron*
3A Catahoula*
3A Claiborne*
3A Concordia*
3A De Soto*
2A East Baton Rouge*
3A East Carroll
2A East Feliciana*
2A Evangeline*
3A Franklin*
3A Grant*
2A Iberia*
2A Iberville*
3A jackson*
2A jefferson*
2A jefferson Davis*
2A Lafayette*
2A Lafourche*
3A La Salle*
3A Lincoln*
2A Livingston*
3A Madison*
3A Morehouse
3A Natchitoches*
2A Orleans*
3A Ouachita*
2A Plaquemines*
2A Pointe Coupee*
2A Rapides*
3A Red River*
3A Richland*
3A Sabine*
2A St. Bernard*
2A St. Charles*
2A St. Helena*
2A St. james*
2A St. john the Baptist*
2A St. Landry*
2A St. Martin*
2A St. Mary*
2A St. Tammany*
2A Tangipahoa*
3A Tensas*
2A Terrebonne*
3A Union*
2A Vermilion*
3A Vernon*
2A Washington*
3A Webster*
2A West Baton Rouge*
3A West Carroll
2A West Feliciana*
3A Winn*

MAINE

6A Androscoggin
7 Aroostook
6A Cumberland
6A Franklin
6A Hancock
6A Kennebec
6A Knox
6A Lincoln
6A Oxford
6A Penobscot
6A Piscataquis
6A Sagadahoc
6A Somerset
6A Waldo
6A Washington
6A York

MARYLAND

4A Allegany
4A Anne Arundel
4A Baltimore
4A Baltimore (city)
4A Calvert
4A Caroline
4A Carroll
4A Cecil
4A Charles
4A Dorchester
4A Frederick
SA Garrett
4A Harford
4A Howard
4A Kent
4A Montgomery
4A Prince George's
4A Queen Anne's
4A Somerset
4A St. Mary's
4A Talbot
4A Washington
4A Wicomico
4A Worcester

MASSACHUSETTS

SA (all)

MICHIGAN

6A Alcona
6A Alger
SA Allegan
6A Alpena
6A Antrim
6A Arenac
7 Baraga
SA Barry
SA Bay
6A Benzie
SA Berrien
SA Branch
SA Calhoun
SA Cass
6A Charlevoix
6A Cheboygan
7 Chippewa
6A Clare
SA Clinton
6A Crawford
6A Delta
6A Dickinson
SA Eaton
6AEmmet
SA Genesee
6A Gladwin
7 Gogebic
6A Grand Traverse
SA Gratiot
SA Hillsdale
7 Houghton
6A Huron
SA Ingham
SA Ionia
6A Iosco
7 Iron
6A Isabella
SA jackson
SA Kalamazoo
6A Kalkaska
SA Kent
7 Keweenaw
6A Lake
SA Lapeer
6A Leelanau
SA Lenawee
SA Livingston
7 Luce
7 Mackinac
SA Macomb
6A Manistee
6A Marquette
6A Mason
6A Mecosta
6A Menominee
SA Midland
6A Missaukee
SA Monroe
SA Montcalm

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

6A Montmorency
SA Muskegon
6A Newaygo
SA Oakland
6A Oceana
6A Ogemaw
7 Ontonagon
6A Osceola
6A Oscoda
6A Otsego
SA Ottawa
6A Presque Isle
6A Roscommon
SA Saginaw
6A Sanilac
7 Schoolcraft
SA Shiawassee
SA St. Clair
SA St. Joseph
SA Tuscola
SA Van Buren
SA Washtenaw
SA Wayne
6A Wexford

MINNESOTA

7 Aitkin
6A Anoka
7 Becker
7 Beltrami
6A Benton
6A Big Stone
6A Blue Earth
6A Brown
7 Carlton
6A Carver
7 Cass
6A Chippewa
6A Chisago
7 Clay
7 Clearwater
7 Cook
6A Cottonwood
7 Crow Wing
6A Dakota
6A Dodge
6A Douglas
6A Faribault
6A Fillmore
6A Freeborn
6A Goodhue
7 Grant
6A Hennepin
6A Houston
7 Hubbard
6A Isanti
7 Itasca
6AJackson
7 Kanabec
6A Kandiyohi
7 Kittson
7 Koochiching
6A Lac qui Parle
7 Lake
7 Lake of the Woods
6A Le Sueur
6A Lincoln
6A Lyon
7 Mahnomen
7 Marshall
6A Martin
6A McLeod
6A Meeker
7 Mille Lacs
6A Morrison
6AMower
6A Murray
6A Nicollet
6A Nobles
7 Norman
6A Olmsted
7 Otter Tail
7 Pennington
7 Pine
6A Pipestone
7 Polk
6A Pope
6A Ramsey
7 Red Lake
6A Redwood
6A Renville
6A Rice
6A Rock
7 Roseau
6A Scott
6A Sherburne
6A Sibley
6A Stearns
6A Steele
6A Stevens
7 St. Louis
6A Swift
6A Todd
6A Traverse
6A Wabasha
7 Wadena
6A Waseca
6A Washington
6A Watonwan
7 Wilkin
6A Winona
6A Wright
6A Yellow Medicine

MISSISSIPPI

3A Adams*
3A Alcorn
3A Amite*
3A Attala
3A Benton
3A Bolivar
3A Calhoun
3A Carroll
3A Chickasaw
3A Choctaw
3A Claiborne*
3A Clarke
3A Clay
3A Coahoma
3A Copiah*
3A Covington*
3A DeSoto
3A Forrest*
3A Franklin*
3A George*
3A Greene*
3A Grenada
2A Hancock*
2A Harrison*
3A Hinds*
3A Holmes
3A Humphreys
3A Issaquena
3A Itawamba
2A Jackson*
3A Jasper
3A Jefferson*
3A Jefferson Davis*
3A Jones*
3A Kemper
3A Lafayette
3A Lamar*
3A Lauderdale
3A Lawrence*
3A Leake
3A Lee
3A Leflore
3A Lincoln*
3A Lowndes
3A Madison
3A Marion*
3A Marshall
3A Monroe
3A Montgomery
3A Neshoba
3A Newton
3A Noxubee
3A Oktibbeha
3A Panola
2A Pearl River*
3A Perry*
3A Pike*
3A Pontotoc
3A Prentiss
3A Quitman
3A Rankin*
3A Scott
3A Sharkey
3A Simpson*
3A Smith*
2A Stone*
3A Sunflower
3A Tallahatchie
3A Tate
3A Tippah
3A Tishomingo
3A Tunica
3A Union
3A Walthall*
3A Warren*
3A Washington
3A Wayne*
3A Webster
3A Wilkinson*
3A Winston
3A Yalobusha
3A Yazoo

MISSOURI

SA Adair
SA Andrew
SA Atchison
4A Audrain
4A Barry

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS
BY STATE, COUNTY AND TERRITORY

4A Barton
4A Bates
4A Benton
4A Bollinger
4A Boone
SA Buchanan
4A Butler
SA Caldwell
4A Callaway
4A Camden
4A Cape Girardeau
4A Carroll
4A Carter
4A Cass
4A Cedar
SA Chariton
4A Christian
SA Clark
4A Clay
SA Clinton
4A Cole
4A Cooper
4A Crawford
4A Dade
4A Dallas
SA Daviess
SA DeKalb
4A Dent
4A Douglas
4A Dunklin
4A Franklin
4A Gasconade
SA Gentry
4A Greene
SA Grundy
SA Harrison
4A Henry
4A Hickory
SA Holt
4A Howard
4A Howell
4A Iron
4Ajackson
4A jasper
4A jefferson
4Ajohnson
SA Knox
4A Laclede
4A Lafayette
4A Lawrence
SA Lewis
4A Lincoln
SA Linn
SA Livingston
SA Macon
4A Madison
4A Maries
SA Marion
4A McDonald
SA Mercer
4A Miller
4A Mississippi
4A Moniteau
4A Monroe
4A Montgomery
4A Morgan
4A New Madrid
4A Newton
SA Nodaway
4A Oregon
4A Osage
4A Ozark
4A Pemiscot
4A Perry
4A Pettis
4A Phelps
SA Pike
4A Platte
4A Polk
4A Pulaski
SA Putnam
SA Ralls
4A Randolph
4ARay
4A Reynolds
4A Ripley
4A Saline
SA Schuyler
SA Scotland
4A Scott
4A Shannon
SA Shelby
4A St. Charles
4A St. Clair
4A Ste. Genevieve
4A St. Francois
4A St. Louis
4A St.Louis (city)
4A Stoddard
4A Stone
SA Sullivan
4A Taney
4A Texas
4A Vernon
4A Warren
4A Washington
4A Wayne
4A Webster
SA Worth
4A Wright

MONTANA

6B (all)

NEBRASKA

SA (all)

NEVADA

SB Carson City (city)
SB Churchill
3B Clark
SB Douglas
SB Elko
SB Esmeralda
SB Eureka
SB Humboldt
SB Lander
SB Lincoln
SB Lyon
SB Mineral
SB Nye
SB Pershing
SB Storey
SB Washoe
SB White Pine

NEW HAMPSHIRE

6A Belknap
6A Carroll
SA Cheshire
6A Coos
6A Grafton
SA Hillsborough
6A Merrimack
SA Rockingham
SA Strafford
6A Sullivan

NEW JERSEY

4A Atlantic
SA Bergen
4A Burlington
4A Camden
4A Cape May
4A Cumberland
4A Essex
4A Gloucester
4A Hudson
SA Hunterdon
SA Mercer
4A Middlesex
4A Monmouth
SA Morris
4A Ocean
SA Passaic
4A Salem
SA Somerset
SA Sussex
4A Union
SA Warren

NEW MEXICO

4B Bernalillo
SB Catron
3B Chaves
4B Cibola
SB Colfax
4B Curry
4B DeBaca
3B Dona Ana
3B Eddy
4B Grant
4B Guadalupe
SB Harding
3B Hidalgo
3B Lea
4B Lincoln
SB Los Alamos
3B Luna
SB McKinley
SB Mora
3B Otero
4B Quay
SB Rio Arriba
4B Roosevelt
SB Sandoval
SB San juan
SB San Miguel
SB Santa Fe
4B Sierra
4B Socorro
SB Taos
SB Torrance
4B Union
4B Valencia

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

NEW YORK
5A Albany
6A Allegany
4A Bronx
6A Broome
6A Cattaraugus
5A Cayuga
5A Chautauqua
5A Chemung
6A Chenango
6A Clinton
5A Columbia
5A Cortland
6A Delaware
5A Dutchess
5A Erie
6A Essex
6A Franklin
6A Fulton
5A Genesee
5A Greene
6A Hamilton
6A Herkimer
6A Jefferson
4A Kings
6A Lewis
5A Livingston
6A Madison
5A Monroe
6A Montgomery
4A Nassau
4A New York
5A Niagara
6A Oneida
5A Onondaga
5A Ontario
5A Orange
5A Orleans
5A Oswego
6A Otsego
5A Putnam
4A Queens
5A Rensselaer
4A Richmond
5A Rockland
5A Saratoga
5A Schenectady
6A Schoharie
6A Schuyler
5A Seneca
6A Steuben
6A St. Lawrence
4A Suffolk
6A Sullivan
5A Tioga
6A Tompkins
6A Ulster
6A Warren
5A Washington
5A Wayne
4A Westchester
6A Wyoming
5A Yates

NORTH CAROLINA
4A Alamance
4A Alexander
5A Alleghany
3A Anson
5A Ashe
5A Avery
3A Beaufort
4A Bertie
3A Bladen
3A Brunswick*
4A Buncombe
4A Burke
3A Cabarrus
4A Caldwell
3A Camden
3A Carteret*
4A Caswell
4A Catawba
4A Chatham
4A Cherokee
3A Chowan
4A Clay
4A Cleveland
3A Columbus*
3A Craven
3A Cumberland
3A Currituck
3A Dare
3A Davidson
4A Davie
3A Duplin
4A Durham
3A Edgecombe
4A Forsyth
4A Franklin
3A Gaston
4A Gates
4A Graham
4A Granville
3A Greene
4A Guilford
4A Halifax
4A Harnett
4A Haywood
4A Henderson
4A Hertford
3A Hoke
3A Hyde
4A Iredell
4A Jackson
3A Johnston
3AJones
4ALee
3A Lenoir
4A Lincoln
4A Macon
4A Madison
3A Martin
4A McDowell
3A Mecklenburg
5A Mitchell
3A Montgomery
3A Moore
4A Nash
3A New Hanover*
4A Northampton
3A Onslow*
4A Orange
3A Pamlico
3A Pasquotank
3A Pender*
3A Perquimans
4A Person
3A Pitt
4A Polk
3A Randolph
3A Richmond
3A Robeson
4A Rockingham
3A Rowan
4A Rutherford
3A Sampson
3A Scotland
3A Stanly
4A Stokes
4A Surry
4A Swain
4A Transylvania
3A Tyrrell
3A Union
4A Vance
4A Wake
4A Warren
3A Washington
5A Watauga
3A Wayne
4A Wilkes
3A Wilson
4A Yadkin
5A Yancey

NORTH DAKOTA
6A Adams
7 Barnes
7 Benson
6A Billings
7 Bottineau
6ABowman
7 Burke
6A Burleigh
7 Cass
7 Cavalier
6A Dickey
7 Divide
6A Dunn
7 Eddy
6A Emmons
7 Foster
6A Golden Valley
7 Grand Forks
6A Grant
7 Griggs
6A Hettinger
7 Kidder
6A LaMoure
6A Logan
7 McHenry
6A McIntosh
6A McKenzie
7 McLean
6A Mercer
6A Morton
7 Mountrail
7 Nelson
6A Oliver
7 Pembina
7 Pierce
7 Ramsey

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

6A Ransom
7 Renville
6A Richland
7 Rolette
6A Sargent
7 Sheridan
6A Sioux
6A Slope
6A Stark
7 Steele
7 Stutsman
7 Towner
7 Traill
7 Walsh
7 Ward
7 Wells
7 Williams

OHIO

4A Adams
5A Allen
5A Ashland
5A Ashtabula
5A Athens
5A Auglaize
5A Belmont
4A Brown
5A Butler
5A Carroll
5A Champaign
5A Clark
4A Clermont
5A Clinton
5A Columbiana
5A Coshocton
5A Crawford
5A Cuyahoga
5A Darke
5A Defiance
5A Delaware
5A Erie
5A Fairfield
5A Fayette
5A Franklin
5A Fulton
4A Gallia
5A Geauga
5A Greene
5A Guernsey
4A Hamilton
5A Hancock
5A Hardin
5A Harrison
5A Henry
5A Highland
5A Hocking
5A Holmes
5A Huron
5A Jackson
5A Jefferson
5A Knox
5A Lake
4A Lawrence
5A Licking
5A Logan
5A Lorain
5A Lucas
5A Madison
5A Mahoning
5A Marion
5A Medina
5A Meigs
5A Mercer
5A Miami
5A Monroe
5A Montgomery
5A Morgan
5A Morrow
5A Muskingum
5A Noble
5A Ottawa
5A Paulding
5A Perry
5A Pickaway
4A Pike
5A Portage
5A Preble
5A Putnam
5A Richland
5A Ross
5A Sandusky
4A Scioto
5A Seneca
5A Shelby
5A Stark
5A Summit
5A Trumbull
5A Tuscarawas
5A Union
5A Van Wert
5A Vinton
5A Warren
4A Washington
5A Wayne
5A Williams
5A Wood
5A Wyandot

OKLAHOMA

3A Adair
3A Alfalfa
3A Atoka
4B Beaver
3A Beckham
3A Blaine
3A Bryan
3A Caddo
3A Canadian
3A Carter
3A Cherokee
3A Choctaw
4B Cimarron
3A Cleveland
3A Coal
3A Comanche
3A Cotton
3A Craig
3A Creek
3A Custer
3A Delaware
3A Dewey
3A Ellis
3A Garfield
3A Garvin
3A Grady
3A Grant
3A Greer
3A Harmon
3A Harper
3A Haskell
3A Hughes
3A Jackson
3A Jefferson
3A Johnston
3AKay
3A Kingfisher
3A Kiowa
3A Latimer
3A Le Flore
3A Lincoln
3A Logan
3A Love
3A Major
3A Marshall
3A Mayes
3A McClain
3A McCurtain
3A McIntosh
3A Murray
3A Muskogee
3A Noble
3A Nowata
3A Okfuskee
3A Oklahoma
3A Okmulgee
3A Osage
3A Ottawa
3A Pawnee
3A Payne
3A Pittsburg
3A Pontotoc
3A Pottawatomie
3A Pushmataha
3A Roger Mills
3A Rogers
3A Seminole
3A Sequoyah
3A Stephens
4B Texas
3A Tillman
3A Tulsa
3A Wagoner
3A Washington
3A Washita
3A Woods
3A Woodward

OREGON

5B Baker
4C Benton
4C Clackamas
4C Clatsop
4C Columbia
4C Coos
5B Crook
4C Curry
5B Deschutes
4C Douglas
5B Gilliam
5B Grant
5B Harney
5B Hood River
4C Jackson
5B Jefferson
4C Josephine

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

SA Yankton
6A Ziebach

TENNESSEE

4A Anderson
4A Bedford
4A Benton
4A Bledsoe
4A Blount
4A Bradley
4A Campbell
4A Cannon
4A Carroll
4A Carter
4A Cheatham
3A Chester
4A Claiborne
4A Clay
4A Cocke
4A Coffee
3A Crockett
4A Cumberland
4A Davidson
4A Decatur
4A DeKalb
4A Dickson
3A Dyer
3A Fayette
4A Fentress
4A Franklin
4A Gibson
4A Giles
4A Grainger
4A Greene
4A Grundy
4A Hamblen
4A Hamilton
4A Hancock
3A Hardeman
3A Hardin
4A Hawkins
3A Haywood
3A Henderson
4A Henry
4A Hickman
4A Houston
4A Humphreys
4A jackson
4A jefferson
4Ajohnson
4A Knox
3A Lake
3A Lauderdale
4A Lawrence
4A Lewis
4A Lincoln
4A Loudon
4A Macon
3A Madison
4A Marion
4A Marshall
4A Maury
4A McMinn
3A McNairy
4A Meigs
4A Monroe
4A Montgomery
4A Moore
4A Morgan
4A Obion
4A Overton
4A Perry
4A Pickett
4A Polk
4A Putnam
4A Rhea
4A Roane
4A Robertson
4A Rutherford
4A Scott
4A Sequatchie
4A Sevier
3A Shelby
4A Smith
4A Stewart
4A Sullivan
4A Sumner
3A Tipton
4A Trousdale
4A Unicoi
4A Union
4A Van Buren
4A Warren
4A Washington
4A Wayne
4A Weakley
4A White
4A Williamson
4A Wilson

TEXAS

2A Anderson*
3B Andrews
2A Angelina*
2A Aransas*
3A Archer
4B Armstrong
2A Atascosa*
2A Austin*
4B Bailey
2B Bandera*
2A Bastrop*
3B Baylor
2A Bee*
2A Bell*
2A Bexar*
3A Blanco*
3B Borden
2A Bosque*
3A Bowie*
2A Brazoria*
2A Brazos*
3B Brewster
4B Briscoe
2A Brooks*
3A Brown*
2A Burleson*
3A Burnet*
2A Caldwell*
2A Calhoun*
3B Callahan
2A Cameron*
3A Camp*
4B Carson
3A Cass*
4B Castro
2A Chambers*
2A Cherokee*
3B Childress
3A Clay
4B Cochran
3B Coke
3B Coleman
3A Collin*
3B Collingsworth
2A Colorado*
2A Comal*
3A Comanche*
3B Concho
3A Cooke
2A Coryell*
3B Cottle
3B Crane
3B Crockett
3B Crosby
3B Culberson
4B Dallam
3A Dallas*
3B Dawson
4B Deaf Smith
3A Delta
3A Denton*
2A DeWitt*
3B Dickens
2B Dimmit*
4B Donley
2A Duval*
3A Eastland
3B Ector
2B Edwards*
3A Ellis*
3B El Paso
3A Erath*
2A Falls*
3A Fannin
2A Fayette*
3B Fisher
4B Floyd
3B Foard
2A Fort Bend*
3A Franklin*
2A Freestone*
2B Frio*
3B Gaines
2A Galveston*
3B Garza
3A Gillespie*
3B Glasscock
2A Goliad*
2A Gonzales*
4B Gray
3A Grayson
3A Gregg*
2A Grimes*
2A Guadalupe*
4B Hale
3B Hall
3A Hamilton*
4B Hansford
3B Hardeman
2A Hardin*
2A Harris*
3A Harrison*
4B Hartley
3B Haskell

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

2A Hays*
3B Hemphill
3A Henderson*
2A Hidalgo*
2A Hill*
4B Hockley
3A Hood*
3A Hopkins*
2A Houston*
3B Howard
3B Hudspeth
3A Hunt*
4B Hutchinson
3B Irion
3A Jack
2A Jackson*
2A Jasper*
3B Jeff Davis
2A Jefferson*
2AJim Hogg*
2A Jim Wells*
3A Johnson*
3B Jones
2A Karnes*
3A Kaufman*
3A Kendall*
2A Kenedy*
3B Kent
3B Kerr
3B Kimble
3B King
2B Kinney*
2A Kleberg*
3B Knox
3A Lamar*
4B Lamb
3A Lampasas*
2B La Salle*
2A Lavaca*
2A Lee*
2A Leon*
2A Liberty*
2A Limestone*
4B Lipscomb
2A Live Oak*
3A Llano*
3B Loving
3B Lubbock
3B Lynn
2A Madison*
3A Marion*
3B Martin
3B Mason
2A Matagorda*
2B Maverick*
3B McCulloch
2A McLennan*
2A McMullen*
2B Medina*
3B Menard
3B Midland
2A Milam*
3A Mills*
3B Mitchell
3A Montague
2A Montgomery*
4B Moore
3A Morris*
3B Motley
3A Nacogdoches*
3A Navarro*
2A Newton*
3B Nolan
2A Nueces*
4B Ochiltree
4B Oldham
2A Orange*
3A Palo Pinto*
3A Panola*
3A Parker*
4B Parmer
3B Pecos
2A Polk*
4B Potter
3B Presidio
3A Rains*
4B Randall
3B Reagan
2B Real*
3A Red River*
3B Reeves
2A Refugio*
4B Roberts
2A Robertson*
3A Rockwall*
3B Runnels
3A Rusk*
3A Sabine*
3A San Augustine*
2A San Jacinto*
2A San Patricio*
3A San Saba*
3B Schleicher
3B Scurry
3B Shackelford
3A Shelby*
4B Sherman
3A Smith*
3A Somervell*
2A Starr*
3A Stephens
3B Sterling
3B Stonewall
3B Sutton
4B Swisher
3A Tarrant*
3B Taylor
3B Terrell
3B Terry
3B Throckmorton
3A Titus*
3B Tom Green
2A Travis*
2A Trinity*
2A Tyler*
3A Upshur*
3B Upton
2B Uvalde*
2B Val Verde*
3A Van Zandt*
2A Victoria*
2A Walker*
2A Waller*
3B Ward
2A Washington*
2B Webb*
2A Wharton*
3B Wheeler
3A Wichita
3B Wilbarger
2A Willacy*
2A Williamson*
2A Wilson*
3B Winkler
3A Wise
3A Wood*
4B Yoakum
3A Young
2B Zapata*
2B Zavala*

UTAH

5B Beaver
6B Box Elder
6B Cache
6B Carbon
6B Daggett
5B Davis
6B Duchesne
5B Emery
5B Garfield
5B Grand
5B Iron
5B Juab
5B Kane
5B Millard
6B Morgan
5B Piute
6B Rich
5B Salt Lake
5B San Juan
5B Sanpete
5B Sevier
6B Summit
5B Tooele
6B Uintah
5B Utah
6B Wasatch
3B Washington
5B Wayne
5B Weber

VERMONT

6A (all)

VIRGINIA

4A (all)

WASHINGTON

5B Adams
5B Asotin
5B Benton
5B Chelan
4C Clallam
4C Clark
5B Columbia
4C Cowlitz
5B Douglas
6B Ferry
5B Franklin
5B Garfield
5B Grant
4C Grays Harbor
4C Island
4C Jefferson
4C King
4C Kitsap

(continued)

TABLE 301.1-continued
CLIMATE ZONES, MOISTURE REGIMES, AND WARM-HUMID DESIGNATIONS BY STATE, COUNTY AND TERRITORY

SB Kittitas
SB Klickitat
4C Lewis
SB Lincoln
4C Mason
6B Okanogan
4C Pacific
6B Pend Oreille
4C Pierce
4C San Juan
4C Skagit
SB Skamania
4C Snohomish
SB Spokane
6B Stevens
4C Thurston
4C Wahkiakum
SB Walla Walla
4C Whatcom
SB Whitman
SB Yakima

WEST VIRGINIA

SA Barbour
4A Berkeley
4A Boone
4A Braxton
SA Brooke
4A Cabell
4A Calhoun
4A Clay
SA Doddridge
SA Fayette
4A Gilmer
SA Grant
SA Greenbrier
SA Hampshire
SA Hancock
SA Hardy
SA Harrison
4A Jackson
4A Jefferson
4A Kanawha
SA Lewis
4A Lincoln
4A Logan
SA Marion
SA Marshall
4A Mason
4A McDowell
4A Mercer
SA Mineral
4A Mingo
SA Monongalia
4A Monroe
4A Morgan
SA Nicholas
SA Ohio
SA Pendleton
4A Pleasants
SA Pocahontas
SA Preston
4A Putnam
SA Raleigh
SA Randolph
4A Ritchie
4A Roane
SA Summers
SA Taylor
SA Tucker
4A Tyler
SA Upshur
4A Wayne
SA Webster
SA Wetzel
4A Wirt
4A Wood
4A Wyoming

WISCONSIN

6AAdams
7 Ashland
6A Barron
7 Bayfield
6A Brown
6A Buffalo
7 Burnett
6A Calumet
6A Chippewa
6A Clark
6A Columbia
6A Crawford
6A Dane
6A Dodge
6A Door
7 Douglas
6A Dunn
6A Eau Claire
7 Florence
6A Fond du Lac
7 Forest
6A Grant
6A Green
6A Green Lake
6A Iowa
7 Iron
6A Jackson
6A Jefferson
6AJuneau
6A Kenosha
6A Kewaunee
6A La Crosse
6A Lafayette
7 Langlade
7 Lincoln
6A Manitowoc
6A Marathon
6A Marinette
6A Marquette
6A Menominee
6A Milwaukee
6A Monroe
6A Oconto
7 Oneida
6A Outagamie
6A Ozaukee
6A Pepin
6A Pierce
6A Polk
6A Portage
7 Price
6A Racine
6A Richland
6A Rock
6A Rusk
6A Sauk
7 Sawyer
6A Shawano
6A Sheboygan
6A St. Croix
7 Taylor
6A Trempealeau
6A Vernon
7 Vilas
6A Walworth
7 Washburn
6A Washington
6A Waukesha
6A Waupaca
6A Waushara
6A Winnebago
6A Wood

WYOMING

6B Albany
6B Big Horn
6B Campbell
6B Carbon
6B Converse
6B Crook
6B Fremont
SB Goshen
6B Hot Springs
6B Johnson
6B Laramie
7 Lincoln
6B Natrona
6B Niobrara
6B Park
SB Platte
6B Sheridan
7 Sublette
6B Sweetwater
7 Teton
6B Uinta
6B Washakie
6B Weston

US TERRITORIES

AMERICAN SAMOA

1A (all)*

GUAM

1A (all)*

NORTHERN MARIANA ISLANDS

1A (all)*

PUERTO RICO

1A (all)*

VIRGIN ISLANDS

1A (all)*

TABLE 301.3(1)
INTERNATIONAL CLIMATE ZONE DEFINITIONS

MAJOR CLIMATE TYPE DEFINITIONS
Warm-humid Definition-Moist (A) locations where either of the following wet-bulb temperature conditions shall occur during the warmest six consecutive months of the year: *1.* *67°P* (19.4°C) or higher for 3,000 or more hours; or *2.* *73°P* (22.8°C) or higher for 1,500 or more hours
Dry (B) Definition-Locations meeting the following criteria: Not marine and $P_{in} < 0.44 \times (TF - 19.5)$ $[P_{cm} < 2.0 \times (TC + 7)$ in 51 units] where: P_{in} = Annual precipitation in inches (em) T = Annual mean temperature in of (OC)
Moist (A) Definition-Locations that are not marine and not dry.

For 51: °C = [(OF)-32]/1.8; 1 inch = 2.54 cm.

TABLE 301.3(2)
INTERNATIONAL CLIMATE ZONE DEFINITIONS

ZONE NUMBER	THERMAL CRITERIA	
	IP Units	51 Units
1	9000 < CDD500P	5000 < CDD10°C
2	6300 < CDD500P ≤ 9000	3500 < CDD10°C ≤ 5000
3A and 3B	4500 < CDD500P ≤ 6300 AND HDD65°P ≤ 5400	2500 < CDD 10°C ≤ 3500 AND HDD18°C ≤ 3000
4A and 4B	CDD500P ≤ 4500 AND HDD65°P ≤ 5400	CDD10°C ≤ 2500 AND HDD18°C ≤ 3000
3C	HDD65°P ≤ 3600	HDD18°C ≤ 2000
4C	3600 < HDD65°P ≤ 5400	2000 < HDD18°C ≤ 3000
5	5400 < HDD65°P ≤ 7200	3000 < HDD18°C ≤ 4000
6	7200 < HDD65°P ≤ 9000	4000 < HDD18°C ≤ 5000
7	9000 < HDD65°P ≤ 12600	5000 < HDD18°C ≤ 7000
8	12600 < HDD65°P	7000 < HDD18°C

For 51: °C = [(OF)-32]/1.8

SECTION 302
DESIGN CONDITIONS

302.1 Interior design conditions. The interior design temperatures used for heating and cooling load calculations shall be a maximum of 72°F (22°C) for heating and minimum of 75°F (24°C) for cooling.

SECTION 303
MATERIALS, SYSTEMS AND EQUIPMENT

303.1 Identification. Materials, systems and equipment shall be identified in a manner that will allow a determination of compliance with the applicable provisions of this code.

303.1.1 Building thermal envelope insulation. An R-value identification mark shall be applied by the manufacturer to each piece of *bUilding thermal envelope* insulation 12 inches (305 mm) or greater in width. Alternately, the insulation installers shall provide a certification listing the type, manufacturer and R-value of insulation installed in each element of the *bUilding thermal envelope.* For blown or sprayed insulation (fiberglass and cellulose), the initial installed thickness, settled thickness, settled R-value, installed density, coverage area and number of bags installed shall be *listed* on the certification. For sprayed polyurethane foam (SPF) insulation, the installed thickness of the areas covered and *R*-value of installed thickness shall be *listed* on the certification. The insulation installer shall sign, date and post the certification in a conspicuous location on the job site.

303.1.1.1 Blown or sprayed roof/ceiling insulation. The thickness of blown-in or sprayed roof/ceiling insulation (fiberglass or cellulose) shall be written in inches (mm) on markers that are installed at least one for every 300 square feet (28 m^2) throughout the attic space. The markers shall be affixed to the trusses or joists and marked with the minimum initial installed thickness with numbers a minimum of 1 inch (25 mm) in height. Each

marker shall face the attic access opening. Spray polyurethane foam thickness and installed *R*-value shall be *listed* on certification provided by the insulation installer.

303.1.2 Insulation mark installation. Insulating materials shall be installed such that the manufacturer's R-value mark is readily observable upon inspection.

303.1.3 Fenestration product rating. V-factors of fenestration products (windows, doors and skylights) shall be determined in accordance with NFRC 100 by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking such a labeled V-factor shall be assigned a default V-factor from Table 303.1.3(1) or 303.1.3(2). The solar heat gain coefficient (SHGC) of glazed fenestration products (windows, glazed doors and skylights) shall be determined in accordance with NFRC 200 by an accredited, independent laboratory, and labeled and certified by the manufacturer. Products lacking such a labeled SHGC shall be assigned a default SHGC from Table 303.1.3(3).

TABLE 303.1.3(1)
DEFAULT GLAZED FENESTRATION U-FACTOR

FRAME TYPE	SINGLE PANE	DOUBLE PANE	SKYLIGHT	
			Single	Double
Metal	1.20	0.80	2.00	1.30
Metal with Thermal Break	1.10	0.65	1.90	1.10
Nonmetal or Metal Clad	0.95	0.55	1.75	1.05
Glazed Block	0.60			

TABLE 303.1.3(2)
DEFAULT DOOR U-FACTORS

DOOR TYPE	U-FACTOR
Uninsulated Metal	1.20
Insulated Metal	0.60
Wood	0.50
Insulated, nonmetal edge, max 45% glazing, any glazing double pane	0.35

TABLE 303.1.3(3)
DEFAULT GLAZED FENESTRATION SHGC

SINGLE GLAZED		DOUBLE GLAZED		GLAZED BLOCK
Clear	Tinted	Clear	Tinted	
0.8	0.7	0.7	0.6	0.6

303.1.4 Insulation product rating. The thermal resistance (R-value) of insulation shall be determined in accordance with the U.S. Federal Trade Commission R-value rule (CFR Title 16, Part 460, May 31,2005) in units ofh x ft2 x of/Btu at a mean temperature of 75°F (24°C).

303.2 Installation. All materials, systems and equipment shall be installed in accordance with the manufacturer's installation instructions and the *International Building Code.*

303.2.1 Protection of exposed foundation insulation. Insulation applied to the exterior of basement walls, crawlspace walls and the perimeter of slab-on-grade floors shall have a rigid, opaque and weather-resistant protective covering to prevent the degradation of the insulation's thermal performance. The protective covering shall cover the exposed exterior insulation and extend a minimum of 6 inches (153 mm) below grade.

303.3 Maintenance information. Maintenance instructions shall be furnished for equipment and systems that require preventive maintenance. Required regular maintenance actions shall be clearly stated and incorporated on a readily accessible label. The label shall include the title or publication number for the operation and maintenance manual for that particular model and type of product.

TABLE 402.1.3
EQUIVALENT U-FACTORSa

CLIMATE ZONE	FENESTRATION U-FACTOR	SKYLIGHT U-FACTOR	CEILING U-FACTOR	FRAME WALL U-FACTOR	MASS WALL U-FACTOR[b]	FLOOR U-FACTOR	BASEMENT WALL U-FACTOR[d]	CRAWL SPACE WALL U-FACTOR[c]
1	1.20	0.75	0.035	0.082	0.197	0.064	0.360	0.477
2	0.65	0.75	0.035	0.082	0.165	0.064	0.360	0.477
3	0.50	0.65	0.035	0.082	0.141	0.047	0.091 c	0.136
4 except Marine	0.35	0.60	0.030	0.082	0.141	0.047	0.059	0.065
5 and Marine 4	0.35	0.60	0.030	0.057	0.082	0.033	0.059	0.065
6	0.35	0.60	0.026	0.057	0.060	0.033	0.050	0.065
7 and 8	0.35	0.60	0.026	0.057	0.057	0.028	0.050	0.065

a. Nonfenestration Ufactors shall be obtained from measurement, calculation or an approved source.

b. When more than halfthe insulation is on the interior, the mass wall Ufactors shall be a maximum of0.17 in Zone 1, 0.14 in Zone 2, 0.12 in Zone 3, 0.10 in Zone 4 except Marine, and the same as the frame wall Ufactor in Marine Zone 4 and Zones 5 through 8.

c. Basement wall Ufactor of 0.360 in warm-humid locations as defined by Figure 301.1 and Table 301.2.

d. Foundation Ufactor requirements shown in Table 402.1.3 include wall construction and interior air films but exclude soil conductivity and exterior air films. Ufactors for determining code compliance in accordance with Section 402.1.4 (total *VA* alternative) of Section 405 (Simulated Performance Alternative) shall be modified to include soil conductivity and exterior air films.

402.1.3 V-factor alternative. An assembly with a V-factor equal to or less than that specified in Table 402.1.3 shall be permitted as an alternative to the R-value in Table 402.1.1.

402.1.4 Total *VA* alternative. If the total *building thermal envelope VA* (sum of V-factor times assembly area) is less than or equal to the total *VA* resulting from using the *V-factors* in Table 402.1.3 (multiplied by the same assembly area as in the proposed building), the building shall be considered in compliance with Table 402.1.1. The *VA* calculation shall be done using a method consistent with the ASHRAE *Handbook of Fundamentals* and shall include the thermal bridging effects of framing materials. The SHGC requirements shall be met in addition to *VA* compliance.

402.2 Specific insulation requirements (Prescriptive).

402.2.1 Ceilings with attic spaces. When Section 402.1.1 would require R-38 in the ceiling, R-30 shall be deemed to satisfy the requirement for R-38 wherever the full height of uncompressed R-30 insulation extends over the wall top plate at the eaves. Similarly, R-38 shall be deemed to satisfy the requirement for R-49 wherever the full height of uncompressed R-38 insulation extends over the wall top plate at the eaves. This reduction shall not apply to the V-factor alternative approach in Section 402.1.3 and the total *VA* alternative in Section 402.1.4.

402.2.2 Ceilings without attic spaces. Where Section 402.1.1 would require insulation levels above R-30 and the design of the roof/ceiling assembly does not allow sufficient space for the required insulation, the minimum required insulation for such roof/ceiling assemblies shall be R-30. This reduction of insulation from the requirements of Section 402.1.1 shall be limited to 500 square feet (46 m^2) or 20 percent of the total insulated ceiling area, whichever is less. This reduction shall not apply to the V-factor alternative approach in Section 402.1.3 and the total *VA* alternative in Section 402.1.4.

402.2.3 Access hatches and doors. Access doors from conditioned spaces to unconditioned spaces (e.g., attics and crawl spaces) shall be weatherstripped and insulated to a level equivalent to the insulation on the surrounding surfaces. Access shall be provided to all equipment that prevents damaging or compressing the insulation. A wood framed or equivalent baffle or retainer is required to be provided when loose fill insulation is installed, the purpose of which is to prevent the loose fill insulation from spilling into the living space when the attic access is opened, and to provide a permanent means of maintaining the installed R-value of the loose fill insulation.

402.2.4 Mass walls. Mass walls for the purposes of this chapter shall be considered above-grade walls of concrete block, concrete, insulated concrete form (ICF), masonry cavity, brick (other than brick veneer), earth (adobe, compressed earth block, rammed earth) and solid timber/logs.

402.2.5 Steel-frame ceilings, walls, and floors. Steel-frame ceilings, walls and floors shall meet the insulation requirements of Table 402.2.5 or shall meet the V-factor requirements in Table 402.1.3. The calculation of the *V-factor* for a steel-frame envelope assembly shall use a series-parallel path calculation method.

Exception: In Climate Zones 1 and 2, the continuous insulation requirements in Table 402.2.4 shall be permitted to be reduced to R-3 for steel frame wall assemblies with studs spaced at 24 inches (610 mm) on center.

TABLE 402.2.5
STEEL-FRAME CEILING, WALL AND FLOOR INSULATION (R-VALUE)

WOOD FRAME R-VALUE REQUIREMENT	COLD-FORMED STEEL EQUIVALENT R-VALUE[a]
Steel Truss Ceilings[b]	
R-30	R-38 or R-30 + 3 or R-26 + 5
R-38	R-49 or R-38 + 3
R-49	R-38 + 5
Steel Joist Ceilings[b]	
R-30	R-38 in 2 x 4 or 2 x 6 or 2 x 8 R-49 in any framing
R-38	R-49 in 2 x 4 or 2 x 6 or 2 x 8 or 2 x 10
Steel-Framed Wall	
R-13	R-13 + 5 or R-15 + 4 or R-21 + 3 or R-O + 10
R-19	R-13 + 9 orR-19 + 8 orR-25 + 7
R-21	R-13 + 10 or R-19 + 9 or R-25 + 8
Steel Joist Floor	
R-13	R-19 in 2 x 6 R-19 + 6 in 2 x 8 or 2 x 10
R-19	R-19 + 6 in 2 x 6 R-19 + 12 in 2 x 8 or 2 x 10

a. Cavity insulation *R*-value is listed first, followed by continuous insulation R-value.
b. Insulation exceeding the height of the framing shall cover the framing.

402.2.6 Floors. Floor insulation shall be installed to maintain permanent contact with the underside of the subfloor decking.

402.2.7 Basement walls. Walls associated with conditioned basements shall be insulated from the top of the *basement wall* down to 10 feet (3048 mm) below grade or to the basement floor, whichever is less. Walls associated with unconditioned basements shall meet this requirement unless the floor overhead is insulated in accordance with Sections 402.1.1 and 402.2.6.

402.2.8 Slab-on-grade floors. Slab-on-grade floors with a floor surface less than 12 inches (305 mm) below grade shall be insulated in accordance with Table 402.1.1. The insulation shall extend downward from the top of the slab on the outside or inside of the foundation wall. Insulation located below grade shall be extended the distance provided in Table 402.1.1 by any combination of vertical insulation, insulation extending under the slab or insulation extending out from the building. Insulation extending away from the building shall be protected by pavement or by a minimum of 10 inches (254 mm) of soil. The top edge of the insulation installed between the *exterior wall* and the edge of the interior slab shall be permitted to be cut at a 45-degree (0.79 rad) angle away from the *exterior wall.* Slab-edge insulation is not required in jurisdictions designated by the *code official* as having a very heavy termite infestation.

402.2.9 Crawl space walls. As an alternative to insulating floors over crawl spaces, crawl space walls shall be permitted to be insulated when the crawl space is not vented to the outside. Crawl space wall insulation shall be permanently fastened to the wall and extend downward from the floor to the finished grade level and then vertically and/or horizontally for at least an additional 24 inches (610 mm). Exposed earth in unvented crawl space foundations shall be covered with a continuous Class I vapor retarder. All joints of the vapor retarder shall overlap by 6 inches (153 mm) and be sealed or taped. The edges of the vapor retarder shall extend at least 6 inches (153 mm) up the stem wall and shall be attached to the stem wall.

402.2.10 Masonry veneer. Insulation shall not be required on the horizontal portion of the foundation that supports a masonry veneer.

402.2.11 Thermally isolated sunroom insulation. The minimum ceiling insulation R-values shall be R-19 in Zones 1 through 4 and R-24 in Zones 5 through 8. The minimum wall R-value shall be R-13 in all zones. New wall(s) separating a sunroom from *conditioned space* shall meet the *building thermal envelope* requirements.

402.3 Fenestration. (Prescriptive).

402.3.1 V-factor. An area-weighted average of fenestration products shall be permitted to satisfy the *U*-factor requirements.

402.3.2 Glazed fenestration SHGC. An area-weighted average of fenestration products more than 50 percent glazed shall be permitted to satisfy the SHGC requirements.

402.3.3 Glazed fenestration exemption. Up to 15 square feet (1.4 m^2) of glazed fenestration per dwelling unit shall be permitted to be exempt from *U*-factor and SHGC requirements in Section 402.1.1. This exemption shall not apply to the *U-factor* alternative approach in Section 402.1.3 and the Total UA alternative in Section 402.1.4.

402.3.4 Opaque door exemption. One side-hinged opaque door assembly up to 24 square feet (2.22 m^2) in area is exempted from the *U*-factor requirement in Section 402.1.1. This exemption shall not apply to the *U*-factor alternative approach in Section 402.1.3 and the total UA alternative in Section 402.1.4.

402.3.5 Thermally isolated sunroom V-factor. For Zones 4 through 8, the maximum fenestration *U*-factor shall be 0.50 and the maximum skylight *U-factor* shall be 0.75. New windows and doors separating the sunroom from *conditioned space* shall meet the *building thermal envelope* requirements.

402.3.6 Replacement fenestration. Where some or all of an existing fenestration unit is replaced with a new fenestration product, including sash and glazing, the replacement fenestration unit shall meet the applicable requirements for *U-factor* and SHGC in Table 402.1.1.

402.4 Air leakage (Mandatory).

402.4.1 Building thermal envelope. The *building thermal envelope* shall be durably sealed to limit infiltration. The sealing methods between dissimilar materials shall allow for differential expansion and contraction. The following shall be caulked, gasketed, weatherstripped or otherwise sealed with an air barrier material, suitable film or solid material:

1. All joints, seams and penetrations.

2. Site-built windows, doors and skylights.
3. Openings between window and door assemblies and their respective jambs and framing.
4. Utility penetrations.
5. Dropped ceilings or chases adjacent to the thermal envelope.
6. Knee walls.
7. Walls and ceilings separating a garage from conditioned spaces.
8. Behind tubs and showers on exterior walls.
9. Common walls between dwelling units.
10. Attic access openings.
11. Rim joist junction.
12. Other sources of infiltration.

402.4.2 Air sealing and insulation. Building envelope air tightness and insulation installation shall be demonstrated to comply with one of the following options given by Section 402.4.2.1 or 402.4.2.2:

402.4.2.1 Testing option. Building envelope tightness and insulation installation shall be considered acceptable when tested air leakage is less than seven air changes per hour (ACH) when tested with a blower door at a pressure of 33.5 psf (50 Pa). Testing shall occur after rough in and after installation of penetrations of the building envelope, including penetrations for utilities, plumbing, electrical, ventilation and combustion appliances.

During testing:

1. Exterior windows and doors, fireplace and stove doors shall be closed, but not sealed;
2. Dampers shall be closed, but not sealed, including exhaust, intake, makeup air, backdraft and flue dampers;
3. Interior doors shall be open;
4. Exterior openings for continuous ventilation systems and heat recovery ventilators shall be closed and sealed;
5. Heating and cooling system(s) shall be turned off;
6. HVAC ducts shall not be sealed; and
7. Supply and return registers shall not be sealed.

402.4.2.2 Visual inspection option. Building envelope tightness and insulation installation shall be considered acceptable when the items listed in Table 402.4.2, applicable to the method of construction, are field verified. Where required by the *code official,* an *approved* party independent from the installer of the insulation shall inspect the air barrier and insulation.

402.4.3 Fireplaces. New wood-burning fireplaces shall have gasketed doors and outdoor combustion air.

402.4.4 Fenestration air leakage. Windows, skylights and sliding glass doors shall have an air infiltration rate of no more than 0.3 cfm per square foot (1.5 *L/s/m²*), and swinging doors no more than 0.5 cfm per square foot (2.6 *L/s/m²*), when tested according to NFRC 400 or *AAMA/WDMA/CSA 101/I.S.2/A440* by an accredited, independent laboratory and *listed* and *labeled* by the manufacturer.

Exceptions: Site-built windows, skylights and doors.

402.4.5 Recessed lighting. Recessed luminaires installed in the *building thermal envelope* shall be sealed to limit air leakage between conditioned and unconditioned spaces. All recessed luminaires shall be IC-rated and *labeled* as meeting ASTM E 283 when tested at 1.57 psf (75 Pa) pressure differential with no more than 2.0 cfm (0.944 *L/s*) of air movement from the *conditioned space* to the ceiling cavity. All recessed luminaires shall be sealed with a gasket or caulk between the housing and the interior wall or ceiling covering.

402.5 Maximum fenestration U-factor and SHGC (Mandatory). The area-weighted average maximum fenestration U-factor permitted using trade-offs from Section 402.1.4 or 404 shall be 0.48 in Zones 4 and 5 and 0.40 in Zones 6 through 8 for vertical fenestration, and 0.75 in Zones 4 through 8 for skylights. The area-weighted average maximum fenestration SHGC permitted using trade-offs from Section 405 in Zones 1 through 3 shall be 0.50.

SECTION 403
SYSTEMS

403.1 Controls (Mandatory). At least one thermostat shall be provided for each separate heating and cooling system.

403.1.1 Programmable thermostat. Where the primary heating system is a forced-air furnace, at least one thermostat per dwelling unit shall be capable of controlling the heating and cooling system on a daily schedule to maintain different temperature set points at different times of the day. This thermostat shall include the capability to set back or temporarily operate the system to maintain zone temperatures down to 55°F (13°C) or up to 85°F (29°C). The thermostat shall initially be programmed with a heating temperature set point no higher than 70°F (21°C) and a cooling temperature set point no lower than 78°F (26°C).

403.1.2 Heat pump supplementary heat (Mandatory). Heat pumps having supplementary electric-resistance heat shall have controls that, except during defrost, prevent supplemental heat operation when the heat pump compressor can meet the heating load.

403.2 Ducts.

403.2.1 Insulation (Prescriptive). Supply ducts in attics shall be insulated to a minimum of R-8. All other ducts shall be insulated to a minimum of R-6.

Exception: Ducts or portions thereof located completely inside the *building thermal envelope.*

403.2.2 Sealing (Mandatory). All ducts, air handlers, filter boxes and building cavities used as ducts shall be sealed.

Joints and seams shall comply with Section M1601.4.1 of the *International Residential Code.*

Duct tightness shall be verified by either of the following:

1. Postconstruction test: Leakage to outdoors shall be less than or equal to 8 cfm (226.5 L/min) per 100 ft^2 (9.29 m^2) of *conditioned floor area* or a total leakage less than or equal to 12 cfm (12 L/min) per 100 ft^2 (9.29 m^2) of *conditioned floor area* when tested at a pressure differential of 0.1 inches w.g. (25 Pa) across the entire system, including the manufacturer's air handler enclosure. All register boots shall be taped or otherwise sealed during the test.
2. Rough-in test: Total leakage shall be less than or equal to 6 cfm (169.9 L/min) per 100 ft^2 (9.29 m^2) of *conditioned floor area* when tested at a pressure differential of 0.1 inches w.g. (25 Pa) across the roughed in system, including the manufacturer's air handler enclosure. All register boots shall be taped or otherwise sealed during the test. If the air handler is not installed at the time of the test, total leakage shall be less than or equal to 4 cfm (113.3 L/min) per 100 ft^2 (9.29 m^2) of *conditioned floor area.*

Exceptions: Duct tightness test is not required if the air handler and all ducts are located within *conditioned space.*

TABLE 402.4.2
AIR BARRIER AND INSULATION INSPECTION COMPONENT CRITERIA

COMPONENT	CRITERIA
Air barrier and thermal barrier	Exterior thermal envelope insulation for framed walls is installed in substantial contact and continuous alignment with building envelope air barrier. Breaks or joints in the air barrier are filled or repaired. Air-permeable insulation is not used as a sealing material. Air-permeable insulation is inside of an air barrier.
Ceiling/attic	Air barrier in any dropped ceiling/soffit is substantially aligned with insulation and any gaps are sealed. Attic access (except unvented attic), knee wall door, or drop down stair is sealed.
Walls	Corners and headers are insulated. Junction of foundation and sill plate is sealed.
Windows and doors	Space between window/door jambs and framing is sealed.
Rim joists	Rim joists are insulated and include an air barrier.
Floors (including above-garage and cantilevered floors)	Insulation is installed to maintain permanent contact with underside of subfloor decking. Air barrier is installed at any exposed edge of insulation.
Crawl space walls	Insulation is permanently attached to walls. Exposed earth in unvented crawl spaces is covered with Class I vapor retarder with overlapping joints taped.
Shafts, penetrations	Duct shafts, utility penetrations, knee walls and flue shafts opening to exterior or unconditioned space are sealed.
Narrow cavities	Batts in narrow cavities are cut to fit, or narrow cavities are filled by sprayed/blown insulation.
Garage separation	Air sealing is provided between the garage and conditioned spaces.
Recessed lighting	Recessed light fixtures are air tight, IC rated, and sealed to drywall. Exception-fixtures in conditioned space.
Plumbing and wiring	Insulation is placed between outside and pipes. Batt insulation is cut to fit around wiring and plumbing, or sprayed/blown insulation extends behind piping and wiring.
Shower/tub on exterior wall	Showers and tubs on exterior walls have insulation and an air barrier separating them from the exterior wall.
Electrical/phone box on exterior walls	Air barrier extends behind boxes or air sealed-type boxes are installed.
Common wall	Air barrier is installed in common wall between dwelling units.
HVAC register boots	HVAC register boots that penetrate building envelope are sealed to subfloor or drywall.
Fireplace	Fireplace walls include an air barrier.

403.2.3 Building cavities (Mandatory). Building framing cavities shall not be used as supply ducts.

403.3 Mechanical system piping insulation (Mandatory). Mechanical system piping capable of carrying fluids above 105°F (41°C) or below 55°F (13°C) shall be insulated to a minimum ofR-3.

403.4 Circulating hot water systems (Mandatory). All circulating service hot water piping shall be insulated to at least R-2. Circulating hot water systems shall include an automatic or readily *accessible* manual switch that can turn off the hot-water circulating pump when the system is not in use.

403.5 Mechanical ventilation (Mandatory). Outdoor air intakes and exhausts shall have automatic or gravity dampers that close when the ventilation system is not operating.

403.6 Equipment sizing (Mandatory). Heating and cooling equipment shall be sized in accordance with Section M1401.3 of the *International Residential Code*.

403.7 Systems serving multiple dwelling units (Mandatory). Systems serving multiple dwelling units shall comply with Sections 503 and 504 in lieu of Section 403.

403.8 Snow melt system controls (Mandatory). Snow- and ice-melting systems, supplied through energy service to the building, shall include automatic controls capable of shutting off the system when the pavement temperature is above 50°F, and no precipitation is falling and an automatic or manual control that will allow shutoff when the outdoor temperature is above 40°F.

403.9 Pools (Mandatory). Pools shall be provided with energy-conserving measures in accordance with Sections 403.9.1 through 403.9.3.

403.9.1 Pool heaters. All pool heaters shall be equipped with a readily *accessible* on-off switch to allow shutting off the heater without adjusting the thermostat setting. Pool heaters fired by natural gas shall not have continuously burning pilot lights.

403.9.2 Time switches. Time switches that can automatically turn off and on heaters and pumps according to a preset schedule shall be installed on swimming pool heaters and pumps.

Exceptions:

1. Where public health standards require 24-hour pump operation.
2. Where pumps are required to operate solar- and waste-heat-recovery pool heating systems.

403.9.3 Pool covers. Heated pools shall be equipped with a vapor-retardant pool cover on or at the water surface. Pools heated to more than 90°F (32°C) shall have a pool cover with a minimum insulation value of R-12.

Exception: Pools deriving over 60 percent of the energy for heating from site-recovered energy or solar energy source.

SECTION 404
ELECTRICAL POWER AND LIGHTING SYSTEMS

404.1 Lighting equipment (Prescriptive). A minimum of 50 percent of the lamps in permanently installed lighting fixtures shall be high-efficacy lamps.

SECTION 405
SIMULATED PERFORMANCE ALTERNATIVE
(Performance)

405.1 Scope. This section establishes criteria for compliance using simulated energy performance analysis. Such analysis shall include heating, cooling, and service water heating energy only.

405.2 Mandatory requirements. Compliance with this section requires that the mandatory provisions identified in Section 401.2 be met. All supply and return ducts not completely inside the *building thermal envelope* shall be insulated to a minimum of R-6.

405.3 Performance-based compliance. Compliance based on simulated energy performance requires that a proposed residence *(proposed design)* be shown to have an annual energy cost that is less than or equal to the annual energy cost of the *standard reference design*. Energy prices shall be taken from a source *approved by* the *code official*, such as the Department of Energy, Energy Information Administration's *State Energy Price and Expenditure Report*. *Code officials* shall be permitted to require time-of-use pricing in energy cost calculations.

Exception: The energy use based on source energy expressed in Btu or Btu per square foot of *conditioned floor area* shall be permitted to be substituted for the energy cost. The source energy multiplier for electricity shall be 3.16. The source energy multiplier for fuels other than electricity shall be 1.1.

405.4 Documentation.

405.4.1 Compliance software tools. Documentation verifying that the methods and accuracy of the compliance software tools conform to the provisions of this section shall be provided to the *code official*.

405.4.2 Compliance report. Compliance software tools shall generate a report that documents that the *proposed design* complies with Section 405.3. The compliance documentation shall include the following information:

1. Address or other identification of the residence;
2. An inspection checklist documenting the building component characteristics of the *proposed design* as listed in Table 405.5.2(1). The inspection checklist shall show results for both the *standard reference design* and the *proposed design*, and shall document all inputs entered by the user necessary to reproduce the results;
3. Name of individual completing the compliance report; and

4. Name and version of the compliance software tool.

   Exception: Multiple orientations. When an otherwise identical building model is offered in multiple orientations, compliance for any orientation shall be permitted by documenting that the building meets the performance requirements in each of the four cardinal (north, east, south and west) orientations.

405.4.3 Additional documentation. The *code official* shall be permitted to require the following documents:

1. Documentation of the building component characteristics of the *standard reference design.*
2. A certification signed by the builder providing the building component characteristics of the *proposed design* as given in Table 405.5.2(1).
3. Documentation of the actual values used in the software calculations for the *proposed design.*

405.5 Calculation procedure.

405.5.1 General. Except as specified by this section, the *standard reference design* and *proposed design* shall be configured and analyzed using identical methods and techniques.

405.5.2 Residence specifications. The *standard reference design* and *proposed design* shall be configured and analyzed as specified by Table 405.5.2(1). Table 405.5.2(1) shall include by reference all notes contained in Table 402.1.1.

405.6 Calculation software tools.

405.6.1 Minimum capabilities. Calculation procedures used to comply with this section shall be software tools capable of calculating the annual energy consumption of all building elements that differ between the *standard reference design* and the *proposed design* and shall include the following capabilities:

1. Computer generation of the *standard reference design* using only the input for the *proposed design.* The calculation procedure shall not allow the user to directly modify the building component characteristics of the *standard reference design.*
2. Calculation of whole-building (as a single *zone)* sizing for the heating and cooling equipment in the *standard reference design* residence in accordance with Section M1401.3 of the *International Residential Code.*
3. Calculations that account for the effects of indoor and outdoor temperatures and part-load ratios on the performance of heating, ventilating and air-conditioning equipment based on climate and equipment sizing.
4. Printed *code official* inspection checklist listing each of the *proposed design* component characteristics from Table 405.5.2(1) determined by the analysis to provide compliance, along with their respective performance ratings (e.g., R-value, V-factor, SHGC, HSPF, AFUE, SEER, EF, etc.).

405.6.2 Specific approval. Performance analysis tools meeting the applicable sections of Section 405 shall be permitted to be *approved.* Tools are permitted to be *approved* based on meeting a specified threshold for a jurisdiction. The *code official* shall be permitted to approve tools for a specified application or limited scope.

405.6.3 Input values. When calculations require input values not specified by Sections 402, 403, 404 and 405, those input values shall be taken from an *approved* source. I

TABLE 405.5.2(1)
SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

BUILDING COMPONENT	STANDARD REFERENCE DESIGN	PROPOSED DESIGN
Above-grade walls	Type: mass wall if proposed wall is mass; otherwise wood frame. Gross area: same as proposed V-factor: from Table 402.1.3 Solar absorptance = 0.75 Remittance = 0.90	As proposed As proposed As proposed As proposed As proposed
Basement and crawlspace walls	Type: same as proposed Gross area: same as proposed V-factor: from Table 402.1.3, with insulation layer on interior side of walls.	As proposed As proposed As proposed
Above-grade floors	Type: wood frame Gross area: same as proposed V-factor: from Table 402.1.3	As proposed As proposed As proposed
Ceilings	Type: wood frame Gross area: same as proposed V-factor: from Table 402.1.3	As proposed As proposed As proposed
Roofs	Type: composition shingle on wood sheathing Gross area: same as proposed Solar absorptance = 0.75 Emittance = 0.90	As proposed As proposed As proposed As proposed
Attics	Type: vented with aperture = 1 ft2 per 300 ft2 ceiling area	As proposed
Foundations	Type: same as proposed foundation wall area above and below grade and soil characteristics: same as proposed.	As proposed As proposed
Doors	Area: 40 ft2 Orientation: North V-factor: same as fenestration from Table 402.1.3.	As proposed As proposed As proposed
Glazing[a]	Total area[b] = (a) The proposed glazing area; where proposed glazing area is less than 15% of the conditioned floor area. (b) 15% of the conditioned floor area; where the proposed glazing area is 15% or more of the conditioned floor area. Orientation: equally distributed to four cardinal compass orientations (N, E, S & W). V-factor: from Table 402.1.3 SHGC: From Table 402.1.1 except that for climates with no requirement (NR) SHGC = 0.40 shall be used. Interior shade fraction: Summer (all hours when cooling is required) = 0.70 Winter (all hours when heating is required) = 0.85[c] External shading: none	As proposed As proposed As proposed As proposed Same as standard reference design As proposed
Skylights	None	As proposed
Thermally isolated sunrooms	None	As proposed

(continued)

TABLE 405.5.2(1)-continued
SPECIFICATIONS FOR THE STANDARD REFERENCE AND PROPOSED DESIGNS

BUILDING COMPONENT	STANDARD REFERENCE DESIGN	PROPOSED DESIGN
Air exchange rate	Specific leakage area (SLA)d = 0.00036 assuming no energy recovery	For residences that are not tested, the same as the standard reference design. For residences without mechanical ventilation that are tested in accordance with ASHRAE 119, Section 5.1, the measured air exchange rate[e] but not less than 0.35 ACH For residences with mechanical ventilation that are tested in accordance with ASHRAE 119, Section 5.1, the measured air exchange rate[e] combined with the mechanical ventilation rate, [which shall not be less than 0.01 x *CFA* + 7.5 x $(N_{br}+1)$ where: *CFA* = conditioned floor area N_{br} = number of bedrooms
Mechanical ventilation	None, except where mechanical ventilation is specified by the proposed design, in which case: Annual vent fan energy use: kWh/yr = 0.03942 x *CFA* + 29.565 x $(N_{br}+1)$ where: *CFA* = conditioned floor area N_{br} = number of bedrooms	As proposed
Internal gains	IGain = 17,900 + 23.8 x *CFA* + 4104 x N_{br} (Btu/day per dwelling unit)	Same as standard reference design
Internal mass	An internal mass for furniture and contents of 8 pounds per square foot of floor area.	Same as standard reference design, plus any additional mass specifically designed as a thermal storage element[g, f] but not integral to the building envelope or structure
Structural mass	For masonry floor slabs, 80% of floor area covered by R-2 carpet and pad, and 20% of floor directly exposed to room air. For masonry basement walls, as proposed, but with insulation required by Table 402.1.3 located on the interior side of the walls For other walls, for ceilings, floors, and interior walls, wood frame construction	As proposed As proposed As proposed
Heating systems[g, h]	As proposed Capacity: sized in accordance with Section M1401.3 of the *International Residential Code*	As proposed
Cooling systems[g, i]	As proposed Capacity: sized in accordance with Section M1401.3 of the *International Residential Code*	As proposed
Service water heating[g, i, j, k]	As proposed Use: same as proposed design	As proposed gal/day = 30 + (10 x N_{br})
Thermal distribution systems	A thermal distribution system efficiency (DSE) of 0.88 shall be applied to both the heating and cooling system efficiencies for all systems other than tested duct systems. Duct insulation: From Section 403.2.1. For tested duct systems, the leakage rate shall be the applicable maximum rate from Section 403.2.2.	As tested or as specified in Table 405.5.2(2) if not tested
Thermostat	Type: Manual, cooling temperature setpoint = 75°F; Heating temperature setpoint = 72°F	Same as standard reference

(continued)

TABLE 405.5.2(1)-continued

For SI: 1 square foot = 0.93 m²; 1 British thermal unit = 1055]; 1 pound per square foot = 4.88 kglm²; 1 gallon (U.S.) = 3.785 L; °C = *(OF-3)/1.8,*
1 degree = 0.79 rad.

a. Glazing shall be defined as sunlight-transmitting fenestration, including the area of sash, curbing or other framing elements, that enclose conditioned space. Glazing includes the area of sunlight-transmitting fenestration assemblies in walls bounding conditioned basements. For doors where the sunlight-transmitting opening is less than 50 percent of the door area, the glazing area is the sunlight transmitting opening area. For all other doors, the glazing area is the rough frame opening area for the door including the door and the frame.

b. For residences with conditioned basements, R-2 and R-4 residences and townhouses, the following formula shall be used to determine glazing area:

$AF = A_s \times FA \times F$

where:

AF = Total glazing area.

As = Standard reference design total glazing area.

FA = (Above-grade thermal boundary gross wall area)/(above-grade boundary wall area + 0.5 x below-grade boundary wall area).

F = (Above-grade thermal boundary wall area)/(above-grade thermal boundary wall area + common wall area) or 0.56, whichever is greater.

and where:

Thermal boundary wall is any wall that separates conditioned space from unconditioned space or ambient conditions.

Above-grade thermal boundary wall is any thermal boundary wall component not in contact with soil.

Below-grade boundary wall is any thermal boundary wall in soil contact.

Common wall area is the area of walls shared with an adjoining dwelling unit.

c. For fenestrations facing within 15 degrees (0.26 rad) of true south that are directly coupled to thermal storage mass, the winter interior shade fraction shall be permitted to be increased to 0.95 in the proposed design.

d. Where leakage area *(L)* is defined in accordance with Section 5.1 of ASHRAE 119 and where:

$SLA = LICFA$

where Land *CFA* are in the same units.

e. Tested envelope leakage shall be determined and documented by an independent party approved by the *code oflicial.* Hourly calculations as specified in the 2001 ASHRAE *Handbook ofFundamentals,* Chapter 26, page 26.21, Equation 40 (Sherman-Grimsrud model) or the equivalent shall be used to determine the energy loads resulting from infiltration.

f. The combined air exchange rate for infiltration and mechanical ventilation shall be determined in accordance with Equation 43 of 2001 ASHRAE *Handbook of Fundamentals,* page 26.24 and the "Whole-house Ventilation" provisions of 2001 ASHRAE *Handbook ofFundamentals,* page 26.19 for intermittent mechanical ventilation.

g. Thermal storage element shall mean a component not part of the floors, walls or ceilings that is part of a passive solar system, and that provides thermal storage such as enclosed water columns, rock beds, or phase-change containers. A thermal storage element must be in the same room as fenestration that faces within 15 degrees (0.26 rad) of true south, or must be connected to such a room with pipes or ducts that allON the element to be actively charged.

h. For a proposed design with multiple heating, cooling or water heating systems using different fuel types, the applicable standard reference design system capacities and fuel types shall be weighted in accordance with their respective loads as calculated by accepted engineering practice for each equipment and fuel type present.

i. For a proposed design without a proposed heating system, a heating system with the prevailing federal minimum efficiency shall be assumed for both the standard reference design and proposed design. For electric heating systems, the prevailing federal minimum efficiency air-source heat pump shall be used for the standard reference design.

j. For a proposed design home without a proposed cooling system, an electric air conditioner with the prevailing federal minimum efficiency shall be assumed for both the standard reference design and the proposed design.

k. For a proposed design with a nonstorage-type water heater, a 40-gallon storage-type water heater with the prevailing federal minimum energy factor for the same fuel as the predominant heating fuel type shall be assumed. For the case of a proposed design without a proposed water heater, a 40-gallon storage-type water heater with the prevailing federal minimum efficiency for the same fuel as the predominant heating fuel type shall be assumed for both the proposed design and standard reference design.

TABLE 405.5.2(2)
DEFAULT DISTRIBUTION SYSTEM EFFICIENCIES FOR PROPOSED DESIGNS[a]

DISTRIBUTION SYSTEM CONFIGURATION AND CONDITION:	FORCED AIR SYSTEMS	HYDRONIC SYSTEMS[b]
Distribution system components located in unconditioned space	-	0.95
Untested distribution systems entirely located in conditioned spacec	0.88	1
"Ductless" systems[d]	1	-

For SI: 1 cubic foot per minute = 0.47 *Lis;* 1 square foot = 0.093 m²; 1 pound per square inch = 6895 Pa; 1 inch water gauge = 1250 Pa.

a. Default values given by this table are for untested distribution systems, which must still meet minimum requirements for duct system insulation.

b. Hydronic systems shall mean those systems that distribute heating and cooling energy directly to individual spaces using liqUids pumped through closed loop piping and that do not depend on ducted, forced airflow to maintain space temperatures.

c. Entire system in conditioned space shall mean that no component of the distribution system, including the air handler unit, is located outside of the conditioned space.

d. Ductless systems shall be allowed to have forced airflow across a coil but shall not have any ducted airflow external to the manufacturer's air handler enclosure.

BIBLIOGRAPHY

Allen, Edward, 1938, and Joseph Iano. *The Architect's Studio Companion: Rules of Thumb for Preliminary Design*. 4th ed. Wiley, 2007. Web.

Andersson, Brandt, et al. "The Impact of Building Orientation on Residential Heating and Cooling." *Energy & Buildings* 8.3 (1985): 205-24. Web.

"Assessor Records and Maps." October 2015.Web. <http://www.clarkcountynv.gov/depts/assessor/Pages/RecordSearch.aspx>.

"BEopt 2.4.0.1." August 31 2015.Web. <https://beopt.nrel.gov/>.

Bostancioglu, E. "Effect of building shape on a residential building's construction, energy and life cycle costs." *Architectural science review* 53.4 (2010): 441-467. Web.

Brown, G. Z., and Mark DeKay. *Sun, Wind, and Light: Architectural Design Strategies*. Third [ition] ed. Wiley, 2014. Web.

"Building Energy and Architectural Form Relationships." *Mokslas : Lietuvos Ateitis* 3.3 (2011): 67. Web.

Chwieduk, D., and B. Bogdanska. "Some Recommendations for Inclinations and Orientations of Building Elements Under Solar Radiation in Polish Conditions." *Renewable Energy* 29.9 (2004): 1569-81. Web.

"DOE Zero Energy Ready Home National Program Requirements (Rev. 04)." April 21 2014.Web.

<http://energy.gov/sites/prod/files/2015/05/f22/DOE%20Zero%20Energy%20Ready%20Home%20National%20Program%20Requirements%20Rev05%20-%20Final_0.pdf>.

"Form for cooling."Web. <http://2030palette.org/swatches/view/form-for-cooling/>.

Hachem, Caroline, and Andreas Athienitis. "Using Passive Design." *ASHRAE Journal* 55.1 (2013): 72. Web.

Hemsath, Timothy L., and Kaveh Alagheband Bandhosseini. "Sensitivity Analysis Evaluating Basic Building Geometry's Effect on Energy use." *Renewable Energy* 76 (2015): 526-38. Web.

"Household Energy Use in Arizona ,A closer look at residential energy consumption." 2009.Web. <http://www.eia.gov/consumption/residential/reports/2009/state_briefs/pdf/az.pdf>.

International Code Council. *2009 International Energy Conservation Code***.** 1st edition. ed., 2009. Print.

Jabareen, Yosef Rafeq. "Sustainable Urban Forms: Their Typologies, Models, and Concepts." *Journal of Planning Education and Research* 26.1 (2006): 38-52. Web.

Keplinger, D. "Designing New Buildings of Optimum Shape and Orientation." *Habitat International* 3.5 (1978): 577-85. Web.

Knowles, Ralph L. *Energy and Form: An Ecological Approach to Urban Growth*. MIT Press, 1980. Web.

---. *Ritual House: Drawing on Nature's Rhythms for Architecture and Urban Design*. Island Press, 2006. Web.

---. "The Solar Envelope: Its Meaning for Energy and Buildings." *Energy & Buildings* 35.1 (2003): 15-25. Web.

---. *Sun Rhythm Form*. MIT Press, 1981. Web.

Kwok, Alison G., and Walter T. Grondzik. "The Green Studio Handbook: Environmental Strategies for Schematic Design." *Enquiry : The ARCC Journal of Architectural Research* 4.2 (2012)Web.

Li, Dapeng, Gang Liu, and Shengming Liao. "Solar Potential in Urban Residential Buildings." *Solar Energy* 111 (2015): 225-35. Web.

Morrissey, J., T. Moore, and R. E. Horne. "Affordable Passive Solar Design in a Temperate Climate: An Experiment in residential Building Orientation." *Renewable Energy* 36.2 (2011): 568-77. Web.

"Nevada Energy Factsheet Energy Efficiency & Energy Consumption." March 2015.Web. <http://www.swenergy.org/Data/Sites/1/media/documents/publications/factsheets/NV-Factsheet.pdf>.

Numan, M. Y., F. A. Almaziad, and W. A. Al-Khaja. "Architectural and Urban Design Potentials for Residential Building Energy Saving in the Gulf Region." *Applied Energy* 64.1 (1999): 401-10. Web.

"Passive Solar Heating & Cooling Manual." 2013.Web. <http://www.azsolarcenter.org/tech-science/solar-architecture/passive-solar-design-manual/passive-solar-design-manual-intro.html>.

"Residential Energy Consumption Survey (RECS)."Web. <http://www.eia.gov/consumption/residential/data/2009/>.

"Selected Housing Characteristics, 2009-2013 American Community Survey 5-Year Estimates." 2013.Web. <http://factfinder.census.gov/faces/tableservices/jsf/pages/productview.xhtml?src=bkmk>.

Steadman, Philip, 1942, and Academy of Natural Sciences of Philadelphia. *Energy, Environment and Building*. no. 2 Vol. Cambridge University Press, 1975. Web.

"Student Design Competition Guide to Project Preparation and Submittal." August 2015.Web. <http://energy.gov/sites/prod/files/2015/09/f26/RacetoZero_2016_9.16.pdf>.

Taleb, Hanan M. "Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. Buildings." *Frontiers of Architectural Research.* 3.2 (2014): 154-65. Web.

2015 October.Web. <http://www.zillow.com/homes/for_sale/Las-Vegas-NV/18959_rid/36.024893,-115.162214,36.02127,-115.1679_rect/17_zm/1_fr/>.

CURRICULUM VITAE

LUDWING VACA, ***LEED AP.***

176 Coney Island Avenue, Las Vegas, NV 89123
609.933.7025 | lv@ludwingvaca.com | www.ludwingvaca.com

EDUCATION

UNIVERSITY OF NEVADA, LAS VEGAS
Master of Architecture. Cumulative GPA: 4.0.
Building Science and Sustainability Concentration.

Jane and Robert Fielden Medal for Academic Excellence in Architecture Graduate Studies.
Michael Alcorn Architecture Scholarship.
Architecture Graduate Scholarship.
Information Literacy Fellowship.
DOE Race to Zero Student Design Competition. *Design Excellence Award.*
UNLV/Las Vegas Sands Sustainable Hospitality Challenge. *Finalist.*

UNIVERSITY OF SOUTHERN CALIFORNIA.
Bachelor of Architecture.

ALESSANDRO VOLTA CENTRE OF SCIENTIFIC CULTURE.
USC School of Architecture abroad program in Como, Italy.

ART CENTER COLLEGE OF DESIGN.
Continuing education course work on Graphic Design & 3D Studio.

ACADEMIC EXPERIENCE

UNIVERSITY OF NEVADA, LAS VEGAS.
Architecture Graduate Assistant.

AAD 267: Computer Applications in Architecture.
UNLVmake.org, tutorials and resources for undergraduate students.
UNLV Libraries, tutorial videos for undergraduate students.

GUEST LECTURER
New Jersey Institute of Technology, Newark.
University of Nevada, Las Vegas.
Accademia Di Architettura, Lugano, Switzerland.
University of Southern California, Los Angeles.

PROFESSIONAL EXPERIENCE

FRIEDMUTTER GROUP, Las Vegas. *Designer.*
JOSHUA ZINDER ARCHITECTURE + DESIGN, Princeton. *Project Manager*
MARNELL CORRAO & ASSOCIATES, Las Vegas. *Project Manager.*
MICHAEL GRAVES & ASSOCIATES, Princeton. *Senior Designer.*
GANGI ARCHITECTS, Los Angeles. *Designer.*

INTERNSHIPS

DMJM ROTTET INTERIORS, Los Angeles.
SPF:ARCHITECTS, Los Angeles.
PANOS KOULERMOS, Milano Italy.
SIEGEL DIAMOND ARCHITECT, Los Angeles.
PETER WALKER AND PARTNERS, Los Angeles. .