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Identify an Ideal Residential Wall Assembly for Las Vegas Climate Considering Construction Cost, Energy Performance and Embodied Energy

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IDENTIFY AN IDEAL RESIDENTIAL WALL ASSEMBLY FOR LAS VEGAS CLIMATE CONSIDERING CONSTRUCTION COST, ENERGY PERFORMANCE AND EMBODIED ENERGY

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ABSTRACT

Global warming and climate change has drawn great concerns in recent years due to the impact residential buildings have on the environment. Heating and cooling consumption make up most of household energy in the desert southwest. This energy demand is a big contributor of carbon emissions being release on to the environment. In an effort to minimize energy consumption, this research study aims to identify an energy efficient wall assembly that can be use in the U.S. desert southwest, that is suitable for the environment. With the use of research and simulations, using BEopt version 2.4.0.1, this investigation compares and evaluates different exterior wall assemblies to the standard code compliant construction. After ranking each wall, an ideal assembly was selected based on best performance. The information and results of this paper used in a case study project for the U.S. Department of Energy, Race to Zero Student Design Competition to find out that the chosen wall assembly would in fact help reduce energy consumption in the U.S. desert southwest.

The findings indicate that all of the seven wall assemblies studied show a significant improvement in site energy, CO_2 emission reductions, and lowered energy annual costs compared to the base case scenario. In contrast, all wall assemblies, except for the R-17.1 2x6, 24" o.c. advanced practice wall assembly, show an increase of initial construction costs of up to 21.1% or up to an additional $12,532. However, all initial extra investment on any of the wall assemblies studied would be paid back within six months or less.

The least desirable wall assembly would be the R-17.1 2x6, 24" o.c. advanced practice wall type, as this one had the least amount of energy savings, CO_2 emissions reductions, and energy annual costs cutbacks out of all the types studied. It also had the longest amount of simple payback and the smallest amount of additional initial construction cost of $276.

The R-28.8 ICF 2 in EPS, 12” Concrete, 2 in. EPS wall type is less favorable. Though it provided moderate energy savings of 953 kWh annually, and CO_2 emission and energy cost reductions, its initial cost of over $12,000 or 21% was more, compared to the base case wall.

The R-20.6 ICF 2 in. EPS, 4" Concrete, 2 in. EPS, the R-28.3 Double Wood Stud 2x4 Centered, 24 in. o.c., and the R-28.5 Double Wood Stud 2x4 Staggered, 24 in. o.c. show a medium range of energy savings, as well as moderate initial construction cost.

Last, the two wall systems that this study found that provided the most benefits in terms of annual energy savings, carbon emissions, energy cost reductions, initial costs, and shortest amount of pay back were the R-29.2 SIP 7.4 in EPS Core, and the R-36 SIP 9.4 in EPS Core wall assemblies. These two wall types would be the most desirable options for single family residential wall construction for the desert southwest.

ACKNOWLEDGEMENTS

I would like to thank you Professor Fernandez-Gonzalez for the continuous support of my Graduate studies and research, for your motivation and guidance. Specifically, for encouraging us to participate in the U.S. Department of Energy, Race to Zero Student Design Competition. Moreover, my gratitude extends to: Prof. Vermillion, Prof. Glen Novak and Dr. James for their support.

I thank my fellow team members at for all the great work done for the DOE Race to Zero Student Design Competition, the long hours of energetic discussions and sharing of information and knowledge; this has helped me grow my knowledge base.

DEDICATION

I dedicate this thesis to my parents, Vicente Corona and Cipriana Corona whose love, unselfish support and example over many years laid the foundations for the discipline and application necessary to complete this work. Thank you for fostering my talents and strengths, and for helping me improve on my weaknesses. Both of you have been an outstanding inspiration to me.

I also dedicate this research work to the love of my life, my wife, Viviana, because your love, acceptance, patience and encouragement have seen us through our first year of marriage and last year thesis. Without you I could never have accomplish so much.

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CHAPTER 1: INTRODUCTION

1.1 Background.

For years, the largest source of energy demand in the United States has been for buildings. In 2014, residential and commercial used approximately 41% of the total prime energy use, outpacing demand for both transportation and industrial sectors (Fig. 1.1).

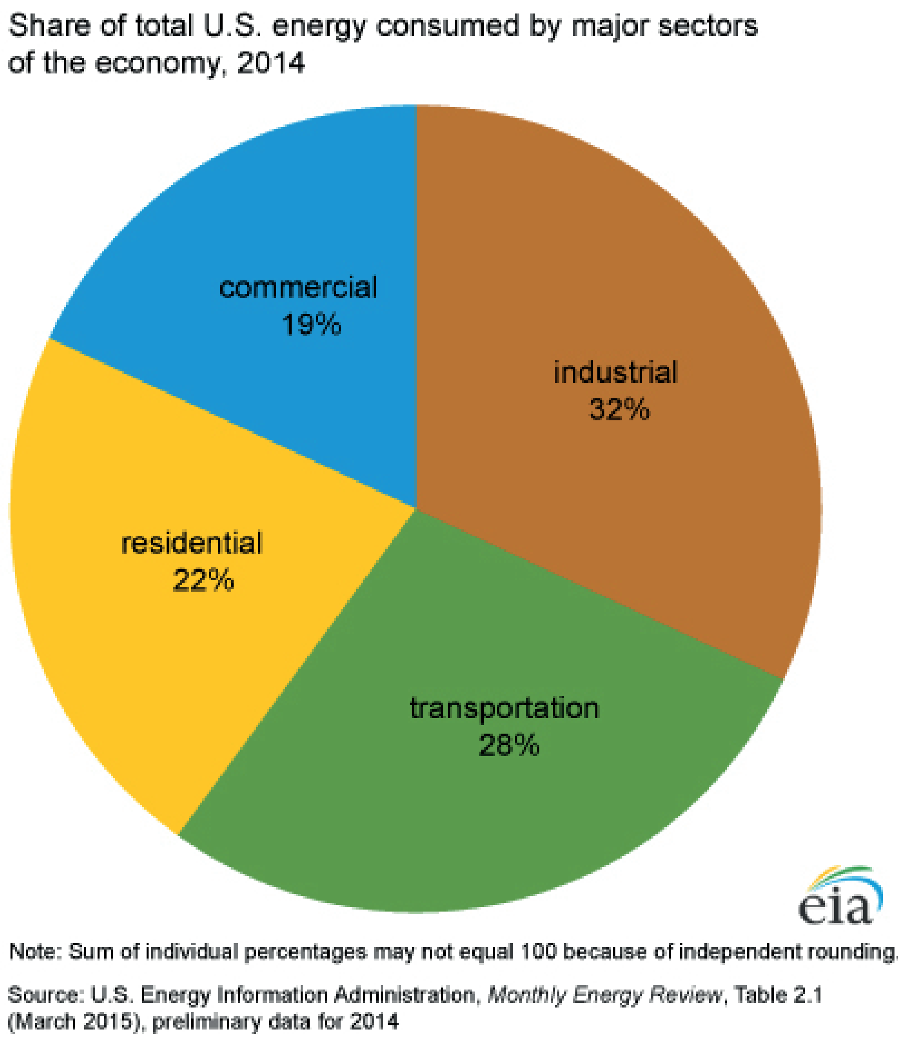


Figure 1.1. U.S. Energy Consumption by Sector, from Energy Information Administration 2015.

The largest consumer of electricity in the United States is the building sector. In 2014, residential and commercial sectors used approximately 73% of the total electricity use while the industrial and transportation sectors consumes 26% and less than 1% respectively (Fig. 1.2).

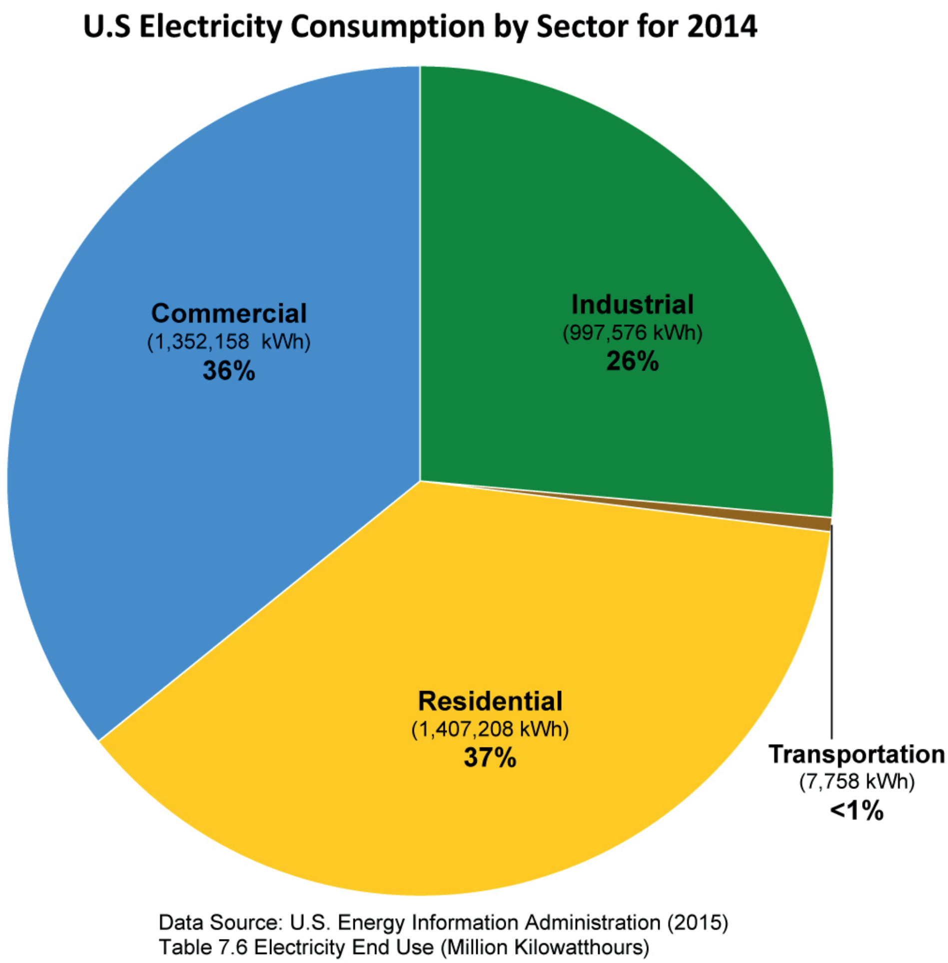


Figure 1.2. U.S. Electricity Consumption by Sector, from Energy Information Administration 2015.

In 2014, residential and commercial structures in the United States were responsible for emitting the highest amount of CO_2 emissions at 39% compared to transportation at 34% and the industrial sector at 27% (Figure 1.3).

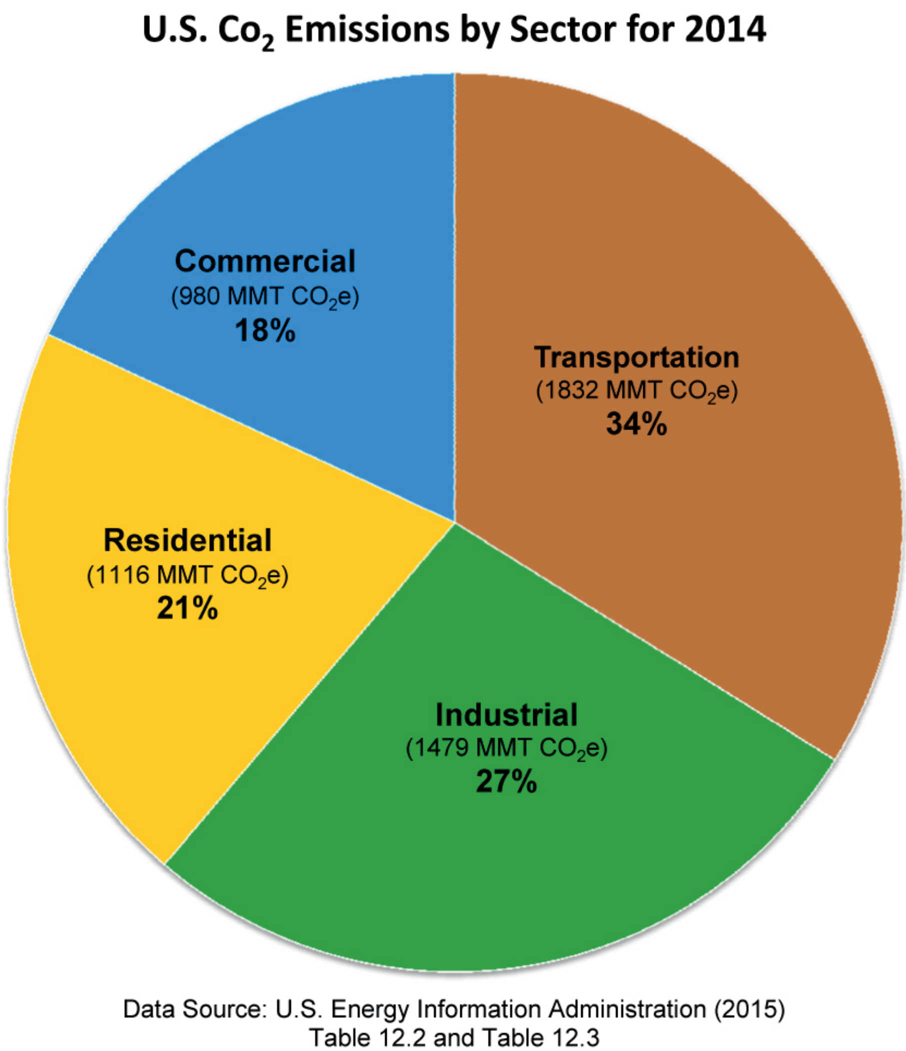


Figure 1.3. CO_e Emissions by Sector, from Energy Information Administration 2015.

In 2014, residential homes consumed 22% of energy while the commercial buildings used an additional 19% totaling 41% of all the energy utilized in the U.S. (U.S Energy Information Administration [USEIA], 2015). Moreover, the building sector emits the highest amount of carbon emissions at 39% compared to transportation and industrial sectors. In the desert southwest region, local electric utilities are facing challenges to keep up with electrical demand and peak loads (Sadineni et al., 2011). Las Vegas' metropolitan area will continue facing electrical demand problems in the future as the square footage in homes keeps increasing in size. As more energy will be consumed for heating and cooling, thus more fossil fuels burned.

As shown in figure 1.4., residential homes built in the 1990's are on average 27% larger compared to homes built in the 1970's and 1980's in all four regions of the U.S. The number of homes built in the 1970s and 1980s were less than 1,800 square feet. That number increased to approximately 2,200 square feet for homes built in the 1990s and to 2,465 square feet for homes built in the 2000s (U.S. Energy Information Administration, 2015) This same source also points out: while the floor area continues to increase in newer homes, so will the ceiling heights. Of the homes built in the 1970's, 17% had higher than traditional eight-foot ceilings. This number increased to 52% in homes built in the 2000s. As the average square footage in residential homes keep increasing, the demand for heating and cooling these spaces will also rise.

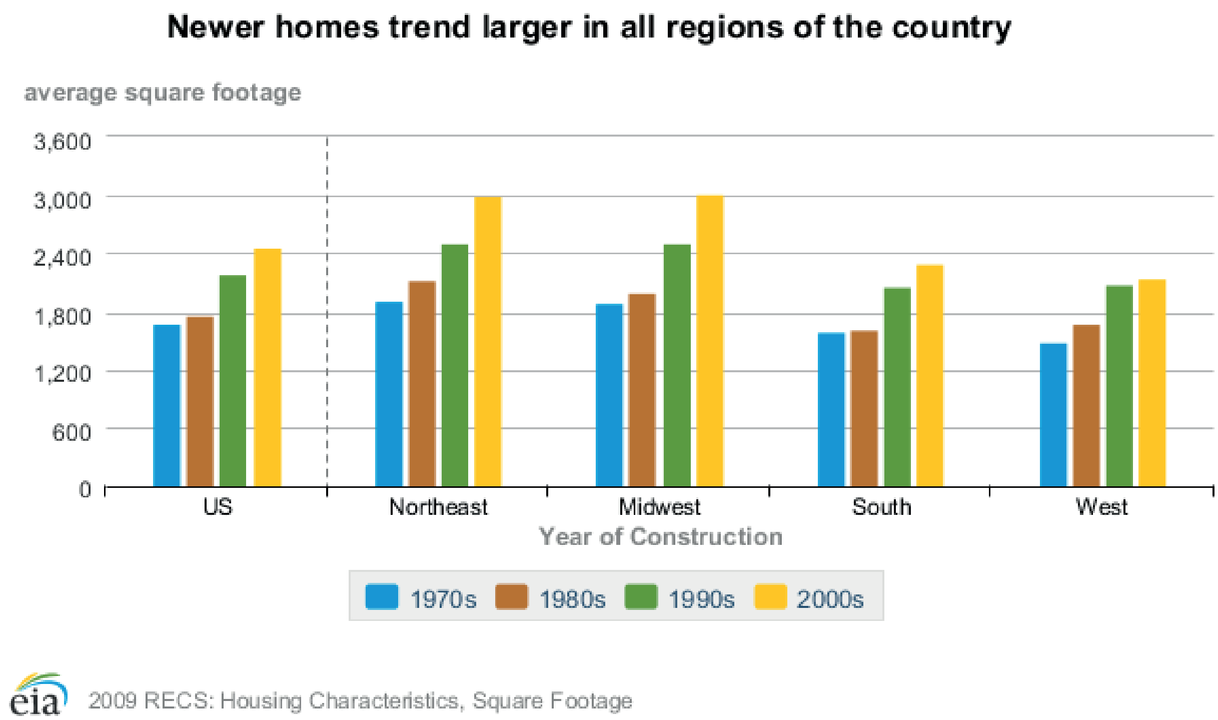


Figure 1.4. Housing Characteristics Square Footage, from Energy Information Administration 2012.

1.2 Population.

The 2015 population for Nevada is estimated at 2,890,845, which is a 6% increase from 2,700,552 in 2010 (U.S. Census Bureau, Population Division). The Nevada Energy Fact Sheet shows that Nevada has a population growth rate from 2005-2013 by about 1% per year. Moreover, the total number of residential households in 2010 was 979,621, while in 2014 this number grew to 1,005,958 million, a 2.6% increase in five years (U.S. Census Bureau, 2014). As the population keeps growing in Nevada, demand for homes will also increase, resulting in more electricity demand. Lowering the energy consumption would help consumers save money and cut back on the demand for the fossil fuels: coal, oil, and natural gas. Less consumption of fossil fuels also leads to fewer emissions of carbon dioxide -- the dominant provider to global warming. In addition, the need for new power plants and expensive upgrades to existing power infrastructure would be much less.

1.3 Nevada Energy Estimates.

According to the Nevada Energy Fact Sheet, Nevada ranks 41 in energy consumption per capita and 38 for total energy consumption. Natural gas is the primary fuel for power generation at 73%, while 16% of the total is coal, followed by renewable resources at 11% (Figure 1.5.). In 2012, natural gas was the leading source of energy consumed in Nevada at 45%. Only 11% of energy consumption in the state came from renewable energy, with petroleum at 35%, and coal at 9% of the total as illustrated in Figure 1.6., (Nevada Fact Sheet, 2015).

As shown in Figure 1.7., electric utilities used 68% of the total amount of natural gas while the residential sector accounted for 15%, followed by and the commercial sector at 12% and the industrial sector at 5% (Nevada Fact Sheet, 2015). In 2012, the transportation sector consumed 33% of the energy in state of Nevada; while the industrial sector used 25%, followed by residential and commercial at 24% and 18% respectively (Figure 1.8).

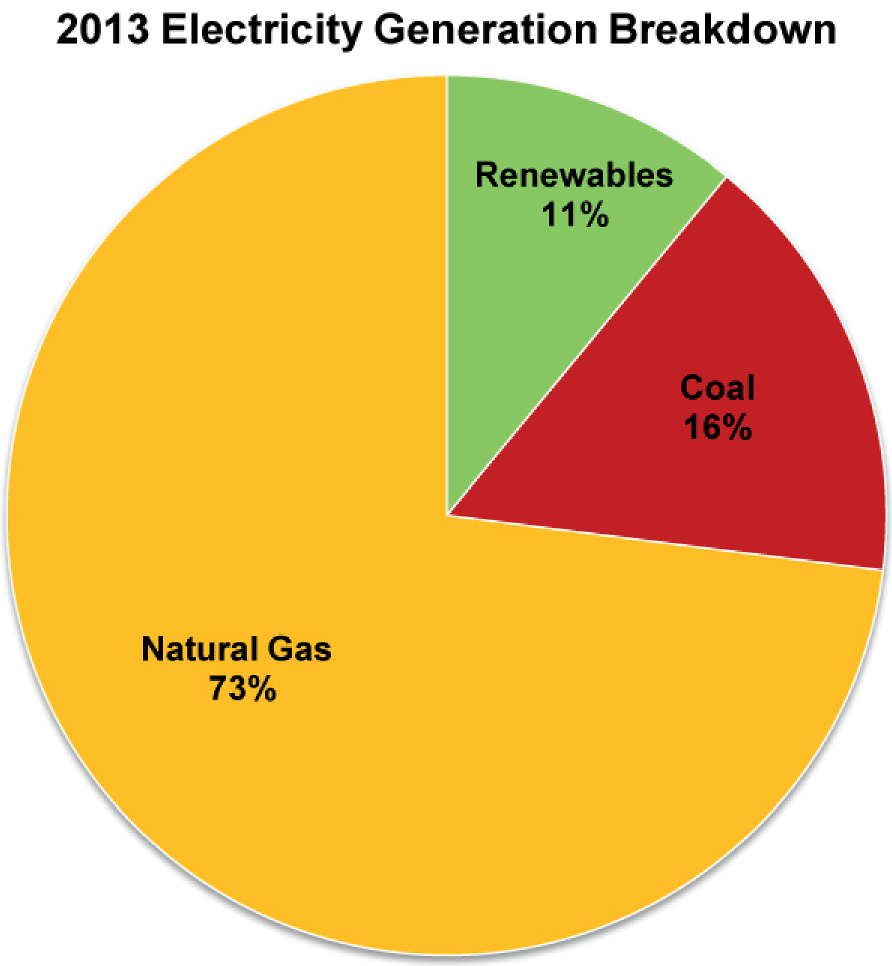


Figure 1.5. 2013 Electricity Generation Breakdown, from Nevada Fact Sheet 2015.

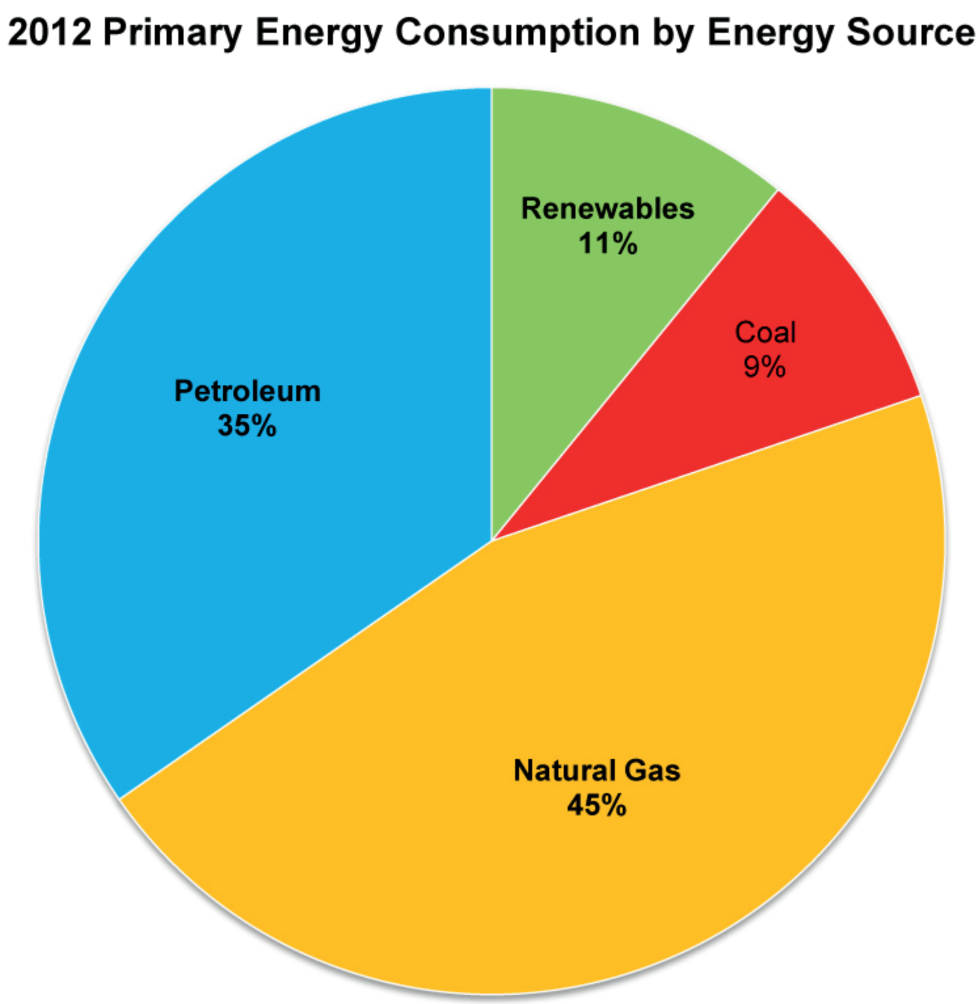


Figure 1.6. 2012 Primary Energy Consumption by Energy Source, from Nevada Fact Sheet 2015.

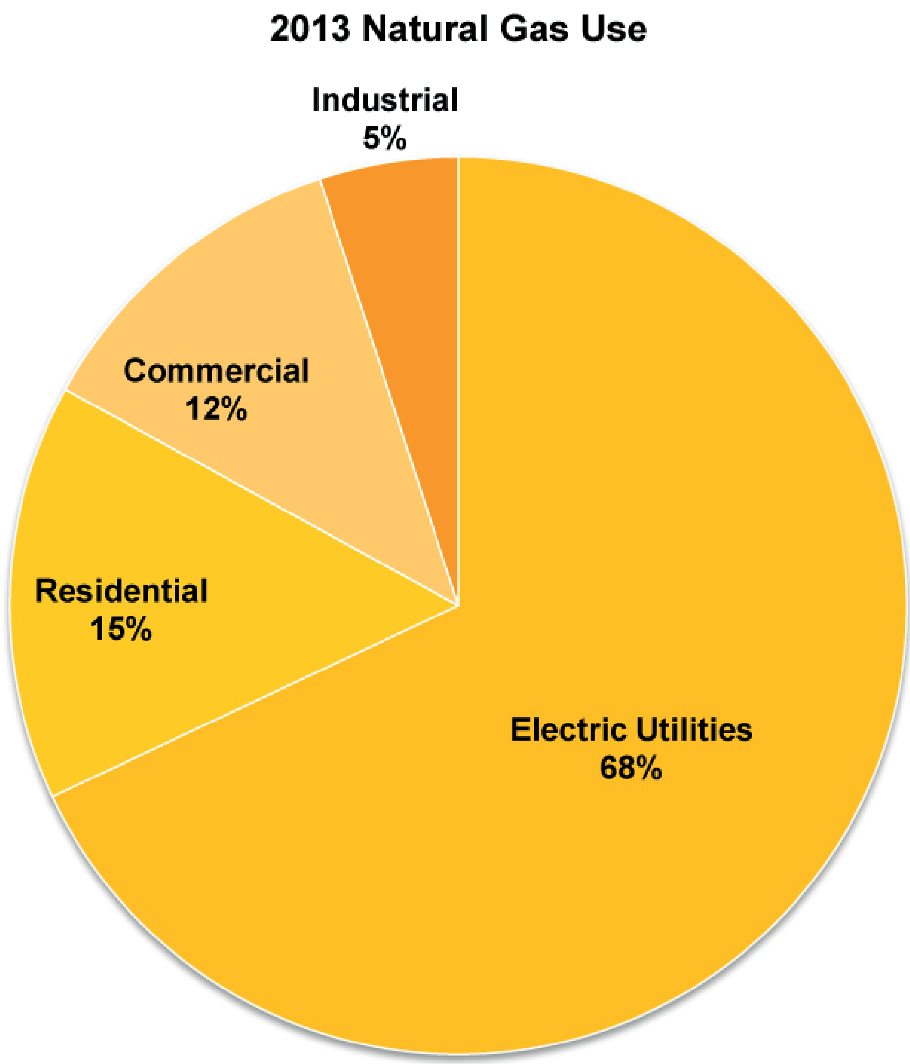


Figure 1.7. 2013 Natural Gas Use, from Nevada Fact Sheet 2015.

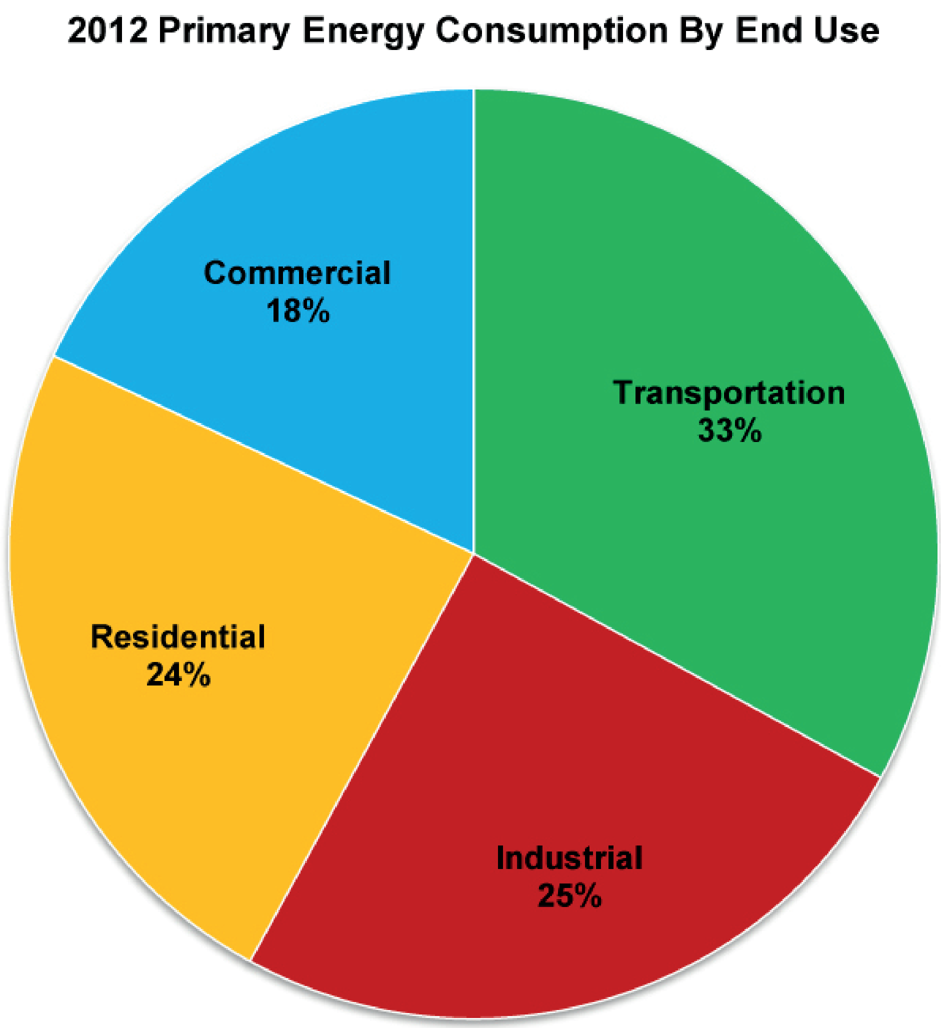


Figure 1.8. 2012 Primary Energy Consumption By End Use, Nevada Fact Sheet 2015.

1.4 Climate Conditions

The article *Designing a Sustainable House in the Desert of Abu Dhabi*, (Al-Sallal et al., 2012) suggests that architects and engineers need to consider the surrounding environment and climate at the early stage of the design to rely less on cooling and air conditioning of buildings. Proper design of building form, orientation and energy efficient envelope has the advantage to lower heats gains and energy consumption of a building. Taking the local climate and site conditions and implement passive design strategies is another key design to maximize the relaxation and health of the occupant -- while minimizing energy use (Taleb, 2014).

A previous article showed that semi-arid areas like Phoenix, AZ impact the heating and cooling energy requirements of a building by a large amount (Hester et al., 2011). Sadineni and Boehm (2011) studied the effects of the desert climate in the southwest region of the U.S., on domestic energy use, and found that high temperatures result in increased energy consumption.

Boehm, lists southern Nevada as a hot, arid region (2008). Weather conditions in Las Vegas are normally hot throughout the year, during day time, while night temperatures are cooler. Summer days have commonly large temperature swings -- from day to night -- and can last from May to September. Temperatures during this season range from 81°F to 106°, and can even exceed to 115°F. With the abundant sunshine and clear sky at night, buildings in Las Vegas will warm considerably during the day time, demanding more energy for cooling. This is why it is important to consider an energy efficient wall assembly to help decrease heat gains and energy use in the desert southwest region of the U.S. The winter season in Las Vegas is short generally mild. Temperatures during the winter months of November to March average between 58°F to 38°F, but can also drop to low freezing temperatures of 20°F.

As shown in Figure 1.9., the annual temperature in Las Vegas is widely diffused; the design high and design low temperature tend to fall outside of the comfort zone. It also shows the extended duration of heat that buildings are exposed to during the summer season.

Figure 1.9. Temperature Range for Las Vegas from Climate Control Software.

Figure 1.10., shows the dry bulb temperature for Las Vegas is usually above the comfort zone during a 24 hour period, which means that during the night time the temperature is above 78°F. There are only a few hours during the day when the comfortable temperature is reached during the months of November and January. The temperature does not reach or go above 68°F, only the month of December.

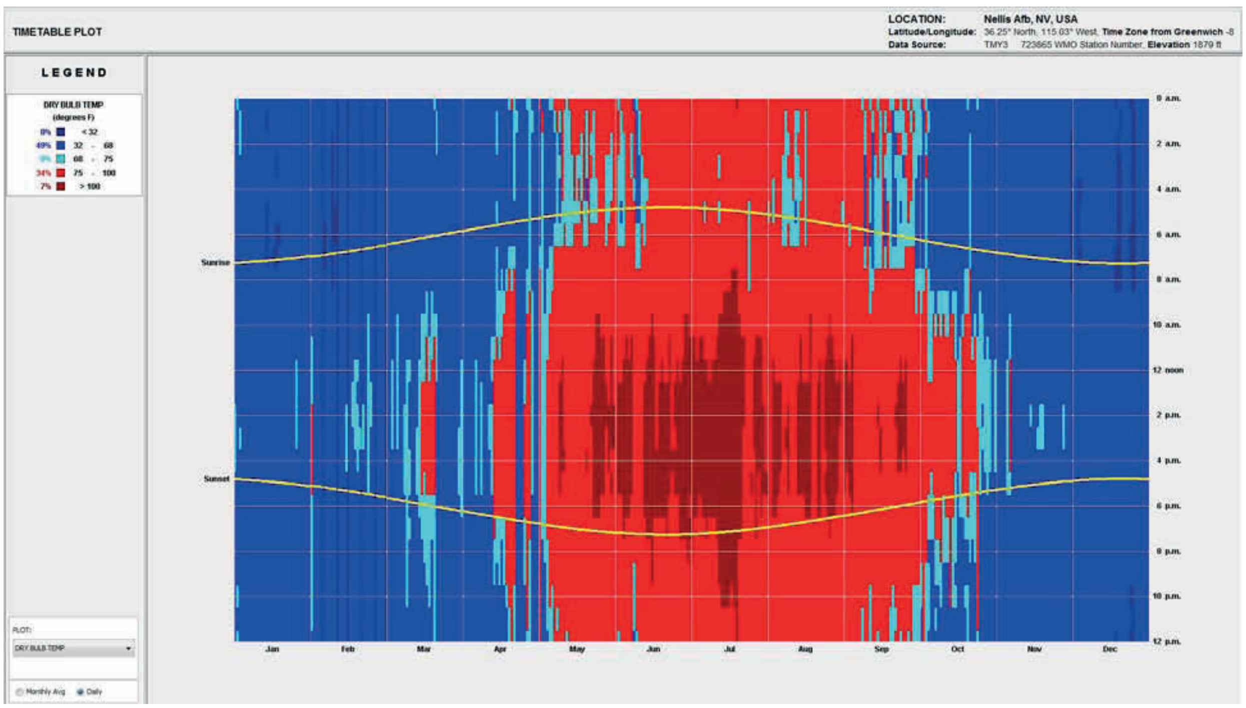


Figure 1.10. Dry Bulb Temperature Range for Las Vegas from Climate Control Software.

1.5 Exterior walls

Shelter provides protection and comfort for individuals against the harsh climatic elements of the environment. Residential housing has become that form of shelter for people, fulfilling the need safety well-being. This has led to various technological advances in residential housing. One of the first types of wall assembly was made out of Wattle and Daub, which consisted of branches or vertical stakes creating a lattice covered with plaster combined of dirt, clay sand, animal hair and animal dug and straw. Today this combination forms the basis of modern stucco applications on residential wall surfaces (Lustiburek, 2014). The mass production of nails and dimensional lumber, in the 1850's, led to the Balloon framing which dominates residential construction to this day.

With the increase in population, today, more homes are being built only to meet the minimum building code standards. Designers need to carefully consider environmental friendly design strategies from the beginning of the design process to help ease the negative impact of new homes on the environment.

A variety of solutions have been investigated towards the efficiency and economic reduction of energy consumption in heating and cooling, for homes located in hot arid climates. Examples of design solutions include site orientation, building footprint and surface area, green rooftops, implementation of trees and shrubs to provide shading, materials and human behavior, fenestration and surface area, and thermal mass application (Al-Sallal et al., 2013). These same methods can be advantageous in the U.S. Desert Southwest to lower the demand for cooling and heating consumption.

An energy-efficient wall is another option to minimize thermal bridging by providing a tight building envelope to function as the boundary between the weather outside the house and the temperature inside the home. This will benefit the consumer with lowered energy bills,

therefore eliminating the regular urgency to turn on the air condition unit and as a result it will provide the homebuyer with greater thermal comfort.

Today, with the negative impacts on the environment and human activities in buildings, designers understand the needs for control layers such as rain control, air control, thermal control and advance framing techniques to help ease this stress on the environment.

Lstiburek's article *The Perfect Wall* as shown on Figure 1.11., writes about three ideal wall types for different types of buildings: institutional, commercial, and residential. He lists four layers for each of the wall types in the following critical order:

- A rain control layer
- An air control layer
- A thermal control layer
- A vapor control layer

The author explains that an air control layer is unnecessary if the rain can get through. The vapor barrier is unnecessary if you can't control the air, and don't bother about the control thermal layer if the vapor is not controlled (Lstiburek, 2007). In other words, build it simple by having the perfect wall become the environmental separator -- keep the outside out and the inside in.

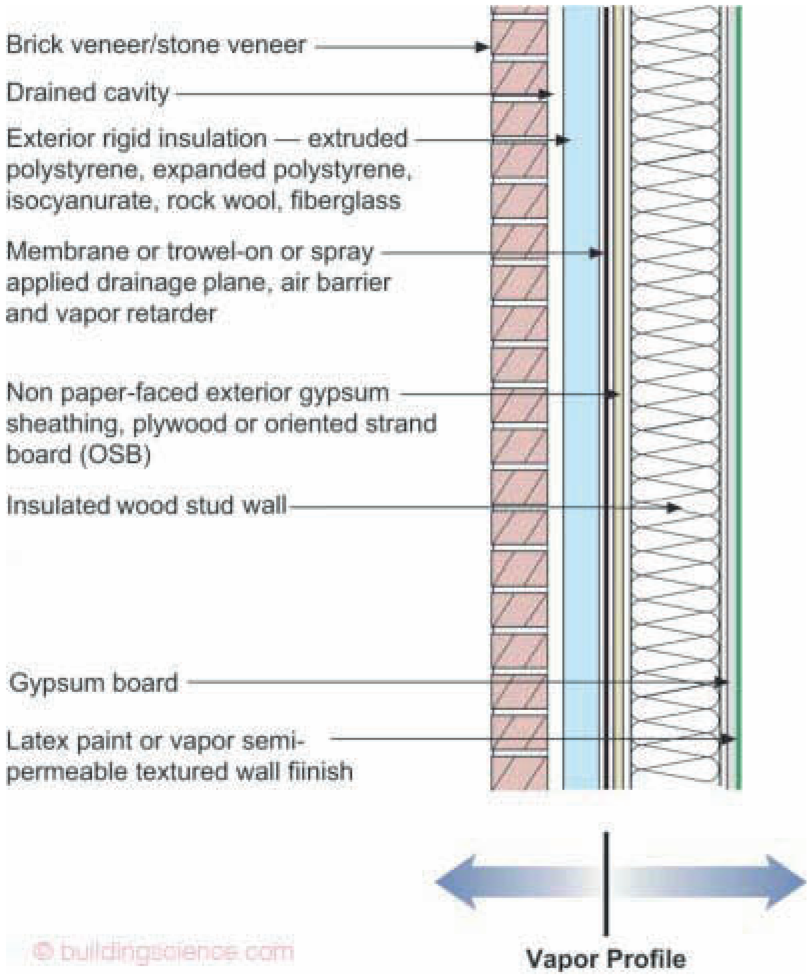


Figure 1.11. The Perfect Wall in concept, from Lstiburek, J.W. (2007). Building Science Corporation.

CHAPTER 2: RESEARCH LITERATURE REVIEW

2.1 Energy

The amount of energy consumed and greenhouse gas emissions by the residential housing and commercial sectors are the largest in the U.S. (Aldawi et al., 2013). The consumption and greenhouse gas emission not only put additional pressure on fossil fuel resources, it also causes global warming and climate change. The studies performed by Aldawi included the simulation of three wall systems with optimal thermal masses and a conventional wall. An important aspect of the study is to note is that thermal performance modeling was carried out before the actual construction of a residential house was built. The research estimated the total ongoing heating and cooling energy requirements for a conventional wall built out of timber with batt insulation and three high performance walls. One of the three walls built with re-inforce concrete and polystyrene on the outside, resulted in possessing high energy saving of 47% compared to the standard conventional wall. Although there is a high construction cost for the high performance wall system the user will recuperate its investment within 6-14 years depending on the types of mechanical system is used. This means the building envelope is an approach everyone in the world could benefit by improving its thermal performance and minimize the energy use in the residential and commercial category while lowering greenhouse gas emissions.

Zhu et al. in their article *Detailed Energy Saving Performance Analyses on Thermal Mass Walls Demonstrated in Zero Energy House,* presents findings from a side-by-side case study of the construction of two homes: one conventional wood framing and one Insulated Concrete Panel (ICP). Heat flux readings were evaluated and concluded that the baseline house external wall temperature varies significantly compared to the ICP panel wall.

The results from Zhu et al. show that heat transferred through the massive walls into the inside space while it transferred outside through the conventional walls. This is because the mass wall construction has the ability to store and absorbed solar heat during the peak time and shifts it back at night. With the desert climate of high ambient temperature and intense sunlight, too much heat will be stored unable to be released back outside resulting in high energy for cooling for the ICP thermal mass wall (Zhu).

Another example stated by Swan (2011), show that renewable construction materials with low bodied energy, like adobe, earthen construction and straw bale wall assembly have the opportunity to reduce energy from the start of the design process. However, these systems are not generally taken into consideration, only a few selected local building codes accept these types of alternate methods. Lstiburek states, "if we are going to address the energy problem the perfect wall is needed now more than ever; we should be demanding the integration of these wall systems and be perfect." (2007).

Buildings are major consumers of energy throughout their life cycle; they have a serious impact on energy usage and the environment. The design and construction industry have the potential to improve energy efficiency during their life time (Jackson, 2010).

Energy rating systems are tools to help designers and builders reduce the negative impacts buildings have on the environment. However, Jackson's article *Green Home-Rating Systems: A preservation Perspective*, examines the wide spread disparity for seven rating software programs: The U.S. Green Building Council LEED for Homes, Green Building / Green Points, Built it Green, Built Green, BREEAM Ecohomes, Vermont Builds Greener and Austin Energy Green Building. He adds that these home-rating systems do not provide good benchmarks for assessing whole building performance. The typical actions measured in green rating systems are highly variable and ultimately reveal some assumption of environmental benefit. (Jackson, 2010). In addition, three of the seven compared systems do not give any points to building reuse. Two give only meaningless points on purchasing new materials. Only

the BREEAM system provides reliable information for building reuse that is equivalent to those of the new-materials ratings.

The author concludes that most of the rating systems have become measures of how much humans consume, rather than asking the more important questions -- should we consume? And if so, how much? Current green home-rating systems too often lead to the conclusion that the green home “tear down” is preferable to the “green Home makeovers.” (Jackson, 2010). The need to find the right combination of preservation practices and efficiency measures needs to be improved for green conservation to help reduce the building’s negative impact on the environment.

The Article by Crawford et al. *A comprehensive Framework for Assessing the Life-Cycle energy of a Construction Assembl*ies points-out that there is a limited amount of information available when it comes to considering the embodied energy and life-cycle of a structures. Without this information, the designers worldwide are unable to make informed decisions before construction begins on a new building. This in return contributes to more pollution and more energy use during the life cycle of the structure. Crawford et al. add that a dependable and complete plan for evaluating and select superior building assemblies to defined environmental outcomes currently do not exist (2010).

Crawford et al. present a method for ranking building assemblies based on their life-cycle energy performance by integrating embodied energy assessment techniques with thermal performance modeling. The initial findings were used to compile a database with information associated with a large number of building construction assemblies that can be available for designers and builders worldwide.

The embodied energy assessment was performed using an in-put and output-based hybrid analysis from the Australia National Accounts (ABS) and combined with energy intensity factors by fuel type (Crawford, 2010). Eight material assemblies were ranked from lowest to highest life cycle energy requirement. While a superior wall assembly with higher energy

performance may have a higher initial embodied energy requirement, compared to a less favorable system, the need to replace that material may result in a lower net energy result over the life of the building (Crawford et al., 2010).

Current studies of embodied energy are quite unclear and vary greatly globally due to problems of variation and incomparability of information that exist in databases that the International Standardization Organization (ISO) provides.

Most countries follow the LCA standards to keep track or build information of products and then store into databases to make it available for governments to set their own standards. However, the LCA standard falls short; it does not provide the information needed and does not address some important issues, such as having a standard benchmark for all manufacturing companies to measure the energy require for extracting materials.

Studies that involved the calculation of embodied energy in building and building materials either did not mention using any standard or used standards provided by ISO and the Society for Environmental Toxicology and Chemistry (SETAC). ISO and SETAC are the two key organizations that are working towards standardization and scientific development (Manish et al., 2012).

The author recommends developing a set of standards to streamline the embodied energy data to resolve issues in current LCA standards. With the use of the guidelines a database with information could be shared globally for countries to benefit from and make liable choices. The embodied energy is a complex topic to assess. However, it is needed to ease the embodied impact on the environment.

2.2 Simulation and Modeling

Residential building energy simulation is playing an increasingly important role in building design. There are a growing number of software tools being used for analyzing the energy consumption in buildings to establish the basis of design and their energy efficiency requirements. Being able to model a new structure at various design stages can help designers achieve optimization and meet the energy requirements needed.

Although energy simulations are important at the beginning stages of design, they are complicated process involving modeling and analytical skills. Designers often find it difficult to carry out the building energy analysis and understand the simulation results. Valovcin et al. state that the programs are not perfect as they make assumptions, this causes impartial results. For example, actual versus assumed behavior of occupants can result in errors from formula inputs that are built into the model. (Valovcin et al., 2014). With increasing concern in energy, the demand of simulation and modeling to be done on buildings prior to construction is greater than ever; allowing designers to understand the design and performance relationships.

Different studies have shown that building energy simulation can help designer predict various potential energy savings on a residential buildings. The journal article by Suresh et al. *Economic Feasibility of Energy Efficiency Measures in Residential Buildings,* show a building energy simulation software being used to help identify several potential efficiency upgrades for production of homes in Las Vegas (Suresh et al., 2011). Energy-10 simulations were used to calculate the annual energy savings for each energy efficient upgrade. To verify the accuracy of the Energy-10 building input parameters and mechanical equipment, the simulations were compared against measured data (Suresh et al., 2011). The building model was instrumental, it allowed the engineers to validated and predict the annual energy savings and payback periods for numerous components. It concluded that the cost benefits of basic energy efficiency upgrades, like the need for cellulose insulation in walls and roofs, would be most beneficial. In

addition, the cost benefit of advance energy efficient components show energy efficient windows and PV 3.192 kW to have a benefit cost, while the other upgrades show zero benefits to cost.

2.3 Cost Analysis

Saha's article *Cost Effective Thermal Wall System for Residential Housing*, states that the Australian Bureau of Meteorology predicts that temperatures will rise between 0.4° and 2° C by 2030 across Australia (Saha, 2011). Because of this growing awareness heating and cooling in the residential sector will increase, thus resulting in more carbon emissions being release onto the environment. There are approximately 28% of households without insulation in this hot climate.

The author conducted a study to find the cost savings by comparing the thermal efficiency of four of the most common external walls for residential construction in Sydney Australia. These included clay masonry veneer, a cement sheet, and weatherboard and cavity clay masonry wall assemblies.

The research consisted of finding the cost of the thermal wall insulation and the cost of the four wall structures. Their total cost was calculated as "per m² and in order to make a fair cost comparison, data was collected from "Reed Construction Data," which deals with variations in price of materials and labor between different suppliers and tradesman.

The results showed the cement wall was the most affordable at $130.17 the second was the weatherboard at a cost of $201.38 followed by the cavity clay masonry at $232.6. As for the insulation, fiberglass was the most affordable compared to rockwool and was used in the cost equations. It is important to note different insulation thicknesses were used in each of the walls to evaluate their thermal performance.

The largest saving in annual heating a cooling is found in all wall types when the nominal amount of insulation is added (Saha, 2011). Cement sheet is the most cost effective wall system compared to the cavity clay masonry being the most expensive. The clay masonry veneer and the weatherboard wall systems are similar in price.

The pay back of a wall system is dividing it cost by the amount savings achieved compared to the benchmark air film wall. The payback is as follows: cement wall took 5.8 years; masonry veneer and the weather boards take 8 years: followed by the clay masonry which took 9 years for paying back the cost of these wall systems (Saha, 2011).

2.4 Standard Wall Practices

The standard exterior wall construction for new residential homes in Las Vegas is based on the 2012 International Residential Code requirements (2012 IRC) and the 2009 International Energy Conservation Code (2009 IECC). 2x4 16 in o.c. wood constructions is the most commonly used exterior wall type in the Las Vegas Valley. Section R602.2 of the 2012 IRC states that studs need to be a minimum No.3, standard or stud grade lumber and Section R602.3 requires the exterior wall systems of wood-frame construction are in conformity with AF&PA's NDS fastener schedule. In addition, wall sheathing should be fastened directly to framing structure to resist wind pressures. As seen on Figure 2.1 and 2.2 the 2009 IECC requires that for Clark County (3B) climate zone, walls are to have an R-value of R-13 minimum with an equivalent U-factor of 0.082 or less (2009 IECC, 27-28).

TABLE 402.1.1
INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION U-FACTOR[b]	SKYLIGHT[b] U-FACTOR	GLAZED FENESTRATION SHGC[b,e]	CEILING R-VALUE	WOOD FRAME WALL R-VALUE	MASS WALL R-VALUE[i]	FLOOR R-VALUE	BASEMENT[c] WALL R-VALUE	SLAB[d] R-VALUE & DEPTH	CRAWL SPACE[c] WALL R-VALUE
1	1.2	0.75	0.30	30	13	3/4	13	0	0	0
2	0.65[j]	0.75	0.30	30	13	4/6	13	0	0	0
3	0.50[j]	0.65	0.30	30	13	5/8	19	5/13[f]	0	5/13
4 except Marine	0.35	0.60	NR	38	13	5/10	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.35	0.60	NR	38	20 or 13+5[h]	13/17	30g	10/13	10, 2 ft	10/13
6	0.35	0.60	NR	49	20 or 13+5[h]	15/19	30[g]	15/19	10, 4 ft	10/13
7 and 8	0.35	0.60	NR	49	21	19/21	38[g]	15/19	10, 4 ft	10/13

For SI: 1 foot = 304.8 mm.

a. R-values are minimums. U-factors and SHGC are maximums. R-19 batts compressed into a nominal 2 x 6 framing cavity such that the R-value is reduced by R-1 or more shall be marked with the compressed batt R-value in addition to the full thickness R-value.

b. The fenestration U-factor column excludes skylights. The SHGC column applies to all glazed fenestration.

c. "15/19" means R-15 continuous insulated sheathing on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. "15/19" shall be permitted to be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulated sheathing on the interior or exterior of the home. "10/13" means R-10 continuous insulated sheathing on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.

d. R-5 shall be added to the required slab edge R-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less in Zones 1 through 3 for heated slabs.

e. There are no SHGC requirements in the Marine Zone.

f. Basement wall insulation is not required in warm-humid locations as defined by Figure 301.1 and Table 301.1.

g. Or insulation sufficient to fill the framing cavity, R-19 minimum.

h. "13+5" means R-13 cavity insulation plus R-5 insulated sheathing. If structural sheathing covers 25 percent or less of the exterior, insulating sheathing is not required where structural sheathing is used. If structural sheathing covers more than 25 percent of exterior, structural sheathing shall be supplemented with insulated sheathing of at least R-2.

i. The second R-value applies when more than half the insulation is on the interior of the mass wall.

j. For impact rated fenestration complying with Section R301.2.1.2 of the *International Residential Code* or Section 1608.1.2 of the *International Building Code*, the maximum U-factor shall be 0.75 in Zone 2 and 0.65 in Zone 3.

2009 INTERNATIONAL ENERGY CONSERVATION CODE® 27

Figure 2.1 Insulation and Fenestration Requirements By Component for Climate Zone 3

(IECC, 2009)

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 of 0.17 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.

Figure 2.2 Equivalent U-Factors for Climate Zone 3 (IECC, 2009)

2.5 Best Building Practice

Through the contribution from the US Department of Energy (DOE) a team collaboration between the engineering department at the University of Nevada Las Vegas, Pulte Homes (home builder) and NV Energy (local utility) was formed with a mission to reduce peak electricity need by 65% at a substation level (Sadineni et al., 2011).

The result of this collaboration led to the first LEED (Leadership in Energy and Environmental Design) Platinum certification standards with HERS (Home Energy Rating System) that is greater than 50% more efficient than the similar sized homes built with standard building practices (Frances, 2009).

The new residential community named Villa Trieste features energy efficient building envelope, efficient HVAC system and efficient lighting. Villa Trieste homeowners will enjoy homes that are more energy efficient and have a lower impact on the environment as compared to a code compliant built home (Sadineni et al.,2011).

2.6 2x4 Wood Stud Walls

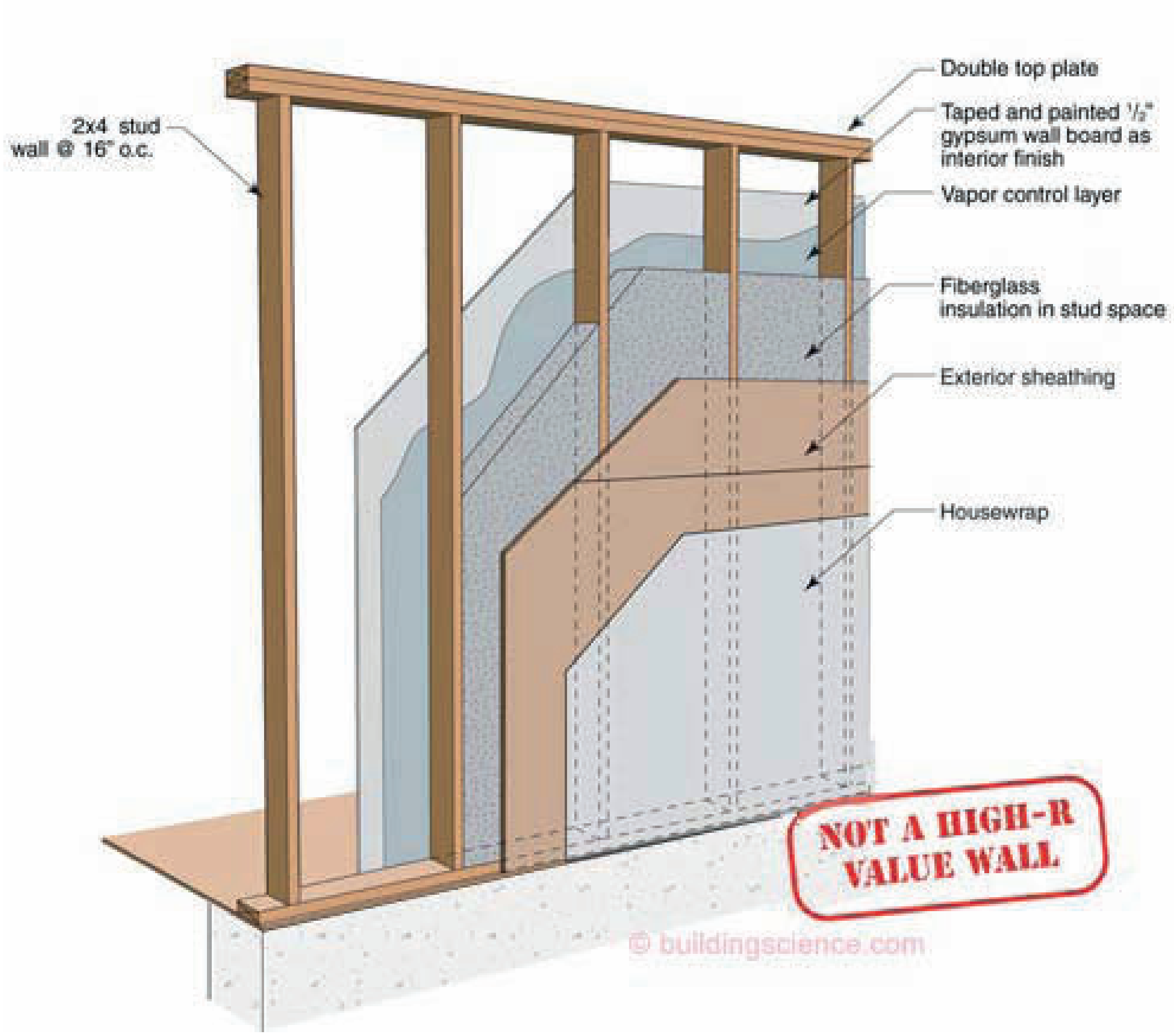


Figure 2.3. 2x4 Standard Wood Construction Wall from Building Science Corporation, 2014.

Conventional framing, the industry standard for framing residential construction, typically consists of: 2x4 wood framing spaced 16 inches on center, double top plates, three-stud corners, multiple jack studs, and double or triple headers. In most cases, the framework is filled with fiberglass or cellulose insulation, and then covered with a layer of 1/2" layer of oriented strand board (OSB), that is made of wood chip pieces glued and compressed together. This is followed by an air barrier layer and the exterior finish, which is typically stucco.

2.7 2x6 Wood Stud Walls

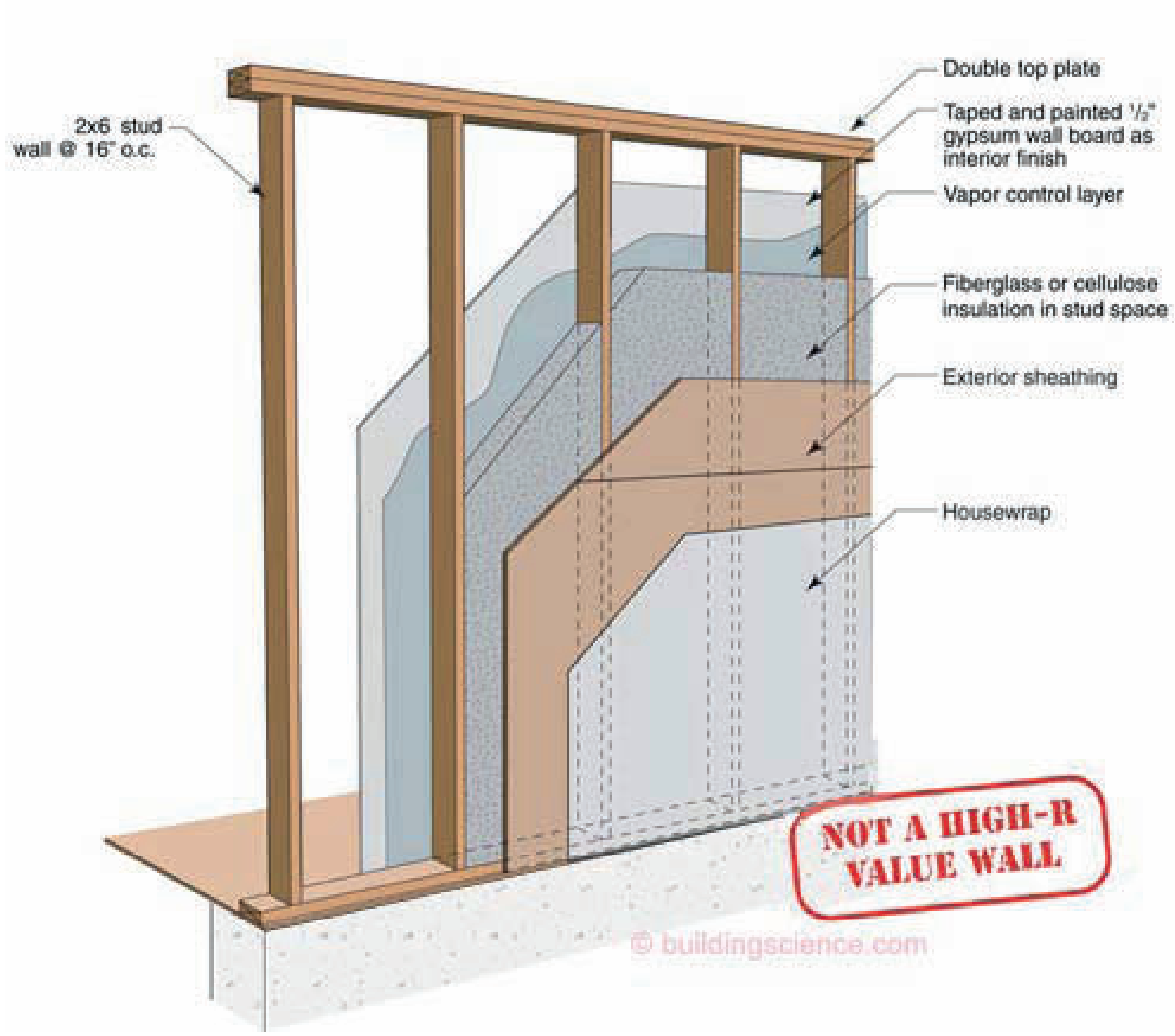


Figure 2.4. 2x6 Wood Stud Centered from Building Science Corporation, 2014

2x6 wood framing 24 inches on center is considered advance framing (Sadineni et al., 2011). It consists of: double top plates, three-stud corners, multiple jack studs, and double or triple headers. The framework is filled with fiber glass or cellulose insulation, when combined with EPS insulation the R-value increases to 23 (Sadineni et al., 2011). Next is 1/2" layer of oriented strand board (OSB) sheathing followed by an air barrier layer and the exterior finish -- which gains is typically stucco.

2.8 Double Stud Centered

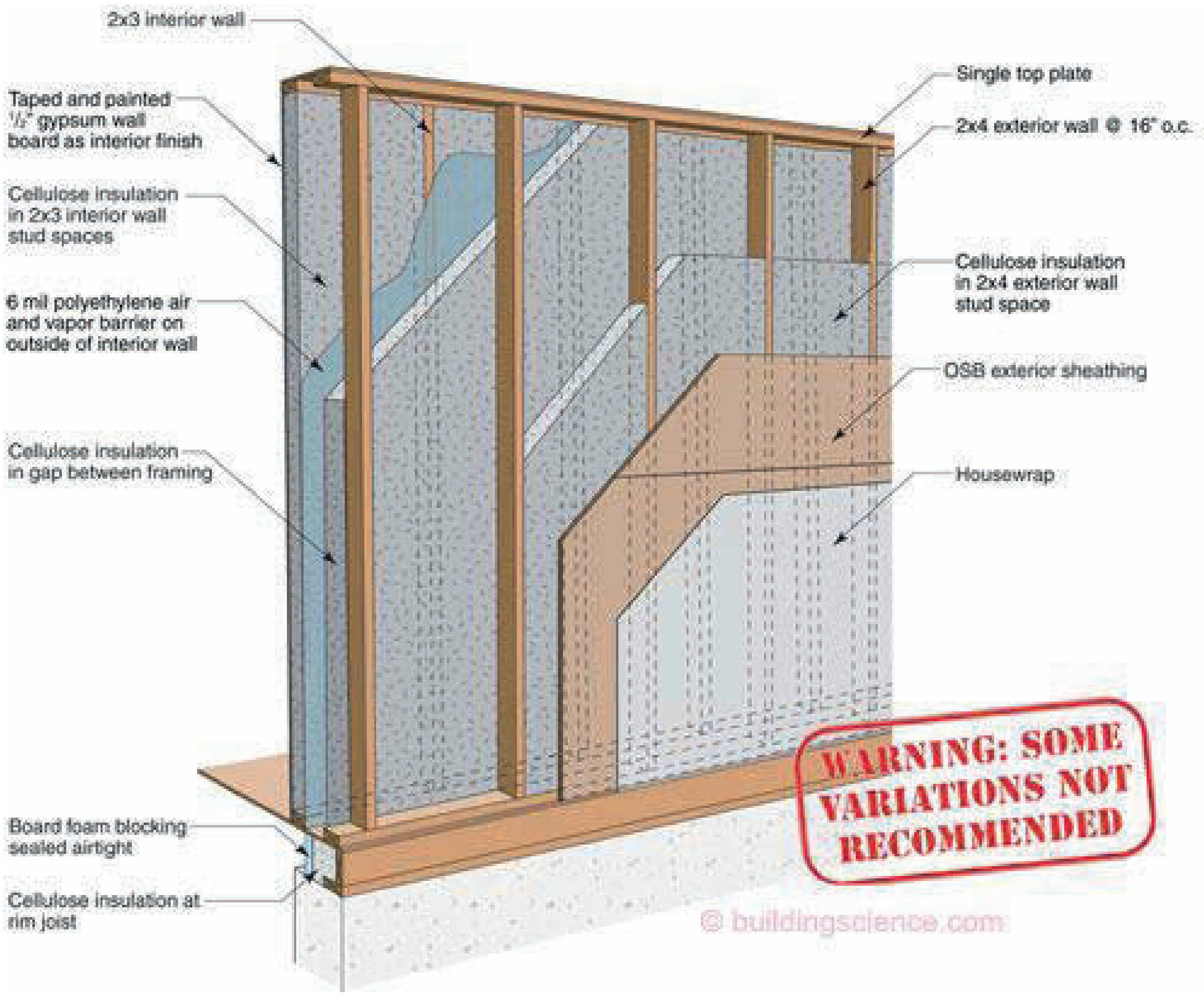


Figure 2.5. Double Wood Stud Centered from Building Science Corporation, 2014.

Double 2x4 walls are built in the same way as conventional 2x4 walls. Instead of a single exterior wall, the house has two parallel exterior walls. After the 2x4 exterior wall, which is 16 inches or 24 inches on center, is constructed – it is followed by a 2x3 or a 2x4 stud wall staggered or centered and 5 inches apart from the exterior wall. The cavity can be filled in with cellulose insulation.

2.9 ICF 8" and 16" Wall

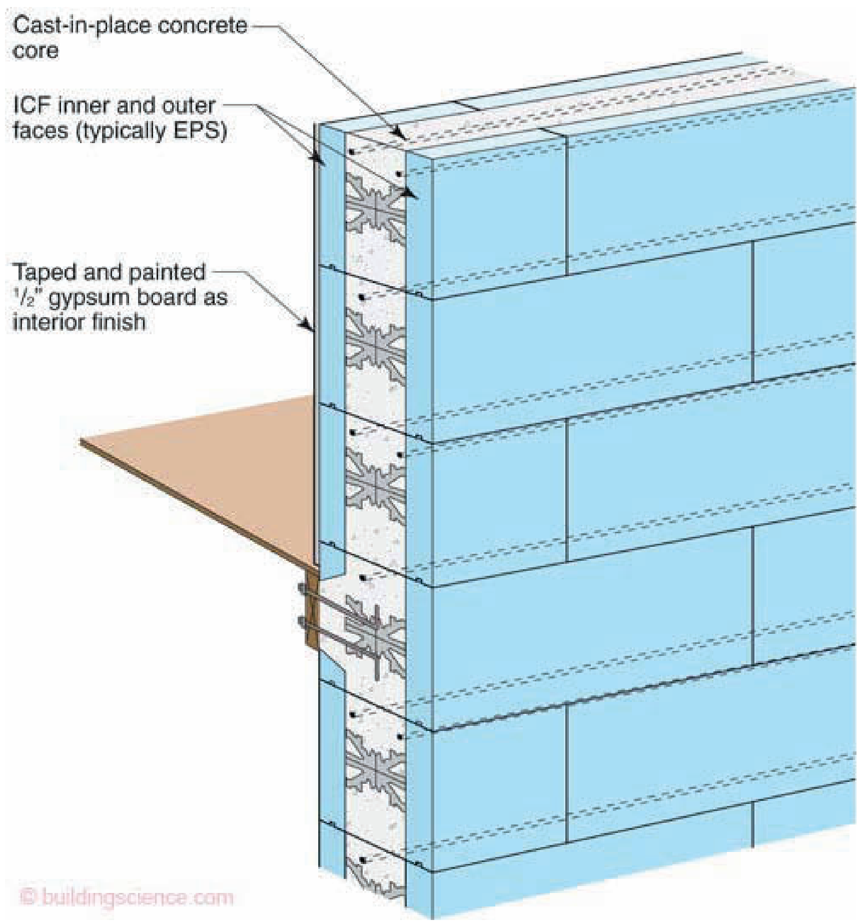
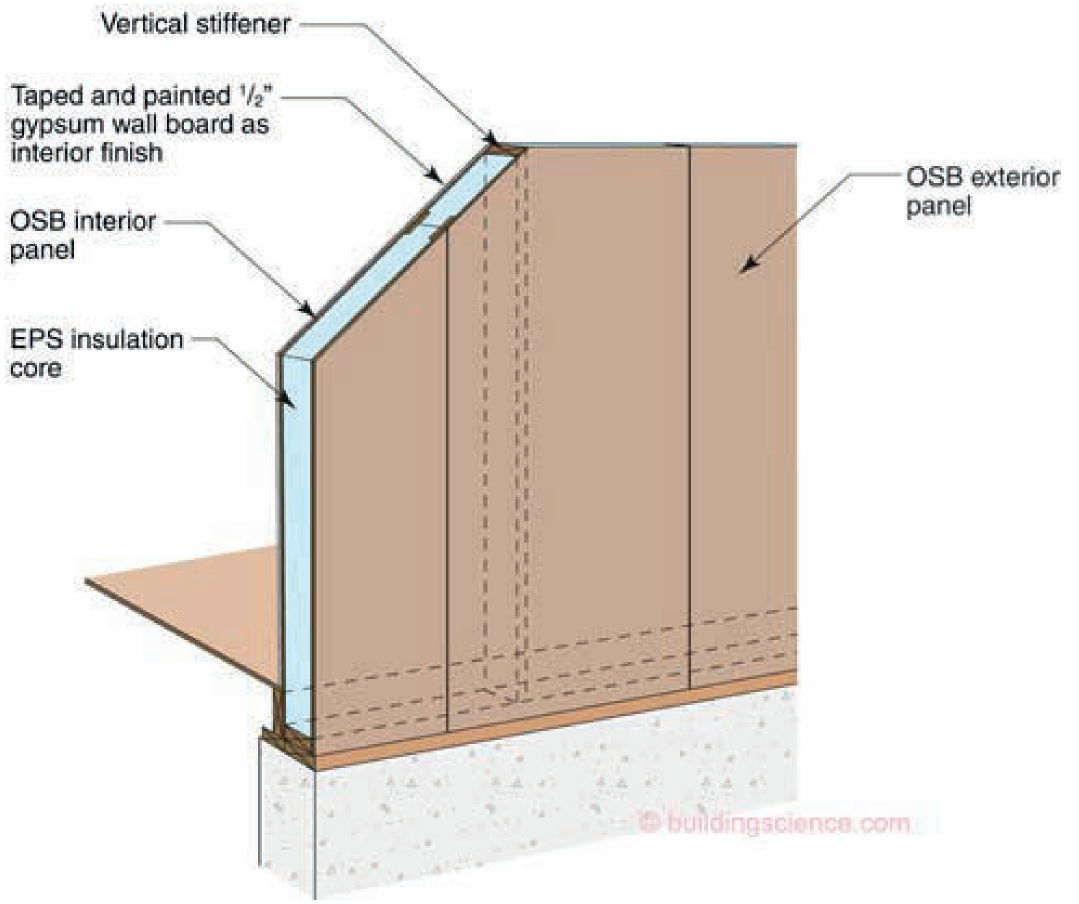


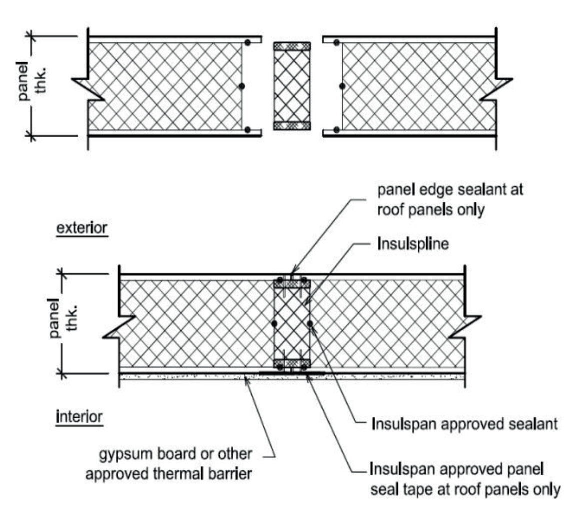
Figure 2.6. Insulated Concrete Form (ICF's) from Building Science Corporation, 2014.

Insulated Concrete Forms (IFCs) are considered an advance new wall technology, it consisting of an EPS inner and outer face (sometimes cement wood fiber) and filled with a cast-in-place concrete. The thickness of EPS and concrete panels varies with higher R-value options (Zhu et al., 2008). It is used for residential and light commercial construction.

2.10 SIP Wall



Insulated Spline Connection



OSB Spline Connection

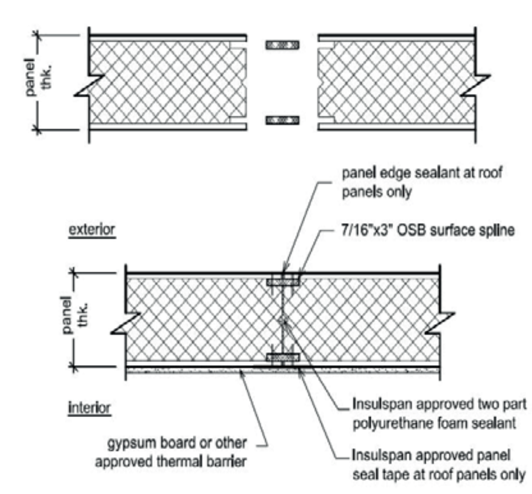


Figure 2.7. Structural Insulated Panel (SIPs) Building Science Corporation, 2014.

Structural Insulated Panels (SIPs) represent another option for designers and builders in the construction industry and gradually is increasing interest as an alternative material for both the residential and commercial buildings.

SIPS are a prefabricated unit made up of sections using two oriented-strand-boards (OSB) on each side encasing a core of expanded polystyrene foam insulation (EPS). The materials used for the exterior facers and the foam insulation core can vary depending on the manufacturer and the desired properties of the final wall system. Alternate insulation cores include extruded polystyrene (XPS), polyisocyanurate and polyurethane. The overall thickness of the foam core varies but is typically available in dimensions closely resembling traditional framed walls. In addition OSB facers can include some manufacturers specialize in plywood, straw board and cement board.

SIPs are an inherently energy efficient system. Thermal bridging through framing members is extremely reduced and can easily achieve a low infiltration system. In addition, studies have shown SIPs posses considerable strength and stiffness necessary to sustain required design goals. Relative to standard framing, SIPs produce much less construction waste because they are built in factories where production processes can be fine-tuned.

Panel connections are a crucial part of the SIP system. Being that the structural joint is critical to the integrity of the building, it is also the location where air leakage can happen. Splines firmly connects each panel together at the joints, this prevents air infiltration into the building. The most common are the insulated spline connection and the OSB surface spline shown in the illustration above.

CHAPTER 3: RESEARCH QUESTION

3.1 Purpose

Shelter provides protection and comfort for individuals against the harsh climatic elements of the environment. Residential housing has become that form of shelter for people, providing to the need for their well-being and safety. This has led to various technological advances in residential housing. Without shelter, human survival in the harsh climates we inhabit would be difficult, if not impossible. However, these structures have serious consequences on energy consumption and on the environment.

The U.S residential buildings account for about 22% of the nation's energy consumption, which releases an estimated 1,116 million metric tons of carbon dioxide emissions into the environment annually (U.S. Energy Information Administration [USEIA], 2015). In the desert southwest region, local electric utilities are facing challenges to keep up with the electrical demand and peak loads (Sadineni et al., 2011). Today, as global warming increases, homebuyers are progressively demanding and purchasing energy-efficient homes that are suitable towards the climate in their designated region. The residential housing sector is beginning to supply consumer demands, through the means of designers and builders, by implementing energy-efficient design methods. These methods include thorough selection of building materials with low embodied energy that will benefit the homebuyer financially, as well as ease the impact of the home on the environment.

A variety of solutions have been investigated towards the efficiency and economic reduction of energy consumption in heating and for cooling homes located in hot arid climates. Examples of design solutions include site orientation, building footprint and surface area, green rooftops, implementation of trees and shrubs to provide shading, materials and human behavior, fenestration and surface area, and thermal mass application (Al-Sallal et al., 2013). These same

methods can be advantageous in the U.S. desert southwest to lower the demand for cooling and heating consumption.

An energy-efficient wall can be another option to minimize thermal bridging by providing a tight building envelope to function as the boundary between the weather outside the house and the interior temperature. This will benefit the consumer with lowered energy bills, eliminating the regular urgency to turn on the air condition unit and as a result this will provide the homebuyer with greater thermal comfort. Identifying an ideal wall assembly for residential buildings in the U.S. Desert Southwest is crucial for designers and builders who strive to achieve exceptional energy efficiency in houses while reducing the embodied energy that has an impact on the environment.

3.2 Research Question

The objective of this study is to answer the main question of identifying an ideal residential exterior wall assembly in the U.S. desert southwest. This will be achieved by using research studies and computer simulations to examine three sub-problems. The sub-problems that will be analyzed include the cost associated with different wall assemblies, energy efficiency of each selected wall choice, and the environmental impact of embodied energy. The article *"A comprehensive Framework for Assessing the Life-Cycle Energy of Building Construction Assemblies"* (Crawford et al., 2011) evaluated eight residential construction assemblies considering embodied energy and thermal performance and ranked them according to their efficiency. Another article *"Analysis of Residential System Strategies Targeting Least-Cost Solutions Leading to Net Zero Energy Homes"* (Anderson et al., 2006) explains what factors are considered when evaluating the construction cost for wall assemblies. Similar to these two articles, the proposed approach for this thesis study is energy efficiency, cost comparisons and life-cycle assessments in the residential sector of the U.S. Desert Southwest to be able to determine the best residential wall assembly.

3.3 Wall Assembly Evaluation

While there are numerous high-performance wall systems to be assessed, the assemblies below are the preferred approach for residential buildings for the U.S. desert southwest climate. This research focused on comparing a typical code compliant traditional framed house 2x4 wood stud 16 in o.c. that has R-13 batt insulation in the cavity wall. The wall assemblies that were researched include:

1. A base case model 2x4 in 16 o.c. with R-13
2. 2x6 in 24 in o.c. with R-17.1
3. Double wood stud 2x4 in centered, 24 in o.c.
4. Double wood stud 2x4 in staggered, 24 in o.c
5. SIP Panel with R-29.2
6. SIP Panel with R-36
7. ICF Panel with R-20.6
8. ICF Panel with R-22.8

3.4 Case Study

This study and thesis was done in conjunction with the Race to Zero Student Design Competition sponsored by the U.S. Department of Energy. This event involves students and teachers from universities in the United States and Canada. There are two goal options for the competition:

1). A real-world scenario where a builder needs to update an existing structure (house plan) to a high-performance house design.

2) Developing a new high performance home that is net zero energy ready but still reasonably affordable.

Teams are challenge with a specific design problem and are responsible to either redesign an existing floor plan or create a new house design that meet the project requirements. The purpose of the competition study is to provide the next generation of architects, engineers, construction managers, and entrepreneurs with knowledge and skills necessary to start careers in clean energy and solve real-world problems related to energy (U.S. DEO, 2014).

The UNLV team decided to pursue the latter option, as the bases of their design for the design competition. Each of the students from the UNLV team was assigned to research various design components that could be advantageous for the new design of the house. The areas that were studied include, site orientation, roof assemblies, wall assemblies, fenestration, mechanical systems and Indoor Air Quality. This information was collectively used as the benchmark simulation model.

Table 3.1 shows all the values that meet the 2009 IECC code standards that included envelope materials for walls, roof, glass and HVAC sizing that are typically used in the southwest climate for residential homes. Water heater, lighting, plug loads, and appliances were set to zero for the simulation and only space conditioning energy data was extracted from the simulation.

The competition requirement was to assess the energy analysis of a base model. The guidelines of the competition recommended and encourage student to use the BEopt software developed by (NREL).

BEopt evaluates residential building designs and identifies cost-optimal efficiency packages at various levels of a whole house energy savings along the path to zero net energy, which is when a home consumes as much energy as it produces annually. Both new construction and existing home retrofits can be analyzed through evaluation of single building designs, parametric sweeps, and cost-based optimizations. In addition, BEopt can simulate based on analysis on different types of characteristic, like size, building construction materials, location, equipment, and utility costs (Valovcin et al., 2014).

Each team member obtained the data from the BEopt simulations to establish which systems or construction assemblies were good candidates to be incorporated in the design competition house. Once the optimal parameters were selected, a simulation model with these systems was generated and evaluated based on performance. It is also important to note that BEopt allowed the students to make quick changes to their systems in the model even after all the parameters were already included in the simulation, this granted student the ability to make last minute changes to enhance optimization performance of the house. The information gathered from the simulations was site energy used, cost of each system, efficiency measurements and CO2 emissions.

Simulation Parameters Base Case Model	
Categories	**System Description**
Building EPW Location	Las Vegas, McCarran International Airport
Orientation	South
Neighbors	None
Walls	R-13 Fiberglass batt insulation with 2x4 studs 16 inches on center with1/2" 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 3.1 Building simulation parameters used in BEopt. Data collected by John Carroll, Ludwing Vaca, Nick Inouye, David McCredo and Johny Corona.

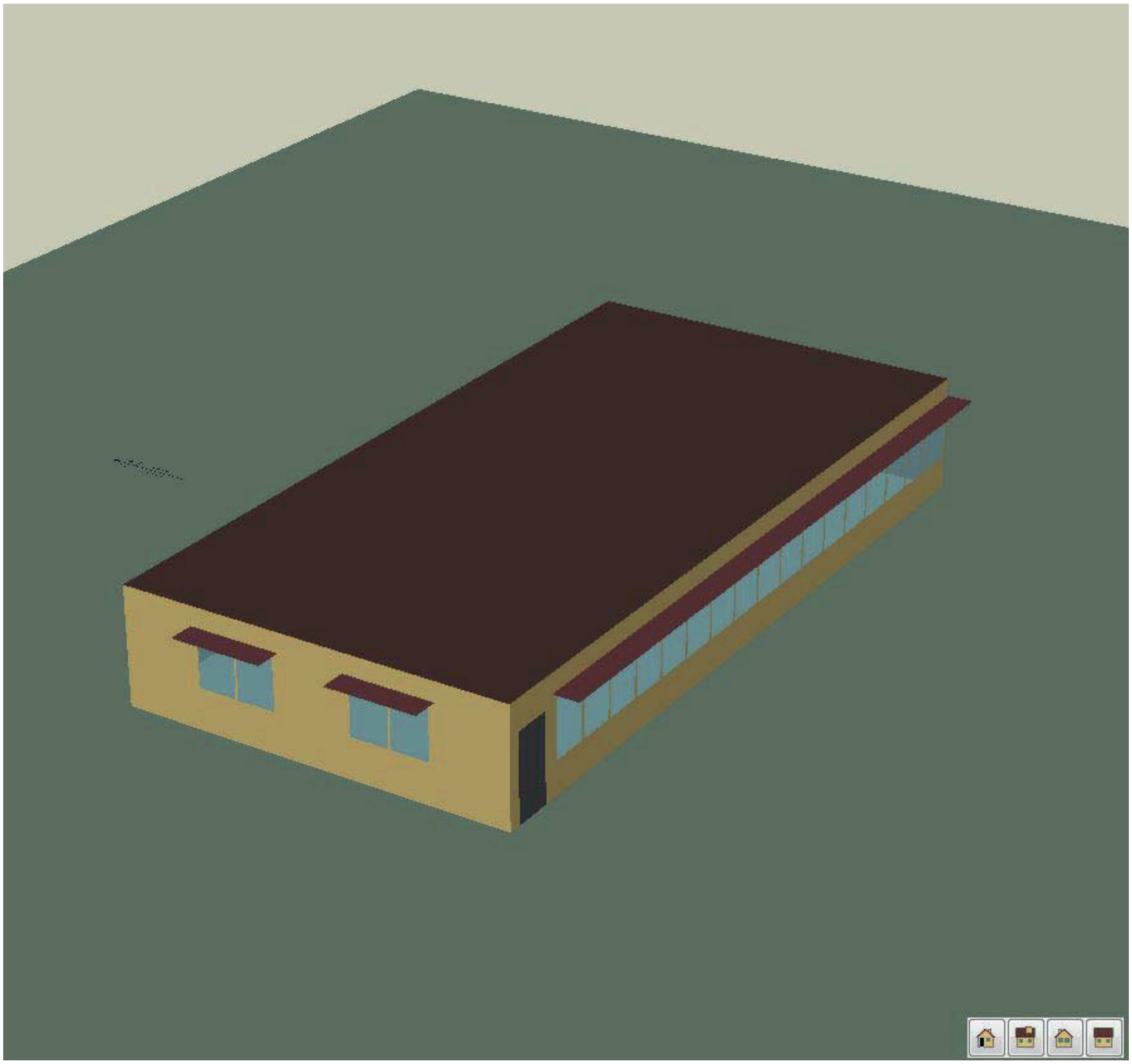


Figure 3.1. 3D simulation model from BEopt.

CHAPTER 4: METHODS

4.1 Context

The purpose of this research project is to test several residential wall assemblies through building simulation modeling and to determine which wall construction is superior in terms of energy effectiveness and cost. Exploring these factors to discover the ideal wall assembly was critical to optimize building construction performance. The data from the simulation model concluded which wall structure proved to be the best option for the U.S. desert southwest and was chosen to answer the research question. In addition, it contributed data to suggest which methods should not be used.

Through the series of parametric analyses carried out using BEopt, the team of students selected the ideal configuration, assemblies, and systems that allowed the design of a net-zero energy home.

4.2. Approach

In order to evaluate different residential wall assemblies different computer software programs were researched. Having worked with other energy modeling programs like RESNET, Equest, Revit, and Green Building Studio -- BEopt was the most instrumental for this research study. Its user-friendly, component properties are selected from predefined list, and options are easy to optimize. The output information clearly supports benchmarking and alternative comparisons. The building performance is compared with a code compliant energy efficient design. BEopt allows full control of all the systems of the building. Equest on the other hand, generates data simulation that is complicated to understand therefore it is unable to use properly in the later stages of the design. The screen interface is manly text; which has limited

geometrical display that is not architectural oriented. Revit and Green Building Studio only give you limited control of the building model, not allowing you to make customization to the other properties of the simulation and make quick changes like Beopt does.

Properties were modified in BEopt to generate a virtual model using Energy Plus simulations. This model provided thermal temperature with simulated environmental conditions that a residential home in Las Vegas could be exposed to in real life. The computer model allowed different building wall assemblies to be proposed and adjust changes to their physical and thermal properties to simulate and evaluate the performance of each. These simulations were a vital component in determining performance outcomes. The physical and thermal properties of each wall assembly were carefully revised until adequate performance levels were reached. After the data was collected, bar graphs were generated to provide and show each wall's performance by ranking from most favorable to least, in terms of thermal efficiency and cost effectiveness. This improved the interpretability of the results by the students in the decision making process.

4.3 Assembly Tested

The baseline assembly that was tested was a standard code compliant 2x4 in stud wall 16 in o.c. with fiberglass insulation, sheathing on the outside and drywall on the inside. Refer to Figure 2.1 for the construction assembly of each component.

4.4 Capital Recovery Cost

Calculating the Cost of Saved/ Avoided Energy, Resources, and /or Pollution. Typically, the cost of an energy and /or resource efficiency measure (or the cost of avoiding some form of pollution) is mostly an initial *Capital Cost* or investment for the technology and /or measure implemented and its associated design, program, or administrative costs. In this case, *CSE* is the cost of the saved energy/resources and is calculated as follows:

*CSE= Capital Cost * CRF/ Annual Energy or Resource Savings (or Annual Avoided Pollution)*

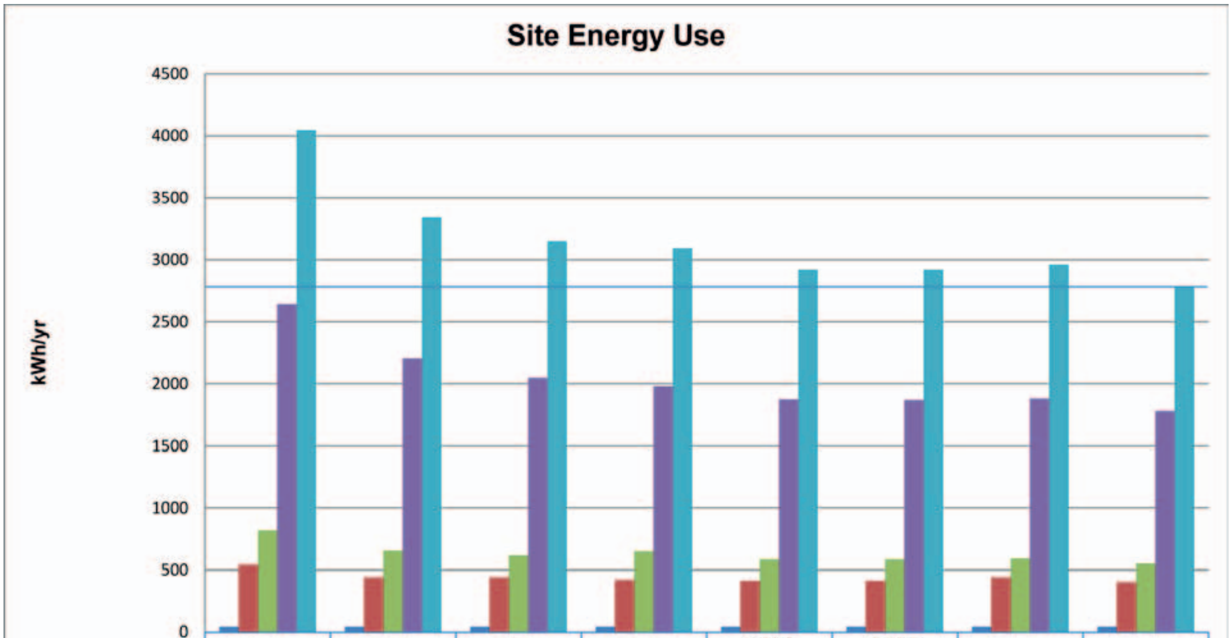
CRF = Capital Recovery Factor, which is the ratio of a uniform annual value (Annuity) and the worth value of the annual stream. The CRF depends on the dividend rate and the time horizon or period considered. In cases where annual operating costs increase or decrease significantly, this value would be added to, or subtracted from, the numerator (Kutcher et al., 2007).

Tables 5.2. through 5.8. show the capital recovery factor, the cost of saved energy (CSE) per square foot and simple payback per square foot in years for each wall construction. The base case of the standard home is used as a comparison to the other assemblies that were tested to see how long before the initial investment is paid back.

Moreover, while the initial investment cost for each wall assembly is higher, compared to the base model, there is capital recovery factor since day one and a cost of energy savings for all the assembly walls.

CHAPTER 5: RESULTS

5.1 Simulation Outputs for Site Energy Use



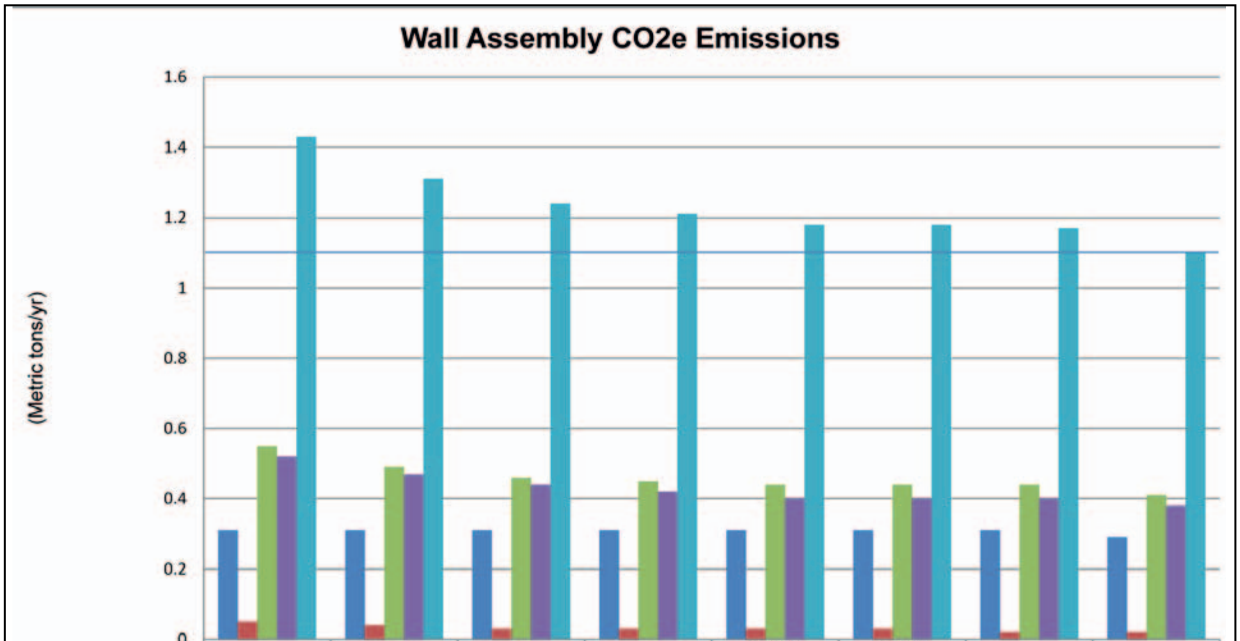
	R-13 Base Case 2x4 16 in o.c.	R-17.1 2x6 24 in o.c. Advanced Practice	R-20.6 ICF 2 in EPS, 4" Concrete, 2 in EPS	R-22.8 ICF 2 in EPS, 12" Concrete, 2 in EPS	R-28.3 Double Wood Stud 2x4 Centered, 24 in o.c.	R-28.5 Double Wood Stud 2x4 Staggered, 24 in o.c.	R-29.2 SIP 7.4 in EPS Core	R-36 SIP 9.4 in EPS Core
Vent Fan (E)	41.03	41.03	41.03	41.03	41.03	41.03	41.03	41.03
HVAC Fan/Pump (E)	542.03	442.43	442.56	421.31	413.56	413.56	442.56	402.25
Cooling (E)	820.29	656.51	618.41	650.75	586.17	586.17	592.03	551.51
Heating (G)	2642.88	2206.31	2048.09	1980.07	1877.07	1872.29	1884.01	1784.39
Total	4046.23	3346.28	3150.09	3093.16	2917.83	2917.83	2959.63	2779.18

Figure 5.1 Site Energy Use

Figure 5.1, show the site electricity consumption in kWh/yr. All seven wall assemblies studied show a significant improvement from the base case scenario. Even the R-17.1 2x6, 24" o.c. advanced practice wall shows a 700 kWh/yr energy savings or an 17.3% reduction in energy consumption. However, the wall assembly that performs the best is the R-36 SIP 9.4 in EPS Core wall assembly with a reduction of 1,267 kWh/yr or 31.3% less energy use than the base case model. Not too far from these figures are the R28.3 Double Wood Stud 2x4 Centered, 24 in. o.c., R-28.5 Double Wood Stud 2x4 Staggered, 24 in. o.c., and the R-29.2 SIP 7.4 in EPS Core. These three wall assemblies show an energy reduction of 1,128 kWh/yr, 1,133 kWh/yr, and 1,087 kWh/yr or 27.9%, 28.0% and 26.9% respectively, compared to the 2x4 16 in. o.c. standard wall construction for new residential homes in the U.S. Desert Southwest.

Additionally, except for a minimal difference in the R-29.2 SIP 7.4 in EPS Core, the R-value increase in the different wall constructions caused a reduction in energy use. It is also important to note that in all cases, including the base model, between 63% to 65% of the total energy use in space conditioning goes into heating during the winter season. Cooling is less than the heating requirement, which points out that the issue is not the heat coming in but the flow of heat going out that is much problematic.

5.2 Wall Assembly CO2e Emissions



	R-13 Base Case 2x4 16 in o.c.	R-17.1 2x6 24 in o.c. Advanced Practice	R-20.6 ICF 2 in EPS, 4" Concrete, 2 in EPS	R-22.8 ICF 2 in EPS, 12" Concrete, 2 in EPS	R-28.3 Double Wood Stud 2x4 Centered, 24 in o.c.	R-28.5 Double Wood Stud 2x4 Staggered, 24 in o.c.	R-29.2 SIP 7.4 in EPS Core	R-36 SIP 9.4 in EPS Core
Vent Fan (E)	0.31	0.31	0.31	0.31	0.31	0.31	0.31	0.29
HVAC Fan/Pump (E)	0.05	0.04	0.03	0.03	0.03	0.03	0.02	0.02
Cooling (E)	0.55	0.49	0.46	0.45	0.44	0.44	0.44	0.41
Heating (G)	0.52	0.47	0.44	0.42	0.4	0.4	0.4	0.38
Total	1.43	1.31	1.24	1.21	1.18	1.18	1.17	1.1

Figure 5.2 Wall Assembly CO2e Emissions

The results in Figure 5.2, show the annual equivalent carbon emissions in Metric tons/yr. The R-36 SIP 9.4 in EPS Core wall assembly produced more than one quarter less CO_2 into the atmosphere or 0.33 Metric tons/yr. than the base case model. Similar to the energy analysis simulation, the R28.3 Double Wood Stud 2x4 Centered, 24 in. o.c., R-28.5 Double Wood Stud 2x4 Staggered, 24 in. o.c., and the R-29.2 SIP 7.4 in EPS Core wall assemblies performed almost evenly in reducing carbon emissions to the atmosphere. A reduction of between 17.5% to 18.2% of CO_2 emissions was found among the latter wall construction types compared to the typical wall assembly. It is also important to note that higher reductions were encountered in the use of heating for the winter season as compared to the use of the cooling system almost evenly across all wall types except for the R-17.1 2x6, 24" o.c. advanced practice and R-22.8 ICF 2 in. EPS, 12" Concrete, 2"in. EPS wall types. Last, only an 8.4% reduction in carbon emissions was found using the R-17.1 2x6, 24" o.c. advanced practice wall assembly, making it this wall assembly the least beneficial in improving the atmosphere.

5.3 Cost of Assembly Walls

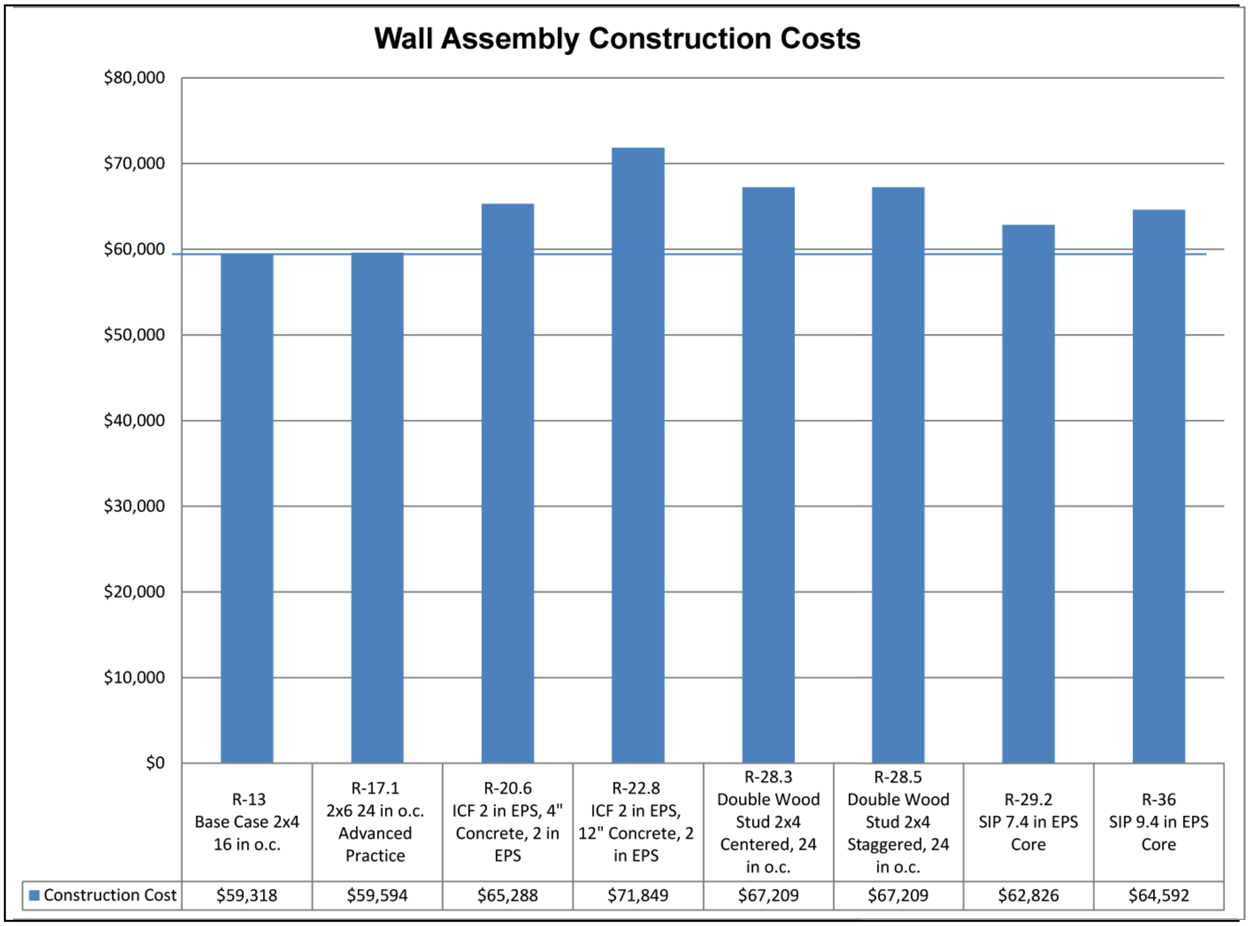
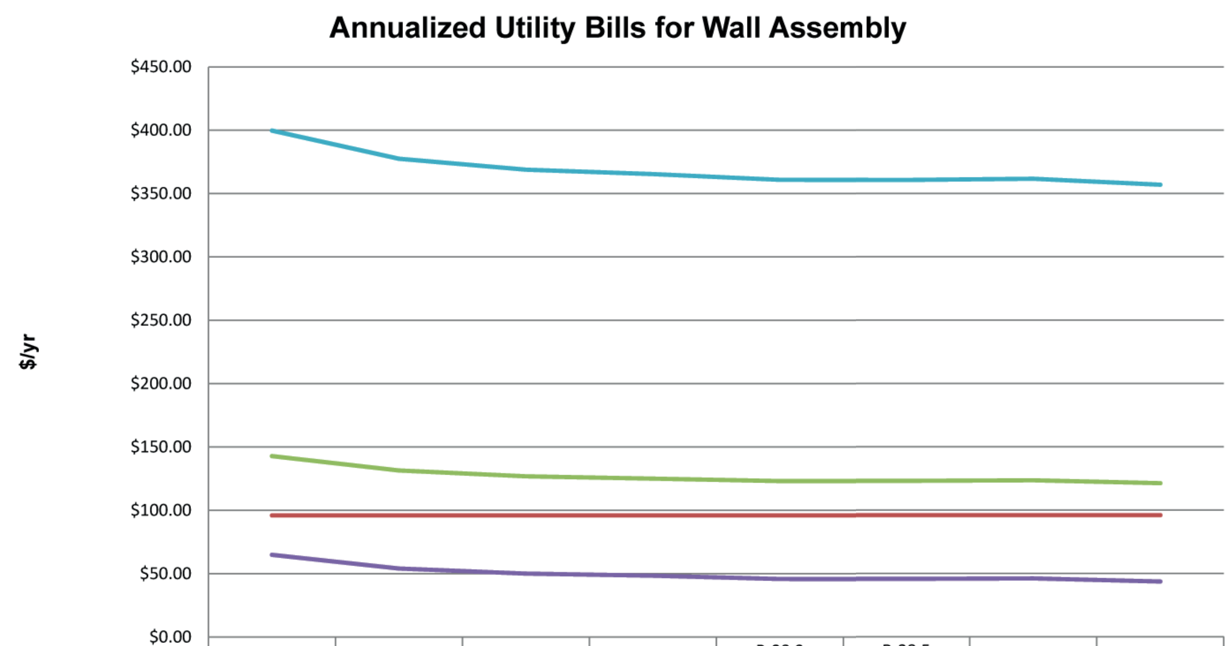


Figure 5.3 Wall Assembly Construction Cost

The results in Figure 5.3 show the upfront material and labor cost of the wall assemblies, regardless of whether the technology is actually being paid for immediately or with cash. This cost is not directly used in cash flow calculations for the various y-axis metric; the value here is only for informational display purposes. No financing, rebates, or incentives are applied to these values.

The analysis of first costs for the different wall assemblies show that there is an increase of between 0.5% to 21.1% compared that to the base model. The R-17.1 2x6, 24" o.c. advanced practice wall assembly shows almost a negligible increase in price of $276 from the $59,318 total cost, or a 0.5% increase. In the other side of the analysis we find that the R-22.8 ICF 2 in. EPS, 12" Concrete, 2"in. EPS wall type shows the highest price difference with an additional $12,531 to the total construction cost. The R-36 SIP 9.4 in EPS Core wall assembly, which had performed well in energy and carbon emission reductions, showed an increase of 8.9% or an addition of $5,274 to that of the typical wall construction in the U.S. Desert Southwest, making it the third most economical wall type option. The other SIP wall, the R-29.2 SIP 7.4 in EPS Core, is the second lowest alternative with an additional $3,508 or an increase of 5.9% to that of the base simulation model. At an increase of $5,970 or just over 10%, is the R-20.6 ICF 2 in. EOS, 4" Concrete, 2 in. EPS wall assembly. Finally, at the same price increase of $7,891 or 13.3% are the Double Wood Stud wall assemblies.

5.4 Annual Utility Cost



	R-13 Base Case 2x4 16 in o.c.	R-17.1 2x6 24 in o.c. Advanced Practice	R-20.6 ICF 2 in EPS, 4" Concrete, 2 in EPS	R-22.8 ICF 2 in EPS, 12" Concrete, 2 in EPS	R-28.3 Double Wood Stud 2x4 Centered, 24 in o.c.	R-28.5 Double Wood Stud 2x4 Staggered, 24 in o.c.	R-29.2 SIP 7.4 in EPS Core	R-36 SIP 9.4 in EPS Core
Fixed Charge (E)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Fixed Charge (G)	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99	$95.99
Energy Charge (E)	$142.77	$131.48	$126.85	$125.01	$123.13	$123.08	$123.57	$121.28
Energy Charge (G)	$64.91	$54.05	$50.07	$48.39	$45.77	$45.68	$46.02	$43.60
Total	$399.70	$377.50	$368.90	$365.40	$360.90	$360.70	$361.60	$356.90

Figure 5.4 Annual Utility Bills

The results in Figure 5.4, show the energy consumption of the different wall assemblies types studied as an annual energy cost. The base case model, the 2x4 16 in. o.c., showed the highest annual energy cost at just under $400 a year. The R-36 SIP 9.4 in EPS Core wall assembly showed the most savings compared to this figure with a saving of $42.80 annually or a 10.7% reduction. The R-17.1 2x6, 24" o.c. advanced practice wall assembly showed the least amount of savings at $22.20 or 5.6% less per year. Once again the three wall types, the R28.3 Double Wood Stud 2x4 Centered, 24 in. o.c., R-28.5 Double Wood Stud 2x4 Staggered, 24 in.o.c., and the R-29.2 SIP 7.4 in EPS Core wall assemblies performed almost similarly with savings of just under 10% or between $38 and $39 annually. It is also important to note that as an average between all simulations, the total heating annual charges were about 39.5% of the total energy use in space conditioning, while the cooling costs were 60.5%.

5.5 Simple Payback Costs

Wall Assembly	Energy Use (kBTU/sf/yr)		System Cost (per sq.ft.)		Utility Cost ($/sf/yr)		CSE ($/sf/yr)	Simple Payback (yrs)
	Heating	Cooling	Absolute	Over Base	Heating	Cooling		
Base base 2x4 16 in o.c.	4.94	2.44	$33.00	$0.00	$0.03606	$0.07931	$0.00	0.5
R-17.1 2X6 24 in o.c.	4.11	2.27	$33.10	$2.71	$0.03002	$0.07304	$0.00	0.4
R-20.6 ICF 2 in EPS, 4" Concrete, 2 in EPS	3.77	2.16	$36.27	$7.53	$0.02781	$0.07047	$0.00	0.4
R-22.8 ICF 2 in EPS, 12" Concrete, 2 in EPS	3.66	2.16	$40.00	$11.58	$0.02688	$0.06945	$0.00	0.3
R-28.3 Double Wood Stud 2x4 Centered, 24 in o.c.	3.5	2.11	$37.33	$7.43	$0.02542	$0.06840	$0.00	0.3
R-28.5 Double Wood Stud 2x4 Staggered, 24 in o.c.	3.44	2.11	$37.33	$7.43	$0.02537	$0.06837	$0.00	0.3
R-29.2 SIP 7.4 in EPS Core	3.5	2.11	$34.90	$6.01	$0.02556	$0.06865	$0.00	0.3
R-36 SIP 9.4 in EPS Core	3.33	2.05	$35.90	$7.10	$0.02422	$0.06737	$0.00	0.3

Table 5.1 Simple Payback Costs

Table 5.1 shows the simple payback results for all wall assemblies studied, including the base case model. These are divided in the energy use in kBTU/sf/yr, system cost per square feet, utility cost in dollars per square feet yearly, the CSE (cost of saved energy) in dollar per kWh, and finally the simple payback in total amount of years. The simulations performed in BEopt helped us gather the data for energy use and system cost for heating and cooling, while the utility cost, again for both cooling and heating, was obtained by adding the total annualized utility bills and divided by the square footage of the house to get the cost. The CSE and simple payback were calculated using the capital recovery cost formula explained in section 4.4. The base case model with the typical U.S. Desert Southwest wall assembly is used to compare the amount of years it would require to pay back the initial investment.

The results show a minimal simple payback on all wall systems ranging from 0.3 to 0.5 years, making all these walls become a feasible option for any homebuyer. After a six month period the extra investment for the R-17.1 2x6, 24" o.c. advanced practice wall assembly would be returned to the buyer. While for the R-20.6 ICF 2 in. EPS, 4" Concrete, 2 in. EPS and the R-22.8 ICF 2 in. EPS, 12" Concrete, 2 in. EPS wall types that period is only 0.4 years. Finally, the R-28.3 Double Wood Stud 2x4 Centered, 24 in. o.c., R-28.5 Double Wood Stud 2x4 Staggered, 24 in. o.c., and the R-29.2 SIP 7.4 in EPS Core, and the R-36 SIP 9.4 in EPS Core wall assemblies would take only 0.3 years to pay back the initial investment.

Therefore, besides the other benefits found in this study, like energy and CO2 emissions reductions, the simple payback of using any of these wall assemblies being less than a year is an important reason why home builders, designers, and buyers should consider the use of different wall types in residential construction for the U.S. Desert Southwest.

Capital Recovery Factor (CRF):

where:		units:
Capital Cost (investment) =	$33.10	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	30	years
CRF =	**0.033**	
Present Worth =	**$33.10**	dollars
Compound Factor =	**1.009**	
Future Worth =	**$33.40**	dollars
Interest Paid =	**$0.30**	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	699	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	20970	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.5	years

Figure 5.5. Capital Recovery Factor and Simple Payback for R-17.1 - 2x6 Wall

Capital Recovery Factor (CRF):

where:		units:
Capital Cost (investment) =	$36.27	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	30	years
CRF =	**0.033**	
Present Worth =	$36.27	dollars
Compound Factor =	1.009	
Future Worth =	$36.60	dollars
Interest Paid =	$0.33	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	896	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	26880	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.4	years

Figure 5.6. Capital Recovery Factor and Simple Payback for R-20.6 ICF

Capital Recovery Factor (CRF):

	where:	units:
Capital Cost (investment) =	$40.00	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	30	years
CRF =	**0.033**	
Present Worth =	**$40.00**	dollars
Compound Factor =	**1.009**	
Future Worth =	**$40.36**	dollars
Interest Paid =	**$0.36**	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	953	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	28590	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.4	years

Figure 5.7. Capital Recovery Factor and Simple Payback for R-22.8 ICF

Capital Recovery Factor (CRF):

	where:	units:
Capital Cost (investment) =	$37.33	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	30	years
CRF =	**0.033**	
Present Worth =	**$37.33**	dollars
Compound Factor =	**1.009**	
Future Worth =	**$37.67**	dollars
Interest Paid =	**$0.34**	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	1128	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	33840	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.3	years

Figure 5.8. Capital Recovery Factor and Simple Payback for R-28.3 2x4 Double Wood Centered

Capital Recovery Factor (CRF):

where:		units:
Capital Cost (investment) =	$37.10	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	**30**	years
CRF =	**0.033**	
Present Worth =	**$37.10**	dollars
Compound Factor =	**1.009**	
Future Worth =	**$37.44**	dollars
Interest Paid =	**$0.34**	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	1128	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	33840	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.3	years

Figure 5.9. Capital Recovery Factor and Simple Payback for R-28.5 2x4 Double Wood-staggered

Capital Recovery Factor (CRF):

where:		units:
Capital Cost (investment) =	$34.90	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	30	years
CRF =	**0.033**	
Present Worth =	**$34.90**	dollars
Compound Factor =	**1.009**	
Future Worth =	**$35.22**	dollars
Interest Paid =	**$0.32**	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	1086	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	32580	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.3	years

Figure 5.10. Capital Recovery Factor and Simple Payback for R-29.2 SIP

Capital Recovery Factor (CRF):

where:		units:
Capital Cost (investment) =	$35.90	dollars
i (dividend rate as fraction) =	0.03%	%
n (period) =	30	years
CRF =	**0.033**	
Present Worth =	$35.90	dollars
Compound Factor =	1.009	
Future Worth =	$36.22	dollars
Interest Paid =	$0.32	dollars

Simple Payback

		units:
System Savings	0	W
System weekly operation	0	h / week
System annual operation	0	h / year
Annual Energy Savings	1267	kWh
Cost of Saved Energy	$0.00	$ / kWh
Energy Saved Over Period	38010	kWh
Cost of Saved Unit	$0.10	$ / unit
Simple Payback	0.3	years

Figure 5.11. Capital Recovery Factor and Simple Payback for R-36 SIP

5.6 Embodied Energy

Embodied energy is an approach to measure the energy that is required to develop, process, manufacture, and transport a product (Randolph, 2008).

Attia's article *State of the Art of Existing Early Design Simulation Tools for Net Zero Energy Buildings: A Comparison of Ten Tools* seen on Figure 5.12. analyses various energy simulation software programs based performance for each category given, the Embodied energy criteria was not evaluated. This may be due to the complexity to quantify the embodied energy process that may not be available in the software programs.

The life cycle assessment evaluates all of the impacts over the whole life of a material or element, while embodied energy only considers the front-end- aspect of the impact of the building material, it also does not include the operation or disposal of materials (Crawford et al., 2010).

The BEopt software does not have the options to measure the embodied energy of building materials; it could be because of the same problem that a reliable database is not currently available to gather accurate information for parameters to be implemented in the software. Nonetheless, Beopt has the option to simulate the Life Cycle Cost (LCC), which refers to the full cost of ownership over the life of a technology. The life cycle energy related to costs is calculated identically to annualized energy related costs, except that:

1. Cash flows are converted to the present value, rather than annualized and,
2. All cash flows are absolute (not relative to the reference)

When comparing the life cycle costs of two technologies, the lower LCC indicates a more favorable investment. However, there may be capital costs constraints that limit the selection of technologies. Being that the tool options to measure the embodied energy of buildings are not available in BEopt, the embodied energy was not factored in this search.

Results of the NZEB Tools Matrix

NZEB Criteria	HEED	eQUEST	Energy 10	Vasari	Solar Shoebox	Openstudio	IES VE-Ware	ECOTECT	DesignBuilder	BeOpt
Metrics	•	•	•	•	•	•	•	•	•	•
Energy	•	•	•	•	•	•	•	•	•	•
Environmental (CO_2)	•	•	•				•		•	•
Economic	•	•	•						•	•
Embodied Energy										
Urban Scale NZEBs										
Comfort & Climate	•	•	•		•		•	•	•	•
Climate Analysis	•	•	•	•			•	•	•	
Static	•	•	•	•			•	•	•	•
Adaptive					•					
Comfort Visualisation					•			•	•	
Passive Solar	•	•	•	•	•	•	•	•	•	•
Geometry, Massing				•	•	•	•			•
Daylighting	•	•	•				•		•	
Natural Ventilation	•		•				•		•	•
WWR		•	•				•		•	•
Thermal Mass	•		•				•		•	•
Shading Devices	•	•	•			•	•	•	•	•
Energy Efficiency	•	•	•	•	•	•	•	•	•	•
Envelope Insulation	•	•	•	•	•	•	•	•	•	•
Glazing Performance	•	•	•	•	•		•	•	•	•
Envelope Air Tightness	•	•	•				•	•	•	•
Artificial lighting	•	•	•				•		•	•
Plug Loads	•	•	•				•		•	•
Infiltration rate	•	•	•		•				•	•
Mechanical Ventilation	•		•						•	•
Cooling System	•	•	•	•			•		•	•
Heating system	•	•	•	•			•		•	•
Renewable ES	•		•		•		•			•
Photovoltaic (PV)	•		•		•		•			•
Building Integrated PV										
Solar Therm. Collectors			•				•			•
Innovative Solution & Technologies					•		•			•
Mixed Mode Ventilation					•					
Advanced Fenestration							•		•	
Green Roofs							•			
Cool Roofs	•									
Double Skin Facade									•	
Solar Tubes										
Phase change materials										

Figure 5.12. NZEB Tool Matrix. Data Collected by Shady Attia

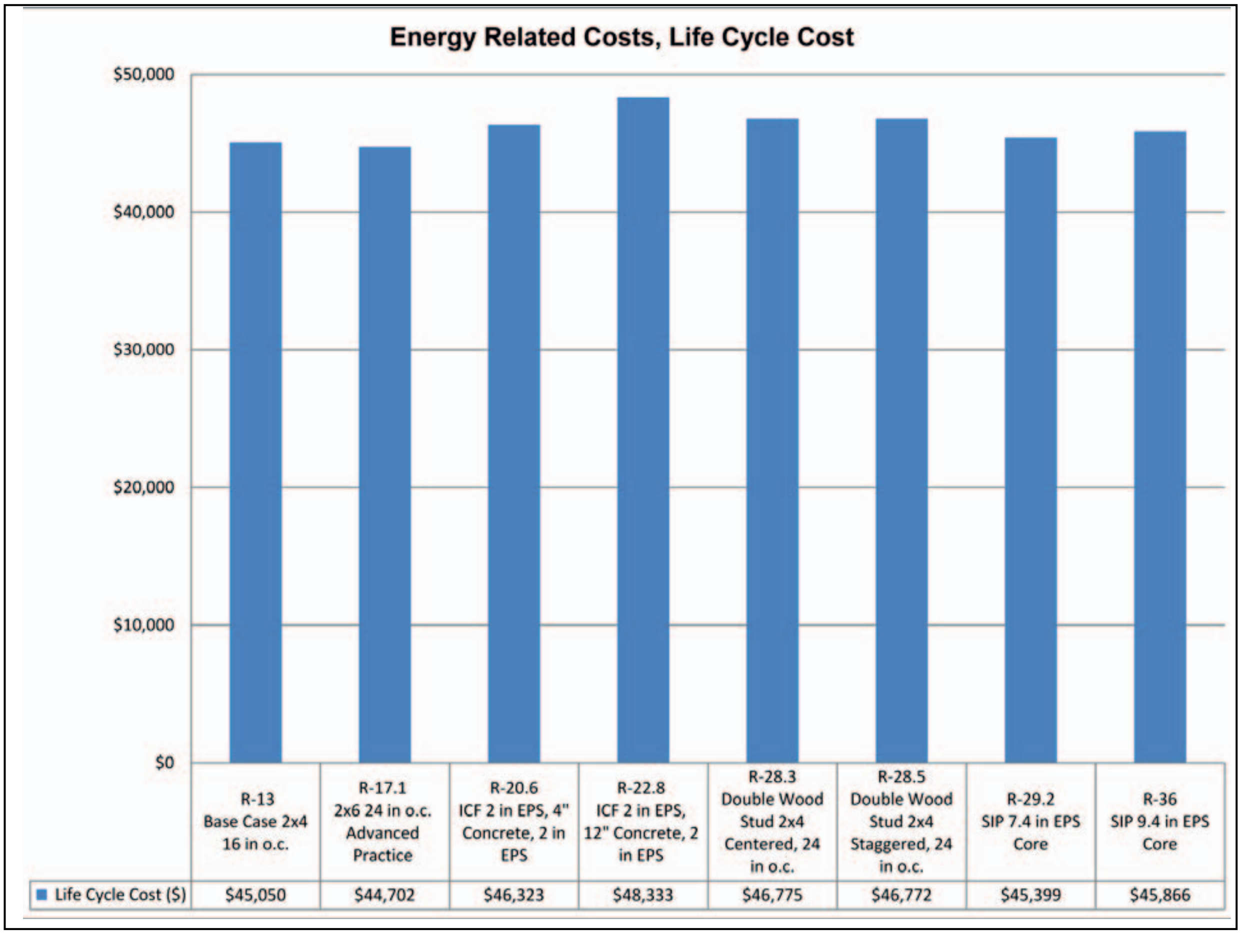


Figure 5.13. Energy Related Costs, Life Cycle Cost

The results from figure 5.13 showed that the R-22.8 ICF 2 in EPS, 12" Concrete, 2 in. EPS wall assembly had the highest life cycle costs, with an additional $3,283 being spent on the lifetime of the assembly, compared to that of the base case model. Moreover, the R-17.1 2x6 24 in o.c. advanced practice wall assembly showed the lowest life cycle costs out of all the wall assemblies. This wall type was even less than the typical wall type with a reduction of $348 compared to the life cycle cost of the R-13 Base Case 2x4 16 in o.c. wall.

Both SIP wall panels, the R-29.2 SIP 7.4 in EPS Core and the R-36 SIP 9.4 in EPS Core, showed the second lowest life cycle costs, with an additional $349 and $817 respectively

compared that to the base simulation wall type. The rest of the wall assemblies, the R-20.6 ICF 2 in EPS, 4" Concrete, 2 in EPS, the R-28.3 Double Wood Stud 2x4 Centered, 24 in o.c., and the R-28.5 Double Wood Stud 2x4 Staggered, 24 in o.c. showed an increase of LCC of between $1,274 to $1,725 compared to the typical wall assembly used in the region.

CHAPTER 6: CONCLUSION

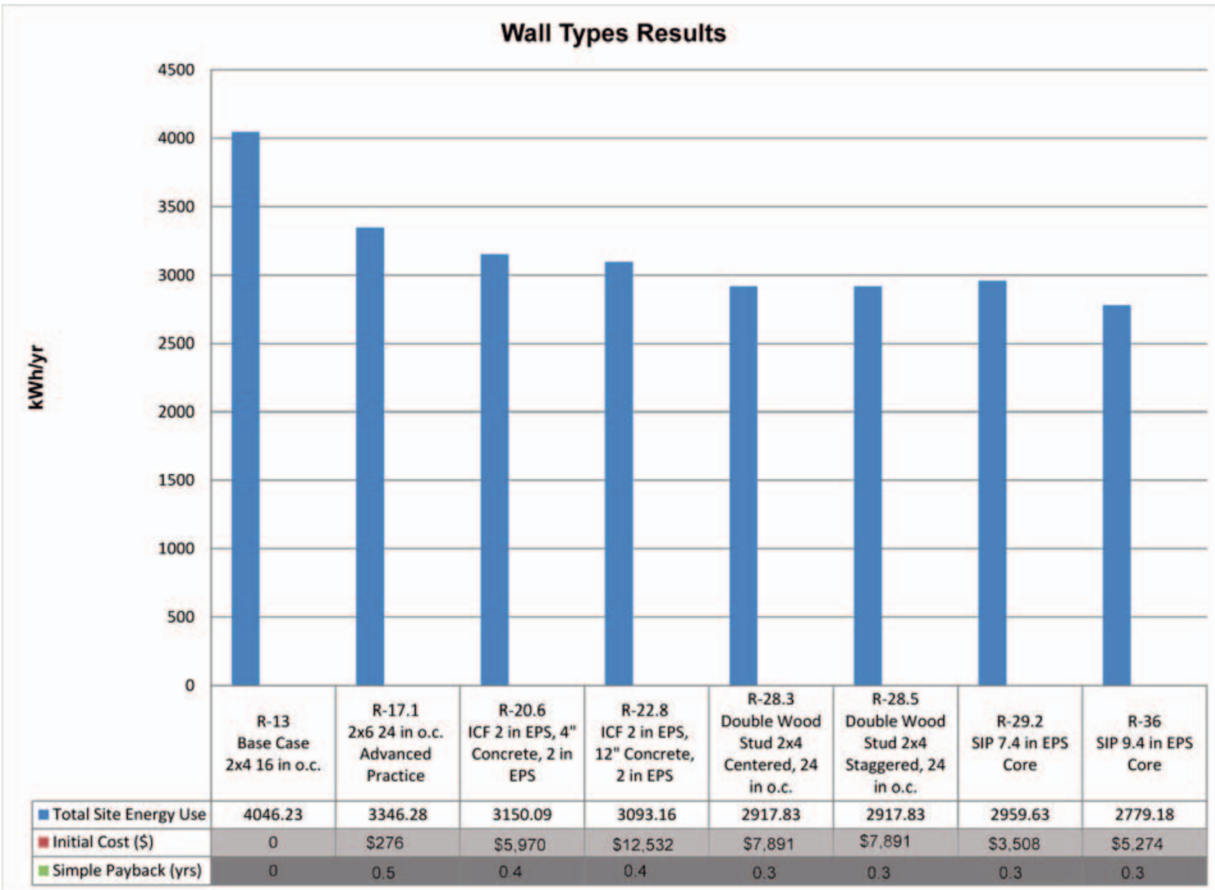


Figure 6.1 Wall Types Results

1 – Most Desirable	R-29.2 SIP 7.4 in. EPS CORE R-36 SIP 9.4 in. EPS CORE
2 –	R-20.6 ICF 2 in. EPS, 4” Concrete, 2 in. EPS R-28.3 Double Wood Stud 2X4 Centered 24 in. o.c. R-28.5 Double Wood Stud 2x4 Staggered, 24 in. o.c.
3 –	R-22.8 ICF 2 in. EPS, 12” Concrete, 2 in. EPS
4 – Most Desirable	R-17.1 2x6, 24” o.c.

Table 6.1 Final Rankings

The buildings in which we live, work, and play protect us from the climatic elements of our surroundings, yet they also affect the environment in countless ways. It is evident from the literature review that climate, shape, size, orientation, construction techniques, materials, occupancy behavior and renewable energy systems are all part of a range of considerations the designer must make at the early stage of a design to ease the negative impact to the environment.

This paper's aim was to simulate and model the wall assembly that is typically used in the desert southwest region, as well as seven additional walls options and provide evidence to support for early decisions making in the design process. Results are presented by comparing each wall assemblies next to each other representing how well they performed with one another in terms of cost and energy efficiency.

As discuss earlier, all of the seven wall assemblies studied show a significant improvement in site energy use, CO_2 emission reductions, and lowered energy annual costs compared to the base case scenario. In contrast, all wall assemblies, except for the R-17.1 2x6, 24" o.c. advanced practice wall assembly, show an increase of initial construction costs of up to 21.1% or up to an additional $12,532. However, all initial extra investment on any of the wall assemblies studied would be paid back within six months or less, as shown in the simple payback calculations in Section 5.5.

We can therefore rank the seven wall types studied based on the results from figure 6.1 into four categories as shown in table 6.1. The least desirable wall assembly would be the R-17.1 2x6, 24" o.c. advanced practice wall type, as this one had the least amount of energy savings, CO_2 emissions reductions, and energy annual costs cutbacks out of all the types studied. It also had the longest amount of simple payback and the smallest amount of additional initial construction cost of $276.

On the third tier would be the R-22.8 ICF 2 in. EPS, 12" Concrete, 2 in. EPS wall type. The reason being that even though it provided moderate savings of energy of 953 kWh

annually, and therefore CO_2 emissions and energy cost reductions, its initial cost of over $12,000 or 21% compared to the base case wall, made this wall type less favorable to a homebuyer or builder.

On the second group of preferred wall types we have the R-20.6 ICF 2 in. EPS, 4" Concrete, 2 in. EPS, the R-28.3 Double Wood Stud 2x4 Centered, 24 in. o.c., and the R-28.5 Double Wood Stud 2x4 Staggered, 24 in. o.c. wall assemblies because they had a medium range of energy savings to the home owner, as well as the moderate initial construction costs.

Last, the two wall systems that this study found that provided the most benefits in terms of annual energy savings, carbon emissions, energy cost reductions, initial costs, and shortest amount of pay back were the R-29.2 SIP 7.4 in EPS Core, and the R-36 SIP 9.4 in EPS Core wall assemblies. These two wall types would be the most desirable options for single-family residential wall construction for the desert southwest.

The findings of this study show that choosing the proper wall assembly to construct a residential building has the potential to reduce energy consumption and lower CO_2 emissions in the desert southwest region. Although, this research focuses specifically on walls, it is important to note that often times greater savings are achieved when optimization of various building component systems take place. When you do numerous improvements to the building at the beginning of the design stage, the size of your mechanical equipment tends to be smaller and less expensive for heating and cooling (Hester et al., 2011).

APPENDIX A: IRC 2012

R602.1 Identification.
R602.2 Grade.
R602.3 Design and construction.
R602.4 Interior load-bearing walls.
R602.5 Interior nonbearing walls.
R602.6 Drilling and notching of studs.
R602.7 Headers.
R602.8 Fireblocking required.
R602.9 Cripple walls.
R602.10 Wall bracing.
R602.11 Wall anchorage.
R602.12 Simplified wall bracing.

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SECTION R602 WOOD WALL FRAMING

R602.1 Identification.
Load-bearing dimension lumber for studs, plates and headers shall be identified by a grade mark of a lumber grading or inspection agency that has been *approved* by an accreditation body that complies with DOC PS 20. In lieu of a grade mark, a certification of inspection issued by a lumber grading or inspection agency meeting the requirements of this section shall be accepted.

R602.1.1 End-jointed lumber.
Approved end-jointed lumber identified by a grade mark conforming to Section R602.1 may be used interchangeably with solid-sawn members of the same species and grade. End-jointed lumber used in an assembly required elsewhere in this code to have a fire-resistance rating shall have the designation "Heat Resistant Adhesive" or "HRA" included in its grade mark.

R602.1.2 Structural glued laminated timbers.
Glued laminated timbers shall be manufactured and identified as required in ANSI/AITC A190.1 and ASTM D 3737.

R602.1.3 Structural log members.
Stress grading of structural log members of nonrectangular shape, as typically used in log buildings, shall be in accordance with ASTM D 3957. Such structural log members shall be identified by the grade mark of an *approved* lumber grading or inspection agency. In lieu of a grade mark on the material, a certificate of inspection as to species and grade, issued by a lumber-grading or inspection agency meeting the requirements of this section, shall be permitted to be accepted.

R602.1.4 Structural composite lumber.
Structural capacities for structural composite lumber shall be established and monitored in accordance with ASTM D 5456.

R602.2 Grade.
Studs shall be a minimum No. 3, standard or stud grade lumber.

Exception: Bearing studs not supporting floors and nonbearing studs may be utility grade lumber, provided the studs are spaced in accordance with Table R602.3(5).

R602.3 Design and construction.
Exterior walls of wood-frame construction shall be designed and constructed in accordance with the provisions of this chapter and Figures R602.3(1) and R602.3(2) or in accordance with AF&PA's NDS. Components of exterior walls shall be fastened in accordance with Tables R602.3(1) through R602.3(4). Wall sheathing shall be fastened directly to framing members and, when placed on the exterior side of an exterior wall, shall be capable of resisting the wind pressures listed in Table R301.2(2) adjusted for height and exposure using Table R301.2(3). Wood structural panel sheathing used for exterior walls shall conform to DOC PS 1, DOC PS 2 or, when manufactured in

Canada, CSA O437 or CSA O325. All panels shall be identified for grade, bond classification, and Performance Category by a grade mark or certificate of inspection issued by an approved agency and shall conform to the requirements of Table R602.3(3). Wall sheathing used only for exterior wall covering purposes shall comply with Section R703.

Studs shall be continuous from support at the sole plate to a support at the top plate to resist loads perpendicular to the wall. The support shall be a foundation or floor, ceiling or roof diaphragm or shall be designed in accordance with accepted engineering practice.

Exception: Jack studs, trimmer studs and cripple studs at openings in walls that comply with Tables R502.5(1) and R502.5(2).

TABLE R602.3(1) FASTENER SCHEDULE FOR STRUCTURAL MEMBERS

ITEM	DESCRIPTION OF BUILDING ELEMENTS	NUMBER AND TYPE OF FASTENER[a, b, c]	SPACING OF FASTENERS
		Roof	
1	Blocking between joists or rafters to top plate, toe nail	3-8d ($2^1/_2$" × 0.113")	—
2	Ceiling joists to plate, toe nail	3-8d ($2^1/_2$" × 0.113")	—
3	Ceiling joists not attached to parallel rafter, laps over partitions, face nail	3-10d	—
4	Collar tie to rafter, face nail or $1^1/_4$" × 20 gage ridge strap	3-10d (3" × 0.128")	—
5	Rafter or roof truss to plate, toe nail	3-16d box nails ($3^1/_2$" × 0.135") or 3-10d common nails (3" × 0.148")	2 toe nails on one side and 1 toe nail on opposite side of each rafter or truss[j]
6	Roof rafters to ridge, valley or hip rafters: toe nail face nail	4-16d ($3^1/_2$" × 0.135") 3-16d ($3^1/_2$" × 0.135")	—
		Wall	
7	Built-up studs-face nail	10d (3" × 0.128")	24" o.c.
8	Abutting studs at intersecting wall corners, face nail	16d ($3^1/_2$" × 0.135")	12" o.c.
9	Built-up header, two pieces with $^1/_2$" spacer	16d ($3^1/_2$" × 0.135")	16" o.c. along each edge
10	Continued header, two pieces	16d ($3^1/_2$" × 0.135")	16" o.c. along each edge
11	Continuous header to stud, toe nail	4-8d ($2^1/_2$" × 0.113")	—
12	Double studs, face nail	10d (3" × 0.128")	24" o.c.
13	Double top plates, face nail	10d (3" × 0.128")	24" o.c.
14	Double top plates, minimum 24-inch offset of end joints, face nail in lapped area	8-16d ($3^1/_2$" × 0.135")	—
15	Sole plate to joist or blocking, face nail	16d ($3^1/_2$" × 0.135")	16" o.c.
16	Sole plate to joist or blocking at braced wall panels	3-16d ($3^1/_2$" × 0.135")	16" o.c.
17	Stud to sole plate, toe nail	3-8d ($2^1/_2$" × 0.113") or 2-16d ($3^1/_2$" × 0.135")	——
18	Top or sole plate to stud, end nail	2-16d ($3^1/_2$" × 0.135")	—
19	Top plates, laps at corners and intersections, face nail	2-10d (3" × 0.128")	—
20	1" brace to each stud and plate, face nail	2-8d ($2^1/_2$" × 0.113") 2 staples 1 $^3/_4$" ×	——
21	1" × 6" sheathing to each bearing, face nail	2-8d ($2^1/_2$" × 0.113") 2 staples 1 $^3/_4$"	——
22	1" × 8" sheathing to each bearing, face nail	2-8d ($2^1/_2$" × 0.113") 3 staples 1 $^3/_4$	——
23	Wider than 1" × 8" sheathing to each bearing, face nail	3-8d ($2^1/_2$" × 0.113") 4 staples $1^3/_4$"	——
		Floor	
24	Joist to sill or girder, toe nail	3-8d ($2^1/_2$" × 0.113")	—
25	Rim joist to top plate, toe nail (roof applications also)	8d ($2^1/_2$" × 0.113")	6" o.c.
26	Rim joist or blocking to sill plate, toe nail	8d ($2^1/_2$" × 0.113")	6" o.c.

27	1″ × 6″ subfloor or less to each joist, face nail	2-8d ($2^1/_2$″ × 0.113″) 2 staples $1^3/_4$″	— —
28	2″ subfloor to joist or girder, blind and face nail	2-16d ($3^1/_2$″ × 0.135″)	—
29	2″ planks (plank & beam - floor & roof)	2-16d ($3^1/_2$″ × 0.135″)	at each bearing
30	Built-up girders and beams, 2-inch lumber layers	10d (3″ × 0.128″)	Nail each layer as follows: 32″ o.c. at top and bottom and staggered. Two nails at ends and at each splice.
31	Ledger strip supporting joists or rafters	3-16d ($3^1/_2$″ × 0.135″)	At each joist or rafter

(continued)

TABLE R602.3(1)—continued FASTENER SCHEDULE FOR STRUCTURAL MEMBERS

ITEM	DESCRIPTION OF BUILDING MATERIALS	DESCRIPTION OF FASTENER[b, c, e]	SPACING OF FASTENERS	
			Edges (inches)[i]	Intermediate supports[c, e] (inches)
	Wood structural panels, subfloor, roof and interior wall sheathing to framing and particleboard wall sheathing to framing			
32	$^3/_8$" - $^1/_2$"	6d common (2" × 0.113") nail (subfloor wall)[j] 8d common ($2^1/_2$" × 0.131") nail (roof)[f]	6	12[g]
33	$^{19}/_{32}$" - 1"	8d common nail ($2^1/_2$" × 0.131")	6	12[g]
34	$1^1/_8$" - $1^1/_4$"	10d common (3" × 0.148") nail or 8d ($2^1/_2$" × 0.131") deformed nail	6	12
	Other wall sheathing[h]			
35	$^1/_2$" structural cellulosic fiberboard sheathing	$1^1/_2$" galvanized roofing nail, $^7/_{16}$" crown or 1" crown staple 16 ga., $1^1/_4$" long	3	6
36	$^{25}/_{32}$" structural cellulosic fiberboard sheathing	$1^3/_4$" galvanized roofing nail, $^7/_{16}$" crown or 1" crown staple 16 ga., $1^1/_2$" long	3	6
37	$^1/_2$" gypsum sheathing[d]	$1^1/_2$" galvanized roofing nail; staple galvanized, $1^1/_2$" long; $1^1/_4$ screws, Type W or S	7	7
38	$^5/_8$" gypsum sheathing[d]	$1^3/_4$" galvanized roofing nail; staple galvanized, $1^5/_8$" long; $1^5/_8$" screws, Type W or S	7	7
Â	**Wood structural panels, combination subfloor underlayment to framing**			
39	$^3/_4$" and less	6d deformed (2" × 0.120") nail or 8d common ($2^1/_2$" × 0.131") nail	6	12
40	$^7/_8$" - 1"	8d common ($2^1/_2$" × 0.131") nail or 8d deformed ($2^1/_2$" × 0.120") nail	6	12
41	$1^1/_8$" - $1^1/_4$"	10d common (3" × 0.148") nail or 8d deformed ($2^1/_2$" × 0.120") nail	6	12

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 mile per hour = 0.447 m/s; 1 Ksi = 6.895 MPa.

a. All nails are smooth-common, box or deformed shanks except where otherwise stated. Nails used for framing and sheathing connections shall have minimum average bending yield strengths as shown: 80 ksi for shank diameter of 0.192 inch (20d common nail), 90 ksi for shank diameters larger than 0.142 inch but not larger than 0.177 inch, and 100 ksi for shank diameters of 0.142 inch or less.

b. Staples are 16 gage wire and have a minimum $^7/_{16}$-inch on diameter crown width.

c. Nails shall be spaced at not more than 6 inches on center at all supports where spans are 48 inches or greater.

d. Four-foot by 8-foot or 4-foot by 9-foot panels shall be applied vertically.

e. Spacing of fasteners not included in this table shall be based on Table R602.3(2).

f. For regions having basic wind speed of 110 mph or greater, 8d deformed ($2^1/_2$″ × 0.120) nails shall be used for attaching plywood and wood structural panel roof sheathing to framing within minimum 48-inch distance from gable end walls, if mean roof height is more than 25 feet, up to 35 feet maximum.

g. For regions having basic wind speed of 100 mph or less, nails for attaching wood structural panel roof sheathing to gable end wall framing shall be spaced 6 inches on center. When basic wind speed is greater than 100 mph, nails for attaching panel roof sheathing to intermediate supports shall be spaced 6 inches on center for minimum 48-inch distance from ridges, eaves and gable end walls; and 4 inches on center to gable end wall framing.

h. Gypsum sheathing shall conform to ASTM C 1396 and shall be installed in accordance with GA 253. Fiberboard sheathing shall conform to ASTM C 208.

i. Spacing of fasteners on floor sheathing panel edges applies to panel edges supported by framing members and required blocking and at all floor perimeters only. Spacing of fasteners on roof sheathing panel edges applies to panel edges supported by framing members and required blocking. Blocking of roof or floor sheathing panel edges perpendicular to the framing members need not be provided except as required by other provisions of this code. Floor perimeter shall be supported by

framing members or solid blocking.

j. Where a rafter is fastened to an adjacent parallel ceiling joist in accordance with this schedule, provide two toe nails on one side of the rafter and toe nails from the ceiling joist to top plate in accordance with this schedule. The toe nail on the opposite side of the rafter shall not be required.

TABLE R602.3(2) ALTERNATE ATTACHMENTS TO TABLE R602.3(1)

NOMINAL MATERIAL THICKNESS (inches)	DESCRIPTION[a, b] OF FASTENER AND LENGTH (inches)	SPACING[c] OF FASTENERS	
		Edges (inches)	Intermediate supports (inches)
Wood structural panels subfloor, roof[g] and wall sheathing to framing and particleboard wall sheathing to framing[f]			
Up to $^1/_2$	Staple 15 ga. $1^3/_4$	4	8
	0.097 - 0.099 Nail $2^1/_4$	3	6
	Staple 16 ga. $1^3/_4$	3	6
$^{19}/_{32}$ and $^5/_8$	0.113 Nail 2	3	6
	Staple 15 and 16 ga. 2	4	8
	0.097 - 0.099 Nail $2^1/_4$	4	8
$^{23}/_{32}$ and $^3/_4$	Staple 14 ga. 2	4	8
	Staple 15 ga. $1^3/_4$	3	6
	0.097 - 0.099 Nail $2^1/_4$	4	8
	Staple 16 ga. 2	4	8
1	Staple 14 ga. $2^1/_4$	4	8
	0.113 Nail $2^1/_4$	3	6
	Staple 15 ga. $2^1/_4$	4	8
	0.097 - 0.099 Nail $2^1/_2$	4	8
NOMINAL MATERIAL THICKNESS (inches)	**DESCRIPTION[a,b] OF FASTENER AND LENGTH (inches)**	**SPACING[c] OF FASTENERS**	
		Edges (inches)	**Body of panel[d] (inches)**
Floor underlayment; plywood-hardboard-particleboard[f]			
Plywood			
$^1/_4$ and $^5/_{16}$	$1^1/_4$ ring or screw shank nail-minimum $12^1/_2$ ga. (0.099") shank diameter	3	6
	Staple 18 ga., $^7/_8$, $^3/_{16}$ crown width	2	5
$^{11}/_{32}$, $^3/_8$, $^{15}/_{32}$, and $^1/_2$	$1^1/_4$ ring or screw shank nail-minimum $12^1/_2$ ga. (0.099") shank diameter	6	8[e]
$^{19}/_{32}$, $^5/_8$, $^{23}/_{32}$ and $^3/_4$	$1^1/_2$ ring or screw shank nail-minimum $12^1/_2$ ga. (0.099") shank diameter	6	8
	Staple 16 ga. $1^1/_2$	6	8
Hardboard[f]			
0.200	$1^1/_2$ long ring-grooved underlayment nail	6	6
	4d cement-coated sinker nail	6	6
	Staple 18 ga., $^7/_8$ long (plastic coated)	3	6
Particleboard			
$^1/_4$	4d ring-grooved underlayment nail	3	6
	Staple 18 ga., $^7/_8$ long, $^3/_{16}$ crown	3	6
$^3/_8$	6d ring-grooved underlayment nail	6	10
	Staple 16 ga., $1^1/_8$ long, $^3/_8$ crown	3	6
$^1/_2$, $^5/_8$	6d ring-grooved underlayment nail	6	10
	Staple 16 ga., $1^5/_8$ long, $^3/_8$ crown	3	6

For SI: 1 inch = 25.4 mm.

a. Nail is a general description and may be T-head, modified round head or round head.

b. Staples shall have a minimum crown width of $^7/_{16}$-inch on diameter except as noted.

c. Nails or staples shall be spaced at not more than 6 inches on center at all supports where spans are 48 inches or greater. Nails or staples shall be spaced at not more than 12 inches on center at intermediate supports for floors.

d. Fasteners shall be placed in a grid pattern throughout the body of the panel.

e. For 5-ply panels, intermediate nails shall be spaced not more than 12 inches on center each way.

f. Hardboard underlayment shall conform to CPA/ANSI A135.4

g. Specified alternate attachments for roof sheathing shall be permitted for windspeeds less than 100 mph. Fasteners attaching wood structural panel roof sheathing to gable end wall framing shall be installed using the spacing listed for panel edges.

TABLE R602.3(3) REQUIREMENTS FOR WOOD STRUCTURAL PANEL WALL SHEATHING USED TO RESIST WIND PRESSURES[a, b, c]

MINIMUM NAIL		MINIMUM WOOD STRUCTURAL PANEL SPAN RATING	MINIMUM NOMINAL PANEL THICKNESS (inches)	MAXIMUM WALL STUD SPACING (inches)	PANEL NAIL SPACING		MAXIMUM WIND SPEED (mph)		
							Wind exposure category		
Size	Penetration (inches)				Edges (inches o.c.)	Field (inches o.c.)	B	C	D
6d Common (2.0″ × 0.113″)	1.5	24/0	$^{3}/_{8}$	16	6	12	110	90	85
8d Common (2.5″ × 0.131″)	1.75	24/16	$^{7}/_{16}$	16	6	12	130	110	105
				24	6	12	110	90	85

For SI: 1 inch = 25.4 mm, 1 mile per hour = 0.447 m/s.

a. Panel strength axis parallel or perpendicular to supports. Three-ply plywood sheathing with studs spaced more than 16 inches on center shall be applied with panel strength axis perpendicular to supports.

b. Table is based on wind pressures acting toward and away from building surfaces per Section R301.2. Lateral bracing requirements shall be in accordance with Section R602.10.

c. Wood structural panels with span ratings of Wall-16 or Wall-24 shall be permitted as an alternate to panels with a 24/0 span rating. Plywood siding rated 16 o.c. or 24 o.c. shall be permitted as an alternate to panels with a 24/16 span rating. Wall-16 and Plywood siding 16 o.c. shall be used with studs spaced a maximum of 16 inches on center.

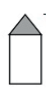
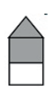
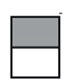
TABLE R602.3(4) ALLOWABLE SPANS FOR PARTICLEBOARD WALL SHEATHING[a]

THICKNESS (inch)	GRADE	STUD SPACING (inches)	
		When siding is nailed to studs	When siding is nailed to sheathing
$^{3}/_{8}$	M-1 Exterior glue	16	—
$^{1}/_{2}$	M-2 Exterior glue	16	16

For SI: 1 inch = 25.4 mm.

a. Wall sheathing not exposed to the weather. If the panels are applied horizontally, the end joints of the panel shall be offset so that four panels corners will not meet. All panel edges must be supported. Leave a $^{1}/_{16}$-inch gap between panels and nail no closer than $^{3}/_{8}$ inch from panel edges.

TABLE R602.3(5) SIZE, HEIGHT AND SPACING OF WOOD STUDS[a]

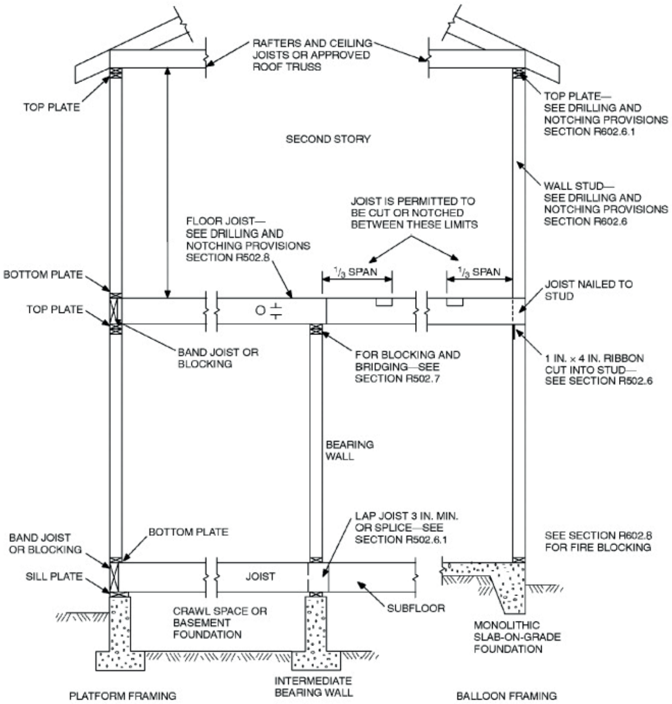
STUD SIZE (inches)	BEARING WALLS					NONBEARING WALLS	
	Laterally unsupported stud height[a] (feet)	Maximum spacing when supporting a roof-ceiling assembly or a habitable attic assembly, only (inches)	Maximum spacing when supporting one floor, plus a roof-ceiling assembly or a habitable attic assembly (inches)	Maximum spacing when supporting two floors, plus a roof-ceiling assembly or a habitable attic assembly (inches)	Maximum spacing when supporting one floor height[a] (feet)	Laterally unsupported stud height[a] (feet)	Maximum spacing (inches)
							
2 × 3[b]	—	—	—	—	—	10	16
2 × 4	10	24[c]	16[c]	—	24	14	24
3 × 4	10	24	24	16	24	14	24
2 × 5	10	24	24	—	24	16	24
2 × 6	10	24	24	16	24	20	24

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 square foot = 0.093 m^2.

a. Listed heights are distances between points of lateral support placed perpendicular to the plane of the wall. Increases in unsupported height are permitted where justified by analysis.

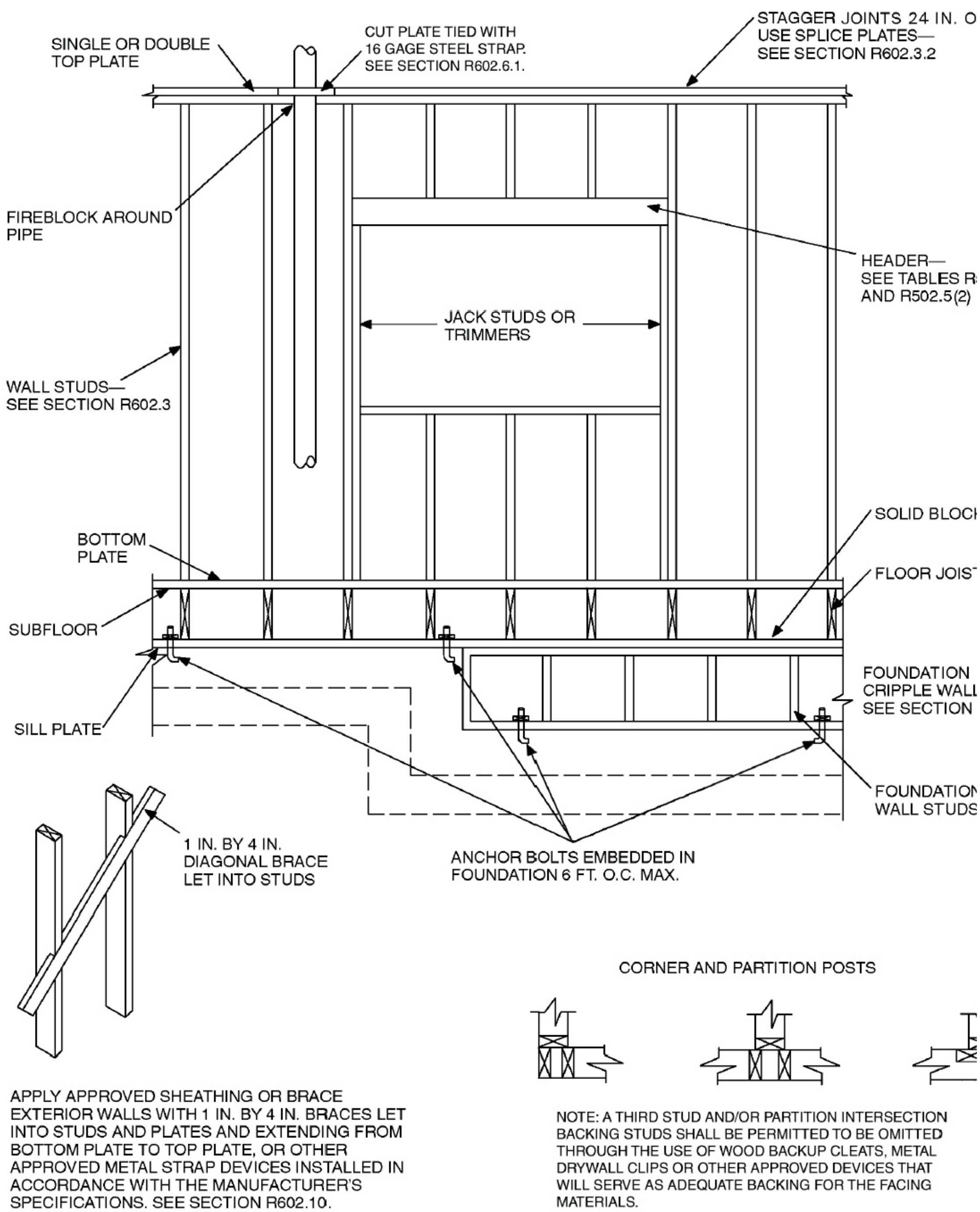
b. Shall not be used in exterior walls.

c. A habitable attic assembly supported by 2 × 4 studs is limited to a roof span of 32 feet. Where the roof span exceeds 32 feet, the wall studs shall be increased to 2 × 6 or the studs shall be designed in accordance with accepted engineering practice.



For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

FIGURE R602.3(1) TYPICAL WALL, FLOOR AND ROOF FRAMING



For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

FIGURE R602.3(2) FRAMING DETAILS

R602.3.1 Stud size, height and spacing.
The size, height and spacing of studs shall be in accordance with Table R602.3(5).

Exceptions:

1. Utility grade studs shall not be spaced more than 16 inches (406 mm) on center, shall not support more than a roof and ceiling, and shall not exceed 8 feet (2438 mm) in height for exterior walls and load-bearing walls or 10 feet (3048 mm) for interior nonload-bearing walls.

2. Studs more than 10 feet (3048 mm) in height which are in accordance with Table R602.3.1.

TABLE R602.3.1 MAXIMUM ALLOWABLE LENGTH OF WOOD WALL STUDS EXPOSED TO WIND SPEEDS OF 100 MPH OR LESS IN SEISMIC DESIGN CATEGORIES A, B, C, D_0, D_1 and D_2[b, c]

HEIGHT (feet)	ON-CENTER SPACING (inches)			
	24	16	12	8
Supporting a roof only				
> 10	2 × 4	2 × 4	2 × 4	2 × 4
12	2 × 6	2 × 4	2 × 4	2 × 4
14	2 × 6	2 × 6	2 × 6	2 × 4
16	2 × 6	2 × 6	2 × 6	2 × 4
18	NA[a]	2 × 6	2 × 6	2 × 6
20	NA[a]	NA[a]	2 × 6	2 × 6
24	NA[a]	NA[a]	NA[a]	2 × 6
Supporting one floor and a roof				
> 10	2 × 6	2 × 4	2 × 4	2 × 4
12	2 × 6	2 × 6	2 × 6	2 × 4
14	2 × 6	2 × 6	2 × 6	2 × 6
16	NA[a]	2 × 6	2 × 6	2 × 6
18	NA[a]	2 × 6	2 × 6	2 × 6
20	NA[a]	NA[a]	2 × 6	2 × 6
24	NA[a]	NA[a]	NA[a]	2 × 6
Supporting two floors and a roof				
> 10	2 × 6	2 × 6	2 × 4	2 × 4
12	2 × 6	2 × 6	2 × 6	2 × 6
14	2 × 6	2 × 6	2 × 6	2 × 6
16	NA[a]	NA[a]	2 × 6	2 × 6
18	NA[a]	NA[a]	2 × 6	2 × 6
20	NA[a]	NA[a]	NA[a]	2 × 6
22	NA[a]	NA[a]	NA[a]	NA[a]
24	NA[a]	NA[a]	NA[a]	NA[a]

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.0479 kPa
1 pound per square inch = 6.895 kPa, 1 mile per hour = 0.447 m/s.

a. Design required.

b. Applicability of this table assumes the following: Snow load not exceeding 25 psf, f_b not less than 1310 psi determined by multiplying the AF&PA NDS tabular base design value by the repetitive use factor, and by the size factor for all species except southern pine, E not less than 1.6 × 106 psi, tributary dimensions for floors and roofs not exceeding 6 feet, maximum span for floors and roof not exceeding 12 feet, eaves not over 2 feet in dimension and exterior sheathing. Where the conditions are not within these parameters, design is required.

c. Utility, standard, stud and No. 3 grade lumber of any species are not permitted.

(continued)

TABLE R602.3.1—continued MAXIMUM ALLOWABLE LENGTH OF WOOD WALL STUDS EXPOSED TO WIND SPEEDS OF 100 MPH OR LESS IN SEISMIC DESIGN CATEGORIES A, B, C, D_0, D_1 and D_2

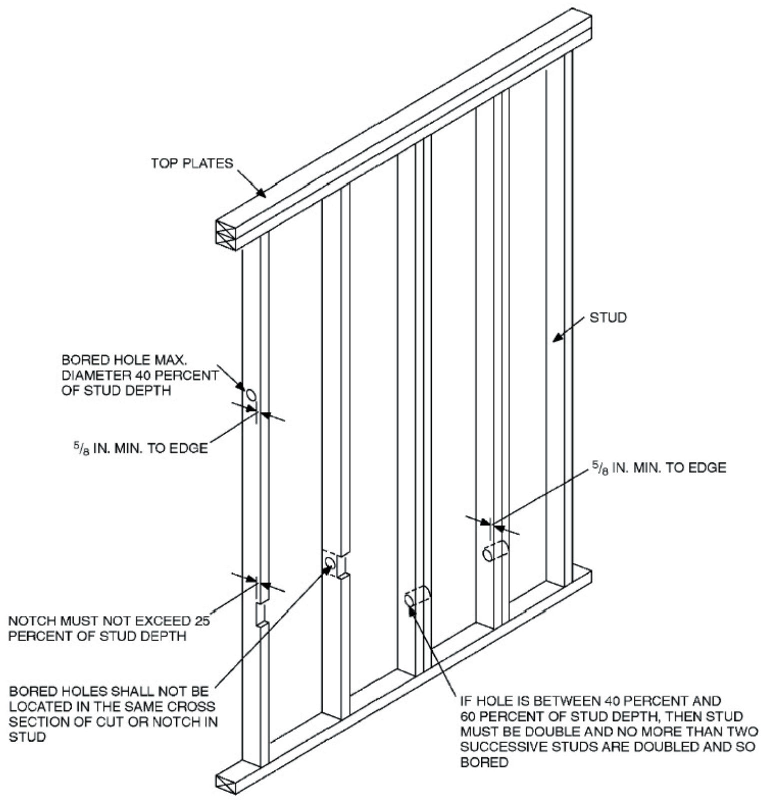
braced wall line, 2 inch by 4 inch (51 mm by 102 mm) flat studs spaced at 16 inches (406 mm) on center. Interior nonbearing walls shall be capped with at least a single top plate. Interior nonbearing walls shall be fireblocked in accordance with Section R602.8.

R602.6 Drilling and notching of studs.
Drilling and notching of studs shall be in accordance with the following:

1. Notching. Any stud in an exterior wall or bearing partition may be cut or notched to a depth not exceeding 25 percent of its width. Studs in nonbearing partitions may be notched to a depth not to exceed 40 percent of a single stud width.

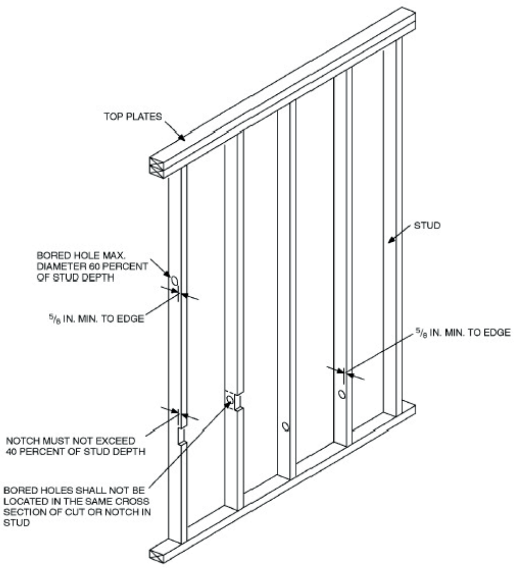
2. Drilling. Any stud may be bored or drilled, provided that the diameter of the resulting hole is no more than 60 percent of the stud width, the edge of the hole is no more than $^{5}/_{8}$ inch (16 mm) to the edge of the stud, and the hole is not located in the same section as a cut or notch. Studs located in exterior walls or bearing partitions drilled over 40 percent and up to 60 percent shall also be doubled with no more than two successive doubled studs bored. See Figures R602.6(1) and R602.6(2).

Exception: Use of *approved* stud shoes is permitted when they are installed in accordance with the manufacturer's recommendations.



For SI: 1 inch = 25.4 mm.
Note: Condition for exterior and bearing walls.

FIGURE R602.6(1) NOTCHING AND BORED HOLE LIMITATIONS FOR EXTERIOR WALLS AND BEARING WALLS

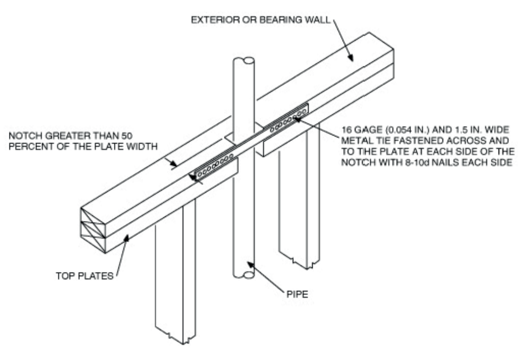


For SI: 1 inch = 25.4 mm.

FIGURE R602.6(2) NOTCHING AND BORED HOLE LIMITATIONS FOR INTERIOR NONBEARING WALLS

R602.6.1 Drilling and notching of top plate.
When piping or ductwork is placed in or partly in an exterior wall or interior load-bearing wall, necessitating cutting, drilling or notching of the top plate by more than 50 percent of its width, a galvanized metal tie not less than 0.054 inch thick (1.37 mm) (16 ga) and $1^1/_2$ inches (38 mm) wide shall be fastened across and to the plate at each side of the opening with not less than eight 10d (0.148 inch diameter) having a minimum length of $1^1/_2$ inches (38 mm) at each side or equivalent. The metal tie must extend a minimum of 6 inches past the opening. See Figure R602.6.1.

Exception: When the entire side of the wall with the notch or cut is covered by wood structural panel sheathing.



For SI: 1 inch = 25.4 mm.

FIGURE R602.6.1 TOP PLATE FRAMING TO ACCOMMODATE PIPING

R602.7 Headers.
For header spans see Tables R502.5(1), R502.5(2) and R602.7.1.

R602.7.1 Single member headers.
Single headers shall be framed with a single flat 2-inch-nominal (51 mm) member or wall plate not less in width than the wall studs on the top and bottom of the header in accordance with Figures R602.7.1(1) and R602.7.1(2).

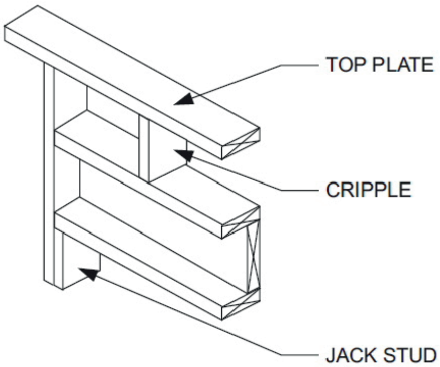


FIGURE R602.7.1(1) SINGLE MEMBER HEADER IN EXTERIOR BEARING WALL

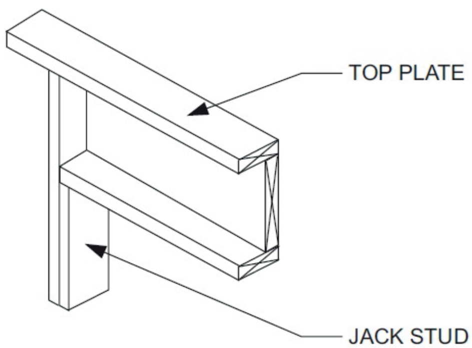


FIGURE R602.7.1(2) ALTERNATIVE SINGLE MEMBER HEADER WITHOUT CRIPPLE

R602.7.2 Wood structural panel box headers.
Wood structural panel box headers shall be constructed in accordance with Figure R602.7.2 and Table R602.7.2.

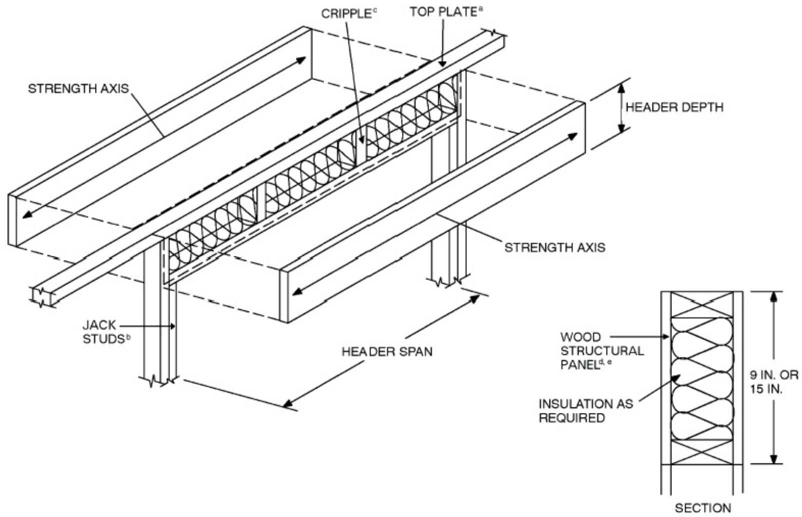
TABLE R602.7.2 MAXIMUM SPANS FOR WOOD STRUCTURAL PANEL BOX HEADERS[a]

HEADER CONSTRUCTION[b]	HEADER DEPTH (inches)	HOUSE DEPTH (feet)				
		24	26	28	30	32
Wood structural panelâ€"one side	9 15	4 5	4 5	3 4	3 3	— 3
Wood structural panelâ€"both sides	9 15	7 8	5 8	5 7	4 7	3 6

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

a. Spans are based on single story with clear-span trussed roof or two-story with floor and roof supported by interior-bearing walls.

b. See Figure R602.7.2 for construction details.



For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm.

NOTES:

a. The top plate shall be continuous over header.

b. Jack studs shall be used for spans over 4 feet.

c. Cripple spacing shall be the same as for studs.

d. Wood structural panel faces shall be single pieces of $^{15}/_{32}$-inch-thick Exposure 1 (exterior glue) or thicker, installed on the interior or exterior or both sides of the header.

e. Wood structural panel faces shall be nailed to framing and cripples with 8d common or galvanized box nails spaced 3 inches on center, staggering alternate nails $^{1}/_{2}$ inch. Galvanized nails shall be hot-dipped or tumbled.

FIGURE R602.7.2 TYPICAL WOOD STRUCTURAL PANEL BOX HEADER CONSTRUCTION

R602.7.3 Nonbearing walls.
Load-bearing headers are not required in interior or exterior nonbearing walls. A single flat 2-inch by 4-inch (51 mm by 102 mm) member may be used as a header in interior or exterior nonbearing walls for openings up to 8 feet (2438 mm) in width if the vertical distance to the parallel nailing surface above is not more than 24 inches (610 mm). For such nonbearing headers, no cripples or blocking are required above the header.

R602.8 Fireblocking required.
Fireblocking shall be provided in accordance with Section R302.11.

R602.9 Cripple walls.
Foundation cripple walls shall be framed of studs not smaller than the studding above. When exceeding 4 feet (1219 mm) in height, such walls shall be framed of studs having the size required for an additional *story*.

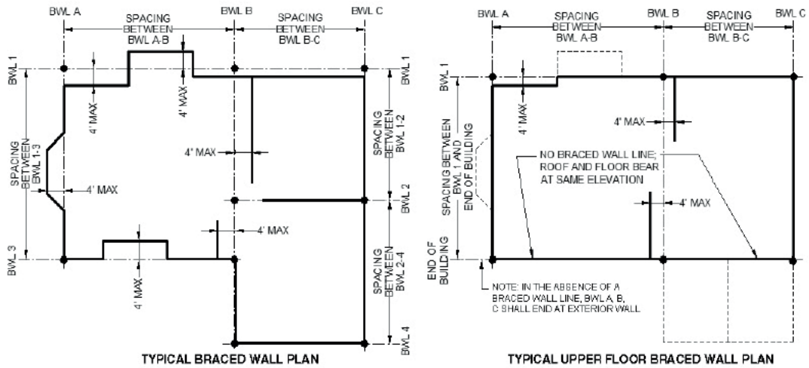
Cripple walls with a stud height less than 14 inches (356 mm) shall be continuously sheathed on one side with wood structural panels fastened to both the top and bottom plates in accordance with Table R602.3(1), or the cripple walls shall be constructed of solid blocking.

All cripple walls shall be supported on continuous foundations.

R602.10 Wall bracing.
Buildings shall be braced in accordance with this section or, when applicable, Section R602.12. Where a building, or portion thereof, does not comply with one or more of the bracing requirements in this section, those portions shall be designed and constructed in accordance with Section R301.1.

R602.10.1 Braced wall lines.
For the purpose of determining the amount and location of bracing required in each story level of a building, *braced wall lines* shall be designated as straight lines in the building plan placed in accordance with this section.

R602.10.1.1 Length of a braced wall line.
The length of a *braced wall line* shall be the distance between its ends.Â The end of a *braced wall line* shall be the intersection with a perpendicular *braced wall line*, an angled *braced wall line* as permitted in Section R602.10.1.4 or an exterior wall as shown in Figure R602.10.1.1.



For SI: 1 foot = 304.8 mm.

FIGURE R602.10.1.1 BRACED WALL LINES

R602.10.1.2 Offsets along a braced wall line.
All exterior walls parallel to a *braced wall line* shall be offset not more than 4 feet (1219 mm) from the designated *braced wall line* location as shown Figure R602.10.1.1. Interior walls used as bracing shall be offset not more than 4 feet (1219 mm) from a *braced wall line* through the interior of the building as shown in Figure R602.10.1.1.

R602.10.1.3 Spacing of braced wall lines.
The spacing between parallel *braced wall lines* shall be in accordance with Table R602.10.1.3. Intermediate *braced wall lines* through the interior of the building shall be permitted.

TABLE R602.10.1.3 BRACED WALL LINE SPACING

APPLICATION	CONDITION	BUILDING TYPE	BRACED WALL LINE SPACING CRITERIA	
			Maximum Spacing	Exception to Maximum Spacing
Wind bracing	85 mph to < 110 mph	Detached, townhouse	60 feet	None
Seismic bracing	SDC A â€" C	Detached	Use wind bracing	
	SDC A â€" B	Townhouse	Use wind bracing	
	SDC C	Townhouse	35 feet	Up to 50 feet when length of required bracing per Table R602.10.3(3) is adjusted in accordance with Table R602.10.3(4).
	SDC D_0, D_1, D_2	Detached, townhouses, one- and two-story only	25 feet	Up to 35 feet to allow for a single room not to exceed 900 square feet. Spacing of all other braced wall lines shall not exceed 25 feet.
	SDC D_0, D_1, D_2	Detached, townhouse	25 feet	Up to 35 feet when length of required bracing per Table R602.10.3(3) is adjusted in accordance with Table R602.10.3(4).

For SI: 1 foot = 304.8 mm, 1 square foot = 0.0929 m^2, 1 mile per hour = 0.447 m/s.

R602.10.1.4 Angled walls.
Any portion of a wall along a *braced wall line* shall be permitted to angle out of plane for a maximum diagonal length of 8 feet (2438 mm).Â Where the angled wall occurs at a corner, the length of the *braced wall line* shall be measured from the projected corner as shown in Figure R602.10.1.4. Where the diagonal length is greater than 8 feet (2438 mm), it shall be considered a separate *braced wall line* and shall be braced in accordance with Section R602.10.1.

- International Residential Code for One- and Two-Family Dwellings
  - [2012 (Second Printing)]
- Chapter 6 - Wall Construction
  - SECTION R613 STRUCTURAL INSULATED PANEL WALL CONSTRUCTION

R613.1 General.
R613.2 Applicability limits.
R613.3 Materials.
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R613.7 Drilling and notching.
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SECTION R613 STRUCTURAL INSULATED PANEL WALL CONSTRUCTION

R613.1 General.

Structural insulated panel (SIP) walls shall be designed in accordance with the provisions of this section. When the provisions of this section are used to design structural insulated panel walls, project drawings, typical details and specifications are not required to bear the seal of the architect or engineer responsible for design, unless otherwise required by the state law of the *jurisdiction* having authority.

R613.2 Applicability limits.

The provisions of this section shall control the construction of exterior structural insulated panel walls and interior load-bearing structural insulated panel walls for buildings not greater than 60 feet (18 288 mm) in length perpendicular to the joist or truss span, not greater than 40 feet (12 192 mm) in width parallel to the joist or truss span and not greater than two stories in height with each wall not greater than 10 feet (3048 mm) high. All exterior walls installed in

accordance with the provisions of this section shall be considered as load-bearing walls. Structural insulated panel walls constructed in accordance with the provisions of this section shall be limited to sites subjected to a maximum design wind speed of 120 miles per hour (54 m/s), Exposure A or B or 110 miles per hour (49 m/s) Exposure C, and a maximum ground snow load of 70 pounds per foot (3.35 kPa), and Seismic Design Categories A, B and C.

R613.3 Materials.
SIPs shall comply with the following criteria:

R613.3.1 Core.
The core material shall be composed of foam plastic insulation meeting one of the following requirements:

1. ASTM C 578 and have a minimum density of 0.90 pounds per cubic feet (14.4 kg/m^3); or

2. Polyurethane meeting the physical properties shown in Table R613.3.1, or;

3. An *approved* alternative.

All cores shall meet the requirements of Section R316.

TABLE R613.3.1 MINIMUM PROPERTIES FOR POLYURETHANE INSULATION USED AS SIPS CORE

PHYSICAL PROPERTY	POLYURETHANE
Density, core nominal (ASTM D 1622)	2.2 lb/ft^3
Compressive resistance at yield or 10% deformation, whichever occurs first (ASTM D 1621)	19 psi (perpendicular to rise)
Flexural strength, min. (ASTM C 203)	30 psi
Tensile strength, min. (ASTM D 1623)	35 psi
Shear strength, min. (ASTM C 273)	25 psi
Substrate adhesion, min. (ASTM D 1623)	22 psi
Water vapor permeance of 1.00-in. thickness, max. (ASTM E 96)	2.3 perm
Water absorption by total immersion, max. (ASTM C 272)	4.3% (volume)
Dimensional stability (change in dimensions), max. [ASTM D 2126 (7 days at 158°F/100% humidity and 7 days at -20°F)]	2%

For SI: 1 pound per cubic foot = 16.02 kg/m^3, 1 pound per square inch = 6.895 kPa, °C = [(°F) - 32]1.8.

R613.3.2 Facing.
Facing materials for SIPs shall be wood structural panels conforming to DOC PS 1 or DOC PS 2, each having a minimum nominal thickness of $^7/_{16}$ inch (11 mm) and shall meet the additional minimum properties specified in Table R613.3.2. Facing shall be identified by a grade mark or certificate of inspection issued by an *approved* agency.

TABLE R613.3.2 MINIMUM PROPERTIES[a] FOR ORIENTED STRAND BOARD FACER MATERIAL IN SIP WALLS

Thickness (in.)	Product	Flatwise Stiffness[b] (lbf-in^2/ft)		Flatwise Strength[c] (lbf-in/ft)		Tension[c] (lbf/ft)		Density[d] (pcf)
		Along	Across	Along	Across	Along	Across	
7/16	Sheathing	55,600	16,500	1,040	460	7,450	5,800	34

For SI: 1 inch = 25.4 mm, 1 lbf-in^2/ft = 9.415 × 10^{-6} kPa/m, 1 lbf-in/ft = 3.707 × 10^{-4} kN/m, 1 lbf/ft = 0.0146 N/mm, 1 pound per cubic foot = 16.018 kg/m^3.

a. Values listed in Table R613.3.2 are qualification test values and are not to be used for design purposes.

b. Mean test value shall be in accordance with Section 7.6 of DOC PS 2.

c. Characteristic test value (5th percent with 75% confidence).

d. Density shall be based on oven-dry weight and oven-dry volume.

R613.3.3 Adhesive.

Adhesives used to structurally laminate the foam plastic insulation core material to the structural wood facers shall conform to ASTM D 2559 or *approved* alternative specifically intended for use as an adhesive used in the lamination of structural insulated panels. Each container of adhesive shall bear a *label* with the adhesive manufacturer's name, adhesive name and type and the name of the quality assurance agency.

R613.3.4 Lumber.

The minimum lumber framing material used for SIPs prescribed in this document is NLGA graded No. 2 Spruce-pine-fir. Substitution of other wood species/grades that meet or exceed the mechanical properties and specific gravity of No. 2 Spruce-pine-fir shall be permitted.

R613.3.5 SIP screws.

Screws used for the erection of SIPs as specified in Section R613.5 shall be fabricated from steel, shall be provided by the SIPs manufacturer and shall be sized to penetrate the wood member to which the assembly is being attached by a minimum of 1 inch (25 mm). The screws shall be corrosion resistant and have a minimum shank diameter of 0.188 inch (4.7 mm) and a minimum head diameter of 0.620 inch (15.5 mm).

R613.3.6 Nails.

Nails specified in Section R613 shall be common or galvanized box unless otherwise stated.

R613.4 SIP wall panels.

SIPs shall comply with Figure R613.4 and shall have minimum panel thickness in accordance with Tables R613.5(1) and R613.5(2) for above-grade walls. All SIPs shall be identified by grade mark or certificate of inspection issued by an *approved* agency.

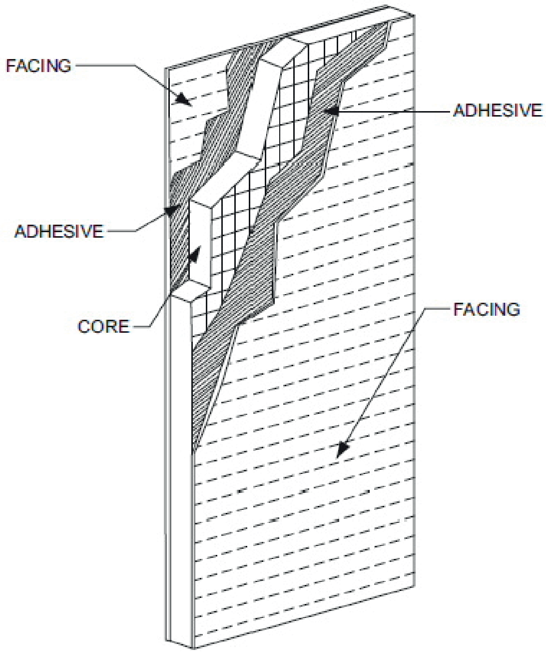


FIGURE R613.4 SIP WALL PANEL

R613.4.1 Labeling.
All panels shall be identified by grade mark or certificate of inspection issued by an *approved* agency. Each (SIP) shall bear a stamp or *label* with the following minimum information:

1. Manufacturer name/logo.

2. Identification of the assembly.

3. Quality assurance agency.

R613.5 Wall construction.
Exterior walls of SIP construction shall be designed and constructed in accordance with the provisions of this section and Tables R613.5(1) and R613.5(2) and Figures R613.5(1) through R613.5(5). SIP walls shall be fastened to other wood building components in accordance with Tables R602.3(1) through R602.3(4).

Framing shall be attached in accordance with Table R602.3(1) unless otherwise provided for in Section R613.

TABLE R613.5(1) MINIMUM THICKNESS FOR SIP WALL SUPPORTING SIP OR LIGHT-FRAME ROOF ONLY (inches)[a]

Building Width (ft)																	
Wind Speed (3-second gust)		Snow Load (psf)	24			28			32			36			40		
Exp. A/B	Exp. C		Wall Height (feet)			Wall Height (feet)			Wall Height (feet)			Wall Height (feet)			Wall Height (feet)		

			8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
85	—	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
100	85	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	N/A
110	100	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	6.5
		50	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	6.5	4.5	4.5	N/A	4.5	4.5	N/A
		70	4.5	4.5	6.5	4.5	4.5	N/A	4.5	4.5	N/A	4.5	6.5	N/A	4.5	N/A	N/A
120	110	20	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A
		30	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A	4.5	4.5	N/A	4.5	6.5	N/A
		50	4.5	4.5	N/A	4.5	6.5	N/A	4.5	N/A	N/A	4.5	N/A	N/A	4.5	N/A	N/A
		70	4.5	N/A	N/A	4.5	N/A	N/A	4.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.0479 kPa.

N/A = Not Applicable.

a. Design assumptions:

Deflection criteria: *L*/240.

Roof load: 7 psf.

Ceiling load: 5 psf.

Wind loads based on Table R301.2 (2).

Strength axis of facing materials applied vertically.

TABLE R613.5(2) MINIMUM THICKNESS FOR SIP WALLS SUPPORTING SIP OR LIGHT-FRAME ONE STORY AND ROOF (inches)[a]

Wind Speed (3-second gust)		Snow Load (psf)	Building Width (ft)														
			24			28			32			36			40		
Exp. A/B	Exp. C		Wall Height (feet)			Wall Height (feet)			Wall Height (feet)			Wall Height (feet)			Wall Height (feet)		
			8	9	10	8	9	10	8	9	10	8	9	10	8	9	10
85	—	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
		50	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	N/A
		70	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	N/A	4.5	N/A	N/A
100	85	20	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	6.5	4.5	4.5	N/A	4.5	4.5	N/A
		30	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	N/A	4.5	4.5	N/A	4.5	N/A	N/A
		50	4.5	4.5	6.5	4.5	4.5	N/A	4.5	4.5	N/A	4.5	N/A	N/A	N/A	N/A	N/A
		70	4.5	4.5	N/A	4.5	6.5	N/A	4.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		20	4.5	4.5	N/A	4.5	4.5	N/A	4.5	6.5	N/A	4.5	N/A	N/A	N/A	N/A	N/A

110	100	30	4.5	4.5	N/A	4.5	4.5	N/A	4.5	N/A	N/A	4.5	N/A	N/A	N/A	N/A	N/A
		50	4.5	6.5	N/A	4.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		70	4.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
120	110	20	4.5	N/A	N/A	4.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		30	4.5	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		50	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		70	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.0479 kPa.

N/A = Not Applicable.

a. Design assumptions:

Deflection criteria: *L*/240.

Roof load: 7 psf.

Ceiling load: 5 psf.

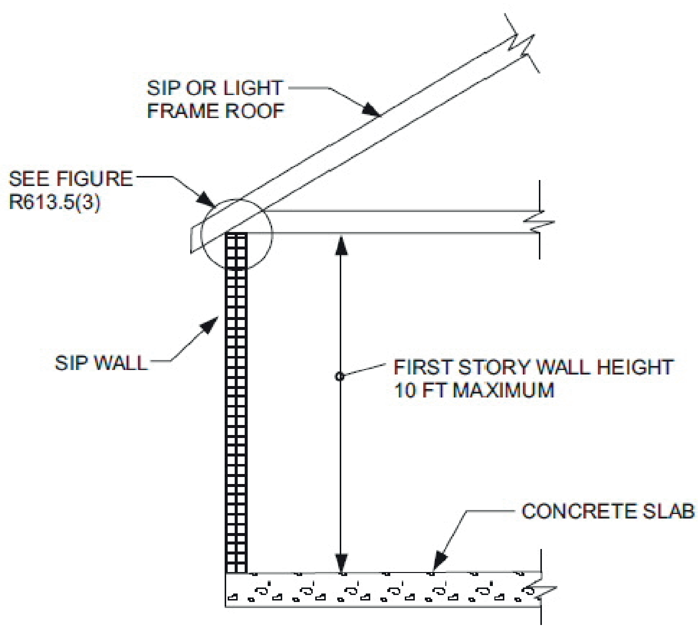
Second floor live load: 30 psf.

Second floor dead load: 10 psf.

Second floor dead load from walls: 10 psf.

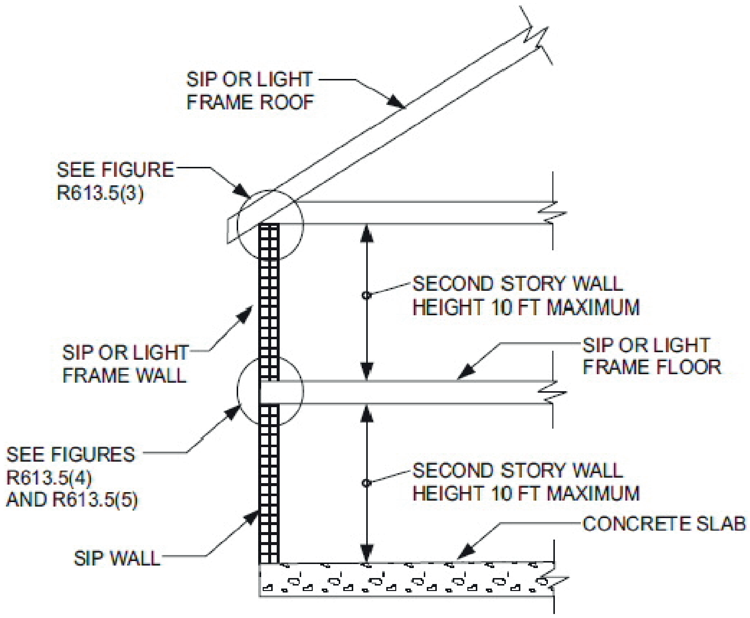
Wind loads based on Table R301.2(2).

Strength axis of facing materials applied vertically.



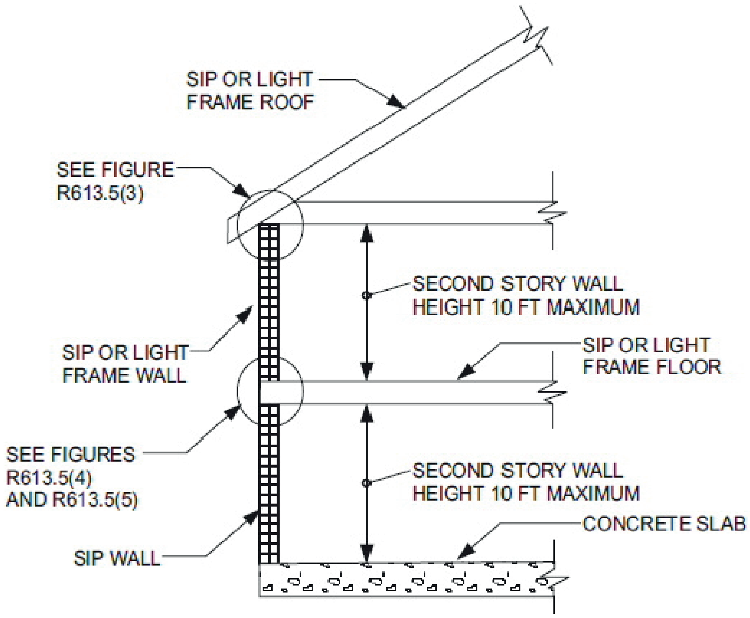
For SI: 1 foot = 304.8 mm.

FIGURE R613.5(1) MAXIMUM ALLOWABLE HEIGHT OF SIP WALLS



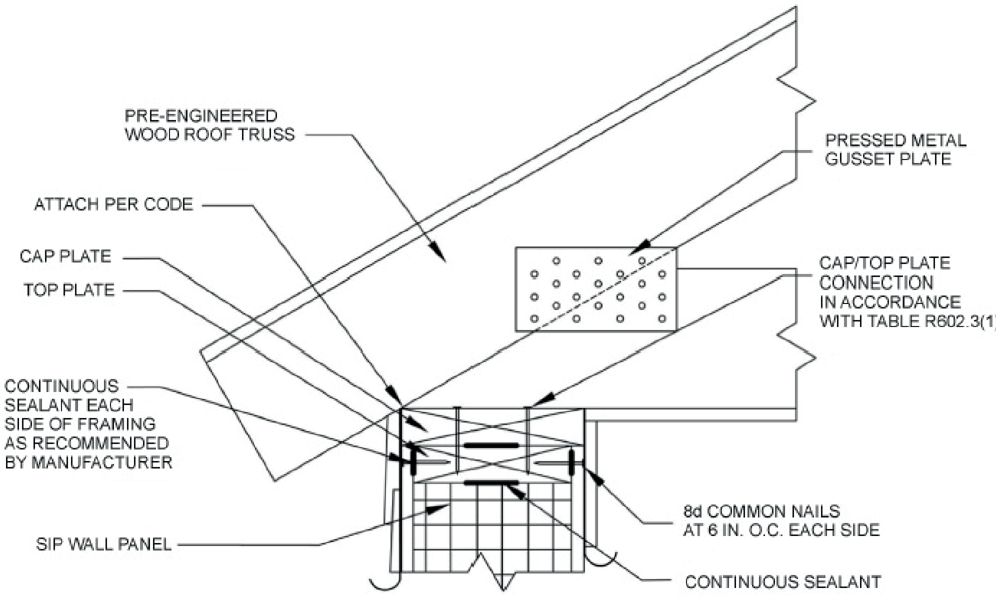
For SI: 1 foot = 304.8 mm.

FIGURE R613.5(2) MAXIMUM ALLOWABLE HEIGHT OF SIP WALLS



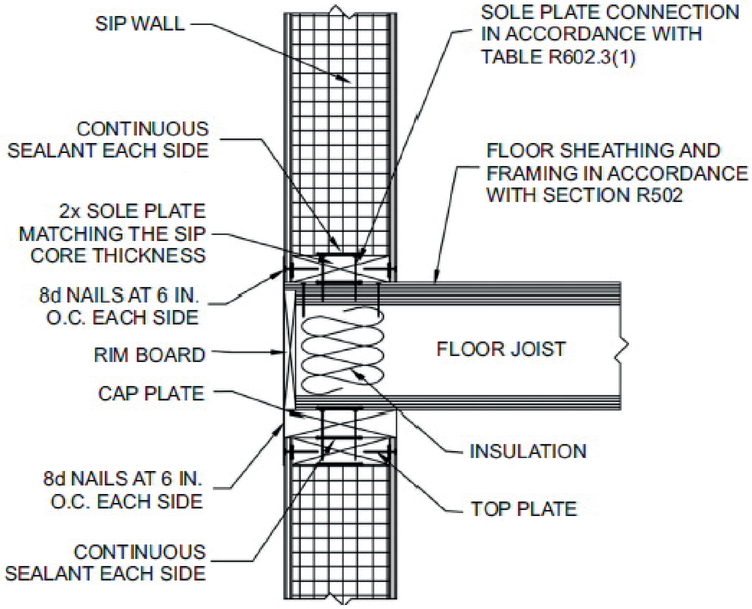
For SI: 1 foot = 304.8 mm.

FIGURE R613.5(2) MAXIMUM ALLOWABLE HEIGHT OF SIP WALLS



For SI: 1 inch = 25.4 mm.

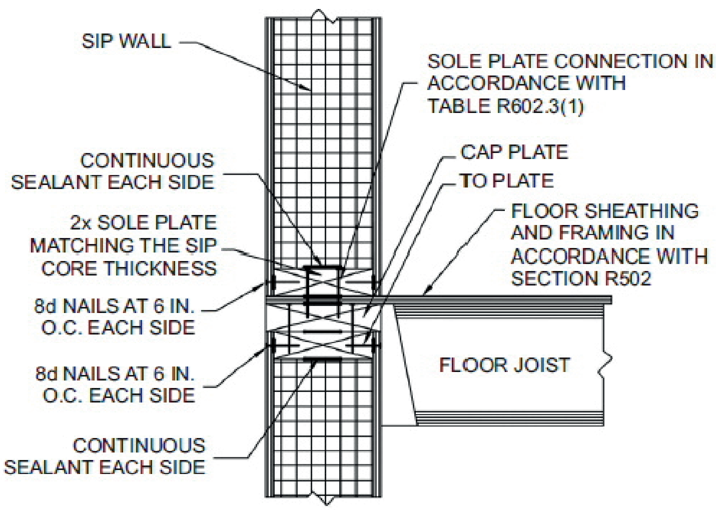
FIGURE R613.5(3) TRUSSED ROOF TO TOP PLATE CONNECTION



For SI: 1 inch = 25.4 mm.

Note: Figures illustrate SIP-specific attachment requirements. Other connections shall be made in accordance with Tables R602.3(1) and (2) as appropriate.

FIGURE R613.5(4) SIP WALL-TO-WALL PLATFORM FRAME CONNECTION



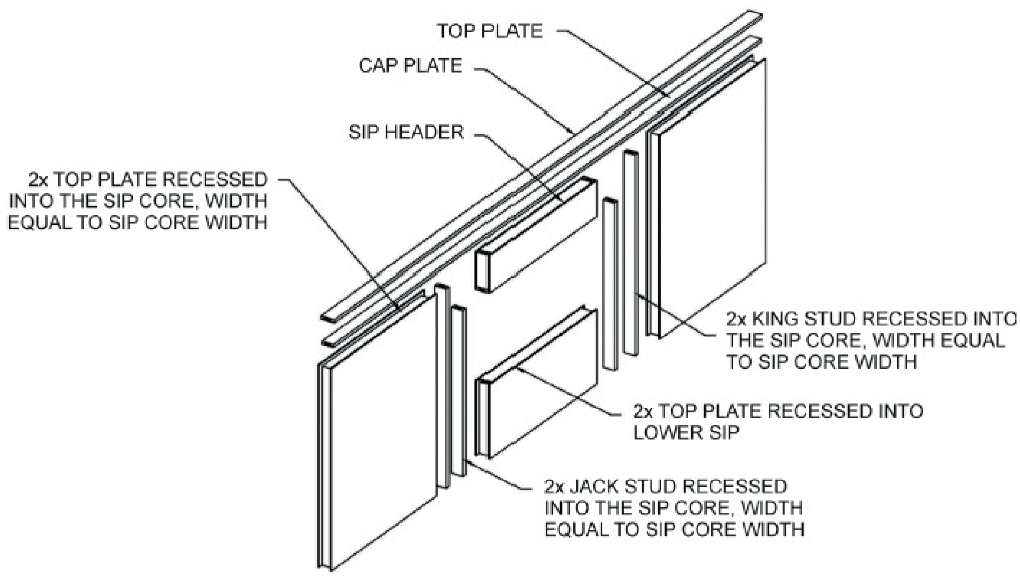
For SI: 1 inch = 25.4 mm.

Note: Figures illustrate SIP-specific attachment requirements. Other connections shall be made in accordance with

Tables R602.3(1) and (2), as appropriate.

FIGURE R613.5(5) SIP WALL-TO-WALL BALLOON FRAME CONNECTION (I-Joist floor shown for Illustration only)

R613.5.1 Top plate connection.
SIP walls shall be capped with a double top plate installed to provide overlapping at corner, intersections and splines in accordance with Figure R613.5.1. The double top plates shall be made up of a single 2 by top plate having a width equal to the width of the panel core, and shall be recessed into the SIP below. Over this top plate a cap plate shall be placed. The cap plate width shall match the SIP thickness and overlap the facers on both sides of the panel. End joints in top plates shall be offset at least 24 inches (610 mm).



>

For SI: 1 inch = 25.4 mm.

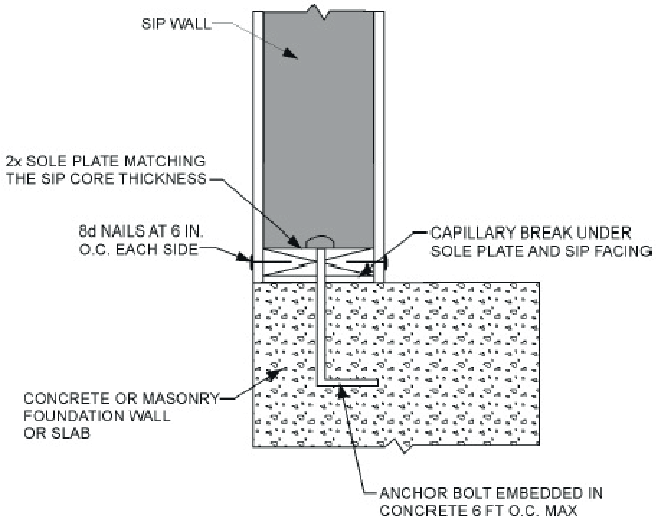
Notes:

1. Top plates shall be continuous over header.
2. Lower 2x top plate shall have a width equal to the SIP core width and shall be recessed into the top edge of the panel. Cap plate shall be placed over the recessed top plate and shall have a width equal to the SIPs width.
3. SIP facing surfaces shall be nailed to framing and cripples with 8d common or galvanized box nails spaced 6 inches on center.
4. Galvanized nails shall be hot-dipped or tumbled. Framing shall be attached in accordance to Section R602.3(1) unless otherwise provide for in Section R613.

FIGURE R613.5.1 SIP WALL FRAMING CONFIGURATION

R613.5.2 Bottom (sole) plate connection.
SIP walls shall have full bearing on a sole plate having a width equal to the nominal width of the foam core.

When SIP walls are supported directly on continuous foundations, the wall wood sill plate shall be anchored to the foundation in accordance with Figure R613.5.2 and Section R403.1.



For SI: 1 foot = 304.8 mm.

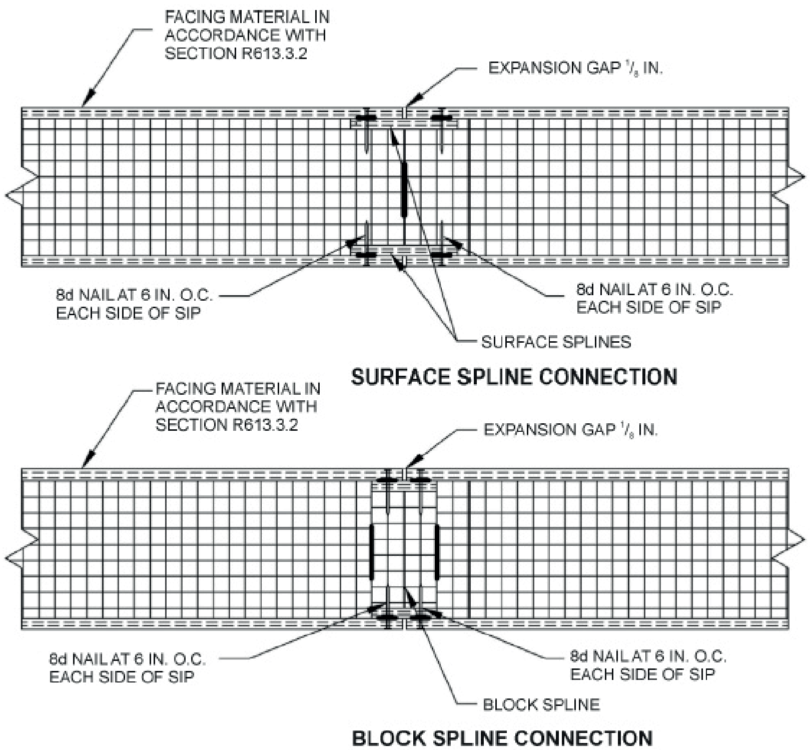
FIGURE R613.5.2 SIP WALL TO CONCRETE SLAB FOR FOUNDATION WALL ATTACHMENT

R613.5.3 Wall bracing.
SIP walls shall be braced in accordance with Section R602.10. SIP walls shall be considered continuous wood structural panel sheathing for purposes of computing required bracing. SIP walls shall meet the requirements of Section R602.10.4.2 except that SIPs corners shall be fabricated as shown in Figure R613.9. When SIP walls are used for wall bracing, the SIP bottom plate shall be attached to wood framing below in accordance with Table R602.3(1).

R613.6 Interior load-bearing walls.
Interior load-bearing walls shall be constructed as specified for exterior walls.

R613.7 Drilling and notching.
The maximum vertical chase penetration in SIPs shall have a maximum side dimension of 2 inches (51 mm) centered in the panel core. Vertical chases shall have a minimum spacing of 24-inches (610 mm) on center. Maximum of two horizontal chases shall be permitted in each wall panel, one at 14 inches (360 mm) from the bottom of the panel and one at mid-height of the wall panel. The maximum allowable penetration size in a wall panel shall be circular or rectangular with a maximum dimension of 12 inches (305 mm). Overcutting of holes in facing panels shall not be permitted.

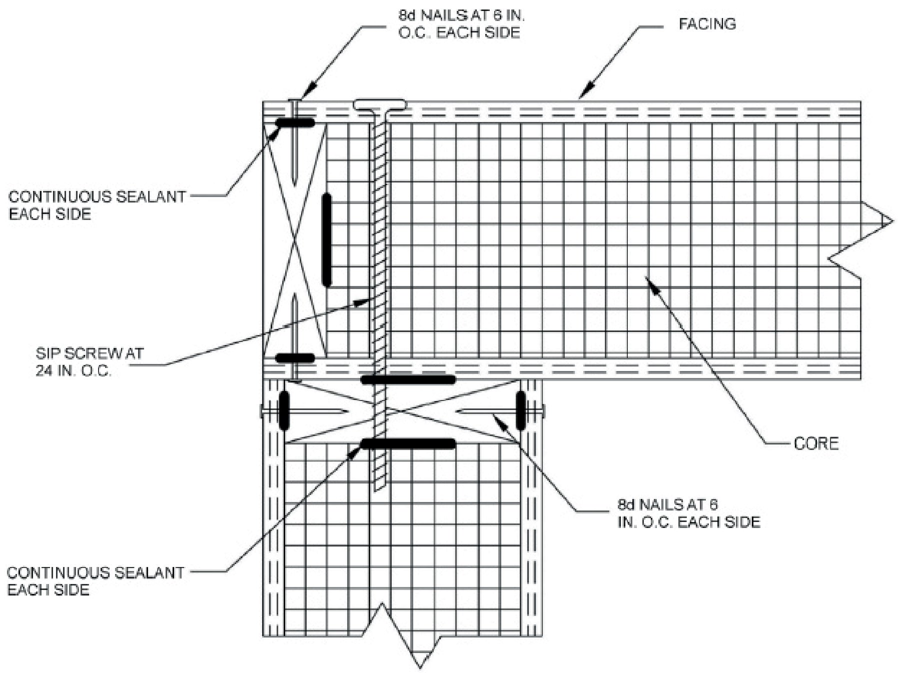
R613.8 Connection.
SIPs shall be connected at vertical in-plane joints in accordance with Figure R613.8 or by other *approved* methods.



For SI: 1 inch = 25.4 mm

FIGURE R613.8 TYPICAL SIP CONNECTION DETAILS FOR VERTICAL IN-PLANE JOINTS

R613.9 Corner framing.
Corner framing of SIP walls shall be constructed in accordance with Figure R613.9.



For SI: 1 inch = 25.4 mm.

FIGURE R613.9 SIP CORNER FRAMING DETAIL

R613.10 Headers.
SIP headers shall be designed and constructed in accordance with Table R613.10 and Figure R613.5.1. SIPs headers shall be continuous sections without splines. Headers shall be at least $11^7/_8$ inches (302 mm) deep. Headers longer than 4 feet (1219 mm) shall be constructed in accordance with Section R602.7.

TABLE R613.10 MAXIMUM SPANS FOR $11^7/_8$-INCH-DEEP SIP HEADERS (feet)[a]

LOAD CONDITION	SNOW LOAD (psf)	BUILDING width (feet)				
		24	28	32	36	40
Supporting roof only	20	4	4	4	4	2
	30	4	4	4	2	2
	50	2	2	2	2	2
	70	2	2	2	N/A	N/A
Supporting roof and one-story	20	2	2	N/A	N/A	N/A
	30	2	2	N/A	N/A	N/A
	50	2	N/A	N/A	N/A	N/A
	70	N/A	N/A	N/A	N/A	N/A

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.0479 kPa.

- International Residential Code for One- and Two-Family Dwellings
  - [2012 (Second Printing)]
    - Chapter 7 - Wall Covering
      - SECTION R701 GENERAL
      - SECTION R702 INTERIOR COVERING
      - SECTION R703 EXTERIOR COVERING

R703.1 General.
R703.2 Water-resistive barrier.
R703.3 Wood, hardboard and wood structural panel siding.
R703.4 Attachments.
R703.5 Wood shakes and shingles.
R703.6 Exterior plaster.
R703.7 Stone and masonry veneer, general.
R703.8 Flashing.
R703.9 Exterior insulation and finish system (EIFS)/EIFS with drainage.
R703.10 Fiber cement siding.
R703.11 Vinyl siding.
R703.12 Adhered masonry veneer installation.

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SECTION R703 EXTERIOR COVERING

R703.1 General.

Exterior walls shall provide the building with a weather-resistant exterior wall envelope. The exterior wall envelope shall include flashing as described in Section R703.8.

R703.1.1 Water resistance.

The exterior wall envelope shall be designed and constructed in a manner that prevents the accumulation of water within the wall assembly by providing a water-resistant barrier behind the exterior veneer as required by Section R703.2 and a means of draining to the exterior water that enters the assembly. Protection against condensation in the exterior wall assembly shall be provided in accordance with Section R702.7 of this code.

Exceptions:

1. A weather-resistant exterior wall envelope shall not be required over concrete or masonry walls designed in accordance with Chapter 6 and flashed according to Section R703.7 or R703.8.

2. Compliance with the requirements for a means of drainage, and the requirements of Sections R703.2 and R703.8, shall not be required for an exterior wall envelope that has been demonstrated to resist wind-driven rain through testing of the exterior wall envelope, including joints, penetrations and intersections with dissimilar materials, in accordance with ASTM E 331 under the following conditions:

2.1. Exterior wall envelope test assemblies shall include at least one opening, one control joint, one wall/eave interface and one wall sill. All tested openings and penetrations shall be representative of the intended end-use configuration.

2.2. Exterior wall envelope test assemblies shall be at least 4 feet by 8 feet (1219 mm by 2438 mm) in size.

2.3. Exterior wall assemblies shall be tested at a minimum differential pressure of 6.24 pounds per square foot (299 Pa).

2.4. Exterior wall envelope assemblies shall be subjected to the minimum test exposure for a minimum of 2 hours.

The exterior wall envelope design shall be considered to resist wind-driven rain where the results of testing indicate that water did not penetrate control joints in the exterior wall envelope, joints at the perimeter of openings penetration or intersections of terminations with dissimilar materials.

R703.1.2 Wind resistance.
Wall coverings, backing materials and their attachments shall be capable of resisting wind loads in accordance with Tables R301.2(2) and R301.2(3). Wind-pressure resistance of the siding and backing materials shall be determined by ASTM E 330 or other applicable standard test methods. Where wind-pressure resistance is determined by design analysis, data from approved design standards and analysis conforming to generally accepted engineering practice shall be used to evaluate the siding and backing material and its fastening. All applicable failure modes including bending rupture of siding, fastener withdrawal and fastener head pull-through shall be considered in the testing or design analysis. Where the wall covering and the backing material resist wind load as an assembly, use of the design capacity of the assembly shall be permitted.

R703.2 Water-resistive barrier.
One layer of No. 15 asphalt felt, free from holes and breaks, complying with ASTM D 226 for Type 1 felt or other approved water-resistive barrier shall be applied over studs or sheathing of all exterior walls. Such felt or material shall be applied horizontally, with the upper layer lapped over the lower layer not less than 2 inches (51 mm). Where joints occur, felt shall be lapped not less than 6 inches (152 mm). The felt or other approved material shall be continuous to the top of walls and terminated at penetrations and building appendages in a manner to meet the requirements of the exterior wall envelope as described in Section R703.1.

Exception: Omission of the water-resistive barrier is permitted in the following situations:

1. In detached accessory buildings.

2. Under exterior wall finish materials as permitted in Table R703.4.

3. Under paperbacked stucco lath when the paper backing is an approved water-resistive barrier.

R703.3 Wood, hardboard and wood structural panel siding.

R703.3.1 Panel siding.
Joints in wood, hardboard or wood structural panel siding shall be made as follows unless otherwise approved. Vertical joints in panel siding shall occur over framing members, unless wood or wood structural panel sheathing is used, and shall be shiplapped or covered with a batten. Horizontal joints in panel siding shall be lapped a minimum of 1 inch (25 mm) or shall be shiplapped or shall be flashed with Z-flashing and occur over solid blocking, wood or wood structural panel sheathing.

R703.3.2 Horizontal siding.
Horizontal lap siding shall be installed in accordance with the manufacturer's recommendations. Where there are no recommendations the siding shall be lapped a minimum of 1 inch (25 mm), or $^1/_2$ inch (13 mm) if rabbeted, and shall have the ends caulked, covered with a batten or sealed and installed over a strip of flashing.

R703.4 Attachments.
Unless specified otherwise, all wall coverings shall be securely fastened in accordance with Table R703.4 or with other *approved* aluminum, stainless steel, zinc-coated or other *approved* corrosion-resistive fasteners. Where the basic wind speed in accordance with Figure R301.2(4)A is 110 miles per hour (49 m/s) or higher, the attachment of wall coverings shall be designed to resist the component and cladding loads specified in Table R301.2(2), adjusted for height and exposure in accordance with Table R301.2(3).

TABLE R703.4 WEATHER-RESISTANT SIDING ATTACHMENT AND MINIMUM THICKNESS

SIDING MATERIAL		NOMINAL THICKNESS[a] (inches)	JOINT TREATMENT	WATER-RESISTIVE BARRIER REQUIRED	TYPE OF SUPPORTS FOR THE SIDING MATERIAL AND FASTENERS[b, c, d]					
					Wood or wood structural panel sheathing into stud	Fiberboard sheathing into stud	Gypsum sheathing into stud	Foam plastic sheathing into stud	Direct to studs	Number or spacing of fasteners
	Without insulation	0.019[f]	Lap	Yes	0.120 nail 1 1/2″ long	0.120 nail 2″ long	0.120 nail 2″ long	0.120 nail[y]	Not allowed	
		0.024	Lap	Yes	0.120 nail	0.120 nail	0.120 nail	0.120	Not	

Horizonal aluminum[e]					$1\frac{1}{2}$″ long	2″ long	2″ long	nail[y]	allowed	Same as stud spacing
	With insulation	0.019	Lap	Yes	0.120 nail $1\frac{1}{2}$″ long	0.120 nail $2\frac{1}{2}$″ long	0.120 nail $2\frac{1}{2}$″ long	0.120 nail[y]	0.120 nail $1\frac{1}{2}$″ long	
Anchored veneer: brick, concrete, masonry or stone		2	Section R703	Yes	See Section R703 and Figure R703.7[g]					
Adhered veneer: concrete, stone or masonry[w]		—	Section R703	Yes Note w	See Section R703.6.1[g] or in accordance with the manufacturer's instructions.					
Hardboard[k] Panel siding-vertical		$^7/_{16}$	—	Yes	Note m	Note m	Note m	Note m	Note m	6″ panel edges 12″ inter. sup.[n]
Hardboard[k] Lap-siding-horizontal		$^7/_{16}$	Note p	Yes	Note o	Note o	Note o	Note o	Note o	Same as stud spacing 2 per bearing
Steel[h]		29 ga.	Lap	Yes	0.113 nail $1\frac{3}{4}$″ Staple- $1\frac{3}{4}$″	0.113 nail $2\frac{3}{4}$″ Staple-$2\frac{1}{2}$″	0.113 nail $2\frac{1}{2}$″ Staple- $2\frac{1}{4}$″	0.113 nail[v] Staple[v]	Not allowed	Same as stud spacing
Particleboard panels		$^3/_8$ - $^1/_2$	—	Yes	6d box nail (2″ × 0.099″)	6d box nail (2″ × 0.099″)	6d box nail (2″ × 0.099″)	box nail[v]	6d box nail (2″ × 0.099″), $^3/_8$ not allowed	6″ panel edge, 12″ inter. sup.
		$^5/_8$	—	Yes	6d box nail (2″ × 0.099″)	8d box nail ($2\frac{1}{2}$″ × 0.113″)	8d box nail ($2\frac{1}{2}$″ × 0.113″)	box nail[v]	6d box nail (2″ × 0.099″)	
Wood structural panel[i] ANSI/APA-PRP 210 siding[i] (exterior grade)		$^3/_8$ - $^1/_2$	Note p	Yes	0.099 nail-2″	0.113 nail-$2\frac{1}{2}$″	0.113 nail-$2\frac{1}{2}$″	0.113 nail[v]	0.099 nail-2″	6″ panel edges, 12″ inter. sup.
Wood structural panel lapsiding		$^3/_8$ - $^1/_2$	Note p Note x	Yes	0.099 nail-2″	0.113 nail-$2\frac{1}{2}$″	0.113 nail-$2\frac{1}{2}$″	0.113 nail[x]	0.099 nail-2″	8″ along bottom edge
Vinyl siding[l]		0.035	Lap	Yes	0.120 nail (shank) with a 0.313 head or 16-gage staple with $^3/_8$ to $^1/_2$-inch crown[y, z]	0.120 nail (shank) with a 0.313 head or 16-gage staple with $^3/_8$ to $^1/_2$-inch crown[y]	0.120 nail (shank) with a 0.313 head or 16-gage staple with $^3/_8$ to $^1/_2$-inch crown[y]	0.120 nail (shank) with a 0.313 head per Section R703.11.2	Not allowed	16 inches on center or specified by the manufacturer instructions or test report
Wood[j] rustic, drop	$^3/_8$ Min	Lap	Yes	Fastener penetration into stud-1″					0.113 nail-$2\frac{1}{2}$″ Staple-2″	Face nailing up to 6″ widths, 1 nail per bearing; 8″ widths and over, 2 nails per bearing

(continued)

TABLE R703.4—continued WEATHER-RESISTANT SIDING ATTACHMENT AND MINIMUM THICKNESS

SIDING MATERIAL	NOMINAL THICKNESS[a] (inches)	JOINT TREATMENT	WATER-RESISTIVE BARRIER REQUIRED	TYPE OF SUPPORTS FOR THE SIDING MATERIAL AND FASTENERS[b, c, d]					
				Wood or wood structural panel sheathing into stud	Fiberboard sheathing into stud	Gypsum sheathing into stud	Foam plastic sheathing into stud	Direct to studs	Number or, spacing of fasteners
Shiplap	$^{19}/_{32}$ Average	Lap	Yes	Fastener penetration into stud-1″				0.113 nail-2$^{1}/_{2}$″ Staple-2″	Face nailing up to 6″ widths, 1 nail per bearing; 8″ widths and over, 2 nails per bearing
Bevel	$^{7}/_{16}$								
Butt tip	$^{3}/_{16}$	Lap	Yes						
Fiber cement panel siding[q]	$^{5}/_{16}$	Note q	Yes Note u	6d common corrosion-resistant nail[r]	6d common corrosion-resistant nail[r]	6d common corrosion-resistant nail[r]	6d common corrosion-resistant nail[r, v]	4d common corrosion-resistant nail[r]	6″ o.c. on edges, 12″ o.c. on intermed. studs
Fiber cement lap siding[s]	$^{5}/_{16}$	Note s	Yes Note u	6d common corrosion-resistant nail[r]	6d common corrosion-resistant nail[r]	6d common corrosion-resistant nail[r]	6d common corrosion-resistant nail[r, v]	6d common corrosion-resistant nail or 11-gage roofing nail[r]	Note t

For SI: 1 inch = 25.4 mm.

a. Based on stud spacing of 16 inches on center where studs are spaced 24 inches, siding shall be applied to sheathing approved for that spacing.

b. Nail is a general description and shall be T-head, modified round head, or round head with smooth or deformed shanks.

c. Staples shall have a minimum crown width of $^{7}/_{16}$-inch outside diameter and be manufactured of minimum 16-gage wire.

d. Nails or staples shall be aluminum, galvanized, or rust-preventative coated and shall be driven into the studs where fiberboard, gypsum, or foam plastic sheathing backing is used. Where wood or wood structural panel sheathing is used, fasteners shall be driven into studs unless otherwise permitted to be driven into sheathing in accordance with the siding manufacturer's installation instructions.

e. Aluminum nails shall be used to attach aluminum siding.

f. Aluminum (0.019 inch) shall be unbacked only when the maximum panel width is 10 inches and the maximum flat area is 8 inches. The tolerance for aluminum siding shall be +0.002 inch of the nominal dimension.

g. All attachments shall be coated with a corrosion-resistant coating.

h. Shall be of approved type.

i. Three-eighths-inch plywood shall not be applied directly to studs spaced more than 16 inches on center when long dimension is parallel to studs. Plywood $^{1}/_{2}$-inch or thinner shall not be applied directly to studs spaced more than 24 inches on center. The stud spacing shall not exceed the panel span rating provided by the manufacturer unless the panels are installed with the face grain perpendicular to the studs or over sheathing approved for that stud spacing.

j. Wood board sidings applied vertically shall be nailed to horizontal nailing strips or blocking set 24 inches on center. Nails shall penetrate 1$^{1}/_{2}$ inches into studs, studs and wood sheathing combined or blocking.

k. Hardboard siding shall comply with CPA/ANSI A135.6.

l. Vinyl siding shall comply with ASTM D 3679.

m. Minimum shank diameter of 0.092 inch, minimum head diameter of 0.225 inch, and nail length must accommodate sheathing and penetrate framing 1$^{1}/_{2}$ inches.

n. When used to resist shear forces, the spacing must be 4 inches at panel edges and 8 inches on interior supports.

o. Minimum shank diameter of 0.099 inch, minimum head diameter of 0.240 inch, and nail length must accommodate sheathing and penetrate framing $1^1/_2$ inches.

p. Vertical end joints shall occur at studs and shall be covered with a joint cover or shall be caulked.

q. See Section R703.10.1.

r. Fasteners shall comply with the nominal dimensions in ASTM F 1667.

s. See Section R703.10.2.

t. Face nailing: one 6d common nail through the over lap ping planks at each stud. Concealed nailing: one 11 gage $1^1/_2$ inch long galv. roofing nail through the top edge of each plank at each stud.

u. See Section R703.2 exceptions.

v. Minimum nail length must accommodate sheathing and penetrate framing $1^1/_2$ inches.

w. Adhered masonry veneer shall comply with the requirements of Section R703.6.3 and shall comply with the requirements in Sections 6.1 and 6.3 of TMS-402 ACI 530/ASCE 5.

x. Vertical joints, if staggered shall be permitted to be away from studs if applied over wood structural panel sheathing.

y. Minimum fastener length must accommodate sheathing and penetrate framing 0.75 inches or in accordance with the manufacturer's installation instructions.

z. Where approved by the manufacturer's instructions or test report siding shall be permitted to be installed with fasteners penetrating not less than 0.75 inches through wood or wood structural sheathing with or without penetration into the framing.

R703.5 Wood shakes and shingles.
Wood shakes and shingles shall conform to CSSB *Grading Rules for Wood Shakes and Shingles.*

R703.5.1 Application.
Wood shakes or shingles shall be applied either single-course or double-course over nominal $^1/_2$-inch (13 mm) wood-based sheathing or to furring strips over $^1/_2$-inch (13 mm) nominal nonwood sheathing. A permeable water-resistive barrier shall be provided over all sheathing, with horizontal overlaps in the membrane of not less than 2 inches (51 mm) and vertical overlaps of not less than 6 inches (152 mm). Where furring strips are used, they shall be 1 inch by 3 inches or 1 inch by 4 inches (25 mm by 76 mm or 25 mm by 102 mm) and shall be fastened horizontally to the studs with 7d or 8d box nails and shall be spaced a distance on center equal to the actual weather exposure of the shakes or shingles, not to exceed the maximum exposure specified in Table R703.5.2. The spacing between adjacent shingles to allow for expansion shall not exceed $^1/_4$ inch (6 mm), and between adjacent shakes, it shall not exceed $^1/_2$ inch (13 mm). The offset spacing between joints in adjacent courses shall be a minimum of $1^1/_2$ inches (38 mm).

R703.5.2 Weather exposure.
The maximum weather exposure for shakes and shingles shall not exceed that specified in Table R703.5.2.

TABLE R703.5.2 MAXIMUM WEATHER EXPOSURE FOR WOOD SHAKES AND SHINGLES ON EXTERIOR WALLS[a, b, c] (Dimensions are in inches)

LENGTH	EXPOSURE FOR SINGLE COURSE	EXPOSURE FOR DOUBLE COURSE
Shingles[a]		
16	$7^1/_2$	12[b]
18	$8^1/_2$	14[c]
24	$11^1/_2$	16
Shakes[a]		
18	$8^1/_2$	14
24	$11^1/_2$	18

For SI: 1 inch = 25.4 mm.

a. Dimensions given are for No. 1 grade.

b. A maximum 10-inch exposure is permitted for No. 2 grade.

c. A maximum 11-inch exposure is permitted for No. 2 grade.

R703.5.3 Attachment.
Each shake or shingle shall be held in place by two hot-dipped zinc-coated, stainless steel, or aluminum nails or staples. The fasteners shall be long enough to penetrate the sheathing or furring strips by a minimum of $^1/_2$ inch (13 mm) and shall not be overdriven.

R703.5.3.1 Staple attachment.
Staples shall not be less than 16 gage and shall have a crown width of not less than $^7/_{16}$ inch (11 mm), and the crown of the staples shall be parallel with the butt of the shake or shingle. In single-course application, the fasteners shall be concealed by the course above and shall be driven approximately 1 inch (25 mm) above the butt line of the succeeding course and $^3/_4$ inch (19 mm) from the edge. In double-course applications, the exposed shake or shingle shall be face-nailed with two casing nails, driven approximately 2 inches (51 mm) above the butt line and $^3/_4$ inch (19 mm) from each edge. In all applications, staples shall be concealed by the course above. With shingles wider than 8 inches (203 mm) two additional nails shall be required and shall be nailed approximately 1 inch (25 mm) apart near the center of the shingle.

R703.5.4 Bottom courses.
The bottom courses shall be doubled.

R703.6 Exterior plaster.
Installation of these materials shall be in compliance with ASTM C 926 and ASTM C 1063 and the provisions of this code.

R703.6.1 Lath.
All lath and lath attachments shall be of corrosion-resistant materials. Expanded metal or woven wire lath shall be attached with $1^1/_2$-inch-long (38 mm), 11 gage nails having a $^7/_{16}$-inch (11.1 mm) head, or $^7/_8$-inch-long (22.2 mm), 16 gage staples, spaced at no more than 6 inches (152 mm), or as otherwise *approved.*

R703.6.2 Plaster.
Plastering with portland cement plaster shall be not less than three coats when applied over metal lath or wire lath and shall be not less than two coats when applied over masonry, concrete, pressure-preservative treated wood or decay-resistant wood as specified in Section R317.1 or gypsum backing. If the plaster surface is completely covered by veneer or other facing material or is completely concealed, plaster application need be only two coats, provided the total thickness is as set forth in Table R702.1(1).

On wood-frame construction with an on-grade floor slab system, exterior plaster shall be applied to cover, but not extend below, lath, paper and screed.

The proportion of aggregate to cementitious materials shall be as set forth in Table R702.1(3).

R703.6.2.1 Weep screeds.
A minimum 0.019-inch (0.5 mm) (No. 26 galvanized sheet gage), corrosion-resistant weep screed or plastic weep screed, with a minimum vertical attachment flange of $3^1/_2$ inches (89 mm) shall be provided at or below the foundation plate line on exterior stud walls in accordance with ASTM C 926. The weep screed shall be placed a minimum of 4 inches (102 mm) above the earth or 2 inches (51 mm) above paved areas and shall be of a type that will allow trapped water to drain to the exterior of the building. The weather-resistant barrier shall lap the attachment flange. The exterior lath shall cover and terminate on the attachment flange of the weep screed.

R703.6.3 Water-resistive barriers.
Water-resistive barriers shall be installed as required in Section R703.2 and, where applied over wood-based sheathing, shall include a water-resistive vapor-permeable barrier with a performance at least equivalent to two layers of Grade D paper. The individual layers shall be installed independently such that each layer provides a separate continuous plane and any flashing (installed in accordance with Section R703.8) intended to drain to the water-resistive barrier is directed between the layers.

Exception: Where the water-resistive barrier that is applied over wood-based sheathing has a water resistance equal to or greater than that of 60-minute Grade D paper and is separated from the stucco by an intervening, substantially nonwater-absorbing layer or designed drainage space.

R703.6.4 Application.
Each coat shall be kept in a moist condition for at least 48 hours prior to application of the next coat.

Exception: Applications installed in accordance with ASTM C 926.

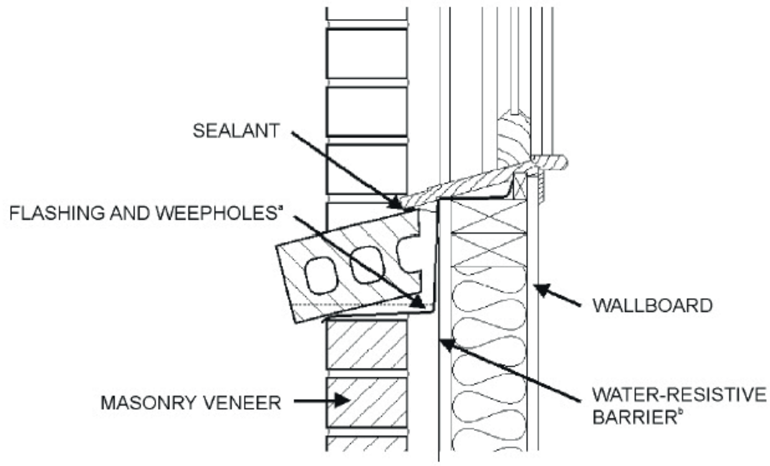
R703.6.5 Curing.
The finish coat for two-coat cement plaster shall not be applied sooner than seven days after application of the first coat. For three-coat cement plaster, the second coat shall not be applied sooner than 48 hours after application of the first coat. The finish coat for three-coat cement plaster shall not be applied sooner than seven days after application of the second coat.

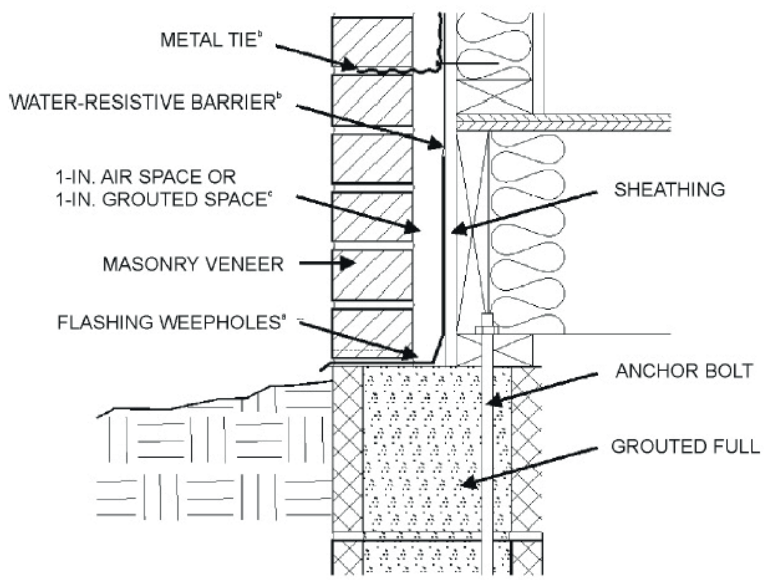
R703.7 Stone and masonry veneer, general.
Stone and masonry veneer shall be installed in accordance with this chapter, Table R703.4 and Figure R703.7. These veneers installed over a backing of wood or cold-formed steel shall be limited to the first *story* above-grade plane and shall not exceed 5 inches (127 mm) in thickness. See Section R602.10 for wall bracing requirements for masonry veneer for wood-framed construction and Section R603.9.5 for wall bracing requirements for masonry veneer for cold-formed steel construction.

Exceptions:

1. For all buildings in Seismic Design Categories A, B and C, exterior stone or masonry veneer, as specified in Table R703.7(1), with a backing of wood or steel framing shall be permitted to the height specified in Table R703.7(1) above a noncombustible foundation.

2. For detached one- or two-family *dwellings* in Seismic Design Categories D_0, D_1 and D_2, exterior stone or masonry veneer, as specified in Table R703.7(2), with a backing of wood framing shall be permitted to the height specified in Table R703.7(2) above a noncombustible foundation.

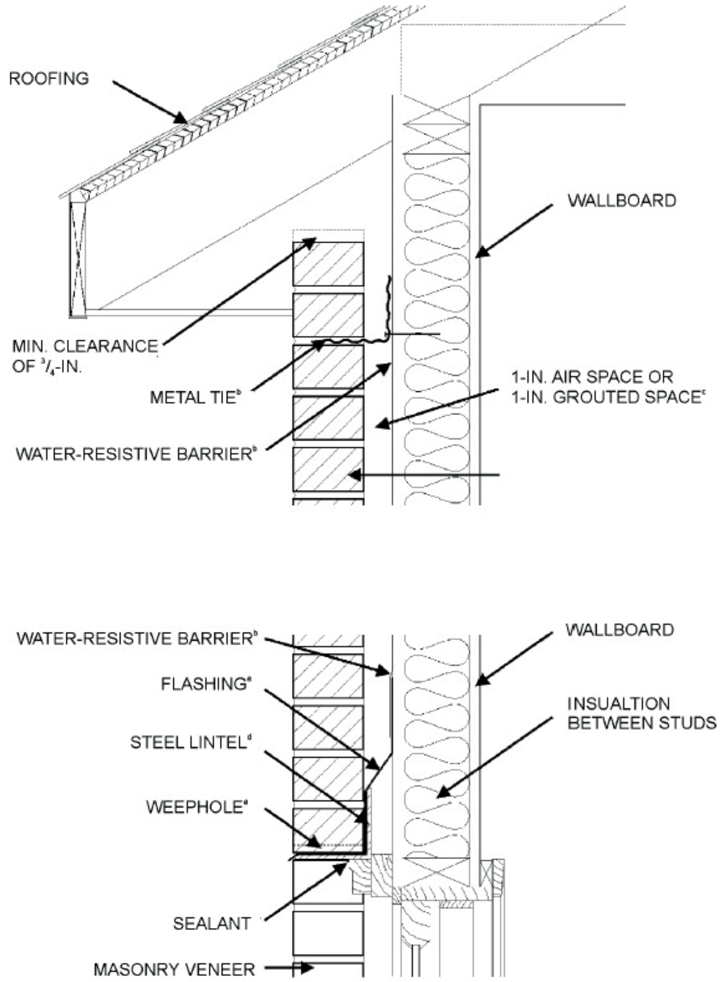




For SI: 1 inch = 24.5 mm.

FIGURE R703.7 MASONRY VENEER WALL DETAILS

(continued)



For SI: 1 inch = 25.4 mm.

a. See Sections R703.7.5, R703.7.6 and R703.8.

b. See Sections R703.2 and R703.7.4.

c. See Section R703.7.4.2 and Table R703.7.4.

d. See Section R703.7.3.

FIGURE R703.7—continued MASONRY VENEER WALL DETAILS

TABLE R703.7(1) STONE OR MASONRY VENEER LIMITATIONS AND REQUIREMENTS, WOOD OR STEEL FRAMING, SEISMIC DESIGN CATEGORIES A, B AND C

SEISMIC	NUMBER OF WOOD	MAXIMUM HEIGHT OF VENEER ABOVE	MAXIMUM NOMINAL	MAXIMUM	WOOD OR STEEL-

DESIGN CATEGORY	OR STEEL-FRAMED STORIES	NONCOMBUSTIBLE FOUNDATION[a] (feet)	THICKNESS OF VENEER (inches)	WEIGHT OF VENEER (psf)[b]	FRAMED STORY
A or B	Steel: 1 or 2 Wood: 1, 2 or 3	30	5	50	all
C	1	30	5	50	1 only
	2	30	5	50	top
					bottom
	Wood only: 3	30	5	50	top
					middle
					bottom

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.479 kPa.

a. An additional 8 feet is permitted for gable end walls. See also story height limitations of Section R301.3.

b. Maximum weight is installed weight and includes weight of mortar, grout, lath and other materials used for installation. Where veneer is placed on both faces of a wall, the combined weight shall not exceed that specified in this table.

TABLE R703.7(2) STONE OR MASONRY VENEER LIMITATIONS AND REQUIREMENTS, ONE- AND TWO-FAMILY DETACHED DWELLINGS, WOOD FRAMING, SEISMIC DESIGN CATEGORIES D_0, D_1 AND D_2

SEISMIC DESIGN CATEGORY	NUMBER OF WOOD FRAMED STORIES[a]	MAXIMUM HEIGHT OF VENEER ABOVE NONCOMBUSTIBLE FOUNDATION OR FOUNDATION WALL (feet)	MAXIMUM NOMINAL THICKNESS OF VENEER (inches)	MAXIMUM WEIGHT OF VENEER (psf)[b]
D_0	1	20[c]	4	40
	2	20[c]	4	40
	3	30[d]	4	40
D_1	1	20[c]	4	40
	2	20[c]	4	40
	3	20[c]	4	40
D_2	1	20[c]	3	30
	2	20[c]	3	30

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square foot = 0.479 kPa, 1 pound-force = 4.448 N.

a. Cripple walls are not permitted in Seismic Design Categories D_0, D_1 and D_2.

b. Maximum weight is installed weight and includes weight of mortar, grout and lath, and other materials used for installation.

c. The veneer shall not exceed 20 feet in height above a noncombustible foundation, with an additional 8 feet permitted for gable end walls, or 30 feet in height with an additional 8 feet for gable end walls where the lower 10 feet has a backing of concrete or masonry wall. See also story height limitations of Section R301.3.

d. The veneer shall not exceed 30 feet in height above a noncombustible foundation, with an additional 8 feet permitted for gable end walls. See also story height limitations of Section R301.3.

R703.7.1 Interior veneer support.
Veneers used as interior wall finishes shall be permitted to be supported on wood or cold-formed steel floors that are designed to support the loads imposed.

R703.7.2 Exterior veneer support.
Except in Seismic Design Categories D_0, D_1 and D_2, exterior masonry veneers having an installed weight of 40 pounds per square foot (195 kg/m^2) or less shall be permitted to be supported on wood or cold-formed steel construction. When masonry veneer supported by wood or cold-formed steel construction adjoins masonry veneer supported by the foundation, there shall be a

R702.1 General.
R702.2 Interior plaster.
R702.3 Gypsum board.
R702.4 Ceramic tile.
R702.5 Other finishes.
R702.6 Wood shakes and shingles.
R702.7 Vapor retarders.
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SECTION R702 INTERIOR COVERING

R702.1 General.

Interior coverings or wall finishes shall be installed in accordance with this chapter and Table R702.1(1), Table R702.1(2), Table R702.1(3) and Table R702.3.5. Interior masonry veneer shall comply with the requirements of Section R703.7.1 for support and Section R703.7.4 for anchorage, except an air space is not required. Interior finishes and materials shall conform to the flame spread and smoke-development requirements of Section R302.9.

TABLE R702.1(1) THICKNESS OF PLASTER

PLASTER BASE	FINISHED THICKNESS OF PLASTER FROM FACE OF LATH, MASONRY, CONCRETE (inches)	
	Gypsum Plaster	Cement Plaster
Expanded metal lath	$^{5}/_{8}$, minimum[a]	$^{5}/_{8}$, minimum[a]
Wire lath	$^{5}/_{8}$, minimum[a]	$^{3}/_{4}$, minimum (interior)[b]

		7/8, minimum (exterior)[b]
Gypsum lath[g]	1/2, minimum	3/4, minimum (interior)[b]
Masonry walls[c]	1/2, minimum	1/2, minimum
Monolithic concrete walls[c, d]	5/8, maximum	7/8, maximum
Monolithic concrete ceilings[c, d]	3/8, maximum[e]	1/2, maximum
Gypsum veneer base[f, g]	1/16, minimum	3/4, minimum (interior)[b]
Gypsum sheathing[g]	—	3/4, minimum (interior)[b] 7/8, minimum (exterior)[b]

For SI: 1 inch = 25.4 mm.

a. When measured from back plane of expanded metal lath, exclusive of ribs, or self-furring lath, plaster thickness shall be 3/4 inch minimum.

b. When measured from face of support or backing.

c. Because masonry and concrete surfaces may vary in plane, thickness of plaster need not be uniform.

d. When applied over a liquid bonding agent, finish coat may be applied directly to concrete surface.

e. Approved acoustical plaster may be applied directly to concrete or over base coat plaster, beyond the maximum plaster thickness shown.

f. Attachment shall be in accordance with Table R702.3.5.

g. Where gypsum board is used as a base for cement plaster, a water-resistive barrier complying with Section R703.2 shall be provided.

TABLE R702.1(2) GYPSUM PLASTER PROPORTIONS[a]

NUMBER	COAT	PLASTER BASE OR LATH	MAXIMUM VOLUME AGGREGATE PER 100 POUNDS NEAT PLASTER[b] (cubic feet)	
			Damp Loose Sand[a]	Perlite or Vermiculite[c]
Two-coat work	Base coat	Gypsum lath	2.5	2
	Base coat	Masonry	3	3
	First coat	Lath	2[d]	2

Three-coat work	Second coat	Lath	3[d]	2[e]
	First and second coats	Masonry	3	3

For SI: 1 inch = 25.4 mm, 1 cubic foot = 0.0283 m^3, 1 pound = 0.454 kg.

a. Wood-fibered gypsum plaster may be mixed in the proportions of 100 pounds of gypsum to not more than 1 cubic foot of sand where applied on masonry or concrete.

b. When determining the amount of aggregate in set plaster, a tolerance of 10 percent shall be allowed.

c. Combinations of sand and lightweight aggregate may be used, provided the volume and weight relationship of the combined aggregate to gypsum plaster is maintained.

d. If used for both first and second coats, the volume of aggregate may be 2.5 cubic feet.

e. Where plaster is 1 inch or more in total thickness, the proportions for the second coat may be increased to 3 cubic feet.

TABLE R702.1(3) CEMENT PLASTER PROPORTIONS, PARTS BY VOLUME

COAT	CEMENT PLASTER TYPE	CEMENTITIOUS MATERIALS				VOLUME OF AGGREGATE PER SUM OF SEPARATE VOLUMES OF CEMENTITIOUS MATERIALS[b]
		Portland Cement Type I, II or III or Blended Cement Type IP, I (PM), IS or I (SM)	Plastic Cement	Masonry Cement Type M, S or N	Lime	
First	Portland or blended	1			3/4 - 1 1/2[a]	2 1/2 - 4
	Masonry				1	2 1/2 - 4
	Plastic		1			2 1/2 - 4
Second	Portland or blended	1			3/4 - 1 1/2	3 - 5
	Masonry			1		3 - 5
	Plastic		1			3 - 5
Finish	Portland or blended	1			3/4 - 2	1 1/2 - 3
	Masonry			1		1 1/2 - 3
	Plastic		1			1 1/2 - 3

For SI: 1 inch = 25.4 mm, 1 pound = 0.545 kg.

a. Lime by volume of 0 to 3/4 shall be used when the plaster will be placed over low-absorption surfaces such as dense clay tile or brick.

b. The same or greater sand proportion shall be used in the second coat than used in the first coat.

R702.2 Interior plaster.

R702.2.1 Gypsum plaster.
Gypsum plaster materials shall conform to ASTM C 5, C 22, C 28, C 35, C 59, C 61, C 587, C 631, C 847, C 933, C 1032 and C 1047, and shall be installed or applied in compliance with ASTM C 843 and C 844. Gypsum lath or gypsum base for veneer plaster shall conform to ASTM C 1396. Plaster shall not be less than three coats when applied over metal lath and not less than two coats when applied over other bases permitted by this section, except that veneer plaster may be applied in one coat not to exceed $^{3}/_{16}$ inch (4.76 mm) thickness, provided the total thickness is in accordance with Table R702.1(1).

R702.2.2 Cement plaster.
Cement plaster materials shall conform to ASTM C 91 (Type M, S or N), C 150 (Type I, II and III), C 595 [Type IP, I (PM), IS and I (SM), C 847, C 897, C 926, C 933, C 1032, C 1047 and C 1328, and shall be installed or applied in compliance with ASTM C 1063. Gypsum lath shall conform to ASTM C 1396. Plaster shall not be less than three coats when applied over metal lath and not less than two coats when applied over other bases permitted by this section, except that veneer plaster may be applied in one coat not to exceed $^{3}/_{16}$ inch (4.76 mm) thickness, provided the total thickness is in accordance with Table R702.1(1).

R702.2.2.1 Application.
Each coat shall be kept in a moist condition for at least 24 hours prior to application of the next coat.

Exception: Applications installed in accordance with ASTM C 926.

R702.2.2.2 Curing.
The finish coat for two-coat cement plaster shall not be applied sooner than 48 hours after application of the first coat. For three coat cement plaster the second coat shall not be applied sooner than 24 hours after application of the first coat. The finish coat for three-coat cement plaster shall not be applied sooner than 48 hours after application of the second coat.

R702.2.3 Support.
Support spacing for gypsum or metal lath on walls or ceilings shall not exceed 16 inches (406 mm) for $^{3}/_{8}$-inch-thick (9.5 mm) or 24 inches (610 mm) for $^{1}/_{2}$-inch-thick (12.7 mm) plain gypsum lath. Gypsum lath shall be installed at right angles to support framing with end joints in adjacent courses staggered by at least one framing space.

R702.3 Gypsum board.

R702.3.1 Materials.
All gypsum board materials and accessories shall conform to ASTM C 22, C 475, C 514, C 1002, C 1047, C 1177, C 1178, C 1278, C 1396 or C 1658 and shall be installed in accordance with the provisions of this section. Adhesives for the installation of gypsum board shall conform to ASTM C 557.

- International Residential Code for One- and Two-Family Dwellings
  - [2012 (Second Printing)]
    - Chapter 11 [RE] - Energy Efficiency
- SECTION N1101 GENERAL
- SECTION N1102 BUILDING THERMAL ENVELOPE
- SECTION N1103 SYSTEMS
- SECTION N1104 ELECTRICAL POWER AND LIGHTING SYSTEMS (MANDATORY)
- SECTION N1105 SIMULATED PERFORMANCE ALTERNATIVE (PERFORMANCE)

N1102.1 (R402.1) General (Prescriptive).
N1102.2 (R402.2) Specific insulation requirements (Prescriptive).
N1102.3 (R402.3) Fenestration (Prescriptive).
N1102.4 (R402.4) Air leakage (Mandatory).
N1102.5 (R402.5) Maximum fenestration

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SECTION N1102 BUILDING THERMAL ENVELOPE

N1102.1 (R402.1) General (Prescriptive).
The *building thermal envelope* shall meet the requirements of Sections N1102.1.1 through N1102.1.4.

N1102.1.1 (R402.1.1) Insulation and fenestration criteria.
The *building thermal envelope* shall meet the requirements of Table N1102.1.1 based on the climate zone specified in Section N1101.10.

TABLE N1102.1.1 (R402.1.1) INSULATION AND FENESTRATION REQUIREMENTS BY COMPONENT[a]

CLIMATE ZONE	FENESTRATION *U*-FACTOR[b]	SKYLIGHT[b] *U*-FACTOR	GLAZED FENESTRATION SHGC[b, e]	CEILING *R*-VALUE	WOOD FRAME WALL *R*-VALUE	MASS WALL *R*-VALUE[i]	FLOOR *R*-VALUE	BASEMENT[c] WALL *R*-VALUE	SLAB[d] *R*-VALUE & DEPTH	CRAWL SPACE[c] WALL *R*-VALUE
1	NR	0.75	0.25	30	13	3/4	13	0	0	0
2	0.40	0.65	0.25	38	13	4/6	13	0	0	0
3	0.35	0.55	0.25	38	20 or 13 + 5[h]	8/13	19	5/13[f]	0	5/13
4 except Marine	0.35	0.55	0.40	49	20 or 13 + 5[h]	8/13	19	10/13	10, 2 ft	10/13
5 and Marine 4	0.32	0.55	NR	49	20 or 13 + 5[h]	13/17	30[g]	15/19	10, 2 ft	15/19
6	0.32	0.55	NR	49	20 + 5 or 13 + 10[h]	15/20	30[g]	15/19	10, 4 ft	15/19
7 and 8	0.32	0.55	NR	49	20 + 5 or 13 + 10[h]	19/21	38[g]	15/19	10, 4 ft	15/19

For SI: 1 foot = 304.8 mm.

a. *R*-values are minimums. *U*-factors and SHGC are maximums. When insulation is installed in a cavity which is less than the label or design thickness of the insulation, the installed *R*-value of the insulation shall not be less than the *R*-value specified in the table.

b. The fenestration *U*-factor column excludes skylights. The SHGC column applies to all glazed fenestration.

Exception: Skylights may be excluded from glazed fenestration SHGC requirements in Climate Zones 1 through 3 where the SHGC for such skylights does not exceed 0.30.

c. "15/19" means R-15 continuous insulation on the interior or exterior of the home or R-19 cavity insulation at the interior of the basement wall. "15/19" shall be permitted to be met with R-13 cavity insulation on the interior of the basement wall plus R-5 continuous insulation on the interior or exterior of the home. "10/13" means R-10 continuous insulation on the interior or exterior of the home or R-13 cavity insulation at the interior of the basement wall.

d. R-5 shall be added to the required slab edge *R*-values for heated slabs. Insulation depth shall be the depth of the footing or 2 feet, whichever is less in Zones 1 through 3 for heated slabs.

e. There are no SHGC requirements in the Marine Zone.

f. Basement wall insulation is not required in warm-humid locations as defined by Figure N1101.10 and Table N1101.10.

g. Or insulation sufficient to fill the framing cavity, R-19 minimum.

h. First value is cavity insulation, second is continuous insulation or insulated siding, so "13 + 5" means R-13 cavity insulation plus R-5 continuous insulation or insulated siding. If structural sheathing covers 40 percent or less of the exterior, continuous insulation *R*-value shall be permitted to be reduced by no more than R-3 in the locations where structural sheathing is used – to maintain a consistent total sheathing thickness.

i. The second *R*-value applies when more than half the insulation is on the interior of the mass wall.

N1102.1.2 (R402.1.2) *R*-value computation.
Insulation material used in layers, such as framing cavity insulation and insulating sheathing, shall be summed to compute the component *R*-value. The manufacturer's settled *R*-value shall be used for blown insulation. Computed *R*-values shall not include an *R*-value for other building materials or air films.

N1102.1.3 (R402.1.3) *U*-factor alternative.
An assembly with a *U*-factor equal to or less than that specified in Table N1102.1.3 shall be permitted as an alternative to the *R*-value in Table N1102.1.1.

TABLE N1102.1.3 (R402.1.3) EQUIVALENT U-FACTORS[a]

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	CRAWL SPACE WALL *U*-FACTOR
1	0.50	0.75	0.035	0.082	0.197	0.064	0.360	0.477
2	0.40	0.65	0.030	0.082	0.165	0.064	0.360	0.477
3	0.35	0.55	0.030	0.057	0.098	0.047	0.091[c]	0.136
4 except Marine	0.35	0.55	0.026	0.057	0.098	0.047	0.059	0.065
5 and Marine 4	0.32	0.55	0.026	0.057	0.082	0.033	0.050	0.055
6	0.32	0.55	0.026	0.048	0.060	0.033	0.050	0.055
7 and 8	0.32	0.55	0.026	0.048	0.057	0.028	0.050	0.055

a. Nonfenestration U-factors shall be obtained from measurement, calculation or an approved source.

b. When more than half the insulation is on the interior, the mass wall U-factors shall be a maximum of 0.17 in Zone 1, 0.14 in Zone 2, 0.12 in Zone 3, 0.087 in Zone 4 except Marine, 0.065 in Zone 5 and Marine 4, and 0.057 in Zones 6 through 8.

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

N1102.1.4 (R402.1.4) Total UA alternative.
If the total *building thermal envelope* UA (sum of *U*-factor times assembly area) is less than or equal to the total UA resulting from using the *U*-factors in Table N1102.1.3 (multiplied by the same assembly area as in the proposed building), the building shall be considered in compliance with Table N1102.1.1. The UA 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 UA compliance.

N1102.2 (R402.2) Specific insulation requirements (Prescriptive).
In addition to the requirements of Section N1102.1, insulation shall meet the specific requirements of Sections N1102.2.1 through N1102.2.12.

N1102.2.1 (R402.2.1) Ceilings with attic spaces.
When Secton N1102.1.1 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 *U*-factor alternative approach in Secton N1102.1.3 and the total UA alternative in Secton N1102.1.4.

N1102.2.2 (R402.2.2) Ceilings without attic spaces.
Where Secton N1102.1.1 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 Secton N1102.1.1 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 *U*-factor alternative approach in Secton N1102.1.3 and the total UA alternative in Secton N1102.1.4.

N1102.2.3 (R402.2.3) Eave baffle.
For air permeable insulations in vented attics, a baffle shall be installed adjacent to soffit and eave vents. Baffles shall maintain an opening equal or greater than the size of the vent. The baffle shall extend over the top of the attic insulation. The baffle shall be permitted to be any solid material.

N1102.2.4 (R402.2.4) 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.

N1102.2.5 (R402.2.5) 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.

N1102.2.6 (R402.2.6) Steel-frame ceilings, walls, and floors.
Steel-frame ceilings, walls, and floors shall meet the insulation requirements of Table N1102.2.6 or shall meet the *U*-factor requirements of Table N1102.1.3. The calculation of the *U*-factor for a steel-frame envelope assembly shall use a series-parallel path calculation method.

TABLE N1102.2.6 (R402.2.6) 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 × 4 or 2 × 6 or 2 × 8 R-49 in any framing
R-38	R-49 in 2 × 4 or 2 × 6 or 2 × 8 or 2 × 10
Steel-Framed Wall, 16″ o.c.	
R-13	R-13 + 4.2 or R-19 + 2.1 or R-21 + 2.8 or R-0 + 9.3 or R-15 + 3.8 or R-21 + 3.1
R-13 + 3	R-0 + 11.2 or R-13 + 6.1 or R-15 + 5.7 or R-19 + 5.0 or R-21 + 4.7
R-20	R-0 + 14.0 or R-13 + 8.9 or R-15 + 8.5 or R-19 + 7.8 or R-19 + 6.2 or R-21 + 7.5
R-20 + 5	R-13 + 12.7 or R-15 + 12.3 or R-19 + 11.6 or R-21 + 11.3 or R-25 + 10.9
R-21	R-0 + 14.6 or R-13 + 9.5 or R-15 + 9.1 or R-19 + 8.4 or R-21 + 8.1 or R-25 + 7.7
Steel-Framed Wall, 24″ o.c.	
R-13	R-0 + 9.3 or R-13 + 3.0 or R-15 + 2.4
R-13 + 3	R-0 + 11.2 or R-13 + 4.9 or R-15 + 4.3 or R-19 + 3.5 or R-21 + 3.1
R-20	R-0 + 14.0 or R-13 + 7.7 or R-15 + 7.1 or R-19 + 6.3 or R-21 + 5.9
R-20 + 5	R-13 + 11.5 or R-15 + 10.9 or R-19 + 10.1 or

	R-21 + 9.7 or R-25 + 9.1
R-21	R-0 + 14.6 or R-13 + 8.3 or R-15 + 7.7 or R-19 + 6.9 or R-21 + 6.5 or R-25 + 5.9
Steel Joist Floor	
R-13	R-19 in 2 × 6, or R-19 + 6 in 2 × 8 or 2 × 10
R-19	R-19 + 6 in 2 × 6, or R-19 + 12 in 2 × 8 or 2 × 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.

N1102.2.7 (R402.2.7) Floors.
Floor insulation shall be installed to maintain permanent contact with the underside of the subfloor decking.

N1102.2.8 (R402.2.8) 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 N1102.1.1 and N1102.2.7.

N1102.2.9 (R402.2.9) 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 N1102.1.1. 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 N1102.1.1 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 *building official* as having a very heavy termite infestation.

N1102.2.10 (R402.2.10) 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 in accordance with this code. 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.

N1102.2.11 (R402.2.11) Masonry veneer.
Insulation shall not be required on the horizontal portion of the foundation that supports a masonry veneer.

N1102.2.12 (R402.2.12) Sunroom insulation.
All *sunrooms* enclosing conditioned spaces shall meet the insulation requirements of this code.

Exception: For *sunrooms* with *thermal isolation,* and enclosing conditioned spaces, the following exceptions to the insulation *requirements* of this code shall apply:

1. The minimum ceiling insulation *R*-values shall be R-19 in Zones 1 through 4 and R-24 in Zones 5 through 8; and

2. The minimum wall *R*-value shall be R-13 in all zones. Wall(s) separating a *sunroom* with a *thermal isolation* from *conditioned space* shall meet the *building thermal envelope* requirements of this code.

N1102.3 (R402.3) Fenestration (Prescriptive).
In addition to the requirements of Secton N1102, fenestration shall comply with Sections N1102.3.1 through N1102.3.6.

N1102.3.1 (R402.3.1) *U*-factor.
An area-weighted average of fenestration products shall be permitted to satisfy the *U*-factor requirements.

N1102.3.2 (R402.3.2) Glazed fenestration SHGC.
An area-weighted average of fenestration products more than 50-percent glazed shall be permitted to satisfy the SHGC requirements.

N1102.3.3 (R402.3.3) 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 Secton N1102.1.1. This exemption shall not apply to the *U*-factor alternative approach in Secton N1102.1.3 and the Total UA alternative in Secton N1102.1.4.

N1102.3.4 (R402.3.4) 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 Secton N1102.1.1. This exemption shall not apply to the *U*-factor alternative approach in Secton N1102.1.3 and the total UA alternative in Secton N1102.1.4.

N1102.3.5 (R402.3.5) Sunroom *U*-factor.
All *sunrooms* enclosing conditioned spaces shall meet the fenestration requirements of this code.

Exception: For *sunrooms* with *thermal isolation* and enclosing conditioned spaces, in Zones 4 through 8, the following exceptions to the fenestration requirements of this code shall apply:

1. The maximum fenestration *U*-factor shall be 0.45; and

2. The maximum skylight *U*-factor shall be 0.70. New fenestration separating the *sunroom* with *thermal isolation* from *conditioned space* shall meet the *building thermal envelope* requirements of this code.

N1102.3.6 (R402.3.6) 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 N1102.1.1.

N1102.4 (R402.4) Air leakage (Mandatory).
The building thermal envelope shall be constructed to limit air leakage in accordance with the requirements of Sections N1102.4.1 through N1102.4.4.

N1102.4.1 (R402.4.1) Building thermal envelope.
The *building thermal envelope* shall comply with Sections N1102.4.1.1 and N1102.4.1.2. The sealing methods between dissimilar materials shall allow for differential expansion and contraction.

N1102.4.1.1 (R402.4.1.1) Installation.
The components of the *building thermal envelope* as listed in Table N1102.4.1.1 shall be installed in accordance with the manufacturer's instructions and the criteria listed in Table N1102.4.1.1, as applicable to the method of construction. Where required by the *building official*, an *approved* third party shall inspect all components and verify compliance.

TABLE N1102.4.1.1 (R402.4.1.1) AIR BARRIER AND INSULATION INSTALLATION

COMPONENT	CRITERIA[a]
Air barrier and thermal barrier	A continuous air barrier shall be installed in the building envelope. Exterior thermal envelope contains a continuous air barrier. Breaks or joints in the air barrier shall be sealed. Air-permeable insulation shall not be used as a sealing material.
Ceiling/attic	The air barrier in any dropped ceiling/soffit shall be aligned with the insulation and any gaps in the air barrier sealed. Access openings, drop down stair or knee wall doors to unconditioned attic spaces shall be sealed.
Walls	Corners and headers shall be insulated and the junction of the foundation and sill plate shall be sealed. The junction of the top plate and top of exterior walls shall be sealed. Exterior thermal envelope insulation for framed walls shall be installed in substantial contact and continuous alignment with the air barrier. Knee walls shall be sealed.
Windows, skylights and doors	The space between window/door jambs and framing and skylights and framing shall be sealed.
Rim joists	Rim joists shall be insulated and include the air barrier.
Floors (including above-garage and cantilevered floors)	Insulation shall be installed to maintain permanent contact with underside of subfloor decking. The air barrier shall be installed at any exposed edge of insulation.
Crawl space walls	Where provided in lieu of floor insulation, insulation shall be permanently attached to the crawlspace walls. Exposed earth in unvented crawl spaces shall be covered with a Class I vapor retarder with overlapping joints taped.
Shafts, penetrations	Duct shafts, utility penetrations, and flue shafts opening to exterior or unconditioned space shall be sealed.
Narrow cavities	Batts in narrow cavities shall be cut to fit, or narrow cavities shall be filled by insulation that on installation readily conforms to the available cavity space.
Garage separation	Air sealing shall be provided between the garage and conditioned spaces.
Recessed lighting	Recessed light fixtures installed in the building thermal envelope shall be air tight, IC rated, and sealed to the drywall.

Plumbing and wiring	Batt insulation shall be cut neatly to fit around wiring and plumbing in exterior walls, or insulation that on installation readily conforms to available space shall extend behind piping and wiring.
Shower/tub on exterior wall	Exterior walls adjacent to showers and tubs shall be insulated and the air barrier installed separating them from the showers and tubs.
Electrical/phone box on exterior walls	The air barrier shall be installed behind electrical or communication boxes or air-sealed boxes shall be installed.
HVAC register boots	HVAC register boots that penetrate building thermal envelope shall be sealed to the subfloor or drywall.
Fireplace	An air barrier shall be installed on fireplace walls. Fireplaces shall have gasketed doors.

a. In addition, inspection of log walls shall be in accordance with the provisions of ICC-400.

N1102.4.1.2 (R402.4.1.2) Testing.
The building or dwelling unit shall be tested and verified as having an air leakage rate of not exceeding 5 air changes per hour in Zones 1 and 2, and 3 air changes per hour in Zones 3 through 8. Testing shall be conducted with a blower door at a pressure of 0.2 inches w.g. (50 Pascals). Where required by the *building official,* testing shall be conducted by an *approved* third party. A written report of the results of the test shall be signed by the party conducting the test and provided to the *building official.* Testing shall be performed at any time after creation of all penetrations of the *building thermal envelope.*

During testing:

1. Exterior windows and doors, fireplace and stove doors shall be closed, but not sealed, beyond the intended weatherstripping or other infiltration control measures;

2. Dampers including exhaust, intake, makeup air, backdraft and flue dampers shall be closed, but not sealed beyond intended infiltration control measures;

3. Interior doors, if installed at the time of the test, shall be open;

4. Exterior doors for continuous ventilation systems and heat recovery ventilators shall be closed and sealed;

5. Heating and cooling systems, if installed at the time of the test, shall be turned off; and

6. Supply and return registers, if installed at the time of the test, shall be fully open.

N1102.4.2 (R402.4.2) Fireplaces.
New wood-burning fireplaces shall have tight-fitting flue dampers and outdoor combustion air.

N1102.4.3 (R402.4.3) 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/m^2), and swinging doors no more than 0.5 cfm per square foot (2.6 L/s/m^2), 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.

Exception: Site-built windows, skylights and doors.

N1102.4.4 (R402.4.4) 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 having an air leakage rate not more than 2.0 cfm (0.944 L/s) when tested in accordance with ASTM E 283 at a 1.57 psf (75 Pa) pressure differential. All recessed luminaires shall be sealed with a gasket or caulk between the housing and the interior wall or ceiling covering.

N1102.5 (R402.5) Maximum fenestration *U*-factor and SHGC (Mandatory).
The area-weighted average maximum fenestration *U*-factor permitted using tradeoffs from Secton N1102.1.4 or N1105 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 tradeoffs from Secton N1105 in Zones 1 through 3 shall be 0.50.

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CURRICULUM VITAE

Johny Corona

Background:

Ten years of experience in the coordination of construction documents, coordination of project consultant's work and developing project specifications. Successfully led all phases of design starting from initial client meetings and site visits through construction documents and construction administration. This includes site analysis, zoning analysis, office administration, construction phase observation, project close-out procedures, punch-list and pay applications to contractors.

Education:

University of Nevada, Las Vegas – Las Vegas, NV
Master of Architecture (in progress)
Projected graduation date, May 2016

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

Professional Experience:

Robert A Fielden Inc, Henderson. Project Director
Gary Guy Wilson Architecture, Las Vegas. Job Captain
Sandberg Salemme Design Group, Las Vegas. Intern Designer
Jim Stroh Architecture, Las Vegas. Drafter

Awards:

Design Excellence Award at the U.S. Department of Energy's 2015 Race to Zero competition

Congressional citation presented by the United States Senator Harry Reid for the housing competition for the Moapa Paiute Tribe.

Software Knowledge

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

Interests and Activities

Habitat for Humanity, Soccer, Painting, Art Sculpting, Photography, Traveling, Hiking with my wife and my awesome rescue dogs,