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HOW ARCHITECTURAL DESIGN CAN IMPACT THE VALUE OF SUSTAINABLE HOMES:

THE CASE OF CENTRE COUNTY’S SINGLE-FAMILY HOUSING

A Thesis in
Architecture

by
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ABSTRACT

What motivates people to invest in sustainable houses? What factors can drive them to buy these houses? As architects, what is the best course of action to encourage people to buy homes designed and constructed using sustainable practices?

While trends are changing in the era of ecological and economic crisis, most single-family houses in the United States are still built in a conventional way with few environmental considerations. The problem is that ecologically sustainable buildings usually are initially more costly compared to ordinary ones and many people prefer not to spend money on them unless they find something to convince them that it is worth the additional expense.

This thesis tries to provide an answer to this question: How can architects design green homes that are appealing for the buyers to an extent that they are encouraged to buy them even if they are more expensive? Through interviews with real estate agents and a thorough reading of literature as well as analysis of a number of case studies, this research attempts to assess the impact of architectural design on the value of single-family houses, and the potential benefits of investing in sustainable houses.
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CHAPTER 1 INTRODUCTION

1.1. Background

In the past few decades, concerns about conservation of the environment have dramatically risen. Various evidence of accelerating speed of global warming, extinction of species, and reaching the limits of natural resources, reinforce the necessity of environmental actions that seek to save the health of the planet.

According to the U.S. Energy Information Administration (EIA), buildings are involved in more than 40 percent of total energy usage in the US. In addition, buildings consume about 65 percent of total electricity and are substantial greenhouse gas emitters causing approximately 30 percent of greenhouse gas emissions (EPA green buildings).

![Figure 1-1. U.S. Energy Flow, 2016 Image Source: www.EIA.gov.](image-url)
Homes comprise a large percentage of the total building sector. According to United States Census Bureau, in 2016 more than one million permits for new residential units were issued ("New Privately Owned Housing Units Authorized Unadjusted Units for Regions, Divisions, and States," 2017). As can be seen in figure 1-1, homes are responsible for 21.53% of the total energy consumption in the US.

While ecologically sustainable housing has been an alternate suggestion for traditional trends of housing, there has always been a debate on its economic advantages for consumers. As a result of the incorporation of more efficient equipment, the use of advanced techniques and materials and additional hiring of specialists, the cost of sustainable construction frequently are prohibitive compared to conventional constructions. According to McGraw-Hill’s smart market report, although less important than before, higher upfront cost is still one of the main obstacles to increased green building activity ("World Green Building Trends SmartMarket Report," 2013). However, many studies suggest that the upfront cost of sustainable homes is recouped after a few years of operation. According to Brian Edwards, sustainable construction will pay for itself over the first eight to ten years of service by saving energy or water consumption (Edwards, 2003). Yet, in most of the cases, housing investors are driven by immediate monetary factors. American house owners, with a high rate of residential mobility¹ ("HomeInsight: The Evolution of Home Ownership," 2015), are unwilling to wait for years for their money to be recouped.

¹ According to Home Insight website, the typical American homeowner sells his or her home every five to seven years and the average individual will move 11.7 times during his or her lifetime.
The added value created by energy efficient design and construction of homes in the U.S. has not been fully captured in their sales prices (Stovall, Beldock, LeBaron, & Rinaldi, 2011). Theoretically, homes that are energy efficient and environmental friendly should be sold at a higher price than comparable homes without these “green” features. This price difference, which is termed the “Green Premium” and is explained in more detail in Chapter 2, is the market-driven incentive for the builders to invest in energy efficient homes. On the other side, when the homebuyers are confident that a property has justified “green premiums”, they are more likely to justify their higher purchase rate with the ability to recoup their money when they sell, while also benefiting a property with environmentally friendly features (Stovall et al., 2011). Verifying the green premium has been challenging for the market in appraising green properties at an appropriate price.

Several recent endeavors have sought to reduce the initial costs of green homes. For example, the U.S. Green Building Council (USGBC) has established a green building community which is active in building affordable green homes. They have stated that 60% of the homes with the LEED® green building program certification for homes program built in 2011 were identified as affordable projects. In addition, “nearly half of all the LEED® certified homes in existence today provide affordable housing” (“Green Affordable Homes Valuing Healthy and Efficient Housing for All,” 2012). These efforts have made a considerable change in the green residential markets. A McGraw-Hill Construction report shows that the green share of new single-family residential construction has increased from 2% of the market in 2005 to 22-25% in 2013. (“New and Remodeled Green Homes: Transforming the Residential Marketplace,” 2012). By contrast, in 2012, green commercial and institutional buildings had represented about 44% of the market. In the same year the share is 20% for green homes. This suggest there is still so much room for increasing the share of sustainable home in the residential sector. (“Green Outlook 2013,” 2013).
1.2. Statement of the Problem

In the marketing of homes, especially affordable housing, innovative architectural design is usually in the shadows. Home builders prefer to apply typical predesigned plans to multiple housing lots rather than employing architects for customized design. However, many homebuyers look for homes or are impressed by homes that have “good” architecture with features like agreeable exterior design, pleasant interior spaces, efficient use of space and maximum usage of natural lighting.

Good architectural design is often considered as an “amenity” among all other amenities within the residential market rather than as a necessity (Millhouse, 2005). There have been some studies to assess the role of good design in residential marketing. One of the difficulties in understanding the impact of architecture on the value of the property is the complication of quantifying the quality of “architecture”. This is especially true when the quality not only generates financial benefit, but also creates social or environmental value (Millhouse, 2005). There have been some attempts to quantify qualities such as a view or natural landscape elements. For instance, Bookout et al. (1994) indicate that in some cases well-designed landscapes have impacted 5% increases in rents or sales.

In this research, “considered” and “responsible” architectural design, refers to a customized design performed by an architect, which minimizes negative environmental impacts, eliminates waste in terms of material, space and cost, and respects the occupants’ well-being. Examples of strategies for good sustainable architecture are respecting the site elements, proper orientation, considered space configuration and flexible design, Responsible architecture and its strategies is elaborated on in chapter four (4) of this thesis.
The design and construction of “good architecture” generally costs more than conventional and less customized design (Vandell, 1989). The added costs associated with a building using sustainable techniques may deter the hiring of architects whose design fees may add more to the overall cost of the project. Yet, “good” architecture is able to add to the value of the house and make it more desirable for home owners, while advantages of passive architecture\(^2\), can reduce a homes’ energy consumption.

This research evaluates the hypothesis that good architecture is effective in the marketing of green homes, resulting in the realization of increased value. In other words, can sustainable architecture methods produce a “green premium”? It attempts to assess this idea using various methods including literature review, interviews with experts, and statistical analysis.

### 1.2.1 Sustainability and Its Complex Definition

Sustainability, formed by “sustain” and “ability”, in biology means the ability of a system to remain diverse and productive. The concept of sustainability was first introduced by the World Conservation Strategy of the International Union for Conservation of Nature and Natural Resources (Nature, Resources, & Fund, 1980). While the concept has evolved, perhaps the most enduring definition of sustainability is a quote from the Brundtland report: “Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (Keeble, 1988)

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\(^2\) Passive solar design refers to methods of designing building in which the need for active use of mechanical and electrical systems to heat, cool, and ventilate the building, is minimized. This is achieved through taking advantage of a building’s site, climate, and materials. Passive design and its strategies are further discussed in chapter 4.
In 1981, Freer Spreckley, expanded the definition and added social and ecological performance to define the Triple Bottom Line (TBL or 3BL) (Spreckley, 1981). TBL has been developed and now serves as a framework for the business sector to define ways of balancing ecology and equity, in order to meet the demands of a viable economy (Figure 1-2).

The 2005 World Summit on Social Development suggest an integration between the three sustainable development goals of economic development, social development and environmental protection (Assembly, 2005). The concept has then been illustrated in a Venn diagram of sustained development where overlapping circles help visualize the concept of interconnectedness of environment, equity and economy resulting in sustainability (figure 1-3).
The Venn diagram is an approach in which all three pillars of sustainability are equally important. This research is not limited to the TBL definition, but it is its main framework to refer to sustainability. As will be explained in future chapters, this research suggests that considered home design (social and ecological sustainability), results in growth in the housing market (economic sustainability). In this research, terms “sustainable” and “green” have been used interchangeably, although “sustainable” is a much broader term than mere “green”.

One of the most common ways of measuring sustainable buildings is through green certification programs. Some of the most common ones in the US are ENERGY STAR, LEED®, NAHB green and Passive House.

Using these systems makes it easier to determine the degree to which a building may be considered sustainable. However, getting certified in most cases involves considerable amount of paperwork and may be too costly. Therefore, not everyone is willing to go through the process of getting certified. In addition, many times some improvements that are made to a building do not necessarily make it qualified to get certified. In this study, any considered design element that elevates the building towards a more considerate and environmental friendly manner, can be called “sustainable”, whether it makes the home qualified to get a green certificate or not.
1.3. Research Objectives

The goal of this research is to assess the role of the architectural design on the value of sustainable homes in order to suggest a path for future sustainable home designers as well as to advocate for sustainability. This goal is broken down into the three (3) following objectives:

**Objective 1: Understanding how architecture is valued in appraisal of sustainable homes**

This research will first study the methods that are used for marketing of the green homes in order to find out where architectural design stands compared to general attributes of a house. A brief overview of general methods of home marketing is necessary for achieving this objective.

**Objective 2: Define specific methods of good sustainable architecture**

Through an extensive literature review, this research provides a set of methods for good sustainable architecture. Most of the methods are incorporated and thus verified through two student home design competitions and have received feedback.

**Objective 3: Measure and analyze the actual impact of a few of the methods of sustainable architecture on pricing of homes in a specific region using statistical methods**

The impact of three of the most influential sustainable architecture methods on the price of the homes are statically analyzed to achieve this objective. This objective verifies the hypothesis that good architecture is effective in the marketing of green homes and seeks its relevancy to the current housing market. Based on the outcomes of this analysis, a plan of action is suggested for designers and marketing agents of sustainable homes. In addition, a few research topics are suggested to future researchers.
An overview of the methodology for this research is presented in Figure 1-4. In the first phase of the research, a literature review is conducted to study the impact of architectural design on the price of sustainable homes. This is performed through an overview of impact of sustainability along with the effects of “good” architecture on housing prices. Also, an overview of the means and methods of home sales and marketing is provided. This section is discussed in detail in Chapter 2.

Next, as an important marketing factor, the main systems of evaluating sustainable homes in the US are studied. This is firstly in order to understand the meaning of sustainability in the
residential sector, and secondly to seek traces of architecture in the guidelines that are provided in the evaluation systems. This overview is presented in Chapter 3.

The marketing overview is followed by research on methods of good sustainable architecture presented in Chapter 4. This research is done using both literature and the practice of green housing design. In order to narrow down the wide and sometimes contrasting methods of passive architecture, the focus of this section is on US climate zone 5.

Many of the methods presented in the previous section are directly used in two student home design competitions. The two homes are designed in close cooperation with the owners/investors of the projects and their evaluation of the sustainable architecture features is presented. An overview of this design process and the outcomes is summarized in Chapter 5.

Two of the most influential passive architecture methods, orientation and elongation, are analyzed using statistical models to find their impact on the price of homes in Centre County, PA. The details of gathering the data and data analysis is discussed in Chapter 6.

And finally, the results of the statistical analysis in comparison with outcomes of student competitions is discussed in Chapter 7 of this research. Suggestions for future architects, marketing agents and researchers are also presented in this chapter.
CHAPTER 2 FEASIBILITY OF THE HYPOTHESIS³

While a number of studies have discussed the effect of sustainable certificates and amenities on the value of properties, little attention has been given to the design aspect of these buildings. This is an opportunity for research, especially since there have been other studies that correlate good design and architectural features with increased property values. In this chapter, an overview of the literature on the effect of sustainable features, decisions and amenities on property value is provided. Then the relationship between design and the market is investigated. Since the majority of the literature consider commercial buildings each section of this chapter starts with research on commercial and office buildings and then discusses the studies related to residential sector. In the final section, lessons that can be learned and the gaps in the current research are discussed.

2.1. Real Estate and Sustainability

The literature in real estate has predominantly focused attention on commercial buildings in the United States and beyond. A number of these studies have focused on the necessity of defining goals and values of sustainability in real estate. Myers, Reed and Robinson study commercial buildings in New Zealand and argue that one of the obstacles for construction of sustainable buildings is the absence of market evidence and detailed sales and lease transactions which restricts the feasibility of sustainable projects for investors. They urge researchers to come

³ This chapter has been previously presented in modified form in International Conference on Sustainable Design and Construction, (Fadaei, S., Iulo, L.D. and Yoshida, J., 2015. Architecture: A missing piece in real-estate studies of sustainable houses. Procedia Engineering, 118, pp.813-818.)
up with viable evidence for profitability of sustainable projects and make a business case for them (Myers, Reed, & Robinson, 2008).

One of the topics that numerous studies have discussed is the effect of eco-labeling on property values. Dermisi studied the effect of the USGBC LEED® rating system on assessed and market value of offices in the United States. She used assessor-generated values from the CoStar Group, USGBC and County/City Assessors and Treasurers websites across the U.S. to evaluate 351 office buildings in 36 states. From this information regression analysis was used to determine the impact of different variables such as area, age, LEED® and ENERGY STAR certification. The research concludes that ENERGY STAR certification has a considerable positive impact on both assessed and market value of buildings while the effects of LEED® varies based on the level of certification and geographic aggregation (Dermisi, 2009). In a 2011 research report Das, Tidwell and Ziobrowski used CoStar and USGBC data from 2007 through 2010 in the San Francisco and Washington DC areas to study rental rate dynamics of certified green office properties in these two cities. They found that there is a rental premium for green office properties; however, green premiums are not static. Instead, in order to offset negative effects of down-markets, the rents are stabilized in many conditions of the real estate market (Das, Tidwell, & Ziobrowski, 2011).

Another approach that has been taken in the market evaluation of green commercial buildings is analysis of investment risk. Jackson used empirical evidence from CoStar and uses Net Present Value (NPV), Internal Rate of Return (IRR) and riskiness analysis to evaluate risk and return associated with LEED® or ENERGY STAR certified green buildings. He finds that compared to LEED®, ENERGY STAR adds less upfront cost to the project, is slightly less risky and provides slightly more financial benefit for the project (Jackson, 2009).
While the amount of research conducted in the housing sector is considerably less, there are a number of real estate studies that address the residential market. In an article evaluating the effect of ENERGY STAR certification on green houses, Bloom, Nobe and Nobe studied a sample of 300 homes in Fort Collins, Colorado consisting of 150 ENERGY STAR qualified homes and compared them to 150 non-ENERGY STAR qualified homes using hedonic regression analysis. They concluded that ENERGY STAR homes initially sell for approximately $93.22 per square meter ($8.66 per square foot) more than conventional ones (Bloom, Nobe, & Nobe, 2011). Two years later, Yoshida and Sugiura used transaction prices of 1,452 green projects and 10,481 non-green ones in Tokyo. They reported that the initial transaction premium of green buildings might be negative due to higher expected maintenance costs of these buildings. However, the premium becomes positive after two years due to slower depreciation of green buildings (Yoshida & Sugiura, 2013).

In a 2011 study from the demand side, Goodwin analyzed responses from 9,138 survey respondents from the 2009 NAR (National Association of Realtors) Home Buyer and Seller Survey about the importance of green home amenities. He found that sustainable amenities are more important for first-time homebuyers and those who buy a home through its first transaction. In addition, these amenities were of less importance for homebuyers under 40 compared to those older than 40 (Goodwin, 2011).

In conclusion, these studies show that there is generally a price premium associated with green amenities and sustainable buildings including homes. However the premium is not always predictable as was seen in the comparison where LEED® certification was valued to be less beneficial than ENERGY STAR in the residential sector.

In the following section a similar approach to the review of recent literature has been used to evaluate the impact of design on conventional buildings.
2.2. Real Estate and Architecture

Architecture and design related features are not easy to quantify with a measurable variable and therefore are generally not being considered during appraisals and in hedonic pricing models of homes (Plaut & Uzulena, 2006). The cost-side of hiring architects and associated good design has received better attention than the demand-side (Vandell & Lane, 1989). That being said, many studies have linked architecture to the value of buildings and they mostly have found a positive relation between good design and the value of properties.

In one of the earliest, Hough and Kratz assessed the effect of “good” architecture on 135 office spaces’ rents in downtown Chicago using regression analysis (Hough & Kratz, 1983). Their measure of good architecture falls into two categories: Landmark status for older structures and Chicago American Institute of Architects (CAIA) jury award recipient projects for new buildings. The paper concludes that there is a 22% rent premium for good new architecture of CAIA award projects, while there is a price discount when the building is a landmark, perhaps since the process of renovation and making changes in the building is difficult and requires permission of the city government (Hough & Kratz, 1983). While the premium was unexpectedly significant at the time, the paper was criticized for not providing cost information by Vendell and Lane. In 1989 they evaluated 102 office buildings in Boston and Cambridge to understand the effect of good architecture on their construction costs, rent levels and vacancy rates (Vandell & Lane, 1989). In providing a measure for good architecture they surveyed architects and used disaggregation analysis. They found that there is a strong positive relationship between rent levels and good architecture but a weak relation between vacancy rates and the design. They also acknowledged that good design usually costs more but that is not necessarily the case (Vandell & Lane, 1989).
Smith and Moorhouse also studied the effect of architecture on residential sector prices in Boston. Their regression analysis considered variables of lot and house size, neighborhood characteristics, construction materials, architectural style, and individual architectural features and found that in total, these features account for 14% of the price. Their findings, again, support the notion that architecture and planning can have a positive impact on property values (Smith & Moorhouse, 1993).

Internationally, there are bodies of literature discussing architecture’s effect on the value of buildings. In a 2006 housing study, Latvia, Plaut and Uzulena also used hedonic pricing to evaluate which style of architecture is more popular to the extent that people are willing to pay a price premium. Using data from 3500 transactions that took place between 1997 and 2003, they ran regression analysis to determine the impact of different architecture styles on the value of the homes. They concluded that new or renovated units have higher-value coefficients and there are premiums associated with some features such as brick material, high ceilings or having balconies (Plaut & Uzulena, 2006)

2.3. Feasibility of relationship between real estate, sustainability and architecture

As can be seen from the literature discussed above, many studies have attempted to connect “sustainability,” on one hand, and “architectural design,” on the other, to property value. Most of these however, are focused on commercial buildings and less attention has been given to the residential sector. In addition, since the subject of sustainability is a rapidly evolving one, much of the existing literature is outdated and needs to be revised or re-assessed. Moreover, evident from Jackson’s study of the risk of sustainable real estate projects, the relationship between sustainability and property value is not always predictable. Similarly, for the case of
architecture, the price discount associated with landmarks was not obvious at first and needed empirical evidence to be proven (Hough & Kratz, 1983).

Good architecture could be a derivative for people to buy sustainable homes. While many argue that good architecture adds to the costs of the project, especially in the case of the U.S. residential sector where most homes do not involve an architect, it is valuable to assess the validity of this statement. As discussed by some people cited in this chapter, good architecture is not necessarily more expensive (Myers et al., 2008). Good design such as passive solar features, fitting the house with the prevailing views, and using local materials may add to the financial value of sustainable houses and result in price premiums. When it comes to investors, it’s extremely important to have realistic data analysis showing that the investment is profitable and not overly risky.

There is a lack of recent literature analyzing the impact of good design on the value of sustainable houses. The method that has been used to find out the impact of single elements on the price has been predominantly hedonic regression analysis, while some have used other methods such as surveys. While there have been discussions on value of good architecture (Macmillan, 2006), a detailed transaction analysis is something important that is still missing. The following chapters aims to address this missing piece through defining sustainable houses and categorizing design elements that serve sustainability and running the hedonic pricing model on a number of housing projects with and without the defined sustainable elements. This analysis is particularly important in establishing clarified and detailed evidences on the impact of valuable sustainable architecture on the residential market. While this relation is expected to be positive it is important to support the idea through real estate analysis.
2.5. Chapter Summary

This chapter provided an overview on the literature regarding the relationship of sustainability and real estate as well as architecture and price. Based on the literature, it is feasible to assume that architecture can be effective in marketing of green homes as well.
CHAPTER 3 HOW ARE GREEN HOMES EVALUATED?

This chapter aims to explain the current methods to identify, measure and classify sustainability in homes. It provides a brief overview of different programs for the certification of "green" or "Sustainable" homes. It also provides an overview of methods for appraising sustainability-related features in homes. The chapter then identifies the gaps related to acknowledgment of sustainable architectural design both in current certification programs and in current methods of appraising the homes.

3.1. Sustainability Evaluation: Green Certification Programs

Green Certification Programs or Ecolabelling are 3rd party voluntary programs for testing and certifying that a product is “sustainable”. Ecolabelling was originally created for foods and consumer’s products but have been adopted in the building industry as well. Green Certificates help the industry to differentiate environmentally sound buildings from those that are conventional, which might be translated into a marketing advantage for more sustainable ones.

There are several green labels in place for residential buildings. While they are all intended to provide useful information on the level of the sustainability of a home, they have fundamental differences. Some of them only focus on energy efficiency of the building (i.e. HERS and ENERGY STAR) while some others have a more holistic approach towards sustainability (i.e. LEED® for Homes, NAHB Green). Table 3-1 provides an overview of some of the well-known green certification programs for residential sector in the US. The criteria for these Ecolabels are explained in more detail in the following sections.
<table>
<thead>
<tr>
<th>Certification System</th>
<th>Classification</th>
<th>Application</th>
<th>How to get verified</th>
<th>Number of the homes/certified projects</th>
<th>cost</th>
<th>Year Established</th>
<th>Update Year</th>
<th>Latest Version</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENERGY STAR Commercial Industrials</td>
<td>New Homes</td>
<td>Single Family Homes, Multifamily-Low rise, Multifamily-Mid rise, Multifamily-High rise</td>
<td>3rd party verification by a certified Home Energy Rater</td>
<td>74,102 single family homes</td>
<td>½ to 1 cent per square foot</td>
<td>1995</td>
<td>2014</td>
<td>Version 3.1</td>
</tr>
<tr>
<td>LEED® for Homes</td>
<td>New Homes</td>
<td>Low-rise Residential, Mid-rise Residential, High-rise Residential Neighborhood</td>
<td>3rd party verification: Provider Organization, Green Rater, Energy rater</td>
<td>71,400 certified, 181,000 registered</td>
<td>Varying. Check this source: <a href="http://www.usgbc.org/cert-guide/fees/homes">http://www.usgbc.org/cert-guide/fees/homes</a></td>
<td>2005</td>
<td>Required from June 1, 2015</td>
<td>LEED V4</td>
</tr>
<tr>
<td>DOE Zero Energy Ready Home</td>
<td>New Homes</td>
<td>single family homes, Dwellings in multifamily buildings up to 5 stories with limitations (see DOE Zero Energy Ready Home National Program Requirements (Rev.04))</td>
<td>3rd party verification: ENERGY STAR® for Homes Version 3 and Building America certification as prerequisite</td>
<td>14,000</td>
<td>PHIUS provide certification for DOE zero energy ready home and energy star with the same price as PHIUS certification</td>
<td>2008</td>
<td>DOE Challenge Home</td>
<td>Rev 04</td>
</tr>
</tbody>
</table>

Table 3-1. Overview of green certificate programs completed in 2015. All of the systems are periodically updated.
3.1.1. Home Energy Rating Systems (HERS)

Home Energy Rating System (HERS), an index developed by Residential Energy Service Network (RESNET), is an industry standard which is used to measure a home’s energy efficiency. Certified RESNET raters perform assessments on the homes to define how energy efficient it is based on a scale of 0 to 150, with 100 representing a home conforming with the 2006 International Energy Conservation Code. The more energy efficient a home is the lower is the HERS score, to an extent that HERS score 0 indicates that the house is Net Zero Energy. In contrary, if the home is extremely inefficient, the HERS score will be around 150. Typical homes with no specific energy standards score 130 in this index while standard new homes typically get 100 (“What is the HERS Index? | RESNET,” 2016).

Some of the variables impacting the HERS score are:

- Exterior walls
- Floors over unconditioned spaces
- Ceilings and roofs
- Attics, foundations and crawlspace
- Windows and doors, vents and ductwork
- HVAC systems, water heating system, and thermostat (“What is the HERS Index? | RESNET,” 2016)

When performing an energy rating, a certified RESNET Home Energy Rater looks for performance indicators such as the amount and location of leakage in the building envelope,
HVAC distribution systems and effectiveness of insulation. In order to calculate the HERS score, the rater will run a series of diagnostic tests such as a blower door test\(^4\), duct leakage tested and infrared cameras (“Improve Energy Efficiency with a lower HERS Index Score | RESNET,” 2017). HERS index is a nationally recognized system and is the basic metric for many of the other Residential Green Labels.

### 3.1.2. ENERGY STAR

ENERGY STAR, is a voluntary program developed by the Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) that aims to help individuals and the industry save money while protecting the environment. It has programs to certify products, new homes, commercial buildings and industrial plants through third–party certification and testing. The certification takes place during the construction of the home and the builder should work closely with the rater in order to get certified (“About ENERGY STAR | About ENERGY STAR | ENERGY STAR,” 2015).

ENERGY STAR requires performance of a HERS target score and its criteria are:

- A complete thermal enclosure system including a comprehensive air sealing, insulation and high performance windows;
- High efficiency heating, cooling and ventilation system that is designed and installed for optimal performance;

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\(^4\) In a blower door test, a powerful fan is mounted to the inside frames of an exterior door. The fan pulls air out of the house and lowers the pressure inside the house, resulting the higher outside pressure to flow through the leaks. With the help of the auditors may detect locations of the air leaks. Source: www.energy.gov
A Complete Water Management System protecting walls, roofs and foundations; and

Energy-Efficient Lighting and Appliances that are high performance while consuming minimal energy. (Jackson, 2009) (“How New Homes Earn the ENERGY STAR,” 2015)


3.1.3. LEED® for Homes

LEED® for Homes is a voluntary rating system developed by The U.S. Green Building Council (USGBC) that promotes design and construction of sustainable homes and is a measure for assessing how green a house is. LEED® for Homes applies to single family homes, low-rise multi-family (one to three stories), or mid-rise multi-family (four to six stories).

LEED® for homes is a point-based system with a maximum possible point of 110. A home will be LEED® certified with 40 to 49 points, LEED® silver with 50 to 59 points, LEED® gold with 60 to 79 points, and LEED® platinum with 80 to 110 points. The certification process involves four main steps of registration, 3rd party verification, review and finally certification. There are 12 credit categories in LEED® version 4 for Homes:

- Integrative Process, with maximum of 2 points, is not a category, but it promotes interdisciplinary approach during the pre-design period
- Location and transportation, with maximum of 15 points, promotes projects within relatively dense areas with access to various forms of transportation.
23

- Materials and Resources, with maximum of 9 points, emphasizes on using sustainable and recycled material.
- Water efficiency, with maximum of 12 points, promotes smart potable water usage.
- Energy and atmosphere, with maximum of 37 points, encourages better energy performance of the home.
- Sustainable sites, with maximum of 7 points, promotes strategies that reduce negative impact on the environment.
- Indoor environmental quality, with maximum of 18 points, promotes better indoor air quality and better access to views and daylight.
- Innovation, with maximum of 18 points, addresses any design or construction measures that are not covered under other categories.

Although LEED® for Homes is a very popular rating systems, there are some criticisms about it. For example, it requires a lot of paper work, is expensive and instead of a holistic approach towards sustainability in many cases the projects have only “chased” points to get certified.

3.1.4. NGBS

National Green Building Standard (NGBS) is a program developed by Home Innovation Research Labs which is an independent subsidiary of the National Association of Home Builders (NAHB) ("Mission and History | Home Innovation Research Labs," 2016). Like LEED®, NGBS
is 3rd party verification and point-based system. It uses the terms bronze, silver, gold, and emerald for its different compliance levels based on a point system.

NGBS criteria for certifications are:

- Lot design, preparation and development; which promotes preserving the site and minimizing negative impacts on the site
- Resource efficiency; which encourages using natural material such as wood, recycled and sustainable products and reducing waste generated during construction.
- Energy efficiency; which addresses improvements such as high-performance envelope, use of energy efficient equipment and appliances.
- Water efficiency; which promotes implementations of measures that reduce indoor and outdoor water consumption.
- Indoor environmental Quality; which addresses control of pollutants, moisture and moisture effects, ventilation and sanitation,
- Operation, maintenance and building owner education; which encourages providing information on home’s use, maintenance and green components as well as post occupancy performance assessment (“National Green Building Standard (NGBS) | Home Innovation Research Labs,” 2016).

NGBS is approved by American National Standard (ANSI) and in addition to the homes, they certify products that can be used in projects towards their certification. By the end of year 2016, 12,936 single-family homes are NGBS certified (“Current NGBS Certification Projects | Home Innovation Research Labs,” 2017).
3.1.5. DOE Zero Energy Ready Home (ZERH)

The DOE Zero Energy Ready Home is developed by the U.S. Department of Energy (DOE). It is a 3rd party verification system and suggest that its certification, results in homes that are more 40%-50% more energy efficient that typical new homes (“Guidelines for Participating in the DOE Zero Energy Ready Home | Department of Energy,” 2017).

DOE Zero Energy Ready Home Requirements are:

- Energy. ENERGY STAR for Homes Baseline. Homes must be certified under ENERGY STAR Qualified Homes Program Version 3 or 3.1.
- Envelope. Fenestration shall meet or exceed ENERGY STAR requirements. There are also specific requirements for U-value, R-value (related to the "insulative" or thermal resistance values for windows and walls, respectively) and insulation.
- Duct System. Duct distribution systems must either be installed within the conditioned interior of the home or in optimal proximity
- Water Efficiency. With focus on hot water delivery systems which shall meet efficient design requirements.
- Lighting & appliances. All appliances as well as 80% of lighting fixtures should be ENERGY STAR qualified.
- Indoor Air Quality. Homes should be certified under EPA Indoor airPLUS, which is a labeling program for improving quality of indoor air by minimizing exposure to airborne pollutants and contaminants
- Renewable Ready. There should be provisions for installing Photovoltaic (a solar electric system) in future.
The DOE Zero Energy Ready Home is built on the past experiences of the Energy Star certified homes and prerequisites the EPA Indoor airPLUS and EPA WaterSense for responsible water resource use in order to add air quality to the energy efficiency requirements.

3.1.6. PHIUS+

PHIUS+ passive building standard is a voluntary program developed by Passive House Institute US (PHIUS) with emphasize on climate-specific criteria. The program aims to present homes that are affordable, durable and resilient while presenting the best energy-efficient solutions for a specific location. The program has ENERGY STAR, EPA Indoor airPLUS, and Zero Energy Ready Home (ZERH) specifications as prerequisites. Other requirements of the program are:

- Heating and cooling maximum requirements which are modified for each climate
- Source energy requirements in order to minimize energy use and carbon footprint
- Air-tightness and moisture design criteria in order to insure building durability.

PHIUS is a continuation of Energy Star and DOE Zero Energy Ready Home path (Figure 3-1). DOE ZERH is a prerequisite to ensure "high-performance," efficient homes (Rashkin, 2015). Figure 3-1 represents how each of these programs build up on previous experienced and add to them towards a more efficient home.
3.1.7. Sustainable Architecture in Homes

An overview of sustainable certification programs in homes suggest that most of these program assess technical aspects of sustainability, especially related to energy-performance, that are defined and measurable. Table 3-1 exhibits the strategies that have been required or have been emphasized the most in these programs.
<table>
<thead>
<tr>
<th>Technical Sustainability Criteria</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Building Envelope</td>
<td>Elements of the building, including all external building materials, windows, and walls, that enclose the internal space. Structure, thermal, water barriers and air and moisture control layers are also defined under building envelope.</td>
</tr>
<tr>
<td>2 Carbon Footprint</td>
<td>A calculation of the amount of greenhouse gases produced as a result of commercial, industrial, and individual activities.</td>
</tr>
<tr>
<td>3 Daylighting</td>
<td>Designing a building to take advantage of natural sunlight illumination.</td>
</tr>
<tr>
<td>4 Durability</td>
<td>A factor that affects the life cycle performance of a material or assembly. All other factors being equal, the more durable item is environmentally preferable, as it means less frequent replacement.</td>
</tr>
<tr>
<td>5 Energy Consumption</td>
<td>The amount of energy or power used.</td>
</tr>
<tr>
<td>6 Energy Efficient Appliances</td>
<td>Products that use less energy than conventional models, such as ENERGY STAR labeled products</td>
</tr>
<tr>
<td>7 Indoor Air Quality (IAQ)</td>
<td>Term which refers to air quality within and around buildings and structures especially in relation with pollutants (health) and temperature/humidity issues (comfort)</td>
</tr>
<tr>
<td>8 Local/Regional Materials</td>
<td>Building products manufactured and/or extracted within a defined radius of the building site.</td>
</tr>
<tr>
<td>9 Low Emissivity (low-E) Windows</td>
<td>Window technology that lowers the amount of energy loss through windows by inhibiting the transmission of radiant heat while still allowing sufficient light to pass through.</td>
</tr>
<tr>
<td>10 Natural Ventilation</td>
<td>The process of supplying air to and removing air from an indoor space without using mechanical systems.</td>
</tr>
<tr>
<td>11 Occupants’ Comfort</td>
<td>Set of strategies to keep people comfortable, efficient, healthy, and safe in the buildings.</td>
</tr>
<tr>
<td>12 Passive Solar</td>
<td>Strategies for using the sun’s energy to heat (or cool) a space, mass, or liquid. Passive solar strategies use no pumps or controls to function.</td>
</tr>
<tr>
<td>13 Solar Electric</td>
<td>The field of technology and research related to the application of solar cells for energy by converting solar energy (sunlight, including ultra violet radiation) directly into electricity.</td>
</tr>
<tr>
<td>14 Solar Thermal</td>
<td>Strategies to capture sun’s energy in order to heat up water or spaces in buildings</td>
</tr>
<tr>
<td>15 Water Quality</td>
<td>Refers to the chemical, physical, biological, and radiological characteristics of water.</td>
</tr>
</tbody>
</table>

These certification programs are voluntary, and most are point-based systems to assess sustainability standards in a home. Very seldom, in any of these programs, architectural design of a house is being directly referred to.

Generally, in order to achieve the requirements in a certification system, the architectural design plays an important role. For example, north-south orientation, or window placement, could highly impact the energy use in a house. These strategies represent best-practices in energy-efficient and sustainable homes referred to as "passive design". These strategies generally relate to a home's spatial configuration, an important layer of sustainable architecture that affects resident's everyday life and comfort. Space configuration, avoiding wasted spaces and connection to the environment (for example prevailing wind directions or access to sunlight) are among them. These aspects, along with other recommendations for enhancing the spatial layout of sustainable homes, such as avoiding wasted spaces, will be discussed in more detail in chapter 4. However, passive design features are evaluated in home appraising and will be discussed in more detail below (refer to figure 3-2 for an overview).

3.2. Sustainability evaluation through appraising: The Green MLS

The green MLS is a recent effort by National Association of REALTORS® (NAR) and NAR's Green Resource Council (GRC) that aims to capture the green features of a property. It allows for simpler finding, promotion and evaluation of green homes through incorporation of searchable data fields that capture verified data about a house regarding its energy performance and energy efficient components and certifications (Stovall et al., 2011). This information is represented in Multiple Listing Services (MLSs).
3.2.1. The green premium and its importance

Green premium is defined as “the cost difference between green and nongreen (conventionally constructed) versions of the same building” (Kats, 2013). All the costs of construction, design certification, etc. is included in this definition. Green premium also refer to when sustainable homes are sold more quickly compared to conventional homes (Stovall et al., 2011).

A difficulty in recognizing the green premium is that in many cases, sustainable improvements are “invisible”. For example, a well-sealed building envelope may require a third party certification. While there are a range of standards and scoring systems being used, there is a need for a system that allows for comparison/quantifying the systems at a local level. One of the reasons to develop the Green MLS has been to address this need (Stovall et al., 2011).

3.2.2. Definition of MLS

Multiple Listing Services provide organized and searchable information for real estate agents, appraisers and potential buyers in an area. They used to be physical books and now are large computer databases containing detailed information about each property such as neighborhood, architectural style, construction type, finished living area, unfinished areas, number of bedrooms, number of bathrooms and so on. Access to this database is usually limited to member agents who regularly enter data about their property listings to the relevant fields in the MLS while omitting excess information (Stovall et al., 2011).
3.2.3. How greening the MLS system works

There are more than 860 individual MLSs throughout the U.S. that perform locally. They are controlled by a local board of directors and not by the National Association of Realtors or any other official national MLS (Stovall et al., 2011). Therefore any change to the MLS data systems is locally implemented. In order to provide a guidance for other MLSs and their support teams, NAR has developed a step-by-step toolkit that can be used for adaptation of the green fields into the current system (NAR, 2012).

There are three (3) types of fields of entry in the Green MLS Toolkit (NAR, 2014):

1. 3rd party verified fields (certifications and labels). This field addresses certifications, labels, ratings and scores achieved through a 3rd party verification program.

2. Green search/marketing fields (Unverified). This field addresses the specific green features that are listed under 6 main performance categories:
   - Green Energy Efficiency, focuses on energy efficient attributes
   - Green Energy Generation, focuses on methods of generating energy
   - Green Sustainability, focuses on use of sustainable materials and avoiding waste
   - Green Water Conservation, focuses on general water conservation attributes
   - Green Indoor Air Quality, focuses on indoor air quality measures
   - Green Location, focuses on walkability and transportation proximity

3. Specific/technical fields. This field focuses on specific features of a house that are not necessarily a certification or a performance category, for example a blower door test, native plants, permeable paving and so on. These fields are the most difficult to verify and represent the need for educating the appraisers.
<table>
<thead>
<tr>
<th>Number</th>
<th>State</th>
<th>MLS Service Name</th>
<th>IECC Climate zone</th>
<th>MLS Service Name</th>
<th>IECC Climate zone</th>
<th>MLS Service Name</th>
<th>IECC Climate zone</th>
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<th>MLS Service Name</th>
<th>IECC Climate zone</th>
<th>MLS Service Name</th>
<th>IECC Climate zone</th>
</tr>
</thead>
</table>

Table 3-3. Frequency of the Green MLS fields in Sample Counties. Source of data: www.greenthemls.org
<table>
<thead>
<tr>
<th>Number</th>
<th>State</th>
<th>IECC Climate zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>VA</td>
<td>4 &amp; S</td>
</tr>
<tr>
<td>15</td>
<td>TX</td>
<td>2</td>
</tr>
<tr>
<td>14</td>
<td>TX</td>
<td>2</td>
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<tr>
<td>13</td>
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<tr>
<td>12</td>
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<tr>
<td>11</td>
<td>TX</td>
<td>2</td>
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<tr>
<td>10</td>
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<tr>
<td>9</td>
<td>TX</td>
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<tr>
<td>8</td>
<td>TX</td>
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<td>7</td>
<td>TX</td>
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<tr>
<td>6</td>
<td>TX</td>
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<tr>
<td>5</td>
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<tr>
<td>4</td>
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<td>3</td>
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<tr>
<td>2</td>
<td>TX</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>TX</td>
<td>2</td>
</tr>
</tbody>
</table>

**Total Frequency**

<table>
<thead>
<tr>
<th>Number</th>
<th>State</th>
<th>IECC Climate zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
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<tr>
<td>15</td>
<td>TX</td>
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<td>14</td>
<td>TX</td>
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<td>12</td>
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<td>4</td>
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<td>3</td>
<td>TX</td>
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<tr>
<td>2</td>
<td>TX</td>
<td>2</td>
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<tr>
<td>1</td>
<td>TX</td>
<td>2</td>
</tr>
</tbody>
</table>

**Table 3.3 (Cont.), Frequency of the Green MLS fields in Sample Counties. Source of data: www.greenMLS.org**

<table>
<thead>
<tr>
<th>Energy Features</th>
<th>MLS Service Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy-Green Fields • • • •</td>
<td>ENERGY STAR (ES) Appliances</td>
</tr>
<tr>
<td>Total Frequency 25 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1</td>
<td>ENERGY STAR label on the equipments</td>
</tr>
<tr>
<td></td>
<td>ENERGY STAR qualified windows, doors, skylights</td>
</tr>
<tr>
<td></td>
<td>ENERGY STAR qualified lighting, CFLs, or LEDs</td>
</tr>
<tr>
<td></td>
<td>Programmable thermostat</td>
</tr>
<tr>
<td></td>
<td>Tankless water heater</td>
</tr>
<tr>
<td></td>
<td>Low flow showerhead</td>
</tr>
<tr>
<td></td>
<td>Dual flush toilet</td>
</tr>
<tr>
<td></td>
<td>Energy audit avail.</td>
</tr>
<tr>
<td></td>
<td>Green roof</td>
</tr>
<tr>
<td></td>
<td>Utility bills</td>
</tr>
<tr>
<td></td>
<td>Solar water heater</td>
</tr>
<tr>
<td></td>
<td>off-grid</td>
</tr>
<tr>
<td></td>
<td>Solar photovoltaic (PV) system</td>
</tr>
<tr>
<td></td>
<td>Wind turbine</td>
</tr>
<tr>
<td></td>
<td>HERS rating</td>
</tr>
<tr>
<td></td>
<td>Geothermal Heat Pump</td>
</tr>
<tr>
<td></td>
<td>ENERGY STAR qualified home</td>
</tr>
<tr>
<td></td>
<td>EarthCraft House</td>
</tr>
<tr>
<td></td>
<td>LEED®</td>
</tr>
<tr>
<td></td>
<td>NAHB National Green Building Program</td>
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<tr>
<td></td>
<td>ANSI National Green Building Standard</td>
</tr>
<tr>
<td></td>
<td>Passive House Certification</td>
</tr>
<tr>
<td></td>
<td>Other green building program certification</td>
</tr>
<tr>
<td></td>
<td>Triple Windows</td>
</tr>
<tr>
<td></td>
<td>Green Materials</td>
</tr>
<tr>
<td></td>
<td>Passive solar features</td>
</tr>
<tr>
<td></td>
<td>Natural Day Lighting</td>
</tr>
<tr>
<td></td>
<td>Shading/Overhang on south side</td>
</tr>
<tr>
<td></td>
<td>South Orientation</td>
</tr>
<tr>
<td></td>
<td>West side shade by trees</td>
</tr>
<tr>
<td></td>
<td>North/south exposure</td>
</tr>
</tbody>
</table>
3.2.4. Frequency of Using Specific Fields in the Green MLS

More than 125 of these individual MLSs have implemented the green MLS toolkit and about 30 sample forms of implementations are publically shared on the Green MLS website ("Additional Resources | The Green MLS Tool Kit," 2017). Table 3-2 exhibits the frequency of use of specific sustainability related fields in the counties that have incorporated the Green MLS into their MLS system by 2015. Fields that are documented as separate fields (columns in the table), are predicted to be strong green premiums. As can be seen in the table, the certification labels such as ENERGY STAR and LEED® are the most repetitive fields in the Green MLS which means that these certificate are predicted to be green premiums in most of the counties that have implemented the green MLS.

“Passive solar features” or “passive design” field was used in the MLS samples of 17 counties out of 29. In most of the samples, this field had no further explanations and was not broken down into any subfields⁵. Although passive features field suggests great potential towards acknowledgement of sustainable architectural design, but the terming is too broad and does not provide enough information for neither the appraiser nor the future buyer. For example, it is not clear for a home with passive solar features, whether it has proper north-south orientation, or it has less windows on the north and more on the south elevation. An MLS form example from Austin, among few others, shows a break-down of passive solar strategies that can be checked if observed during a home appraisal (Figure 3-2).

⁵ Refer to Appendix A for an example of the Green MLS Data Entry Form
Similar to sustainability certification programs, the incorporation of the Green MLS, has been mostly aligned with technical and easily measurable sustainability indicators. The Green MLS, in its guidelines, specifically discusses passive solar assessment and defines variable examples of passive solar strategies in the homes. However, sustainable architectural design is not a significant element in assessment of the green premiums. Even the Passive Features entry field, is vague and does not define passive sustainable design strategies. Architectural decisions play important roles in improving energy efficiency, performance and well-being of occupants. However, these decisions are seldom acknowledged in sustainability certification programs or in sustainability appraisal of the residential sector.

This research, argues that the “considered” and “responsible” architectural design, which here is referred to as “good” architecture, changes the understanding of customers about sustainable architecture. In the long term, as demand rises, responsible design can impact the market of sustainable homes. In other words, the approach in this research is to marry technical sustainability with design in order to assess how willing are the homeowners to pay for them.
3.3. Chapter Summary

Chapter 3 provided an overview of the sustainable residential certification programs. It listed the main sustainability requirements for these programs and concluded that they are mainly focused on technical aspects of sustainability. The chapter then presented and overviewed the Green MLS which is the current practice of appraising homes while taking their sustainable features into account. Again, the incorporation of the Green MLS, for the most part, has neglected the importance of architectural design in achieving "livable" sustainable homes.

Chapter 4 provides an overview of the sustainable architecture strategies, or “good” sustainable architecture, which is customized design that is both considerate of environmental impacts, and improves the overall layout of the home in order to enhance the occupants’ well-being. The importance of sustainable architecture strategies and their alignment with technical sustainability will be discussed in more detail in Chapters 4 and 5.
CHAPTER 4 STRATEGIES FOR SUSTAINABLE ARCHITECTURE

In chapter three, an overview of the technical aspects of sustainable home design was provided with a statement that this research is going to focus on less technical aspects and strategies related to passive design and human use. These strategies, which are derived by architectural design and are less tangible or quantifiable, are discussed in Chapter 4. This chapter explains what this research means by “good” architectural design.

4.1. Methods for Identifying the Strategies

Defining “good” architecture has been a challenging part of this research. With the architectural design considered more an art than a science, and “good” being a highly relative term, identifying the principles required hard work and going back and forth between different sources.

This research started with a set of simple questions: Will homebuyers differentiate between “customized” designed homes and pre-made house plans? Could architecture be helpful in improving the marketing of sustainable homes? Answering these questions required defining sustainable homes on one hand and “good” or “proper” architectural design on the other hand. After these qualities were quantified, it was possible to do a market analysis on a few specific strategies (see Chapter 6). Defining these two qualitative subjects, which seemed to be separate at the beginning, started about the same time and ended up finding highly correlated suggestions for both.

The term “good” architecture is at the first place adopted from Sam Rashkin’s definition of “good architecture” in the book “Retooling the US Housing Industry: How It Got Here, Why
It’s Broken, How to Fix It”. Sam Rashkin is Chief Architect of the Building Technologies Office in the Office of Energy Efficiency and Renewable Energy at the Department of Energy (DOE), which maintains both ENERGYSTAR and ZERH programs. His definition of “good architecture” was identified to be tangible, thorough and meaningful suggestions. Therefore it was adopted as a point of departure for the rest of the thesis.

Rashkin’s definition of “good architecture” was also highly in accordance with the guidelines of DOE Race to Zero and DOE Challenge Home Student Design Competitions. These competitions, which are international collegiate competitions based on DOE ZERH guidelines, were other very helpful experiences in order to define “good architecture” for the purposes of this research.

Although “integration” and “integrative process” are of the most important approaches in sustainable homes, and it is really difficult to differentiate the role of each different sector, some of the decisions during the process of design are mostly related to architects/designers. These decisions, especially those that had an effect on the feeling and perceiving of the spaces, are the target of this study.

Climatic and local considerations is an important aspect of any sustainable design. Contrary to a set of international rules as in Modern architecture, there is not a “recognizable style” for sustainable architecture. A strategy that is perfect for a hot climate, could be essentially wrong for a humid continental one. In that sense, diversity and customization are important characteristics of sustainable architecture (Moro & Spirandelli, 2011, p. 12). Discussing all types of strategies for multiple climate types is beyond the scope of this research. Here, the focus is on US climate zone 5, humid continental climate, and the strategies are filtered to best fit this climate type.
It is also worth noting that even the most sustainable single family home cannot be perfectly sustainable, as it fails in density criteria. Density per square foot of single family homes is too low compared to almost all other types of residential typologies (Moro & Spirandelli, 2011, p. 13). This translates into higher needs for urban infrastructures and higher rate of transportation among all other consequences.

Finally, although strategies suggested by Rashkin were the basis for this research, it was not its limitation. A number of suggestions are brought from other sources and in a few cases, the original ones are replaced with different or even contrasting strategies from other research.

In the following sections, the scale and scope of the research and the specific characteristics of climate zone 5 are discussed. Next, two submittals for DOE student design competitions are explained as case studies. Finally, the identified strategies for good architecture are briefly discussed. These strategies are mainly proven strategies found in many sustainable design resources. What is important for this research is, however, their selection and the rationale for this selection.

4.2. Scale and Scope of the Design Strategies

Each climate has its own characteristics and requirements and sustainability strategies that work for one climate, and may not necessarily be applicable to another. Different climates are generally categorized based on two parameters of temperature and moisture. Temperature is measured based on accumulated temperature calculations called degree days. Degree days are calculated based on the time and temperature difference with a 65° base temperature.
The International Energy Conservation Code (IECC) has divided the map of US into 8 zones. Each zone has been assigned to a number starting from 1 for the hottest climate and going up to 8 which is assigned to the coldest US climate (IECC, 2015).

For the purpose of this study, and in order to narrow down the topic to achieve a more focused research, climate zone 5 has been selected which is the climate zone of both case studies (Pennsylvania).

4.2.1 Climate Zone 5 Characteristics

IECC climate zone 5 is considered a cold climate in which a region has between 5,400 and 9,000 heating degree days on a 65°C basis (Baechler et al., 2015). IECC defines specific code requirements for each climate zone. Table 4-1 shows the code requirements for climate zone 5.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ceiling R-value</td>
<td>38</td>
</tr>
<tr>
<td>Wood Frame Wall R-value</td>
<td>20 or 13+5h</td>
</tr>
<tr>
<td>Mass Wall R-value</td>
<td>13/17</td>
</tr>
<tr>
<td>Floor R-value</td>
<td>30g</td>
</tr>
<tr>
<td>Basement Wall R-value</td>
<td>10/13</td>
</tr>
<tr>
<td>Slab R-value</td>
<td>Depth 10, 2 ft</td>
</tr>
<tr>
<td>Crawlspace Wall R-value</td>
<td>10/13</td>
</tr>
<tr>
<td>Fenestration U-Factor</td>
<td>0.35</td>
</tr>
<tr>
<td>Skylight U-Factor</td>
<td>0.60</td>
</tr>
<tr>
<td>Glazed fenestration SHGC</td>
<td>NR</td>
</tr>
</tbody>
</table>

Table 4-1. IECC Code for Climate Zone 5. Source: energycode.pnl.gov
4.2. Strategies

In this chapter, the strategies that are driven by architects and result in saving energy and/or occupants’ well-being are discussed. Most of these strategies are well-known, have been repeatedly mentioned in textbooks and can be found in different case studies.

4.2.1. Passive Solar Strategies

Passive solar homes are designed in a way that do not need or have minimal need for mechanical and electrical equipment to provide heating, ventilation, and air conditioning. Instead, through proper orientation, placement of openings, thermal materials and so on, they collect, store and distribute sun’s energy in winter and reject it during the summer. Incorporating these strategies can cut the heating energy consumption by up to 90% and total energy usage of the homes by 50 to 70 percent (Torres Moskovitz, 2013, p. 10). This number can be up to 60% in cold climates (Johnston & Gibson, 2010). The added cost associated with these strategies, apart from costs associated with the design process itself, is usually minimal (“Passive Solar Design,” 2015). In this section, some of the most important passive solar strategies are briefly discussed.
4.2.1.1. Solar Orientation

North-south orientation, with up to 20 degrees off true south\(^6\), the long sides of the home facing north and south and short sides facing east and west the desired orientation specifications for the homes ("Solar Site Design - Oikos Green Building Library," 2015). This direction enables the homes to benefit from the southern sun exposure (in Northern hemisphere) throughout the year. In winter time, homes can receive solar energy from 9am to 3pm while in the summer, with the sun being higher in the sky and with proper use of overhangs, sunlight will be blocked (Friedman, 2013).

\[\text{Figure 4-1. Solar orientation diagram. Source: Climate Consultant software}\]

\(^6\) True south is the direction towards the southern end of the axis which the earth rotates around. True south is 13 degrees off of the magnetic south.
4.2.1.2. Proper Window Placement

Windows benefit the homes by allowing the sun’s heat and light enter the spaces, yet they are the hardest parts of the home to be properly insulated. Therefore their placement is of great importance. Most of the openings should be placed in the south side allowing the desirable sunlight and heat in. Windows should be minimal in the east and west side since the low morning and evening sun exposure is not easy to control (Rashkin, 2010).

Windows are important in providing natural ventilation in the summer time. It’s best if they are placed on two sides of a room and if that is not an option, windows are better to be as widely spaced as possible (Friedman, 2013).

4.2.1.3. Proper Overhang Usage

Proper using of overhangs can be really helpful in letting the desired sunlight inside the house and preventing the undesired heat. Since the sun is lower in the sky in winter and higher in the summer, a properly sized overhang (about 2 to 3 feet in North America) allow for the sunlight to penetrate through windows in winters and blocks the rays in the summer (Rashkin, 2010).

4.2.1.4. Proper Use of Vegetation

In order to benefit the most from planting trees around the house it is important to choose trees carefully. “Solar friendly” trees, deciduous trees with thin branching and dense foliage during the summer, preferably those that don’t grow too high, are most desirable to be used in the south side of the house (“Solar Site Design - Oikos Green Building Library,” 2015). By absorbing
the sun’s energy during the summer, they are also helpful in reducing the ambient temperature around the building and provide a comfortable environment (Friedman, 2013).

Evergreen trees are also recommended to be planted in the north side, to block arctic winds, and on the west side to prevent summer intense heat of setting sun (“Solar Site Design - Oikos Green Building Library,” 2015).

![Diagram of vegetation use](image)

**Figure 4-2. Use of vegetation diagram. Source: Climate Consultant software**

### 4.2.1.5. Thermal Mass Usage

Passive solar design allows for desired solar energy to be stored in thermal mass materials during the winter. This not only prevents the heat to escape but also prevents uncomfortable heat accumulation. Thermal mass materials warm up gradually by receiving sunlight during the day and when the temperature drops at night they eventually release the heat. (Rashkin, 2010). Thermal mass should not exceed 6 inches of thickness (Friedman, 2013). In
addition, it is recommended to use thinner layers of thermal mass throughout an area rather than smaller areas of thermal mass, in order to provide a smooth radiation of heat, ("Passive Solar Design," 2015). The best materials for thermal mass are those that have high heat capacity and high density such as concrete, clay bricks, and stone.

![Figure 4-3. Use of thermal mass diagram. Source: Climate Consultant software](image)

4.2.2. Compact Building Form

With the rising prices of energy the owners of large homes will have to pay higher bills. In addition, larger homes are more expensive to buy due to their larger square footage. For the same reason, large homes consume more resources such as materials, have a larger life cycle cost, higher maintenance cost and pay higher taxes. Also, as the homes get larger, there is excess need for road construction and other infrastructure such as utilities (Losantos & Noden, 2006;  

\[\text{Sum of all recurring and one-time (non-recurring) costs over the full life span or a specified period of a good, service, structure, or system.}\]

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Morcos, 2009). These all translate into a less sustainable environment that is excessively oversized.

Changing lifestyles and living in smaller homes is a preferred sustainability strategy. However, the idea of compacting homes does not intend to change people’s lifestyle. Instead, it mainly tries to remove wasted spaces, and suggests design strategies that would help the space feel large while they might be smaller. Such a strategy allows for investments to go towards improving the quality, safety and durability of homes (Rashkin, 2010).

![Compact building form diagram. Source: Climate Consultant software](image)

4.2.2.1. Open Layout: Horizontal Connection

Studies suggest that new generations of home buyers are not looking for traditional dining or dining rooms and prefer fewer walls (Burney, 2010). Horizontal connections such as open floor plans, as opposed to having multiple separated and single-purpose spaces, helps the
space to feel larger. They also eliminate the need for transitional spaces such as hallways and corridors. In addition, if properly oriented with properly sized south facing windows, open layouts are great in allowing the sun’s energy to enter the spaces during winter time, and provides outside views improving the connection between inside and outside and implies the perception that the house is larger than what it actually is (Friedman, 2013).

![Figure 5-5. Laurentians Home by BONE Structure®. Source: www.archdaily.com](image)

**4.2.2.2. Open Layout: Vertical Connection**

Same as horizontal connections, vertical connections of spaces, such as double height ceilings or interior bridges help spaces to feel larger. These types of connection are also helpful in allowing the light and sun’s energy to penetrate through interior spaces. Even if vertical connections are not possible, having high ceilings is helpful in making a small space feel big without increasing footprint (Burney, 2010). While vertical connections such as high ceilings are beneficial, they may increase the need for stairs. Therefore, designing homes with vertical
connections may require further strategies in order to avoid wasted space. Also, high ceilings are not recommended for small spaces such as bathrooms and small bedrooms.

![Figure 4-6. TED house by Onion Flats architects. Image Source: www.onionflats.com](image)

### 4.2.2.3. Creating Diverse Spaces

Diversity of space creates virtual interest and flow and with lack of virtual interest spaces feel smaller. One of the common methods of creating space diversity is creating ceiling height variety. “A building in which the ceiling heights are all the same is virtually incapable of making people comfortable” (Alexander, 1977, p. 877). Alexander also suggests that high ceilings imply formality while low ceilings are better for intimacy. This strategy can be used to create spaces that feel larger.
4.2.2.4. Considered Use of Space

In designing a compact house each square foot matters. Therefore unnecessary spaces and geometric complexities should be avoided. Combining small rooms together and making a large room with fewer walls was previously discussed in the open layout sections (Section 4.2.2.2). Another important strategy in space layout is to have minimal circulation space which translates into fewer hallways and staircases. However, it is important to have the remaining circulation spaces generously wide. To avoid narrow hallways that imply “smallness” (Rashkin, 2010).

4.2.3. Considered Space Configuration

Proper placement of each space is highly important when designing a compact house. Primary spaces such as living room, bedroom and kitchen should receive the best possible sun exposure and views and should not be blocked by secondary spaces such as circulation areas and bathrooms (Sassi, 2006).

Staircases tend to waste a lot of space and if not properly placed, they may block sun’s exposure and views. It is recommended that staircases be minimally designed to feel lightweight (Friedman, 2013). Alternatively the designers may consider wasted spaces under the staircases as extra storage spaces.
Most single family homes have a garage. If garages are located to the side of the building where they face the coldest winds and don’t block sun’s exposure, they can act as insulation (Ligget & Milne, 2008). In addition, vestibules can act as buffers and reduce the amount of air infiltration and heat exchange when the exterior door is open (Ligget & Milne, 2008; Rashkin, 2010).
4.2.4. Respecting the Site Elements

Each site is unique and has its own features. One of the basic recommendations in sustainable design is avoiding stock or pre-drawn housing plans or at least customize them based on each site’s elements. Among site characteristics, respecting prevailing view is one that not only improves the quality of indoor spaces but also has positive marketing effects (Bookout et al., 1994). In many of the neighborhoods it is possible to find an attractive view, whether it is natural or artificial (Rashkin, 2010). Capturing the prevailing views into design of the primary spaces (living rooms, bedrooms, etc.) is one of the sustainable approaches in designing homes. In addition to views, topography of the site, responding to prevailing winds and respecting neighborhood are important in design of appropriate homes that are acceptable in the community and do not cause any harm.

4.2.5. Flexibility

Adoptable homes such as those that are designed for aging in place, create environments in which modifying a house is possible and is easier, less expensive and therefore more desirable than relocating. Residing in the same location not only is more affordable than moving, but also allows homeowners to have a stronger relationship with their communities.

Flexibility and possibility of future growth, which are discussed here, are two of the key elements in having adoptable spaces
4.2.5.1. Flexible Layout

Enclosed spaces and fixed walls reduce flexibility in spaces. The more open the floor plan, the more flexible it is, since the occupants can configure the space and move the furniture the way they aim for. This, not only is helpful in having diverse spaces, but also improves their functionality, usage, and the feeling of freedom and control over space (Chan, 2007).

In addition to having open spaces, in order to increase adoptability, the spaces should be as large and as square as possible. Friedman (Friedman, 2002) suggests that rooms with the size of 12’ by 12’ up to 15’ by 15’ are large enough to allow for most of the future adaptation needs. In addition, he suggests these spaces to be free of any fixed feature such as closets that will limit future configurations (Friedman, 2002).

4.2.5.2. Possible Future Growth

As the families grow or save money, they may need or want larger homes. If future growth is considered while designing and constructing a home, it will be more probable that the homeowners configure and modify their home through trending do-it-yourself (DIY) projects rather than relocating or without compromising existing sustainable design strategies. The two common ways of growing homes are internal and external expansion while a combination of these two methods are also desirable for many homeowners.

External expansion or add-on can happen both in horizontal and vertical dimensions. Horizontal expansion is relatively more difficult due to land or municipal limitations. Vertical expansion of homes is usually done by expanding into the attic or renovating basement. It also can take place through adding a full or partial floor on top of the last floor of a house. Adding to the home requires careful structural considerations. In addition, placement of doors and windows,
circulation and situation in regards to surrounding buildings and neighborhood are of great importance.

Internal expansion or add-in is renovation within the existing shell of a house. It applies to the situation where a house is built larger and partially unfinished. In the 1st phase of building the house, main areas of the house are complete and ready to be occupied, while other spaces such as another floor, a basement or even a room is remained unfinished and to be completed in the 2nd phase when more space is needed. This approach is beneficial since it is less expensive than building a new space and it also allows for it to be completed by the owner through DIY projects (Friedman, 2013).

4.3. Summary of Good Sustainable Architecture Methods

Perhaps the most repeated sustainable architecture strategies are passive solar strategies. As already explained, proper usage of these strategies can help saving more than 50% of energy consumption in homes. Not only are these strategies cost effective, but they also have been practiced and incorporated in home design practices for a very long time and therefore, homeowners are usually more familiar with them. Cost-effective strategies such as compact design, may not always appeal the end-users that are used to live in generous spaces.

A unique opportunity allowed for the practice of home design with the strategies elaborated on in this chapter. DOE Race to Zero Student Design Competition allowed for incorporation of some of the “good” architecture design strategies. The competitions also allowed for the evaluation of the strategies based on the feedback from the real clients. Chapter 5, provides a more in depth overview of the competitions and their outcome.
CHAPTER 5 CASE STUDIES

In chapter 4 an overview of the good sustainable architecture strategies was provided. In chapter 5, these strategies have been put into practice to design homes in climate zone 5 for actual clients. This practice helped to illustrate how the strategies can actually be used in design of the homes, and whether they are acceptable in terms of cost and constructability as well as from the end user’s point of view.

As a method of validation, the strategies were assessed and incorporated into submissions to an annual competition held by the U.S. Department of Energy. The competitions were Challenge Home Student Design Competitions (2014) and subsequent Race to Zero Student Design Competition (2015). The two cases were completed by Penn State team members with the author being involved as “architecture group” team leader in 2014 and as architecture student advisor in 2015.

The submissions to these competitions are particularly relevant to this research because they were required to be high-performance homes that meet DOE standards for Zero-Energy Ready Home and since being “market-ready” was a very important criterion for the competition.

5.1. Competition Overview

Race to Zero Student Design Competition (previously, Challenge Home Student Design Competitions) is an annual student competition sponsored by the U.S. Department of Energy. The competition engages undergraduate students, graduate students, and university faculty from various disciplines to collaborate towards designing a reasonably priced, preferably an affordable,

The homes are designed based on a real-world scenario, should meet the mandatory performance target for the competition which is the DOE Zero Energy Ready Home specification, briefly discussed in chapter 3. Teams participating in the competition must be sponsored by a collegiate institution, have at least three students and have a student leader. They are also encouraged to pair-up with industry partners or at least have industry advisors.

The two cases presented here are the Penn State team’s submission for the competition and have received awards and highly positive feedback.

![Figure 5-1. The Bridge, front view rendering](image)
5.2. Case Study 1: The Bridge- Pennsylvania State University

“The bridge” is a residential home design completed for the U.S. Department of Energy Challenge Home Student Design Competitions by Team Nittany Lions E-den from Penn State. The main idea in designing this home was to implement readily available technologies and strategies to create an affordable sustainable home.

5.2.1. General Information

Project Name: The Bridge
Location: Berwick, PA.
Climate Zone: 5
Number of Bedrooms: 3
Number of Bathrooms: 2
Number of stories: 2
Building Footprint: 28’x24’
Area: 1400 ft²

5.2.2. Context

The project lot, located in Berwick, PA is one of the 40 lots that were identified for an initiative program called “Community Blue Print Project”. This project provides tools for the

8 The source for all of the images in this section is the Pennsylvania state University team submission for the U.S. Department of Energy Challenge Home Student Design Competitions, 2014.
municipality to provide affordable housing both through renovation and construction of single-family and multi-family dwellings. Berwick residents, with the average income of $30,000 annually, could highly benefit from these such projects. Therefore, designing a house that was replicable to other lots in the community became one of the goals of this project. Although the median income of Berwick is $30,000, the team set county median income levels for the construction budget which is $57,800 since the house was going to be subsidized.

In order to have the most realistic design, the team decided to work with an industry partner and had a real client. The client wanted an affordable low budget home that was suitable for a family with an elderly member or a member who has a disability. Therefore, aging in place was considered a design goal for this project.

5.2.3. Architectural Design Goals and Strategies

Through a number of discussions and case studies, the team set the following goals and strategies for the architecture of the home:

1. Designing a home that is as small as possible. Small homes are less expensive to build and less expensive to operate.
2. Home is small but should feel spacious. The team tried to create a pleasant and spacious interior space through open floor plan, and vertical connection of 1st and 2nd floors.
3. Avoiding wasted space. The team tried to minimize corridors and circulation spaces.
4. Having a central wet core. The kitchen, bathroom, laundry and utility room are either adjacent or stacked, so that plumbing costs are reduced and less energy is wasted through the pipes.
5. Optimal organization of spaces. Although the lot has a northeast-southwest orientation, with a relatively large neighboring building casting shadow on it, the team tried to configure the spaces in a way that living areas receive the best sunlight and bathrooms and corridors are centralized since they had least need for direct natural light. The double height space is placed in the south so that the sun exposure can penetrate through the building for daylighting and heat gain in the winter.

6. Designing a home that is as flexible as possible. One of the features that adds to the quality of a small home is flexibility and the possibility to change the layout. An open floor plan responds to this need to some extent. In addition, this design allows the occupants to fill out the double-height space and add 1 more bedroom or finish the unfinished basement and have an office space.

7. Respecting the neighborhood. The building height and the main exterior measurements are in accordance with neighbors, while the house has its own specific features at the same time.

Figure 5-2. The Bridge, interior space rendering
5.3. Case study 2: Heritage Homes - Pennsylvania State University

“Heritage Homes: High performance Homes in Harmony with community” or H4 is a duplex home (two adjacent, attached homes) design completed for the U.S. Department of Energy (DOE) Race to Zero Student Design Competitions by Penn State team of architecture, architectural engineering and civil engineering students. In 2014-2015 the team partnered with

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9 The source for all of the images in this section is the Pennsylvania state University team submission for the U.S. Department of Energy Race to Zero Student Design Competitions, 2015.
the State College Community Land Trust (SCCLT), an affordable housing provider, to design a house that was affordable and could be a model for the next generation of sustainable homes in the community.

![Figure 5-4. H4, front view rendering](image)

### 5.3.1. General Information

- **Project Name:** H4; Heritage Homes
- **Location:** 1394 University Drive, State College, PA 16801
- **Climate Zone:** 5
- **Square Footage:** 1,440 ft² per duplex (2,880 ft² total)
- **Number of bedrooms:** 3 per duplex
- **Number of bathrooms:** 2 full bathrooms per duplex
- **Number of stories:** 1 story with full basement per duplex
5.3.2. Context

The project site is in proximity with Penn state Campus in the State College Borough. The State College Community Land Trust (SCCLT), who purchases, renovates and sells affordable homes to the community, approached to Penn State Energy Efficiency Housing Research group to build their first new affordable home. Penn state faculty created a class, to address both the purposes of DOE student competition and SCCLT which, for the most part, were aligned together.

The main goal for this design was to design a house that not only is affordable to construct but is affordable to operate and is in line with rich heritage of State College and Pennsylvania. In order to incorporate the best strategies and technologies into the design, the team decided to engage all the different involved teams (i.e. design, marketing, energy, construction, client, etc.) in meetings happening early in the project. In addition, the teams worked closely with SCCLT especially in three charrettes that took place in the Stuckeman School of Architecture and Landscape Architecture at Penn State.

5.3.3. Architectural Design Goals and Strategies

Below is the list of the main goals and strategies for the building design.
Optimizing southern exposure and views. The homes are 10 degrees off true north so that the sun can warm up the houses in the morning and they face the best views of the site. This also allows for maximum presence from the street. In addition, the roofs are sloped and oriented for future photovoltaic (solar) electric power generation.

Figure 5-5. H4, floor plans
2. Responding to site elements specifically views, wind patterns and location of the trees. Mass trees on the western side of the building protect units from prevailing western winds.

3. Responding to topography by creating two story units with the lower level bermed within the sloping ground and providing walkout basements.
4. Responding to passive solar strategies. The longest façades are facing south and the shortest are facing west and east. Apart from that, the homes have overhangs in the south and benefit from a concrete floor on the ground floor which serves as thermal mass.

5. Considered space configuration by capturing the most amounts of sun exposure and best views for primary spaces. Therefore the bedrooms are located downstairs and the main social areas are upstairs capturing the best views. The driveway and carports are located in the northern part of the side to avoid blocking the views and solar exposures.

6. In order to encourage long-term home ownership, the homes are designed to meet “aging in place” standards, are flexible and are suitable for “aging-in-place”.
7. Flexibility. Units are designed in a way that allow for future reconfiguration of space. The large living room upstairs can be divided into a smaller living room and a bedroom, and one of the bedrooms downstairs can be converted to a family room and vice versa.

8. The interior plan is clearly segregated into “living” and “service” areas to maximize the living space and allow for efficient circulation and services.
5.4. Good Sustainable Strategies and Criteria of Technical Sustainability

While the architectural strategies discussed in chapter 4 and implemented in chapter 5, may sound like pure architectural strategies, the connection between each of them and the technical sustainability criteria (discussed in chapter 3) is considerable. Figure 5-12 illustrates how each of the “good architecture” strategies connects to one or more of the technical sustainability measures. For example, solar orientation helps with reducing energy consumption and carbon footprint of the home while it improves daylighting, occupant’s comfort, active solar and active thermal control of the building.

![Figure 5-12. Illustration of relation of sustainability criteria with “good” sustainable architecture strategies](image)

Figure 5-12. Illustration of relation of sustainability criteria with “good” sustainable architecture strategies
5.5. Selecting Orientation and Elongation for Sales Data Analysis

In order to verify the effectiveness of the sustainable architecture strategies on the home prices, two of the most effective strategies of good sustainable architecture have been selected. These two are solar orientation and elongation. Orientation, as already explained, has impacts on energy consumption, dayligting and occupants comfort. Elongation, although not defined as one of the standalone good sustainable architecture strategies, defines how much the form of the building allows the sun’s energy to penetrate the house.

An ideal elongation is one that combines with the best orientation, resulting the long side of the home face true south. In such case, through proper window placement at the south side of the house, daylighting can be maximized. An open layout that has most of the primary spaces on the south side of the building and the secondary space on the north will also be achievable (i.e. H4 SCCLT duplex case study). In addition, energy consumption and carbon footprint of the house is reduced and occupant’s comfort is increased.

Orientation and elongation are related with the most number of quantitative as well as qualitative criteria and presented the essence of all the strategies previously discussed. Therefore, they were chosen for further financial analysis which will be discussed in chapter 5.

5.6. Discussion of the Case studies

The case studies explained illustrate many of the strategies discussed in chapter 4. They are both designed to incorporate passive solar strategies (This was limited in "The Bridge," the first project analyzed), eliminate wasted space, to be compact and efficient and be flexible and adoptable.
Both of the homes were designed with the owner/clients involved in the process of design and for their desired lot. In the first case, the owner shared his goals and objectives which were in high alignment with the competition goals. Where the goals were variant, the team decided to comply with requirements of competition and slightly modify it later to address the owner’s requirements.

In the 2nd case study, the house was designed in close collaboration with the SCCLT, the owner. Their main goal was affordability during the construction and long-term energy use. The team worked on a basis of integrating involved teams based on the concept of “Engage Everybody Early on Everything” and engaged all the teams very early in the process of design, forming an integrated project delivery.

The 2014 submission of the Berwick project won the Best Technical Integration Award at the U.S. Department of Energy’s (DOE) and, H4 SCCLT duplex, won two of three award categories: Design Excellence and Systems Integration Excellence.

The important takeaway from the experience of the two competitions, is that it is possible to design homes that are sustainable, affordable, and desirable for the homeowners. In the following chapter, the goal is to analyze the key evaluated strategies of sustainable architecture design to see if they are reflected in the residential market. As already stated, the strategies are not equally easy to measure. Analyzing how efficient and compact the homes are, would rely on numerous home plans which are difficult to access to. Using Real Estate and GIS databases, this thesis analyzed Centre County data for two of the important passive solar strategies: Orientation and Elongation. Chapter 6, explains the details and results of this process.
5.7. Chapter Summary

Chapter 5 presented two student design competition submissions in which the strategies of good sustainable architecture presented in chapter 4 were illustrated. In addition, in chapter 5, relation of technical sustainability criteria and good architecture criteria are aligned and the connection of the past 3 chapters is presented. At the end of this chapter, selection of orientation and elongation for further analysis is justified and its results are presented in chapter 6.
CHAPTER 6 SALES DATA ANALYSIS

As discussed in chapter 5, orientation and elongation are among the most important factors in reducing energy needs with almost no added cost to the building. North-south orientation with the long sides of the home facing north and south are the desired orientation specifications for these houses. Apart from saving energy, north-south orientation allows for southern exposure to penetrate the house while elongation determines the extent to which the interior spaces are exposed to desirable natural light. Therefore it’s likely to assume that these factors exert an influence on the customer’s choice.

In this chapter, single-family detached homes of Centre County, Pennsylvania are analyzed to examine this idea. The method that is being incorporated to assess these effects is regression analysis. It helps to find the impact of different independent variables (i.e. south-facing windows or roof balcony) on the dependent variable which is price. In real-estate studies this method is called Hedonic pricing.

Firstly, detailed information of these homes was extracted from real-estate sources. These data are then joined with GIS building footprints shapefiles created by The Pennsylvania Spatial Data Clearinghouse (PASDA) followed by incorporating GIS methods to analyze their orientation and elongation. Considering that building area, age, spatial features, neighborhood, 

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10 This chapter has been previously presented in modified form in 16th International Conference on Computing in Civil and Building Engineering, Osaka, Japan (Fadaei, S., Rahimi, S. Yoshida, J. and, Iulo, L.D. 2016. The Effects of Orientation and Elongation on the Price of the Homes in Central Pennsylvania.)

11 A shapefile is a simple, nontopological format for storing the geometric location and attribute information of geographic features. Geographic features in a shapefile can be represented by points, lines, or polygons (areas).
etc. are important for prices, hedonic pricing model is used to isolate the effect of the defined two factors on house prices.

6.1. Methodology of Finding and Analysis of Data

For this thesis two sets of data were incorporated. The first set of the data was retrieved from a real estate website (Interfaceexpress, 2015) for all single family housing units constructed after 1800 and before 2015 in Centre County, Pennsylvania which numbered to 18,646 units. This data included information on the units’ addresses and building features (e.g. number of bedrooms and bathrooms, heating system, roof type, exterior façade material, building area, lot area, parking type, year built, current and sold prices, and a brief description on general features of the house). The second set of data was retrieved from The Pennsylvania Spatial Data Clearinghouse (PASDA) and included 2,379,678 polygons and 4,147,110 points. This data was a result of a program launched in 2007 that collected building footprints and geocoded addresses from different counties in Pennsylvania however, of all 67 counties within Pennsylvania only, 18 counties had the data for both the building footprints and addresses.

Figure 6-1. Single family houses concentration in Centre County
The PASDA data for Centre County included 83,182 building footprints. These polygons did not completely correspond with the geocoded points since the number of points were higher than the polygons. To apply the addresses in the geocoded points to the building footprints a spatial join was conducted and 51,360 points were found to be completely within the polygons. Another table connection was needed to associate the building footprints with real estate data. One challenge here was to join the two tables (i.e. the table including the Real Estate data and the shapefile including the polygons with addresses) by basing the join on the address, the only potential connection, since the addresses in the two tables were not in in the same format.

Having all the real estate data joined to the shapefile of single family houses made the studying of the impact of elongation and orientation of single family housing on their prices possible. To do so, three new variables were added to the data set: Orientation of buildings, elongation, and a variable calculated from the combination of two indicating the exposure of the building to the true south (i.e. 13 degrees different from the geographical south). The problem, however, was that the buildings’ footprints did not have rectangular geometries in all cases. In order to calculate these three variables, a minimum bounding rectangle was created using the “minimum bounding geometry” tool in ArcGIS (ArcGIS, 2014). The three variables were then calculated for these minimum bounding rectangles (figure 6-2).
Figure 6-2 illustrates how elongation and orientation were defined in this analysis. Minimum bounding rectangle for this building footprint is signified by dashed lines. Using the minimum bounding simplifies the calculation process. \( \alpha \) denoted the angle between the width of the building and geographical south. \( \beta \) signifies the angle between the width and the true south which is 13 degrees different from \( \alpha \). The closer \( \beta \) to 90 degrees the more sunlight is received from the south.

The elongation variable illustrates the extent to which the building is stretched and is simply calculated by dividing the minimum bounding rectangle’s length to its shape. This value is larger than or equal to one. To account for the orientation of the buildings the angle between the length of the building and the true south line was calculated. The ArcGIS software automatically stores the angle between the width of the minimum bounding rectangle and the geographical south plane (\( \alpha \) in Figure 6-2) in a separate field. However, this study is interested in the angle
between the width and true south. The true south is the direction that the most favorable direct sun exposure is received from and most easily controlled.

Accordingly, the angle that this study is interested in is $\beta = \alpha - 13$ where $0 < \alpha < 180$. The closer $\beta$ to 90 degrees the more directly the building receives sunlight from the south. Therefore, the orientation factor was calculated as $\sin(|\beta|) = \sin(|\alpha - 13|)$.

Since the amount of sunlight that a building receives from south is a function of both elongation and orientation a dummy variable was defined to account for both at the same time. In other words, a building in which the proportion of length to width is high and faces towards south receives the maximum amount of sunlight from the south. Therefore, the elongation-orientation variable is simply calculated by multiplying the orientation factor (i.e. $\sin(|\alpha - 13|)$) by elongation factor (i.e. $L/W$). Four (4) categorical variables for orientation (0-0.25, 0.25-0.5, 0.5-0.75, 0.75-1) and 2 categorical variables for elongation (1-1.43 (median) and 1.43 and larger).

Finally, a linear regression analysis was conducted with the following specifications:

1. The natural logarithm of home sale price was used as the dependent variable in the regression.

2. Logarithm of square foot variables (i.e. lot size, finished size, and total size) were used in the regression.

3. The number of bedrooms and bathrooms were used as categorical variables.

4. Dummy variables were created to account for buildings’ features (i.e. two stories, shingle roof, vinyl exterior, wood fireplace).
5. Dummy variables were created for buildings age groups (0, 1-5,…, 25-30, 30-40, 40-50, 50 and older)\textsuperscript{12}.

6. Categorical variables were defined to account for the municipality in which the building is located (e.g. Bellefonte, State College, etc.)

7. Dummy variables for transaction years are created to account for general price trend.

6.2. Results of Data Analysis

The detailed results from the regression analysis is presented in Appendix B. The R-squared is 0.77 meaning that the model explains 77 percent of the variation in the dataset (Table 6-1). Overall, the building and lot area, number of bathrooms, location, building’s age, and the year of listing, and building style are major variables responsible for the most of the variance.

Table 1 shows the estimated log price differences between large and small orientation groups. Overall, the group of houses with large orientation values is associated with 2.2% smaller transaction prices relative to the group of small orientation values. The difference is statistically significant at the 1% level. The magnitude of price difference is particularly large (-3.2%) when the orientation value is large (0.75-1.00).

|                | Log price difference | Std. Err. | T   | P>|t| |
|----------------|----------------------|-----------|-----|-----|
| Overall        | -0.0215              | 0.0059    | -3.66 | 0.00 |
| Orientation (0.00-0.25) | 0.0029 | 0.0195 | 0.15 | 0.88 |
| Orientation (0.25-0.50) | -0.0249 | 0.0145 | -1.71 | 0.09 |
| Orientation (0.50-0.75) | -0.0127 | 0.0101 | -1.26 | 0.21 |
| Orientation (0.75-1.00) | -0.0324 | 0.0090 | -3.61 | 0.00 |

\textsuperscript{12} 1 for when the variable is within the specific range, 0 for when it is not. This was in order to avoid dealing with too many variables each accounting for one year.
Table 6-1. Log price difference between large and small orientation groups

Table 6-1 shows the log price difference between groups of large elongation values and the group of the smallest elongation value. A large value of orientation has a positive effect on house price especially when the elongation value is relatively small. For example, house prices are 3.6% higher for the group with the largest orientation value (0.75-1.00) than the group with the smallest orientation value (0.00-0.25). The effect of orientation is also positive but not statistically significant when the elongation value is large. The effect of orientation becomes somewhat larger when observations with an elongation value greater than 2.5 were removed.

<table>
<thead>
<tr>
<th></th>
<th>Log price difference</th>
<th>Std. Err.</th>
<th>T</th>
<th>P&gt;t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small elongation group</td>
<td>Orientation (0.25-0.50)</td>
<td>0.0396</td>
<td>0.0187</td>
<td>2.12</td>
</tr>
<tr>
<td></td>
<td>Orientation (0.50-0.75)</td>
<td>0.0193</td>
<td>0.0174</td>
<td>1.11</td>
</tr>
<tr>
<td></td>
<td>Orientation (0.75-1.00)</td>
<td>0.0362</td>
<td>0.0169</td>
<td>2.15</td>
</tr>
<tr>
<td>Large elongation group</td>
<td>Orientation (0.25-0.50)</td>
<td>0.0118</td>
<td>0.0156</td>
<td>0.76</td>
</tr>
<tr>
<td></td>
<td>Orientation (0.50-0.75)</td>
<td>0.0037</td>
<td>0.0134</td>
<td>0.27</td>
</tr>
<tr>
<td></td>
<td>Orientation (0.75-1.00)</td>
<td>0.0010</td>
<td>0.0131</td>
<td>0.07</td>
</tr>
</tbody>
</table>

Table 6-2. Log price difference relative to the smallest orientation groups

This analysis indicates that home sale prices are positively associated with buildings orientation, particularly when elongation is close to 1.00. The elongation has a significantly negative affect on prices, meaning that the more stretched the house the lower the price.

6.3. Analysis of the Results

It is important to consider the number and distribution of buildings based on their elongation and orientation. As can be seen, in the majority of the buildings studies the elongation
factor falls below 1.5 (i.e. the proportion of length to width is below 1.5 for most single family houses).

Figure 6-3. The graph indicates the frequency of different elongations. For most buildings the value is less than 1.5

Figure below indicates the frequency of buildings with different orientations divided in four (4) broad groups: below 22.5 degrees with the true south, between 22.5 and 45, between 45 and 67.5 and above 67.5 and less than 90. The majority of buildings are between 22.5 and 67.5 allowing most of these buildings to receive between 70 to 92 percent of the sunlight from the true south.

Figure 6-4. The orientation of buildings categorized in 4 groups. As can be seen the majority of buildings are between 22.5 and 67.5 degrees off true south

Figure 6-5 is a thematic map indicating the condition of orientation and elongation in different municipalities. Although the map illustrates slight differences between different
municipalities, no significant pattern was identified. A closer look at the neighborhood level might be more telling. To see if there is any identifiable spatial structure in the data set, or in better words to see if the orientation and elongation of housing prices correlate with distance we incorporated the Moran's I method. Moran's I is a measure of spatial autocorrelation that measures correlation in a signal among nearby locations in space. Figure 6-6 indicates the univariate local Moran’s I analysis on single-family houses in the State College area. The significant clusters of building with same orientation can be seen in numbers (Moran’s I = 0.21). The major reason for this is that most houses are built along the streets and the orientation of buildings is heavily related on the orientation of the streets that they have been placed on; which in fact is a product of the ridge and valley topography of Centre County.

Figure 6-5. A ranking for different municipalities in Centre County based on both orientation and elongation
Figure 6-6. Univariate local Moran’s I analysis for orientation of buildings in State College produced by GeoDa (Geoda, 2006).

Figure 6-7. Univariate local Moran’s I analysis for elongation of buildings in State College produced by GeoDa (Geoda, 2006).

Clustering patterns were also identified in the elongation of the buildings in state college (figure 6-6). However the significance of these clustering patterns (Moran’s I = 0.08) is not as much as it was for orientation.

As already mentioned in the results, the effect of orientation on house prices, although generally positive, is not uniformly significant. As shown in Figure 6-7, a reason for this can be
the significance of street layout on the orientation. Another possible cause of these insignificant
effects might be the type and location of garages. Even when the orientation value is large, a
garage may be attached to the south side of a house. This lack of data can create errors in
variables and attenuates estimates. Future research can evaluate type and placement of garages
into the analysis and come up with accurate outcomes.

Apart from that, buildings that have East-West orientation, may lack proper interior
layout and window placement or be under the shade of trees or adjacent buildings. Therefore, the
quality of interior spaces might not be elevated as expected and the potential homebuyers may not
value the proper orientation. Analysis of window placement is beyond the scope of current GIS
tools, however a future study to take into account the proximity and shadow casting of adjacent
buildings and evaluate them into Hedonic Pricing analysis.

The results show that home-buyers are not necessarily aware of opportunities such as
proper orientation and elongation that can be highly effective in saving energy and promoting the
quality of interior spaces. Here, the necessity of educating homebuyers and marketing agents
about these opportunities and developing tools that acknowledge these choices seem valuable
topics to be discussed in future studies.

6.4. Chapter Summary

8,164 single-family houses in Centre County were analyzed to gauge the effect of
orientation and elongation on housing prices. Both orientation and elongation are two important
factors that directly affect the amount of sunlight that the building receives from the south.
Elongation and orientation of buildings are two low-cost strategies for designers to take into
consideration since the impact of these factors on the quality of lighting as well as building’s
energy consumption are positive. The analysis indicates that the extent to which the building receives sunlight from the south has an effect on house prices as predicted, but the effect is not uniformly significant. The analysis shows that orientation of a building is heavily based on the orientation of the streets that it has been placed on. This means that the orientation problem is rather a large-scale issue that can be addressed in planning policies. In addition, variables such as window placement, interior layout and proximity of adjacent buildings are other site factors that may affect the effectiveness of orientation and elongation into pricing of homes.
CHAPTER 7 CONCLUSION

The results from the previous chapter showed that there is not a significant correlation between orientation and elongation of the homes in Centre County and their market value. However, knowing that many of architectural decisions have minimal effect on the price and yet they can be highly effective in reducing the consumption of resources (materials, energy and water, specifically), this question comes to mind: “How can we raise awareness about usefulness of sustainability strategies, especially architectural ones, and increase the demand for such solutions?”

7.1. Summary of findings

Over the years, the efforts to create new sustainable homes or retrofit old ones has significantly increased. However, as already discussed, there is still a lot of room for improvement. To date, the added value of energy efficient solutions and improvements has not been fully reflected in the housing prices. Findings of this research affirms that there is not any significant correlation between value and orientation and elongation of the homes. In chapter two of this research, however, some correlations were observed between sustainability and market value, but even these observations are not comprehensive and address only a few of the sustainable features of the homes. In addition, there is the need for ways to prove to homebuilders that investing in sustainable technologies will be recouped during the sale, to convince homebuyers to pay for these technologies and to help willing homebuyers to find homes with specific green features.
7.1.1. The Importance of Role of Architect in the Design of Sustainable Homes

A significant emphasis of this research, mainly in chapters 4 and 5, was on the architectural design decisions that improve the quality of the experience of living in a home. The architects are trained to deal with various issues and strategies at the same time and come up with the best solution. Although the good architecture strategies presented in this research can be used and referenced by anyone, yet it is ideal that an architect be involved in order to deal with limitations unique to each project, and use the strategies to come up with a space that is pleasant for the users.

7.1.2. Implementation of the Green MLS as a Plan of Action for Local MLSs

Specifying the existence of a “green premium” and quantifying specific ones is highly challenging. The fact that this study could not demonstrate added value of “green” strategies does not mean that these features are not valuable. Instead, this shows an information gap between what the research suggests and what is being evaluated in the general real estate marketing practice.

The green MLS is a suggested approach to utilize in Centre County in addition to training the realtor agents about the architectural green premiums. To understand how each premium should be evaluated, research is needed to analyze how much each one has added to the value of a property in the places that have incorporated the green MLS.

Several studies suggest that the 3rd party-verified green properties sell faster or more than their conventional counterparts. Conducting these types of research has many times possible because the local MLS has added data entry field for those verifications many years ago. The
datasets are still small and the number of research are limited, however they suggest the potential for similar findings if the green MLS is more vastly implemented (Stovall et al., 2011).

**Fayetteville Example**

Based on the experience of some of the previous adaptations of the Green MLS, one of the main impediments that have slowed down the process has been the fear that implementation of the toolkit is a long and expensive process. However, in 2013 the Green MLS toolkit was adopted by the Northwest Arkansas Board of Realtors (NABOR) after they found out that changing the drop down menus in the software would require 4 hours of effort and only $787.92. The funds were raised in a few hours with the help of NABOR employees (M. Shoffit, phone interview, August 6, 2015).

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**Figure 7-1. Price and payment receipt for implementation of the Green MLS toolkit in NABOR**
7.1.3. Improvement of the Green MLS to Include Sustainable Architecture Strategies

As shown in chapter 3, while the Green MLS is an important step towards acknowledgment of sustainable features in the homes, the current MLS entry fields lack many of the good sustainable architecture strategies. At the end of chapter 5, the relation of these strategies and the technical sustainability criteria was illustrated. Many of the good architecture strategies actually improve quantifiable sustainability measures such as energy consumption, which in fact, can be translated into cost in the long term. Therefore, these strategies should be justified for the home investors and home buyers in the real estate market. This research suggests implementation of good sustainable strategies presented in this research into the Green MLS system in order to enable accounting for their positive impact on the price.

7.2. Contributions of the work

This study provides an overview of residential buildings measurement systems which can be referenced to in the similar studies. It also provides a comprehensive quantifiable set of strategies for sustainable architecture for the residential sector in cold climate. These strategies are put together based on literature review and many of them have been utilized and verified in a series of student design competitions. This list can be useful for architects designing customized sustainable homes, and future researchers performing similar studies. However additional studies of other factors could be undertaken.

The strategies are also paralleled with technical sustainability criteria. Among these strategies, orientation and elongation had the most amount of correlation with technical aspects of sustainability as well as spatial design and layout of the homes. Therefore, were chosen for further financial analysis.
This research statistically analyzed the correlation between orientation and elongation and value of the homes on Centre County. Although there was not a significant correlation observed, this research suggest implementation of the Green MLS into the MLS system, as well as improving the Green MLS to include more qualitative and architectural design related fields. The research presents that good sustainable strategies are correlated with the quantitative technical sustainability approaches and will have an effect on the price and long term energy costs. The methodology used in this research can be used to study relationship of other sustainable architectural design strategies and the value as well as the impact of future implementation of the Green MLS on the local markets.

7.3. Future work

This research has analyzed the correlation between orientation and elongation and the value of homes in Centre County. A future research may expand the sales data location and analyze the impact of orientation and elongation in a large scale with different types of topographies. Another suggested work may analyze the sales data for other strategies of sustainable homes especially compactness and spatial factors (open floor plan, flexibility, etc.) by analyzing the floor plans.

Future research may focus on analyzing the sales data in counties that have incorporated the Green MLS in their appraisal system. This research is very useful in measuring the impact of sustainable features of a home on its price. If a positive correlation is found, the results of this research can be used in the argument with appraisers to convince them to use the Green MLS. In addition to the price of the home, the number of days that a home has been advertised before being sold, is an indicator of what is more favorable to home buyers. Analyzing the correlation of
variable green architectural design features of the home and the number of advertised dates, can also inform future research.
Cited Works


Green Affordable Homes Valuing Healthy and Efficient Housing for All. (2012). Retrieved June


Appendix A: San Juan County Green MLS Data Entry Form Example

Generic Green Attributes
The following lists are not all inclusive, but are examples of ways to display green or efficient attributes of properties. Because specific features, such as dual pane windows, will not always be considered green or efficient, providing the option of entering the more generic "energy efficient windows? Allow sellers to promote efficient aspects in a simple way that will not age.

This approach also simplifies buyers' search for specific efficiencies. For example, instead of having to understand a number of different window types (and, whether they are currently considered green), users merely need to know that they are interested in efficient windows. However, listing agents and sellers will need to provide explanation and backing of the green attributes they chose to display in the MLS.

The following is an example of six fields with their pick list options that could be considered. These lists are not meant to be exhaustive, but rather representative of the types of generic options you might include in your MLS.

<table>
<thead>
<tr>
<th>ENERGY EFFICIENT</th>
<th>ENERGY GENERATION</th>
<th>WATER CONSERVATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Solar</td>
<td>Landscaping</td>
</tr>
<tr>
<td>Insulation</td>
<td>Wind</td>
<td>Flow Control</td>
</tr>
<tr>
<td>Windows</td>
<td>Geothermal</td>
<td>Reclamation</td>
</tr>
<tr>
<td>Doors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roofing</td>
<td>SUSTAINABILITY</td>
<td>INDOOR AIR QUALITY</td>
</tr>
<tr>
<td>Exposure/Shade</td>
<td>Materials</td>
<td>Filtration</td>
</tr>
<tr>
<td>Appliances</td>
<td>Renewable Materials</td>
<td>Ventilation</td>
</tr>
<tr>
<td>HVAC</td>
<td>Recyclable Materials</td>
<td>No or Low VOC Materials</td>
</tr>
<tr>
<td>Thermostat/Controllers</td>
<td>Biodegradable Materials</td>
<td>LOCATION</td>
</tr>
<tr>
<td>Water Heater</td>
<td>Conserving Materials/Methods</td>
<td>Walk ability</td>
</tr>
<tr>
<td>Electrical/Lighting</td>
<td></td>
<td>Transportation Proximity</td>
</tr>
<tr>
<td>Incentives &amp; Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Specific Green Attributes
Check As Many As Applicable In Each Category - All That Apply

**ROOF**
- [ ] TPO Membranes (Thermoplastic polyisolen)
- [ ] Roof Foam
- [ ] Composition
- [ ] Concrete
- [ ] Green / Living Roof
- [ ] Rock / Stone
- [ ] Reflective Roof Coating
- [ ] Shake
- [ ] Wood
- [ ] Other

**CONSTRUCTION**
- [ ] ICF Wall System (Insulated Concrete Forms)
- [ ] SIP Systems (Structured Insulated Panels)
- [ ] Rammed Earth
- [ ] Thermal Mass Construction
- [ ] Trombe Wall
- [ ] Modular Prefabrication
- [ ] Passive Solar
- [ ] Solar Rough-In
- [ ] Sealed Crawl Space
- [ ] Sealed Ducting

Page 1 of 3  Sellers Initials
<table>
<thead>
<tr>
<th>Property Address</th>
<th>MLS #</th>
<th>Green Property Data Form</th>
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<td></td>
</tr>
<tr>
<td>◯ Ceiling R Factor</td>
<td></td>
<td>Low Emittance Windows</td>
</tr>
<tr>
<td>◯ Wall R Factor</td>
<td></td>
<td>Energy Star Windows</td>
</tr>
<tr>
<td>◯ Floor R Factor</td>
<td></td>
<td>Insulated Glass Windows</td>
</tr>
<tr>
<td>◯ Type __________</td>
<td></td>
<td>Sunscreen</td>
</tr>
<tr>
<td>◯ Cellulose Insulation</td>
<td></td>
<td>Multi-Pane Windows</td>
</tr>
<tr>
<td>◯ Post Consumer Recycled Content</td>
<td></td>
<td>Thermal Triple Pane</td>
</tr>
<tr>
<td>◯ Insulation Blown</td>
<td></td>
<td>Other __________________</td>
</tr>
<tr>
<td>◯ Insulation Foam In Place</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Spray Foam Insulation</td>
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<td></td>
</tr>
<tr>
<td>◯ NES Insulation Package</td>
<td></td>
<td></td>
</tr>
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<tr>
<td>◯ Blown Cellulose</td>
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<tr>
<td>◯ Fiber Cement</td>
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<td></td>
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<td>◯ R Value Upgrades</td>
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<tr>
<td>◯ Other __________________</td>
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<td></td>
</tr>
<tr>
<td><strong>HVAC</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ HVAC (16 SEER+)</td>
<td></td>
<td>Attic Ventilator</td>
</tr>
<tr>
<td>◯ Geothermal HVAC</td>
<td></td>
<td>High Efficiency HVAC</td>
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<td>Energy Star</td>
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</tr>
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<td>◯ Energy Recover Ventilator</td>
<td></td>
<td>Heat / Cool Combo</td>
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<tr>
<td>◯ VINMAR</td>
<td></td>
<td>Other __________________</td>
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<td>◯ High Efficiency Furnace</td>
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<td></td>
</tr>
<tr>
<td>◯ Zoned Air Conditioning</td>
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<td></td>
</tr>
<tr>
<td>◯ Zoned Heating</td>
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<td></td>
</tr>
<tr>
<td>◯ HVAC &gt; 13 SEER</td>
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<td></td>
</tr>
<tr>
<td>◯ Radiant Heated Floors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Solar Hybrid</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Heat / Cool Combo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Programmable Thermostats</td>
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</tr>
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<td>◯ Heat Exchanger</td>
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<td>◯ Attic Fan</td>
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</tr>
<tr>
<td>◯ Heat Pump</td>
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<tr>
<td>◯ Other __________________</td>
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<td><strong>WINDS</strong></td>
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<tr>
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<td></td>
<td></td>
</tr>
<tr>
<td>◯ Insulated Glass Windows</td>
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</tr>
<tr>
<td>◯ Sunscreen</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Multi-Pane Windows</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Thermal Triple Pane</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Other __________________</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>DOORS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Insulated Garage Door</td>
<td></td>
<td>Storm Doors</td>
</tr>
<tr>
<td>◯ Insulated Doors</td>
<td></td>
<td>Energy Star Doors</td>
</tr>
<tr>
<td>◯ Other __________________</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>COOLING</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Attic Ventilator</td>
<td></td>
<td>High Efficiency HVAC</td>
</tr>
<tr>
<td>◯ High Efficiency HVAC</td>
<td></td>
<td>SEER Rated</td>
</tr>
<tr>
<td>◯ Energy Star</td>
<td></td>
<td>Energy Star</td>
</tr>
<tr>
<td>◯ Natural Gas</td>
<td></td>
<td>Natural Gas</td>
</tr>
<tr>
<td>◯ Heat / Cool Combo</td>
<td></td>
<td>Heat / Cool Combo</td>
</tr>
<tr>
<td>◯ Other __________________</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>HOT WATER HEATERS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Energy Star</td>
<td></td>
<td>Energy Star</td>
</tr>
<tr>
<td>◯ Instant Hot Water</td>
<td></td>
<td>Solar Assisted Hot Water</td>
</tr>
<tr>
<td>◯ Wood</td>
<td></td>
<td>Humidifier</td>
</tr>
<tr>
<td>◯ Solar Assisted Hot Water</td>
<td></td>
<td>Other __________________</td>
</tr>
<tr>
<td>◯ Humidifier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>◯ Other __________________</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Page 2 of 3  Sellers Initials ________ ________
Appendix B: Sales Data Regression Equation

We estimate the following log-linear regression equation (1) by the ordinary least square method (OLS).

\[(1) \ln P_{ijt} = \alpha + \beta_1 Orientation_i + \beta_2 Elongation_i + \beta_3 Orientation_i \times Elongation_i + X_i \gamma + y_t + c_j + \varepsilon_{it},\]

where \(\ln P_{ijt}\) is the natural logarithm of transaction price of house \(i\) in city \(j\) in year \(t\), \(y_t\) is year fixed effects, \(c_j\) is city fixed effects, \(\varepsilon_{it}\) is the error term, and \(X_i\) is a vector of control variables: the lot size, total floor area, finished floor area, and dummy variables for numbers of bedrooms and bathrooms, two-story house, shingle roof, vinyl exterior, wood fireplace, and 5-year building age groups. In order to allow non-linear effects of orientation and elongation, we also estimate regression equation (2):

\[(2) \ln P_{ijt} = \alpha + \sum_{q=2}^{4} \beta_{1q} Orientation\ Group_q + \beta_2 Large\ Elongation_i + X_i \gamma + y_t + c_j + \varepsilon_{it},\]

where \(Orientation\ Group_q\) are dummy variables that correspond to the ranges of 0.00-0.25, 0.25-0.50, 0.50-0.75, and 0.75-1.00, \(Large\ Elongation\) is a dummy variable that takes a value of one if elongation is greater than the median value of 1.43. Table A1 shows the descriptive statistics of the data that area used in the regression analysis. We use 8,164 transactions to estimate the equation.
Table A1: Descriptive Statistics

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>mean</td>
<td>sd</td>
</tr>
<tr>
<td>Sales price</td>
<td>8,164</td>
<td>213,549</td>
<td>128,931</td>
</tr>
<tr>
<td>Orient</td>
<td>8,164</td>
<td>0.656</td>
<td>0.251</td>
</tr>
<tr>
<td>Elongation</td>
<td>8,164</td>
<td>1.523</td>
<td>0.422</td>
</tr>
<tr>
<td># of bedrooms</td>
<td>8,164</td>
<td>3.456</td>
<td>0.804</td>
</tr>
<tr>
<td># of bathrooms</td>
<td>8,164</td>
<td>1.957</td>
<td>0.834</td>
</tr>
<tr>
<td>Lot size (sqft)</td>
<td>8,164</td>
<td>61,466</td>
<td>474,600</td>
</tr>
<tr>
<td>Floor area (total)</td>
<td>8,164</td>
<td>2,203</td>
<td>930.1</td>
</tr>
<tr>
<td>Floor area (finished)</td>
<td>8,164</td>
<td>1,899</td>
<td>770.6</td>
</tr>
<tr>
<td>Building Age</td>
<td>8,164</td>
<td>38.52</td>
<td>35.12</td>
</tr>
<tr>
<td>D(State College) = 1</td>
<td>8,164</td>
<td>0.610</td>
<td>0.488</td>
</tr>
<tr>
<td>D(2 Story) = 1</td>
<td>8,164</td>
<td>0.380</td>
<td>0.485</td>
</tr>
<tr>
<td>D(shingle roof) = 1</td>
<td>8,164</td>
<td>0.934</td>
<td>0.248</td>
</tr>
<tr>
<td>D(vinyl exterior) = 1</td>
<td>8,164</td>
<td>0.503</td>
<td>0.500</td>
</tr>
</tbody>
</table>

Table A2 summarizes the estimation result. Column (1) shows the estimated coefficients for equation (1). The coefficients on orientation and elongation are positive and negative, respectively, but they are not statistically significant. Column (2) shows the result for equation (2). The coefficients on the Orientation variables indicate the price differential for houses with smaller values of elongation (i.e., relatively square shaped footprint). Relative to the group with the smallest value of orientation (0.00-0.25), the group with a greater value of orientation is associated with a higher house price. In particular, when the orientation value is between 0.25 and 0.50, house prices are 4.0% larger than for the reference group. Similarly, when the orientation value is between 0.75 and 1.00, house prices are 3.6% larger than for the reference group. Column (3) shows a similar result based on a subsample with the elongation value smaller than 1.5. In column (2), the interaction term between Orientation and Elongation indicates the additional price differentials for houses with larger values of elongation. For houses with large elongation values, the largest value of orientation is associated a negative effect (-0.035).
Table A2: Regression Result

<table>
<thead>
<tr>
<th>Dependent Variable:</th>
<th>(1)</th>
<th>(2)</th>
<th>(3) Subsample Elongation &lt; 1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>log house price</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>(1)</th>
<th></th>
<th>(2)</th>
<th></th>
<th>(3)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Orientation</td>
<td>0.051</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.043)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongation</td>
<td>-0.009</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.019)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation × Elongation</td>
<td>-0.032</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.026)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation (0.00-0.25)</td>
<td></td>
<td>Reference</td>
<td>Reference</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation (0.25-0.50)</td>
<td></td>
<td>0.040**</td>
<td>0.039**</td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.019)</td>
<td>(0.017)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation (0.50-0.75)</td>
<td></td>
<td>0.019</td>
<td>0.020</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.017)</td>
<td>(0.016)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation (0.75-1.00)</td>
<td></td>
<td>0.036**</td>
<td>0.034**</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.017)</td>
<td>(0.015)</td>
<td></td>
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</tr>
<tr>
<td>D(Elongation &gt; median)</td>
<td></td>
<td>0.003</td>
<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td>(0.019)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Orientation (0.25-0.50) × D(Elongation &gt; median)</td>
<td></td>
<td>-0.028</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>(0.024)</td>
<td></td>
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<tr>
<td>Orientation (0.50-0.75) × D(Elongation &gt; median)</td>
<td></td>
<td>-0.016</td>
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<tr>
<td></td>
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<td>(0.022)</td>
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</tr>
<tr>
<td>Orientation (0.75-1.00) × D(Elongation &gt; median)</td>
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<td>-0.035*</td>
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<td></td>
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<td>(0.021)</td>
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<td>Other control variables</td>
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<td>YES</td>
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<tr>
<td>Observations</td>
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<td>8,164</td>
<td></td>
<td>4,660</td>
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</tr>
<tr>
<td>Adjusted R-squared</td>
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<td>0.772</td>
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<td>0.782</td>
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</tr>
</tbody>
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White’s heteroscedasticity-robust standard errors in parentheses.

*** p<0.01, ** p<0.05, * p<0.1