Costs & Benefits of NGBS Certified Single-Family Green Homes

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Table of Contents

List of Tables

List of Figures

Executive Summary

The predicted green residential market growth in the following years along with an increasing environmental awareness in the society, has led to an increased need for home-builders to sharpen their understanding of additional costs and benefits emanating from green residential practices.

To aid home-builders in this need, this study presents:

- An extensive literature review and interviews with home-builders;
- A framework to guide home-builders in cost-benefit analyses of green residential projects;
- A deep examination of costs and benefits of NGBS single-family homes; and

The **key study observations** include the following:

1. Climate zones and local codes are the base to determine the additional costs and benefits from green buildings;
2. Additional construction costs to achieve green certification are higher in hot-humid climate zones;
3. After satisfying local codes following IECC standards, NGBS bronze or silver certification entails a very low additional construction cost, NGBS gold might be quite affordable, and NGBS emerald is very pricey;
4. Based on previous industry reports payback periods to cover additional costs from NGBS bronze, silver and gold levels for single-family homes are more than 13 years, nonetheless, some home-builders claim that they can be 3 or less years.
5. There are clients willing to buy smaller but greener homes; and
6. Prioritizing inclusion of specific green features, e.g., advanced framing techniques, facilitate achieving from NGBS bronze to gold certification at a low or no additional cost.

1. Introduction

Study Goal:
*To illustrate the **costs** and **benefits** of NGBS certified **single-family green residential projects**.*

Many home-builders and most home-buyers struggle with the details and concepts of green homes and especially with the additional initial costs versus long-term benefits of green features. Recently in 2014, McGraw Hill Construction published a report informing that the single-family home market will keep increasing during 2016 up to $307 billion of which 30% approximately (i.e., $91 billion) is expected to involve green single-family homes. [(1)] The main motivators for customers to demand green buildings are primarily lower energy use and money savings, and also but less important, better health and comfort. On the other hand, the main obstacles relate to customers' reluctance to pay additional construction costs.

Therefore, it is crucial that costs and benefits of green single-family homes are clearly depicted to allow customers confidently assess the adequacy of investing in green buildings. Nevertheless, currently many government funding agencies, building code officials or home-builders lack a proper understanding of how to effectively develop a cost-benefit analysis of sustainable practices. This inability to develop a cost-benefit analysis it is likely to impede a higher increase in customers' demand for green building due to their uncertainty about potential benefits surpassing additional costs.

Aiming to address this problem, this report pursues the following **goal**: *To illustrate the costs and benefits of National Green Building Standards (NGBS) certified green single-family residential projects in comparison to regular projects to help make the case for sustainable construction practices for home-building*. The **objectives** of the study are to help home-builders understand:

1. How to perform a cost and benefit analysis of green residential projects; and
2. The additional costs and benefits of pursuing NGBS certification in single-family homes.

Within the scope of this study, an extensive literature review of industry resources and interviews with at least two green home-builders will be performed. The study will focus on residential projects and NGBS certified single-family homes.

2. Background

*There are three main green rating systems for residential projects in the U.S.: **NGBS, ENERGY STAR,** and **LEED**.*

According to the Home Innovation Research Lab (2015) "The most important step in selling a green home is to convey to the buyer what makes the home green and how its environmental impact is rated." [(2)] During the last years buildings have been responsible for the consumption of 73% of electricity, 41% of energy, 40% of raw materials and 13.6% of potable water, the emission of 30% of CO_2 gas, and the disposal of 170 million tons of waste during building construction and disposal activities.[(3)] Concerned with the harmful effects that these actions directly exert into the environment and subsequently into human beings' health, the green movement in the construction industry emerged in the 1990s promoting construction practices that prioritize a sustainable relationship between buildings, the environment and human beings. Since then, many local policies and green rating systems have been instituted to help develop green buildings and measure the degree to which they are sustainable. However, green or sustainable practices have faced two main problems that have dragged down their adoption in the construction industry: the need of a holistic approach to building design requiring higher levels of collaboration to produce complex and effective designs, and increased construction costs that have been frequently believed to be difficult to afford. Below the most popular green rating systems in the U.S. market are briefly described.

2.1. Green Rating Systems for Homes in the U.S.

There are more than ten green rating systems for homes in the market, however builders' degree of awareness about them is greatly disparate resulting in a very wide adoption of a few of the and very low utilization of the majority. The most prominent green certifications for residential projects include NGBS, ENERGY STAR, and LEED which are briefly explained in the following subsections.

2.1.1. National Green Building Standards (NGBS)

National Green Building Standard (NGBS) was developed by the National Association of Home-Builders (NAHB) in collaboration with the International Code Council (ICC) and the American National Standards Institute (ANSI). The system has four levels of certification namely, bronze, silver gold and emerald and six areas of sustainability: lot design, preparation and development; resource efficiency; energy efficiency; water efficiency; indoor environmental quality; and operation, maintenance and building owner education. Developed in 2008 the NGBS provides green certification for new construction and remodeling of single-family homes, multi-family buildings and residential units within mixed-use/residential buildings, land developments and lots within NGBS land developments. [(4)] The second version, ICC 700-2012 NGBS, was approved in 2013 to outperform the 2009 IECC [(5)] [(6)] and is still in force. The new 2015 NGBS version is currently underway and will be soon approved in 2016. [(7)] The Home Research Innovation Research Labs' website has available a number of independent green verifiers classified by state [(8)] to verify projects' compliance with NGBS standards and award the certification.

2.1.2. ENERGY STAR

ENERGY STAR is the longest running certification system among the three systems. It was developed by the Environmental Protection Agency (EPA) in 1992 (9) and provides certification to single-family homes and residential units in low-rise multi-family buildings. [10] The ENERGY STAR focuses on five main green areas that emphasize energy performance: [11] building enclosure, HVAC and water management systems, lighting, and appliances. Since 2012 the ENERGY STAR Certified Homes Version 3 [10] [12] is the current version in force which was last revised in 2013. This version strongly relies on 2009 IECC energy performance standards as a benchmark to create energy-efficient homes. [12] ENERGY STAR requires a third party or independent rater which inspect compliance of the final product with established requirements and issues an ENERGY STAR label. [13] These raters can be found in the ENERGY STAR's website classified by state. [14]

2.1.3. Leadership in Energy and Environmental Design (LEED) for Homes

The Leadership in Energy and Environmental Design (LEED) system for homes was first developed by the U.S. Green Building Council (USGBC) in 2008. Recently in 2015, the second version came up as LEED v4 Homes Design + Construction which is applicable to single-family homes, and low/mid-rise multi-family projects. [15] This green system presents four levels including certified, silver, gold and platinum, and measures performance in eight sustainable areas: [16] location and transportation, sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation, and regional priority. The USGBC's website offers a directory of green raters [17] who serve as third independent parties that submit the appropriate documentation to the LEED for Homes Provider. This provider reviews the quality of the documentation and later submits it to the Green Building Certification Institute (GBCI) which issues the final certification. [18]

2.2. Comparison among Green Rating Systems for Homes

Since the ENERGY STAR system focuses on energy efficiency, it brings to the table less areas of sustainability than the NGBS and LEED systems which propose two different holistic approaches that are similar in objectives and rigor. [19] A recent report developed by Jackson [5] (2014) compared the ENERGY STAR, NGBS and LEED green rating systems and observed the following:

- NGBS and LEED earn most of the credits in the design and procurement phases;
- All three certification processes are similar except for how the final certification is awarded;
- Some of the strengths in each system are the following:
    - NGBS ensures even sustainable performance throughout all building systems and offers higher affordability;
    - ENERGY STAR process is greatly flexible; and
    - LEED offers outstanding technical support;

- On the other hand, they might present some handicaps:
  - The high amount of credits might make NGBS certification processes lengthy;
  - ENERGY STAR has a reduced scope and ignores site development aspects of a project; and
  - The LEED system might frequently set many constrains and be costly.

3. Cost and Benefit Analysis of Green Rating Systems

Incorporating green practices into buildings leads to additional design and construction costs which constitute the main barrier for costumers to pursue green certification. [1] On the other hand, costumers' main motivation to acquire green products relate to lower energy and water consumption resulting in money savings, and, in a lesser degree, to healthier indoor conditions. [1] Ultimately, the main problem is that costumers lack an understanding of green buildings' added value, [1] that is, they ignore how to assess whether benefits produced by green buildings such as energy and water savings overcome the first initial increased cost of achieving green certification.

A number of studies have assessed the costs and benefits to gain NGBS, ENERGY STAR, and LEED certifications for diverse types of projects (e.g., single- and multi-family homes, schools and commercial buildings). These studies mostly refer to industry reports and are listed below in Table 1 indicating the green system(s) that they analyze:

Table 1. Studies Examining Costs and Benefits of Green Rating Systems

Green Rating System(s)	***Studies***
NGBS and LEED	▪ *Home Innovation Research Labs (2014).* ***"Cost and stringency comparison of 2012 NGBS, LEED-H 2008, and LEED v4 for homes design and construction."*** *A Report for NAHB.* [6] ▪ *FitzGerald Associates Architects (2011).* ***"Urban green building rating systems cost comparison."*** *A Report for HBA of Greater Chicago.* [20] ▪ *AIA Cincinnati (2010).* ***"Comparison of USGBC's LEED for Homes 2008 and NAHB's NGBS TM ICC 700-2008."*** *A Report for Cincinnati Office of Environmental Quality.* [21] ▪ *NAHB Research Center, Inc. (2008).* ***"Green home building rating systems: a sample comparison."*** *A Report for NAHB.* [19]
ENERGY STAR and LEED	▪ *Andrews, C., Senick, J., Kornitas, M., Crandall, K., Montfort, K., Plotnik, D. & Tuvel, E. (2011).* ***"Costs and benefits of residential energy efficiency investments."*** *A Report for the New Jersey Association of REALTORS.* [22] ▪ *Hiser, S. R. (2011).* ***"LEED vs. ENERGY STAR: a cost/benefit analysis of sustainability labels for commercial buildings."*** *Masters Project (Duke University).* [23]
NGBS	▪ *NAHB Research Center, Inc. (2012).* ***"An evaluation of affordable housing using the NGBS."*** *A Report for U.S. Department of Housing and Urban Development.* [24]
LEED	▪ *Kats, G., Perlman, J. & Jamadagni, S. (2005).* ***"National review of green schools: costs, benefits, and implications for MA."*** *A Report for the MA Technology Collaborative.* [25] ▪ *Kats, G., Alevantis, L., Berman, A., Mills, E., Berkeley, L. & Perlman, J. (2003).* ***"The costs and financial benefits of green buildings."*** *A Report for CA's Sustainable Build. Task Force.* [26]

Overall, the studies above conclude that, if technologies and construction methods are selected based on a minimum cost approach, obtained benefits from green buildings cover additional up-front costs in payback periods that range from less than 5 years to more than 30 years depending on the intended green level (e.g. silver or gold, in LEED or NGBS) and project type. In general, the processes that these studies follow to develop a cost-benefit analysis of green buildings can be integrated as illustrated in Figure 1. The next subsections explain in more detail the steps to be followed.

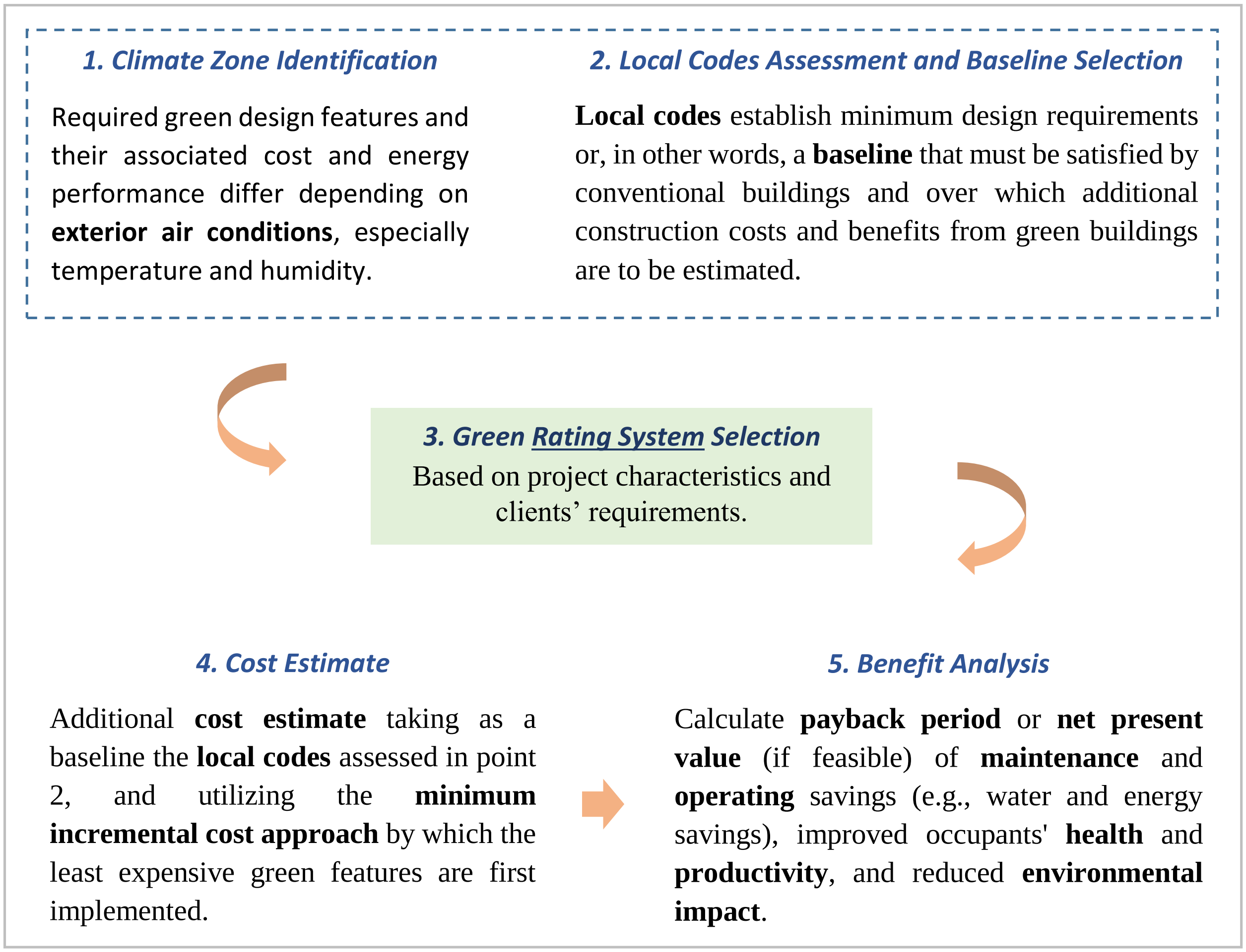

Figure 1. Process Map to Develop a Cost-Benefit Analysis of Green Buildings

3.1. Climate Zone Identification

The International Energy Conservation Code (IECC) broke down in 2000 the United States map into eight different areas depending on temperature patterns (1-8), and into other three different areas based on moisture features (A, B and C), ultimately resulting into multiple distinct climate zones [(27)] (bottom Figure 2). Later, in 2003, the Building American Program simplified this map into other eight climate zones based on temperature, heating degree days, cooling degree days and precipitation (top Figure 2). Determining the climate zone is essential since exterior air temperature and humidity directly influence key building science principles such heat transfer, moisture movement and air pressure. [(28)] Consequently, strategies for energy conservation such as material type and sizing for envelope insulation, air barriers and other building envelop elements are designed based on exterior air features. For instance, appropriate energy conservation in residential buildings [(29)] in climate zone 2 requires that the ceiling R-value stays around 30 whereas in climate zone 6 it should be of higher quality and reach 49. Therefore, optimal green building designs and their associated costs are reasonably expected to significantly differ from one another based on climate zone.

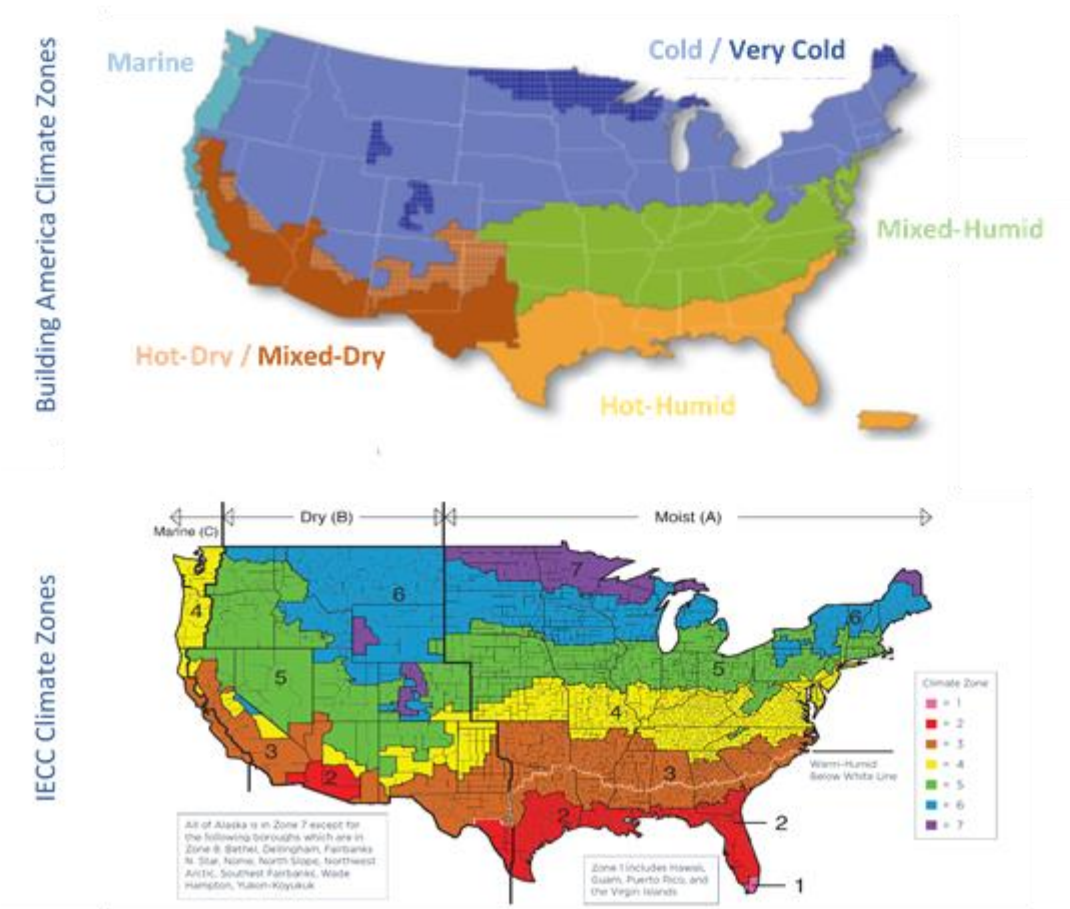

Figure 2. Climate Zones in the U.S. Courtesy of Building America (2013) [(56)]

3.2. Local Codes Assessment and Baseline Selection

Local green practices policies and incentives vary in each state and city [30] as shown in Figure 3 below. The most widely adopted code to develop energy-related green policies is the International Energy Code Compliance (IECC). [31] This code offers an up-to-date framework for enhanced building energy conservation through high performance building envelope, and mechanical, lighting and power systems. [32] The IECC has currently several versions in force (e.g., 2009, 2012, and 2015) and frequently releases updated or new versions [31] that further improve building energy performance outcomes. [6] [33] Some cities use them as a reference to develop their own green policies such as Chicago which complements the latest IECC versions with another local code resulting in a more stringent green policy. [34]

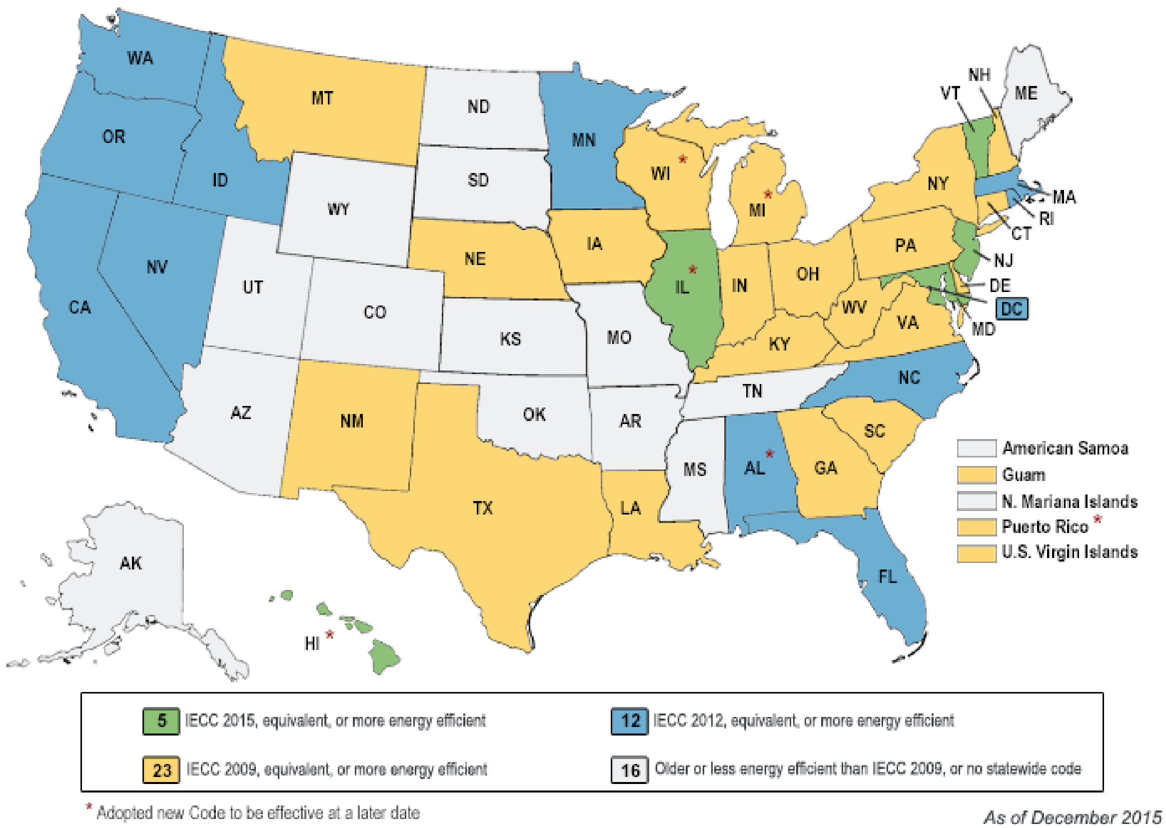

Figure 3. Energy Local Codes for Residential Construction Adopted per State in the U.S. Courtesy of U.S. Department of Energy [57]

The IECC is continuously updated to new improved versions every three years, [35] and green systems (e.g., NGBS or LEED) also evolve to outperform IECC energy performance standards to offer to clients a differentiated product. Most analysis of additional costs and benefits caused by implementing green rating systems in residential projects have been developed taking as a baseline conventional buildings satisfying IECC standards due to their broad implementation in the U.S. For example, single-family homes achieving NGBS or LEED certification might entail an additional cost of $5,000 more than those satisfying only 2012 IECC standards, whereas this additional cost might increase up to $10,400 when compared to homes built following 2009 IECC requirements. [6] Therefore, pursuing green certification becomes easier or less expensive to obtain depending on local policies stringency.

3.3. Green System Certification Selection

Previous studies developing cost-benefit analysis of building green in residential construction mostly focus on NGBS, ENERGY STAR, and LEED systems. Some of these studies make comparisons in specific contexts (e.g., single-family homes in hot versus cold climate zones) among them concluding that none can be considered superior in general from a cost/benefit perspective; nevertheless, they suggest some advantages and handicaps such as the following:

- Emerald level in 2012 NGBS for single-family homes yields better energy performance than platinum level in LEED-Hv4 in cold climates, but this effect is reverted in hot climates; [6]
- Certified and silver LEED-Hv4 tend to slightly improve single-family homes energy efficiency more than bronze and silver 2012 NGBS but at a higher cost; [6] and
- ENERGY STAR for commercial building renovation projects offers lower construction costs and shorter payback periods, whereas "LEED-Existing Building Operation and Maintenance" provides better energy efficiency performance. [23]

> *Selection of **green certification system depends on** building type, climate zone, local code requirements, available budget, and owner/builder goals such as level of certification intended to be achieved.*

Overall, green rating system selection depends on building type, climate zone, local codes requirements, available budget, and intended green level (e.g., NGBS bronze/silver or LEED certified/silver). [5]

3.4. Cost Estimate to Achieve Green Certification

The most commonly utilized technique to estimate costs from adding green design features is the **minimum incremental cost approach**. [6] [24] This method consists of calculating the cost per point for each green item and prioritizing the incorporation of those with the minimum cost per point that address design needs according to the climate zone and intended energy performance. Exceptions might be made for cases in which green items entail a bunch of points that cannot be divided into smaller portions and exceed the threshold to achieve certain green level. These items might result in higher total costs than only adding the needed points provided by other green items with a higher cost per point.

> *The **minimum incremental cost approach** is typically used for green design and additional costs estimate. **Prescriptive path** for energy efficient design allows a greater control over additional costs, but **performance path** is more suitable for higher energy performance design.*

NGBS and LEED energy performance credits can be earned through two energy efficiency methods which might differently contribute to both additional costs and energy performance levels: [21]

- **Prescriptive path**: dictates a set of procedures including materials and construction methods that lead to a specific and previously calculated energy performance. The main advantage of this path is the ease of implementation, the accuracy of predicted energy performance outcomes, and thus a greater control over additional costs. However, the prescriptive method only allows achieving up to gold level in the NGBS system. [36]
- **Performance path**: provides designers with a more flexible and suitable for creative, complex and unique designs. [36] This method requires developing an energy model of the building and might entail higher cost for third party verification. [37] This path allows achieving NGBS emerald level [36] and is recommended by the U.S. Green Building Council to earn LEED credits to create energy efficient design in residential projects. [15]

3.5. Benefit Analysis of Green Certification

The main objectives from green building are twofold: minimizing impact on the environment due to greenhouse gases emission and natural resources consumption, and creating a healthy indoor climate for the occupants. [38] Highlighted economic benefits propitiated by the accomplishment of these objectives involve the following:

- Lower maintenance and operating (e.g., energy and water consumption) costs; [6] [20] [22] [23] [24]
- Improved occupants' work productivity, [25] [39] and reduction of health care expenses because of alleviation of allergies and asthma; [40] and
- Decrease of states' monetary penalties due to emission of harmful gases [26] such as Oxides of Nitrogen (NO_x) or Carbon Dioxide (CO_2) due to decreasing their generation when manufacturing, transporting, installing, maintaining, and disposing the materials utilized in green buildings. [41]

Evaluation of green building benefits can be approached through **life cycle costing (LCC)** or **life cycle assessment (LCA)**: [22] [25] [26]

- LCC examines particular cash inflows and outflows of a specific product or system (e.g., water conservation system) over an agreed period of time (e.g., 7 years, the typical tenure for home ownership [22]); and
- LCA involves taking into account all possible cash inflows and outflows (e.g., those coming from the highlighted economic benefits listed above) produced by a green building during its entire lifetime (e.g., 60 years).

> ***Green economic benefits** include lower maintenance and operating costs, improved productivity and health, and reduced penalties for gas emission. Commonly, benefit analyses only examine **energy and water savings**, and their associated **payback period** or **net present value**.*

The LCC is the most appropriate tool to evaluate green building benefits since, generally, decisions about whether to invest in green practices are based on the first construction cost, and energy and water savings, [24] [26] since determining all actual cash inflows and outflows from building green to be inaccurate. [26]

Once it has been estimated the first investment or construction cost needed to develop an NGBS single-family home, the appropriateness of this investment can be examined by the **payback period** [22] [24] and/or the **net present value** (NPV) [22] [25] [26] produced by green building benefits:

- The payback period calculates, taking into account interest rate of return (IRR), the period over which accrued monetary benefits cover the additional construction costs to achieve a specific NGBS green level. Thus the payback period allows detecting at what point in time after constructing a green building the investor starts making profit.
- The NPV complements the payback period assessment and calculates the present value of future savings over a specific period of time for a given IRR. In other words, the NPV allows a client to examine what percentage of the initial investment will be covered over a certain period of time.

4. NGBS Certified Single-Family Homes: A Deeper Look at Costs and Benefits

Previous studies examining costs and benefits resulting from NGBS single-family homes develop a comprehensive and extensive cost estimate for achieving NGBS certification. These studies were highlighted in Section 3 and are the following:

1. *Home Innovation Research Labs (2014).* ***"Cost and stringency comparison of 2012 NGBS, LEED-H 2008, and LEED v4 for homes design and construction."*** *A Report for NAHB.* (6)
2. *NAHB Research Center, Inc. (2012).* ***"An evaluation of affordable housing using the NGBS."*** *A Report for U.S. Department of Housing and Urban Development.* (24)
3. *FitzGerald Associates Architects (2011).* ***"Urban green building rating systems cost comparison."*** *A Report for HBA of Greater Chicago.* (20)

Compiling the results and findings offered by the studies above, this section performs the following steps:

- **Section 4.1:** Examination of additional construction cost estimates to achieve NGBS bronze, silver, gold and emerald levels in climate zones 2, 3, 4, 5, and 6; and assessment and discussion of differences in additional construction cost estimates depending on NGBS level and/or climate zone.
- **Section 4.2:** Based on additional construction cost estimates in Section 4.1 for NGBS single-family homes, assessment of <u>required</u> energy and water savings for a given payback period; and analysis of <u>actual</u> energy and water savings and their associated payback periods.

4.1. Cost Estimate to Achieve NGBS Green Levels

The NGBS is the most commonly adopted certification for single-family homes. [42] Currently, there are 9,894 NGBS certified single-family homes and 1,406 are in process. [4] The NGBS involves six major sustainable areas and four rating levels (Table 2). This green rating system requires addressing specific mandatory practices to obtain the certification and achieving a minimum threshold under each sustainable area which varies depending on the intended rating level (Table 2). This approach aims to ensure a balanced green design that is similarly strong in all sustainable areas. [5]

Table 2. 2012 National Green Building Standards (NGBS)

2012 NGBS Threshold Points by Sustainable Area and Rating Level				
	Rating Level			
	Bronze	Silver	Gold	Emerald
Sustainable Area				
Lot Design, Preparation & Development	50	64	93	121
Resource Efficiency	43	59	89	119
Energy Efficiency	30	60	80	100
Water Efficiency	25	39	67	92
Indoor Environmental Quality	25	42	69	97
Operation, Maintenance & Building Owner Education	8	10	11	12
Additional from any Category	50	75	100	100
Minimum Threshold Points	***231***	***349***	***509***	***641***

4.1.1. Additional Costs to Achieve NGBS Certification

Integration of previous studies results estimating increased construction costs to build NGBS certified single-family homes depending on climate zones is illustrated in Figure 4 below. In total, prior studies examined twelve diverse case studies including detached houses, townhouses, row-houses, and site-built homes, containing from one to four bedrooms, and with or without attached garage. These case studies range from 956 to 2,483 square feet and are located in climate zones 2, 3, 4, 5 and 6. Furthermore, all cases studies earned the energy-related credits following the performance path.

***Additional construction costs** to obtain NGBS certification is likely to be higher in **hot-humid climates** than in cold or mixed climates.*

These studies estimated the additional cost of implementing the latest version of NGBS over the latest version of IECC which was taken as baseline. Thus nine case studies calculate added costs of implementing 2008 NGBS over the 2006 IECC baseline; and three of them of 2012 NGBS over the 2009 IECC baseline. To verify the appropriateness of combing results from studies utilizing different version of NGBS and IECC, two additional parallel analyses were performed: on one hand, only 2008 NGBS vs 2006 IECC baseline case studies were taken into account; and on the other hand, solely 2012 NGBS vs 2009 IECC case studies. In both cases the additional cost patterns to achieve NGBS certification were similar to those shown in Figure 4.

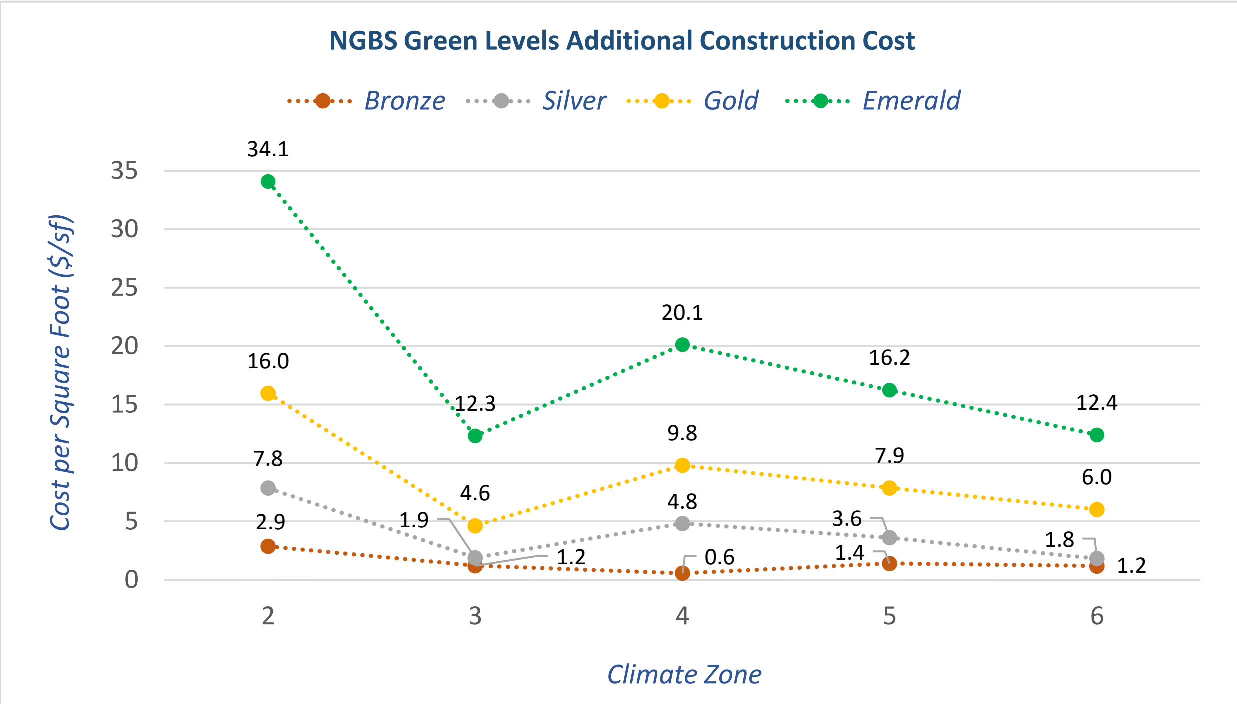

Figure 4. Estimated Additional Costs to Achieve NGBS Certification Based on Studies Cited at the Beginning of Section 4

In 2014 the average price of a typical single-family home in the U.S. was $100 per Sq. Ft. (43) and the average size 2,625 Sq. Ft. (44) resulting in an average construction cost of $262,500. According to Figure 4, increased construction cost of pursuing NGBS certification in typical single-family homes in the U.S. ranges between $0.6 and $34.1 per Sq. Ft. with an average of $8.34 per Sq. Ft, thus yielding an additional cost between $1,575 and $89,513 with an average of $21,893.

4.1.2. Differences in Required Green Design Features Depending on Climate Zone

As observed in Figure 4, climate zone 2 (hot-humid) tends to result in higher construction costs to achieve any NGBS green level. On the other hand, climate zones 3 (hot-dry, mixed-dry or mixed-humid) and 6 (cold) are the least expensive. According to Building America Best Practices, (45) design requirements for efficient energy performance are more rigorous and numerous in hot-humid climates than in cold climates which may result in higher labor and material costs. Some of these requirements in hot-humid climates include the following:

- Design of slab-on-grade foundations surrounded by graded areas to guide water away from the building structure.
- Placement of concrete or pressure-treated piers in the foundation if the area is by the coast and prone to water floods.
- Installation of ventilation systems creating positive pressure within a tight thermal envelope to expel stale air to the exterior air.
- Employment of radiant barriers in the roof, pressure-treated lumber in structural frames, windows with low emissivity and solar heat gain factor, overhangs, awnings, shade trees, dehumidifiers, thermostats equipped with humidity controls, cement panels in showers, pest resistant materials in walls, paints with mildewcides, door jambs water and rot resistant, ceiling fans, and non-heat releasing lights.
- If the area is exposed to hurricanes and/or floods, placement of strapping elements in the structure, hurricane shingles in the roof, electrical generators to cover electric power outages, and steel-reinforced concrete walls.

On the other hand, fewer requirements are suggested Building America Best Practices [46] for cold climate areas and some of them relate to practices that should be avoided:

- Avoidance of balconies and stairs below eaves, roof electric systems to melt snow, and gutters if there are high snow load periods.
- Utilization of high-durability and low-maintenance exterior products.
- Installation of furnaces and duct system out of attics and within a tight thermal envelope; and inclusion within this thermal envelope of conditioned basements and crawlspaces.
- Placement of footings below frost depth, and building envelope design to avoid ice dam formation.

4.1.3. Energy Consumption Depending on Climate Zone

Additional cost differences illustrated in Figure 4 can be partially explained due to different energy consumption and required HVAC systems in different climates. As illustrated in Table 3 below, climate zone 2 involves an average of 7,650 CDD during the cooling season and none HDD during the heating season; the major part of climate zone 3 demands an average of 5,400 CDD; and climate zone 6 needs an average of 8,100 HDD during the heating season. [47]

> ***Hot-humid climates*** *are likely to require more expensive* ***HVAC systems*** *than cold climates.*

According to the IECC residential prescriptive requirements, [29] optimal energy performance in cold environments such as climate zone 6 necessitate stronger building envelope insulation to avoid heat transfer to the exterior resulting in higher R-values for ceilings, walls and foundations, and lower U-Factors for fenestration. On the other hand, hot-humid climates such as zones 2 and 3 require lesser insulation, thus R-values tend to be lower and U-Factors higher. The underlying reason is that homes in hot-humid climates allow greater heat transfer across walls to keep its interior layers at a higher temperature to promote water diffusion and avoid condensation. [48]

Therefore, although climate zone 6 seems to require higher power demand (8,100 HDD), the better building envelope insulation might lead to the installation of a smaller and less expensive HVAC system than those installed in climate zone 2 where power demand looks slightly lower (7,650 CDD) but homes suffer higher heat losses requiring increased power demands to keep interior temperature comfortable and stable. Climate zone 3 is utilizes less expensive HVAC systems than in zone 2 because the building envelope insulation is similar and power needs are lower (i.e., more than 2,000 CDD less). Indeed, the U.S. Energy Information Administration [49] informs that in 2014 the average monthly power consumption per person was 1,092 KWh in Florida (climate zone 2), 562 KWh in California (climate zone 3), and 810 KWh in Minnesota (climate zone 6). The HVAC system entails approximately an average cost of $11,000 constituting a 5% of the total cost to build a 2,600 Sq. Ft. conventional single-family home. [50]

Table 3. Heating (HDD) and Cooling (CDD) Degree Days for U.S. Climate Zones [47]

Climate Zone	***Thermal Criteria***	
	IP Units	***SI Units***
1A (Very Hot-Humid) and **1B** (Very Hot-Dry)	9000 < ***CDD (50°F)***	5000 < ***CDD (10°C)***
2A (Hot-Humid) and **2B** (Hot-Dry)	6300 < ***CDD (50°F)*** ≤ 9000	3500 < ***CDD (10°C)*** ≤ 5000
3A (Warm-Humid) and **3B** (Warm-Dry)	4500 < ***CDD (50°F)*** ≤ 6300	2500 < ***CDD (10°C)*** ≤ 3500
3C (Warm Marine)	***CDD (50°F)*** ≤ 4500 and ***HDD (65°F)*** ≤ 3600	***CDD (10°C)*** ≤ 2500 and ***HDD (18°C)*** ≤ 2000
4A (Mixed-Humid) and **4B** (Mixed-dry)	***CDD (50°F)*** ≤ 4500 and ***HDD (65°F)*** ≤ 5400	***CDD (10°C)*** ≤ 2500 and ***HDD (18°C)*** ≤ 3000
4C (Mixed-Marine)	3600 < ***HDD (65°F)*** ≤ 5400	2000 < ***HDD (18°C)*** ≤ 3000
5A (Cold-Humid), **5B** (Cold - Dry) and **5C** (Cold -Marine)	5400 < ***HDD (65°F)*** ≤ 7200	3000 < ***HDD (18°C)*** ≤ 4000
6A (Cold-Humid) and **6B** (Cold-dry)	7200 < ***HDD (65°F)*** ≤ 9000	4000 < ***HDD (18°C)*** ≤ 5000
7 (Very Cold)	9000 < ***HDD (65°F)*** ≤ 12600	5000 < ***HDD (18°C)*** ≤ 7000
8 (Subarctic)	12600 < ***HDD (65°F)***	7000 < ***HDD (18°C)***

4.1.4. Differences in Additional Costs per NGBS Level and Local Codes Stringency

Overall, the cost to pass from bronze to silver levels is low, whereas it seems to exponentially increase from silver to gold, and from gold to emerald (Figure 4). Overall it can be observed that the cost to achieve each NGBS level is double from the previous lower level. This might be a consequence of the minimum incremental cost approach to calculate costs to achieve each level. This method classifies green features and brings them into the design based on minimum cost and appropriateness. Therefore, the most expensive green items remain the only options when pursuing higher levels.

> *Achieving **NGBS at bronze** or **silver levels** is considered to be at low additional costs after satisfying **IECC**'s requirements. NGBS **gold** and especially **emerald** can however lead to significant additional costs.*

Achieving NGBS bronze and even silver levels seems a very economical option, especially in climate zones 3, 5 and 6 where additional cost per square foot is below $5. The underlying reasons might be twofold: first, the IECC requirements are very stringent and significantly improved every three years, [35] thus getting closer to those energy performance levels offered by the green certifications which also are updated but not as frequently. And second, utilization of passive design techniques to improve energy performance by taking advantage of the climate without additional or very low costs. For instance, in cold climate regions, orienting the longest building side towards the south results in solar heat gains that reduce the required amount of heat load to be artificially produced.[46]

4.2. Benefit Analysis of NGBS Green Levels

As highlighted previously, major benefits from green buildings include lower maintenance and operating costs (e.g., reduced consumption of energy and water), reduced environmental impact, and enhanced occupants' productivity and health. This section focuses on quantifying monetary benefits produced by energy savings and water conservation. This quantification is estimated based on a typical single-family home which characteristics are defined based on the average of:

- Single-family homes square footage;
- Number of family members;
- Average electricity consumption by an American home; and
- Water consumption per person.

These data are shown in Table 4 below. Furthermore, calculations will focus on the states of Michigan (climate zone 5 – cold) and Florida (climate zone 2 – hot-humid) which represent opposite climate characteristics and entail lower and higher costs respectively to achieve green certification (Figure 4). Although Michigan embraces climate zones 5 and 6 (bottom Figure 2), only zone 5 will be considered since it contains the main cities of the state.

Table 4. Typical Single-Family Homes in the States of Florida and Michigan

	United Sates	
Average Single-Family Home Square Footage in the U.S. [44]	2,625 Sq. Ft.	
Average Water Consumption per Person in the U.S. [51]	100 Gallons per Day	
Average Water Price in the U.S. [52]	$7 per 1,000 Gallons	
	Florida (Climate Zone 2)	***Michigan (Climate Zone 5)***
Average Family Members [53]	2.53 People per Household	2.61 People per Household
Average Electricity Consumption per Home [49]	1,092 kwh/month	654 kw/month
Average Electricity Price [49]	11.9 cents/kwh	14.5 cents/kwh

4.2.1. Required Annual Energy and Water Savings, and Their Associated Payback Periods

This section examines the required annual energy and water savings that would pay off the additional construction costs to acquire NGBS certification over a specific payback period. The following is performed:

1. Based on the estimates illustrated in Figure 4, it is calculated the additional construction costs of pursuing NGBS certification for typical single-family homes in Florida and Michigan (Table 5).
2. Then, it is estimated the minimum annual savings coming from water and energy savings that should be produced to recover this additional construction cost for a given simple payback period. These estimates are illustrated in Figure 6. They do not take into account the time value of money, therefore, they are obtained by dividing additional construction costs (Table 5) by simple payback periods.

For instance, Figure 6 shows that the minimum required energy and water annual savings to recover the $2,745 additional construction cost of pursuing NGBS bronze in climate zone 5 (e.g., Michigan) (Table 5) should be $499 for a simple payback period of 7 years. Whereas these savings should yield $1,071 during 7 years for climate zone 2 (e.g. Florida) to recover the additional $7,526 construction cost. The most important simple payback period for consideration is 7 years which is the common tenure for home ownership; [22] thus Figure 5 highlights the minimum annual savings required for a simple payback period of 7 years. Other pertinent payback periods would be 15 years which is the typical duration of a medium-term mortgage, or 30 years which is the typical duration of a long-term mortgage. [22]

Table 5. Additional Construction Costs for Typical Single-Family Homes Depending on Climate Zone and NGBS Rating Level

NGBS Green Levels Additional Construction Costs for Typical Single-Family Homes				
NGBS Green Level	Bronze	Silver	Gold	Emerald
Climate Zone 2 *(e.g., Florida)*	$7,526	$20,597	$41,918	$89,444
Climate Zone 5 *(e.g., Michigan)*	$3,730	$9,462	$20,640	$42,617

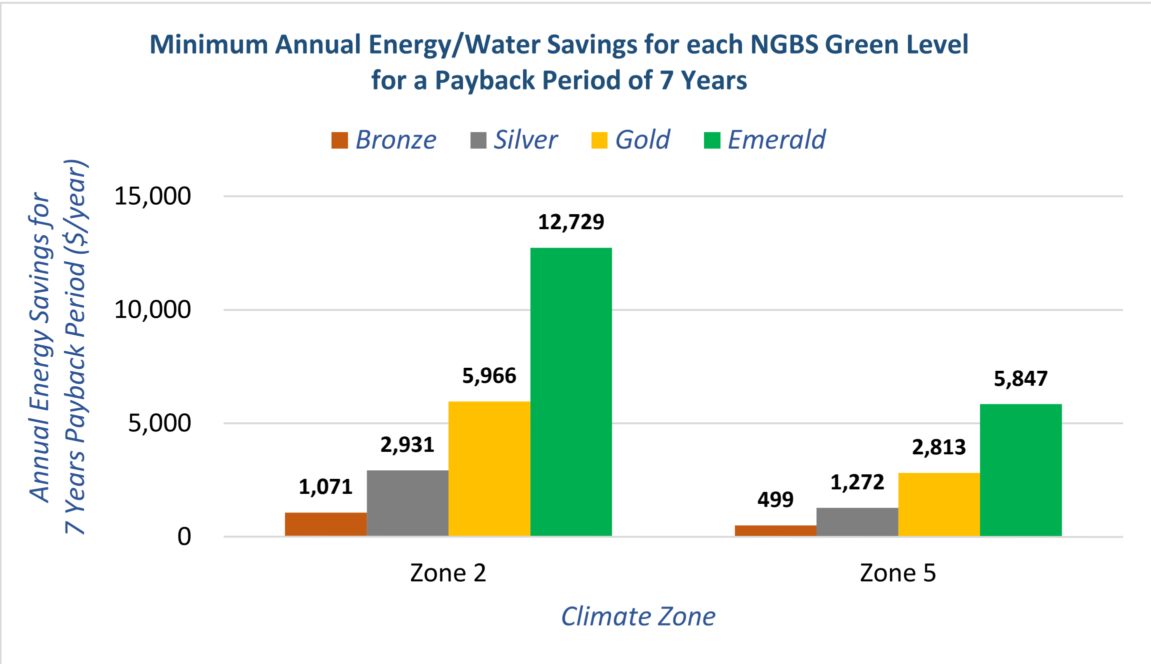

Figure 5. Minimum Required Annual Energy Savings for NGBS Certified Typical Single-Family Homes (2,625 Sq. Ft.) to Recover Additional Construction Costs in a 7 Years Payback Period

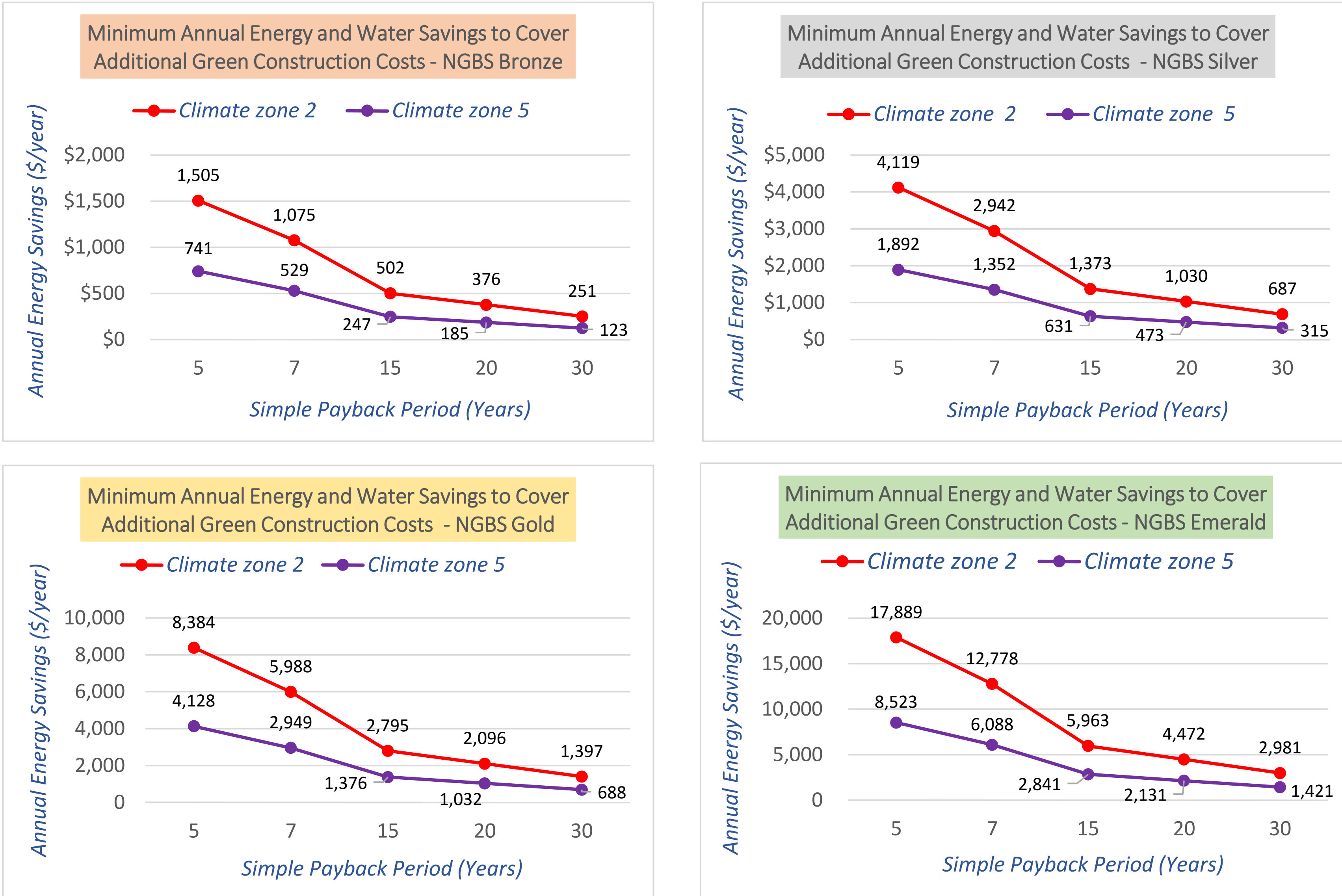

Figure 6. Minimum Required Annual Energy and Water Savings for NGBS Certified Typical Single-Family Homes (2,625 Sq. Ft.) to Recover Additional Green Construction Costs for a Given Payback Period

4.2.2. Actual Annual Energy and Water Savings, and Their Associated Payback Periods

Once it has been examined in the previous section the minimum annual monetary savings to recover additional construction costs in a given simple payback period, subsequently it is assessed which are currently the actual monetary energy and water savings, and their associated payback periods so that actual and required annual energy and water savings can be compared.

Estimated improved energy performance and water conservation in climate zones 2 and 5 are shown in Table 6. Based on these estimates, savings produced in NGBS certified typical single-family homes are contained in Table 7. Results suggest the following:

*Currently **actual annual energy and water savings** from NGBS single-family homes might require **payback periods** longer than 7 years.*

- Actual annual energy and water savings in Michigan (climate zone 5) range from $290 to $699 and payback periods from 13 to 61 years; actual savings look very far from required savings for a payback period of 7 years ($499/year, Figure 5);
- In Florida (climate zone 2), annual energy and water savings are overall higher between $338 and $1,206 but with longer payback periods between 22 and 74 years; as for Michigan, actual savings seem very far from required savings for 7 years of payback period ($1,071/year, Figure 5); and
- Overall, it seems that currently investments in NGBS certified single-family homes are difficult to recover in less than 7 years without taking into account health benefits.

*Table 6. NGBS **Energy Performance** Improvement Based on Studies No. 1 and 2 Cited at the Beginning of Section 4, and **Water Conservation** Improvement Based on Study No. 2 in Climate Zones 2 and 5*

NGBS Energy Performance and Water Conservation Improvement								
Location	***Climate Zone 2** (e.g., Florida)*				***Climate Zone 5** (e.g., Michigan)*			
Rating Level	Bronze	Silver	Gold	Emerald	Bronze	Silver	Gold	Emerald
Energy Efficiency	15.50%	30.00%	53.00%	65.05%	15.82%	23.32%	40.76%	46.23%
Water Conservation	14.45%	18.25%	26.70%	28.80%	17.00%	17.00%	26.70%	26.70%

Table 7. Actual Annual Savings and Simple Payback Period for a Typical Single-Family Home Based on Location and NGBS Rating Level

Estimated Annual Actual Savings and Actual Payback Periods for NGBS Certified Typical Single-Family Homes								
Location	***Florida*** *(Climate Zone 2)*				***Michigan*** *(Climate Zone 5)*			
Rating Level	Bronze	Silver	Gold	Emerald	Bronze	Silver	Gold	Emerald
Annual Energy Savings	$242	$468	$826	$1,014	$180	$265	$464	$526
Annual Water Savings	$96	$122	$178	$192	$110	$110	$173	$173
Actual Annual Savings	***$338***	***$590***	***$1,005***	***$1,206***	***$290***	***$375***	***$636***	***$699***
Additional Construction Cost *(Table 5)*	$7,526	$20,597	$41,918	$89,444	$3,730	$9,462	$20,640	$42,617
Actual Payback Period *(Years)*	***22***	***35***	***42***	***74***	***13***	***25***	***32***	***61***

4.2.3. Single-Family Homes: Influence of Size on Costs and Benefits

In the last 10 years, the average home size has passed from 1,500 to 2,625 Sq. Ft. [44] which significantly increases additional costs for green certification as shown in Figure 7. When compared to 2,625 Sq. Ft. homes in climate zone 5; 1,500 Sq. Ft. single-family homes can be around $1,400 or $16,000 less expensive at the bronze and emerald levels respectively. If estimated energy and water savings for single-family homes in Michigan (Table 7) are considered proportional to the square footage, then annual savings in 1,500 Sq. Ft. single-family homes would range between $213 (i.e., bronze level) and $473 (i.e., emerald level) (Figure 8), resulting in payback periods from 10 to 51 years respectively (Figure 9). Thus decreasing the square footage might make additional costs to pursue NGBS certification more affordable to clients; nonetheless, their willingness to accept smaller homes might be an important barrier that will be explored later in the methods section.

Additional construction costs *and* ***payback periods*** *of NGBS single-family homes can be significantly reduced by reasonably decreasing* ***homes' size.***

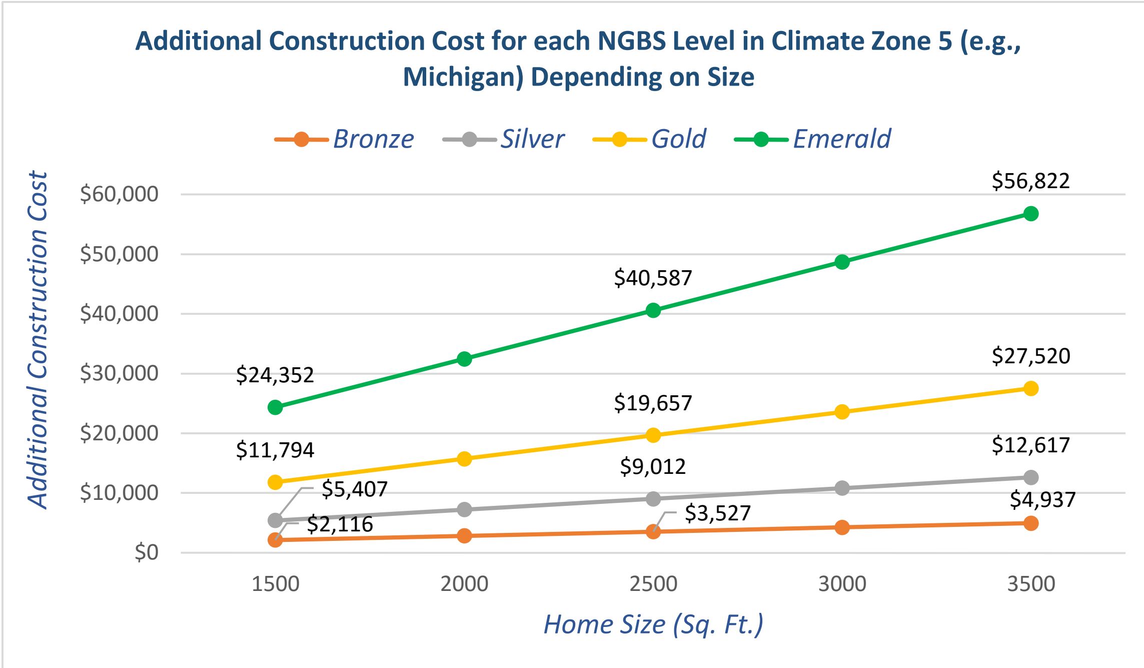

Figure 7. Additional Construction Cost to Pursue NGBS Certification in Single-Family Homes in Climate Zone 5 (e.g., Michigan) Depending on Home Size

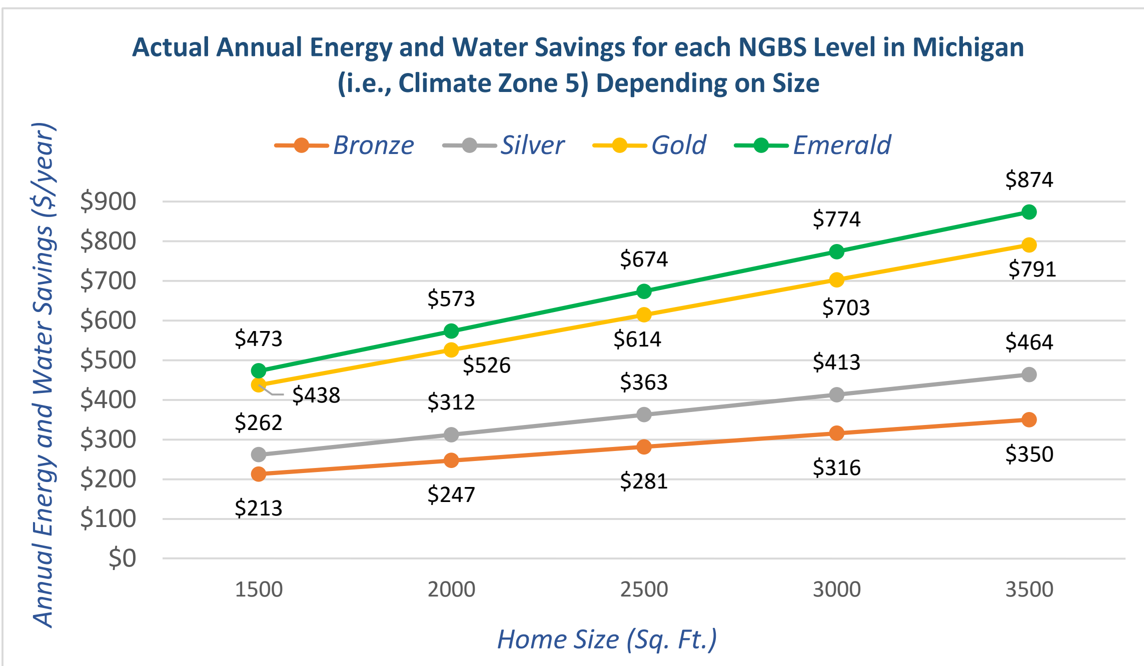

Figure 8. Actual Annual Energy and Water Savings from Pursuing NGBS Certification in Single-Family Homes in Michigan (i.e., Climate Zone 5) Depending on Home Size

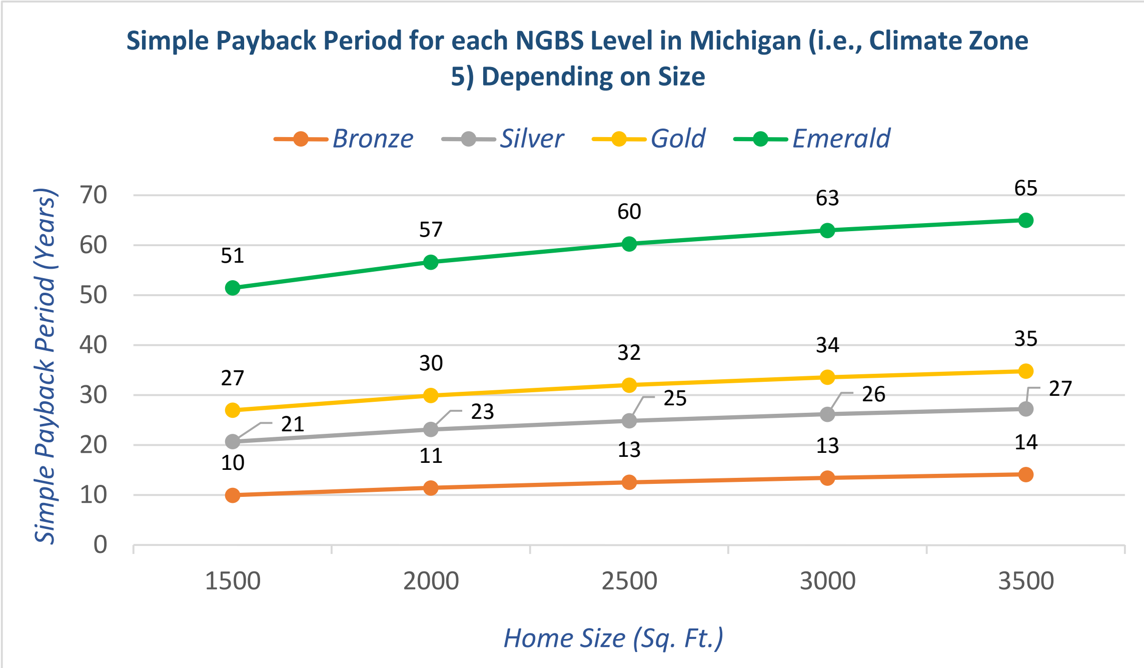

Figure 9. Simple Payback Periods from Pursuing NGBS Certification in Single-Family Homes in Michigan (i.e., Climate Zone 5) Depending on Home Size

4.2.4. *Green Design Features: Additional Costs and Payback Periods*

A number of energy and water green design features from a case study developed by the NAHB Research Center [(24)] (2012) are compiled in the Appendix A. This case study consists of a single-family home of 1,908 Sq. Ft. in climate zone 5 which was built based on the 2006 IECC standards, and estimates additional construction costs to achieve 2008 NGBS green levels and simple payback periods.

The designers from this NGBS green single-family home utilized **minimum incremental cost approach** for design, and followed the **performance path** to earn energy efficiency credits. Design features in Appendix A included under each NGBS green level are added to previous mandatory practices and green design features for lower levels if any. A sample of these green features related to the "Energy Efficiency" Chapter are listed in Table 8 below. Although these features and their associated cost and payback period are specific to a single case study following the 2008 NGBS version, they can provide an appropriate overview of important green features that, if given priority, might be more appropriate in terms of cost and payback periods for single-family homes pursuing the most up-to-date NGBS version.

Table 8. Sample of Green Features from the NGBS "Energy Efficiency" Chapter

NGBS Level	NGBS Energy Efficient Features Description	Cost	Payback Period*
Bronze	Energy efficiency features achieve energy cost performance that exceeds 2006 IECC by **15%**. Development of a documented analysis following procedures described in the ICC IECC – ***"Brought ducts inside unit and tightened to 12%. (8% leakage/sf)."***	$655	16 Years
Silver	Energy efficiency features achieve energy cost performance that exceeds 2006 IECC by **30%**. Development of a documented analysis following procedures described in the ICC IECC – ***"R-49 ceiling; 2x6 at 24"; 4.5ACH50; 6% duct leakage; 92% gas tankless water heater."***	$1,810	11 Years
Emerald	Energy efficiency features achieve energy cost performance that exceeds 2006 IECC by **50%**. Development of a documented analysis following procedures described in the ICC IECC – ***"Raised heel R-60; R-10 sheathing; .23/.35 windows; 2ACH50; 96% heat; therma-tru doors 0.18."***	$10,601	34 Years
	Balanced HVAC air flows are demonstrated by flow hood or other acceptable flow measurement tool. Test results in accordance with both of the following: (a) Measured flow at each supply and return register is within 25% of design flow; and (b) Total airflow is within 10% of design flow.	$296	

*Payback periods are calculated based on the energy savings produced by the aggregated effect of all the features included in the "Energy Efficiency" Chapter, and not savings produced by a particular feature.

4.3. Summary

This section examined the costs and benefits of NGBS certified single family homes. They key results comprise the following:

- Additional construction costs in hot-humid climates for NGBS homes are higher than in any other climate due to requiring higher number of green features and a more expensive HVAC system;
- If the minimum incremental approach is followed for green design, then NGBS bronze and silver levels are fairly affordable after satisfying IECC standards whereas gold and emerald levels require much higher additional costs;
- Actual energy and water savings from NGBS single-family homes are lower than required savings for payback periods of 7 years; and
- Reducing NGBS single-family homes' size might be a key factor to make green certification affordable.

5. Verification of the Literature Findings via Home-Builder Reports

5.1. Summary of Literature Review and Analysis Results

The goal of this study is to help home-builders assess the costs and benefits of implementing green practices in residential projects with a special focus on green NGBS single-family homes. The key observations based on the in-depth literature review comprise the following:

1. **Effective cost-benefit analyses** from green buildings go through a process whereby first climate zone is identified, local codes are assessed and a baseline is selected, second additional construction costs from implementing green practices are estimated, and finally benefits are assessed (Section 3, Figure 1);
2. Additional **construction costs** for green homes are higher in **hot-humid climates zones** than in any other zone due to the necessity to incorporate more green features, and a more sophisticated HVAC system than in cold climates zones to achieve efficient energy performance (Sections 4.1.1, 4.1.2 and 4.1.3);
3. **Local codes stringency** in the U.S., especially the IECC, is high leading to low additional costs to achieve NGBS lower levels such as bronze or silver; and additional costs tend to increase exponentially from one level to another if **minimum incremental approach** for design is followed, for example, additional costs for NGBS bronze and silver might be very low whereas gold and emerald drastically higher (Section 4.1.4);
4. Overall actual annual **energy and water savings** from NGBS single-family homes are lower than required annual savings for **payback periods** shorter than 7 years (Sections 4.2.1 and 4.2.2);
5. Single-family **homes size** considerably influences additional costs and payback periods, frequently being an important factor to make green certification affordable to many clients (Section 4.2.3); and
6. When following the **minimum incremental cost approach** for design there might be **specific green features** that if given priority over others facilitate obtaining NGBS certification (Section 4.2.4).

5.2. Methods to Verify Literature Findings

To verify the key observations above, this study analyzed the content from an independent study report that was developed by a Master's student in the Construction Management Program at Michigan State University. [54] This independent study conducted two interviews with two home-builders which will be referred to later on as **interviewees** or **home-builders A** and **B**. These interviewees have wide experience in building NGBS certified single-family homes primarily in climate zone 5. They were found through the Home Innovation Research Labs' website which provided the student with a list of home-builders that developed NGBS certified single-family homes by state. The home-builders were contacted by the student by phone and were asked to make an appointment for a phone call interview for about 25 minutes.

The questionnaire followed in the interviews is shown in Appendix A and included thirteen main questions focusing on the key findings mentioned before and additional matters such experience in building green, motivations and obstacles to pursue both green certification and intended green level. The student recorded the interviews and coded them for reporting purposes. The content of the interviewees' responses and comments were analyzed qualitatively in this report by comparing them with the study key observations (Section 6).

5.3. Comparison of Literature Findings and Home-Builder Reports on Building Green

In the following sub-sections, the key observations listed at the beginning of Section 5 are compared with interviewees A's and B's comments to assess their validity and discuss them.

5.3.1. Cost-Benefit Analysis for Green Homes

It was highlighted in Section 2 the framework to develop an effective cost-benefit analysis for green projects based on a number of industry reports. However, according to the interviewees, prior calculation of additional costs and monetary benefits over conventional buildings does not seem to be used as a primary tool to convince the client to obtain green certification. Rather, home-builders with a wide number of green buildings in their portfolio tend to focus their business in solely green buildings as our interviewees, thus offering clients only high quality buildings which are friendly with occupants and reduce the carbon dioxide emissions.

> *"We do talk to them [clients] about indoor air quality, indoor comfort, energy savings… The main obstacle is that **they're not aware.**"*

Home-builder A stated that *"I let them [clients] know what I'm going to do and then I give them a price for doing the way I build… they're either going to build my way or they're going to find another builder… I just like to be friendly with the environment."* And interviewee B asserted that *"We do not do a specific cost benefit analysis… [however] we do talk to them about indoor air quality, indoor comfort, energy savings, we walk through the whole process with them,"* and later added that cost is not the main for clients to adopt green practices: *"The main obstacle is that they're not aware… the education isn't out there or wasn't out there ten years ago when we started about green."*

However, the interviewees admitted that inevitably, as suggested in Figure 1 (Section 3), before project design starts it is crucial to assess climate zone parameters and local codes. They do not need to select a green system since their specialty relies on NGBS green standards, and asserted that they explain to clients the potential benefits from buying their green homes essentially based on reduced energy and water bills, lower maintenance costs, and improved indoor air quality.

5.3.2. Hot-Humid versus Other Climates

Additional construction costs in hot-humid climates tend to be greater than in any other climate zone and, on the other hand, in cold climate zones or areas with soft summer and winter seasons tend to be lower as illustrated in Figure 4. This point was confirmed by home-builder B: *"Well, I know building in hot requires a lot [additional green features] – a different [HVAC] system… more items to control for humidity and the damage done*

> *"My general knowledge of that [green system in NGBS single-family homes] is that it is a **more expensive [green] system in a hot and humid climate**."*

by the moisture. So, my general knowledge of that [green system] is that it is a more expensive [green] system in a hot and humid climate." Previous Sections 4.1.2 and 4.1.3 deeply discussed the underlying factors increasing additional costs in hot-humid areas.

5.3.3. Local Codes

It was observed previously in this study that local codes energy performance requirements such as those established by the last versions of the IECC are currently very high, which combined with the minimum incremental cost approach (i.e., prioritizing inclusion of less expensive green design features) to design green buildings results in very low costs per Sq. Ft. to achieve NGBS bronze or silver certification in many locations (Figure 4). The interviewee B agreed: *"Building bronze or silver is building to the current building codes [2009/2012 IECC] that we have, so that does not set us apart, so we pursue gold all the time."*

> *"Building **bronze** or **silver** is building to the current **building codes** [2009/2012 IECC] that we have, so that does not set us apart, **so we pursue gold** all the time."*

As Figure 4 suggests, additional costs per sq. ft. to pass from bronze to silver tend to be very low, whereas they increase significantly from NGBS silver to gold, and even more from gold to emerald. Therefore, utilizing the minimum incremental cost approach to design green buildings makes additional costs per Sq. Ft. to increase exponentially when passing from an NGBS level to the following one. This pattern was confirmed by the interviewees:

- First, home-builder B's statement in the first paragraph of this section supports that bronze and silver costs are very similar.
- Second, both interviewees primarily targeted NGBS gold levels for their green homes in climate zone 5 (cold and dry/humid). However, their additional costs for green building were quite different: whereas one of them regularly delivered NGBS gold single-family home for around $2 per Sq. Ft. on average, the other home-builder would need at least $25. The more plausible explanation is that the first home-builder followed the minimum incremental cost approach for design, thus focusing on the inclusion of passive design techniques and lower cost green items (see section 6.6); whereas the second home-builder would like to include pricey green practices such as geothermal systems (see section 6.6).

  Therefore, NGBS gold level might be obtained at a low price as opposed to the expected much higher cost due an exponential increase from silver to gold levels. Nonetheless, exponential cost growth from each NGBS level to the next one does not necessarily mean that the additional cost to achieve gold or emerald levels must be much higher than bronze or silver. Instead, it means that there is one point where costs suddenly drastically increase. Thus, based on our interviewees' responses, if home-builders properly utilize the minimum incremental cost approach for green design, then they can avoid this severe cost increase from bronze to gold levels.
- Finally, both interviewees agreed that pursuing emerald level dramatically increases additional costs. home-builder A said that *"It is very difficult to get emerald because so many people are not willing to spend the money for like for electric and stuff like that something that can really push*

the house over the top, so that's why I always ask for the gold because the emerald was a little bit pricey for the customer," and similarly home-builder B claimed that *"Gold, like I said it just requires maybe a couple thousand dollars maybe 2% to achieve the gold… Emerald, that's much more expensive to achieve."*

5.3.4. Payback Periods

Interviewees responses regarding the utilization of payback periods to make the case for green homes were disparate. Home-builder A explained that he/she emphasizes the higher quality of his/her products discarding the need to calculate payback periods for green features, and asserted that *"I'm building a house right now in [location] and that customer doesn't care about the payback, the only thing they care about is their carbon footprint. So, you know, their carbon footprint is more important to them than the payback of building energy efficient and green."* On the other hand, interviewee B pointed that he/she estimated payback periods to make decisions about what NGBS green level should be pursued.

Section 4.2.2 argued that additional construction costs to pursue NGBS certified single-family homes require long payback periods (e.g., around 22 years for bronze and 74 for emerald in hot-humid climates; and 13 and 61 years approximately for bronze and emerald respectively in cold climates), if only energy and water saving benefits are considered, and maintenance, environmental and health benefits are ignored. This point was only partially confirmed by the interviewee B: he/she stated that *"We don't pursue emerald because the payback is not there;"* however, he/she added that *"I would say [that based on my experience building single-family homes] within two to three years you are recouping your money [for NGBS gold level]."* Consequently, it seems that if home-builders develop green homes following the minimum incremental cost approach, they can not only reduce additional costs below $5/Sq. Ft. as highlighted in Section 6.2, but also keep payback periods at three or less years for bronze, silver and gold NGBS levels.

> *"Within **two to three years** you are recouping your money [for NGBS **gold** level]… We don't pursue **emerald** because the payback is not there."*

Home-builder B remarked that acceptable payback periods for clients are 5 years or less: *"They don't even want a ten-year payback period, they want it as quickly as possible, they are looking for five or less."* Moreover, he/she clarified that although payback periods are estimated mainly based on energy and water savings, clients are also concerned in a lesser degree with maintenance and environmental impact. *"Essentially it's energy, their electric and gas bills, their water bills absolutely. But they're also looking for durability and sustainability in everything that is being used in their homes."*

Interested in reducing payback periods and additional costs, home-builders might come across clients willing to discard specific mandatory green practices which are costly at the expense of not obtaining green certification. For instance, interviewee B shared that *"There's one or two people that in the past have not wanted to pay for the testing and we didn't do it, but they're regretting it… just wanted to save, you know, $600, $700 in the testing fees. But, the majority of them have said bit later, 'Oh, you know, I really should have just gotten that so I had it' because a lot of them talk to realtors which in our area are trying to make the HERS rating part of a searchable field for real estate. And so, when you don't have the blower door test done and you don't pay for that testing you don't have that certification."*

5.3.5. *Cost Premium Link to Home Size*

Additional construction costs and payback periods for green NGBS single-family homes are greatly sensitive to square footage (Section 4.2.3), making green certification much more affordable if home size is reduced from the current average value (2,625 Sf. Ft.). [44] However, the interviewed home-builders had opposed opinions regarding clients' willingness to buy smaller but greener single-family homes. Interviewee A said that *"[Single-family homes usually range] from 2,000 to, you know, 2,600 or 2,800 square feet. So, it's highly unusual to find somebody that wants that small house."*

> *"**We're building smaller**, our buyers are coming to us because they want the niceties in the home, but they don't want waste, they want something they can **afford but nice**."*

Nonetheless, the home-builder B disagreed: *"We're building smaller anyway, our buyers are coming to us because they want the niceties in the home, but they don't want waste, they want something they can afford but nice. Our average home is 1,800 Sq. Ft. We don't build for a market that wants 2,600 square feet because we are more than empty nester builder, so retirees, older people, downsizing, people that may be are in their 50's that are looking to build their forever home now that the kids are gone. So, we don't build for a lot of families we don't build for a lot of people that want more than 2,000 square feet. So they will take smaller houses and we're very thankful because that's our market."* Therefore, there are many clients in the market that depending on their needs are willing to acquire smaller houses to be able to afford green certification.

5.3.6. *Key Green Features to Obtain NGBS Certification*

Our interviewees suggested some key green design features to achieve **NGBS gold** certification which was their most frequently targeted level:

> *"Green **design features** that greatly improve **energy performance** at **very low or no additional cost** include advance framing techniques, tight building envelope, HVAC system location, and energy efficient lighting and appliances."*

- <u>Home-builder A</u> highlighted the importance of ***Advanced Framing Techniques*** (or Optimum Value Engineering) which reduce the amount of lumber needed to build the structural framework resulting in enhanced energy performance due minimizing thermal bridging and heat loss because of conduction. [28] This technique keeps intact homes' structural integrity and decreases construction costs. [28]

  Furthermore, home-builder A suggested the ***Geothermal System*** although being costly: *"[Cost might be] $8,000 for gas and about $14,500 for the geo. Now, what I point out to the customer is through the end of next year 2016, they can get a 30% tax credit on the installation of that geo, so that brings the price down."* *Geothermal Systems* frequently consist of either a vertical piping that exchanges heat with wells or ponds, or a horizontal piping placed in trenches below the frost line exchanging heat with the earth. [28]

- Since <u>interviewee B</u> followed the minimum incremental cost approach for green design, he/she suggested a number of green design features that greatly improve energy efficiency but barely entail additional construction costs if compared to conventional buildings (i.e., as indicated previously, $2/Sq. Ft. on average of additional cost to achieve NGBS gold):

- Tight ***Building Thermal Envelope*** paying special attention to not only selecting appropriate materials for insulation and sheeting, but also to sealing every single connection between envelope elements to achieve a continuous boundary that facilitates control over heat, air, and moisture exchange between the home and exterior environment.

- Placement of the ***HVAC System*** including the air handler unit and the duct system within the *Building Thermal Envelope.* Home-builder B assured that *"If the ducts are in the slab you're going to have a much more efficient warm house than if they're overhead."* It is extremely important for this strategy that the *Building Thermal Envelope* is properly tight to avoid the "stack effect," that is, upward movement of the warm air that leaves to the exterior through cracks in the upper part of the house, while creating negative pressure at the lower part of the house that sucks exterior air through cracks. [28]

- Artificial ***Lighting*** might be responsible for almost 15% of homes' electricity consumption.[28] For *Interior Lighting* home-builder B claimed "*We're using almost exclusively CFLs or LED bulbs, but we do try to use fixtures that are efficient and are rated ENERGY STAR without having the green tag to them because that tends to make them more expensive,*" and he/she added that "*We're finding a lot of the CFLs don't last as long as they claim they will last, so we've been using that for quite a few years now and we're not really convinced that they're a lot better than the incandescent. We replaced a lot of them.*" Whereas for *Exterior Lighting* he/she suggested only utilizing dark sky lighting. In terms of additional costs, home-builder B said that *"[Energy efficient lighting systems cost] are getting closer to conventional [systems] as the ball of prices come back to earth and get less expensive as they become more common."*

- Finally, by selecting proper ***Appliances*** home owners can save up to 30% of the $2,100 that are spent on average per year in energy bills in the U.S. [28] IECC standards followed by many local codes limit appliances' power consumption which can be satisfied utilizing ENERGY STAR or equivalent appliances. [55] Interviewee B commented that *"We obtain points if we use ENERGY STAR rated appliances… We only install the built-ins that are the micro-hood, dishwasher, and garbage disposal… but washers, dryers, ranges, and refrigerators, those are consumer provided, we encourage that to them but we don't dictate to them what type of appliances they put in."*

5.4. Summary

This section compared the key observation from the literature review performed in previous sections with two home-builders' knowledge elicited via interviews. The key findings are the following:

- They main obstacle for clients to adopt green practices is their unawareness of green certification. Home-builders do not use a detailed cost-benefit analysis to convince clients to pursue green certification; instead, they highlight potential benefits and offer a price.
- Pursuing green certification in hot-humid climate zones is more expensive than in any other climate.
- After satisfying local codes' requirements following IECC's standards, NGBS bronze and silver certifications can be obtained at a very low cost.
- If the minimum incremental cost approach for design is properly implemented, NGBS gold certification can be obtained at a very low cost close to NGBS bronze or silver. NGBS emerald tends to be always very pricey.
- Additional costs from pursuing NGBS bronze, silver and gold do not necessarily require payback periods beyond 7 years; payback periods might be three or less years.
- There are clients in the market willing to buy smaller but greener single-family homes that they can afford.
- Specific green features critically improving home energy performance at a low or no cost include advance framing techniques, tight building envelope, HVAC system location, and energy efficient lighting and appliances.

6. Conclusions

The goal of this study is to help home-builders assess costs and benefits of green residential projects so they can confidently make decisions about the appropriateness of pursuing NGBS certification for green single-family homes. The main observations of this report include the following:

✓ ***Key Observation 1:***

Effective **cost-benefit analyses** of green residential buildings should follow the next steps:

1. **Climate zone** assessment since exterior conditions, especially humidity and temperature, greatly influence green design;
2. **Local codes** assessment since they establish minimum design requirements or, in other words, a **baseline** that must be satisfied by conventional buildings and over which additional construction costs and benefits from green buildings are to be estimated;
3. **Green rating system selection** based on project characteristics and clients' requirements;
4. Additional **cost estimate** taking as a baseline the **local codes** assessed in point 2; and
5. **Economic benefits** analysis taking into account at least **water** and **energy savings**; additional benefits include improved occupants' health and productivity, lower maintenance and operating costs, and softer environmental impact (e.g., reduced greenhouse gases emission and natural resources consumption).

Many home-builders, especially those solely embedded in the green market, do not use cost-benefit analyses as a primary tool to convince clients to obtain green certification, but rather focus on green homes' benefits and offer a price to clients. In addition, cost is not the only main obstacle dragging down the adoption of green practices but also **clients' unawareness**.

✓ ***Key Observation 2:***

Additional construction costs to obtain green certification in **hot-humid climates** tend to be greater than in cold climate zones or areas with soft summer and winter seasons. This study estimated that additional construction costs to build green NGBS single-family homes in Michigan (climate zone 5, cold) ranges from \$2 to \$13 per Sq. Ft. whereas in Florida (climate zone 2, hot-humid) goes from \$3 to \$35 per Sq. Ft.

✓ ***Key Observation 3:***

Most local codes in the U.S. take the newest versions of the **IECC (e.g., 2009, 2012 or 2015)** which **energy performance requirements stringency is very high**, which combined with the minimum incremental cost approach to green design (i.e., prioritizing implementing the least expensive green features) make **NGBS bronze, silver and even gold certification quite affordable.** Nevertheless, emerald level tends to be extremely high and keep home-builders away from pursuing it.

Overall, this study estimated that additional costs to achieve NGBS bronze and silver is generally below $5 per Sq. Ft., and costs for gold are close to this same value in some climate zones. Taking into account that last year the average cost for homes was $100 per Sq. Ft., [43] and that almost 70% of clients in the market are willing to pay up to around 5% of additional costs to obtain green certification, [1] **cost should not be the main barrier** in the future to increase the adoption of green practices for single-family homes, at least for **NGBS bronze and silver which additional costs typically do not exceed 5%.**

✓ ***Key Observation 4:***

Additional construction costs to pursue NGBS certified single-family homes **do not necessarily require long payback periods.** This study estimated that, based on previous industry reports payback periods based on water and energy savings might range from 22 to 64 years in Florida (climate zone 2, hot-humid), and from 13 to 61 years in Michigan (climate zone 5, cold). Nevertheless, although these results are aligned with those in previous studies, it was found out that a home-builder in climate zone 5 was able to, following the minimum incremental cost approach, build green **NGBS gold single-family homes for around an additional cost of 2$ per Sq. Ft. on average with payback periods of 3 or less years.**

✓ ***Key Observation 5:***

Smaller homes might drastically reduce additional costs for gaining green certification and be a key factor to make green homes **affordable to specific clients.** There is a specific sector of society that is willing to buy smaller but greener homes such retirees, elderly, or families where the kids already left.

✓ ***Key Observation 6:***

There are **specific green design features** that are likely to **facilitate obtaining NGBS** green certification from bronze to gold at a low additional cost due to their significant impacting homes' energy performance. These features include the following: advanced framing techniques for lumber structures, tight building thermal envelope, HVAC system placement, lighting fixtures, and green appliances.

This study has several limitations. First, cost estimates are calculated based on the implementation of specific versions of the NGBS system and taking as a baseline specific versions of the IECC. Thus, being rigorous, it could be argued that the estimates are generalizable when other versions of the NGBS and IECC are implemented. Nonetheless, cost estimates in this report can also serve to shade light on understanding potential costs and benefits when implementing future versions of the NGBS taking the newest updates of the IECC as a baseline.

*The next step is to spread green practices in the residential construction market is to focus on increasing **clients' awareness** of green practices highlighting their **valuable benefits.***

Second, it was assumed that designers follow the performance path to develop buildings design and utilize the least incremental cost approach to decide what sustainable features should be implemented to achieve a specific green level, thus suggested costs and payback periods might vary if prescriptive path is performed.

Third, payback period based on energy and water savings are calculated without taking into account interest rates of return (IRRs) because the difference between costs and benefits is such that IRRs above 3 or 4% yield infinite payback periods. And finally, climate zones 1, 7 and 8 are not included in the study due to lack of data.

In summary, this study shows that additional costs to build **green NGBS single-family homes can be fairly affordable for bronze, silver and even gold levels**. Therefore, the next step to spread green design in the residential construction market should focus on increasing **clients' awareness** of green practices highlighting their **valuable benefits** addressing both clients' interest in saving money, and the necessity to protect the environment for the sake of future generations.

References

(1) **McGraw Hill Construction (2014).** "Green multifamily and single family homes: growth in a recovering market." SmartMarket Report, McGraw Hill Financial, New York City, NY. *<http://www.menckwindows.com/wp-content/uploads/2014/08/GreenMultifamilySingleFamilyHomesSMR2014.pdf> Accessed 9/23/2015*

(2) **Home Innovation Research Labs (2013).** "What do homebuyers really want in a green home?" Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/trends_and_reports/trends/what_do_homebuyers_really_want_in_a_green_home> Accessed 12/12/2015*

(3) **U.S. Green Building Council (2015).** "Green building facts." U.S. Green Building Council, Washington, D.C. *<http://www.usgbc.org/articles/green-building-facts> Accessed 10/29/2015*

(4) **Home Innovation Research Labs (2015).** "Current NGBS certification activity." Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/ngbsgreenstats> Accessed 12/29/2015*

(5) **Jackson, J. C. (2014).** "An exploratory study of three paths to green homes: Energy Star Homes, LEED for Homes, and the National Green Building Standard." Master's Report submitted to the School of Planning, Design, and Construction of the Michigan State University. *<http://www.spdc.msu.edu/uploads/files/Programs/CM/Housing_Education_and_Research_Center/mastersreport_greenhomes_JawandaJackson_abridged_101414.pdf> Accessed 9/23/2015*

(6) **Home Innovation Research Labs (2014).** "Cost and stringency comparison of 2012 National Green Building Standard™ ICC 700-2012, LEED-H 2008, and LEED v4 for homes design and construction." A Report for National Association of Home Builders, Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/~/media/Files/Reports/2012_NGBS_Cost_Comparison.pdf> Accessed 9/23/2015*

(7) **Home Innovation Research Labs (2015).** "Home Innovation begins preparations for 2015 National Green Building Standard update." Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/about/news_and_events/home_innovation_news/2014_0201_home_innovation_begins_preparations_for_national_green_building_standard_update> Accessed 11/2/2015*

(8) **Home Innovation Research Labs (2015).** "Find a verifier for NGBS project certification." Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/findngbsverifier> Accessed 12/29/2015*

(9) **ENERGY STAR (2015).** "About ENERGY STAR." ENERGY STAR, U.S. Environmental Protection Agency, Washington, D.C. *<https://www.energystar.gov/about> Accessed 12/29/2015*

(10) **ENERGY STAR (2013).** "ENERGY STAR certified homes, version 3 (Rev. 07) national program requirements." ENERGY STAR, U.S. Environmental Protection Agency, Washington, DC. *<https://www.energystar.gov/ia/partners/bldrs_lenders_raters/downloads/National_Program_Requirements.pdf> Accessed 12/29/2015*

(11) **ENERGY STAR (2015).** "The next generation of ENERGY STAR certified new homes." ENERGY STAR, U.S. Environmental Protection Agency, Washington, DC. *<http://www.energystar.gov/index.cfm?c=next_generation.ng_qualified_new_homes> Accessed 12/29/2015*

(12) **ENERGY STAR (2015).** "History of the ENERGY STAR guidelines for new homes." ENERGY STAR, U.S. Environmental Protection Agency, Washington, DC. *<http://www.energystar.gov/index.cfm?c=new_homes.nh_history> Accessed 12/29/2015*

(13) **ENERGY STAR (2015).** "New homes partner locator." ENERGY STAR, U.S. Environmental Protection Agency, Washington, DC. *<http://www.energystar.gov/index.cfm?fuseaction=new_homes_partners.locator> Accessed 12/29/2015*

(14) **ENERGY STAR (2015)**. "How new homes earn the ENERGY STAR." ENERGY STAR, U.S. Environmental Protection Agency, Washington, DC. *<http://www.energystar.gov/index.cfm?c=new_homes.nh_verification_process> Accessed 12/29/2015*

(15) **U.S. Green Building Council (2015).** "LEED v4: homes design + construction guide." U.S. Green Building Council, Washington, D.C. *<http://www.usgbc.org/guide/homes> Accessed 12/21/2015*

(16) **U.S. Green Building Council (2015).** "LEED v4 for homes design and construction." U.S. Green Building Council, Washington, D.C. *<http://www.usgbc.org/sites/default/files/LEED%20v4%20ballot%20version%20(Homes)%20-%2013%2011%2013.pdf> Accessed 12/29/2015*

(17) **U.S. Green Building Council (2015).** "Directory: green raters." U.S. Green Building Council, Washington, D.C. *<http://www.usgbc.org/people/green-raters> Accessed 12/29/2015*

(18) **U.S. Green Building Council (2015).** "Guide to certification: homes." U.S. Green Building Council, Washington, D.C. *<http://www.usgbc.org/cert-guide/homes> Accessed 12/29/2015*

(19) **National Association of Home Builders Research Center, Inc. (2008).** "Green home building rating systems: a sample comparison." A Report for National Association of Home Builders, Washington, D.C. *<http://www.hbact.org/Resources/Documents/Files%20D-G/GreenHomeRatingComparison.pdf> Accessed 9/23/2015*

(20) **FitzGerald Associates Architects (2011).** "Urban green building rating systems cost comparison." A Report for Home Builders Association of Greater Chicago, Chicago, IL. *<http://www.homeinnovation.com/~/media/Files/Reports/UrbanGreenBuildingRatingSystemsCostComparison.ashx> Accessed 9/23/2015*

(21) **Cincinnati American Institute of Architects (2010).** "Comparison of United States Green Building Council's LEED for Homes First Edition 2008 and National Association of Home Builders' National Green Building Standard TM ICC 700-2008." A Report for City of Cincinnati Office of Environmental Quality, Cincinnati, OH. *<http://www.aiacincinnati.org/community/leed_nahb_final.pdf> Accessed 9/23/2015*

(22) **Andrews, C., Senick, J., Kornitas, M., Crandall, K., Montfort, K., Plotnik, D. & Tuvel, E. (2011).** "Costs and benefits of residential energy efficiency investments." A Report for the New Jersey Association of REALTORS. The Rutgers Center for Green Building, New Brunswick, NJ. *<http://www.rcgb.rutgers.edu/wp-content/uploads/2013/11/NJAR-Final-Report-July-2011_submitted.pdf> Accessed 9/23/2015*

(23) **Hiser, S. R. (2011).** "LEED vs. ENERGY STAR: a cost/benefit analysis of sustainability labels for commercial buildings." Masters Project submitted to Duke University's concurrent Master of Environmental Management and Master of Business Administration Degree Program. *<http://www.dukespace.lib.duke.edu/dspace/bitstream/handle/10161/3571/MP%20Report_Hiser_FINAL.pdf?sequence=1> Accessed 9/23/2015*

(24) **National Association of Home Builders Research Center, Inc. (2012).** "An evaluation of affordable housing using the national green building standard." A Report for U.S. Department of Housing and Urban Development, Washington, D.C. *<http://www.huduser.gov/publications/pdf/evaluation_of_affordablehousing.pdf> Accessed 9/23/2015*

(25) **Kats, G., Perlman, J. & Jamadagni, S. (2005).** "National review of green schools: costs, benefits, and implications for Massachusetts." A Report for the Massachusetts Technology Collaborative. *<http://www.azdeq.gov/ceh/download/natreview.pdf> Accessed 9/23/2015*

(26) **Kats, G., Alevantis, L., Berman, A., Mills, E., Berkeley, L. & Perlman, J. (2003).** "The costs and financial benefits of green buildings." A Report for California's Sustainable Building Task Force. *<http://www.usgbc.org/Docs/Archive/General/Docs1992.pdf> Accessed 9/23/2015*

(27) **Pacific Northwest National Laboratory & Oak Ridge National Laboratory (2010).** "Guide to determining climate regions by county." U.S. Department of Energy, Washington, D.C. *<http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/ba_climateguide_7_1.pdf> Accessed 10/14/2015*

(28) **National Association of Home Builders (2013).** "Student guide: green building for green professionals." National Association of Home Builders, Washington, D.C.

(29) **International Code Council (2009).** "2009 International Energy Conservation Code: residential prescriptive requirements." International Code Council, Washington, D.C. *<https://energycode.pnl.gov/EnergyCodeReqs/> Accessed 10/24/2015*

(30) **NC Clean Energy (2015).** "Database of state incentives for renewables & efficiency." North Carolina Clean Energy Technology Center, Raleigh, NC. *<http://www.dsireusa.org/> Accessed 10/14/2015*

(31) **International Code Council (2015).** "International codes-adoption by state." International Code Council, Washington, D.C. *<http://www.iccsafe.org/wp-content/uploads/stateadoptions.pdf> Accessed 10/14/2015*

(32) **International Code Council (2015).** "Overview of the International Energy Conservation Code." International Code Council, Washington, D.C. *<http://www.iccsafe.org/about-icc/government-relations/international-energy-conservation-code-resource-page/> Accessed 10/14/2015*

(33) **U.S. Department of Energy (2012).** "National energy and cost savings for new single- and multi-family homes: a comparison of the 2006, 2009, and 2012 editions of the IECC." Building Technologies Program, U.S. Department of Energy, Washington, D.C. *<https://www.energycodes.gov/sites/default/files/documents/NationalResidentialCostEffectiveness.pdf> Accessed 10/18/2015*

(34) **City of Chicago (2015).** "Chicago energy conservation code." The City of Chicago's Official Website, Chicago, IL. *<http://www.cityofchicago.org/city/en/depts/bldgs/supp_info/chicago-energy-conservation-code.html> Accessed 10/14/2015*

(35) **Institute for Market Transformation (2015).** "International Energy Conservation Code." Institute for Market Transformation, Washington, D.C. *<http://www.imt.org/codes/iecc> Accessed 10/16/2015*

(36) **Home Innovation Research Labs (2015).** "Chapter 7 energy efficiency points analysis." A Report (Draft) for Task Group 5 on Energy Efficiency. Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/services/standards_development/american_national_standards/national_green_building_standard/~/media/Files/Standards%20Development/NGBS/2015-NGBS/NGBS-Energy-Efficiency-Points-Analysis-Report-DRAFT-20150529.pdf> Accessed 10/14/2015*

(37) **Home Innovation Research Labs (2014).** "Which costs more, getting third-party verification, or not getting it?" Home Innovation Research Labs, Upper Marlboro, MD. *<http://www.homeinnovation.com/about/blog/which_costs_more_-_getting_third-party_verification_or_not_getting_it> Accessed 10/13/2015*

(38) **Laquatra, J., Pillai, G., Singh, A. & Syal, M. M. (2008).** "Green and healthy housing." Journal of Architectural Engineering, 14(4), 94-97.

(39) **Singh, A., Syal, M., Korkmaz, S. & Grady, S. (2010).** “Costs and benefits of IEQ improvements in LEED office buildings.” Journal of Infrastructure Systems, 17(2), 86-94.

(40) **Kats, G. (2003).** “Green building costs and financial benefits.” Massachusetts Technology Collaborative, Boston, MA.
<http://www.dnr.sc.gov/marine/NERR/present/highperf/Green%20Building%20Costs_Kats.pdf>
Accessed 10/1/2015

(41) **National Association of Home Builders (2015).** “Greenhouse gases and home building: manufacturing, transportation, and installation of building materials.” National Association of Home Builders, Washington, D.C.
<https://www.nahb.org/en/research/housing-economics/special-studies/greenhouse-gasses-and-home-building-2008.aspx> Accessed 10/29/2015

(42) **National Association of Home Builders (2015).** “Green building certification for single-family homes.” Eye on Housing, National Association of Home Builders, Washington, D.C.
<http://eyeonhousing.org/2014/07/green-building-certification/> Accessed 10/29/2015

(43) **U.S. Census Bureau (2015).** “Number of single-family homes sold and price between 2002 and 2014.” U.S. Census Bureau, Suitland, MD.
<https://www.census.gov/construction/chars/pdf/soldpricesqft.pdf> Accessed 10/20/2015

(44) **National Association of Home Builders (2015).** “Size of new single-family homes.” Eye on housing, National Association of Home Builders, Washington, D.C.
<http://eyeonhousing.org/2015/02/new-single-family-home-size-declined-in-2014/>
Accessed 10/26/2015

(45) **Pacific Northwest National Laboratory & Oak Ridge National Laboratory (2011).** “40% whole-house energy savings in the hot-humid climate.” Building America Best Practices Series, Volume 15. Building Technologies Program, U.S. Department of Energy, Washington, D.C.
<http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-20768.pdf>
Accessed 10/24/2015

(46) **Pacific Northwest National Laboratory & Oak Ridge National Laboratory (2011).** “40% whole-house energy savings in the cold and very cold climates.” Building America Best Practices Series, Volume 12. Building Technologies Program, U.S. Department of Energy, Washington, D.C.
<https://www.mpw.org/webres/File/energy-smarts/cold_climate_guide_40percent.pdf>
Accessed 10/24/2015

(47) **ANSI/ASHRAE/IESNA (2007).** “Building envelope climate criteria.” ANSI/ASHRAE/IESNA Standard 90.1-2007 Normative Appendix B, American National Standards Institute (ANSI), Washington, D.C.
<https://www.ashrae.org/file%20library/doclib/public/20081111_cztables.pdf>
Accessed 10/22/2015

(48) **Lstiburek, J. W. (2010).** “The Perfect Wall.” Building Science, ASHRAE Journal.
<http://buildingscience.com/file/5311/download?token=zmZBCkbM> Accessed 10/24/2015

(49) **U.S. Energy Information Administration (2015).** “Average monthly residential electricity consumption, prices, and bills by state.” Independent Statistics and Analysis, U.S. Energy Information Administration, Washington, D.C. *<http://www.eia.gov/tools/faqs/faq.cfm?id=97&t=3> Accessed 10/22/2015*

(50) **National Association of Home Builders (2015).** “Cost of constructing a single-family home in 2013.” Eye on Housing, National Association of Home Builders, Washington, D.C. *<http://eyeonhousing.org/2014/01/cost-of-constructing-a-single-family-home-in-2013/> Accessed 10/29/2015*

(51) **Water Sense (2015).** “Indoor water use in the United States.” Environmental Protection Agency, Washington, D.C. *<http://www3.epa.gov/watersense/pubs/indoor.html> Accessed 10/29/2015*

(52) **Circle of Blue (2015).** “Price of water 2015: up 6 percent in 30 major U.S. cities; 41 percent rise since 2010.” Circle of Blue, Traverse City, MI. *<http://www.circleofblue.org/waternews/2015/world/price-of-water-2015-up-6-percent-in-30-major-u-s-cities-41-percent-rise-since-2010/> Accessed 10/29/2015*

(53) **Index Mundi (2015).** “United States, average household size, 2009-2013 by State.” *<http://www.indexmundi.com/facts/united-states/quick-facts/all-states/average-household-size#map> Accessed 10/29/2015*

(54) **Mayank, S. (2015).** “A field study: verification of literature findings on cost and benefits of NGBS certified single family homes.” Independent Study Under Dr. Sinem Mollaoglu-Korkmaz, Construction Management Program, Michigan State University, Lansing, MI.

(55) **HIS & HERS Energy Efficiency (2015).** “Eight strategies to pass the 2012 IECC code.” HIS & Home Energy Rating System Energy Efficiency, Northampton, MA. *<http://hhefficiency.com/blog/2014/1/2/8-strategies-to-pass-the-2012-iecc-code> Accessed 12/21/2015*

(56) **Building America (2013).** “Building science-based climate maps.” U.S. Department of Energy, Washington, D.C. *<http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/4_3a_ba_innov_buildingscienceclimatemaps_011713.pdf> Accessed 10/13/2015*

(57) **U.S. Department of Energy (2015).** “Status of State Energy Code Adoption.” Building Energy Codes Program, U.S. Department of Energy, Washington, D.C. *<https://www.energycodes.gov/status-state-energy-code-adoption> Accessed 12/21/2015*

Appendix A: Sample Green Design Features

Sample of implemented green design features for a 1,908 Sq. Ft. single-family home in climate zone 5 related to "Energy Efficiency" and "Water Efficiency" Chapters of 2008 NGBS to achieve NGBS certification according to NAHB Research Center [24] (2012) are described in Tables 9 to 14.

Table 9. Sample of Implemented Green Design Features for a 1,908 Sq. Ft. Single-Family Home in Climate Zone 5 that Do Not Entail Additional Cost although Included in 2008 NGBS due to Compliance with the 2006 IECC Baseline

Green Design Features that Do Not Entail Additional Cost although Included in 2008 NGBS due to Compliance with the **2006 IECC Baseline**	Cost
Energy Efficiency	
The NFRC-certified U-factor and SHGC for windows, exterior doors, skylights, and tubular daylighting devices (TDDs) are U-factor=.30; and SHGC=.31.	-
Furnace and/or boiler efficiency AFUE = 92%	-
A minimum of 50% of the total hard-wired lighting fixtures, or the bulbs in those fixtures, qualify as ENERGY STAR or equivalent.	-
The number of recessed light fixtures that penetrate the thermal envelope are less than 1 per 400 square feet of total conditioned floor area and comply with the following: recessed light fixtures that penetrate the thermal envelope are airtight, IC rated, and sealed with gasket, caulk, or foam.	-
ENERGY STAR or equivalent appliance(s) are installed: refrigerator, dish washed and washing machine.	-
Return ducts or transfer grilles are installed in every room with a door. This practice does not apply to bathrooms, kitchens, closets, pantries, and laundry rooms – "Second floor supplied by returns to each room via attic."	-
Water Efficiency	
Indoor hot water usage is reduced by the following procedure: all hot water piping which runs to the plumbing fixtures in both the kitchen and bathrooms is 40-feet or less in length from the water heater and is sized in accordance with the code for the specified application.	-
Energy Star® or equivalent water-conserving appliances are installed for dishwasher and washing machine.	-
A minimum of one food waste disposer is installed at the primary kitchen sink.	-
(1) The total showerhead flow rate at any point in time, for all showerheads in each shower compartment is less than 2.5 gpm, tested at 80 psi per ASME A112.18.1/CSA B125.1.	-
All shower compartments installed meet the above conditions and are 2.0 to less than 2.5 gpm.	-
No irrigation is installed and a landscape plan is developed in accordance with the following from lot design chapter: a plan is formulated to restore or enhance natural vegetation hat is cleared during construction. Landscaping is phased to coincide with achievement of final grades to ensure denuded areas are quickly vegetated.	-

Table 10. Sample of Implemented Mandatory Green Design Features for a 1,908 Sq. Ft. Single-Family Home in Climate Zone 5

Mandatory Green Design Features to Achieve any NGBS Level	Cost
Energy Efficiency	
Ducts are sealed with tape complying with UL 181, mastic, gaskets, or an approved system as required by the ICC IRC (Section M1601.3.1, or ICC IMC Section 603.9) to reduce leakage – *"Specified to maximum leakage of 6% and sealing."*	-
Building cavities are not used as supply ducts – *"Ducted supplies brought up outside wall."*	-
Insulation shall be installed in accordance with the manufacturer's instructions or local code, as applicable.	-
The NFRC-certified U-factor and SHGC windows, exterior doors, skylights, and tubular daylighting devices (TDDs) are in accordance with ENERGY STAR, or equivalent, or Table 701.4.4.1 *(this table is utilized in this case, U-Factor=0.35 and SHGC can be any)*. Decorative fenestration elements with a maximum area of 15 square feet or 10 % of the total glazing area, whichever is less, are not required to comply with this practice.	-

Table 11. Sample of Implemented Mandatory Green Design Features for a 1,908 Sq. Ft. Single-Family Home in Climate Zone 5 to Achieve Bronze Level

Single-Family Home **Green Design Features** Which Aggregated Effect Results in **NGBS Bronze** Level	Cost
Energy Efficiency – 16 Years *Simple Payback Period from Energy Savings*	
Mandatory – A review by the Adopting Entity or designated third party shall be conducted to verify design and compliance with Chapter 7.	$520
Mandatory – Energy efficiency features are implemented to achieve energy cost performance that exceeds ICC IECC (2006) by 15%. A documented analysis using software in accordance with ICC IECC, Section 404, or ICC IECC Section 506.2 through 506.5, applied as defined in the ICC IECC, is required – *"Brought ducts inside unit and tightened to 12%. (8% leakage/sf)."*	$655
Ductwork is in accordance with all of the following: (1) Building cavities are not used as return ductwork; (2) Heating and cooling ducts and mechanical equipment are installed within the conditioned building space; and (3) Ductwork is not installed in exterior walls.	-
Water Efficiency – 0 Years Simple Payback Period from Water Savings	
All shower compartments installed are 1.6 to less than 2.0 gpm.	-

Table 12. Sample of Implemented Mandatory Green Design Features for a 1,908 Sq. Ft. Single-Family Home in Climate Zone 5 to Achieve Silver Level

Single-Family Home **Green Design Features** Which Aggregated Effect Results in **NGBS Silver**	Cost
Energy Efficiency – 11 Years *Simple Payback Period from Energy Savings*	
Mandatory – Energy efficiency features are implemented to achieve energy cost performance that exceeds ICC IECC (2006) by 30%. A documented analysis using software in accordance with ICC IECC,	$1,810

Single-Family Home **Green Design Features** Which Aggregated Effect Results in **NGBS Silver**	Cost
Section 404, or ICC IECC Section 506.2 through 506.5, applied as defined in the ICC IECC, is required – *"R-49 ceiling; 2x6 at 24"; 4.5ACH50; 6% duct leakage; 92% gas tankless water heater."*	
Third party onsite inspection is conducted to verify conformance with all of the following, as applicable. Minimum of 2 inspections are performed. One inspection after insulation is installed and prior to being covered, and another inspection upon completion of the project. Where multiple building or dwelling units of the same model are built by the same builder, a representative sample inspection of a minimum of 15% of the buildings or dwelling units is permitted.	-
Third party testing is conducted to verify performance – The maximum leakage rate is in accordance with 5 ACH50 / 0.25 nat.	-
The entire central HVAC duct system, including air handlers and register boots, is tested for leakage at a pressure differential of 0.1 inches w.g. (25 Pa). The maximum leakage as a percent of the system design flow rate is in accordance with 6% for ductwork entirely inside the building's thermal envelope.	-

Table 13. Sample of Implemented Mandatory Green Design Features for a 1,908 Sq. Ft. Single-Family Home in Climate Zone 5 to Achieve Gold Level

Single-Family Home **Green Design Features** Which Aggregated Effect Results in **NGBS Gold** Level	Cost
Energy Efficiency – 27 Years *Simple Payback Period from Energy Savings*	
Mandatory – Energy efficiency features are implemented to achieve energy cost performance that exceeds ICC IECC (2006) by 50%. A documented analysis using software in accordance with ICC IECC, Section 404, or ICC IECC Section 506.2 through 506.5, applied as defined in the ICC IECC, is required – *"(1) Closed loop solar; 2.6ACH50; R-5 sheathing; and (2) applied a Solar Hot Water Systems: SEF – Electric Tank (1.30-1.50); SEF – Gas Tank (0.85-1.00) for $7,500."*	$9,803
ACCA Manual S or equivalent is used to select heating and/or cooling equipment	-
HVAC contractor and service technician are certified by a nationally or regionally recognized program such as North American Technician Excellence, Inc. (NATE), Building Performance Institute (BPI), Radiant Panel Association, or manufacturers' tr.	-
Performance of the heating/cooling system is verified by the HVAC contractor in accordance with all of the following: (1) Start-up procedure is performed according to manufacturer's instructions; (2) Refrigerant charge is verified by super-heat and/or sub-cooling method; (3) Burner is set to fire at nameplate input; (4) Air handler setting/fan speed is set per manufacturer's instructions; (5) Total air flow is within 10% of design flow; and (6) Total external system static does not exceed equipment capability at rated airflow.	$222
Third party testing is conducted to verify performance – The maximum leakage rate is in accordance with 3 ACH50 / 0.15 nat.	-
Water Efficiency – 3 Years *Simple Payback Period from Water Savings*	
A water closet is installed with an effective flush volume of 1.28 gallons or less when tested in accordance with ASME A112.19.2 (all water closets) and ASME A112.19.14 (all dual flush water closets), and is in accordance with EPA WaterSense Tank-Type High-Efficiency Toilet.	$525

Single-Family Home **Green Design Features** Which Aggregated Effect Results in **NGBS Gold** Level	Cost
All water closets and all urinals are in accordance with previous point or the following: A urinal is installed with a flush volume of 0.5 gallons or less when tested in accordance with ASME A112.19.2.	-

Table 14. Sample of Implemented Mandatory Green Design Features for a 1,908 Sq. Ft. Single-Family Home in Climate Zone 5 to Achieve Emerald Level

Single-Family Home **Green Design Features** Which Aggregated Effect Results in **NGBS Emerald** Level	Cost
Energy Efficiency – 34 Years *Simple Payback Period from Energy Savings*	
Mandatory – Energy efficiency features are implemented to achieve energy cost performance that exceeds ICC IECC (2006) by 50%. A documented analysis using software in accordance with ICC IECC, Section 404, or ICC IECC Section 506.2 through 506.5, applied as defined in the ICC IECC, is required – *"Raised heel R-60; R-10 sheathing; .23/.35 windows; 2ACH50; 96% heat; therma-tru doors 0.18."*	$10,601
Third party testing is conducted to verify performance – The maximum leakage rate is in accordance with 2 ACH50 / 0.1 nat.	-
Balanced HVAC air flows are demonstrated by flow hood or other acceptable flow measurement tool. Test results in accordance with both of the following: (a) Measured flow at each supply and return register is within 25% of design flow; and (b) Total airflow is within 10% of design flow.	$296
Water Efficiency – 5 Years *Simple Payback Period from Water Savings*	
Rainwater is collected and used.	$382
Rainwater is distributed using a renewable energy source or gravity.	-

Appendix B: Interview Questionnaire

1. What is your experience with NGBS certified homes? How many have you built so far? In what regions of the US / climate zones do you have experience with?
2. What is the main barrier for clients to pursue green certification such as NGBS?
3. What is the main motivation for owners to pursue green certification?
4. How do you and the owners decide which certification level to pursue?
5. How do you explain to the client what are the main costs and benefits of green certification? Do you do a cost-benefit analysis for decision making to purse green certification? Does this process first identify climate zone is identified, assess local codes and select a baseline, second estimate additional construction costs from implementing green practices, and finally assess benefits?
6. In your experience, how much is the additional cost per Sq. Ft. to pursue NGBS certification in your climate zone? Do you know the additional cost in other climate zones? If so, how do they differ?
7. Which are the most important practices in your experience to achieve NGBS certification in single-family homes in your climate zone (e.g., features related to building envelope, air infiltration, heating/cooling system, duct sealing, water heating system, lighting, and appliances)?
8. Are there any differences in HVAC systems features and cost depending on climate zone (e.g., hot-humid vs cold)? What climate zone parameters affect more the design (e.g., temperature or humidity?
9. Do the additional costs to achieve bronze and silver level certification under NGBS tend to be fairly affordable? Are they similar? Are additional costs to achieve NGBS gold or emerald drastically much higher than bronze and silver? Have you had clients that can afford bronze and silver but not gold or emerald levels of NGBS certification?
10. Overall, what are the payback periods for each NGBS green level in single-family homes in your climate zone? What are acceptable payback periods for the owners? What benefits do these payback periods take into account?
11. Are owners open to incorporating specific green features into design that offer low payback periods (e.g., 5 years) although not achieving green certification?
12. In the last 10 years, the average home size has passed from 1500 to 2600 Sq. Ft. which significantly increases additional costs for green certification. Would owners accept to buy smaller houses to make green certification affordable for them?
13. How are the local codes and policies motivating adoption of green certification? Do they help to reduce payback periods? Are local codes' requirements (e.g., IECC's minimum energy performance) getting closer to NGBS standards?