GREEN RESIDENTIAL HOME STUDY:
A SHORE COMMUNITY IN NEW JERSEY

Source: Fluid Construction, LLC

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A SHORE COMMUNITY IN NEW JERSEY

FEBRUARY 2011

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Prepared for:
U.S. Green Building Council – NJ Chapter

Sponsored by:
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EXECUTIVE SUMMARY

Overview and Scope

This case study was prepared by the Rutgers Center for Green Building (RCGB) and commissioned by the New Jersey Chapter of the U.S. Green Building Council (USGBC-NJ). It is a product of the Green Building Benefits Consortium (GBBC): a partnership between the Rutgers Center for Green Building and the New Jersey Chapter of the U.S. Green Building Council. The consortium is made up of a broad range of stakeholders in the building industry, including building owners, developers, facility managers, contractors, manufacturers, architects, engineers, green building experts, consultants, investment funds, government agencies and professional associations. The partnership creates the opportunity for industry stakeholders to guide research on topics of green post occupancy evaluation (POE), such as increased energy savings and enhanced occupant satisfaction and performance, which have the potential to maximize benefits to companies and industries.

This case study focuses on a high-performance single family home built to the Silver standard set by the U.S. Green Building Council’s Leadership in Energy and Environmental Design for Homes (LEED-H) by Fluid Construction in a shore community in New Jersey. Two other high-performance homes, a “Code Plus” home, and an ENERGY STAR-rated home—both also built by Fluid Construction in the same community—are analyzed for comparative purposes throughout the study. This two-year study brings together analyses on physical performance measures in such areas as energy and water consumption, indoor air quality, and construction and operation costs, and survey work in the areas of occupant comfort and satisfaction. This work includes the following:

- Analysis of utility data (electricity, natural gas, and water bills) collected from homeowners.
- Analysis of indoor air quality samples (volatile organic compounds) collected pre- and post-occupancy.
- Interviews with homeowners to gather information on household water use, energy use, and indoor environment quality, and the factors affecting these.
- Assessment of economic impacts through a Life Cycle Costing (LCC) analysis.

The combination of the above research provides the basis for this report that highlights the home built to the LEED-H Silver standard’s performance, homeowner satisfaction and cost, while comparing the findings of that research to two other homes built to varying levels of energy-efficiency and green building standards.

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1 RGBBC owner members include BASF; Back to Nature, LLC; Department of Treasury, State of New Jersey; Division of Property Management and Construction, State of New Jersey; Gensler; Liberty Property Trust; MaGrann Associates; New Jersey Chapter of the National Association of Industrial and Office Properties (NAIOP); New Jersey Future; New Jersey Home Mortgage Finance Agency (NJHMFA); PNC Real Estate Finance; Skanska; Sustainable Growth Technologies/Willow School; Turner Construction-NJ; Wachovia Bank, N.A.

2 Home built according to 2006 N.J. State Building Code
Key Findings

Energy Usage
The results of the energy analysis suggest that occupant behavior is the determining factor in a home’s relative performance. While energy-efficient technologies do play a significant role in explaining energy consumption patterns, how that technology is used is most important.

- **The home built to LEED-H standards outperforms a typical code home.** Based on data collected between November 2008 and October 2010, the home built to LEED-H Silver standards is using about 21% less electricity per square foot than a typical code home and about 51% less natural gas per square foot on an annual basis.

- **The actual performance of the home built to LEED-H Silver standards differs little from its design/predicted performance.** The LEED-H home uses just 6% more electricity per square foot and about 4% less natural gas per square foot than predicted by the design model on an annual basis.  

- **The Home Built to LEED-H Silver standards was outperformed by the ENERGY STAR home.** The home built to LEED-H silver standards used about 18% more electricity and 11% more natural gas than the ENERGY STAR home. Our research suggests that this is largely driven by occupant habits.

- **Homeowner interviews are critical to understanding energy use.**

- **Homes are performing as expected in terms of electricity usage.** The total monthly electricity usage for the ENERGY STAR home (2.41 kWh/ft²) is about 25% less than that of the LEED-H home (3.27 kWh/ft²), and about half that of the Code Plus home (4.89 kWh/ft²) between November 2009 and October 2010.

- **Performance of homes in terms of natural gas consumption is less clear.** Although the LEED-H was, by design, expected to use 20 percent less natural gas than the Code Plus home, for the 12-month period between November 2009 and October 2010, they performed at roughly the same level: 0.21 therms/sq ft for the Code Plus and 0.20 therms/ft² for the LEED-H home—a difference of only 7%. Data for the ENERGY STAR home is not available.

- **The Home Built to LEED-H Silver standards performs on par with similarly sized homes in terms of water consumption.**

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3Throughout this report, a code home refers to a home built to the New Jersey residential building code based on the International Energy Conservation Code 2006 standards.

4 These results are after normalization for weather and modification of energy consumption for months that were more than 2 standard deviations from the average monthly energy use. The raw utility bill data show much different results, where the home built to LEED-H Silver standards uses 34% more electricity and 26% more natural gas consumption than predicted by the model.
• In terms of economic investment, the energy-efficient improvements to the Home Built to LEED-H Silver standards have a payback period of about 30 years. This is on par with the payback period of a home built to code. The relatively low cost of energy is the major reason why the Home Built to LEED-H Silver standards is not expected to perform better as an investment in the long-term.

• The energy-efficient improvements to the ENERGY STAR home have a payback period of less than 15 years.

• The level of volatile organic compounds in the Home Built to LEED-H Silver standards is well within the normal range for homes studied in the literature.

• Occupants of the Home Built to LEED-H Silver standards are very satisfied with their home and would strongly recommend purchasing one of a similar kind to a friend.

INTRODUCTION

According to the U.S. Green Building Council (USGBC), residential buildings account for 20% of total energy consumed in the U.S. and 74% of potable water. They contribute to climate change by releasing carbon dioxide into the atmosphere, through the use of home heating fuels and electricity generated from non-renewable and carbon-based fuels. A typical home is responsible for emissions of almost 9,000 pounds of carbon dioxide per person every year; altogether, residences make up about 20% of the nation’s carbon dioxide emissions. Moreover, according to the Environmental Protection Agency, Americans spend 90% of their time indoors where concentration of pollutants are often much higher than outside.

Green building is a collection of design, construction, and operation practices that significantly reduce or eliminate the negative impact of development on the environment and occupants by addressing such issues as energy efficiency, water conservation, indoor air quality, waste reduction, and occupant satisfaction and health. The two most popular green building programs helping to drive this transformation in the building construction industry are the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED®) rating system and the U.S. Environmental Protection Agency’s ENERGY STAR® Label for homes and commercial/industrial buildings. The National Association of Home Builders (NAHB), which launched its national green home building certification program in 2008, is another driving force behind green building in the residential sector. Most recently, in January 2009, the ICC-700-2008 National Green Building Standard was approved by the American National Standards Institute (ANSI). It establishes practices for the design and construction of green residential buildings, building sites, subdivisions and renovations thereof. This

study will focus primarily on a home built to LEED-H Silver standards and draw comparisons to an ENERGY STAR home and a home built to code (Code Plus) when illustrative.

The USGBC’s LEED green building certification system is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. Points are awarded for sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and design innovation. LEED certification provides independent third-party verification that a building satisfies the USGBC’s requirements for green building. Higher point scores can result in Silver, Gold, and Platinum ratings. Different LEED rating systems have been developed for various project types, including LEED for Homes, which certifies single-family homes.

The U.S. Environmental Protection Agency’s ENERGY STAR Qualified New Homes Program establishes energy performance standards and utilizes the Home Energy Rating System (HERS) index to score energy performance. As its name implies, this program focuses solely on energy efficiency, as opposed to LEED’s holistic approach which includes energy efficiency as one of several green building categories. In fact, ENERGY STAR label certification is a prerequisite of LEED certification. According to the EPA, ENERGY STAR homes are at least 15% more energy efficient than homes built to the 2006 International Residential Code (IRC), and may include additional energy-saving features that make them, on average, 20–30% more efficient than conventional homes.

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BACKGROUND

Project Description

The primary focus of this Green Residential Home Study is to examine the performance of a home built to the silver standard of the U.S. Green Building Council’s Leadership in Energy and Environmental Design (LEED™) Home rating system in a Monmouth County, New Jersey shore community. For evaluative purposes, this home is compared to two other high-performance homes in the same area: an ENERGY STAR® Certified Home and a Code Plus Home. This two-year study measures the performance of the occupied homes on a variety of different parameters.

Building Performance Evaluation (BPE) data was collected from monitoring systems, utility bills, design and construction documents, and interviews with building team members on a series of Building Performance Evaluation (BPE) metrics that fall into such categories as Energy, Water, Cost, and Environment.

Post Occupancy Evaluation (POE) data on occupant behavior was gathered through homeowner interviews to understand how occupant energy and water use impacts building performance.

This project is a product of the Green Building Benefits Consortium (GBBC): a partnership between the Rutgers Center for Green Building and the U.S. Green Building Council NJ Chapter.

Additional project partners are listed below.
PROJECT OVERVIEW

Energy Analysis Prior to Occupancy: For purposes of ENERGY STAR Certification, MaGrann Associates completed an energy analysis on the ENERGY STAR and LEED-H homes using REM/Rate Home Energy Analysis Software. On-site energy testing was performed by MaGrann Associates on both the ENERGY STAR and LEED-H homes prior to occupancy.

Building Occupant Satisfaction and Performance: The study team conducted kick-off and follow-up in-person and phone interviews.

Energy Analysis Post-Occupancy: The study analyzed energy use in the three homes during the occupancy phase using utility bills provided by the homeowners and information generated from In2's Energy ICM monitoring equipment. In addition to recording run time, the In2 system also stores indoor and outdoor temperatures.

Water Analysis Post-Occupancy: The study analyzed water use in the three homes during the occupancy phase using utility bills provided by the homeowners.

Indoor Air Quality Testing: Indoor Air Quality (IAQ) for volatile organic compounds (VOCs) was tested both pre- and post-occupancy in two of the study homes.

Life Cycle Cost Analysis (LCC): The study looked at the net hard costs for each of the three homes. The study team also conducted a Life Cycle Cost (LCC) and Net Present Value (NPV) analysis on the LEED-H and ENERGY STAR homes. This analysis determined the lifetime cost of operating the homes as well as the opportunity costs associated with the decisions made in designing and constructing the homes.

8REM/Rate™ - Home Energy Analysis Software http://www.archenergy.com/products/rem/rem_rate/
BUILDING FEATURES

The following figure shows the building features of the home built to LEED-H Silver standards as compared to the ENERGY STAR and Code Plus homes.

Figure 1: Building Features

<table>
<thead>
<tr>
<th>House Data:</th>
<th>Home Built to LEED-H Standards</th>
<th>ENERGY STAR Home</th>
<th>Code Plus Home</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Builder:</strong></td>
<td>Fluid Construction, LLC</td>
<td>Fluid Construction, LLC</td>
<td>Fluid Construction, LLC</td>
</tr>
<tr>
<td><strong>Energy Modeling:</strong></td>
<td>MaGrann Associates</td>
<td>MaGrann Associates</td>
<td>MaGrann Associates</td>
</tr>
<tr>
<td><strong>Building Type:</strong></td>
<td>Single-Family</td>
<td>Single-Family</td>
<td>Single-Family</td>
</tr>
<tr>
<td><strong>Lot Size:</strong></td>
<td>Non-conforming, Approx. 9700 SF</td>
<td>75’ x 100’</td>
<td>75’ x 100’</td>
</tr>
<tr>
<td><strong>Date of Occupancy:</strong></td>
<td>Mid-November 2008</td>
<td>End of July 2009</td>
<td>September 2006</td>
</tr>
<tr>
<td><strong>Gross Interior Floor Area:</strong></td>
<td>2980 SF (3048 SF with finished/conditioned basement)</td>
<td>2450 SF (3647 SF with finished/conditioned basement)</td>
<td>2850 SF (4300 SF with finished/conditioned basement)</td>
</tr>
<tr>
<td><strong>Building Orientation (front entrance):</strong></td>
<td>ESE</td>
<td>WNW</td>
<td>WNW</td>
</tr>
<tr>
<td><strong>Ratings and Awards:</strong></td>
<td>Built to LEED-H Silver, Code, and ENERGY STAR Standards</td>
<td>Built to Code and ENERGY STAR Standards; HERS Score of 69</td>
<td>Built to Code Plus; HERS Score of 75</td>
</tr>
</tbody>
</table>

Building Envelope:

<table>
<thead>
<tr>
<th>Roof assemblies (reflectivity):</th>
<th>Asphalt Roof Shingles</th>
<th>Asphalt Roof Shingles</th>
<th>Asphalt Roof Shingles</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Insulation:</strong></td>
<td>Closed-cell spray-applied polyurethane foam insulation system; 2” Closed Cell Spray Foam (R-12) Foundation Walls</td>
<td>R-13 Above Grade 2x4 Walls</td>
<td>R-13 Above Grade 2x4 Walls</td>
</tr>
<tr>
<td></td>
<td>3” Closed Cell Spray Foam (R-18) + 1” Foam Board exterior (R-5) Above Grade 2x4 @ 24 Walls</td>
<td>R-19 Above Grade 2x6 Walls</td>
<td>R-38 Ceilings</td>
</tr>
<tr>
<td></td>
<td>4” Closed Cell Spray Foam (R-24) Floors over ambient, garage</td>
<td>R-6.5 ducts</td>
<td>R-60 Fiberglass batt insulation &amp; closed-cell cellulose spray foam in attic</td>
</tr>
<tr>
<td></td>
<td>4” Closed Cell Spray Foam (R-24) + 18” Cellulose on top (R-60) Attic</td>
<td>R-60 Fiberglass batt insulation</td>
<td>Fiberglass batt insulation</td>
</tr>
<tr>
<td></td>
<td>R-8 Ducts in attic/garage</td>
<td>R-13 Basement Rim and Joists</td>
<td>R-13 Basement Rim and Joists</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-12.5 (Insulated Concrete Walls) Basement Walls</td>
<td>R-13 Walls</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-30 Ceilings</td>
<td>R-30 Ceilings</td>
</tr>
<tr>
<td></td>
<td></td>
<td>R-6 ducts</td>
<td>R-6 ducts</td>
</tr>
<tr>
<td></td>
<td><strong>Home Built to LEED-H Standards</strong></td>
<td><strong>ENERGY STAR Home</strong></td>
<td><strong>Code Plus Home</strong></td>
</tr>
<tr>
<td>--------------------------------</td>
<td>-----------------------------------</td>
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<td>-------------------</td>
</tr>
<tr>
<td><strong>Windows:</strong></td>
<td>Low-e, argon filled; U-value = 0.32, SHGC = 0.33</td>
<td>Low-e, argon filled; U-value = 0.32, SHGC = 0.33</td>
<td>Double-Pane, Low-e</td>
</tr>
<tr>
<td><strong>Framing:</strong></td>
<td>Advanced framing; wood, 2x6, 24” O.C.</td>
<td>Wood, 2x4 and 2x6, 16” O.C.</td>
<td>Wood, 2x4, 16” O.C.</td>
</tr>
<tr>
<td><strong>Siding:</strong></td>
<td>Fiber-cement</td>
<td>Vinyl</td>
<td>Vinyl</td>
</tr>
<tr>
<td><strong>Mechanical Systems &amp; Equipment:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Heating System:</strong></td>
<td>Five-zone, fuel-fired hydronic distribution boiler for radiant heat, 74.0 kBtuh, 95.0 AFUE</td>
<td>Two-zone, fuel-fired forced air distribution furnace, 48.9 kBtuh, 95.0 AFUE</td>
<td>(2) Sealed combustion gas fired furnaces, 90 AFUE</td>
</tr>
<tr>
<td><strong>Cooling System:</strong></td>
<td>(2) air-conditioning units, 36.0 kBtuh/unit, 18 SEER; Fresh Air Intake System with HRV</td>
<td>(2) air-conditioning units, 18.0 kBtuh/unit, 14 SEER</td>
<td>(2) air-conditioning units, 24.0 kBtuh/unit, 13 SEER</td>
</tr>
<tr>
<td><strong>Water Heating:</strong></td>
<td>Dual heat exchanger indirect gas fired hot water tank hooked into to accept solar thermal, EF=.85</td>
<td>Tankless gas water heater, EF=.81</td>
<td>Tankless gas water heater, EF=.80</td>
</tr>
<tr>
<td><strong>Heating/Cooling (temperature set points):</strong></td>
<td>Programmable Thermostat and real-time energy feedback system; 78 F (summer)/68 F (winter)</td>
<td>Programmable thermostat; 75 F-78F (summer)</td>
<td>Programmable thermostat; 65 F (summer)/ 65 F (winter)</td>
</tr>
<tr>
<td><strong>Plumbing:</strong></td>
<td>Low-flow faucets and showerheads</td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Toilet:</strong></td>
<td>Dual-flush</td>
<td>Dual-flush</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Lighting &amp; Appliances:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Washer &amp; Dryer</strong></td>
<td>ENERGY STAR (front loading)</td>
<td>ENERGY STAR (front loading)</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Refrigerator</strong></td>
<td>ENERGY STAR</td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Dishwasher</strong></td>
<td>ENERGY STAR</td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Lighting fixtures</strong></td>
<td>ENERGY STAR 75% fixtures</td>
<td>ENERGY STAR 25% fixtures</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Ceiling fans:</strong></td>
<td>Used often</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Other:</strong></td>
<td>Outdoor gas grill</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Office Equipment &amp; Electronics:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Computer(s):</strong></td>
<td>One desktop; one laser-jet printer, copier, fax machine</td>
<td>One desktop and one laptop; one laser-jet printer</td>
<td>Three desktops; home recording studio equipment.</td>
</tr>
<tr>
<td><strong>Materials &amp; Finishes:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flooring:</strong></td>
<td>Bamboo</td>
<td>90% wood flooring; two bedrooms have carpeting</td>
<td>50% wood/ 50% carpeting</td>
</tr>
<tr>
<td><strong>Paint:</strong></td>
<td>Low VOC</td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Cleaning Products:</strong></td>
<td>Green cleaners</td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td><strong>Landscaping:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Plantings:</strong></td>
<td>Selected hardy grass seed mix (low-water/low-mow, newly planted pear trees) Planted several deciduous trees on southern lawn.</td>
<td>Cut down two 100 foot rotten oak trees that provided shade to the house.</td>
<td></td>
</tr>
<tr>
<td><strong>Driveway and hardscape materials:</strong></td>
<td>Asphalt and pavers</td>
<td>Asphalt and pavers</td>
<td>Asphalt and pavers</td>
</tr>
</tbody>
</table>
**POST OCCUPANCY EVALUATION**

Home building professionals, architects, and homeowners increasingly have embraced the concept of green building as a means to capture the financial and health benefits of sustainability, resource efficiency, and an improved environment. In New Jersey, there are currently nine single-family detached homes certified green with 47 structures on target to be certified through the United States Green Building Council’s Leadership in Energy and Environmental Design (LEED) rating system. There are 47,700 ENERGY STAR Qualified homes built to date in New Jersey, with 3,299 built in 2009 and 3,340 in 2010. While LEED, ENERGY STAR, and other less well-known programs have brought green design and construction practices into the mainstream, systematic assessments of how these buildings perform in practice and affect the occupants is not a routine practice.

Post Occupancy Evaluation (POE) is a method of providing feedback on whether a building is performing as intended, and if so, whether it is performing optimally. To date, most POE studies of green buildings have focused on more easily quantifiable criteria such as energy use, resource efficiency and physical measurements of environmental conditions, but lacked an assessment on how buildings affect the occupants. However, building occupants represent a wealth of information about how well a building works. The challenge is to quickly and inexpensively collect and analyze this input in a robust, systematic and useful manner. The following outlines the phases used by the Rutgers Center for Green Building for this study for conducting a POE on residential homes.

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Figure 2: Phases of Post Occupancy Evaluation on Residential Homes

<table>
<thead>
<tr>
<th>Phase 1 – Homeowner interview</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 2 – Utility data (bills)</td>
</tr>
<tr>
<td>Phase 3 – Real-time energy and water use monitoring</td>
</tr>
<tr>
<td>Phase 4 – Indoor environmental quality testing</td>
</tr>
<tr>
<td>Phase 5 - Follow-up communication</td>
</tr>
</tbody>
</table>

Phase 1 – Homeowner interview

The purpose of the homeowner interview is to gather information on household water use, energy use, and indoor environment quality, and the factors affecting these. At the homeowner interview, a member of the research team provides an overview of the study, describes the roles and responsibilities of the different parties involved in the study, and answers any questions.

Phase 2 – Utility data (bills)

After completing the initial interview, homeowners are asked to share copies of their utility bills (electric, gas, and water) with the project team. Homeowner energy and water use information gained from the homeowner interview provide insight on how the behaviors of the household impact the energy and water utility data.

Phase 3 – Real-time energy and water use monitoring

Real-time energy monitoring equipment can be installed to track hourly temperature and building system runtimes. Combined with utility bills, this information provides a more complete picture of the household’s daily, weekly, and monthly energy usage.

Phase 4 – Indoor environmental quality testing

Volatile organic compounds (VOCs) that can cause eye, nose, and throat irritation, headache, nausea, dizziness, and skin problems are gases given off by a number of indoor sources. Formaldehyde is one of the most common VOCs. It is found in many building materials such as plywood, particleboard, and glues. Formaldehyde can also be found in some drapes and textiles in addition to certain types of foam insulation. Other sources of VOCs include paints, cleaning supplies, pesticides, building materials and furnishings, and home office equipment such as copiers and printers. Two sets of 24-hour VOC tests for indoor and outdoor VOC levels were conducted: one prior to occupancy and one post-occupancy.

Phase 5 - Follow-up communication

During the course of the study, the project team communicates with the homeowners through periodic email or phone conversation and in-person interviews.
Building Occupant Satisfaction

**Purpose**

Occupancy data is an integral component of developing an explanation of building performance. For example, the results of the energy analysis suggest that differences in occupant behavior may help to best explain differences between design and actual energy usage, as well as differences in the consumption patterns among the three homes. The interviews helped to confirm and clarify findings in the areas of energy and water use, indoor air quality, and occupant satisfaction.

**Methodology**

Our methodology for discerning these differences in occupancy behavior includes interviews and follow-up communication with study participants. At the initial interview, the research team provided an overview of the study, described the roles and responsibilities of the different parties involved in the study, and answered any questions. The survey questions located in Appendix B provide a sample of typical questions asked during a face-to-face interviews with study participants.

The homeowners of each the Home Built to LEED-H Silver standards, the ENERGY STAR home and the Code Plus home were interviewed for the first round of interviews. Second round of interviews were conducted with the homeowners of the Home Built to LEED-H Silver Standards and the ENERGY STAR home. The Code Plus homeowner was not available for a second interview.

**Results**

**Home Built to LEED-H Silver Standards**

There were two interviews conducted with the homeowners of the Home Built to LEED-H Silver standards, the first in May 2009 and the second in December 2010.

**Occupants**

The homeowners of the Home Built to LEED-H Silver standards moved in mid- to late-November of 2008. At the time, the family consisted of three people: a husband and wife, both college graduates in their mid-30s, and an infant boy. In March of 2010, the couple had another child, a baby girl. The homeowners went through a three-year building process in which investing in a “green” home was somewhat of an evolution. The owner of Fluid Construction convinced the couple to throw out already completed plans for a traditional home and start afresh with a green architect. For the couple, building green simply made sense. They said that energy efficiency and indoor air quality were the most important factors that influenced their decision to build a high performance home. Although the home was built to LEED-H Silver standards, the homeowners were not set on following through with the certification process. After two years of living in the home, the couple referred to themselves as “somewhat committed” to a “green” lifestyle, but believed that their peers would label them as “very committed.”
**Occupancy Schedule**

- The husband works Monday through Friday between 8am and 6 pm outside of the home but is mostly home on weekends.
- The wife stays at home with the children and has hired help come two hours each day during the week.
- The family travels occasionally on weekends, though took no major vacations during the two years of this study.

**Occupants' Behavior**

- During the summer months, the couple prefers to keep their thermostat at 78°F in the daytime (though sometimes 76°F) and at 82°F during the night. (Recall from above that we used a 74°F set-point for our cooling degree day analysis).
- During the winter months, the couple keeps their thermostat at 68°F during the day and 62°F during the night. (We used a 65°F set-point for our heating degree day analysis).
- The husband showers daily for between 5-10 minutes. The wife showers every other day for about 10-20 minutes. At the first interview, the couple was giving their son a bath regularly, but he has since progressed to taking a shower once every three days. Their youngest daughter receives a bath nightly.
- The family eats at home for every meal and the wife bakes 2-3 times per week. The couple uses a natural gas grill 1-2 times per week during the winter and 3 times per week during the summer.
- The couple runs the dishwasher once a day.
- The couple runs their washing machine—which is powered by natural gas—“constantly,” or about 2-3 times per day. This is in part because they do not use any paper products in the house—napkins, towels, and washcloths are in constant need of laundering. Also, at the time of the first interview, the couple was using cloth diapers for their son, but has since switched to disposables because their washing machine was not getting the job done. The couple uses only cold water for most of their washing, using hot water about once per week when cleaning whites. While the couple’s use of the washing machine may be higher than average, they would use comparatively less natural gas because they do not use hot water for every load.
- At the time of the first interview, the couple would air dry their laundry during the summer months about 50 percent of the time, though at during the second interview they had switched to using the dryer all of the time.
At the time of the first interview, the couple hand-watered their lawn, but during the summer of 2010, the couple watered the lawn and garden “once or twice” then “let them die.”

**Habits Affecting Indoor Air Quality**

As mentioned above, indoor air quality is one of the most important green features for the homeowners.

- The wife of the household is a committed user of “green” and natural cleaners, often deriving her own solutions. She uses such products as Charlie Soap (no lye, phosphate, bleach, dyes, brighteners, filters or cheap perfumes),\(^\text{11}\) vinegar as a regular household cleaner, club soda for windows, and baking soda and dish soap for toilets, though upon occasion uses small amounts of bleach when necessary.
- The homeowners keep several plants throughout the house and keep the windows open as often as possible when the weather permits.
- The family does not burn any candles.
- No one in the family has any allergies.
- The family does not use any pesticides.

**Occupant Satisfaction**

Overall, the homeowners are very pleased with their home and, after living in the space for two years said that they would “definitely” recommend that “a close friend” purchase a house similar to their own. One of the benefits that the couple mentioned was the comfort of the home. The home is not drafty at all and they don’t have to deal with adjusting the thermostat all the time. One of the issues the wife felt about living in a high-performance home was the “responsibility to remain green in all aspects of life” and the guilt associated with not necessarily doing so by their own estimation.

The couple was largely satisfied with the indoor air quality of the home, though did mention that in the summer cigarette smoke from the neighbor comes inside the house through the fresh-air intake.

The daylighting of the home was rated very highly by the couple, though in the winter, they mentioned that sometimes, the low sun was difficult to deal with.

The couple had no complaints about the low-flow water fixtures.

As for the energy savings, this is the couple’s first single-family home and therefore they have nothing against which to compare their current home’s performance. However, the husband did

\(^\text{11}\)www.charliesoap.com
mention that the natural gas bill has been less than he expected, though the electricity bill has been more than expected.

The occupants sometimes had problems adjusting the thermostat when needed, though appreciated the fact that they could do so remotely via the Internet.

ENERGY STAR Home

There were two interviews conducted with the ENERGY STAR homeowners, the first in July 2009 with both the husband and wife, and the second in December 2010 with just the husband.

Occupants

The homeowners of the ENERGY STAR home moved into the residence at the end of June 2009. A husband, wife, and small child occupy the home as well as a dog. One of the family’s goals is to have a low carbon footprint and leave their child a healthy planet. They try to conserve what they use and make eco-friendly purchases and seriously consider the necessity of goods before purchasing them. Although the green features played a small role in the homeowners’ decision to purchase the home, the primary reasons were the location and the fact that it was a newly built home. In fact, the husband noted that the home was not advertised as “green” and he didn’t find out about its green features until the walk-through with the realtor. At the time of the first interview, the homeowner was unaware that the home was ENERGY STAR certified. After living in the home for a year and a half, the husband referred to himself as “committed” to a “green” lifestyle, but believed that his family would label him as “very committed.”

Occupancy Schedule

- At the time of the first interview, the husband worked Monday through Friday outside of the home between 6am and 6 pm, commuting via ferry to Manhattan. However, as of July 2010, he began traveling abroad for work about 5 days each week. When home on weekends, he tries to be at home, but if he is in the country during the week he is usually at work.

- The wife stays at home their child and works part-time from the house.

- The homeowners are frequent hosts to family and friends. They had a family member and fiancé staying with them permanently between May and October 2010. Other family members were often visiting to see the baby.

Occupants’ Behavior

- During the summer months, the couple keeps their downstairs thermostat at 75°F all of the time and the upstairs at about 70°F. (Recall from above that we used a 74°F set-point for our cooling degree day analysis).

- The couple will use their ceiling fans in lieu of air conditioning during the summer so long as it is not muggy outside and they will open their windows whenever possible.
• During the winter months, the couple keeps their thermostat at 68°F during the day and 65°F during the night. (We used a 65°F set-point for our heating degree day analysis).

• When home, the husband showers daily for about 15 minutes. The wife also showers daily. However, the water use may be higher than expected because the water heater takes about 10-15 minutes before it produces hot water. The couple’s child receives a bath every day in the summer and every other day in the winter.

• The family eats most of their meals at home; though eat out once a week at most.

• During the first interview, the couple ran their dishwasher daily and during the second interview, they ran it about 4 times per week.

• The couple runs their natural gas powered washing machine every 3 or 4 days, using only cold water. (By comparison, ENERGY STAR the projected energy use and operation costs on ENERGY STAR product labels assume washing machine use of 8 times per week).

 Habits Affecting Indoor Air Quality

• The household is equipped with a standard array of household cleaners including Clorox disinfecting wipes, Sol toilet bowl cleaner, Lysol disinfectant and soap-scum cleaner, Murphy’s oil for the hardwood, Fantastik and Arm and Hammer pet deodorizer.

• The homeowners keep one plant in the house.

• The homeowners had the basement finished and put in a ventilation system to remove much of the moisture from the air and circulate it throughout the house.

 Occupant Satisfaction

During the second interview, the husband expressed his overall satisfaction with the home. He likes the house because it is new and feels it is a good environment in which to raise a child. He was very pleased with the ability of the home to retain heat during the winter and felt that the heating and cooling systems responded well and the thermostat was easy enough to use. However, he did express that he thought the energy savings would be a little higher. Although, like the homeowners of the Home Built to LEED-H Silver Standards, the ENERGY STAR homeowners do not have a prior experience in a single family home against which to compare their current experience.

The husband was very satisfied with the daylighting in the home, the low flow water fixtures and the durability of the materials used throughout the house. As mentioned above, he felt that the water heater was not as responsive as expected, but conceded that the performance was "typical" of many homes. He also expressed concern with the heating and cooling system’s ability to adequately regulate his daughter’s bedrooms which is at the end of the duct system.
In the future, he hopes to put more insulation in the attic and would like to install solar panels but recognizes neither his roof nor the conditions in the area are optimal. He also would like to install storm windows for added insulation during the winter months.

**Code Plus Home**

There was one interview conducted with the Code Plus homeowners in July 2009.

**Occupants**

The homeowners of the Code Plus home, a husband and wife, moved into the residence in September of 2006. The homeowners are pleased with the home and decided to purchase it because of its location and the quality of the construction.

**Occupancy Schedule**

- At the time of the interview, both husband and wife worked at home five days a week, though the husband’s profession requires frequent travel, ranging from a few days to a week or more at a time.
- The couple takes frequent vacations during the winter months.

**Occupants’ Behavior**

- During the summer months, the couple keeps their thermostat at 68°F. (Recall from above that we used a 74°F set-point for our cooling degree day analysis).
- During the winter months, the couple keeps their thermostat at 65°F. (We used a 65°F set-point for our heating degree day analysis).
- The couple has a full recording studio in the basement.
- The couple rarely cooks at home, eating most meals out of the house.
- The couple uses “green” cleaners and remove their shoes at the door and have added house plants throughout the home.

**Conclusions**

The interviews were critical to clarify and confirm our findings concerning energy and water usage, indoor air quality, and occupant satisfaction. For example, occupants of the three homes differ in their temperature preferences, occupancy patterns, and family sizes, all of which have direct impacts on the performance of the homes. The homeowners’ respective preferences for the indoor temperature of the home vary greatly and would have a significant impact on energy consumption. Understanding who uses the home, when, and how are important determinants of energy use that are incompletely captured in the models.
Another key finding is that we learned that the homeowners each have different attitudes towards the importance of energy efficiency. The homeowners also had different circumstances that led them to be living in a high-performance or green home. For all of the homeowners, location and quality construction were important decision points for purchasing their home, while for some energy efficiency and indoor air quality also contributed to their decision.

The results of these interviews are important to keep in mind when reviewing the results of the building performance analysis that follows.

Building Energy Consumption Performance

Purpose

This assessment of the home built to LEED-H standards analyzes its metered energy usage between November 2008 and October 2010. Further, the home is compared, when possible, to the metered energy usage of two other high-performance over the same period. In addition, the pre-occupancy energy modeling results of the home built to LEED-H standards are compared to the post-occupancy energy data analysis. Again, comparisons are drawn between the other two homes when possible.

Introduction

Households use about one-fifth of the total energy consumed in the United States each year, and the residential sector is responsible for 21% of the nation's carbon dioxide emissions. Homes built to LEED-H and ENERGY STAR standards are designed to outperform their conventional counterparts in terms of energy efficiency. Based on average Home Energy Rating System (HERS) scores, the average home certified under LEED for Homes uses an estimated 30-60% less energy than a comparable home built to the International Energy Conservation Code (IECC); a home specifically built to the LEED-H Silver standards uses approximately 30% less energy. In order to achieve an ENERGY STAR certification, a new home built in the 2006-2010 timeframe must be at least 15% more energy efficient than the 2004 International Residential Code (IRC) by meeting minimum requirements in five areas: effective insulation, high performance windows, tight construction and ducts, efficient heating and cooling equipment, and efficient products. ENERGY STAR certification is also a prerequisite of LEED for Homes.

Based on average energy savings for building to LEED and ENERGY STAR standards and results of modeled energy analysis performed on the study homes, one would expect the LEED-H home and ENERGY STAR home to perform better than the Code Plus home, and for the LEED-H home to

14 ENERGY STAR, Features of ENERGY STAR Qualified New Homes, www.energystar.gov/index.cfm?c=new_homes.nh_features
perform better still than the ENERGY STAR home in terms of energy use (electricity and natural gas) on a per square foot basis.

Methodology

Operating data was collected and analyzed for the home built to LEED-H Silver standards between November 2008 and October 2010. Data was collected for the ENERGY STAR home, which has only been occupied for a year and a half, as well as the Code Plus home. Total monthly electricity usage (kWh/ft²) and total monthly natural gas usage (therms/ft²) were compared for the LEED-H, ENERGY STAR and Code Plus homes.

Results and Discussion

The analysis is based on available monthly electric and natural gas bills provided by the homeowners of the home built to LEED-H Silver standards between March 2009 and October 2010. Monthly electric bills were also analyzed for the Code Plus home from November 2008 to October 2010 and the ENERGY STAR home from November 2009 to October 2010. Additionally, monthly natural gas bills were analyzed for the Code Plus home between November 2008 and October 2010 as well as the ENERGY STAR home from November 2009 to October 2010.

Figure 3 compares monthly average temperatures of the study area for both year 1 (November 2008 - October 2009) and year 2 (November 2009 – October 2010) of this study to 30-year average temperatures (1981-2010). Year 1 had temperatures hotter than average in December and August; warmer than average in March, April, and May; cooler than average in November, June, September and October, and colder than average in January and July.16 By contrast, year 2 was warmer overall, with temperatures hotter than average in November, March, April, May, June, July and September, warmer than average in August and June, and slightly cooler than average in February and December. In light of this information, we would expect greater cooling demand in summer months of year 2 than in year 1 though it is not entirely clear whether there will be greater heating demand in the winter months, as both December and February were colder in year 2 than year 1, but November, January, March and April were warmer in year 2 than year 1.

Figure 4 shows monthly Heating Degree Days (HDD) for the study area. HDD measures how much (in degrees) and how often (in days) the outside temperature was below the base temperature of 65°F. It is used as an approximation of how often and how much heating systems will be in use in a given

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15Unfortunately, for the first few months that the occupants were living in the home built to LEED-H Silver standards, there was confusion on the part of the utility provider with billing, therefore the utility bills prior to March 2010 were not available to be included in this study.

16For purposes of comparison, “hotter” is defined as a monthly average temperature 2.5 degrees Fahrenheit greater than the 30 year average, “warmer” is a monthly average temperature between 0 and 2.5 degrees Fahrenheit greater than the 30 year average, “cooler” is a monthly average temperature between 0 and -2.5 degrees Fahrenheit, and “colder” is a monthly average temperature less than -2.5 degrees Fahrenheit.
time period. A greater number of HDDs correlate with a greater intensity of natural gas or electricity use for heating.

There were a total of 5,731 HDDs in year 1 and 4,852 HDDs in year 2, with the 3-year average totaling 5,177 HDDs. Heating demand peaked in January in both year 1 (1,165 HDD) and year 2 (1,037 HDD).Confirming the temperature data above, compared to the 3-year average, year 1 (November 2008 – October 2009) had relatively greater heating demands than average in November, January, March, April and October (greater and more severe cold days), and a relatively less heating demand than average in December and February (fewer and less severe cold days). By contrast, in year 2 there was overall less heating demand in all months except February as compared with the 3-year average. Comparing year 1 to year 2, there was a greater demand for heating in year 1 in all months but December and February.

Figure 5 shows monthly Cooling Degree Days (CDD). CDD measures how much (in degrees) and how often (in days) the outside temperature was above the base temperature of 74°F. It is used as an approximation of how often and how much cooling systems will be in use in a given time period. A greater number of CDDs correlate with a greater intensity of electricity use for cooling purposes.

There were 219 CDDs in year 1 of this study and 500 CDDs in year 2, with a 3-year average totaling 346 CDDs. Compared to the 3-year average, there were far fewer CDDs in all of the hottest months of year 1 with the exception of August, when the number of CDDs was slightly higher than the 3-year average. The demand for cooling in year 2 was greater in every month with the exception of April, when cooling is typically not necessary. Comparing year 1 to year 2, confirming the temperature data above, we expect that electricity use for cooling purposes would be higher in year 2 without exception.

It is widely understood that cooling is only of several major residential electricity end uses. The following discussion demonstrates that this pattern holds for the case study home. An inductive, data-centric approach is used here to allow a niche discussion of the roles of idiosyncratic occupant behavior in influencing energy usage.

**Figure 3: Average Monthly Temperatures for Study Area**

Source: Office of the NJ State Climatologist, Rutgers University. (Accessed 1/05/2011)
http://climate.rutgers.edu/stateclim_v1/njclimdata.html
Figure 4: Monthly Heating Degree Days - Base 65°F

Source: Degreedays.net (accessed 1/04/2011) www.degreedays.net

Figure 5: Monthly Cooling Degree Days – Base 74°F

Source: Degreedays.net (accessed 1/04/2011)
Energy Overview

Energy used in these homes comes primarily from two sources: natural gas and electricity.

Figure 6 shows the average energy consumption (including all fuel types\textsuperscript{17}) by end-use of a residence in the United States, projected for 2010. Space heating accounts for about 43% of all energy use in an average home, followed by lighting and appliances (26%), water heating (about 20%), air conditioning (about 10%) and refrigeration (about 5%).

These percentages vary considerably by region. Figure 7 below shows the average household consumption of energy by end use for homes located in the in the Middle Atlantic Census Division.\textsuperscript{18} Again, space heating accounts for the largest percentage of energy consumption in the Middle Atlantic (56%), though a larger overall proportion than the country as a whole. This is because the Middle Atlantic Division experiences longer, colder winters, on average, than the rest of the United States. Lighting and appliances account for about 20% of energy use in the Middle Atlantic, followed by water heating (about 18%), air-conditioning (4.3%) and refrigeration (3.7%).

Electricity is used for space cooling, refrigerators and freezers, lighting, and some appliances, including dishwashers. According to the 2001 Residential Energy Consumption Survey (RECS), the largest use of electricity in the average U.S. household is for appliances (including refrigerators, computers, personal audio devices, cell phones, televisions, lights, etc.), which consume approximately two thirds of all the electricity used in the United States residential sector. After lighting and appliances, space cooling (air-conditioning) accounts for the second largest percentage (16%) of an average U.S. home’s electricity consumption.\textsuperscript{19}

With these figures in mind, one would expect that, for high performance homes built in the Middle Atlantic Division, home owners would want to invest more heavily in technologies aimed at reducing the need for heating or improving the efficiency of their heating system.

Natural gas is used to heat 67% of homes in New Jersey.\textsuperscript{20} For these homes, and the three homes in this study, natural gas is used primarily for space heating, water heating, and cooking. Nationwide, natural gas is used primarily for space heating, which accounts for about 69% of an average household’s total consumption, but it is also used for water heating (about 24% of total consumption), and other appliances (8%)—most often for cooking, but it may also be used for the washer and dryer (as is the case with both the home built to LEED-H Silver standards and the

\textsuperscript{17} Fuel types include electricity, natural gas, fuel oil, liquefied petroleum gas, and kerosene.


As with electricity use, these percentages will vary by region, though natural gas use in the Northeast Census Region\textsuperscript{22} is used in similar proportion to the nation as a whole. Table 1 shows a break-down of natural gas use in the United States.

**Figure 6: Projected 2010 U.S. Average Residential Energy by End-Use**

![Graph showing energy consumption by end use](image)


**Figure 7: Average Household Energy Consumption by End Use - Middle Atlantic Census Division, 2005**

![Graph showing energy consumption by end use](image)


\textsuperscript{22}The Northeast Census Region includes the New England and the Middle Atlantic states.
### Table 1: Natural Gas Use in the Nation and in the Northeast Census Region, 2001

<table>
<thead>
<tr>
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<th>Northeast Census Region</th>
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<tr>
<td></td>
<td>Quadrillion Btu</td>
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<td>Space Heating</td>
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<tr>
<td>Appliances</td>
<td>0.37</td>
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</tr>
<tr>
<td>Total</td>
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</tr>
</tbody>
</table>


### Appliances and Plug Load

#### Electricity

- The LEED-H and ENERGY STAR homes have more ENERGY STAR qualified appliances, which use 10-50% less energy than standard appliances.

- The LEED-H and ENERGY STAR homes use electricity for daily household tasks (e.g., washing clothes, cleaning dishes, watching television) compared to the Code Plus home which, in addition to providing for everyday household tasks, supports a home recording studio that utilizes a lot of electrical equipment on a daily basis. Further, the home built to LEED-H standards has four occupants, compared to the ENERGY STAR’s three (one of which travels for work more than 50% of the time), and the Code Plus’s two, who both work from their home, thus using more electricity overall than a home in which occupants worked away from the home. To reflect this, we estimate that the Code Plus electrical base-load is about .18 kWh/ft²/month, the home built to LEED-H Silver standards’ base-load is about .15 kWh/ft²/month, and the ENERGY STAR home’s is about .11 kWh/ft²/month. See Figure 8 and footnote 28 below.

- The LEED-H and ENERGY STAR homes have more ENERGY STAR qualified lighting, which use about 75% less energy, and produce 75% less heat than conventional lighting (in turn reducing cooling loads during summer months and raising heating loads during winter months).\(^\text{24}\)

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\(^{23}\) We estimate each of the homes monthly electrical base-load to be equivalent to the amount of electricity consumed in the month with the least electricity consumed during the duration of the study. For each of the homes, the month with the least electricity consumption was during the winter when cooling was not required and presumably when the least extraneous electrical load was utilized.

\(^{24}\) Lighting is not a more efficient way to heat a home than through a conventional heating system.
Natural Gas

- The LEED-H and ENERGY STAR homes use more of ENERGY STAR qualified lighting, which produces 75% less heat than conventional lighting, in turn increasing heating loads during colder months.

- Occupants of the home built to LEED-H standards cook almost all meals at home, as do the ENERGY STAR occupants. On the other hand, the homeowners of the Code Plus home enjoy a larger percentage of meals out of the house. Given the fact that cooking accounts for 4% of energy use in the average home, and the LEED-H home uses a natural gas stove and outside grill on a regular basis, this may help explain a portion of why their natural gas bills are highest among three homes, especially during the summer months.

Air Conditioning

- During the warmer months, occupants of the home built to LEED-H Silver standards keep their thermostat between 76° and 78° and the occupants of the ENERGY STAR home set theirs at 75°F downstairs and about 70°F upstairs. By comparison, the Code Plus home occupants keep their thermostat set to 68°F during the summer months. (Homeowners can save 1-3% on cooling costs for each degree the thermostat is set above 72 degrees.25)

- The Home Built to LEED-H Silver standards utilizes two super high-efficiency air-conditioning units with seasonal energy efficiency rating (SEER 18) that are about 40% more energy-efficient.

efficient than the ENERGY STAR home’s two SEER 14 air-conditioning units and 50% more energy-efficient than the Code Plus home’s two SEER 13 air-conditioning units.\textsuperscript{26}

- For heating and cooling systems, ENERGY STAR certification requires certain standards of efficiency of both the heating and cooling unit (95 AFUE for heating and 14 SEER for cooling). However, the certification does not provide standards for air-flow volume. One of the reservations the ENERGY STAR homeowner had about the heating and cooling systems was the unevenness of temperature throughout the home. In other words, rooms furthest away from the heating or cooling units were not as well heated or cooled than other parts of the home that are closer to the units. So while the design demands of ENERGY STAR certification does not guarantee comfort, there may be minor, unintended energy savings.

- The Home Built to LEED-H Silver standards utilizes superior building envelope technologies including a closed-cell spray-applied polyurethane foam insulation system, and super-high-efficiency cooling equipment that help keep temperatures within a comfortable range on even the hottest days of the summer.

\textit{Space Heating and Hot Water Heating}

- The home built to LEED-H standards uses an indirect-fired .85 EF natural gas hot water heater compared to the ENERGY STAR and Code Plus home’s tankless .80 EF natural gas hot water heaters. The home built to LEED-H Silver standards uses a lot of hot water on a daily basis to continually run the washing machine (about 2 times daily), bathe an infant once a day, another small child once every 2 to 3 days, and wash dishes from home cooked meals. The ENERGY STAR occupants also have a small child that requires bathing, however, the husband in the family spends only two days at home per week, on average, while traveling the rest of the time. The fact that water heating typically accounts for 12% of a home’s energy use may help to explain a portion of why their natural gas bills are higher than the other homes that do not share the same washing and dining routines. The LEED-H homeowners also increased their use of a natural gas clothes dryer during the second year of this study as they stopped air drying clothes during the warmer months.

- The LEED-H home utilizes a five-zone, 95 AFUE, fuel-fired hydronic distribution boiler for radiant heat, while the ENERGY STAR homes utilize a two-zone,95 AFUE, fuel-fired forced air distribution furnace, compared to the Code Plus home’s two, 90 AFUE, sealed combustion gas fired furnaces. Again, as with the cooling system, the different distribution systems may explain in part the higher level of natural gas use in the home built to LEED-H Silver standards and the ENERGY STAR home as the home built to LEED-H Silver standards is more

\textsuperscript{26} Assume energy savings for higher SEER numbers and 10% savings for every higher SEER number. For example, SEER 13 is 30% more energy-efficient, and SEER 12 is 20% more energy-efficient than SEER 10. (Source: Environmental and Energy Study Institute. Fact Sheet: Air Conditioner Efficiency Standards: SEER 13 vs. SEER 12. [accessed 12/8/2009]http://www.eesi.org/030602_SEER_13)
evenly heated, achieving a uniform temperature throughout the house, whereas in the ENERGY STAR home, parts of the home may be cooler than other by degrees.

- Occupants have set the thermostat in the home built to LEED-H Silver standards and the ENERGY STAR home at 68°F compared to the Code Plus home, whose occupants keep temperatures around 65°F degrees during the winter months. (For every degree homeowners lower their heat in the 60-degree to 70-degree range, they can save up to 5% on heating costs.²⁷)

- The LEED-H home utilizes a closed-cell spray-applied polyurethane foam insulation system that achieves an R-value of six per inch thickness and provides almost-zero air permeability.²⁸ The ENERGY STAR home and Code Plus homes were built with fiberglass batt insulation.

**Electricity USAGE Analysis**

Figure 9 shows the monthly electricity usage (in kWh) of the home built to LEED-H Silver standards over the course of this study. The monthly electricity ranged from a low of 465 kWh in May of 2009 to a high of 1,418 kWh in December 2009 with an overall monthly average of 752 kWh. The home built to LEED-H Silver standards uses electricity to power a SEER 18 air conditioner and would therefore expect to see greater electricity use during the hottest months of the year. However, contrary to convention, the months with the greatest electricity use were December and March of year 2. These deviations are not cooling related, nor are they expected to continue regularly in future years. They are explained below in the discussion of user habits.

Confirming our assumptions from the analysis of temperatures and cooling degree days above, overall electricity use during the summer months was greater in year 2 than in year 1. Electricity use during summer months (May through September) was 656 kWh in year 1 and 785 kWh in year 2. However, it is important to note that, given the greater demand for cooling in year 2 (i.e., hotter outdoor temperatures) the electricity use in the home decreased relative to the number of CDDs. In year 1, for every CDD, 5.74 kWh of electricity were used for cooling purposes and in year 2, this number fell to 3.89 kWh/CDD,²⁹ an increased efficiency of about 32%.

To further illustrate this point, Figure 10 shows the monthly electricity usage of the home built to LEED-H Silver standards normalized by cooling degree days.³⁰ A cursory comparison of Figure 9 and

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²⁹ We estimate the electricity devoted to cooling each month by subtracting 460 kWh—the estimated electricity baseload used to power all other appliances, electronics, lights, etc. in the household. To be conservative, this figure is the lowest electricity amount consumed in any month during the two year study (465 kWh in May of 2009). We assume that during this month, there was no electricity used for cooling purposes and was representative of a constant baseload.

³⁰ Normalization allows for a multi-year comparison of data by accounting for the variations in weather that might cause changes in electricity use. For example, as shown above in Figure 3, the summer months of year two of this study were, on
10 shows that the normalized electricity use\textsuperscript{31} in the warmest months of year 2 fell considerably, though the electricity use during August 2010 remains about 20\% higher than in August of 2009. The total normalized electricity use for the warmest months of year 1 (May through September) is 4,583 kWh, and for year 2 is 3,644 kWh.

As has been shown in other studies of green buildings, these kinds of results—where efficiency gains are made in the second year as compared with the first—are typical. Often times, it takes a year for homeowners or occupants to settle into their homes, become acquainted with the home’s cooling unit, and establish their routines and preferences.

To continue the analysis using CDDs, Figure 11 is a scatter plot diagram with the number of CDDs on the x-axis and the home built to LEED-H Silver standards’ electricity use on the y-axis. The figure also includes a regression line.

One would expect there to be a strong correlation between electricity use and CDD (i.e., need for cooling). Although the regression line does have a positive slope of 1.6 indicating that, on average, the home built to LEED-H Silver standards uses 1.6 kWh more per cooling degree day, the regression is very weak, with an R-squared value of just 0.12. Contrary to what is expected, the months with the highest electricity use were during colder months (December 2009 and March 2010) as opposed to the warmer months. In our discussion with the homeowners, we found that in December 2009, a humidifier was installed in the home due to consistently low humidity levels in the home (around 10\%).\textsuperscript{32} When installed, the humidifier ran constantly for several days to achieve desired humidity levels (around 40\%). As for March 2010, the wife gave birth to a second child at home, and the husband was at home 24 hours a day in the two weeks leading up to the birth as well as a short time after. This was a drastic change in the routine of the husband as he was usually away from the home for work under normal circumstances. We discuss the occupants’ habits further in a discussion below.

Taking into consideration these extraordinary circumstances, Figure 12 shows a scatter plot diagram of CDD and electricity use with the December 2009 and March 2010 figures reduced to normal levels. As expected, the correlation between CDDs and electricity use in the home built to LEED-H Silver standards increases substantially, showing that, on average, for every CDD, 2.6 kWh were used during the two year period. The relative strength of the regression can be seen in the R squared value of 0.56.

\textsuperscript{31}The normalization is done using a baseload of 460 kWh per month. See footnote 17 for further details.

\textsuperscript{32} Convention assumes that homeowners of homes built to LEED-H standards should have concerns for high levels of humidity due to the tightness of the building’s envelope. However, in this case, the tightness of the home induced low levels of humidity.
Figure 9: Home Built to LEED - H Silver Standards Total Monthly kWh Usage

Source: Monthly utility bills from JCP&L March 2009 – October 2010

Figure 10: Home Built to LEED - H Silver Standards Total Monthly kWh Usage Normalized to CDD

Source: Monthly utility bills from JCP&L March 2009 – October 2010

33 The homeowner’s electricity bills were unavailable for the first four months of this study.
Figure 11: Scatter-Plot Diagram of Home Built to LEED-H Silver Standards Showing Monthly Electricity Use and CDDs, November 2008 – October 2009

Source: Monthly utility bills from JCP&L March 2009 – October 2010 and Degreedays.net

Figure 12: Scatter-Plot Diagram of Home Built to LEED-H Silver Standards Showing Monthly Electricity Use and CDDs, November 2008 – October 2009 with December 2009 and March 2010 Adjustments

Source: Monthly utility bills from JCP&L March 2009 – October 2010
Comparison of Electricity Usage of the Home Built to LEED-H Silver Standards with Code Plus and ENERGY STAR Homes

Figure 13 below compares electricity use among the home built to LEED-H Silver standards and the Code Plus and ENERGY STAR homes for year 2 of this study. The electricity use has been normalized by CDDs and is shown by kWh/ft² to allow for an even comparison of the homes despite their different sizes. On average the home built to the LEED-H Silver standards uses roughly half of the electricity per square foot as the Code Plus with the exception of December 2009 as well as March 2010. The ENERGY STAR home also appears to perform significantly better than the Code Plus home and contrary to what was expected, also a better than the home built to LEED-H Silver standards. This finding supports the hypothesis that the LEED-H home and ENERGY STAR home will perform better than the Code Plus home in terms of energy (electricity) usage but is counter to the idea that the LEED-H home will perform better than the ENERGY STAR home. However, it is important to keep in mind that the determinants of electricity usage are not just the components of the home, but more importantly, the occupants’ habits and preferences in each home. For example, the ENERGY STAR home has one fewer occupant (1 less child) and the husband travels a great deal and is home for about two days each week. Again, we will look more closely at these issues later in the discussion.

In order to demonstrate the relative electrical efficiency of each of the homes, Figure 14 is a scatter-plot diagram correlating electricity use per square foot to CDD for two of the three homes. All things being equal and assuming a relatively constant baseload (i.e. appliance and lighting use are constant throughout the year), a regression line with a lesser slope indicates a home with a cooling system that is more efficient and/or a building envelope that is less permeable. A higher y-intercept indicates a higher baseload.

Figure 14 and Table 2 show that the home built to LEED-H Silver standards consumes electricity about 50% more efficiently than the ENERGY STAR home (i.e., has the lowest slope), though the ENERGY STAR home has an electrical baseload about 30% less than the home built to LEED-H Silver standards. These figures are as expected. As for the comparative efficiency, the home built to LEED-H Silver standards was designed to minimize warming during the summer months and has a more efficient air conditioning system. As for the electric baseload, the home built to LEED-H Silver

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34 We consider year 2 only in this context because we have a full set of utility bills for each of the three homes, whereas in year 1, this is not the case.

35 Because electricity is used for a wide array of household functions, monthly consumption often deviates from expected amounts. While we can be certain that during the warmer months, higher electricity use can be safely attributed to cooling purposes, other months with higher than expected consumption rates may skew the CDD regression positively or negatively. For example, as mentioned above, the owners of the home built to LEED-H Silver standards had a humidifier installed in December 2009 which was constantly running to bring the home up to the desired humidity levels. While we cannot isolate the electricity for cooling use only, we have substituted expected consumption levels for the statistical aberrations (i.e. greater than 2 standard deviations from the mean) from the above regression. Further, each of the outliers were explained during our conversations with the homeowners (with the exception of the Code Plus home, as the owner was unavailable for an interview during the second year of the study), justifying the modification of the data.

36 We compare just the home built to LEED-H Silver standards to the ENERGY STAR home because they had similar preferences for air conditioning use during the warmer months, whereas the Code Plus home owners preferred their home temperature to be significantly cooler.
standards houses a family of four, whereas the ENERGY STAR houses a family of three, in which one travels abroad for work more than 60% of the time. However, it is important to bear in mind that these figures can only serve as an approximation of cooling efficiency.

Table 3 shows a comparison of the three homes' total, monthly average and range of electricity usage per square foot for the second year of this study. This table demonstrates the degree to which the ENERGY STAR home outperforming both the Code Plus home and the LEED-H home as the ENERGY STAR’s monthly average electricity consumption is just a .002 kWh/ft² below the Code Plus home’s lowest month of electricity use throughout the year. The ENERGY STAR home low and high range values are about half of the low and high values for the Code Plus home. On the other hand, while the LEED-H home’s low range value is similar to that of the Code Plus home, its high range value is significantly lower.

While much of this difference has to do with the superior energy efficient features of the LEED-H home and the ENERGY STAR home as compared with the Code Plus home, as mentioned above, the occupants’ behavior is an important factor to consider. For example, in conversations with the Code Plus homeowners, we found that the couple keeps their thermostat at about 68 degrees during the summer months, as compared to the homeowners of the ENERGY STAR home and the home built to LEED-H Silver standards, who prefer summer temperatures of 73 and 75 respectively. Further, we found that the Code Plus home carries a larger electricity baseload because of a recording studio in their basement. Further, while both husband and wife work from home out of the Code Plus home whereas in the ENERGY STAR home and the home built to LEED-H Silver standards, the husband does not work from home.

Figure 13: Comparison of Home Built to LEED-H Silver and Code Plus and ENERGY STAR Homes - Total Monthly kWh/ft² Usage Normalized to Cooling Degree Days, November 2009 – October 2010

37 We compare the homes only during year 2 of the study because we did not have sufficient utility bill data from both the home built to LEED-H Silver Standards and the ENERGY STAR home for year 1.
Figure 14: Scatter-Plot Diagram Comparing Correlation of Electricity Use/ft² and Cooling Degree Days in Home Built to LEED-H Silver Standards and ENERGY STAR Home, November 2008 – October 2010

Table 2: Regression Statistics from Figure 14

<table>
<thead>
<tr>
<th></th>
<th>Baseload (Y-Intercept)</th>
<th>% Difference Compared to LEED-H Standards</th>
<th>Cooling Efficiency (Regression Slope)</th>
<th>% Difference Compared to LEED-H Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEED-H Standards</td>
<td>0.1931</td>
<td>0%</td>
<td>0.00085</td>
<td>0%</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>0.1329</td>
<td>-31.18%</td>
<td>0.00128</td>
<td>50.41%</td>
</tr>
</tbody>
</table>

Table 3: Comparison of Electricity Usage/ft² Normalized by Cooling Degree Days among Three Homes, November 2009 – October 2010 (Year 2)

<table>
<thead>
<tr>
<th>Home</th>
<th>Total Use (kWh/ft²)</th>
<th>Monthly Average (kWh/ft²)</th>
<th>Range(kWh/ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Low (Month/Year)</td>
</tr>
<tr>
<td>LEED H</td>
<td>3.090</td>
<td>0.258</td>
<td>0.167 (04/2010)</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>2.183</td>
<td>0.182</td>
<td>0.095 (01/2010)</td>
</tr>
<tr>
<td>Code Plus</td>
<td>4.453</td>
<td>0.371</td>
<td>0.184 (03/2010)</td>
</tr>
</tbody>
</table>
Natural Gas Usage Analysis

Figure 15 shows the monthly natural gas usage (in therms) of the home built to LEED-H Silver standards over the course of this study. The monthly natural gas consumed ranged from a low of 11 therms in July of 2010 to a high of 184 therms in January of 2009 with an overall monthly average of 54 therms. The home built to LEED-H Silver standards uses natural gas for cooking, hot water, and space heating, the last driving most of the demand. We would therefore expect to see greater natural gas use during the coldest months of the year and relatively little use during the warmer months. This is indeed the case. The months with the greatest natural gas use were November, December, January, February and March of both years of the study.

Total natural gas use during the colder months (November through March) was 551 therms in year 1 and 477 therms in year 2. These results are expected, as there were more HDDs in the colder months of year 1 (4,211) than year 2 (3,950). The natural gas use, however, was somewhat erratic in year 1 as compared with year 2, with a spike in January of 2009, a drop in February 2009, and another spike in March 2009. This may be in part due to the timing of meter reading visits. Also, although the homeowners said that they leave the thermostat set to 68 degrees throughout the winter; they indicated that they have had some difficulties figuring out the control interface to adjust the settings when needed. Even when normalized by HDDs, the spikes and drops remain pronounced.

In addition, not only did the total amount of natural gas consumed decrease in year 2 of the study, but as was the case with electricity use, the natural gas use in the home decreased relative to the number of HDDs. In year 1, for every HDD, .12 therms of natural gas was used for heating purposes and in year 2, this number fell to .11 therms/HDD, an increased efficiency of about 10%.

To further illustrate this point, Figure 16 shows the monthly natural gas usage of the home built to LEED-H Silver standards normalized by heating degree days. Comparing Figures 12 and 13 shows that the normalized natural gas use in the coldest months of both year 1 and year 2 converged to match more closely with one another. For example, natural gas use in January of year 1 fell from 184 therms to a normalized value of just about 166 therms, coming closer to the January, year 2 value of 120 therms. Still, the erratic natural gas consumption pattern remains. The total normalized natural gas use for the coldest months of year 1 (November through March) is 530 therms, and for year 2 is 491 therms.

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38 We estimate the natural devoted to cooling each month by subtracting 11.4 therms—the estimated natural gas baseload used for cooking and hot water in the household. To be conservative, this figure is the lowest electricity amount consumed in any month during the two year study (11.4 therms in July 2010). We assume that during this month, there was no natural gas used for heating purposes and was representative of a constant baseload.

39 Normalization allows for a multi-year comparison of data by accounting for the variations in weather that might cause changes in natural gas consumption (i.e., all things held equal, a colder winter in one year as compared to another would cause natural gas use to rise due to a greater need for heat).

40 The normalization is done using a baseload of 11.4 therms per month. See footnote 21 for further details.
As with the electricity consumption above, other studies of green buildings have shown efficiency gains in the second year of ownership as compared with the first. Often times, it takes a year for homeowners or occupants to settle into their homes, become acquainted with the home’s heating mechanisms, and establish their routines and preferences.

Table 4 provides a statistical breakdown of natural gas use for the home built to LEED-H Silver standards normalized by HDDs. In a home such as this, with a super-efficient natural gas fired heating system with a 95 AFUE, one would expect that natural gas use would correlate strongly with heating degree days (which, again, represent the duration and severity of cold weather in a given time period). Figure 17 is a scatter plot diagram with the number of heating degree days on the x-axis and the home built to LEED-H Silver standards’ natural gas use on the y-axis. The figure also includes a regression line. As expected, months with colder weather (i.e. more HDDs) correlate very closely with higher levels of natural gas use. This correlation is much stronger than the correlation of CDDs to electricity consumption because natural gas use for heating is a much larger percentage of total natural gas use than electricity use for cooling. The regression shows that, on average, the home built to LEED-H Silver standards uses .12 therms more per HDD, with a strong R-squared value of .89.

Figure 15: Home Built to LEED - H Silver Standards Total Monthly Natural Gas Used, November 2008-October 2010

![Figure 15: Home Built to LEED - H Silver Standards Total Monthly Natural Gas Used, November 2008-October 2010](image)

Figure 16: Home Built to LEED - H Silver Standards Total Monthly Natural Gas Used Normalized to Heating Degree Days, November 2008-October 2010

![Figure 16: Home Built to LEED - H Silver Standards Total Monthly Natural Gas Used Normalized to Heating Degree Days, November 2008-October 2010](image)
Table 4: Statistical Summary of Natural Gas Use for the Home Built to LEED-H Silver Standards Normalized by Heating Degree Days, November 2008 – October 2010

<table>
<thead>
<tr>
<th></th>
<th>Year 1</th>
<th>Year 2</th>
<th>Years 1 and 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Average</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(therms)</td>
<td>59</td>
<td>54</td>
<td>57</td>
</tr>
<tr>
<td>Range (therms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>15 (May 2009)</td>
<td>11 (July 2010)</td>
<td>11 (July 2010)</td>
</tr>
<tr>
<td>High</td>
<td>180 (Jan 2009)</td>
<td>141 (Dec 2009)</td>
<td>180 (Jan 2009)</td>
</tr>
<tr>
<td>Total (therms)</td>
<td>711</td>
<td>652</td>
<td>1,363</td>
</tr>
</tbody>
</table>

Figure 17: Scatter-Plot Diagram of Home Built to LEED-H Silver Standards Showing Monthly Natural Gas Use and Heating Degree Days, November 2008 – October 2009

\[ y = 0.122x + 2.036 \]

\[ R^2 = 0.886 \]
Comparison of Natural Gas Use of the Home Built to LEED-H Silver Standards with ENERGY STAR and Code Plus Home

In order to demonstrate the relative efficiency of each of the homes natural gas use, Figure 18 below is a scatter-plot diagram correlating natural gas use per square foot to HDD for each of the three homes. All things being equal, a regression line with a lesser slope indicates a home with a more efficient heating system. In other words, on any given day that demands the use of natural gas for heating purposes (i.e., a significantly positive number of HDDs), a home with a more efficient heating system and/or a tighter building envelope would use less natural gas than one with a less efficient heating system or comparatively leaky building envelope.

The regression shows that the home built to LEED-H Silver standards uses natural gas for heating about 20% more efficiently than the Code Plus home, it is about 6% less efficient than the ENERGY STAR home. There is a clustering of data points around the origin which indicate that during the months with few or no HDD, relatively little natural gas was consumed for any of the three houses. As the number of HDDs grew during a given month (i.e., the weather became colder), the amount of natural gas use climbs at a relatively constant rate. We saw previously that this correlation is very strong for the home built to LEED-H Silver standards and it is equally strong for both the ENERGY STAR and Code Plus homes.

As with the electricity use regression in the section above, these figures are but approximations of heating efficiency as we were not able to measure exactly how much natural gas was used for heating as opposed to cooking, water heating, or laundry. However, because natural gas is used primarily for heating, we can be confident in these results.

Figures 19a and 19b compare the natural gas use per square foot of the home built to LEED-H Silver standards with both the ENERGY STAR home and the Code Plus home. In year 1 of the study, the home built to LEED-H Silver standards used less natural gas per square foot overall than the Code Plus home (.22 therms/ft² and .25therms/ft²respectively), though used more natural gas per square foot during all but two months of the year (December, 2008 and February 2009). In year 2, the home built to LEED-H Silver standards used consistently less natural gas per square foot than the Code Plus Home during the colder months with the exception of March 2010, but consistently more than the ENERGY STAR home with the exception of February 2010.

It is expected that the home built to LEED-H Silver standards uses more natural gas per square foot than either the Code Plus home or the ENERGY STAR home during the warmer months of the year as they have more people living in their house (four, as opposed to the ENERGY STAR’s three and Code Plus’s two), therefore their cooking and hot water needs would be relatively higher.

41 We are able to compare the three homes’ natural gas consumption per square foot as all of the homeowners keep their thermostats set to about 68 degrees during the colder months.

42 Although heating is not the only use of natural gas in each of the homes, heating accounts for anywhere from 60 percent to 80 percent or more of natural gas use.
The relatively lower natural gas use per square foot in the colder months of the home built to LEED-H Silver standards is, again confirming the results of the regression above, likely due to the fact that the heating system is more efficient than the Code Plus home’s.
Figure 18: Scatter-Plot Diagram Comparing Correlation of Natural Gas Use and HDDs in Home Built to LEED-H Silver Standards, ENERGY STAR, and Code Plus Homes, November 2008 – October 2010

Source: Monthly utility bills from New Jersey Natural Gas November 2008 – October 2010

Table 5: Regression Statistics from Figure 18

<table>
<thead>
<tr>
<th>Heating Efficiency (Regression Slope)</th>
<th>% Difference Compared to LEED-H Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEED-H Standards</td>
<td>0.00004014</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>0.00003765</td>
</tr>
<tr>
<td>Code Plus</td>
<td>0.00004895</td>
</tr>
</tbody>
</table>
Figure 19a: Year 1 Comparison of Home Built to LEED-H Silver Standards, ENERGY STAR and Code Plus Homes - Total Monthly Therms/ft² Usage Normalized by HDDs (November 2008 – October 2009)

Source: Monthly utility bills from New Jersey Natural Gas November 2008 –October 2010
Note: ENERGY STAR data was only made available for July 2009.

Figure 19b: Year 2 Comparison of Home Built to LEED-H Silver Standards, ENERGY STAR, and Code Plus Homes – Total Monthly Natural Gas Use/ft² Normalized by HDDs (November 2009 – October 2010)

Source: Monthly utility bills from New Jersey Natural Gas November 2008 –October 2010
*This figure shows calculated usage for the months of November 2008, January, March, and May (2009), and October 2010 for the Code Plus Home.
** The LEED-H homeowners took a 5-day vacation in April 2009 and a week-long vacation in November 2009.
Indoor Air Temperature Regulation in Home Built to LEED-H Silver Standards

Figure 20 shows how indoor temperatures in the LEED-H home fluctuate only 2 to 4 degrees during one of the hottest 24-hour periods of the summer (Tuesday, August 18th, 2009) as recorded by each of the home’s four temperature zones. The LEED-H home indoor temperatures stay within 2-4 degrees of the homeowner’s preferred temperature setting of 78 F degrees on one of the hottest days of the year.

Figure 21 shows a blown-up section of the indoor temperature data shown in Figure 20 to illustrate the narrow range of temperature changes.

Figure 22 shows the percentage of time that the LEED-H home’s air-conditioning unit runs each hour over a 24-hour period. The chart shows that the air-conditioning unit kicks on as the outdoor temperatures begin to rise to maintain comfortable average indoor temperatures around 77 +/- 2 degrees Fahrenheit. The air-conditioning unit only runs at full capacity during the hottest part of the day and cuts down on run time as temperatures fall in the evening.

Given this runtime pattern, the air-conditioning unit contributes directly to the peak load experienced by the electric utility. Peak loads are reduced when more efficient equipment is used to deliver the same cooling effect. Although the equipment in the LEED-H home has a SEER of 18 and the Code Plus home a SEER of only 13, the rated cooling capacity of the equipment in the LEED-H home is larger than that in the Code Plus home, so it is unlikely that the greener design delivers a comparative net reduction in peak demand. If the residents sign up for time-of-use electricity pricing, they may want to consider thermal storage that would shift some of the cooling load off peak.

Figure 20: Hourly Indoor vs. Outdoor Temperature Trends, Home Built to LEED-H Silver Standards, Tuesday, August 18th, 2009

Source: Real-time data from In2’s Energy ICM system
Figure 21: Hourly Indoor Temperature Trends, Home Built to LEED-H Silver Standards, Tuesday, August 18th, 2009

Source: Real-time data from In2’s Energy ICM system

Figure 22: Average Hourly Temperature and Air-Conditioning Unit Run Time, Home Built to LEED-H Silver Standards, Tuesday, August 18th, 2009

Source: Real-time data from In2’s Energy ICM system
Design vs. Actual Electricity Usage

As part of the ENERGY STAR certification process (through which both the home built to LEED-H Silver standards and the ENERGY STAR home went), builders are required to have their home designs modeled to ensure that the homes will meet the ENERGY STAR requirements. We use these models in this section to compare the actual performance of the home built to LEED-H Silver standards and the ENERGY STAR home with how they were expected to perform as determined by the model as well as to compare the homes to a home built to the New Jersey housing code, which is based, with some modifications in the International Energy Conservation Code 2006. While we do not have a model for the Code Plus home (built to the 2004 building code rather than the 2006 version), we include the actual utility data for a further comparison of the relative performance of these three homes.

We begin with a complete analysis of the home built to LEED-H Silver standards followed by a comparison of the three homes.

Home Built to LEED-H Silver Standards

The home built to LEED-H Silver standards was designed to use 2.5 kWh of electricity per square foot annually, as compared with 3.4 kWh/ft² annually for a home built to the New Jersey building code, an expected improvement of approximately 25% percent. However, actual electricity use in the home built to LEED-H standards during the second year of this study was higher than expected, at 3.3 kWh/ft²/year, still marginally better than the modeled NJ Code Home (3%), but 30% higher than predicted by the REM/Rate model. Normalizing for climate variation, the actual use falls to 3.1 kWh/ft²/year, somewhat closer, but still 23% higher than expected and only 9% better than the modeled NJ Code Home.

In light of the information uncovered in the personal interview with the homeowners of the home built to LEED-H Silver standards, we adjusted the REM model to reflect the user’s habits, such as cooling set points and appliance use, which brought the expected electricity consumption up to 2.8 kWh/ft²/year, narrowing the gap of expected use and actual use to 0.3 kWh/ft²/year, or a difference of about 10%. Finally, we identified two months of outlier electricity use (i.e., greater than two standard deviations from the mean monthly electricity use) which we are confident can be attributed to extraordinary circumstances, and substituted normal monthly consumption rates in their place. With this adjustment, the actual electricity consumption rate falls to 2.7 kWh/ft²/year, or a 5% less than the rate predicted by the model adjusted for user habits, or 6% higher than the original model's predicted electricity consumption rate.

---

43 These models were created by MaGrann Associates with some modifications by the research team using REM Design.
44 We detail these user habits in the previous section entitled “Building Occupant Satisfaction.”
45 The two months were December 2009, when the homeowners had a new whole-home humidifier installed which ran constantly in order to bring the home’s humidity levels from 10% up to the desired 40%, and March 2009, when both the husband and wife were home constantly for two+ weeks as the wife prepared to have an at home child birth.
46 We simply substituted an average value of the surrounding months. Neither month was at the peak of the heating or cooling season, a point at which an average would have been inappropriate.
After normalizing for weather conditions and adjusting for outliers, the home built to LEED-H standards is consuming approximately 21% less than a NJ Code Home.

Figure 23 shows a comparison of the iterations of both the predicted consumption rates (NJ Code Home model, Default LEED-H Standards model, User Adjusted LEED-H Standards model) and the actual consumption rates, the normalized consumption rates, and the consumption rates less the outliers.

**Figure 23: Comparison of Modeled Electricity Use and Actual Use of Home Built to LEED-H Silver Standards with Modeled NJ Code Home, November 2009 – October 2010**

<table>
<thead>
<tr>
<th>kWh/ft²/year</th>
<th>NJ Code Home</th>
<th>Original Model</th>
<th>User Inputs</th>
<th>Actual</th>
<th>Normalized</th>
<th>Less Outliers</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.4</td>
<td>2.5</td>
<td>2.8</td>
<td>3.3</td>
<td>3.1</td>
<td>2.7</td>
<td></td>
</tr>
</tbody>
</table>

Source: MaGrann Associates REM/Rate analysis
JCP&L electric bills November 2009-October 2010

**Comparison of Three Homes’ Electricity Consumption**

Of the three homes compared in this study, the home built to LEED-H Silver standards was expected to perform best. The ENERGY STAR home was designed to use 2.9 kWh/ft²/year of electricity, about 15% less than the baseline NJ Code Home and about 13% more than the home built to LEED-H Silver standards. The ENERGY STAR home’s actual electricity consumption during the second year of this study was 2.4 kWh/ft²/year, or 15% less than predicted by the ENERGY STAR model, and a 29% improvement over the NJ Code Home model. Although expected to consume more electricity than the home built to LEED-H Silver standards, it actually consumed about 26% less electricity per square foot per year. Normalizing for weather variation, the actual use of the ENERGY STAR home falls to 2.2 kWh/ft²/year, 35% less than the NJ Code Home baseline and 30% less than the normalized electricity consumption of the home built to LEED-H Silver standards.

As with the home built to LEED-H Silver standards, we were able to conduct two interviews with the homeowners of the ENERGY STAR home. From those interviews we were able to adjust the REM/Rate model to account for user habits. With these adjustments, the model for the ENERGY STAR home predicted that the occupants would consume approximately 2.2 kWh/ft²/year of
electricity. Therefore, in light of user habits, the ENERGY STAR home as predicted, would consume 23% less electricity than the predicted amount including user habits for the home built to LEED-H Silver standards. Further, the modified model's prediction is highly accurate—the prediction is less than 1% from actual consumption normalized for weather variation. There were no outlier monthly electricity bills for the ENERGY STAR home.

In sum, while the home built to LEED-H Silver standards was predicted to consume less electricity than the ENERGY STAR home, in actuality, the opposite was true. To confirm these findings, we adjusted the building models for both homes to include user habits and found similar results. The occupants of the ENERGY STAR home use less electricity per square foot per year than the occupants of the home built to LEED-H Silver standards despite the efficiency improvements of the latter.

Tables 6a–6c below compare the predicted electricity consumption rates of the home built to LEED-H Silver standards and the ENERGY STAR home as well as actual consumption rates and all derivations thereof described above.

Although we do not have a REM/Rate model for the Code Plus home, the NJ Code Home model used as a baseline for comparison above is a reasonable approximation of how much electricity the Code Plus home was expected to consume, about 3.4 kWh/ft²/year. The actual electricity consumption of the Code Plus home during year 1 of this study (November 2008 -October 2009) was 4.4 kWh/ft²/year and 5.1 kWh/ft²/year for year 2 (November 2009-October 2010) or 31% and 52% more than expected respectively as compared to the NJ Code Home model. Normalizing for variations in weather, year 1 consumption was 5.9 kWh/ft²/year and year 2 was 4.5kWh/ft²/year. The relative increase of consumption in year 2 can be attributed to one month, June 2009. As mentioned in the section above on CDDs, we used a base of 74°F, which was most appropriate for the home built to LEED-H Silver standards and the ENERGY STAR home as both set of homeowners set their thermostat in the mid-70s during the summer months when cooling is required. However, the Code Plus occupants set their thermostat to 68°F in the summer. As a result, the normalization calculation for June 2009, when the number of actual CDDs was far below the 3-year average, resulted in a total kWh consumption of nearly 4 standard deviations away from the average monthly electricity consumption. Accounting for this statistical aberration, the consumption rate for year 1 falls nearly 16% to 5.0 kWh/ft²/year.

By any measure, the Code Plus home consumes more electricity per square foot per year than any of the other homes. Table7 below compares the year 2 predicted consumption rates of both the home built to LEED-H Silver standards and the ENERGY STAR homes, the actual consumption rates of all three homes, as well as the predicted electricity consumption of the NJ Code Home.
Table 6a: Comparison of Predicted and Actual Electricity Consumption of Home Built to LEED-H Silver Standards and ENERGY STAR home with a Baseline NJ Code Home, October 2009 – November 2010

<table>
<thead>
<tr>
<th></th>
<th>Predictive Models (kWh/ft²/year)</th>
<th>Actual Consumption (kWh/ft²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original User Habits</td>
<td>Raw Data</td>
</tr>
<tr>
<td>NJ Code Home</td>
<td>3.37</td>
<td>3.27</td>
</tr>
<tr>
<td>LEED Standards</td>
<td>2.52 2.81</td>
<td>2.41</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>2.86 2.16</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: MaGrann Associates REM/Rate analysis; JCP&L electric bills November 2008-October 2009

Table 6b: Comparison of Predicted and Actual Electricity Consumption of Home Built to LEED-H Silver Standards and ENERGY STAR home with a Baseline NJ Code Home by Percentage

<table>
<thead>
<tr>
<th></th>
<th>Predictive Models</th>
<th>Actual Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original User Habits</td>
<td>Raw Data</td>
</tr>
<tr>
<td>NJ Code Home*</td>
<td>0.00%</td>
<td>-2.9%</td>
</tr>
<tr>
<td>LEED Standards</td>
<td>-25.3% -16.8%</td>
<td>-28.5%</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>-12.6% -35.9%</td>
<td>-</td>
</tr>
</tbody>
</table>

*Note: All of the percentages are as compared to the NJ Code Home predicted value in the first column. A negative value demonstrates a lower electricity consumption rate and a positive value demonstrates a higher electricity consumption rate.

Source: MaGrann Associates REM/Rate analysis; JCP&L electric bills November 2008-October 2009

Table 6c: Comparison of Predicted and Actual Electricity Consumption of Home Built to LEED-H Silver Standards and ENERGY STAR, October 2009 – November 2010

<table>
<thead>
<tr>
<th></th>
<th>Predictive Models (kWh/ft²/year)</th>
<th>Actual Consumption (kWh/ft²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original User Habits</td>
<td>Raw Data</td>
</tr>
<tr>
<td>LEED Standards</td>
<td>2.52 2.81</td>
<td>3.27</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>2.86 2.16</td>
<td>2.41</td>
</tr>
<tr>
<td>% Difference*</td>
<td>13.4% -23.0%</td>
<td>-26.3%</td>
</tr>
</tbody>
</table>

*Note: All of the percentages compare the ENERGY STAR home to the home built to LEED-H Silver standards. A negative value demonstrates a lower electricity consumption rate for the ENERGY STAR home and a conversely, positive value demonstrates a higher electricity consumption rate.

** Note: The ENERGY STAR home did not have any outlier months of electricity consumption.

Source: MaGrann Associates REM/Rate analysis; JCP&L electric bills November 2008-October 2009
Table 7: Design vs. Actual kWh Usage Comparison (Year 2 Only)

<table>
<thead>
<tr>
<th></th>
<th>NJ Code Home</th>
<th>LEED-H Standards</th>
<th>ENERGY STAR</th>
<th>Code Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Original Model</td>
<td>User Habits</td>
<td>Original Model</td>
</tr>
<tr>
<td>Heating (kWh)</td>
<td>100</td>
<td>65</td>
<td>65</td>
<td>431</td>
</tr>
<tr>
<td>Cooling (kWh)</td>
<td>2,264</td>
<td>1,435</td>
<td>1,430</td>
<td>1,909</td>
</tr>
<tr>
<td>Lights and Appliances (kWh)</td>
<td>7,903</td>
<td>6,179</td>
<td>7,056</td>
<td>8,079</td>
</tr>
<tr>
<td>Annual kWh</td>
<td>10,267</td>
<td>7,679</td>
<td>8,551</td>
<td>10,419</td>
</tr>
<tr>
<td>Annual kWh/ft²</td>
<td></td>
<td>3.37</td>
<td>2.52</td>
<td>2.81</td>
</tr>
</tbody>
</table>

| Actual Use             |             |                  |             |           |           |           |
| Total Annual kWh/ft²   | -           | 3.27             | 2.41        | 5.13      |           |           |
| Total Annual kWh/ft²(Normalized) | - | 3.09 | 2.18 | 4.45 |
| Total Annual kWh/ft²(Less Outliers) | - | 2.66 | - | - |

Source: MaGrann Associates REM/Rate analysis, Rutgers Center for Green Building JCP&L electric bills November 2009-October 2010

**Design vs. Actual Natural Gas Usage**

**Home Built to LEED-H Silver Standards**

The Home Built to LEED-H Silver standards was *designed* to use .21 therms of natural gas per square foot annually, as compared with .42 therms/ft²/year for a home built to the New Jersey building code, an expected improvement of approximately 49%. Actual natural gas use in the home built to LEED-H standards during year 1 of this study was .23 therms/ft²/year (7% higher than predicted by the model) and .20 therms/ft²/year during year 2 (7% lower than predicted). This year 2 natural gas consumption rate is 53% less than the modeled NJ Code Home. Normalizing for weather variation by HDDs, the actual use rises slightly to .21 therms/ft²/year, a scant 4% difference from the predicted amount, and still a 52% reduction in natural gas use over the NJ Code Home model.

As with the electricity use, we adjusted the building model to account for occupants’ habits in light of the information uncovered in the personal interview with the homeowners of the home built to LEED-H Silver standards. This adjustment brought the predicted natural gas use up slightly to .24 therms/ft²/year, a difference of 12% from the original natural gas prediction and 17% more than the normalized natural gas consumption rate.
One would expect the model that includes user habits to be more accurate than a default model, though limitations in the REM Design software that was used for making the modifications may account for the discrepancy. The reason has to do with washing clothes. The homeowners of the home built to LEED-H Silver standards use their washing machine 2-3 times daily—though only once per week do they use hot water. Although we were able to indicate how often the washing machine is used, we were unable to indicate how often hot water was used, thus impacting the overall natural gas projections.

Overall, the home built to LEED-H Silver standards is performing to expectations. Figure 24 shows a comparison of the iterations of both the predicted consumption rates (NJ Code Home model, Default LEED-H Standards model, User Adjusted LEED-H Standards model) and the actual as well as normalized consumption rates for the home built to LEED-H Silver Standards.

**Figure 24: Comparison of Modeled Natural Gas Use and Actual Use of Home Built to LEED-H Silver Standards with Modeled NJ Code Home, November 2009 – October 2010**

Comparison of Three Homes

Of the three homes compared in this study, the home built to LEED-H Silver standards was expected to perform best in terms of natural gas use (.21 therms/ft²/year by design). The ENERGY STAR home was designed to use .28 therms/ft²/year of natural gas, about 33% less than the baseline NJ Code.

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47MaGrann Associates used the REM/Rate program, which is a more sophisticated version of the software that was used at the Rutgers Center for Green Building.
Home and about 33% more than the home built to LEED-H Silver standards as modeled. Figure 25 below shows a comparison of the predicted natural gas consumption of each of the three homes.

The ENERGY STAR home’s actual natural gas consumption during the second year of this study\(^{48}\) was .18therms/ft\(^2\)/year—38% less than predicted by the REM/Rate model and a 57% improvement over the NJ Code Home model. Although expected to consume more natural gas than the home built to LEED-H Silver standards, the ENERGY STAR actually consumed about 12% less natural gas per square foot per year. Normalizing for weather variation, the actual use of the ENERGY STAR home rises about 5% to .19therms/ft\(^2\)/year, still 9% less than the normalized natural gas consumption of the home built to LEED-H Silver standards.

As with the home built to LEED-H Silver standards, we were able to conduct two interviews with the homeowners of the ENERGY STAR home. From those interviews we were able to adjust the building model to account for user habits. With these adjustments, the model for the ENERGY STAR home predicted that the occupants would consume approximately .27therms/ft\(^2\) of natural gas per year, a difference of 5% from the original prediction—still a poor guide of actual natural gas consumption in the home, which remains 35% below the adjusted estimate.

There are some possible reasons for this discrepancy. First, while the basement is considered “conditioned space” and the homeowners had it finished after moving in, it is not as well regulated as the other floors of the home. Second, the home has a two-zone heating and cooling system, one zone for each of the upper floors. The basement’s temperature is thus regulated in tandem with the first floor which may have some impact on the comfort of the space. For example, if the first floor is heated to 68 degrees, the basement may only achieve a temperature of 65 or 66; the calculations of the model assume that the space is heated uniformly to 68 degrees.

As with the electricity consumption, while the home built to LEED-H Silver standards was predicted to consume less natural gas than the ENERGY STAR home, in actuality, the opposite was true. The ENERGY STAR home consumed about 9% less than the home built to LEED-H Silver standards. However, although the REM/Rate model was a strong predictor of natural gas use for the home built to LEED-H Silver standards, it was a poor predictor for the ENERGY STAR home—even when adjusting for user habits obtained during two interviews with the homeowners.

Tables 8a–8c below compare the predicted natural gas consumption rates of the home built to LEED-H Silver standards and the ENERGY STAR home as well as actual consumption rates. Figure 26 is a graphical representation of this data.

Again, as we do not have a REM/Rate model for the Code Plus home, the NJ Code Home model used as a baseline for comparison above is a reasonable approximation of how much natural gas the Code Plus home was expected to consume—about .42therms/ft\(^2\)/year. The actual natural gas consumption of the Code Plus home during year 1 of this study (November 2008 – October 2009) was .25therms/ft\(^2\)/year and .21 therms/ft\(^2\)/year for year 2 (November 2009 – October 2010) or

\(^{48}\) Natural gas utility bills were only available for the second year of the study for the ENERGY STAR home.
40% and 49% less than expected respectively as compared to the NJ Code Home model—relatively close to the natural gas consumption levels of the ENERGY STAR home and the home built to LEED-H Silver standards. Normalizing for weather variation, year 1 consumption was .25 therms/ft²/year and year 2 was .22 therms/ft²/year. This unexpected result likely has to do with the fact that the homeowners prefer to keep their thermostat set at 65°F during the colder months.

Again, as with electricity consumption, the Code Plus home consumes more natural gas per square foot per year than either of the other two homes. The following table compares the year 2 predicted consumption rates of both the home built to LEED-H Silver standards and the ENERGY STAR homes, the actual consumption rates of all three homes, as well as the predicted natural gas consumption of the NJ Code Home.

Figure 25: Predicted Natural Gas Consumption

<table>
<thead>
<tr>
<th></th>
<th>NJ Code Home</th>
<th>LEED-H Stds</th>
<th>ENERGY STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>therms/ft²/year</td>
<td>0.423</td>
<td>0.214</td>
<td>0.284</td>
</tr>
</tbody>
</table>
Table 8a: Comparison of Predicted and Actual Natural Gas Consumption of Home Built to LEED-H Silver Standards and ENERGY STAR home with a Baseline NJ Code Home
October 2009 – November 2010

<table>
<thead>
<tr>
<th></th>
<th>Predictive Models (therms/ft²/year)</th>
<th>Actual Consumption (therms/ft²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original User Habits Raw Data Normalized</td>
<td></td>
</tr>
<tr>
<td>NJ Code Home</td>
<td>.42</td>
<td>.20 .21</td>
</tr>
<tr>
<td>LEED Standards</td>
<td>.21 .24</td>
<td>.20 .21</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>.28 .27</td>
<td>.18 .19</td>
</tr>
</tbody>
</table>

Source: MaGrann Associates REM/Rate analysis

Table 8b: Comparison of Predicted and Actual Natural Gas Consumption of Home Built to LEED-H Silver Standards and ENERGY STAR Home with a Baseline NJ Code Home by Percentage
October 2009 – November 2010

<table>
<thead>
<tr>
<th></th>
<th>Predictive Models</th>
<th>Actual Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original User Habits</td>
<td>Raw Data Normalized</td>
</tr>
<tr>
<td>NJ Code Home*</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>LEED Standards</td>
<td>-50% -45%</td>
<td>-52% -50%</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>-33% -36%</td>
<td>-57% -55%</td>
</tr>
</tbody>
</table>

*Note: All of the percentages are as compared to the NJ Code Home predicted value in the first column. A negative value demonstrates a lower natural gas consumption rate and a positive value demonstrates a higher natural gas consumption rate.

Source: MaGrann Associates REM/Rate analysis
Table 8c: Comparison of Predicted Natural Gas and Actual Natural Gas Consumption of Home Built to LEED-H Silver Standards and ENERGY STAR Home, October 2009 – November 2010

<table>
<thead>
<tr>
<th></th>
<th>Predictive Models (therms/ft²/year)</th>
<th>Actual Consumption (therms/ft²/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original User Habits</td>
<td>Raw Data Normalized</td>
</tr>
<tr>
<td>LEED Standards</td>
<td>.21 .24</td>
<td>.20 .21</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>.28 .27</td>
<td>.18 .19</td>
</tr>
<tr>
<td>% Difference*</td>
<td>25% 11%</td>
<td>-11% -11%</td>
</tr>
</tbody>
</table>

*Note: All of the percentages compare the ENERGY STAR home to the home built to LEED-H Silver standards. A negative value demonstrates a lower natural gas consumption rate for the ENERGY STAR home and a conversely, positive value demonstrates a higher natural gas consumption rate.

** Note: The ENERGY STAR home did not have any outlier months of electricity consumption.

Source: MaGrann Associates REM/Rate analysis
JCP&L electric bills November 2008-October 2009

Figure 26: Comparison of Natural Gas Use for the Home Built to LEED-H Silver Standards and the ENERGY STAR Home to Baseline NJ Code Home Model, October 2009 – November 2010
Table 9: Design vs. Actual Natural Gas Usage Comparison (Year 2)

<table>
<thead>
<tr>
<th></th>
<th>NJ Code Home</th>
<th>LEED-H Standards</th>
<th>ENERGY STAR</th>
<th>Code Plus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original Model</td>
<td>User Habits</td>
<td>Original Model</td>
<td>User Habits</td>
</tr>
<tr>
<td>Heating (therms)</td>
<td>945</td>
<td>393</td>
<td>395</td>
<td>806</td>
</tr>
<tr>
<td>Water Heating (therms)</td>
<td>240</td>
<td>154</td>
<td>228</td>
<td>141</td>
</tr>
<tr>
<td>Lights and Appliances (therms)</td>
<td>104</td>
<td>104</td>
<td>104</td>
<td>89</td>
</tr>
<tr>
<td>Annual therms</td>
<td>1289</td>
<td>651</td>
<td>727</td>
<td>1036</td>
</tr>
<tr>
<td>Annual therms/ft²</td>
<td>0.423</td>
<td>0.214</td>
<td>0.239</td>
<td>0.284</td>
</tr>
</tbody>
</table>

Actual Use

|                      | Annual therms/ft² | 0.198 | 0.177 | 0.213 |
|                      | Annual therms/ft² (Normalized) | 0.205 | 0.186 | 0.222 |

Source: MaGrann Associates REM/Rate analysis, Rutgers Center for Green Building
NJ Natural Gas utility bills November 2009-October 2010

Figure 27: Design vs. Actual Natural Gas Usage Comparison (Year 2)

Source: MaGrann Associates REM/Rate analysis
NJ Natural Gas utility bills November 2009-October 2010
Conclusions

- As expected, the Home Built to LEED-H Standards outperforms a home built to code in every category of energy consumption.
  - The Home Built to LEED-H standards was expected to consume about 25% less electricity than a home built to code. At first glance, actual electricity consumption appeared to be much higher than predicted (only 3% less than the code home), but when the total amount consumed was normalized by degree days and extraordinary electricity consumption events were considered, the amount consumed fell to 23% less than the home built to code—much more closely aligned with what was expected. This demonstrates that, because of the diverse uses of electricity, it is very difficult for a model alone to capture how electricity will be used in a home; only with the complement of homeowner interviews were the gaps between the modeled and the actual consumption rates able to be addressed.
  - The Home Built to LEED-H Silver standards was modeled to consume about 49% less natural gas than a home built to code and actually consumed about 52% less.

- Contrary to expectations, the Home Built to LEED-H Silver standards is not performing as well as the ENERGY STAR home.
  - The Home Built to LEED-H Silver standards was expected to consume about 12% less electricity than the ENERGY STAR home, but actually consumed about 22% more.
  - The Home Built to LEED-H Silver standards was expected to consume about 25% less natural gas than the ENERGY STAR home, but actually consumed about 11% more.
  - There are several possible explanations for this discrepancy. First, the ENERGY STAR home has fewer occupants, with one of the primary occupants traveling a good deal of the time thus reducing overall electricity use. Second, the ENERGY STAR homeowners use a ceiling fan “whenever possible.” Finally, the ENERGY STAR home uses a two-zone heating a cooling system to heat three floors as compared to the Home Built to LEED-H Silver standards five-zone system to heat three floors. The modeled consumption rates assume uniform heating and cooling throughout the house, which the Home Built to LEED-H Silver standards can more realistically achieve than the ENERGY STAR home. This discrepancy may inflate the predicted energy consumption of the ENERGY STAR home.

Table 10 shows a list of factors that may have had some influence on the differential rates of energy consumption in the different homes.
### Table 10: User Habits that May Serve as Explanatory Factors for Differential Energy Usage

<table>
<thead>
<tr>
<th>Explanatory Factor</th>
<th>Direction: Increases energy use (+) vs. decreases energy use (-)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>LEED-H Home</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different design vs. actual temperature set-points</td>
<td>-</td>
<td>Occupants prefer temperatures warmer in the summer and cooler in the winter than was assumed for the design model.</td>
</tr>
<tr>
<td>Different design vs. actual occupancy schedules</td>
<td>+</td>
<td>Husband works away from the house between the hours of 8am-6pm, and stay-at-home mom cares for young child under the age of two.</td>
</tr>
<tr>
<td>Different design vs. actual occupancy characteristics and activities</td>
<td>Base load to heat/cool home stays the same</td>
<td>Five design vs. four actual occupants (two adults and two small children)</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>Occupants almost always cook meals at home.</td>
</tr>
<tr>
<td><strong>ENERGY STAR Home</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different design vs. actual temperature set-points</td>
<td>-</td>
<td>Occupants prefer temperatures warmer in the summer and cooler in the winter than was assumed for the design model.</td>
</tr>
<tr>
<td>Different design vs. actual occupancy schedules</td>
<td>-</td>
<td>Husband travels abroad 3-5 days each week; and stay-at-home mom cares for young child under the age of two, and works part-time during the day on laptop.</td>
</tr>
<tr>
<td>Different design vs. actual occupancy characteristics and activities</td>
<td>-</td>
<td>Five design vs. three actual occupants (two adults and one small child)</td>
</tr>
<tr>
<td></td>
<td>+</td>
<td>Occupants always cook meals at home.</td>
</tr>
<tr>
<td><strong>Code Plus Home</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Different design vs. actual temperature set-points</td>
<td>+</td>
<td>Occupants prefer temperatures cooler in the summer than was assumed for the design model.</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Occupants prefer temperatures cooler in the winter than was assumed for the design model.</td>
</tr>
<tr>
<td>Different design vs. actual occupancy schedules</td>
<td>+</td>
<td>Two adult occupants work from home five days per week. (Follow-up: Check on work hours and check on design assumptions)</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Occupant’s profession requires frequent business trips that range from a few days to a week or more at a time. (Follow-up: Check on details of travel schedule)</td>
</tr>
<tr>
<td>Different design vs. actual occupancy characteristics and activities</td>
<td>Base load to heat/cool home stays the same</td>
<td>Five design vs. two actual occupants</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>Occupants rarely cook meals at home.</td>
</tr>
</tbody>
</table>
Water Usage

PURPOSE

This assessment is an analysis of the metered water consumption of the home built to LEED-H Silver standards between January 2009 and September 2010. The consumption rates will also be compared with the Code Plus home where data is available (April 2008 – March 2010) as well as water consumption levels reported by the Aquacraft, Inc. Water Engineering and Management in various water consumption studies conducted over the past several years. These studies include Mayer et al 2000, Mayer et al 2003 and Mayer et al 2004.

INTRODUCTION

Buildings occupants use 14% of the total potable water consumed in the United States, and the residential sector represents 7% of this total. The average person uses 69.3 gallons of water each day, about 70% of which is used indoors, mostly in the bathroom; the toilet alone can use 27% of household water (See Figure 28 below).

Water conservation measures such as installing water-efficient fixtures (e.g., low flow faucets and shower heads, and high-efficiency toilets) combined with water-conserving behaviors (e.g., shorter showers) can cut water consumption by about 35% to about 45.3 gallons per capita per day (See Table 11 below).

Water efficiency (WE) is one of the eight categories outlined in LEED-H. It accounts for 15 of a total of 63.5 credits required to achieve LEED Silver certification (24%). The home built to LEED-H standards in this study was designed to achieve six WE LEED points: three points for installing very high efficiency fixtures and fittings (e.g., 1.5 gpm low-flow faucets, 2.0 gpm low-flow showerheads, and 1.6/0.8 gpf dual-flush toilets), and three points for installing a rainwater harvesting systems (e.g., rain barrels and rain garden).

---

Figure 28: U.S. Average Single-Family Home Water Consumption by End-Use

Table 11: Comparison of Daily per Capita Water Consumption

<table>
<thead>
<tr>
<th>Use</th>
<th>Conventional</th>
<th></th>
<th>Water Conservation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Gallons</td>
<td>Percent</td>
<td>Gallons</td>
<td>Percent</td>
</tr>
<tr>
<td>Showers</td>
<td>11.6</td>
<td>16.7%</td>
<td>8.8</td>
<td>19.4%</td>
</tr>
<tr>
<td>Clothes Washers</td>
<td>15.0</td>
<td>21.6%</td>
<td>10.0</td>
<td>14.4%</td>
</tr>
<tr>
<td>Dishwashers</td>
<td>1.0</td>
<td>1.4%</td>
<td>0.7</td>
<td>1.0%</td>
</tr>
<tr>
<td>Toilets</td>
<td>18.5</td>
<td>26.7%</td>
<td>8.2</td>
<td>18.1%</td>
</tr>
<tr>
<td>Baths</td>
<td>1.2</td>
<td>1.7%</td>
<td>1.2</td>
<td>2.6%</td>
</tr>
<tr>
<td>Leaks</td>
<td>9.5</td>
<td>13.7%</td>
<td>4.0</td>
<td>8.8%</td>
</tr>
<tr>
<td>Faucets</td>
<td>10.9</td>
<td>15.7%</td>
<td>10.8</td>
<td>23.8%</td>
</tr>
<tr>
<td>Other Domestic Uses</td>
<td>1.6</td>
<td>2.3%</td>
<td>1.6</td>
<td>3.5%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>69.3</strong></td>
<td><strong>100.0%</strong></td>
<td><strong>45.3</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

* Yearly Total

* Totals may not sum due to rounding

METHODOLOGY

The actual water consumption of the home built to LEED-H Silver standards was obtained from the quarterly utility bills from January 2009 through September 2010. For comparison with the literature, data from field studies of single-family homes and with and without water-efficient fixtures and appliances will be presented (e.g., Mayer et al., 1999; Mayer et al., 2003).

RESULTS AND DISCUSSION

Home Built to LEED-H Silver Standards

The home built to LEED-H Silver standards consumed, on average, 10,301 gallons per quarter between January 2009 and September 2010 for a total of 45,455 gallons consumed in 2009 and 26,653 gallons in the first three quarters of 2010. Per capita consumption between January 2009 and March 2010 was on average 41.5 gallons per day (gpd) based on three individuals living in the home. A fourth member of the household was born in the first quarter of 2010. Water consumption per capita fell to 24.0 gpd in the second and third quarter of 2010 based on four individuals living in the home. Figure 29 and Figure 30 show the total water consumption of the home built to LEED-H Silver standards and per capita water consumption. Of note is the relative decline in absolute water consumption of the occupants of the Home Built to LEED-H Silver standards over the course of the study.

Figure 29: Water Consumption Rates of the Home Built to LEED-H Standards, January 2009 (Quarter 1 of 2009) to September 2010 (Quarter 3 of 2010)
Figure 30: Daily Water Consumption per Capita of the Home Built to LEED-H Standards by Quarter, January 2009 to September 2010

Comparison of Home Built to LEED-H Standards with Code Plus Home

Water consumption data was available from April 2008 (Quarter 2 of 2008) to March 2010 (Quarter 1 of 2010). Although the period over which data was available for both the Code Plus home and the Home Built to LEED-H Standards were not identical, there is some overlap and a comparison is useful.

The Code Plus home consumed, on average, 22,270 gallons of water per quarter between April 2008 and March 2010, about 54 percent more than the Home Built to LEED-H Silver standards. The Code Plus home consumed a total of 80,063 gallons in quarters 2-4 of 2008, 81,522 gallons in 2009 (Q1-Q4), and 16,572 gallons in the first quarter of 2010. Per capita consumption on average was 122.0 gpd over the course of the study.

Figures 31 and 32 show a comparison of water consumption of the Home Built to LEED-H Silver standards and the Code Plus home normalized by square feet and by per capita, respectively. The homeowners indicated that they had significantly reduced the frequency with which they ran their washing machine, especially when switching from cloth diapers for their children to disposables.
Comparison of Home Built to LEED-H Silver Standards to Studies of End-Use Water Consumption

To further elucidate the water consumption levels of the Home Built to LEED-H Silver standards, we report the findings of three studies conducted by Aquacraft, Inc. Water Engineering and Management in Seattle, Washington, the Tampa Area in Florida and the East Bay Area in California. For each study, surveys were conducted of residential end-use water consumption. Although the surveys did not specifically exclude homes with high performance appliances or ENERGY STAR
compliant water fixtures, the samples collected was randomized to be representative of single family homes in the respective areas. Given the time-frame the studies were conducted, one would expect that the majority of homes had not yet adopted energy efficient appliances and low-flow water fixtures. The results are as follows:

Table 12: Comparison of Water Consumption in Single-Family Homes Surveyed Throughout the Nation with 2009 Water Consumption Rates of Home Built to LEED-H Silver Standards and Code Plus Home

<table>
<thead>
<tr>
<th>Study</th>
<th>Years</th>
<th>Sample Size</th>
<th>Avg Annual Water Use</th>
<th>Avg Quarterly Water Use</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayer 2003</td>
<td>1999-2000</td>
<td>1,000</td>
<td>106,842</td>
<td>26,711</td>
<td>East Bay, CA</td>
</tr>
<tr>
<td>Mayer 2004</td>
<td>2002</td>
<td>986</td>
<td>83,862</td>
<td>20,966</td>
<td>Tampa Bay Area, FL</td>
</tr>
<tr>
<td>LEED-H Standards</td>
<td>2009</td>
<td>-</td>
<td>45,455</td>
<td>11,364</td>
<td>Monmouth County, NJ</td>
</tr>
<tr>
<td>Code Plus</td>
<td>2009</td>
<td>-</td>
<td>81,522</td>
<td>20,381</td>
<td>Monmouth County, NJ</td>
</tr>
</tbody>
</table>

As can be seen by the table above, the Home Built to LEED-H Standards outperforms the homes in the other studies by a relatively wide margin. However, a weakness in the comparison may lie in the fact that water consumption varies by year and by geography depending on variations in the weather. None of the studies utilized looked at homes during the same time period or in the same region as this study. Still, the data shown are diverse in their geography and time period, providing a reasonable range of annual water consumption for single family homes throughout the country. The purpose of the comparison is served: on average, the Home Built to LEED-H Standards consumes less water annually than the average home across the United States.

Unfortunately, we are not able to distinguish between indoor and outdoor water use of the Home Built to LEED-H Silver standards nor were we able to monitor how water was used, (i.e., what percentage was used for showering, what percentage for laundry, dishwashing, etc.). Therefore it is difficult to distinguish absolutely the impacts of the high-efficiency water fixtures installed in the Home Built to LEED-H Silver standards from the impacts of the users habits themselves. However, the studies mentioned above have shown impacts of homes outfitted similarly to the Home Built to LEED-H Silver Standards.

Before reviewing the results of the Aquacraft Inc. studies, it is important to keep in mind that the studies examined a sample of existing homes retrofitted with high-efficiency plumbing fixtures whereas the homes presented in this case study are newly built. As building codes have improved over time, the standards of water efficiency have increased. Therefore the homes built today would necessarily be more water efficient than homes built 5, 10, or 20 years ago. The age of the homes are not indicated in the studies. Also, leaks are a significant source of water “consumption” in homes throughout the United States. Presumably, with new construction leaks are not as much of an issue. Finally, the studies were also done over a period of four weeks—two weeks to track the
usual water consumption of the home and two weeks to track the consumption of the home with high-efficiency plumbing fixtures.

Overall, the impacts of high-efficiency plumbing fixtures on water consumption was significant. In Seattle, mean daily indoor demand for water dropped 39 percent overall and per capita use decreased in 35 of the 37 homes studied after the installation of the improved fixtures (Mayer, et. al. 2000). Statistically significant changes in water use at the 99 percent confidence level were found for clothes washers, faucets, leaks and total indoor use. In the East Bay Area of California, mean daily indoor demand dropped 35.5 percent and average daily per capita use decreased in 31 of 33 homes (Mayer, et. al. 2003). There were statistically significant changes at the 95 percent confidence level for water use for clothes washers, leaks, toilets, and total indoor use. In the Tampa Bay Area, water consumption dropped 46.3 percent and average daily per capita use decreased in all 26 of the homes studied. Statistically significant changes in water consumption were found for clothes washers, faucets, leaks, showers, toilets, water treatment, indoor use, miscellaneous other use and total indoor use. The following Table 13 summarizes the results.

Table 13: Results of Impact Studies of High Efficiency Plumbing Fixtures*

<table>
<thead>
<tr>
<th>Study/Region</th>
<th>Sample Size</th>
<th>% Reduction in Water Use</th>
<th>Water Use Category Reduced as a Result of High-Efficiency Plumbing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mayer 2000 Seattle, WA</td>
<td>37</td>
<td>39.0%</td>
<td>• Clothes washers • Total indoor use</td>
</tr>
<tr>
<td>Mayer 2003 East Bay, CA</td>
<td>33</td>
<td>35.5%</td>
<td>• Clothes washers • Total indoor use • Leaks</td>
</tr>
<tr>
<td>Mayer 2004 Tampa Bay Area, FL</td>
<td>26</td>
<td>46.3%</td>
<td>• Clothes washers • Showers • Water treatment • Total indoor use</td>
</tr>
</tbody>
</table>

* Note: All results are statistically significant at least the 95 percent level.

CONCLUSIONS

The findings in the literature cited above clearly show that high-efficiency plumbing and water fixtures reduce water consumption dramatically. The comparison of the Home Built to LEED-H Silver standards and the Code Plus home confirm these findings as the four occupants of the Home Built to LEED-H Silver standards used nearly 45% less water than the two Code Plus occupants. While the reduced water consumption is clear, it is impossible to determine how much of it is due to improved technology and how much is due to the “green” habits of the homeowners.

FUTURE RESEARCH

In order to further understand water consumption patterns in high performance single family homes in New Jersey, a possible study could involve the randomized sampling of code homes to a
randomized sampling of either ENERGY STAR or LEED-H Certified homes. A simple comparison of utility bills would work on a basic level, but for the sample of high performance homes, the actual use of the water could be carefully monitored over the course of the study thus providing a more nuanced understanding of water consumption habits. As discussed above, it is difficult to parse out what percentage of water consumption savings is due to improved technology and what reductions are due to the “green” habits of the homeowners.

REFERENCES


Indoor Air Quality

**PURPOSE**

The purpose of this indoor air quality assessment is to determine whether green building practices in general have an impact on indoor volatile organic compound (VOC) levels, and to determine whether the specific types of green building standards have varying impacts on indoor VOC levels. For this purpose, VOC levels were measured in both the LEED-H home and ENERGY STAR home, and their results will be compared to each other and to conventional homes in the literature.

**INTRODUCTION**

Researchers agree that human exposure to volatile organic compounds (VOCs), carbon monoxide, carbon dioxide, particulates, and airborne microorganisms are related to health problems. However, there is an inadequate scientific understanding of the interrelationships among indoor chemical reactions, indoor pollutant exposures, health symptoms, building features and maintenance practices, and occupant behavior. In addition, some findings even provide conflicting data regarding the health risks caused by certain pollutants. Furthermore, there is insufficient scientific understanding of indoor air quality (IAQ) effects of emerging contaminants such as brominated flame retardants (which are found in building materials), textiles, polyurethane padding in furniture and carpets and printed circuit boards of electronic household equipment.

The effect of green building practices on IAQ is even less well understood. Green buildings are high-performance buildings that have been designed to minimize environmental impacts due to low-emitting building materials, sensitive land-use, decreased energy and water consumption, and enhanced IAQ. Thus far, however, IAQ research has focused almost exclusively on conventional buildings with few studies assessing the effects of green buildings on IAQ. As a “green” designation is becoming a relevant selling point for buildings, and as the innovative products and practices found in green buildings are becoming more common, the need to assess the impact of green building on IAQ is becoming a high priority for those investigating the health and well-being of building occupants.

Indoor Environmental Quality (IEQ) is one of the eight categories outlined in LEED for Homes (LEED-H). It accounts for 21 of a total of 136 available credits, of which at least 60 are required to achieve LEED Silver certification. The LEED-H home in this study attained 17 IEQ LEED points.

In this study, VOCs were measured in both the LEED-H and ENERGY STAR homes. Each home was built to a different “green” building standard.

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METHODOLOGY

Levels of volatile organic compounds (VOCs) were measured using passive sampling devices in both the LEED-H and ENERGY STAR home. The first round of sampling was conducted before the owners moved into the houses. For this purpose, the ENERGY STAR home was sampled on May 27, 2009, and LEED-H home was sampled on Nov 19-20, 2008. A second round of sampling was performed after the owners had occupied the houses for several months. This post-occupancy sampling was conducted at both homes on October 20, 2009.

Sampling devices

The passive sampling devices deployed were 3500 OVM (organic vapor monitor) badges from 3M corporation. These were selected because they are inexpensive, silent, and small so they do not disrupt the occupants. Details of the performance of the VOC badges are explained in Chung et al. (1999).

Pre-occupancy sampling

Badges deployed at ENERGY STAR home on 5/27/09 from 12:30 to 12:45 pm. Badge 1 (CN5345) was hung from the pull cord for the attic stairs on the second floor landing. The thermostat nearby reported the indoor temperature to be 68°F and the RH was 46%. Badge 2 (CN5344) was hung from the pull cord of the ceiling fan in the living room on the first floor. The first floor thermostat recorded the temperature to be 65°F and RH 62%. Badge 3 (CN5335) was hung from a piece of string from the ductwork near the back of the basement. Badge 4 (CN5415) was hung using a piece of string from one of the can lights on the front porch. Badges were retrieved on 5/29/09 from 12:16 to 12:29 pm. We collected one blank (CN5378) by opening the metal can and immediately removing the dust cover, replacing it with the plastic cap and placing it on ice. During retrieval, the upstairs thermostat registered 68°F and 44% Rhythm first floor thermostat registered 64°F and 60% RH.

For all badges, the dust covers were removed and the clear plastic caps were snapped on. Because the white caps for the metal canisters were not available, the badges were placed on ice and driven immediately to the Meadowlands Environmental Research Institute (MERI). The samples arrived at MERI at about 1:55 pm and were handed to Jin Young Shin, who immediately placed them in the -20°C freezer.

Pre-occupancy sampling of the LEED-H home was conducted Nov 19-20, 2008. After sample collection, the badges were driven directly to MERI. Badges were deployed in the basement (CN5372), first floor (CN5329), second floor (CN5386) and outdoors (CN5379).

Post-occupancy sampling

These badges were deployed in both study homes on October 20, 2009. Badges were deployed at the ENERGY STAR home around 9:45 am in the following locations (as close as possible to the location used in the pre-occupancy deployment): basement (CN5348), first floor (CN5343), second floor (CN5334), and outdoor (CN5327). The windows in the home were open during deployment.
Analysis

Prior to analysis, the charcoal pad was removed from the badge and transferred to a 1.8 mL GC vial. Then, 1.8 mL of the extraction solvent consisting of a 2:1 v/v mix of acetone and carbon disulfide was added into the vial and spiked with 10 µL of surrogate. The vials were transferred to a holding tray and sonicated with crushed ice for 45 minutes to obtain the final sample extract. Immediately after this, 200 µL of the sample were withdrawn from the sample extracts, and transferred into a sample coded 1.8 mL vial. Before the sample injection, 10 µL of internal standard solution was added into the vial and the vials were placed on the auto-sampler tray for GC-MS analysis. All extracts were analyzed using a coupled gas chromatograph/mass spectrometer (GC/MS) from Hewlett-Packard (Palo Alto, USA), model 6890 GC and 5975 Inert Mass Selective by electron impact (EI) ionization. An RTX-624 (60 m x 250 µm x 1.4 µm) capillary column (Restek, PA) was used with helium as the carrier gas and temperature programming from 30 °C (5 min) to 250 °C at 10 °C min⁻¹. 1 µL was injected in the split-less mode into a split/splitless injector. Duplicate samples were collected during the sampling period and relative standard deviations (RSD) between duplicates were less than 10% for all compounds. Data were blank corrected wherever necessary.

RESULTS AND DISCUSSION

Complete results from are provided in the Appendixes.

Pre-occupancy

Of the 57 VOCs we attempted to measure, 24 were not detected in any of the pre-occupancy samples. 34 were detected in one or more samples. Although it is difficult to generalize from such a small number of samples, it appears that many of these 34 VOCs are higher indoors than outdoors, as expected. This is especially true at both homes for toluene, ethylbenzene, m,p-xylene, o-xylene, styrene, isopropylbenzene, bromobenzene, propylbenzene, 1,3,5-trimethylbenzene, 4-chlorotoluene, tert-butylbenzene, 1,2,4-trimethylbenzene, sec-butylbenzene, and p-isopropyl toluene. At the Home Built to LEED-H Silver standards, 1,1,2,2-tetrachloroethane was also significantly higher indoors. At the ENERGY STAR home, bromodichloromethane was elevated indoors.

Comparing the two homes, bromodichloromethane, o-xylene, styrene, isopropylbenzene and p-isopropyl toluene were higher at the ENERGY STAR home than the Home Built to LEED-H Silver standards. Toluene, trans-1,3-Dichloropropene, 1,1,2-Trichloroethane, Ethylbenzene, m,p-Xylene, 1,1,2,2-Tetrachloroethane, sec-Butylbenzene were generally higher at the Home Built to LEED-H Silver standards. Here we take a difference of a factor of 2 to be significant. This is an arbitrary
cutoff. To run any statistical tests to determine whether these differences are statistically significant would require larger sample sizes. The differences between the two houses are, in general, small. Thus there is no indication in this data set that one type of construction is better than another in terms of indoor VOC levels.

Of these 34 compounds, 23 were measured by Weisel et al. [3] in a study of VOC levels in indoor air in residential homes in New Jersey. The Weisel et al. study used a canister-based sampling apparatus, but the results should still be roughly comparable. A comparison of the results of the present work and the Weisel et al. study is presented in Table 1. In this table, “NM” means that the Weisel et al. study did not attempt to measure this compound, while “ND” means that they attempted to measure it but it was not detected in any samples. This comparison suggests that most compounds were within the range of values typically encountered in New Jersey homes. The exceptions are o-xylene, styrene, and 1,3,5-trimethylbenzene. These are three structurally similar compounds with alkyl groups attached to benzene. O-xylene and styrene were somewhat elevated in the ENERGY STAR home. In this home, o-xylene was above the 95th percentile concentration in the second floor sample only, while styrene was above the maximum level recorded in the Weisel et al. study in both the first and second floor samples. In the Home Built to LEED-H Silver standards, the o-xylene concentrations were between the 75th and 90th percentile concentrations reported by Weisel et al. The styrene levels in the Home Built to LEED-H Silver standards were above the maximum reported by Weisel et al. in the basement and above the 95th percentile on the first and second floors. In both homes 1,3,5-trimethylbenzene was above the 95th percentile concentration but below the maximum concentration measured by Weisel et al. None of these “high” levels were particularly striking, however. The largest discrepancy between the Weisel et al. study and our results was for styrene in the second floor sample from the ENERGY STAR home, but even this concentration was less than a factor of three higher than Weisel et al.’s maximum concentration. Although above we have arbitrarily designated a factor of 2 to be “significant”, this elevated concentration is still not particularly worrisome.

Pre-occupancy testing generally indicated that the VOC levels in both homes were close to normal for suburban New Jersey. However, VOC levels are typically elevated in new construction due to off-gassing from construction materials. Thus the fact that the levels observed in the pre-occupancy samples are similar to levels measured in existing homes by Weisel et al. may indicate that the “green” construction practices are effective at limiting indoor VOC levels soon after construction.

Post-occupancy

Twenty-three of the 57 VOCs measured were below detection limit in all of the post-occupancy samples. Outdoor VOC levels were generally lower than indoor levels, but this difference was less pronounced than in the pre-occupancy samples. This may indicate that off-gassing of VOCs from the VOC-containing materials in these homes has slowed.

Home Built to LEED-H Silver Standards

Again we took a factor of 2 as our threshold for significance. By this criterion, only toluene, ethylbenzene, m,p-xylene, o-xylene, and 1,3,5-trimethylbenzene were significantly elevated above
outdoor levels at the Home Built to LEED-H Silver standards. These structurally-related compounds were also elevated indoors during the pre-occupancy sampling event. Styrene, isopropylbenzene, bromobenzene, tert-butylbenzene, p-isopropyl toluene, 1,4- and 1,3-dichlorobenzene, 1,2-dichlorobenzene and naphthalene were detected indoors but not outdoors.

Concentrations of most VOCs decreased from pre- to post-occupancy. All five of the VOCs that were significantly higher in the indoor samples had declined substantially from the pre-occupancy period. Average declines for toluene, ethylbenzene, m,p-xylene, o-xylene, and 1,3,5-trimethylbenzene were 58%, 62%, 60%, 61%, 79%, and 81%, respectively. A few VOCs increased from pre- to post-occupancy: benzene and 2- and 4-chlorotoluene. The increase for benzene was less than a factor of 3, which may not be significant. 2- and 4-chlorotoluene concentrations were 10 to 40 times higher in the post-occupancy samples that in the pre-occupancy samples. These two chemicals are used in drain pipe solvents. 2-chlorotoluene is also used in air fresheners and deodorants, as well as “miscellaneous paint-related products” (www.scorecard.org). Thus it is possible that the elevated levels of these two chemicals in post-occupancy samples arose from the use of one of these materials by the homeowner.

1,2-dichloroethane, chlorobenzene 1,2,3-trichloropropane, and n-butylbenzene were not detected in pre-occupancy samples but were detected post-occupancy. 1,2-dichloroethaneis used in rug and upholstery cleaners, polystyrene manufacture, and latex production. Chlorobenzene is used in building and construction plastic foam insulation, including pipe and block, miscellaneous paint-related products, and other rubber floor and wall coverings including cove base, wainscoting, etc. (www.scorecard.org).

Energy Star Home

The relative concentrations of VOCs were somewhat different in the ENERGY STAR home vs. the Home Built to LEED-H Silver standards, possibly indicating different VOC sources. The main difference between the two homes was the high concentrations of 1,4- and 1,3-dichlorobenzene in the ENERGY STAR home. Each of these compounds had an average concentration of about 21 ug/m³ indoors during the post-occupancy sampling. These levels are above the 95% percentile concentrations measured by Weisel et al. In fact, 1,3-dichlorobenzene was analyzed but never detected by Weisel et al. These two compounds were virtually absent in the Home Built to LEED-H Silver standards and in the ENERGY STAR home in the pre-occupancy sampling. This probably indicates a source of these two compounds was introduced into the ENERGY STAR home sometime after the pre-occupancy sampling. Since 1,4-dichlorobenzene is mainly used in disinfectants [4], this source could be cleaning products used by the homeowner. According to www.scorecard.org, other uses of 1,4-dichlorobenzene are: building and construction plastic foam insulation, including pipe and block; deodorants/air fresheners (non-personal, non-aerosol); other rubber floor and wall coverings including cove base, wainscoting, etc.; repellants and attractants; scatter rugs, bathmats, and sets (rugs 6 x 9 ft and smaller).

1,1,2-trichloroethane, 1,1,2,2-tetrachloroethane were detected in post-occupancy samples but were below detection limit in the pre-occupancy sampling. Both of these chemicals are used in polystyrene manufacture as well as in wood stains and varnishes (www.scorecard.org).
As at the Home Built to LEED-H Silver standards, concentrations of most VOCs decreased from pre- to post-occupancy. Average declines for toluene, m,p-xylene, o-xylene, and 1,3,5-trimethylbenzene were 48%, 10%, 57%, and 73% respectively. Ethylbenzene concentrations were largely unchanged. Concentrations of bromodichloromethane, 1,2-dichloroethane, styrene, isopropylbenzene, bromobenzene, 1,2,3-trichloropropane, tert-butylbenzene, 1,2,4-trimethylbenzene, p-isopropyl toluene, and naphthalene all decreased from pre- to post-occupancy.

**Summary**

VOC levels in both homes were for the most part within the normal range of concentrations measured by Weisel et al. for New Jersey homes. Concentrations of most VOCs declined from pre- to post-occupancy, possibly indicating that any off-gassing of VOCs from building materials had slowed considerably by the time the post-occupancy samples were collected. The few VOCs that displayed notable increases in concentration from pre- to post-occupancy are linked to products that might have been used by the homeowner (such as deodorants and cleaning products), although they may also be associated with building products. If, as we suspect, these few increasing VOCs are associated with products used by the homeowner, this highlights the role of the occupant in maintaining IAQ. The reasonable levels of VOCs inside these two homes soon after construction may indicate that the choice of “green” building materials does in fact limit impacts on IAQ, at least where VOCs are concerned.

**References**


Life Cycle Cost (LCC) Analysis

PURPOSE

The purpose of this life cycle cost (LCC) analysis is to compare the total life cycle costs and net present value (NPV) associated with building the Home Built to LEED-H Silver standards and the ENERGY STAR home as compared to an IECC 2006 Reference Home. Actual energy use, natural gas and electricity prices, and costs are used for in calculating the NPV in both case study homes. It is important to note that the cost figures do not represent the entire building cost but rather are limited only to the features of the home taken into consideration by the energy model. These features include insulation, windows, heating and ventilation equipment, and some appliances. (A detailed breakdown of the costs for each component is provided below in Table 14).

INTRODUCTION

The life cycle cost (LCC) analysis is an economic tool used to examine the total costs associated with a building from its construction to its demolition. This “cradle-to-grave” assessment incorporates not only the initial costs but also the lifespan operating costs, so that a more complete picture of the total cost can be obtained. The LCC analysis is useful in the context of green building because green features characteristically have higher up-front costs but recover some or all of that cost over a certain period of time. The LCC therefore helps to determine the feasibility of such features from an economic standpoint. This assessment is concerned only with the factors affecting energy consumption and cost.

METHODOLOGY

In order to perform the LCC analysis, information on both construction costs and operating costs was needed. Construction costs were estimated based on the builder’s records, supplemented with data from R.S. Means online database. As noted previously, only the components of each building affecting its energy performance were included in the cost comparisons.

Energy consumption estimates for the three homes provided the basis for comparing their operating costs. To this end, energy modeling software called REM/Rate was utilized. MaGrann Associates, a residential energy and green building consulting firm based in Moorestown, NJ, performed REM/Rate analyses for both the LEED home and the ENERGY STAR home. Since these are projected figures, they do not forecast the actual usage necessarily; much of that is determined by occupant behavior, which may not be captured in an energy model. However, the energy model is particularly useful when comparing alternative building designs, as the differences between them can be analyzed easily. Although we have collected information about occupant behavior, the LCC analysis works best with standardized behavior to minimize variables and isolate the impacts of the physical improvements of the homes. Actual energy prices were used in the analysis. REM/Rate also provided the relative consumption and operating expenditure figures for the IECC 2006 reference home. For
this analysis, the 3,048 square foot IECC 2006 reference home provided in the LEED design model was used.

The second part of the LCC is the Net Present Value (NPV) analysis. Net present value refers to the total present value of the lifetime costs associated with a particular project. Aside from the environmental benefits of energy consumption reduction, it is expected that a decrease in the operational costs over a building’s lifetime will help mitigate the higher up-front costs associated with energy-efficient green buildings. Net present value, therefore, is an extremely useful economic tool in determining the true value of energy saving features in a building.

Once the three homes’ design case energy consumption values were modeled, they were tabulated in an LCC spreadsheet adapted from the one used for the Rutgers Center for Green Building’s Life Cycle Cost Analysis of the New NJMC Building, Final Report, May 2008. The IECC 2006 reference home was used as the “base” model for comparison purposes. The three homes were evaluated on a discrete basis as well as relative to the reference home. In order to account for the differences in building sizes, all analyses were normalized by square footage.

Finally, several sensitivity analyses were performed. A sensitivity analysis examines the effect that different factors have on the relative NPVs of the projects. In this LCC analysis, there are three factors considered in this regard: future energy costs, discount rate, and building lifespan.

RESULTS AND DISCUSSION

Initial Investment

As expected, the initial construction costs of the improved efficiency components of the Home Built to LEED-H Silver standards was $52,417, or $17.73/ft², higher than either the ENERGY STAR home ($49,910 or $13.69/ft²) or the IECC 2006 home ($36,543 or $11.99/ft²). The primary driver of this cost difference is the insulation system of the Home Built to LEED-H Silver standards which was $20,753 or $6.81/ft²—a full 129% more per square foot than the IECC 2006 home. The cost for the insulation system installed in the Home Built to LEED-H Silver standards constituted 38.4% of the initial total cost of the energy model inputs. By contrast the ENERGY STAR home featured an insulation system that cost $15,685 (or $4.30/ft²) which amounts to 31.4% of that home’s total initial construction cost—the second most expensive component. The conventional insulation in the reference home cost $9,053 ($2.97/ft²), or 24.8% of its total. Insulation was the least costly component of the IECC 2006 home.

The mechanical heating and cooling equipment was the second most expensive component of the Home Built to LEED-H Silver standards, costing $6.46/ft², or 36.4% of the total initial cost. For both the ENERGY STAR home and the IECC 2006 home, the heating and cooling equipment were the most costly component of the energy features of the home, constituting 35.6% and 42.3% of the initial costs respectively. Although the heating and cooling equipment cost more per square foot in the Home Built to LEED-H Silver Standards than either the ENERGY STAR home or the IECC 2006 home, this demonstrates the comparative emphasis that the LEED-H standards places on improved
insulation and a tighter building envelope. (See Table 14 below for a comparison of the initial costs of materials and equipment used in the NPV analysis).

The question the LCC attempts to answers is whether or not these comparatively greater upfront costs of the Home Built to LEED-H Silver standards—without taking into consideration quality of life issues, user satisfaction, or reduced environmental impacts—are worth the economic investment over the life of the building.

Table 14: Costs of Materials/Equipment Included in NPV Analysis

<table>
<thead>
<tr>
<th></th>
<th>IECC 2006</th>
<th>LEED-H Standards</th>
<th>ENERGY STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$</td>
<td>$/ft²</td>
<td>% of total</td>
</tr>
<tr>
<td>Insulation</td>
<td>$9,053</td>
<td>$2.97</td>
<td>24.8%</td>
</tr>
<tr>
<td>Windows</td>
<td>$10,776</td>
<td>$3.54</td>
<td>29.5%</td>
</tr>
<tr>
<td>Mech. Equipment/ Heating and Cooling</td>
<td>$15,460</td>
<td>$5.07</td>
<td>42.3%</td>
</tr>
<tr>
<td>Appliances</td>
<td>$1,245</td>
<td>$0.41</td>
<td>3.4%</td>
</tr>
<tr>
<td>Total</td>
<td>$36,534</td>
<td>$11.99</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Source: Fluid Construction

Primary NPV Analysis

As a first step, a primary NPV analysis was conducted using a discount rate of 7.0, annual energy price escalation rates of 1.33% for electricity and 2.15% natural gas, and a 30-year building lifespan. The analysis included actual energy use of both the Home Built to LEED-H Silver standards and the ENERGY STAR home and the REM/Rate modeling for the IECC 2006 home. For the primary analysis, the Home Built to LEED-H Silver standards has a NPV of negative $29.22/ft², or about $0.90/ft² lower than the IECC 2006 baseline home (negative $30.12/ft²) and $5.66/ft² than the ENERGY STAR home which has an NPV of negative $23.56/ft². Negative values of NPV are to be expected as the value of a home declines over time; the “gains” associated with these negative values are the benefits accrued by the homeowners by occupying the home. This primary NPV analysis suggests that, from a purely economic perspective, the Home Built to LEED-H Silver is a slightly better long term investment than an IECC 2006 home, though the ENERGY STAR home appears to provide the most sound long term investment of the three homes. Table 15 shows the results of the primary NPV analysis as well as the initial costs of the high-efficiency improvements to the homes.
Table 15: Primary Net Present Value Analysis Results

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>IECC 2006</td>
<td>$11.99</td>
<td>$0.00</td>
<td>$0.00</td>
<td>($30.12)</td>
<td>$0.00</td>
</tr>
<tr>
<td>LEED-H Standards</td>
<td>$17.73</td>
<td>$5.74</td>
<td>$6.65</td>
<td>($29.22)</td>
<td>$0.90</td>
</tr>
<tr>
<td>ENERGY STAR</td>
<td>$13.69</td>
<td>$1.70</td>
<td>$8.26</td>
<td>($23.56)</td>
<td>$6.56</td>
</tr>
</tbody>
</table>

Note: A positive $/ft² relative to IECC 2006 value means that the model home has a greater surplus than the IECC 2006 building. Negatives means the modeled building costs more.

NPV Sensitivity Analysis

One of the challenges of conducting an LCC is that there is great uncertainty in several components of the forecasting. Three of the most important assumptions are the discount rate, predicted energy prices, and expected life-span of the building. In the following section, we conduct a sensitivity analysis of the NPV for each of the three homes based on those variables, thereby offering a wide range of NPV possibilities. The Home Built to LEED-H Silver standards has a positive NPV relative to the IECC 2006 home when the building lifespan increases, the discount rate decreases and the energy price escalation rates are higher, whereas the ENERGY STAR home has a positive NPV relative to the IECC 2006 home in all scenarios. We discuss each variable and their relative impact on the NPV in turn.

Building Life Span

In the sensitivity analysis, we include a 15-, 30-, and 50-year building lifespan to determine the impact of the building’s longevity on the NPV. As shown above, the Home Built to LEED-H Silver standards had a higher up-front cost than either the ENERGY STAR home or the IECC 2006 home, and the ENERGY STAR home had higher up-front costs than the IECC 2006 home. New homes built to higher efficiency standards will generally cost more up-front than their standard counterparts but, given all things equal, cost less to operate over the life-span of the building. Therefore, the NPV of higher-efficiency homes would be expected to increase in the sensitivity analysis as the building life-span is extended. Further, the greater a home’s energy efficiency, the greater impact the building life-span would have on the NPV. This is precisely what we find.

Given a 7.0% discount rate and the medium energy price escalation rates, (1.33% for electricity and 2.15% for natural gas), the NPV of the Home Built to LEED-H Silver standards relative to the IECC 2006 home was negative $1.26/ft² with a 15-year life span and positive $2.12/ft² with a 50-year life span.

53 Note: This LCC analysis does not consider replacement costs of the appliances, heating and cooling equipment, or insulation.
span, for a range of $3.38/ft^2. By comparison, the NPV of the ENERGY STAR home relative to the IECC 2006 home was $3.90/ft^2 with a 15-year life span and $8.05/ft^2 with a 50-year life span, for a range of $4.15/ft^2. (See Figure 33 below.)

The impact of the building lifespan on the NPV is significant. This implies that in order to realize a greater return on investment for high performance homes, building standards such as LEED-H or ENERGY STAR may consider incorporating quality standards rather than simply efficiency standards of the home’s high-performance components to ensure longevity that will help justify the investment over the long term.

**Figure 33: NPV Sensitivity Analysis Based on Building Lifespan, Relative to IECC 2006 Reference Home**

Note: A positive dollars/ft^2 relative to IECC 2006 value means that the model home has a greater surplus than the IECC 2006 building. Negatives means the modeled building costs more.

**Energy Price Escalation Rate**

For the NPV sensitivity analysis of energy prices, energy price escalation rates were derived from historical data from the Department of Energy, Energy Information Administration’s *Short Term Annual Energy Outlook*. The three cases/scenarios were 1) low, assuming a 0% energy price increase, which is consistent with the projections found in the 2010 *Annual Energy Outlook*, 2) medium, based on the historical increase in energy prices between 1992 and 2010 and 3) high, based on the historical increase in energy prices between 2000 and 2010. The derived rates are listed in Table 16 below.

In terms of NPV, higher performance homes—such as the Home Built to LEED-H Silver standards and the ENERGY STAR home—would benefit from higher energy escalation rates because they use less energy overall than their standard code-built counterparts. The higher the energy price for both electricity and natural gas, the greater the relative savings would be for the homeowners of high-performance homes.
Given a 7.0% discount rate and a building lifespan of 30 years, the NPV/ft² of the Home Built to LEED-H Silver standards relative to the IECC 2006 home was negative $0.37/ft² based on the low energy price escalation scenario and $2.90/ft² based on the high scenario, for a range of $2.53/ft². The NPV/ft² of the ENERGY STAR home relative to the IECC 2006 home was $5.03/ft² for the low economic growth scenario and $9.01/ft² for the high economic growth scenario, for a range identical to the Home Built to LEED-H Silver standards of $3.98/ft². (See Figure 34 below.)

Table 16: Projected Energy Price Escalation Rates for the Residential Sector in the Middle Atlantic Census Division

<table>
<thead>
<tr>
<th></th>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>0.00%</td>
<td>1.33%</td>
<td>3.31%</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>0.00%</td>
<td>2.15%</td>
<td>4.34%</td>
</tr>
</tbody>
</table>

Source: Rates derived from historic energy prices from USDOE EIA Short Term Annual Energy Outlook [http://www.eia.doe.gov/oiaf/aeo/tablebrowser/]

Figure 34: NPV/ft² Based on Energy Price Escalation Rate, Relative to IECC 2006 Reference Home

Discount Rate

Three different discount rates were analyzed in the NPV sensitivity analysis: 5.26%, 7.0% and 12.0%. The variation in discount rate, which represents the opportunity cost of the home’s investment, proved to have the most impact on the NPV sensitivity analysis. One would expect that the NPV of the higher performance homes would improve relative to code-built homes as the discount rate fell. This is because there is a greater up-front investment in the higher performance homes that requires many years of reduced energy bills to offset it.
Given the medium energy price escalation rate and a 30 year building lifespan, the NPV of the Home Built to LEED-H Silver standards relative to the IECC 2006 home was negative $2.42/ft² with a 5.26% discount rate and negative $1.64/ft² with a 12% discount rate for a range of $4.06/ft². The NPV of the ENERGY STAR home relative to the IECC 2006 home was $8.44/ft² with a 5.26% discount rate and $3.42/ft² with a 12% discount rate for a range of $5.02/ft². (See Figure 35 below).

**Figure 35: NPV Sensitivity Analysis Based on Discount Rate Relative to IECC 2006 Reference Home**

<table>
<thead>
<tr>
<th>Discount Rate Scenario</th>
<th>LEED-H Stds</th>
<th>ENERGY STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.26%</td>
<td>$2.42</td>
<td>$8.44</td>
</tr>
<tr>
<td>7.00%</td>
<td>$0.90</td>
<td>$6.57</td>
</tr>
<tr>
<td>12.00%</td>
<td>$3.42</td>
<td>$1.64</td>
</tr>
</tbody>
</table>

Note: A positive dollars/ft² relative to IECC 2006 value means that the model home has a greater surplus than the IECC 2006 building. Negatives means the modeled building costs more.

**Combined Variable Sensitivity Analysis**

For a complete understanding of the overall impact and interplay of the variables in question in this sensitivity analysis, a complete array of all the combinations of each of the variables is presented below in Table 17.

The analysis confirms the primary NPV analysis above as well as the partial sensitivity analysis discussed thus far. The Home Built to LEED-H Silver standards shows a lower NPV relative to the IECC 2006 home in 12 of the 27 scenarios considered. As expected, these are the scenarios in which the building life span is relatively longer, the discount rate is lower, and energy price escalation rates are higher. The Home Built to LEED-H Silver standards shows a negative NPV relative to the IECC 2006 home when the discount rate is 12.0% regardless of other factors. The lowest NPV of the Home Built to LEED-H Silver standards relative to the IECC 2006 home was negative $2.80/ft² under the least advantageous conditions (12.0% discount rate, low energy price escalation rate, and 15 year lifespan); the highest NPV value relative to the IECC 2006 home was a positive $10.32/ft² under the most advantageous conditions (5.26% discount rate, high energy price escalation rate, and 50 year lifespan) for a range of $13.12/ft². By comparison, under all circumstances, the ENERGY STAR home shows a positive NPV relative to the IECC 2006 home, from
$2.00/ft² under the least advantageous conditions and $18.06/ft² under the most advantageous conditions, for a range of $16.06/ft².

Table 17: NPV Sensitivity Analysis with All Possible Combinations of Energy Price Escalation Rate, Building Lifespan and Discount Rate, Relative to IECC 2006

### Home Built to LEED-H Silver Standards

<table>
<thead>
<tr>
<th>Building Lifespan</th>
<th>Energy Price Escalation Rate</th>
<th>Discount Rate 5.26%</th>
<th>Discount Rate 7.00%</th>
<th>Discount Rate 12.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 years</td>
<td>Low</td>
<td>($1.33)</td>
<td>($1.80)</td>
<td>($2.80)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>($0.69)</td>
<td>($1.26)</td>
<td>($2.44)</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$0.17</td>
<td>($0.53)</td>
<td>($1.97)</td>
</tr>
<tr>
<td>30 years</td>
<td>Low</td>
<td>$0.72</td>
<td>($0.37)</td>
<td>($2.26)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>$2.42</td>
<td><strong>$0.90</strong></td>
<td>($1.64)</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$5.13</td>
<td>$2.90</td>
<td>($0.71)</td>
</tr>
<tr>
<td>50 years</td>
<td>Low</td>
<td>$1.82</td>
<td>$0.21</td>
<td>($2.15)</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>$4.71</td>
<td>$2.12</td>
<td>($1.42)</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$10.32</td>
<td>$5.62</td>
<td>($0.25)</td>
</tr>
</tbody>
</table>

### ENERGY STAR

<table>
<thead>
<tr>
<th>Building Lifespan</th>
<th>Energy Price Escalation Level</th>
<th>Discount Rate 5.26%</th>
<th>Discount Rate 7.00%</th>
<th>Discount Rate 12.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 years</td>
<td>Low</td>
<td>$3.84</td>
<td>$3.24</td>
<td>$2.00</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>$4.60</td>
<td>$3.90</td>
<td>$2.43</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$5.66</td>
<td>$4.80</td>
<td>$4.55</td>
</tr>
<tr>
<td>30 years</td>
<td>Low</td>
<td>$6.40</td>
<td>$5.03</td>
<td>$2.67</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>$8.44</td>
<td><strong>$6.57</strong></td>
<td>$3.42</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$11.77</td>
<td>$9.01</td>
<td>$5.12</td>
</tr>
<tr>
<td>50 years</td>
<td>Low</td>
<td>$7.78</td>
<td>$5.77</td>
<td>$2.81</td>
</tr>
<tr>
<td></td>
<td>Medium</td>
<td>$11.24</td>
<td>$8.05</td>
<td>$3.68</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>$18.06</td>
<td>$12.31</td>
<td>$5.12</td>
</tr>
</tbody>
</table>

Note: Highlighted cells are the results of the primary NPV analysis.

**Discussion**

Given the analysis above, an investment in a home such as the Home Built to LEED-H Standards appears to be more or less on par with a code home. However, the factors influencing the outcome of the NPV analysis are highly uncertain and they are not necessarily as equally likely to be realized. For example, in today’s economic climate, a 12.0% discount rate appears misplaced, though in the early 2000s, it would have been a reasonable scenario. The extremes of the sensitivity analysis are highly unlikely, but are important to understand the factors contributing to the economic success of green buildings.
Recall from above that the largest driver of energy consumption in homes in the Middle Atlantic Census Division is space heating. In the case of the three modeled homes, they all use natural gas for heating purposes. Recall that the Home Built to LEED-H Silver standards used 0.21 therms/ft²/year of natural gas, while heating for the ENERGY STAR home consumed 0.19 therms/ft²/year and, based on the REM/Rate model, the reference home consumes 0.42 therms/ft²/year. Both the superior insulation system of the Home Built to LEED-H Silver standards and the improved heating systems are central factors contributing to its low natural gas consumption relative to the IECC 2006 home. However, these are also the major up-front expenses that contribute to the higher initial investment of the Home Built to LEED-H Silver standards. Also of importance is the rate of electricity consumption. The Home Built to LEED-H Silver standards consumed 2.6 kWh/ft²/year, the ENERGY STAR home consumed 2.2 kWh/ft²/year and, according to the REM/Rate model, the IECC 2006 home consumed 3.4 kWh/ft²/year. Again, the superior insulation system and the improved cooling system of the Home Built to LEED-H Standards contributed to its comparatively low modeled electricity consumption. However, the potential economic gains of these improvements are found in the returns on energy saved. If, as projected by the AEO 2010, the energy prices of both electricity and natural gas remain flat over the next several decades, the economic advantages of adhering to the high environmental standards set by LEED-H will not realized. If energy prices increases are consistent with increases over the past 10 or 20 years, the advantages are more likely to be realized.

An important question then, is why the ENERGY STAR home—also a high performance home—compares relatively well in terms of NPV to both the Home Built to LEED-H Standards and the IECC 2006 home. Part of the answer lies in the initial investment versus the reduction in energy consumption due to that investment. By converting both the natural gas consumption and electricity consumption rates of the three homes to a common energy unit (mega joules [MJ]), we are able to derive the total energy consumption per dollar spent on the high-efficiency improvements relative to the IECC 2006 home for both the Home Built to LEED-H Silver standards and the ENERGY STAR home. Using actual energy consumption rates and the costs of technology improvements as provided by Fluid Construction, we found that the total reduction in energy consumption per dollar of initial investment spent of the Home Built to LEED-H Silver standards relative to the IECC 2006 home was 4.5 MJ. For the ENERGY STAR home relative to the IECC 2006 home, the reduced energy consumption was 17.2 MJ per dollar of initial investment spent. In other words, for every dollar spent on high-performance improvements, the ENERGY STAR home reduced its energy consumption by 286% more than the Home Built to LEED-H Silver standards relative to the IECC 2006 home (see Table 18).

Because occupant habits are a major influencing factor on energy consumption, we also include the same analysis using the energy consumption rates as projected by the REM/Rate models for the purpose of normalization. In this case, the total reduction in energy consumption per dollar of initial investment spent of the Home Built to LEED-H Silver standards relative to the IECC 2006 home was 4.37 MJ. For the ENERGY STAR home relative to the IECC 2006 home, the reduced energy consumption was 9.70 MJ per dollar of initial investment spent. For every dollar spent on high-performance improvements, the ENERGY STAR home reduced its energy consumption by 121% more than the Home Built to LEED-H Silver standards relative to the IECC 2006 home (see Table 19).
Table 18: Reduced Energy Consumption per Dollar Spent on Initial High-Performance Investments Based on Actual Energy Consumption

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>IECC 2006</th>
<th>LEEDStd</th>
<th>ENERGY STAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas (therms/ft²)</td>
<td>0.423</td>
<td>0.205</td>
<td>0.186</td>
</tr>
<tr>
<td>Natural Gas (MJ/ft²)</td>
<td>44.608</td>
<td>21.679</td>
<td>19.629</td>
</tr>
<tr>
<td>Electricity (kWh/ft²)</td>
<td>3.368</td>
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<td>2.183</td>
</tr>
<tr>
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<td>12.126</td>
<td>9.471</td>
<td>7.860</td>
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<tr>
<td>Total (E + NG) (MJ/ft²)</td>
<td>56.734</td>
<td>31.150</td>
<td>27.489</td>
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<tr>
<td>Total relative to IECC 2006 (MJ/ft²)</td>
<td>-</td>
<td>25.584</td>
<td>29.245</td>
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</table>

Cost of Initial Investment

| Total Cost/ft²                          | $11.99    | $17.73  | $13.69      |
| Total Cost/ft² relative to IECC 2006    | $0.00     | $5.74   | $1.70       |

Total reduction in consumption per $ of initial investment spent relative to IECC 2006 (MJ)

| -                                      | 4.5       | 17.2    |

Table 19: Reduced Energy Consumption per Dollar Spent on Initial High-Performance Investments Based on Modeled Energy Consumption

<table>
<thead>
<tr>
<th>Energy Consumption</th>
<th>IECC 2006</th>
<th>LEED Standards</th>
<th>ENERGY STAR</th>
</tr>
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<tr>
<td>Natural Gas (therms/ft²)</td>
<td>0.42</td>
<td>0.21</td>
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<td>44.6</td>
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<tr>
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<td>3.368</td>
<td>2.519</td>
<td>2.857</td>
</tr>
<tr>
<td>Electricity (MJ/ft²)</td>
<td>12.126</td>
<td>9.070</td>
<td>10.284</td>
</tr>
<tr>
<td>Total (E + NG) (MJ/ft²)</td>
<td>56.734</td>
<td>31.599</td>
<td>40.248</td>
</tr>
<tr>
<td>Total relative to IECC 2006 (MJ/ft²)</td>
<td>-</td>
<td>25.135</td>
<td>16.486</td>
</tr>
</tbody>
</table>

Cost of Initial Investment

| Total Cost/ft²                          | $11.99    | $17.73  | $13.69 |
| Total Cost/ft² relative to IECC 2006    | -         | $5.74   | $1.70  |

Total reduction in consumption per $ of initial investment spent relative to IECC 2006 (MJ)

| -                                      | 4.379     | 9.698  |
CONCLUSION

In conclusion, we find that in purely economic terms, the investment in the Home Built to LEED-H Silver standards is on par with the IECC 2006 home. By contrast, the ENERGY STAR home appears to be a more favorable investment for its energy saving features. The factors contributing to the sophistication of the Home Built to LEED-H Silver standards over the ENERGY STAR home are not as cost-effective in terms of reduced operation expenditures over the lifetime of the building. The lifespan sensitivity analysis demonstrates this point: the ENERGY STAR home has a positive NPV under the least favorable conditions for high performance homes and, while the Home Built to LEED-H Silver standards shows a positive NPV only under more advantageous conditions for high performance homes, offering comparatively longer payback period.

Energy prices are at the crux of the economic benefits accrued by high-performance homes. In order to justify the upfront costs from an economic standpoint, the operational gains attained by reduced energy consumption of residences built to the LEED-H standards must be greater. In other words, although only a case study, the findings suggest that energy prices are too low for the LEED-H certification to reach a mainstream construction constituency. The ENERGY STAR standards, which focus exclusively on energy efficiency, have been more widely adopted, in part because the standards are not as strict, but also because the investment is sound and homeowners can expect to “make back” their investment in a relatively short amount of time.

Of course, it is important to keep in mind that there are manifold other “benefits” that might accrue to a homeowner who invests in a home built to higher standards, such as those set out by LEED. Among those considered in this study are comfort (see section on Homeowner Interviews), and environmental impacts (see section on life-cycle analysis).

FUTURE RESEARCH

This LCC analysis suggests several avenues for future research of high performance homes in New Jersey or in the nation at large. First, at what point do the marginal economic benefits of investing in high-performance components of residences equal the marginal costs associated with those investments? This study found that the investment in the ENERGY STAR home in terms of reduced energy consumption was 121% greater than the investment of the Home Built to LEED-H Silver standards. Are there other investments that can improve the reduced consumption to investment ratio? Second, at what energy prices would homes built to the LEED-H standards become economically competitive with the code building and ENERGY STAR?
CONCLUSIONS & NEXT STEPS

Green Building Design & Practice

Builders and homeowners often base decisions on the upfront cost of materials and services, yet these decisions may affect building performance over the entire life cycle of the building. This study takes a more holistic approach to building performance, looking at the environmental, economic, and health impacts of different building materials and design strategies. The comparative case studies and third party analysis give builders and homeowners valuable insight into how environmental impacts, life-cycle costs, and human health issues factor into the building equation.

Green Building Policy

The results of this case study and similar studies can be used to guide future policy-making regarding the construction of green buildings in New Jersey, and may prove useful to the U.S. Green Building Council’s and U.S. EPA’s ongoing evaluation and revision of the LEED Standards and ENERGY STAR Qualified New Homes program.

Future Green Building Research

There is strong evidence that green building – or at least aspects of it – constitutes a long-term trend and not a passing fad. As green building continues to mature, responding to questions as to the performance of green buildings has become critical. A standardized set of metrics and routine data collection needs to be established as part of the growing practice of Post Occupancy Evaluation (POE). For green building practices to evolve, systems need to be put into place to track real-time and long-term trends, and to provide individual and collective feedback on the performance of green buildings. The notion that not all green buildings are alike (and therefore that some may turn out to have more desirable performance characteristics than others) gives rise to a burgeoning area of research. This research will likely need to look at the performance of green building design features and technologies along a continuum and begin to better understand the interactions and tradeoffs between these different green elements. This case study is part of a series of case studies being developed by the Rutgers Center for Green Building that are designed to fulfill this need.
### APPENDICES

**Appendix A1 - Results of Indoor Air Quality Tests – Pre-Occupancy**

<table>
<thead>
<tr>
<th>Home Location</th>
<th>LEED H-Home</th>
<th>ENERGY STAR Home</th>
<th>Weisel et al. 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Badge number</td>
<td>2nd floor</td>
<td>1st floor</td>
</tr>
<tr>
<td>basement</td>
<td>5372</td>
<td>5345</td>
<td>5329</td>
</tr>
<tr>
<td>1st floor</td>
<td>0</td>
<td>0</td>
<td>0.38</td>
</tr>
<tr>
<td>2nd floor</td>
<td>2</td>
<td>2.1</td>
<td>0</td>
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<tr>
<td>outdoor</td>
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<td>0</td>
<td>2.1</td>
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<tr>
<td>Location</td>
<td>0.80</td>
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<td>0.67</td>
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<tr>
<td>2,2-Dichloropropane</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>cis-1,2-Dichloroethene</td>
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<td>Chloroform</td>
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<td>0</td>
</tr>
<tr>
<td>Carbon Tetrachloride</td>
<td>0.59</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Benzene</td>
<td>2.1</td>
<td>0.77</td>
<td>1.8</td>
</tr>
<tr>
<td>1,2-Dichloroethane</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Trichloroethene</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Bromodichloromethane</td>
<td>0.80</td>
<td>0</td>
<td>0.28</td>
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<td>27</td>
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<td>trans-1,3-Dichloropropene</td>
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<td>4.0</td>
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<tr>
<td>Chlorobenzene</td>
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<td>0</td>
<td>0</td>
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<td>Ethylbenzene</td>
<td>5.9</td>
<td>4.0</td>
<td>5.5</td>
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<tr>
<td>m,p-Xylene</td>
<td>8.6</td>
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<td>7.8</td>
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<tr>
<td>o-Xylene</td>
<td>5.1</td>
<td>3.6</td>
<td>4.7</td>
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<td>Styrene</td>
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<td>3.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Bromoform</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Isopropylbenzene</td>
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<td>1.1</td>
<td>1.2</td>
</tr>
<tr>
<td>1,1,2,2-Tetrachloroethane</td>
<td>5.3</td>
<td>4.7</td>
<td>5.1</td>
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<td>Bromobenzene</td>
<td>3.1</td>
<td>2.8</td>
<td>2.7</td>
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<tr>
<td>Propylbenzene</td>
<td>2.8</td>
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<td>2.6</td>
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<td>1,2,3-Trichloropropane</td>
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<td>2-Chlorotoluene</td>
<td>0.093</td>
<td>0.043</td>
<td>0.16</td>
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<td>1,3,5-Trimethylbenzene</td>
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<td>5.0</td>
<td>4.8</td>
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<td>4-Chlorotoluene</td>
<td>0.092</td>
<td>0.043</td>
<td>0.16</td>
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<td>tert-Butylbenzene</td>
<td>2.3</td>
<td>2.0</td>
<td>2.0</td>
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<tr>
<td>1,2,4-Trimethylbenzene</td>
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<td>3.0</td>
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<tr>
<td>Naphthalene</td>
<td>0.73</td>
<td>0.57</td>
<td>0.67</td>
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</table>
### Appendix A2 - Results of Indoor Air Quality Tests – Post-Occupancy

<table>
<thead>
<tr>
<th>Location</th>
<th>LEED H-Home</th>
<th>ENERGY STAR Home</th>
<th>Weisel et al. 2008</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Basement</td>
<td>1st F1</td>
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</tr>
<tr>
<td></td>
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<td>4-Chlorotoluene</td>
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<td>sec-Butylbenzene</td>
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</tr>
</tbody>
</table>

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Appendix B – Sample Interview Guide

The questions below provide a list of potential topic areas to discuss during any given interview session with homeowners. Exactly which questions get used in which way will vary by interview and our a priori knowledge about the case study building.

❖ Home Performance

1. Was the fact that this is a green (or high-performance) home a factor in your purchase of this home?
2. Do you think that there are any benefits to living in a green (high-performance) home? Can you provide any examples from your own experiences?
3. Describe the features of the home that you like most/find most useful about this home?
4. Describe the features of the building that you like least/have most trouble with in this home?
5. Is there anything that you would change about the home?
6. Would you recommend a close friend to purchase a green (high performance) home?
7. Are there any green features would you like to add to your home?
8. Please explain any additional comments or recommendations about your personal experience living in a green (high performance) home?
9. How satisfied are you with your home’s performance in the following areas:
   (Rate on 5-point scale Very Dissatisfied to Satisfied)
   - Indoor Air Quality
   - Energy savings
   - Water savings
   - Low flow fixtures
   - Ability to adjust thermal comfort
   - Daylighting
   - Durability of Sustainable Materials

❖ Occupant Behavior(s)

10. Including yourself, how many people live in your household?
11. Do you have any pets? What kind and how many of each kind?
12. What are your typical work (school) schedules?
13. On average, how many hours do you/family members spend at home per day, per week?
14. How often do you travel? Please include any recent or upcoming travel plans.
15. How many miles do you/family members commute to and from work each day? How many days do you commute each week?

16. How much time on average does you/family members spend watching television? On your computer? Listening to music? Reading?

17. What other hobbies or activities do you regularly engage in, in your home?

❖ Additional Household Practices

18. What type of cleaning products do you use/does your cleaning service use?
19. Do you recycle? How much? How often? What types of materials?
20. Do you compost? What types of materials?
21. Do you have a garden? What do you grow?
22. Do you buy materials that are advertised as “green”? These could be clothes, furniture and other items.

❖ Background of Interviewee

23. What is the highest level of education you/family members have completed?
   - Some high school or less
   - High school diploma or equivalent
   - Some college
   - College diploma
   - Some graduate school
   - Graduate degree

24. What is your age?
   - Under 21 years
   - 21 to 30 years
   - 31 to 40 years
   - 41 to 50 years
   - 51 to 60 years
   - 61 to 65 years

25. What is your income level?
   - $25,000 to $50,000
   - $50,000 to $75,000
   - $75,000 to $100,000
   - $100,000 or more
26. What is your marital status?
   - single (never married)
   - married
   - divorced/separated
   - widowed

27. Where would you place yourself on the following “green” scale?
   - Very committed/responsible (no real improvements needed)
   - Committed/responsible (small amount of improvement needed)
   - Somewhat committed/responsible (significant improvement needed)
   - Not really committed/responsible (very significant improvement needed)

28. How do you think your peers would rate you?
   - Very committed/responsible (no real improvements needed)
   - Committed/responsible (small amount of improvement needed)
   - Somewhat committed/responsible (significant improvement needed)
   - Not really committed/responsible (very significant improvement needed)
ABOUT THE RUTGERS CENTER FOR GREEN BUILDING

The Rutgers Center for Green Building (RCGB) is located at the Edward J. Bloustein School of Planning and Public Policy, Rutgers, The State University of New Jersey. The Center works with industry and government to promote green building best practices, and develops undergraduate, graduate and professional education programs. The Center is quickly establishing itself as the pre-eminent interdisciplinary center for green building excellence in the Northeast, while serving as a single accessible locus for fostering collaboration among green building practitioners and policymakers.

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New Brunswick, New Jersey, 08901
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Website: www.greenbuilding.rutgers.edu