MEASURED PERFORMANCE OF THREE TYPES OF ENERGY PROGRAM HOUSES IN TWO U.S. CITIES

Shaun Hassel[1], Jonathan Coulter[1]*, Ben Hannas[1]

[1]Advanced Energy
909 Capability Drive, Suite 2100
Raleigh, North Carolina 27606, USA
*Email: jcoulter@advancedenergy.org

ABSTRACT

This paper examines two similar studies in Phoenix, Arizona and Houston, Texas that compared the actual energy performance of three classes of homes – ENERGY STAR®, Guaranteed Performance homes and Baseline homes (homes built using standard construction practices and local energy codes at a minimum). In addition to the specific questions of individual residential energy performance, the results illuminate the impact that energy efficiency programs have on the overall building marketplace. The Phoenix study surveyed 7,141 houses, of which 3,336 were Baseline homes, 2,979 were ENERGY STAR homes and 826 were Guaranteed Performance homes. Statistically valid energy data show that ENERGY STAR homes are up to 12% more efficient (kWh/m²) as compared to the typical Baseline homes. The Guaranteed Performance homes were up to 23% more efficient than Baseline homes and 12% more efficient than ENERGY STAR homes. The Houston analysis draws from over 158,698 houses, of which 70,828 were Baseline homes, 81,755 were ENERGY STAR homes and 6,115 were Guaranteed Performance homes. Key findings from this study include:

- Average Baseline homes consumed less energy than the reference homes defined by the modeling program.
- All homes in Houston have become more energy efficient over time - 16% from 2002 to 2007.
- Energy usage differences between the three groups of homes were small.
- Modeling predictions of the energy usage of ENERGY STAR homes are reasonably accurate.
- Regression modeling provided some more detailed results on code influences and construction practices.

An important difference between the Houston study and many others is the robust analysis of real-world data and billing histories rather than models. The data set used here is large enough to have adequate statistical power for high confidence in the results. Finally, evaluating home programs with real-world data allows us to best identify construction techniques and products that deliver truly energy-efficient buildings.

KEYWORDS

Predicted energy usage, actual energy usage, market transformation, energy efficiency programs

INTRODUCTION

For more than 40 years in the United States, a variety of approaches have been tried to improve the energy efficiency of newly-constructed homes. Before 2004, millions of homes had been constructed to local building codes, about 400 000 were ENERGY STAR compliant and over 60,000 qualified for Guaranteed Performance recognition. For all the attention on projected and deemed energy savings these programs were claiming, there was not enough data being analyzed to determine the actual energy reduction impact these programs were having post-occupancy.

In 2004, the United States had 4.6% of the world's population accounting for 24.9% of the world's primary energy consumption. The housing sector accounted for 36% of all U.S. electrical demand with a predicted 39% growth in this sector alone between 2000 and 2010 [1].

Over the past several decades, rising energy prices have driven a demand for more energy-efficient homes. Builders initially responded with simple energy-saving remedies such as increased insulation, double-paned glass, tighter door seals, window awnings and other measures. Recent field applications of building physics advancements (such as high-efficiency HVAC equipment, improved duct sealing, building infiltration barriers, Low-E glass and compact fluorescent lighting) have continued to offer more sophisticated and effective methods of providing predicted energy savings. Each of these measures reduce overall home energy bills in computer modeling, but little is known how these changes effect the homeowners as they live in these homes?

This report documents the methodology and findings of two similar studies: Phoenix Measuring Public Benefits From Energy Efficient Homes study and Houston Home Energy Efficiency study. Both studies were managed and conducted by Advanced Energy with data analysis performed by Michael Blasnik and Associates. The purpose of the studies was to assess and compare energy consumption patterns of homes built to three different energy efficiency standards – Baseline homes, ENERGY STAR homes and Guaranteed Performance homes [2] [3].

In an effort to promote energy-efficient new homes and reduce the emissions associated with home energy use, the EPA launched the ENERGY STAR qualified new homes program in 1995. The program established guidelines for building energy-efficient buildings and developed partnerships with homebuilders to construct energy-efficient homes. To qualify for labeling as an ENERGY STAR home, construction plans and building components must meet specific criteria for energy performance and be certified by a qualified third-party Home Energy Rater. Two methods can be used to assess predicted energy consumption: computer energy simulation modeling or prescriptive construction standards approved by the EPA[1]. In Houston, nearly 100 percent of the ENERGY STAR homes built are modeled with software to demonstrate they will meet the ENERGY STAR guidelines. This computer modeling produces a HERS (Home Energy Rating System) score that indicates the predicted energy performance of the home as compared to a reference home built to the appropriate version of the IECC or local energy code, whichever is more stringent.

[1] http://www.energystar.gov

More recently, several organizations – Masco Corporation with their Environments for Living® program[2], General Electric with their homes inspired by ecomagination℠ program[3], Tucson Electric Power with their Guarantee Home program[4] and Advanced Energy with their *System**Vision***™ program[5] – have been promoting the construction of guaranteed performance homes. These homes are designed to go a step beyond the ENERGY STAR program, using advanced building science materials and techniques to lower home energy use even further. For guaranteed performance homes, the standards and testing protocol are more stringent than ENERGY STAR to ensure predictable energy performance.

To offset the slightly higher cost of these guaranteed performance homes and enhance their marketability, the builders or program administrators guarantee that the annual energy usage for heating and cooling the home will not exceed a modeled annual amount. Any excess costs for heating and cooling energy use are reimbursed to the homeowners. The programs also include a comfort guarantee that compliments the heating and cooling usage guarantee, stating that any room in the home will be within three degrees of the thermostat set point. To date, more than 130,000 houses nationwide have been built and certified to the guaranteed performance standards (Masco, GE, *System**Vision*** and Tucson Electric Power).

Historically, billing data for Baseline, ENERGY STAR and Guaranteed Performance homes has not been collected and analyzed en masse to determine how the homes have performed while occupied under real-world conditions. A handful of studies in Wisconsin [4], New York [5] and Arizona [1] [6] have analyzed actual energy bills in an effort to evaluate the performance of various new home energy standards. The analysis of these studies showed an interesting trend: smaller savings than anticipated between ENERGY STAR and Baseline homes, primarily driven by inaccurate assumptions about the reference homes that ENERGY STAR homes are compared to when predicting energy savings.

While past studies have shown that varying amounts of energy savings were being achieved across distinct programs with different standards, there have always been a number of issues relating to study size, composition of the construction market and the difficulty of acquiring a truly representative data set in terms of types of homes and scope of data. These issues have revealed an ongoing need to conduct additional studies utilizing real-world data that meet the following criteria: develop a data set representative of all of the homes built to different standards in a given market and randomly select an unbiased and statistically significant number of homes in each subset of homes. The Phoenix Measuring Public Benefits From Energy Efficient Homes study was small, but the Houston Energy Efficiency Study was able to develop a much more robust data set for looking at energy efficiency influences.

Study Design and Methodology

Because the Phoenix, Arizona market was an early adopter of both the ENERGY STAR and Guaranteed Performance programs, there is a high concentration of homes with many years worth of energy use data that provided an excellent opportunity to verify energy consumption data on the three home types under real-world conditions.

[2] http://www.environmentsforliving.com/
[3] http://ge.ecomagination.com/index.html
[4] http://www.tucsonelectric.com/Green/GuaranteeHome/index.asp
[5] http://www.systemvision.org/

Metropolitan Houston has become one of the largest markets in the country for new housing construction, with more than 350,000 new home starts since 2000. Houston was also an early adopter of the ENERGY STAR label and currently has one of the highest market shares in the nation with over 50 percent of new homes in 2008 certified as ENERGY STAR. As the market share of ENERGY STAR homes grew in Houston, some builders began to look for new ways of differentiating their homes. The Guaranteed Performance labels from various organizations provided them with the opportunity to take a step beyond ENERGY STAR in terms of energy performance, but without having to sacrifice many of the benefits they received from their participation in the ENERGY STAR program.

Study Objective

The Phoenix and Houston studies were structured to compare the actual energy efficiency of Baseline homes, ENERGY STAR qualified homes and Guaranteed Performance program homes, while taking into consideration a large number of variables in home design. These studies looked at real data and real energy performance of thousands of occupied houses, not computer models. The results could then be used to answer several fundamental questions about the effectiveness of these efficiency programs:

- How much energy did the Baseline, ENERGY STAR and Guaranteed Performance homes actually consume?
- How much energy savings are realized by ENERGY STAR and Guaranteed Performance homes, compared to similar Baseline homes?
- Has the implementation of energy efficiency programs in new home construction resulted in a reduction of total energy consumption?
- Did the energy-efficient homes perform as predicted by the models and program sponsors?
- What construction techniques, components and strategies delivered efficiency?

Survey Design

For the 7,141 houses included in the Phoenix energy study, data was compiled and analyzed based on the following three categories: Baseline homes (3,336 homes not built as part of any energy efficiency program, but resembled other homes in the study), ENERGY STAR homes (2,979 homes built per U.S. EPA ENERGY STAR program standards) and Guaranteed Performance Homes (826 ENERGY STAR homes with additional energy efficiency improvements, as well as a comfort and heating/cooling use guarantee). Once assigned to a category above, the homes were then segregated by builder, year built, square footage, presence of swimming pool, solar orientation, HVAC type and zip code. These groupings helped identify patterns in the data that can point to factors with the greatest effect on home efficiency within the boundaries of the study.

More than 226,000 homes built by dozens of different production building companies in Houston from 2002 to 2007 were included in the Houston Home Energy Efficiency Study: 114,000 Baseline homes, 106,000 ENERGY STAR homes and 6,600 Guaranteed Performance homes. Details on the physical design and construction of the various homes (such as HVAC ratings, window size, types and volume) were obtained from home builders, utilities, contractors and testing companies. Energy use histories for the homes were provided by the local utility provider over the period of 2002 through 2008. One significant factor not addressed by this study is the impact of the energy consumption habits (lifestyle) of the home occupants on overall energy use. To account for this variability, the authors used a statistically large sample of homes to diffuse the impact of the lifestyle variable on the results of the study. It is assumed that the range of homeowner behavior is equally represented across all three categories of homes.

ANALYSIS AND RESULTS

Electric Use Survey Results

Of more than 7,000 original Phoenix study homes, acceptable electric-use records were only available for 6,545 homes. Similarly, 86 attached townhouses and three houses without information on living area were eliminated, leaving 6,480 houses with electric data suitable for the analysis. The Electric Use Summary table displays electric use by home category. The table also provides a breakout by heating fuel type for the total heating and cooling usage per square foot. All-electric homes use heat pumps and electric hot water, while gas heated homes also use gas hot water.

The Baseline homes, as predicted, have the highest overall energy use intensity (kWh/ft^2). However, the ENERGY STAR homes actually showed slightly higher summer/cooling load intensity than the average Baseline homes. The Guaranteed Performance homes averaged roughly 10% lower energy use than the Baseline homes. These simple comparisons are useful in a "big picture" sense. The presumably more efficient homes use about the same total amount of electricity as the Baseline homes because they are larger. These comparisons do not represent a fair assessment of the energy performance of the different homes, as many other factors besides square footage may differ between the home groups and have an effect on energy use, particularly the choice of heating/hot water fuel [2].

The regression modeling yielded a number of conclusions in the Phoenix study:

- Guaranteed Performance homes have significantly lower summer/cooling intensity than Baseline homes. When adjusted to a standardized 1,800 ft^2 home, the estimated savings equals about 1,000 kWh/year or about 16% of the load.
- ENERGY STAR homes have about the same summer/cooling intensity as Baseline homes – the small difference ranging from -1% to 2% is not statistically significant.
- Larger homes have lower cooling intensity (as we found previously).
- Two-story homes have higher cooling intensity than one-story homes even after accounting for living area.
- Baseload electric usage constitutes about 0.15 kWh of additional summer/cooling load for each 1 kWh of annual baseload electric usage. This baseload electric impact is substantial – equal to about 1,300 kWh of summer/cooling for the average baseload usage of 8,571 kWh in the analysis sample – about 20% of the entire summer/cooling load.
- Homes facing northeast have significantly lower summer/cooling intensity than homes facing east (the default category), but no other orientations show statistically significant differences.
- Annual summer/cooling loads estimated to average 6,413 kWh for Baseline homes, 6,493 kWh for ENERGY STAR® (1% savings) and 5,409 kWh for Guaranteed Performance homes (16% savings).

Perhaps the most surprising outcome of the analysis of the Houston Energy Study is the fact that electricity consumption in new homes in Houston dropped dramatically for all three groups built from 2002 to 2007. Figure 1 below shows the 2008 total energy use and baseload energy use for homes built in different years. Both values trend down by construction, as can be seen by the average trend line. The total energy use decreases on average by 16 percent from homes built in 2002 to homes built in 2007.

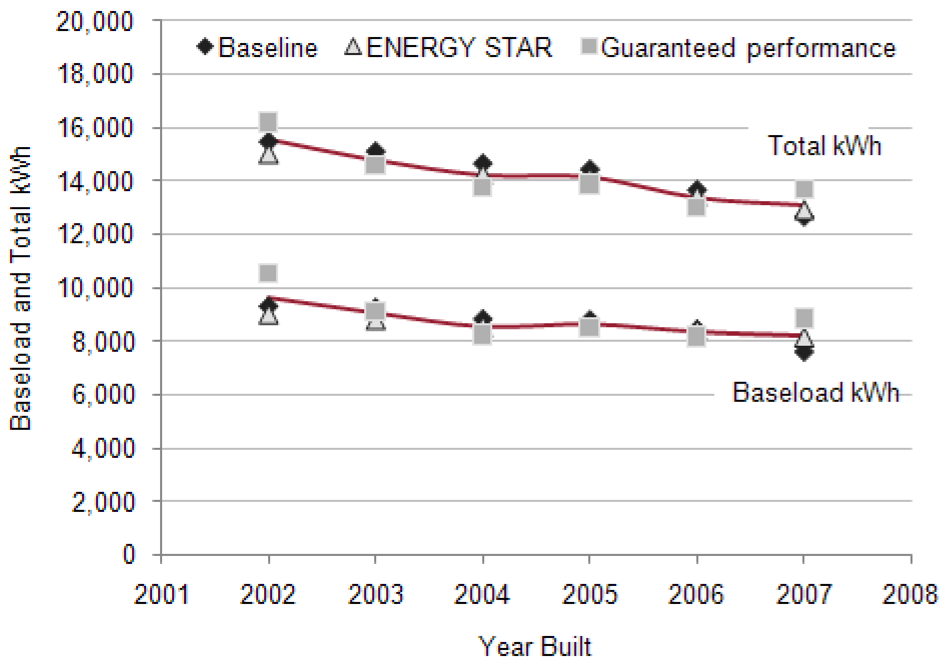

Figure 1: 2008 total and baseload kWh usage by year of construction

This 16 percent drop in total electricity consumption appears to be explained by three factors:

- Establishment of a statewide residential energy code in 2001
- Change in federal standards from SEER 10 to SEER 13 in 2006
- Influential affects of high-performance home programs and initiatives adopted throughout the Houston market, including but not limited to:
  - Programs and incentives
  - Training and technical support
  - Home energy rater infrastructure
  - Consumer marketing
  - Support from product manufacturers

The entire residential new construction marketplace cooperated towards a common goal of reducing energy use across ALL homes. The change in federal SEER standards appears to have accounted for approximately half of the reduction in cooling usage, while the degree of impact from other code changes and spillover effects from the ENERGY STAR program cannot be determined.

These data reveal that all homes in Houston experienced this drop in electricity consumption, and that differences in overall usage and summer/cooling usage (the best usage for comparisons in a cooling dominated climate like Houston) across different groups of homes was small. The summer/cooling load of Baseline homes declined by 18 percent over the period – from 6,194 kWh for homes built in 2002 to 5,068 kWh for homes built in 2007. Over the same period, ENERGY STAR homes dropped by 21 percent and Guaranteed Performance homes dropped by 14 percent. Figure 2 below shows the 2008 summer/cooling energy use for homes built in different years.

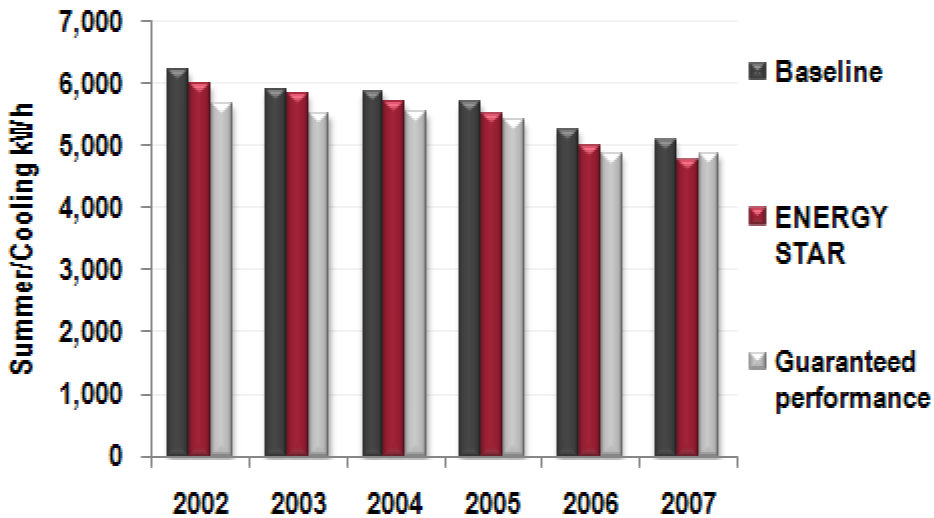

Figure 2: Trends in 2008 summer/cooling usage by year of construction

Although consumption differences across groups of homes are smaller than advertised, ENERGY STAR homes perform very close to the predictions of the models as a whole, while Baseline homes perform better than the reference homes defined by the HERS standard.

Market Impacts

The ENERGY STAR program brought duct leakage testing and building envelope leakage testing into widespread use in the new construction market in Houston. This testing is likely to have contributed toward the common use of better duct installation and building framing practices so that homes could pass the ENERGY STAR testing requirements. Contractors then applied these same approaches to all new homes. This phenomenon is referred to as market transformation or "spillover." The impact of these changes is that Baseline home performance improved, narrowing any observed difference in energy usage between the ENERGY STAR homes and the Baseline homes. Therefore, market transformation effects can make a program appear to have less impact, when in reality it may be having a bigger impact.

Although we are unable to measure the impact of market transformation on the findings, it is clear that, in Houston, typical construction practices are much better than the reference homes as defined by the ENERGY STAR standards. The reference home is defined as having minimum local code specifications combined with the least efficient cooling, heating and water heating equipment available, a building envelope with high infiltration and a leaky duct system. Typical new construction clearly exceeded this level of performance even before the code change, as higher SEER air conditioners were common.

Accuracy of Modeling Predictions

The data collected in this project allowed the study team to examine the relationship between actual and projected energy usage. In this application, the primary quantity of interest is the projected summer/cooling load since baseload usage depends strongly on post-occupancy appliance acquisitions and behaviors. Also, heating loads are small in this market and quite sensitive to behavioral preferences.

Utilizing REM/Rate cooling load projections from 10,258 homes with electric usage results, the study team found that the REM/Rate projected average cooling load of 5,506 kWh/yr was three percent higher than the billing analysis average cooling load of 5,677 kWh/yr. REM/Rate also estimated the average heating usage of program homes fairly well – only four percent lower than the measured loads.

Cooling Load Projections and Usage	
Average Load (kWh/yr)	
REM/Rate estimate	5,506
Billing data	5,677
Difference	171 (3%)
Absolute Error	
Mean	1,235 (21.8%)
Median	992 (17.5%)
% Homes where REM/Rate within	
10% of billing data	28%
25%	64%
50%	91%
Correlations with billing data	
REM/Rate	0.62
Floor area, envelope area	0.67

Table 1: Statistical comparison of the REM/Rate projects and billing analysis results

Although the analysis found no systematic bias in the REM/rate cooling projections, there was a large amount of variability in the data. It was found that the correlation was higher between house size and cooling load than between the REM/Rate projected cooling load and actual usage. However, the study team feels confident in stating that when using current modeling software with energy efficient new homes, there is a strong and fairly consistent relationship between actual and projected performance using REM/Rate for both heating and cooling.

Further Analysis – Regression Modeling

Simple comparisons of energy usage between groups of homes can be informative, but more sophisticated analyses are needed to disentangle the impacts of multiple factors operating at once.

Regression modeling is used to assess the differences in energy usage over time and between groups. A regression modeling approach of homes with REM/Rate file data is also used to explore some technical performance issues. Some of the following results could prove useful for designing programs and determining priorities in terms of technical standards:

- Savings from higher SEER air conditioners are generally consistent with simple projections based on the SEER ratings, although perhaps declining a little for SEER 15 units – this can be seen in Figure 3 below.
- About two-thirds of the reduction in summer/cooling loads from 2005 to 2007 can be accounted for by changes in SEER ratings.
- Building shell leakage appears to increase summer/cooling loads by about 0.4 kWh per CFM50 of leakage, accounting for about 14 percent of summer/cooling loads in ENERGY STAR homes.
- Baseload electric usage is strongly related to summer/cooling loads – at 0.13 kWh cooling per annual kWh consumed, about 1150 kWh (20 percent of cooling load) is removing baseload heat.

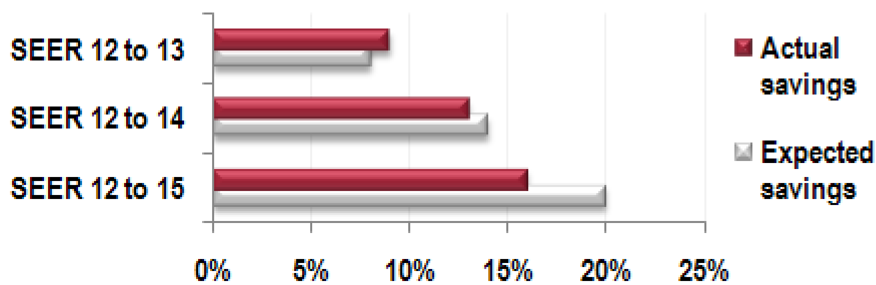

Figure 3: Actual versus predicted SEER savings

CONCLUSION

Market Transformation Impacts

A number of different factors have helped to transform the Phoenix area housing market in terms of energy performance. When the ENERGY STAR program entered the Phoenix market area and gathered a number of avid supporters, it raised the energy performance bar for *all* housing in the market, since few people wanted to purchase an energy *inefficient* home, given the alternatives. Consumers are requesting energy efficient features because programs such as ENERGY STAR and Environments For Living® have educated them. Another major market transformation occurred when the HVAC contracting company that installs more than 70% of all HVAC systems in Phoenix required duct sealing training for all of its installers. In doing so, they initiated a significant change in the entire market which resulted in a steady decline in duct leakage performance numbers. Similarly, training in other energy performance enhancements brought testers, builders and contractors up to speed quickly.

As Low-E glass and higher efficiency HVAC units were incorporated into early ENERGY STAR homes, the price for these products dropped noticeably, due mostly to increased market penetration and competition for supply. Lowered prices equate to more frequent requests by homeowners for efficient glass.

ENERGY STAR and Guaranteed Performance programs brought the concept of “right-sizing” into the market, leading HVAC system designers to use more sophisticated software, such as Manual J, to size HVAC units for homes. This has resulted in smaller units being installed, saving the homeowner money over purchasing a larger unit, while preventing short cycling and allowing the HVAC units to reach their maximum SEER efficiency. Typical HVAC sizing in Phoenix previously was 400 sq. ft. of livable floor space per ton. This figure has increased, as more attention is being given to improved thermal performance.

From the Houston study, savings between program homes and Baseline homes are small. The data indicates that ENERGY STAR does deliver savings in Houston – but the amount of savings is small. When looked at over a five-year period the Houston ENERGY STAR homes used approximately five percent less energy for summer/cooling than a similar group of baseline homes. Guaranteed Performance homes used six percent less summer/cooling energy than Baseline homes in Houston.

It is important to clarify that these results do not mean ENERGY STAR homes are using more energy than predicted. On average, ENERGY STAR homes perform very close to the predictions of the models, but Baseline homes perform much better than the reference homes defined by the HERS standard. The better-than-code construction practices of Baseline homes reduced the difference between ENERGY STAR and Baseline homes substantially.

ENERGY STAR has played an important role in positively impacting standard construction practices and energy savings in residential buildings. For example, the ENERGY STAR program brought duct leakage testing and building envelope leakage testing into widespread use in the new construction market in Houston. This testing is likely to have contributed toward the common use of better duct installation and building framing practices so ENERGY STAR homes would pass the testing requirements. Contractors then applied these same approaches to all new homes. This phenomenon is referred to as market transformation or "spillover." Although we are unable to measure the impact of market transformation on the findings, it is clear that market transformation has taken place in Houston and resulted in very positive benefits to consumers and also delivered electricity savings.

The Phoenix Study Produced Statistically Valid Results

At the beginning of this project, there was much skepticism around the validity of conducting a study to compare homes across the three categories we selected (Baseline, ENERGY STAR and Guaranteed Performance). The concern was that the amount of variability due to factors that have nothing to do with the programs we were studying or that could not be controlled would mask any noticeable differences. However, after having completed this study, and confirming that there is tremendous variability, we still see statistically significant differences among the three categories.

While we have accumulated a body of evidence which indicates that the programs are a driver of these savings, the data should not be viewed as proof. We recognize that there are many issues, such as the exact amount of savings cannot be proved, but we now have a jumping point for further investigation and benchmarking. **The bottom line is that this kind of study can produce valid results, and those results will be strengthened with additional data.**

Statistically valid energy savings were found for both the ENERGY STAR and Guaranteed Performance homes, when compared to Baseline homes. One surprise was how well the Baseline houses performed, but it is our belief that this is partly due to the impact made on the marketplace by the ENERGY STAR and Guaranteed Performance programs. Obviously, savings are directly related to how far a builder/contractor pushes specifications (toward energy efficiency) and improves installation. A major catalyst for this push (market transformation) is programs such as ENERGY STAR and Guaranteed Performance, and all the activities that go into supporting them.

Homes in Houston are More Efficient

The usage data indicated that new homes in Houston have become considerably more efficient in terms of summer/cooling loads for homes built over the period 2002 through 2007. Total electricity usage declined by 16 percent on average while cooling loads dropped by 18 percent. This drop in electricity consumption appears to be explained by three factors: the establishment of a statewide residential energy code in Texas in 2001, the change in federal SEER standards from SEER 10 to SEER 13 in 2006 and market transformation effects resulting from the ENERGY STAR program.

During the early years of the study period, the decline in electricity usage was most likely due to the implementation of a new building code in late-2001 and increased code compliance over time. While high-SEER equipment was already prevalent in most new homes, the move to low-solar gain windows and more efficient distribution systems resulted in clear drops in energy use in Baseline homes.

About half of the decline in electricity use occurred from 2005 to 2007 – most likely related to the increase in the federal air conditioner efficiency standard from SEER 10 to SEER 13. While this decline is substantial, it is only half of what the models would have predicted in moving from SEER 10 to SEER 13 (comparing 2005 to 2007 cooling use). Because of HVAC trade-offs allowed by the code in Houston, the average SEER most likely changed from about 11.5 or 12 to about 13.5 or 14, resulting in a drop in cooling usage closer to the 11 percent observed in the data.

Modeling Software and Energy Use Predictions

On average, REM/Rate accurately predicts heating and cooling loads. The relationship between REM/Rate cooling load projections and actual electric usage was examined graphically and statistically for 10,258 homes with sufficient data. REM/Rate projected an average cooling load of 5,506 kWh/yr while the billing analysis estimated average cooling loads at 5,677 kWh/yr, about three percent higher – excellent overall agreement. Although the data found no systematic bias in the REM/rate cooling projections, there was a large amount of variability and the correlation was higher between house size and cooling load than between REM/Rate-projected cooling load and actual usage.

RECOMMENDATIONS

Baseloads are Large and Need to be Addressed

As there are continued efforts to reduce overall energy usage in Phoenix, the sole focus of residential buildings should not be on space cooling/heating and water heating. While the savings are positive, the larger context of these savings is not as impressive. Space cooling/heating and water heating are the largest individual energy users in a home, although they represent roughly 40% of the home's overall energy usage. This means that even a 10% reduction in cooling/heating and water heating costs – a significant reduction – only equates to a 4% savings on the home's total energy bill. Obviously, all areas of energy use within residential buildings must be investigated to discover the maximum energy savings potential.

Need for Increasing the ENERGY STAR® Standard

The narrowing of energy savings between Baseline and ENERGY STAR homes justifies an increase in the ENERGY STAR standard. In both studies above, the ENERGY STAR specifications are no longer stringent enough. Version three of ENERGY STAR, slated for 2012, intends to answer this need. More clear and stringent standards need to be developed while providing the necessary support to raters so they can push the new construction market and truly differentiate committed builders.

Real-World Data Matters

Billing analysis provides the most accurate measurement of program results and clarifies what specifications provide energy savings in new construction programs such as ENERGY STAR. While modeling and projected savings provide an excellent starting point, there is always a need for ongoing evaluation and feedback loops involving real-world data. Doing so will help clarify our models and develop more accurate assumptions. Likewise, there is a need for conducting studies such as this in less mature markets. Perhaps in a city or region with less market share for energy-efficient homes programs, differences between baseline homes and program homes would be larger. Spillover from programs may have less impact on standard practice in these markets.

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