MEASURED PUBLIC BENEFITS FROM ENERGY-EFFICIENT HOMES

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ABSTRACT

The objective of this paper is to summarize results of two studies that compared Baseline, ENERGY STAR® and Guaranteed Performance homes co-located in Phoenix, Arizona, USA and determine if homes in these three groups could be distinguished from each other in terms of actual summer/cooling energy usage or homeowner satisfaction related to the HVAC systems. The summer/cooling energy use 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 shows that ENERGY STAR homes saved on average 16% in summer/cooling energy use (kWh/m²) as compared to the typical Baseline homes. The Guaranteed Performance homes saved on average 33% in summer/cooling energy use over the Baseline homes and saved 20% compared to ENERGY STAR homes. During the spring and summer of 2005, the homeowner satisfaction study was administered to 708 houses from the same 7,141 house sample set. The second study found that 49% of the Guaranteed Performance homeowners said they were completely satisfied with their home's "ability to keep them comfortable year round" compared to 35% of ENERGY STAR homeowners and only 27% of Baseline homeowners. In fact, this survey found that Guaranteed Performance homeowners were more satisfied with every aspect of their home's HVAC performance – year round comfort, the freshness of air inside the house, evenness of temperatures from room to room, reliability and cooling cost compared to Baseline and ENERGY STAR houses. Combining the results from these two studies shows that Guaranteed Performance homes consume less energy than comparable ENERGY STAR or code-built homes while simultaneously improving homeowner satisfaction.

KEYWORDS

Energy efficiency programs, energy consumption, homeowner satisfaction, guaranteed performance

INTRODUCTION

For more than 30 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 or homeowner satisfaction these programs were having post-occupancy.

In 2004, the United States with 4.6% of the world's population accounted 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 reduces overall home energy bills in computer modeling, but little is known about how these changes effect the homeowners as they live in these homes, or whether overall homeowner satisfaction is being influenced by these building changes. This report summarizes results from two studies to compare local code-built or Baseline, ENERGY STAR and Guaranteed Performance homes and determines if homes in these three groups have different summer cooling energy usage or homeowner satisfaction.

ENERGY STAR Homes Background

In 1995, the U.S. Environmental Protection Agency (EPA) launched its ENERGY STAR Homes program, which established guidelines for reducing home energy use and promoted partnerships with homebuilders to construct homes to be more energy efficient than code-built homes. A thesis study of 291 homes in Phoenix, Arizona in 2000 compared ENERGY STAR homes to code-built homes and concluded that ENERGY STAR homes used 2.3% less energy per square foot than the code-built homes [2]. At the time the energy use and homeowner satisfaction studies were started in 2004, the program standards based on computer modeling proposed savings of 30% for home heating, cooling and water heating as compared to homes built to the requirements of the 1993 Model Energy Code (MEC) or 15% more efficient than state energy code, whichever was more rigorous. These savings were based on guidelines of reduced building envelope infiltration and HVAC duct leakage, improved wall, ceiling and floor insulation levels and more efficient windows, doors and HVAC system. The adherence of these guidelines was field-verified in houses on a random basis. ENERGY STAR certified homes, it was reasoned, would offer homeowners dependable savings on their monthly energy bills while collectively reducing the overall energy consumption and impact of the residential sector nationwide. However, factors such as homeowners' lifestyles (with respect to energy use), effective product installations, operation and maintenance of HVAC systems, house sizes and others, made it difficult to assess the actual impact that these energy conservation intentions had on lowering home energy. Computer-modeled and deemed energy savings were available for the 400,000 plus homes built by 2004, but little was known about the as-built energy performance or homeowner comfort of these houses post-occupancy. Additionally, by 2011 over 1 million homes have now been built in this program.

Guaranteed Performance Homes Background

More recently, several organizations have created and promoted an ENERGY STAR "Plus" program for the new construction market. Called Guaranteed Performance homes, these homes are designed and built to go beyond the EPA ENERGY STAR program by:

- Requiring the use of more energy-efficient building components.
- Requiring 100% of the houses to have field quality assurance checks after framing, wall insulation and completed construction to make sure that the specifications are met at every stage.
- Providing a two-year heating and cooling energy use guarantee to the homeowners (typical house average of $1 U.S. or 12.5 kWh used per day).
- Providing a two-year comfort guarantee to the homeowners (defined as a temperature differential of no greater than plus or minus two degrees C (three degrees F) from the thermostat location to the center of any conditioned room within the zone) to ensure that the house is performing as designed after the homeowners have moved in.

Before this study was conducted in 2004, there were more than 60,000 houses nationwide built and certified to the Guaranteed Performance standards. To date in 2011, there are more than 150,000 homes built in this program.

Studies Objectives

The energy efficiency study was structured to compare the actual summer cooling energy usages of Baseline, ENERGY STAR and Guaranteed Performance homes, while taking into consideration a large number of variables in home design. That study looked at real data and real energy performance of occupied houses – not computer-model data. The results of the study 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 for summer space cooling?
- How much cooling energy savings are actually realized by ENERGY STAR and Guaranteed Performance homes, compared to similar Baseline homes?

The homeowner satisfaction study followed the energy efficiency study to determine homeowner satisfaction with right-sized HVAC systems. Right-sizing is typically applied in conjunction with other energy-reducing materials and construction techniques, such as low-E windows, higher Seasonal Energy Efficiency Rating (SEER) levels, tighter duct leakage standards and proper installation. As a result, overall homeowner satisfaction depends on more than just a right-sized HVAC system. The approach for this survey was to use a quantitative questionnaire to compare attitudes of homeowners of the three major categories of new homes in the Phoenix, Arizona market: Baseline, ENERGY STAR and Guaranteed Performance.

METHODS

Energy Efficiency

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.

For the 7,141 houses included in the 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 plus 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.

Direct comparisons of energy use between the three home categories – Baseline, ENERGY STAR and Guaranteed Performance – are difficult at best, given the vast number of variables that can affect both home performance and total energy use. Swimming pools, in particular, add significantly to the overall energy use of a home. Even seasonal differences in the costs of operating electric water heaters versus gas heaters can alter energy use profiles by as much as 900 kWh/year, invalidating certain study results. To reduce the chance for such variables to skew the results of this study, homes were only compared within certain definite data sets. Since no all-electric Guaranteed Performance homes were available for this study, the cleanest comparison is to look at gas-heated homes with no pool, within different size ranges.

Electric use data provided by the utility for years 2003 and 2004 were analyzed using a variable-base Heating Degree Day (HDD) regression analysis. In addition, periods with unusually low usage were also excluded, which were defined as use of less than 150 kWh/month or less than 400 kWh, and either less than 25% of the median use of the month or less than 40% of the 25th percentile of use for that home. These data screens excluded about 11% of the total 400,027 meter readings from 1998 through 2004, but only about 6% of the 85,963 meter readings in 2004. The use analysis results were considered reliable if they were based on at least nine meter readings that spanned at least half of the heating degree days (base 65°F, HDD65) and cooling degree days (base 75°F, CDD75) of a typical year, included at least one period of true baseload use (very few CDD or HDD) and resulted in an estimated baseload use of at least 2000 kWh/yr (to eliminate likely unoccupied homes not caught by the meter reading screens). This screening eliminated 596 homes (8%), primarily due to the requirement for nine meter readings, leaving 6,545 houses with apparently reliable records of electric use for the study.

The primary method for electric-use data weather normalization was a CDD and HDD adjustment. This approach classified and summed meter reading data and degree days for summer, winter and baseload categories based on HDD65 and CDD75. The resulting three equations were solved to estimate baseload use per day, summer cooling use per CDD75 and winter/heating use per HDD65, assuming a linear relation between use, CDD and HDD. This analysis approach allows for heating and cooling occurring within all seasons and appears to

provide more reliable results in many cases than using a regression model. This analysis was run separately for each home during each calendar year.

A regression analysis of summer cooling use (kWh/m²) was also performed as a function of living area. These regression models attempt to control for factors such as house size, orientation and baseload to avoid having to perform comparisons on increasingly smaller groups of buildings. The study team used the regression modeling to estimate the energy use for a 167 m², gas-heated home without a pool across the three home categories.

Homeowner Satisfaction Survey

The homeowner satisfaction survey was conducted in Phoenix during the spring and summer of 2005. It was conducted in two phases: 1) qualitative research among homeowners, builders and mechanical contractors and 2) a quantitative survey of 708 homeowners.

1. Qualitative Research

   The first steps began with qualitative research among homeowners, builders and contractors to understand what drives homeowner satisfaction and to ensure that the survey document was comprehensive and written in the homeowner's language.

2. Quantitative Research

   A written, four-page survey was mailed to 7,000 homeowners during July and August 2005. In all, 708 homeowners responded with completed surveys. A market research firm designed the survey and tabulated the returned surveys with an overall sampling margin of error of 3.7 percentage points at a 95% confidence level.

Homeowners identified that several factors were important when deciding whether to buy a particular new home. The principal factors were location, design and functionality. However, once the decision was made and the homeowner experienced living in the house, energy cost and performance of the HVAC system became very important. Qualitative research among homeowners and builders in Phoenix identified a set of drivers that determine how satisfied a homeowner is with their house after they have had at least a year's experience living in it. HVAC systems must satisfy four basic needs:

1. **Comfort**. Comfort is a basic need. Clearly, it is hard to be satisfied in a house that does not deliver basic thermal comfort in all seasons of the year. To homeowners, comfort is a function of several things: air freshness, evenness of temperatures from room to room, the ability to regulate temperatures and responsiveness, or the HVAC system's ability to heat or cool the house quickly.

2. **Energy Efficiency**. Homeowners need a system that delivers comfort in all seasons at a reasonable cost.

3. **Reliable Performance**. Along with cost, homeowners also need a system that is easy to operate, reliable and does not require constant repair. Furthermore, they want a system that is not noisy.

4. **Healthiness**. There is emerging awareness of the link between the home and family health. Homeowners are beginning to see how their home can be a source of health threats

from mold, mildew and airborne allergens. The link between health and home systems makes common sense to consumers.

RESULTS

Figure 1 shows the concentration of house type per year built.

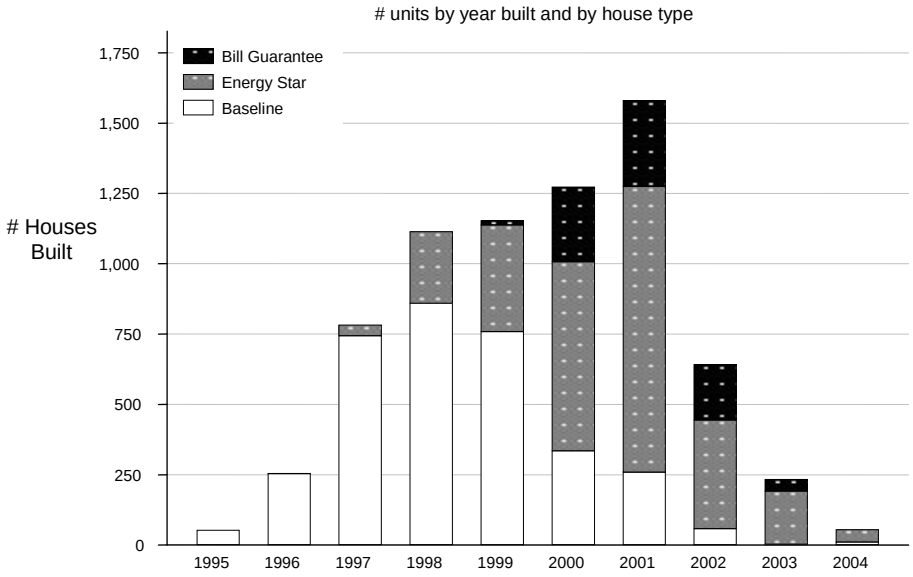

Figure 1: Study Homes by Year Built and Category

Energy Intensity (kWh/m²)

Table 1 outlines the summer/cooling energy use of gas-heated Baseline, ENERGY STAR and Guaranteed Performance homes with no swimming pools. Results are separated by house size into small (< 148 m^2), medium (149-223 m^2) and large (> 223 m^2) homes.

	Baseline	ENERGY STAR	Guaranteed Performance
Homes < 148 m²			
# Homes	282	326	141
kWh/m²/yr	0.41	0.38	0.33
Homes 149-223 m^2			
# Homes	37	660	282
kWh/m²/yr	n/a	0.33	0.25
Homes > 223 m^2			
# Homes	20	208	136
kWh/m²/yr	n/a	0.28	0.21

Table 1. Summer/Cooling Comparison

Energy Savings

After applying regression analysis, the annual summer/cooling intensities were estimated to be 16% lower for ENERGY STAR homes compared to Baseline homes (0.325 kWh/m2 versus 0.386 kWh/m2). Guaranteed Performance homes realized an energy savings of 33% over Baseline homes (0.260 kWh/m2 versus 0.386 kWh/ft2) or roughly 1800 kWh/year. As shown in Table 2, there were 708 responses to the homeowner satisfaction survey.

CATEGORY	CODE	# OF SURVEYS	% OF TOTAL
Baseline Homeowners	B	205	29%
ENERGY STAR Homeowners	ES	255	36%
Guaranteed Performance Homeowners	GP	235	33%
Unknown		13	2%
Grand Total		708	100%

Table 2: Composition of Survey Respondents

There are differences in the demographics of the three groups of homeowners:

- Baseline homeowners were the least affluent and live in the smallest houses. They were also between Guaranteed Performance and ENERGY STAR homeowners in age and the presence of occupants under the age of 18.
- ENERGY STAR homeowners had the biggest households with the most children. They were young and fairly affluent.
- Guaranteed Performance homeowners were older, more affluent and lived in smaller households. Their homes were large and presumably more expensive.

All the homes in the survey were built between 1994 and 2004, with the majority built since 2000. Figure 2 shows the number of homes constructed by year and by category.

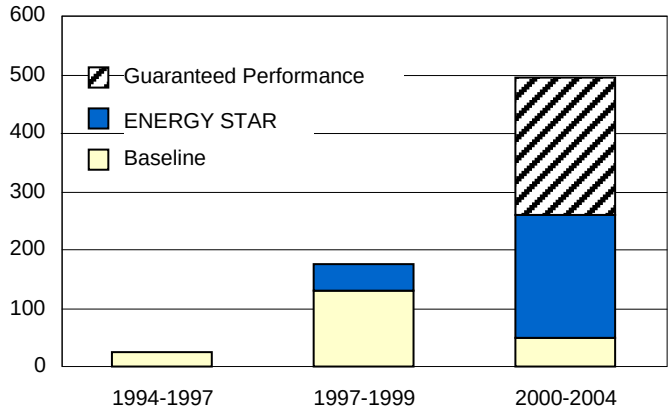

Figure 2: Houses Built By Year and Category

The characteristics of the houses in each of the three categories are depicted in Table 3. Guaranteed Performance homes tend to be larger, one story dwellings. The presence of a swimming pool is not dependent on the category of house, nor is SEER rating of the HVAC system.

CHARACTERISTIC	BASELINE	ENERGY STAR	Guaranteed Performance
Average square meters (Feet^2)	157 (1,685)	174 (1,877)	197 (2,125)
Percent of homes w/gas heat	26%	47%	73%
Percent of homes w/2 or more floors	20%	23%	15%
Percent of homes w/swimming pool	19%	20%	18%
Average SEER rating	11.6	11.9	11.7
Average square meter/ton of cooling (feet^2)	39 (423)	39 (418)	44 (474)

Table 3: Characteristics of Homes That Responded to the Survey

One of the key findings in this survey shows that Guaranteed Performance homeowners are more satisfied than ENERGY STAR or Baseline homeowners on almost every one of the following influences or drivers of satisfaction: comfort, energy efficiency, reliable performance, healthiness. Table 4 summarizes the percent of homeowners that are completely satisfied with each driver of satisfaction as well as the statistical relevance of each measure. Each measurement was statistically significant to 99%.

Category of Home	Need	Driver of Satisfaction	Guaranteed Performance	ENERGY STAR	Baseline
YEAR ROUND DRIVERS FOR ALL HOMEOWNERS	COMFORT	The ability of your home to keep you comfortable year round	49%	35%	27%
		The freshness of the air inside your home during those times you keep doors and windows shut	40%	24%	22%
	HEALTHI-NESS	Ability of heating and cooling systems to reduce allergies and other airborne ailments in your home	32%	19%	15%
SUMMER PERFORMANCE DRIVERS FOR ALL HOMEOWNERS	COMFORT	Your ability to regulate temperatures during the summer	41%	28%	23%
		The ability of your home to keep you comfortable during the summer	37%	22%	20%
		The ability of your air conditioner to cool your home down quickly	36%	25%	19%
		The evenness of temperatures from room to room during the summer	25%	14%	12%
	ENERGY EFFICIENCY	The cost of cooling your home	22%	14%	12%
	RELIABLE PERFORM-ANCE	The reliability of your cooling system (i.e., repair frequency)	53%	41%	32%
		The noise of your cooling system when it's running	29%	19%	15%

Table 4: Homeowner Satisfaction with Drivers of Satisfaction

DISCUSSION

At the beginning of this project, there was 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 cannot be controlled, would mask any noticeable differences. However, after having done this study and confirming there is tremendous variability, the sample size was still large enough to 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 in one specific geographic region, the data should not be viewed as proof for all regions of the U.S. We recognize there are issues and we cannot prove the exact amount of savings nationwide, but we now have a jumping point for further investigation and benchmarking in other locations. Bottom line – this kind of study can produce valid results and those results will be strengthened with additional data. That being said, the important findings from this study include:

- The number of homeowners surveyed was large enough to give statistical reliability, but due to variations in climate, construction practices, etc., these results are not extendable to other markets outside Phoenix.
- Compared to Baseline homes, ENERGY STAR homes used 16% less energy and Guaranteed Performance homes used 33% less energy for total summer/cooling, saving about 1800 kWh/year.
- Larger homes had lower cooling intensity.
- Two-story homes had higher cooling intensity than one-story homes even after accounting for living area.
- Baseload electric use constituted about 0.15 kWh of additional summer/cooling load for each 1 kWh of annual baseload electric used. This baseload electric impact was substantial – equal to about 1300 kWh of total summer/cooling for the average baseload use of 8571 kWh in the analysis sample, equal to about 20% of the entire summer/cooling load.
- Homes facing northeast had significantly lower summer/cooling energy use than homes facing east (the default category), but no other orientations showed statistically significant differences.
- This survey demonstrates that right-size HVAC systems, along with other energy efficient features, results in greater homeowner satisfaction.
- The researchers believe that there is a latent demand for higher performance, or better building science, on the part of the homeowner. Unfortunately, this demand seems to be overshadowed by other factors at the time of purchase.

CONCLUSION

Implementation of the ENERGY STAR and Guaranteed Performance programs can yield improvements in the overall energy efficiency of new homes, as compared to homes built to code. The quantitative actual energy use results and homeowner satisfaction results from three levels of home construction (Baseline, ENERGY STAR and Guaranteed Performance)

demonstrate that when the energy-efficient building requirements of the ENERGY STAR homes program were followed, the houses used 16% less summer/cooling energy and were 35% more comfortable than Baseline homes. But even more energy savings of 33%, as well as increased overall homeowner satisfaction of 49%, were possible when additional energy efficient requirements, 100% field quality assurance checks and a two-year comfort/heating/cooling use guarantee were added, meeting the Guaranteed Performance homes program standards.

These win-win findings will help the managers of the EPA ENERGY STAR, Guaranteed Performance and other energy-efficient new building programs adjust their respective program guidelines to ensure that the most cost-effective, energy-saving measures are identified and implemented into new home construction. For code officials, this may provide ideas for future changes. For homebuilders, contractors and other industry professionals, these measured results will provide evidence to support their claims of increased energy savings, validate the benefits of commissioning and help expand the market share of energy-efficient homes. Utility services may also benefit from this study by using the data to help identify future trends in the housing market and predict patterns of energy use.

One concern that came out of the data analysis is the appearance of the increase in average home size which is a trend the entire U.S. is experiencing (and the subsequent increasing energy use). This tendency offsets, to a large degree, the savings achieved through improvements in home energy efficiency. To realize actual overall energy reductions along with the environmental, economic and health benefits associated with those reductions, the trend to build larger homes may be useful to address.

The performance and satisfaction "bar" for new energy-efficient home construction has been raised in the Phoenix area as a result of the ENERGY STAR and Guaranteed Performance home programs. These programs have been instrumental in the education and training of consumers, builders and contractors about the benefits and construction differences of higher energy performing homes and homes with higher homeowner satisfaction. This study was initiated to provide a model for ongoing efforts to illuminate impact, as well as a feedback mechanism to support continuous improvement of energy-efficient programs for new home construction in the rest of the United States, as well as the world.

ACKNOWLEDGEMENT

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