COOLING PERFORMANCE ASSESSMENT OF BUILDING AMERICA HOMES

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ABSTRACT

Long-term monitoring of building energy use and environmental conditions has been a strong component of FSEC research since the 1980s. Fully-automated data collection, verification, archiving and management ensure accurate logging of large amounts of data simultaneously from numerous field sites prior to being made available for analysis and display via the internet. Homes are typically monitored using 15 to 50 channels of data to measure indoor and outdoor environmental conditions and energy use of heating, cooling, water heating, whole house, and other points (e.g. Solar PV or Solar DHW) if needed.

Energy performance in many Building America homes has been documented with measured data collected over several years to verify savings projections. An evaluation of measured cooling performance is presented with data from nine homes in three climate regions. Data from potential zero energy homes and minimum code homes provide upper and lower performance bounds. Comparisons are based on regression analysis of daily cooling energy per 1,000 square foot of floor area versus average daily temperature difference (outdoor-indoor).

INTRODUCTION

Building America is a private/public partnership sponsored by the U.S. Department of Energy that conducts systems research to improve overall housing performance including durability, comfort and reduced energy use. The ultimate program goal is to achieve a 70% reduction in energy while making up the other 30% with on-site power to provide homes that can cost-effectively produce as much energy as they consume.

As of 2004, 46% of new single-family homes are currently built in the South where air conditioning makes up the largest portion of the annual electric bill (USDOE 2005). Through systems engineering, significant reductions in cooling energy have been successfully achieved in these climates by rigorous application of cooling load reduction strategies. Lower cooling loads lead to smaller air conditioners which, when coupled with high efficiency equipment, have led to reductions of over 70% in cooling energy use.

Long-term measurements of cooling energy use from eight research homes of varying performance levels, mostly in the Central Florida area, were compared with two “minimum-code” homes. The data is drawn from dwellings of various size and construction and with cooling equipment of varying efficiency. Plotting such data on a common graph required generalizations that limit the ability to make direct house to house comparisons, but instead provides a broad assessment of cooling performance.

DATA PLOTTING METHODOLOGY

Cooling equipment consisted of split systems with ducted central air handlers. Sub-metered energy from the condenser and air handler was stored at 15 minute intervals and subsequently combined and totaled on a daily basis during the summer months of various years from 1998 to 2005. Daily cooling energy totals were then divided by the total conditioned area of the home to arrive at daily cooling energy per 1,000 square feet. This provided a means of comparing all homes which range from 1,200 to 4,200 square feet.

The daily cooling energy totals were plotted against average daily temperature difference between outdoors and indoors. Weather stations installed at each site collected dry bulb temperature, relative humidity and solar radiation. Indoor temperatures were taken at or very near the thermostat. The x-axis for each data set consists of the difference between the daily average outdoor and indoor temperatures for the 24 hour period starting at midnight. The values generally fell between negative 10 and positive 15 degrees (outdoor minus indoor). Those residences with lower thermostat settings were characterized by large positive values during the hot summer months. The use of temperature difference is intended to account for both indoor and outdoor temperature variations due to occupant determined thermostat settings and outdoor weather variations.

One pair of homes in the data set can be compared without the generalizations discussed above (except for indoor set point) as they were constructed together with identical floor plans and orientation. These two dwellings located in Lakeland, Florida only differed in equipment efficiency and construction. One was built to minimum code requirements while the other was extensively engineered for reduced cooling load and high efficiency. The original measured results from this 1998 project have since formed the basis for the national Zero Energy Homes program (Parker 1998). The pair effectively sets the upper and lower bounds of the data plotted here.

Baseline For Comparison

A single baseline was needed to provide a common comparison point for cooling performance in the eight research houses. This was achieved with data from two minimum-code homes located in Central Florida. The Lakeland home provided the majority of this data collected over five summers from 1998 to 2002. The other home contributing to the baseline was a code-minimum frame structure located in Cocoa, Florida; built in 1991. Data from this home was collected over three summers from 2002 to 2004. Each of these residences is cooled by the originally installed, minimum efficiency equipment, SEER 10 in Lakeland and SEER 9 in Cocoa.

Figure 1 shows the data points used to develop the baseline as well as the associated trendlines established through linear regression and least-squares analysis. Regressions were performed on each control home to reveal their individual trends and again on the combined data from both homes. The combined data (black line) provided the baseline for determining cooling energy performance in all other homes. Data from the low-energy Lakeland house is also shown for comparison.

The cooling performance level of each research home was quantified by comparison of the areas under the least-squares line. This assumes the areas are directly proportional to energy use and are affected by the length chosen to makeup the bottom edge of the area along the x-axis. The length chosen for this analysis was from -5 to 10 along the x-axis, since the majority of data points fell between these values. This section of the x-axis is where moderate thermostat settings and outdoor temperatures are more likely to fall and tends to exclude high and low extremes.

Also shown in Figure 1 is the coefficient of determination (R^2) for each regression line. This measure of "goodness of fit" of the line to its associated data points ranged from 0.50 to 0.89. Removing outliers will improve these numbers however no attempt was made to do so, except where obvious errors or extremes caused by unusual weather or occupant activity were found. For the most part, the data presented here includes fluctuations caused by occupant activity.

Combined Baseline (from 2 homes)	
Square Feet	2428 & 1700
Cooling Efficiency	SEER 10 & 9
Data period	Summers 1998 – 2004
Linear Fit Equation	y = 1.59x + 14.0
R^2	0.78
Area Under Line	269

PERFORMANCE COMPARISON

The Lakeland high efficiency home was the oldest of those studied (8 years), yet it continues to set the bar for cooling efficiency. The data shown in Figure 1 is typical of the last two years of data collection (2002 & 2003) and represents 72% less cooling energy use than the baseline. While newer the research houses have higher efficiency and sometimes dual-speed cooling equipment, this particular home took advantage of well-designed cooling reduction strategies coupled with a smaller 2-ton cooling system.

Lakeland - Low Energy	
Square Feet	2428
Cooling Efficiency	SEER 14
Data period	May 1 – Sep 30, 2002
Linear Fit Equation	y = 0.39x + 4.1
R^2	0.82
Area Under Line	76
Cooling savings	72%

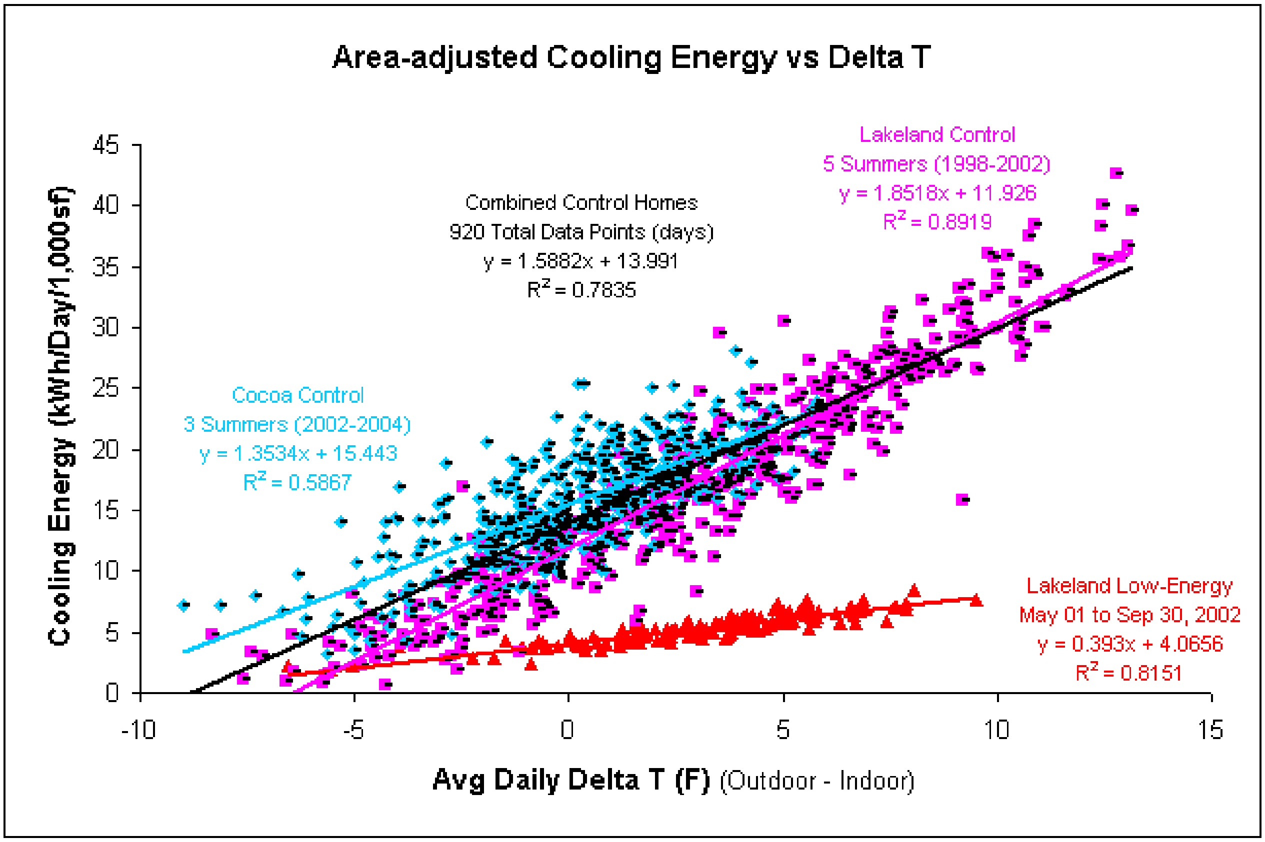

Figure 1. Data and trendlines from two control and one efficient home

The Lenoir City, Tennessee Habitat house was designed as a zero-energy home with a high efficiency, 17 SEER system and SIP roof and wall construction. It is the first of several constructed under the guidance of Oak Ridge National Labs. (Christian 2004). The exceptional efficiency of this residence is notable considering its small size compared to the other research homes. While normalizing the cooling energy data with conditioned square footage allows direct comparison of homes, it appears to present an unfair advantage to larger homes which tend to have lower internal load densities generated by appliances and people.

Lenior City, TN, Habitat	
Square Feet	1200
Cooling Efficiency	SEER 17
Data period	Jun 1 – Sep 23, 2005
Linear Fit Equation	y = 0.45x + 4.4
R^2	0.53
Area Under Line	83
Cooling savings	69%

The Longwood house is the largest of the sample. Built in 2000, it incorporates numerous efficiency features and monitoring continues on this home which has consistently performed at the 63% savings level for the past 4 years as represented by the summer 2002 data set. Outdoor air ventilation is provided via an ERV and supplemental dehumidification is used to maintain favorable humidity. As with all study homes, the energy data includes only compressor and air handler energy and not ventilation or humidity control equipment, which in this case contributed to the overall cooling load.

Longwood, FL	
Square Feet	4200
Cooling Efficiency	SEER 13, dualspeed
Data period	May 1 – Sep 30, 2002
Linear Fit Equation	y = 0.47x + 5.4
R^2	0.65
Area Under Line	99
Cooling savings	63%

The Idaho house was constructed by a HUD Code manufacturer and designed as a zero energy home. Built in 2002, it is located near Lewiston along with another home built to Energy Star standards for a comparison study (Lubliner 2004). It is equipped with whole house ventilation through a heat recovery ventilator and has Energy Star lighting and appliances installed throughout.

Idaho, Manufactured Home	
Square Feet	1640
Cooling Efficiency	SEER 12
Data period	Jun 17 – Sep 8, 2005
Linear Fit Equation	y = 0.42x + 8.0
R^2	0.73
Area Under Line	135
Cooling savings	50%

The Orlando "Not-So-Big House" was built as a 2005 International Builders Show home with data collection beginning in the summer of 2005. It was constructed using Structural Insulated Panels (SIPs) and made use of a relatively new cool roof coating technology which reflects infrared light to reduce heat gain. This allows a variety of colors including the "patina green" used on its standing seam metal roof. It has separate first and second floor cooling systems

Orlando, FL Not-So-Big	
Square Feet	2660
Cooling Efficiency	SEER 16, dual system
Data period	Jul 22 – Sep 22, 2005
Linear Fit Equation	y = 1.09x + 7.9
R^2	0.50
Area Under Line	159
Cooling savings	41%

Data collection on the Ft. Myers home began in summer 2005. While designed with many efficiency features, it has not performed as well as expected. The 5-ton cooling system is slightly oversized and is further hampered by duct leakage measured at 6% of floor area (150 cfm25 to out). The ducts are located in a vented attic under a dark-colored roof. A modest level of outdoor air ventilation (32 cfm) is provided during air handler runtimes via a duct at the return plenum.

Ft. Myers, FL	
Square Feet	2481
Cooling Efficiency	SEER 15
Data period	Jun 1 – Sep 13, 2005
Linear Fit Equation	y = 1.57x + 10.0
R^2	0.82
Area Under Line	210
Cooling savings	22%

The 1991 Cocoa home which was used to establish the combined baseline with data from the summers of 2002 through 2004 was retrofit with a reflective white roof in May 2005. A 5% improvement over the baseline was documented with limited data from the summer of 2005. Data collection will continue in 2006. Comparing the 2005 data to the original cooling energy performance (2002-2004) of this home (independent of the combined baseline) in a before/after fashion, shows a 9% improvement.

Cocoa, FL White Metal Roof	
Square Feet	1700
Cooling Efficiency	SEER 9
Data period	Jun 25 – Aug 31, 2005
Linear Fit Equation	y = 1.18x + 14.2
R^2	0.66
Area Under Line	257
Cooling savings	5%

The final research home was the Manufactured Housing Lab located on the FSEC campus in Cocoa, Florida. The building is unoccupied but is operated under carefully controlled simulated occupancy and is extensively monitored for both research and demonstration purposes. This HUD code home, which is Energy Star compliant, operated slightly below the combined baseline performance level.

Cocoa, FL MHLab	
Square Feet	1600
Cooling Efficiency	SEER 12
Data period	Jun 17 – Sep 8, 2005
Linear Fit Equation	y = 1.44x + 14.8
R^2	0.89
Area Under Line	276
Cooling savings	-2%

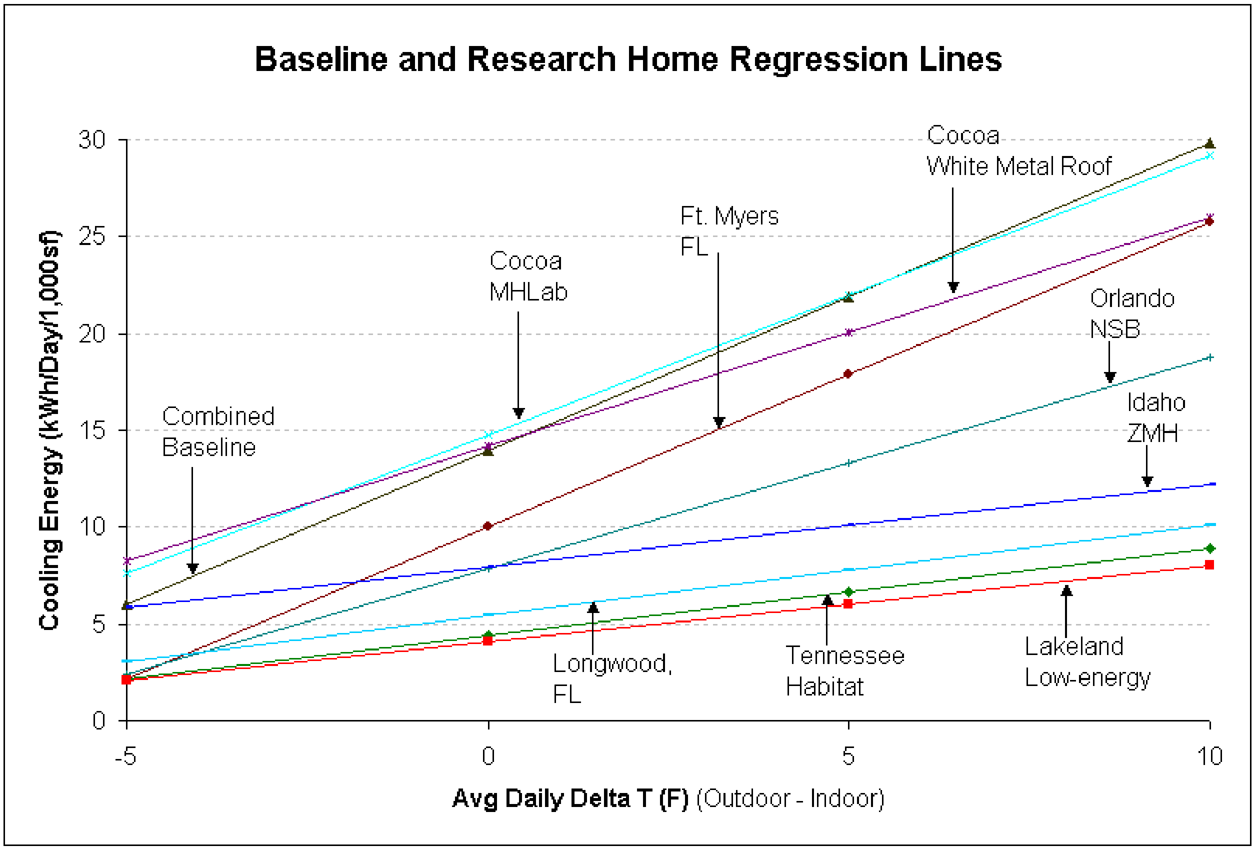

Figure 2 Trendline comparison of Combined Baseline and 8 Research Homes

CONCLUSIONS

Field-collected home performance measurements are needed to gauge progress toward the Building America goal of 70% whole house efficiency. The method developed here made use of measured cooling energy and temperature data analyzed through least-squares linear regression on both code-minimum and research homes. Figure 2 directly compares the linear regression of each data set.

The cooling energy savings of each research home was determined in reference to a combined baseline established with data from two homes built to minimum code. While the baseline houses do not necessarily represent “typical” code-minimum homes, they nonetheless provide a useful baseline for comparison of the eight research houses. Additional data from homes built to standard construction practices are needed to further refine the baseline.

Additional work is required to determine the influence of home size on cooling performance level. A greater number of people and equipment per square foot tends to concentrate internal loads in smaller homes more so than in larger ones. This may partially explain the MHLab performance, which was below the baseline despite its efficient design. The MHLab was 34% to 62% smaller than the other research homes in the same climate (Florida).

Further research on the influence of ground-coupling on cooling performance will improve the accuracy of comparisons between homes in different climate regions and with different levels of ground contact. All but three homes in this study were of slab-on-grade construction. The basement design of the smallest research home (Tennessee Habitat) was likely a strong contributor to its excellent performance, just as the crawlspace design of the MHLab negatively impacted its cooling efficiency.

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