FEATURE

Residential Energy Efficiency:
A Model Methodology for Determining Performance Outcomes

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INTRODUCTION

The current climate of opinion in both the residential and commercial sectors for new and existing building stock gives a prominent role to energy efficiency as a policy tool. Executive and legislative branches of government at both the state and federal levels are considering and adopting policy options to valorize energy efficiency in the service of everything from national security to curbing global warming to creating a green economy. While the authors support this activity, it should be noted that actual evidence regarding the benefits or outcomes of most funding initiatives or policy activity in this area remains difficult to assess meaningfully.[1] Furthermore, the authors stress the need for validation of post-occupancy performance and demonstration of persistence of energy efficiency benefits attributable to energy efficiency initiatives and policy activities.

This article addresses a vital piece of the energy efficiency puzzle by providing a simple, yet viable, method for assessing actual performance using one well-known and nationally important green building rating system for homes: ENERGY STAR. Two previous articles in *Real Estate Issues* addressed some basic program evaluation issues and identified the need for a more robust method for determining how ENERGY STAR-certified homes were actually performing relative to comparable non-ENERGY STAR-certified homes.[2] These earlier studies, though preliminary, pointed to challenges associated with data collection and analysis, both in terms of relative performance in the same geographical location and, more important, over significant time intervals.

To recap the conclusions of the previous articles, the ENERGY STAR homes in the sample performed better than comparable non-ENERGY STAR homes (i.e., they used significantly less energy as measured in equivalent kilowatt hours to account for both electricity and natural gas consumption), but they suffered from a significant deterioration in performance over time. The earliest attempt (Smith and Jones) to quantify performance of a large set of certified homes showed that the sample ENERGY STAR homes were performing approximately fifteen percent better than non-certified homes. This showed the potential significance of ENERGY STAR to lenders and homeowners as a mechanism to decrease homeownership hard costs over the life of the home. This conclusion was of particular import for lower-income households. Therefore, results of the second study (Jones and Vyas) came as a surprise when the study showed that the difference in energy use between the same sets of comparison homes five years after the certification date was statistically insignificant. This cast doubt on the persistence of the earlier positive conclusions. If the performance of ENERGY STAR homes decayed measurably compared with non-ENERGY STAR homes within five years, any attempt to use the certification as the basis of underwriting advantages was in doubt. The future benefits to subsequent purchasers as well as value to a lender would need to be reassessed, internalized and properly discounted into any currently claimed benefits.

A final conclusion was an acknowledgment that even though this vein of research was of value, it could not provide any answers as to what could be causing or directly correlated to the decaying performance rate of the ENERGY STAR homes. Nor did this comparison over time allow for a more generalized method of comparing homes (or a specific subset of homes delineated by location or

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census block) to the larger population of homes in the municipality or region. Further, the acquisition of data for making comparisons over time proved arduous, a process leading to long time lags for adequate analysis and policy application. Recognizing these challenges, the authors set out to craft a methodology that would allow for a more robust use of existing energy consumption data and provide meaningful insights on the relationship between a building's particular energy efficiency attributes and its demonstrated (positive or negative) performance. This evaluation of ENERGY STAR-certified homes over time (ten years) is the first such detailed analysis of performance known to the authors.

Traditionally, information related to the energy performance of residential units was confounding to researchers due to the myriad of variables that could affect the energy use of the residential stock over time. Geography, climate, weather, construction quality, construction practices, local codes, market preferences for size and amenities, and many other attributes made generalizing over time about energy use patterns difficult or impossible. Even more confounding has been the human behavioral element associated with a particular residential unit or cohort. The energy use pattern of a family of five with two teenagers is significantly different from a family of three though their housing attributes may be virtually identical. The only way to normalize for some of the variables of both human behavior and building structure was to develop a methodology that compares the housing under analysis with a sufficiently large number of baseline units, effectively expanding the number of units with which a housing cohort is compared to the maximum extent possible. We believe we have achieved this and that the results have important policy implications. While it does not explain the building science, behavioral and other factors affecting energy performance, this expanded baseline methodology improves the precision and confidence of energy performance comparisons across housing cohorts, and therefore is a useful tool for program evaluation and policy applications.

Previous policy options were often based on biased, inappropriate or anecdotal claims about the benefits associated with residential building energy efficiency improvements. As with many policy choices, the aspirational rhetoric is given more importance than the verification of performance. This is not to say that there has been a lack of attempts to understand the fundamental building science associated with residential energy efficiency.[3] On the contrary, the authors wish to stress only that the sector is highly disaggregated and full of conflicting incentives that in their judgment do not offset the additional transaction costs or risks of validating performance. Verifying the outcomes should be a prerequisite for meaningful public policy creation and continuing implementation. In the public sector, a lack of useful data regarding outcomes only exacerbates the allocative (through direct and indirect subsidization or grants) and productive (through regulatory or public sector-directed research) inefficiencies. In the worst case scenarios, money is spent on programs that do not provide real benefits, while truly beneficial energy efficiency options are not recognized or promoted. The private sector also needs verifiable outcomes in order to make the proper cost-benefit calculations for deploying energy efficiency expenditures. Here, too, there is real interest in energy efficiency options since decreased hard costs can benefit both developers and consumers.

MODELING ENERGY USE AND PERFORMANCE BASELINES

Measures of housing performance (potential and/or realized energy savings) are used to evaluate energy efficiency programs and financially reward energy utilities and, in turn, their customers. Given this incentive structure, the appropriate context, construction, and application of energy use baselines and specification of models to estimate energy savings are critical.[4] Sophisticated engineering, econometric and mixed-model approaches have been developed to improve evaluation of utility energy efficiency programs. Using these standard methods, energy analysts are deriving performance baselines, analyzing actual consumption data, estimating demand response to specific policies and programs, and calculating associated savings. When funding is sufficient, the analyses attempt to quantify effects considered external to the policies or programs themselves (e.g., free rider, spillover and rebound). However, the relatively high cost of such complex modeling approaches and the variability of estimates across utilities and programs justify continued pursuit of simple, valid, transparent, and replicable methods for evaluating performance. In this study, we use a regression analysis approach that aims to satisfy these key methods criteria—simple, valid, transparent, and replicable—while generating robust estimates for the performance measures of concern.

Engineering models to project or estimate energy savings from energy efficiency interventions (such as the EnergyGauge® software that underpins the nationally utilized Home Energy Rating System [HERS] Index)[5] are typically constructed at a micro-scale and are particularly useful for delineating the upper bounds of energy-efficiency potential based on a building's structural, mechanical and electrical attributes. Output from such models serves as benchmarks for measuring changes in performance after an appliance or equipment upgrade and/or for evaluating a new home's actual performance. They are particularly useful when constructed and applied at a whole-house systems level. Energy performance measures derived from engineering models alone, however, are inherently limited in scope of application as they cannot account for post-occupancy factors independent of the home's engineered design (such as weather, economic conditions, and resident demographics and behavior). Furthermore, they cannot easily be scaled up to provide valid expectations about and estimates of performance at the community or utility level, a very significant problem when attempting to generate policy directives.

Conversely, econometric models are typically constructed at a macro-scale using self-reported electric utility data on energy consumption and savings (e.g., those supplied to the Energy Information Administration [EIA] via Form EIA-861 by the utilities themselves[6]). These models often include data on critical energy demand determinants such as service population characteristics, utility rates and climate data to estimate program impacts within and across samples of utilities. While such econometric approaches are well-established and typically robust, they are designed for use at a macro level and results are dependent on the quality of the aggregate utility data.[7] Given these limitations, they may not generate truly meaningful estimates of energy savings and cost-effectiveness when scaled down to the individual household or program level. Furthermore, methods used by individual utilities to calculate energy savings vary and the original data used to estimate key model parameters often are not readily accessible to the empirical research community. Finally, given uncertainties about the derivation of key independent variables applied in large scale econometric models, it is difficult to know whether changes in energy consumption via programs are being measured using the most appropriate performance baselines.

ANNUAL COMMUNITY BASELINES APPROACH

To improve estimates of energy savings attributable to a particular policy or program, the authors used a micro-scale multivariate regression method based on a census of utility and home property appraisal data. This approach was applied to: 1) establish new measures of energy performance by constructing annual community energy consumption baselines (ACBs) against which actual (metered) household-level energy consumption is compared for the years 2000–2009; and 2) estimate energy savings attributable to a subdivision of ENERGY STAR-qualified new homes[8] using ACB estimates as the foundation for year-over-year performance comparisons.

The authors' proposed methodology is unique[9] in that it: 1) defines a new household-level energy consumption baseline measure that they believe produces more accurate and appropriate energy performance measures; 2) uses a census of publicly available data for the population of interest, merging metered utility data with property appraiser data; and 3) uses these census data with the new baseline measure to construct a simple model for evaluating household-level energy performance. For this study, these ACB performance measures are used to estimate energy savings attributable to a subdivision of ENERGY STAR-qualified homes.

The critical element that distinguishes these energy performance measures is that they are calculated and interpreted using baselines that effectively normalize for community energy consumption patterns in any given year. Year-over-year household consumption is evaluated relative to the community baseline, so residuals estimated from the ACB regression directly reflect the authors' definition of meaningful and relevant energy performance measures (i.e., energy savings). Furthermore, because the annual performance measures themselves are derived from a regression-adjusted baseline approach, the data are normalized in such a way that year-over-year performance of individual households or select building cohorts can be compared directly. This prevents the performance impacts and other energy conservation programs from being overstated or obscured as a result of non-program effects (such as economic conditions, rebound, free riders and free drivers, spillover, and so on). In light of debate surrounding the need to account for these effects, which are "notoriously difficult to measure," the authors think that this feature of our model is particularly valuable.[10]

To construct and run the authors' model estimating the relative performance of a cohort of ENERGY STAR homes[11], data were requested and obtained from three sources in Florida: the Alachua County Property Appraiser (ACPA); Gainesville Regional Utilities (GRU) and the Clay Electric Cooperative (CEC). ACPA provided data on the physical characteristics, location and sales of all properties in Alachua County (current as of November 2009). GRU and CEC provided monthly, account-level, electric and natural gas consumption data for each residential and commercial customer from 2000–2009 (See Figure 1).

In identifying data to use in the analysis, model variables were selected based on corresponding data availability, accuracy, and their expected relation to residential energy consumption. Monthly, account-level, electric and natural gas data linked to the premise, customer identification number and physical address were selected from the GRU database. Physical address, building type, U.S. Department of Revenue (DOR) tax code, parcel number, number of bedrooms, number of bathrooms, conditioned floor area, year built, and census block code were selected from the ACPA database. Physical address was used to link and merge the two databases to create the final analysis data set.

Figure 1.

Original Databases Used in Final Analysis Data Set

Alachua County Property Appraiser Database	Gainesville Regional Utility Consumption Database	Clay Electric Company Consumption Database
Parcel Number	Premise Number	Premise Number
Physical Address	Customer Number	Customer Number
Building Type	Physical Address	Physical Address
DOR Code	Meter Read Date	Meter Read Date
Number of Bedrooms	Service Type	Service Type
Number of Bathrooms	Billed Consumption	Billed Consumption
Conditioned Area		
Year Built		
Census Block Code		

Source: Alachua County Property Appraiser; Gainesville Regional Utilities and Clay Electric Cooperative

CLEANING AND SCREENING

Single-family detached homes were selected from the ACPA database, representing the population of comparison homes. Monthly electricity and natural gas consumption data were used to create annual subsets for each home in calendar years 2000–2009 (excluding 2007[12]). For each annual subset, data were screened to ensure that homes in the analysis sample had at least 350, and no more than 380, days of electric consumption data on record and that the necessary property appraisal data were available.[13]

Monthly electric and natural gas consumption were combined and expressed in units of equivalent kilowatt hours (ekWh) to quantify total annual energy use. Annual consumption data were normalized to represent the full calendar year by taking average daily use for the number of days recorded (between 350 and 380 days) and multiplying by 365. Residential units consuming less than 3,000 ekWh per year or more than 65,000 ekWh per year were considered to be either unoccupied or outliers, and were excluded.

ACB MODEL SPECIFICATION

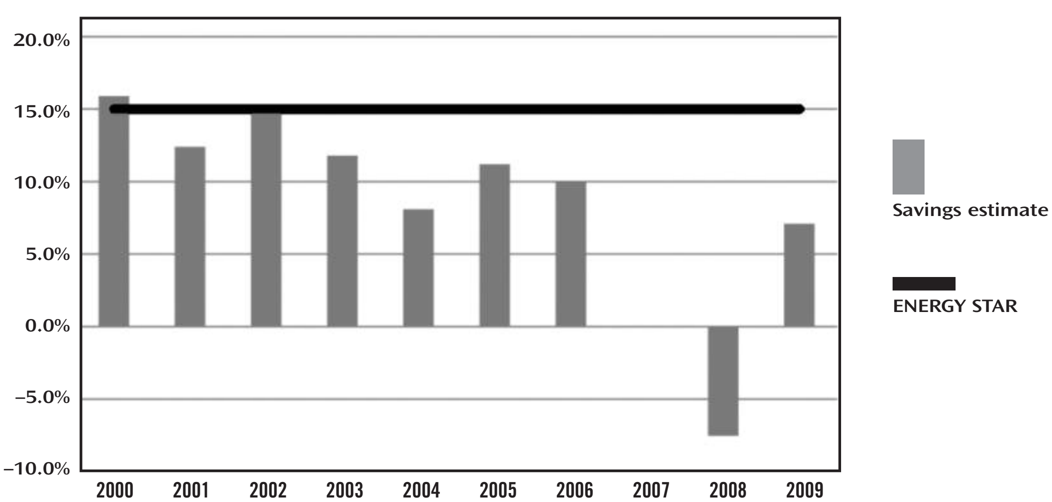
Each calendar year data set was analyzed using the multivariate regression techniques that generate predicted home energy use values for each residential unit in the census. The number of bedrooms and bathrooms, and square footage of conditioned area are important explanatory factors for energy consumption because they are indicators of the number of people living in each home and HVAC demand, respectively. Using a principal components (PC) analysis, we transformed these highly correlated yet distinct measures of home size into a single "size factor" predictor variable. Year built is also an important energy use predictor variable as it captures the building code under which the home was constructed and the common building practice used in that particular time period. To transform it to a more meaningful continuous variable for use in regression, year built was converted to home age by subtracting year built from the analysis year (2010). The U.S. census block code was selected as a geographic indicator for resident behavior and demographics. These variables (size factor, age and census block code) were used to complete a regression analysis (using the equation below), resulting in predicted energy use values for each home in each of the analysis years. These predicted values represent the annual baselines for absolute energy consumption in each year for each residential unit.

Energy Consumption $= \beta_0 + \beta_1(\textit{Size Factor}^{PC}) + \beta_2(\textit{Age}) + \beta_3(\textit{Census Block}) + \epsilon$ where *Size Factor* $^{PC} = f$ *(conditioned area, # of bedrooms, # of bathrooms)*

Residuals derived from this ACB regression are interpreted as annual energy performance measures for each residential unit in each year; mathematically, they are calculated as actual, minus predicted energy use. A second series of regressions, with residuals as the dependent variable, is used to estimate the magnitude and statistical significance of energy savings of the ENERGY STAR subgroup of homes. This series of regressions for each year essentially tests whether the performance of ENERGY STAR homes (N=84) is significantly different from the performance of the full population of homes in the Gainesville area (N=36,872).

Figure 2

Annual Percent Savings Estimates for Mentone Homes Constructed in 1998–1999



Annual Percent Savings of ENERGY STAR® homes estimated using Annual Community Baseline regression methodology. The ENERGY STAR line delineates the 15% greater energy efficiency that approximates the performance required to achieve the ENERGY STAR certification (which applied in the years the homes were built). See *www.energystar.gov/index.cfm?c=new_homes.hm_index*.

DISCUSSION AND CONCLUSION

Results (summarized in figures 2 and 3) are consistent with the "decay rate" conclusion in the Jones and Vyas study. While the ENERGY STAR homes met the program's performance threshold of 15 percent savings in 2000, this relative performance declined over time and was actually negative (i.e., the homes consumed more energy than predicted by their respective baselines) in 2008. In years when performance was positive, estimates of absolute energy savings range from a high of 3,130 ekWh in 2000 to a low of 1,259 ekWh in 2009. Further data collection and analysis is needed to understand why this degradation is occurring and to explain the relative roles that structural integrity and occupants' behavior play in energy performance. While the study population in the earlier comparison analysis was limited to several hundred, the current analysis accounts for 84 ENERGY STAR-certified homes in the Mentone subdivision *and* the population of 36,872 homes in the region in calculating its performance measures. More important, using this regression methodology to establish the appropriate baseline for a community begins the process of worthwhile analyses that can create, alter, inform and evaluate policy in this energy efficiency arena.

Figure 3

Annual Community Baseline Results for Mentone Homes

	Predicted Energy Use (ekWh)	Actual Energy Use (ekWh)	Absolute Savings (ekWh)	Percentage Savings (%)
2000	19,650	16,520	3,130	15.9***
2001	20,098	17,605	2,493	12.4***
2002	20,469	17,424	3,045	14.9***
2003	20,775	18,326	2,449	11.8***
2004	20,577	18,913	1,664	8.1*
2005	19,806	17,592	2,214	11.2*
2006	18,950	17,062	1,888	10.0*
2007	—	—	—	—
2008	13,645	14,663	–1,018	–7.5
2009	17,720	16,461	1,259	7.1*

Annual Community Baseline output is reflected as average predicted use for the Mentone homes (N=84) relative to population of homes in the region (N=36,872). *** indicates statistical significance at 1% level; ** would indicate statistical significance at 5% level; * indicates statistical significance at 10% level. The predicted use minus actual use gives an absolute savings estimate, which is then converted to a percentage savings estimate. Data for 2007 were rejected due to changes in the data management system at Gainesville Regional Utility and the resulting corruption of utility data.

The ENERGY STAR certification for homes is fundamentally different from the ENERGY STAR commercial certifications. Home certifications are done only once, while commercial certifications generally must be done annually. The performance of an ENERGY STAR home has been assumed to continue indefinitely once certification has been achieved. Our analysis shows that while ENERGY STAR homes did perform better than predicted based on the ACB analysis, this assumption about the persistence of ENERGY STAR benefits is not satisfied in the Gainesville, Florida, region. We expect that any public policy or private sector decision-making that shares this assumption is likely to be inappropriate or misguided.

Attempts at a cost-benefit analysis of the value of ENERGY STAR home certifications cannot be done without the kind of results obtained in this study. Initial expenditure premiums must be contextualized with rigorous performance evaluation to determine if the developer, homeowner or lender is properly placed to gain a net positive value. In our example, Figure 2 shows the average Absolute Savings Estimate for the first five years of the Mentone homes is 12,781 ekWh. The cost of electricity in the Gainesville area is .15 dollars/kWh (natural gas is significantly less expensive and thus is ignored here to obtain the most conservative outcome).[14] Therefore, the cost of energy saved over the first five years would be approximately $1,917 (12,781 ekWh x .15 dollars/kWh for a home using only electricity for all energy consumption). This back-of-the-envelope calculation suggests that if the initial cost of the improvement to obtain ENERGY STAR home certification is greater than $2,000 dollars, the certification may be counter-indicated. If we increase the time element beyond five years, the cost-benefit analysis looks less compelling.

The data also suggest that any subsequent purchaser five years after the ENERGY STAR certification might obtain negligible benefit. In fact, the certification may provide an unrealistic expectation of performance. Any seller or broker who is continuing to tout the ENERGY STAR certification as the source of a greener or energy efficient home may be treading on shaky ground as well. Even developers who are well-meaning and hope to provide real benefits to their home purchasers may inadvertently fail to deliver if they rely on ENERGY STAR certifications to obtain energy efficiency performance.

Some of the one million ENERGY STAR-certified homes are no doubt exemplary in their capacity to deliver energy efficiency over long periods of time. These make sense both for public policy and as a signal to the marketplace to deliver better performing housing stock. Unfortunately, the lack of any large-scale validation of ENERGY STAR-certified home performance means that we are left with only anecdotal, incomplete or biased information on which to make crucial decisions in confronting the problem of residential energy efficiency and providing appropriate signals to the market for the value of energy efficiency.

The Program for Resource Efficient Communities at the University of Florida is actively looking to contribute content to a national database that could be of use to researchers of all types. The authors already have begun the process of expanding the data sets and methodology beyond Gainesville to other cities in Florida and nationally.[15] Only by extending the scope of the data sets and the robust methodological application can we hope to further the cause of reaping the true benefits of an ever-expanding population of energy efficient housing in this country. ■

ENDNOTES

1. Woods, James E., Richard Sweetser and Davor Novosel, National Center for Energy Management and Building Technologies *Task 6-02: Scientific Outreach Program Pilot*, July 2009. Though this study concentrates on a number of basic problems in the measurement and analysis of commercial building performance, it is a good examination of many similar problems in the residential market. In fact, the problems associated with the residential market are even more severe since the variability of this building stock and the lack of any concerted data acquisition is even more pronounced.

2. Smith, Marc T. and Pierce Jones, "The Impact of Energy Efficient House Construction on Homeownership Costs: A Comparative Study in Gainesville, Florida," *Family and Consumer Sciences Research Journal*, 2003, Vol. 32, pp. 76–98; and "Energy Performance in Residential Green Developments: a Florida Case Study," Pierce Jones and Ujjval K. Vyas, *Real Estate Issues*, 2008, Vol. 33, No. 3, pp. 65–71.

3. Many public and private institutions and organizations are interested in the energy efficiency of the residential sector but very few, if any, are incentivized to actually monitor and provide analysis of the real performance of this real estate sector. Like school reform, the aspirations are widely expressed but the fear of data revealing the failure of important vested sectors makes it difficult to trust *and* verify. At the same time it should be clear that the vast majority of home buyers continue to make purchasing decisions based on home attributes that are not in consonance with the popularity of green or energy efficiency marketing.

4. Arimura, T., R. Newell and K. Palmer, "Cost-Effectiveness of Electricity Energy Efficiency Programs," *Resources for the Future*, 2009, RFF DP 09–48; P. Parfomak and L. Lave, "How Many Kilowatts are in a Negawatt? Verifying *Ex Post* Estimates of Utility Conservation Impacts at the Regional Level," *The Energy Journal*, 1996, Vol. 17, No. 4, pp. 59–87; and Gillingham, K., Newell, R. and Palmer, K., "Energy Efficiency Policies: A Retrospective Examination,"*Annu. Rev. Environ. Resour., 2006,* Vol. 31, pp. 161-92.

5. See *www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_HERS*, last accessed July 13, 2010.

6. "Form EIA-861 Instructions. Annual Electric Power Industry Report," Energy Information Administration, U.S. Department of Energy, 2007, available at: *www.eia.doe.gov/cneaf/electricity/forms/eia861/eia861instr.pdf*, last accessed April 31, 2010.

7. E.g., Horowitz, M., "Changes in Electricity Demand in the United States from the 1970s to 2003," *The Energy Journal*, 2007, Vol. 28, No. 3, pp. 93–119.

8. The ENERGY STAR home program recently celebrated its one millionth home. See *www.energystar.gov/index.cfm?fuseaction=mil_homes.showSplash*, last accessed July 17, 2010.

9. For a detailed explication of the methodology, please see Pierce Jones, Nicholas Taylor, M. Jennison Kipp, and Hal S. Knowles, "Quantifying Household Energy Performance Using Annual Community Baselines," *International Journal of Energy Sector Management*, 2010, Vol. 4, Issue 3, Emerald Group Publishing. Forthcoming, accepted for publication July 13, 2010.

10. Heins, S., "Energy Efficiency and the Specter of Free-Ridership: Is a Kilowatt Saved Really a Kilowatt Saved?" *Sustainable Facility*, 2006, available at: *www.sustainablefacility.com/Articles/Feature_Article/aaf65d08bd629010VgnVCM100000f932a8c0*, last accessed March 25, 2010; and H. Herring, "Confronting Jevons' Paradox: Does Promoting Energy Efficiency Save Energy?" *International Association for Energy Economics Newsletter*, 2006, Vol. 15, 4th Quarter, pp. 14–15.

11. The cohort of homes examined in this study were among the earliest ENERGY STAR homes built in the Gainesville, Florida, area. These homes were constructed in 1998 and 1999 in the Mentone subdivision. Homes in this study were compared only with homes built before Jan. 1, 2000, to reduce the potential complications due to changes in common building practice or building codes related to energy efficiency.

12. Calendar year 2007 is omitted in this study due to data quality concerns. A change in the collection and cataloging process at Gainesville Regional Utilities led to incomplete or unreliable data in the transferred dataset.

13. Utility data used for this study is collected as billing data for each home. Due to logistical limitations, billing data is collected on different days for homes throughout the utility district. These discrepancies in data collection can lead to abnormalities in the final aggregated values for annual energy use. The techniques used to normalize abnormalities in the data provide a simple and effective solution for creating more reliable annual values.

14. For pricing assumptions for natural gas (.05 dollars/ekWh) see *www.gru.com/Pdf/calculating NaturalGas.pdf*. For pricing assumptions for electricity (.13 dollars/kWh) see *www.gru.com/Pdf/calculatingElectric.pdf*. We assume .15 dollars/kWh to remain highly conservative.

15. The authors are willing to share data sets used in this and other related studies with any interested researchers.