Analyzing the Aging Housing Stock for Energy Consumption and Retrofit Using Assessor and Historical Utility Data

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Residential buildings account for 21.5% of the United States energy consumption and carbon emissions, and about 38% of electricity use. The housing stock in the United States consists of over 132 million residences with over 60% which were constructed prior to 1979. To understand and reduce consumption, a number of energy modeling auditing software has been developed. Computer models have been successful in predicting usage patterns in newer residential structures, but they have been inaccurate in predicting and analyzing energy use in existing homes. What is the best approach in analyzing and understanding consumption patterns in older homes, and how should they be retrofitted? Using a rural community in Iowa, 480 pre-1979 homes were examined to test analysis methods of residential energy consumption and usage patterns. These homes show no significant commonalities in regards to style; year built, condition, and/or appraised cost that would allow a precise computer modeled approach to energy savings calculations. The statistical analysis inferred the necessity of using assessor and actual historical utility data when determining the current home energy usage rather than computer simulation models. Coupled with on-site analysis, the building envelope provided the best opportunity for permanent improvement in comparison to other energy offender solutions.

Keywords: Housing, Energy Efficiency, Retrofits, Utility Data, Sustainability

Introduction

Residential retrofits remain the largest untapped opportunity to reduce the dependence on fossil fuels. While the public and private community continues to invest in new energy sources, today, wind costs are still ranging from $0.08/kWh - $0.20/kWh and solar upwards of $0.24/kWh for large scale productions (US DOE, 2014). By simply retrofitting residential properties, an energy company can produce savings through conservation at a cost of $0.03/kWh (Friedrich, 2009). Research in the area of specific residential retrofits is scarce, but with the opportunities recognized by the DOE, NREL, Berkeley labs, and research universities across the globe, new advancements are being published every day. Current related research is found in the commercial sector but has often been misused in a residential application (Yudelson, 2008). Commercial properties and occupancy habits remain fairly consistent with building practices having been standardized for years. This makes calculating energy usage and savings in the commercial sector much easier and more accurate. When dealing with a residential application, many homes built in the same period and style are often done using various framing and design techniques. Couple these building differences with the specific unique homeowner habits, and it becomes difficult to accurately use commercial science on a residential retrofit (Augenbroe, 1998; McGraw-Hill, 2008; Bowen, 2005). Seeking an opportunity to understand and reduce consumption, the scientific community has developed a number of tools and technologies in an attempt to accurately analyze energy usage. As access to individual consumption data has been limited and the need for a cost effective pre-analysis exists, a number of model driven auditing software have entered the marketplace. While traditional auditing methods such as the Home Energy Rating System (HERS) have shown accuracy in predicting usage patterns in newer residential structures, there has been difficulty in predicting and analyzing the aging housing stock, especially in respect to pre/post retrofit saving calculations. If these methods struggle to accurately analyze energy data, could it be possible to use historical consumption data and property assessor data to effectively analyze community based energy usage patterns?

Today's housing stock stands at over 132 million homes (U.S. Census, 2014). The development of a truly market-driven residential retrofit business model is not only possible, but necessary. Prior to the energy crisis in 1979 which led to insulation and building envelope standards, it was common for homes to purposely be constructed for breathability which we consider today to be envelope leakage. The inefficiency of HVAC systems and the inexpensive energy costs made this envelope leakage desirable to allow for proper indoor air quality with little added cost to the occupant. While building practices post-1980 used proper building envelope sealing and mechanical ventilation systems, the median year built of homes in the U.S. remains 1975 (U.S. Census, 2014). The problem then remains as to how these homes should be retrofitted and what is the best approach in analyzing and understanding consumption patterns, especially those that consume an inappropriate amount of energy. Using a rural community in Iowa, 480 pre-1979 homes were used to expand on the scientific research of residential energy consumption and usage patterns.

Literature Review

Residential energy audit tools have been under development for over two decades in an attempt to identify opportunities for energy efficiency improvements (Stein, 2000; Hendron, 2010; NAHB, 2008).
A review of the literature analyzing residential energy auditing strategy and software was limited, with a number of citations dating to the early 2000s and a comprehensive auditing tool review prepared for the Department of Energy by SENTECH, Inc. (now part of SRA International, Inc.) in November of 2010.

From 2002 – 2004, the Lawrence Berkeley National Laboratory in Berkeley, CA analyzed multiple energy analysis tools focusing on residential capabilities. The LBNL evaluated 65 programs - 50 of them being web-based and 15 disk-based packages (Mills, 2002). Mills determined that there were significant differences in all of the auditing tools. Of the web-based tools, only twenty-one performed whole-house analyses and out of these, thirteen provided open-ended energy calculations, five permitted bill disaggregation and only three contained both functions. Of the 15 disk-based packages, six performed whole-house analysis and three performed both open-ended energy calculations and bill disaggregation. In another 2004 study, they concluded that the wide inconsistency between all the auditing programs suggested that a national standard or benchmark needed to be developed prior to implementing actual energy retrofit strategies (Mills, 2004).

Two relevant literary works with a focus on residential auditing accuracy were identified. Hendron (2003) specifically researched the accuracy of high performance homes for the DOE's Building America Program. They identified simulation tools that met the requirements of HERS BESTEST and the International Energy Conservation Code. The study found significant differences based upon the energy software used. As a result, they identified four features that all auditing software must comply with:

1. Clearly defined reference home.
2. Consistent set of operational assumptions that mimic realistic occupant behavior.
3. Accurate predicted energy saving modeling.
4. Reporting process that communicates effectively where energy savings are being realized and to what magnitude.

With the growing use of the HERS rating, or REMRATE software, Stein and Meir (2000) evaluated rating scores to actual billing data for 500 homes in four states. Disappointing the authors, the study showed that while HERS rating analysis could be used to predict large population annual energy usage and cost, accuracy diminished significantly when analyzing individual homes to actual costs. Even more disappointing was the accuracy of the HERS rating when analyzing older, pre-1979 homes (Stein, 2000). Calibrating the HERS input with actual billing data showed no effect on the variance of the findings.

In 2010, the Department of Energy took the initiative to identify a standardized national program to assess the energy performance of houses across the country. The report prepared by SENTECH, Inc. was found to be the most comprehensive literary review of current auditing tools. Solicited by the DOE to examine the potential of a national residential energy program, SENTECH, Inc. provided a review of the variety and characteristics currently available that had potential national capability. Focusing specifically on the accurate analysis of residential properties regardless of climate zone, energy source, style, and building design, the study focused on the following software:

- REM/Rate
- BEACON Home Energy Advisor
- EnergyInsights
- Home Energy Tune-uP
- EnergyGauge
- TREAT
- National Energy Audit Tool (NEAT)
- Home Energy Saver Professional
- RealHomeAnalyzer

The findings of the comprehensive review found that no one tool is capable of capturing all the characteristics needed for a national home performance assessment program (NAHB, 2008). No current auditing software is able to be accurate, have low cost and reasonable inputs, and the ability to generate improvement recommendations and associated costs. The audit tools as a whole appear to address potential needs for a national program. The review did provide the DOE assistance for future development of a national software strategy (Sentech, 2010).

Methodology

Harrison County, IA, much like many counties across the country, has converted the public county tax assessor information to be accessible online. Specifically, Harrison County, IA uses a web program known as *beacon* developed by The Schneider Corporation. *Beacon* is a government GIS program created specifically to provide public property assessor information and is widely used throughout the Midwest. Specific housing characteristics were extrapolated for each of the homes to be used on the BTU/SqFt/DD calculation spreadsheet. Notably useful are the real property images and footprint layouts provided by the beacon site. These photos allowed a much more visual picture of lot layout, roof pitch, topography, and shading challenges some properties may face.

Access to actual historical utility data information required direct assistance from Woodbine Municipal Utilities. As a "pilot" green community, recognized by the State of Iowa Department of Energy, the Woodbine Municipal Utility consisting of 643 residential meters granted access to three full years of historical data. The data provided, in Microsoft excel format, was presented in three separate parts: electrical kilowatt usage, natural gas CCF usage, and water gallon usage. Each database was individually cleaned to remove properties that did not show 36 months of continuous usage for the dates January 2008 through December 2010. This cleaning of all three databases resulted in a final participation database of 480 residential properties. This monthly consumption data for each of Woodbine's residences allowed for the actual usage to be analyzed with the square footage to normalize consumption data and housing characteristics.

The residential properties could be compared to each other by calculating the BTU's per square footage obtained by the previously mentioned data collections. For future widespread comparison of communities, it is important to consider weather effects concerning energy consumption. To allow for the possibility of future research and comparisons, degree days for each of the 36 months were obtained from the national weather database. These degree days were used to further examine each individual home. What resulted was a final number for each individual home identifying its BTU's per square foot per degree day (BTU/SqFt/DD) over the three year period.

The City of Woodbine is similar to many small Midwestern communities. With a population of 1,564, the community is sustained by both agriculture and manufacturing. Woodbine is one of the few communities in the area that still has its own school district. The demographic information in Table II was provided by the online database provided by city-data.com. It is important to understand the specific housing characteristics of Woodbine, IA. Data provided by the U.S. Housing Census was used. 639 homes were built earlier than the 1960's; 280 homes were built between 1960 and 1980, and 190 homes were built between 1990 and 2005.

The Iowa Department of Economic Development selected Woodbine as well as West Union, IA as a Pilot Green community or otherwise known as its Green Streets Initiative. The IDED assisted the City of Woodbine in developing a sustainable master plan which included a large downtown revitalization and was also to include a sustainable plan for the residential community (Craig, 2011). Having successfully completed numerous projects including energy audits and retrofits of the business district, a community-wide recycling awareness project, implementing a student/community garden, and completing a 3 year Woodbine sustainability impact study, the City of Woodbine was ready for a residential implementation project. With the commitment of the City of Woodbine leadership as well as the State of Iowa's Department of Energy and Economic Development, Woodbine presented itself well for this study. The "Woodbine Project" offered an opportunity to analyze an entire community rather than a sample set. With a tract record of implementation, future research and post retrofit analysis opportunities are available when Woodbine begins implementing a residential retrofit program.

Careful consideration of specific scientific community standards was taken when establishing the research methodology in this study. Standardized testing procedures were used and documented whenever possible in an effort to normalize this project to previous and future residential sustainability projects.

The research participants for this specific project included every single family residential unit within the Woodbine city limits. Every household included in the Woodbine Municipal Utility database was eligible for initial review and participation. All participants were given the opportunity to opt out of the research project during all phases.

Instrumentation

A British Thermal Unit, or BTU, is the most widely used form of measuring an energy source. Energy can be provided by a variety of sources, so the conversion of said given source to a BTU allows researchers to compare differing sources commonly. The energy sources for the Woodbine project were provided in kilowatts for electricity and CCF's for natural gas. The SqFt (Square feet) of the residence was taken directly from the county assessor website. To allow the analysis to be replicated in a variety of climate zones, the degree days, DD, were the third factor of the analysis. The size of the community of Woodbine allowed for a census study of every residential household for the initial BTU/SqFt/DD analysis. Converting the electrical kilowatt hours and natural gas centum cubic feet (CCF) into a standardized British Thermal Unit (BTU) required selecting a conversion factor. It was determined that to maintain consistency, the identical conversion rates used by the Department of Energy would be used for this study. The following sections describe in detail the development of the completed calculation spreadsheet.

The conversion for kilowatts to BTU's used was:

1 kWh = 3,412 BTU

The conversion for CCFs to BTU's used was:

1 CCF = 102,700 BTU

The figure found in the appendix contains the spreadsheet that was used for each of the 480 homes identified as having 36 months of continuous utility usage for the dates January 2008 to December 2010. The spreadsheet created in Microsoft excel analyzed each of the 36 months individually by converting the electricity and natural gas usage into BTU's. The total BTU's were then divided by the square footage of the property provided by the online property assessor database, and finally divided by the total degree days for the given month. What resulted was a single number for each home identifying the BTU/SqFt/DD for the total 36 month period. Once each of the 480 residential properties had been labeled with an individual BTU/SqFt/DD, a ranking from 1 to 480 was developed for data analysis. Due to individual privacy concerns, all 480 homes are not provided, but the complete ranking list is available with property addresses replaced with researcher developed account numbers.

A data set consisting of 480 cases was used for the analysis. The main statistical tool used was a multiple regression analysis, together with the stepwise regression in the instance that some variables did not contribute significantly to the model and needed to be removed. Assess value, style, condition and year built were the variables that were included. All these variables were coded as categorical variables, but assessed value and year built were interval variables in nature. Year built essentially corresponded to the number of (integer) decades since 1900, and Assessed value was the floor number of tens of thousands of dollars. The variables *Condition* and *Style* were categorical in nature, and they required classifying by using dummy variables. Condition had 6 categories, so 5 dummy variables were used (*Very Poor, Poor, Average, Good, and Very Good*) where *Excellent* was the baseline. On the other hand, Style had 6 categories, so 5 dummy variables were used (*Single Story, OnePointFiveStory, Two-story, Split-Level, and Mobile Home*) where *Other* was used as the baseline. The formula to predict variable influence on energy consumption in the multiple regression model is defined below. Where y is the average BTU/SQFT/DD and x is the identifiable variables chosen, the residual ε_i is assumed to be a normal random variable with mean zero and variance σ^2.

$$y_i = a_1x_{i1} + a_2 x_{i2} + a_3x_{i3} + \ldots a_nx_{in} + \varepsilon_i$$

Results

The researchers constructed a quantitative model to estimate energy consumption, measured in BTU/SQFT/DD. Various predictors were used as possible drivers of the variation in energy consumption, based on a data set containing 480 valid cases. The intent of the BTU/SqFt/DD analysis was to establish a ranking system of actual historical energy consumption to compare to residence characteristics. The overlying issue to be addressed was to identify any characteristic similarities that led to overall energy consumption patterns. There was a 0% dropout rate for the initial BTU/SqFt/DD analysis or otherwise stated, of all of the qualifying participants, no property owner refused to have their home analyzed. The individual BTU/SqFt/DD spreadsheet for each of the 480 residences resulted in a completed list of energy consumers rated from best to worst. The median BTU/SqFt/DD number for the community of Woodbine was a rating of 21.75.

These homes showed no significant commonalities in regards to style, year built, condition, and/or appraised cost that would allow a precise computer modeled approach to energy savings calculations. The on-site analysis indicated the building envelope provided the best opportunity for permanent improvement in comparison to other energy offender solutions. The statistical analysis inferred the necessity of using actual historical utility data when determining the current home energy usage rather than computer simulation models.

Correlation Analysis

First, the correlation matrix and scatterplot of energy consumption and the two interval predictors Assessed Value and Year was plotted. Based on the scatterplot, a rather weak association existed between the variables. The affect size of the association was rather low. The correlation between energy consumption and both Assess Value and Year Built was significant and negative, as it was also observed in the scatterplot, but the strength of the association was quite weak.

Multiple Regression Analysis

Based on the Analysis of Variance (ANOVA) model above, the linear regression model was significant overall, $F(12, 467) = 4.520, p < .001$. But in spite of the fact that the model was significant, it explained only 8.1% of the variation in Energy Consumption. Observing that several predictors were not individually significant, it is suggested that some predictors were not useful for the model. The next step was to perform a stepwise regression.

Stepwise Regression Analysis

The best test model obtained included only the following predictors: Assessed Value, Split Level, Single Story and Year Built. This model was significant overall, $F(4, 475) = 13.049, p < .001$, and it explained 9.1% of the variation in Energy Consumption. The model used:

*Energy Consumption = 23.257 – 0.406*Assessed Value + 11.993*Split Level + 3.414*Single Story – 0.298*Year Built*

This model indicates that the variable Condition had no significant effect on energy consumption. In terms of the variable Style, only Split level and Single Story differ significantly from the baseline (Other). For an extra $10,000 of assessed value, the energy consumption decreased by 0.406 units on average. For an extra 10 years of age, the energy consumption decreases 0.298 on average. Split level properties have a mean energy consumption that is 11.993 units higher than that of *Other* properties. Also, Single Stories properties have a mean energy consumption that is 3.414 units higher than that of *Other* properties.

Overall statistical analysis showed little opportunity to identify energy offenders based on style of home, year built, or appraised value. Utilizing real historical energy data coupled with assessor data is the most accurate identifier of high residential energy users in a community. An on-site analysis must be completed to assess which retrofit would be most beneficial.

Discussion

An energy analysis tool was successfully developed to identify which homes in a community would offer the largest opportunity for retrofit payback. The BTU/SQFT/DD tool designed from this study could efficiently be completed by an individual auditor or used to analyze an entire community to dissect actual utility consumption as compared to assumptions made by computer models. Online assessor data and utility information was completed in an average time of less than three minutes per home making it a cost effective tool to begin the auditing process. Energy consumption data from this process generated correlations that indicated that a specific subsector cannot be identified when prequalifying homes for retrofit opportunities. Unpredictable variables exist in homes thus limiting the ability to identify which styles or housing characteristics offered the largest opportunity. Building characteristics offer opportunities for ease of accessibility and workability; however, when correlated directly with actual energy consumption, a direct linkage could not be made. For example, the "condition" of the property is a visual inspection by the local assessor. Simply put, it is an aesthetic representation. Our research finds that the visual inspection or "condition" has no correlation to actual energy consumption and thus should not be used when trying to identify possible homes for energy retrofits. Understanding that subsectors of the housing stock need to be addressed individually, the methodology developed and tested during the Woodbine Project gave evidence that historical energy data can be efficiently used to analyze community opportunities.

The research suggests that the best approach in analyzing and understanding consumption patterns in the aging housing stock is through a partnership with local utility providers. Access to actual historical home consumption is critical to the accuracy of pre-auditing retrofit candidates. With the variables of the housing stock, any computer simulation simply cannot predict savings calculations. Homeowners can always provide personal consumption data, but the utility providers database allows the auditor to analyze the homes as a community and then comparatively on individual basis.

The Woodbine Project emphasized the challenges faced when addressing the residential housing stock in a systematic, standardized approach. While community-based studies on homes built post-1979 have shown promise with regards to identifying commonalities in energy consuming characteristics, communities such as Woodbine with a housing stock predominately of pre-1979 homes are unable to identify a common approach to addressing residential retrofits. The homes have either been remodeled or renovated to reflect a newer home or are deteriorated from age and neglect. With today's appraiser's data, any work performed on the home after build date is unavailable.

The property appraiser data was found to be insufficient when attempting to identify characteristics that lead to specific energy consumption; it is valuable though when coupled with actual property utility data. The Woodbine

Project highlighted the necessity of using actual historical utility data when examining residential energy use. The housing characteristics that can be identified once a home is determined to be outside the median in regards to energy consumption can be extremely useful. The appraiser's data allows for an identifiable scope of work to be established, identifies hazards or challenges to a retrofit, and gives an estimated amount of material that may be required by providing square footage, house style, etc.

Homeowner habits and lifestyle must also play a role in the data collection. Habitual information allows the pre-auditor to provide and assess what influence if any these are having on consumption patterns. All of the above mentioned pre-audit information can be collected prior to any visual inspection of the property. This pre-audit collection can allow community retrofit strategists to prioritize candidates and significantly reduce the audit investment time as well as increase the potential of audits performed on homes that will lead to retrofits with significant energy savings. Furthermore, when an individual property is identified as a retrofit candidate, the building envelope testing should be conducted immediately when arriving at a property. The blower door tests conducted during the study also showed the opportunity and importance of an overall building envelope. The blower door tests on every home identified opportunities for improvements, many of them at low costs to the homeowner. The direct effect of the building envelope to the mechanical systems of the property in this researcher's view is the most critical element in residential building efficiency. Building envelopes that perform poorly on newer homes operating with high efficiency HVAC systems are disappointing, but envelopes that are performing poorly on properties operating with HVAC systems that are sometimes 50–60% efficient are detrimental to the homeowners' pocketbook and the community as a whole.

Future research should and will continue to implement pilot projects in varying communities across the country. Increased partnerships with private industries will allow researchers and investors alike to develop retrofit practices that are not only accurate and sustainable, but also profitable for privatized business models.

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