IMPACT OF THE IMPLEMENTATION OF THE 2000/2001 IECC ON RESIDENTIAL ENERGY USE IN TEXAS: PRELIMINARY VERIFICATION OF RESIDENTIAL ENERGY SAVINGS

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ABSTRACT

In September 2001, Texas adopted the 2000 International Residential Code, including the 2001 Supplement, as the state energy building code. This building code has substantially improved the energy efficiency of housing in Texas, resulting in reduced annual heating/cooling utility bills for residential customers. Since this time, the Texas Legislature has required that the energy savings and emissions reductions from the implementation of the Texas Building Energy Performance Standards (TBEPS) be tracked annually and reported to the Texas Commission on Environmental Quality (TCEQ). To verify the code-compliant DOE-2 simulations several procedures were developed including on-site inspections and utility billing analysis. This paper outlines the utility billing analysis methods for verifying the DOE-2 simulations and reports preliminary results of the application of the methodology to a sample of residential houses in the Bryan/College Station, Texas, area.

INTRODUCTION

In 2001, the Texas State Legislature formulated and passed the Texas Emissions Reduction Plan (TERP) in Senate Bill 5 to further reduce ozone levels by encouraging the reduction of emissions of NO_x by sources that are currently not regulated by the state, including area sources (e.g., residential emissions), on-road mobile sources (e.g., all types of motor vehicles), and non-road mobile sources (e.g., aircraft, locomotives, etc.).[1] An important part of this legislation is the evaluation of the State's new energy efficiency programs, which includes reductions in energy use and demand that are associated with specific utility-based energy conservation measures, and implementation of the International Energy Conservation Code (IECC), published in 2000 as amended by the 2001 Supplement (IECC 2000; 2001). This code addresses the design of energy efficient building envelopes and installation of energy-efficient mechanical, lighting and power systems emphasizing performance. The Texas Legislature has required that the energy savings and emissions reductions from the implementation of the TBEPS be tracked annually and reported to the Texas Commission on Environmental Quality. The savings and emissions reductions have been calculated through code-compliant DOE-2 simulations. These simulations, as with any standards computations, have to be verified to see how the observed performance agrees with the prediction. To fulfill this task, several procedures were proposed, including on-site inspections and utility billing analysis, the latter being the main objective of this work.

[1] In the 2003 Texas State legislative session, the emissions reductions legislation in Senate Bill 5 was modified by House bill 3235 and House bill 1365. In the 2005 Texas State Legislative sessions, the TERP was modified by House bills 965 and 2129. In general, this new legislation strengthens the previous legislation and did not reduce the stringency of the building code or the reporting of the emissions reductions.

ENERGY USE SAVINGS METHODOLOGY

The method to evaluate the effectiveness of the implementation of the IECC through utility bills consists of a comparison of the energy used by two similar groups of houses in a same period, located in the same neighborhood with similar income levels and life styles. Both groups of houses were built by the same builder. One of the groups of houses, the control group, is composed of houses constructed prior to the application of the IECC 2001. The other group consists of houses that were constructed after the implementation of the energy conservation code. If the energy savings are significant (i.e., total energy used by the treatment group is lower than the total energy used by the control group), then this lends credibility to the simulated energy savings.

In general, in the previous studies about evaluations of weatherization programs, this type of analysis would have combined house-by-house and individual savings to reach a conclusion about the two groups. Therefore, as a first step in this type of analysis, it was decided to first look at the differences between the average use of the two combined groups to find outliers to determine how best to proceed. Future analyses will consider individual house savings.

Sample Selection

The selection of the houses utilized in this work was based on the following factors:

a) Two local groups of houses from the same city where the social and economic status is similar.
b) Both groups of houses were built by the same builder.

In addition, the houses were selected randomly by personnel of the City of College Station Utilities who were aware of the main objective of this work. Finally, since the two groups of houses are only a few blocks apart, the same weather source was used (i.e., NOAA weather data for College Station, TX) for the analysis of the two groups.

A brief examination of the selected houses (before and after the code) revealed no significant differences between the two groups. The principal color of the asphalt roof shingles in both groups was light gray. All of the houses had brick veneer or 2x4 wood frame construction. There was no variation in the landscaping and no significant difference in the mean floor areas of the two groups (Figure 1).

Figure 2 shows the average energy use intensity of the two groups of houses constructed before and after the code was implemented. In Figure 2, the energy use intensity (EUI) is plotted against the construction start date. The size of the data point indicates the size of each house.

Figure 1. *House type used in this study.*

Table 1. *Characteristics of the energy use intensity, floor area and construction permit date for the samples of houses in College Station, Texas.*

Before IECC 2000/2001			After IECC 2000/2001		
Construction Permit	Floor Area ft^2	Average Energy Use Wh/day-ft^2	Construction Permit	Floor Area ft^2	Average Energy Use Wh/day-ft^2
11/03/93	1,670	23.3	05/29/03	1,504	21.6
09/27/93	1,807	29.0	07/08/02	1,722	23.8
07/05/94	1,800	19.9	08/07/02	1,731	18.5
03/28/96	1,880	24.1	11/08/02	1,800	18.6
04/30/96	1,702	17.5	12/17/02	1,860	33.1
12/05/97	1,934	22.2	12/01/03	1,868	17.4
07/30/97	1,768	31.2	12/01/03	1,860	28.3
03/23/99	1,906	20.4	02/17/03	1,868	16.9
12/28/99	1,724	22.5	04/04/02	2,029	24.6
04/17/97	1,621	28.4	02/12/02	2,034	29.4
12/21/00	1,720	15.7	03/19/04	2,091	18.5
11/03/93	1,670	23.3	05/29/03	1,504	21.6
09/27/93	1,807	29.0	07/08/02	1,722	23.8

Data Analysis

The energy use data were collected thru the City of College Station Utilities office. The data were first normalized (i.e., Wh/day-ft^2) and then plotted as time series graphs where the mean and standard deviation were also estimated. In both groups, evident outlier patterns were removed and the statistics evaluated once again. The time series plots for each group are shown in Figure 3 and 4, after outlier removal. The energy use data were then arranged for each group of houses (i.e., before and after the implementation of the energy code). Average daily temperatures were also used to provide average billing-period temperatures for individual houses. Outside temperatures were obtained online through the National Climatic Data Center (NOAA, 2006).

ANALYSIS OF THE ENERGY USE PATTERNS

To perform a preliminary analysis of the energy use, two analyses were performed: a grouped analysis using a three-parameter change-point regression (Kissock et al. 2003; Haberl et al. 2003), and a grouped analysis using the Princeton Scorekeeping Method – PRISM (Fels 1986). The analysis using the three-parameter change-point analysis calculates the total energy use (E) using:

$$E = a + b(T - T_{cp})^{+} \qquad \text{Equation (1)}$$

where a is the constant independent load, or miscellaneous load, which includes the electricity base use related to equipment, lighting and other weather-independent loads; b is the rate of variation of the energy use with respect to the outside conditions; T is the outside dry-bulb temperature; and T_{cp} is the change-point temperature that separates the two types of energy use patterns for the group of houses. The + indicates that only positive differences are included in the summation.

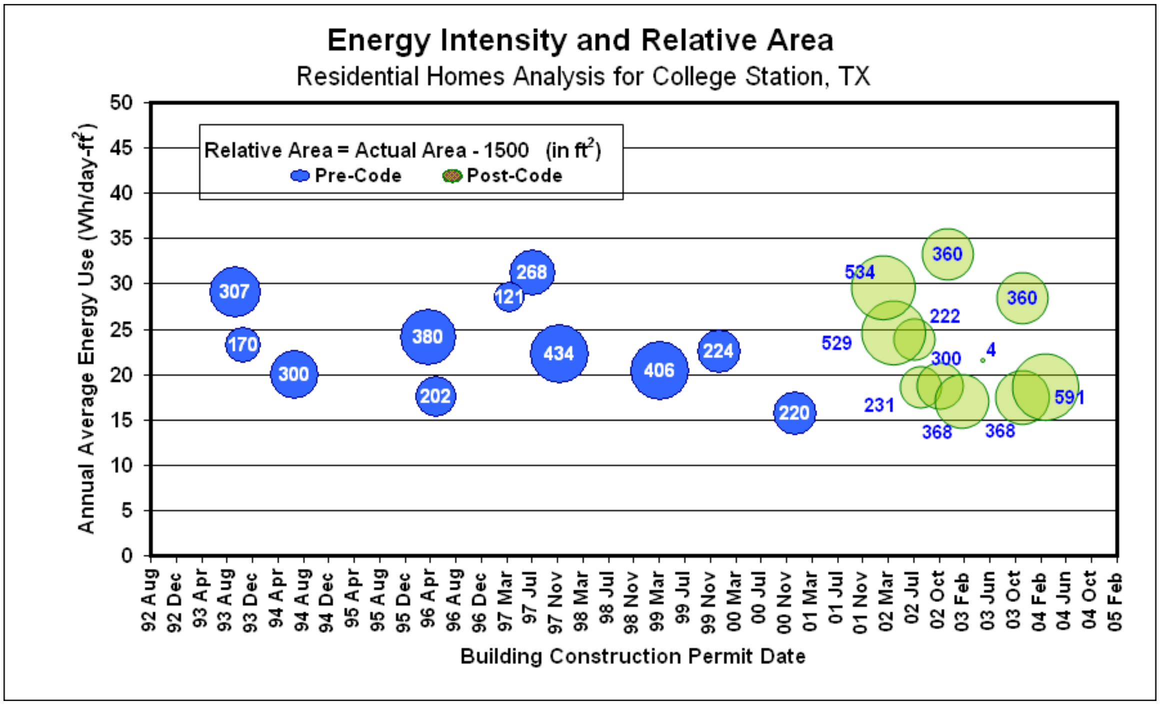

Figure 2. *Energy use intensity of the house groups before and after the implementation of the IECC 2000/2001 in College Station, TX, accordingly with the date of the building construction permit.*

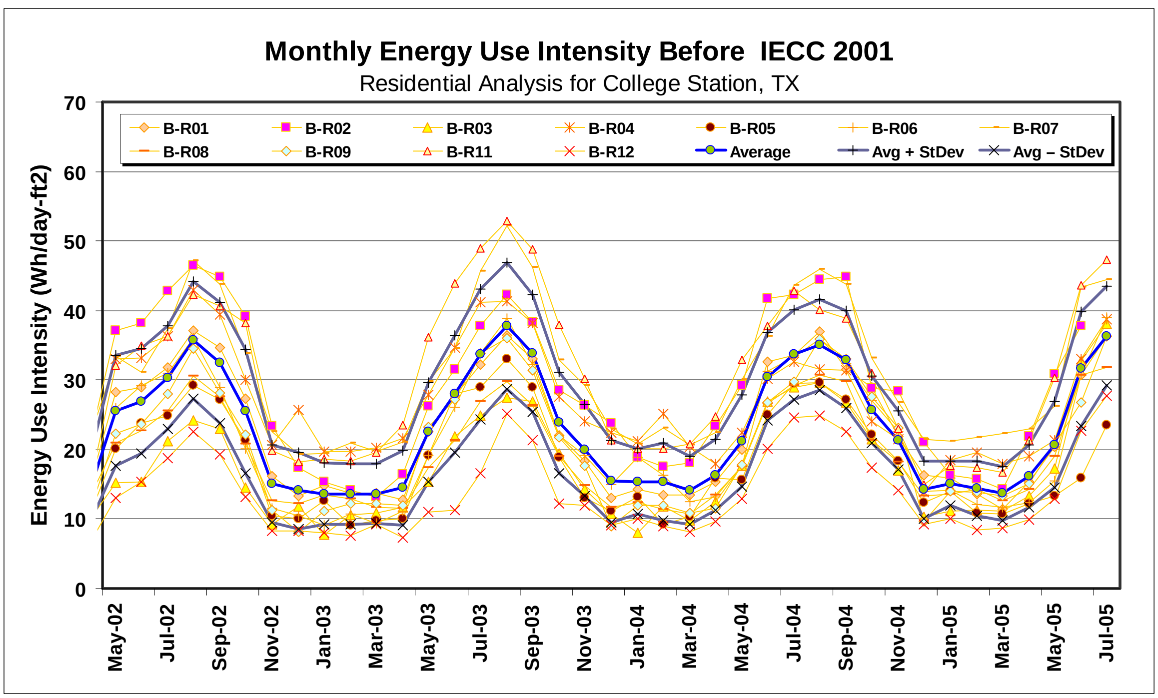

Figure 3. *Energy-use intensity patterns for the group of houses constructed before the implementation of the IECC 2000/2001.*

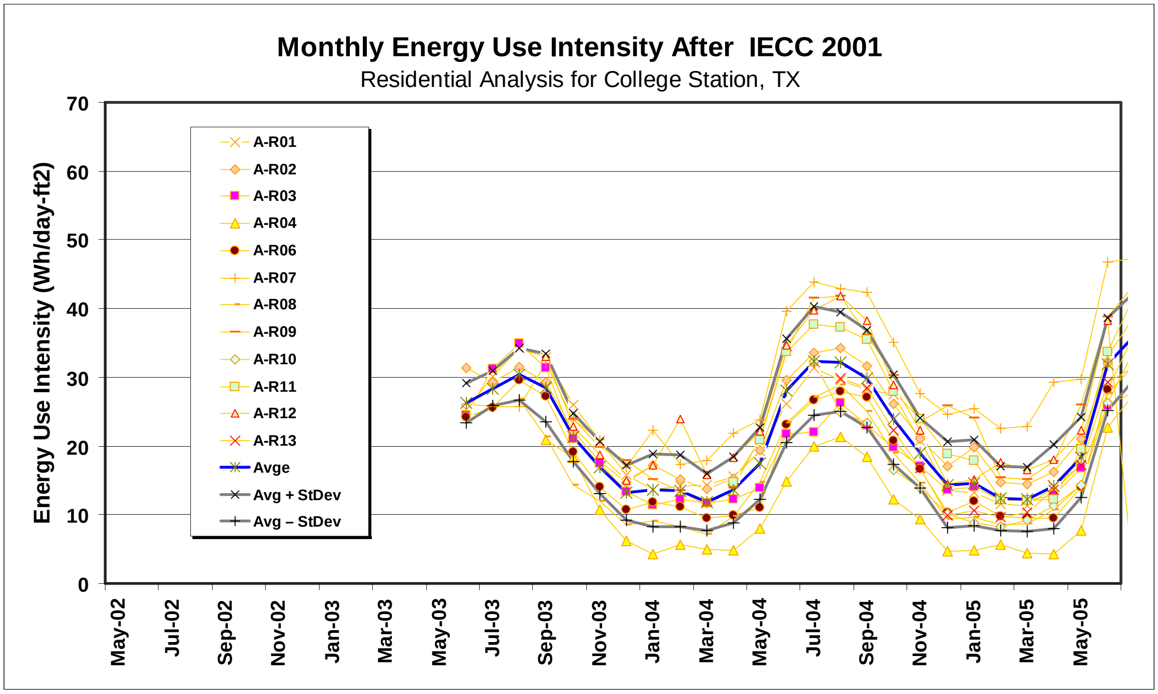

Figure 4. *Energy-use intensity patterns for the group of houses constructed after the implementation of the IECC 2000/2001.*

In Figure 5, it is evident that there is a reduction of the energy use per square foot for the two groups of buildings (i.e., before and after the 2000/2001 IECC). Using the three parameter change-point linear models yielded an annual difference of 16.2% between the two groups.

Table 2. *Change Point statistical parameters for the residential group; before and after the implementation of the IECC2000/2001*

	Before	***After***
a	0.4876	0.4347
b	0.0364	0.0372
T_{cp}	67.6461	70.6201
R^2	0.9682	0.9771
$AdjR^2$	0.9650	0.9748
RMSE	0.0480	0.0341
CV-RMSE	6.8%	5.7%

As a second step in this analysis, the average energy use of the two groups was analyzed using PRISM and sliding PRISM. PRISM uses a variable-based degree-day model to accomplish the same purpose as the three-parameter, change-point model. However, PRISM analysis has the advantage over a change-point analysis because it automatically provides a Normalized Annual Consumption (*NAC*), which is a very useful metric for comparing energy use. PRISM calculates the annual fuel use (F_i) as follows:

$$F_i = \alpha + \beta H_i(\tau) + \varepsilon_I \qquad \text{Equation (2)}$$

where ε_i is the random error term, $H_i(\tau)$ are the degree days per day computed to a reference temperature τ in the time interval I; α and β are found by PRISM's statistical methods and represent the base-level (α) and the cooling (or heating) (β) slope parameters.

The total normalized annual consumption, *NAC*, which can be normalized to local weather conditions, is obtained from the model parameters applied to an average degree-day ($H_o(\tau)$) representative of a typical year. *NAC* is then expressed as

$$NAC = 365\alpha + \beta H_o(\tau) + \varepsilon_I \qquad \text{Equation (3)}$$

where $H_o(\tau)$ are the degree-days for the average weather data period at the base temperature τ. $H_o(\tau)$ is usually calculated with 10+ years of average daily data. Using the a 12-month PRISM analysis on the two groups of houses yielded an energy savings calculated as

$$Energy\ Savings = NAC_{bef} - NAC_{aft} \qquad \text{Equation (4)}$$

which resulted in

$$Energy\ Savings = 8.5494 - 7.3137$$
$$= 1.2357\ kWh/ft^2\ (0.1849)$$

or a 14.5% drop in the average consumption in the houses constructed before the implementation of the code. This result is similar to the change point analysis and roughly matches the 13.7% savings obtained using the DOE-2 simulations for code-complaint construction (Ahmad, et al. 2005). However, these results do not include the impact of equipment degradation or operational changes. Therefore, as a preliminary analysis, a sliding PRISM analysis was performed to assess how much the energy use of the group was changing.

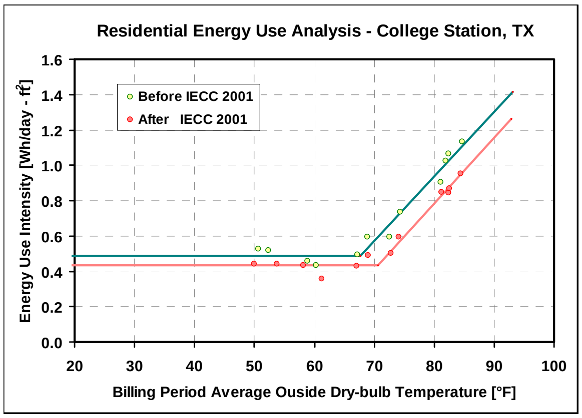

Figure 5. *Comparison of energy use intensity from the implementation of the IECC 2000/2001 for the period of July 2003 through June 2004.*

Table 3. *PRISM estimates for the group of houses constructed before the implementation of the IECC 2000/2001*

	Estimates	Std Errs	CV%
Ref. Temperature	68.000	1.3600	---
Cooling Slope	0.0013	0.0001	8.80%
Base Level	0.0149	0.0007	4.70%
NAC	8.5494	0.1382	1.60%
R-Square	0.9816		
Cooling Part of NAC	3.1234	0.1909	6.10%
Number of Obs.	12		

Table 4. *PRISM estimates for the group of houses constructed after the implementation of the IECC 2000/2001*

	Estimates	Std Errs	CV%
Ref. Temperature	67.24	1.47	---
Cooling Slope	0.0011	0.0001	9.00%
Base Level	0.0122	0.0006	5.10%
NAC	7.3137	0.1228	1.70%
R-Square	0.9817		
Cooling Part of NAC	2.4836	0.1710	6.00%
Number of Obs.	12		

Figure 6 shows the results of a sliding PRISM analysis of the two groups of houses. Unfortunately, in Figure 6, several significant trends can be seen. In the pre-code group, the average NAC rose from 8.24 Wh/ft^2-yr to 8.596 Wh/ft^2-yr, which represents a 4.2% increase. In the code-compliant group, the energy use went from 7.31 Wh/ft^2-yr to 7.869 Wh/ft^2-yr, or a 7.5% rise. These increases occurred mostly in the first twelve months, and represent a substantial portion of the code-related savings. The reason for this increase is unknown; however, one could imagine a number of different causes, including more equipment and appliances being added to the house in the first 12 months of occupancy, equipment degradation, etc. Therefore, a follow-up investigation is underway to determine the possible cause, including analysis of individual households using sliding PRISM.

Table 5. *Average of the energy savings computed by the NAC, from sliding analysis, for the before and after implementation IECC 2000/2001 groups with the standard errors.*

NAC_{Before} **SE(NAC_{bef})**	**NAC_{After}** **SE (NAC_{aft})**	**Savings** **SE (*Sav*)**	
8,452	7,667	785	Wh/(ft^2-Yr)
± 23	± 26	± 35	Wh/(ft^2-Yr)
		9.3%	

CONCLUSIONS

This paper presents preliminary results from efforts to verify the simulated savings attributable to code-compliant construction in two groups of carefully selected houses. The measured savings ranged from 16.2% using a three-parameter change-point model to 14.3% using PRISM. Both results are similar to the anticipated savings from simulations of the code-compliant houses (13.7%).

Results from the application of sliding PRISM to the average data from both groups showed substantial increases in energy use (4.2-7.5%) during the first twelve months the houses were occupied, which can negatively impact the evaluation of code-compliant savings. Therefore, a follow-up investigation is underway to determine the possible cause, including analysis of individual households using sliding PRISM.

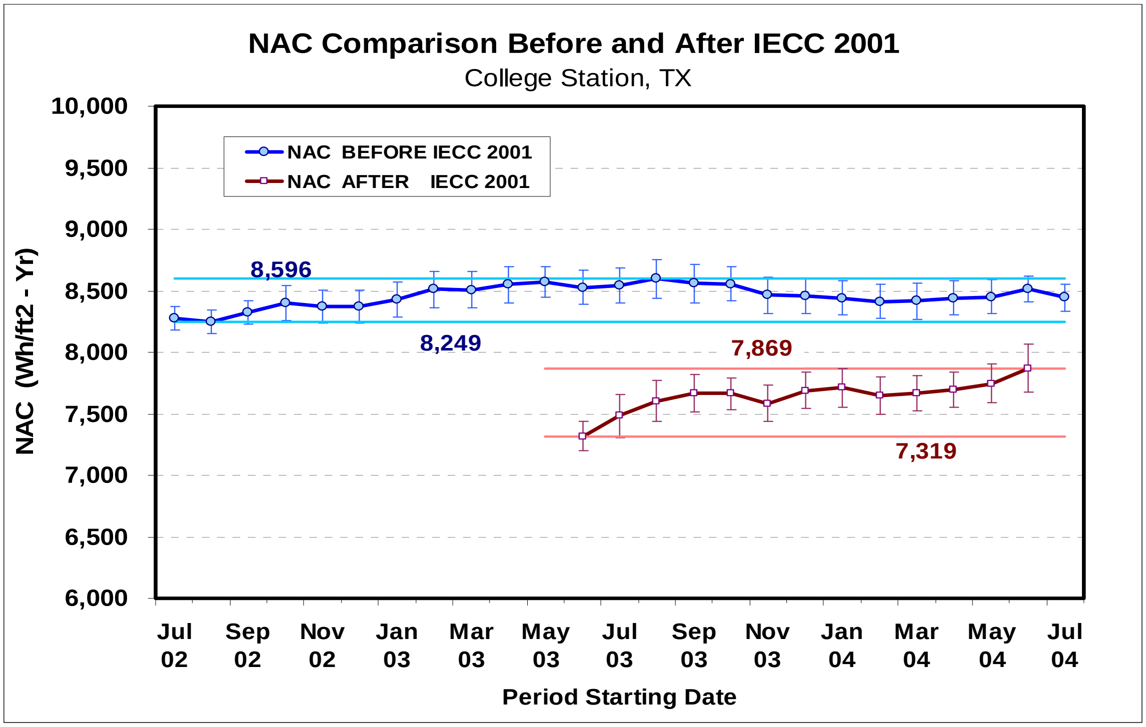

Figure 6. *NAC, from Sliding PRISM, for the before and after IECC 2000/2001 implementation houses groups with their respective standard errors.*

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