Data Quality Requirements for Determining Energy Savings In The Weatherization Assistance Program (WAP)

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ABSTRACT

This paper briefly describes an ongoing energy retrofit program, the Weatherization Assistance Program (WAP) of the Texas Department of Housing and Community Affairs. After briefly reviewing the various parameters that one needs to consider for proper baseline model development, this paper illustrates the differences in energy savings one would obtain by direct utility bill comparison as against weather normalizing. Next, PRISM (PRInceton Scorekeeping Method), a widely used methodology and software for determining retrofit savings, is presented and discussed. The importance of assuring proper data quality is highlighted and its adverse effects on the baseline model is illustrated with data from two College Station homes.

Finally, this paper presents preliminary problems encountered while preparing input data for PRISM runs for 462 houses in 59 Texas cities under WAP. Common problems in the utility bills and temperature data from National Oceanic Atmospheric Agency (NOAA) are discussed and recommendations to avoid such data quality problems are made.

DESCRIPTION OF WAP

Many elderly, handicapped, and other low income Texans reside in dwellings which, due to original construction, poor maintenance or other factors, are disproportionately high energy users. Through outreach and public information as required by the Texas Department of Housing and Community Affairs (TDHCA) weatherization contracts, these households are given top priority for the Weatherization Assistance Program (WAP).

Prior to weatherizing any home, TDHCA ensured that its subgrantees determined the following. A household is eligible for the Weatherization Assistance Program if their income is at 125% of poverty level or less, or contains a member who has received cash assistance payments under Title IV or XVI of the Social Security Act or applicable State or local law during the 12 month period preceding the determination of eligibility for weatherization assistance.

TDHCA will ensure its subgrantees give priority to weatherizing units occupied by the elderly and the handicapped low-income persons. During FY 1995, children residing in the units to be weatherized who are 6 years of age and under will be prioritized after elderly and handicapped.

The average weatherization cost per dwelling for FY 1995 is $1,854. This average is based on the total amount of funds, federal and non-federal, expected to be applied to the Program.

Currently, Texas has 47 contractors to administer weatherization services in all counties in the State.

The Energy Systems Laboratory conducted the first "Energy Consumption Study" for TDHCA on the Weatherization Assistance Program with the use of the PRISM methodology and software to determine energy retrofit savings on single family dwellings. The objective of this paper is to present a brief insight into the PRISM methodology and to highlight the types of data quality issues which we had to circumvent in the framework of this study. Avoiding such problems in future programs will make the program evaluation task easier, faster, and more accurate.

HOW ARE RETROFIT SAVINGS DETERMINED?

Energy conservation retrofits are typically initiated based on predictions of how much energy and money a retrofit will save. Predicted energy savings are generally estimated using the performance specifications of energy-using equipment and estimates of the physical characteristics and operating conditions of the building. Frequently, several values necessary for these calculations, such as the operating hours of lights and electrical equipment, are assumed or estimated using "engineering judgment". The calculation procedure or computer algorithm may also make simplifying assumptions in order to reduce the complexity and time required for calculations. Because of these factors, predicted savings often differ substantially from measured savings.

In a study of over 1,700 building energy retrofits, fewer than one in six came within 20% of measured results (Greely et al., 1990). Another study of 306 Swedish residences found that glazing retrofits achieved only 48% of the predicted savings, while insulation retrofits and electric heating retrofits achieved only 53% and 83% respectively (Anderlind et al., 1986). Meier and Nordman (1988) examined over 400 residential retrofits and found that predicted savings ranged from 50% to 58% of energy use while measured savings ranged from only 17% to 49% of energy use.

The coefficient of determination (R^2 value) between predicted and measured savings in over 300 Minnesota residential retrofits was only 0.11 (Hirst and Goeltz, 1984). Jamieson and Qualmann (1990) found that in a study of 16 commercial retrofits where auditors had been supplied with only pre-retrofit data, the mean absolute deviation between predicted and measured savings was 165% even after four buildings with known changes in post-retrofit energy use had been eliminated from the sample. Discrepancies such as these led Hirst et al., (1986) to conclude that large discrepancies between predicted and actual measured energy savings discourage efficiency investments.

Given this backdrop, it is not surprising that time and effort spent in being able to accurately determine retrofit savings is justified. The success of retrofit programs are best evaluated from "measured savings". Since the building has undergone a retrofit, savings cannot be directly measured and a model for energy use under pre-retrofit conditions is imperative. However, the term "measured savings" is being used to emphasize the fact that retrofit savings are determined based on measured data instead of engineering judgment or audit estimates.

PARAMETERS AFFECTING ENERGY USE

As mentioned above, a model for energy use of the residence under pre-retrofit operating conditions is essential. There are four types of parameters which affect energy use:

(a) Climatic variables of which outdoor dry-bulb temperature, T, is the most widespread. Most models use this variable as the only climatic variable partly because of its predominant influence from an engineering point of view and partly because it is easily measured. Other climatic variables such as solar insolation and humidity are also important but to a lesser degree. Because of cross-correlation with outdoor dry-bulb temperature, a regression model with outdoor dry-bulb temperature alone is capable of partially capturing the effects of these two variables also.

(b) Conditioned building area. An implied assumption when comparing the energy use of a residence which has undergone retrofits is that major changes to the building in terms of changes in conditioned area have not been done.

(c) Occupancy changes. It has been shown that utility bills of the same house may differ by as much as 100% (i.e., may double or halve) when occupied by different families (Socolow, 1978). An implied assumption, while baseline modeling and subsequent retrofit evaluation, is that the building has been operated identically and by the same family during both periods.

(d) Type of building construction and equipment used. It is usually this set of parameters which is modified in case of a retrofit, and it is the intent of the retrofit project to evaluate the effect of this modification on energy use.

Hence, a baseline model of energy use with outdoor dry-bulb temperature as the only regressor variable will explicitly account for differences in outdoor dry-bulb temperature from the pre-retrofit period to the post-period. One has to make sure that the building has not undergone changes in area nor that the occupancy patterns have changed. This is necessary in order to reach the conclusion that any savings in energy use from the pre-retrofit to the post-retrofit period identified are due to changes in the building construction or to more efficient equipment change-out.

SAVINGS DETERMINATION METHODOLOGY

There are essentially five steps involved in the calculation of energy savings when both pre- and post-retrofit data are available (data could be either utility bills or continuously monitored hourly data). Each of these steps is briefly described below.

Step 1. Pre-retrofit energy use data collection and preperation: This step involves that reliable data be collected for a sufficiently long period prior to the retrofit and be formatted into a form suitable for the energy savings software being used. When monthly utility bills are used, one should have at least 12 monthly utility bills along with the exact read dates of the bills. Moreover no abnormal occupancy behavior nor equipment changes should be present.

Step 2. Post-retrofit energy use data collection and preparation: This step is essentially similar to step 1 except that energy use data after the retrofit should be collected and processed.

Step 3. Collection of outdoor temperature data during pre- and post-periods and preparation: Depending on the energy savings methodology used, one needs either daily temperature values (as PRISM does) or monthly-mean temperature values corresponding to the billing period (Reddy et al., 1996). Next the data should be formatted into a form suitable to be read by the program.

Step 4. Model(s) identification: Regression models whose functional forms have an engineering basis are used to identify a pre-retrofit model (certain savings determination methodologies like PRISM require a post-retrofit model to be also determined). Statistical criteria describing the model fit are studied in order to ascertain whether the model identified is satisfactory or not. If it is not, the analyst should verify whether the data collected is not erroneous or that no abnormal occupant behavior occurred (see Appendix A). If no such causes could be identified, then data from the particular house should be either used with great caution or rejected from the analysis data set altogether.

Step 5. Calculation of savings: The regression model describing energy use under pre-retrofit conditions with post-retrofit weather conditions is used to predict energy use had not the retrofit taken place. The difference between this value and the observed post-retrofit energy use gives an estimate of the energy savings due to the retrofit. As we shall explain below, PRISM uses a slightly different methodology which involves using both the pre- and post-retrofit models with temperature data representative of the long-term mean temperature for the location in question in order to identify long-term mean energy savings, and not actual savings.

Step 6. Determining uncertainty bands in our estimates of energy savings: Since regression models have an inherent uncertainty associated with them, there will be a corresponding uncertainty associated with our estimates of savings. It is very important that the uncertainty associated with the savings estimates be determined as well for meaningful conclusions to be reached regarding the impact of the retrofit on energy use. The functional forms of the regression models used to model energy use in residences, though very simple to understand, are not the standard type of regression models found in textbooks. Hence special equations for determining the uncertainty in energy use models have been developed for this purpose (Reddy et al., 1996).

DIRECT BILLING VS WEATHER NORMALIZING

One could question the need to have such an involved baselining methodology as the one described above specially since the month to month variation patterns of outdoor temperature over the years are usually fairly consistent. The results of a study by Reddy et al.(1996) using utility billing data (both electricity use and gas use) for a large army installation in central Texas will be briefly presented here in order to illustrate our point. Figure 1 depicts the month to month variation in outdoor dry-bulb temperature for several years at the army base, and we note that the patterns are fairly consistent. One would be curious to ascertain the differences in estimates of how energy use over the years has changed with respect to a baseline year (FY86 in the particular study) by the present approach and by a much simpler approach involving direct annual utility bills comparison without any weather correction. Figures 2 and 3 illustrates the amount of differences in percentage savings for electricity and gas which one would identify between the two approaches, namely with and without weather correction. We notice that though the differences are small during certain years, these are very large during other years (for example, gas use during FY87 and FY93). More importantly, these seems to be no pattern to the differences in percentage changes between both methods. The above comparison serves to illustrate the fact that weather correction is absolutely necessary in order to obtain reliable estimates of retrofit energy savings.

DESCRIPTION OF PRISM

PRISM (Fels, 1986) is currently the method of choice for measuring retrofit savings by a number of energy conservation programs. Users of the PRISM software have included municipal and state government researchers, national laboratories, private entrepreneurs and utilities (Mills et al., 1987).

PRISM uses monthly energy consumption data from energy bills for pre-weatherization and post-weatherization periods, along with daily average temperature data from a nearby weather station (for the utility billing periods as well as long-term periods) to calculate degree-days (ASHRAE, 1993) and to determine a weather adjusted index of consumption, the Normalized Annual Consumption, for pre-weatherization (NAC_{pre}) and post-weatherization (NAC_{post}) consumption. The NACs represent annual energy use consumption during a year of average weather conditions. Finally, the Normalized Annual Savings (NAS) is calculated as the difference between NAC_{pre} and NAC_{post}.

Therefore, based on the data we have, PRISM seems to be the most appropriate tool to use in the framework of the WAP.

PRISM models are based on a steady-state energy balance of a house operated as a one-zone building (Fels, 1986). For a house where required cooling and heating is supplied by an electric Air Conditioning system (ACs) and a gas heater, respectively, the space cooling load Q_{cool} is:

$$Q_{cool}=Q_{int} + UA(T_{out}-T_{in}) \quad (1)$$

where

Q_{int} = internal heat gains from occupants, solar gain, equipment, etc.
UA= overall heat transfer coefficient of the house including envelope heat transfer, and effects of ventilation/ infiltration.
T_{out} = outdoor dry-bulb temperature.
T_{in} = indoor dry-bulb temperature.

It is convenient to define the balance point temperature τ (Mitchell, 1983) as

$$\tau = T_{in} - \frac{Q_{int}}{UA} \quad (2)$$

In words, τ is the outdoor temperature above which cooling is required and below which heating required. Combining eqs. (1) and (2), we have

$$E_{cool} = \frac{UA}{COP}(T_{out} - \tau) \quad \text{if } T_{out} > \tau \qquad (3)$$
$$= 0 \qquad \text{otherwise}$$

where

E_{cool} = hourly electricity consumed by the AC,
COP = the coefficient of performance of the AC.

Equation (3) can be expressed more compactly as equation (4):

$$E_{cool} = \frac{UA}{COP}(T_{out} - \tau)^{+} \qquad (4)$$

where the superscript "+" indicates that negative values of the term within the brackets should be set to zero.

The whole-house electricity consumption E is the sum of the base-electricity load and E_{cool}. For time periods greater than a day, E may be expressed as

$$E = \alpha + \beta_c (T_{out} - \tau)^{+} = \alpha + \beta_c * CDD \qquad (5)$$

where

α = base-load electricity use such as lights, refrigerator and other electric equipment,
$\beta_c = 24 \times (UA/COP)$,
CDD = Cooling Degree Days (ASHRAE, 1993) for time period.

After weatherization of a house, α may be reduced due to installation of high-efficiency lights, refrigerator, and other equipment; β_c may be reduced due to insulation of attic and walls, replacement of doors and windows, and a high-efficiency AC. τ may be increased due to high-efficiency equipment and decreased by better insulation of the envelope.

Similarly, the whole-house heating consumption is the sum of the base-load gas use and E_{heat} summed over the period:

$$E = \alpha + \beta_h (T_{out} - \tau)^{+} = \alpha + \beta_h * HDD \qquad (6)$$

where

α = base-load gas use for domestic hot water heating, cooking, etc.

$\beta_h = 24 \times (UA/\eta)$,

HDD = Heating Degree Days (ASHRAE, 1993) for time period.

After weatherization, β_h may be reduced due to insulation of attic and walls, replacement of doors and windows, and high-efficiency gas heater; τ may be decreased due to better insulation of the building envelope.

Equation (5) and (6) are the models used by PRISM. PRISM uses least squares regression to determine α and β for various guessed values of τ, and determines the optimal set of physical parameters that minimizes the sum of squares of the model residuals (Fels, 1986). PRISM also provides the user the values of the coefficient of determination, R^2, the coefficient of variation, CV(NAC), or the Flatness Index, F.I., which are used to evaluate the reliability of the regression model.

The optimal sets of parameters for pre- and post-weatherization models are determined based on energy consumption data and temperature data in the pre-weatherization and post-weatherization periods, respectively. The regression models for the pre- and post-weatherization periods are

$$\overline{E}_{pre} = \alpha_{pre} + \beta_{pre} * CDD \qquad (7)$$

where
$\overline{E}_{pre}$ = daily average electricity consumption in the pre-weatherization period. The subscript "pre" indicates pre-weatherization period.

$$\overline{E}_{post} = \alpha_{post} + \beta_{post} * CDD \qquad (8)$$

where the subscript "post" indicates the post-weatherization period.

If α , β , and τ are constant, the consumption for the pre- and post-weatherization periods (NAC_{pre} and NAC_{post} respectively) during an average year with 365 days are

$$NAC_{pre} = \sum_{i=1}^{365} E_{pre,i}$$
$$= 365\alpha_{pre} + \beta_{pre} \sum_{i=1}^{365} (T_{out,i} - \tau_{pre})^{+}$$
$$= 365\alpha_{pre} + \beta_{pre} * CDD_{avg}(\tau_{pre}) \qquad (9)$$

where the subscript "avg." denotes an average year. Likewise,

$$NAC_{post} = 365\alpha_{post} + \beta_{post} * CDD_{avg}(\tau_{post}) \qquad (10)$$

Models with $R^2>0.7$ and $CV(NAC)<0.7$ or F.I. <0.2, for both pre- and post-models meet PRISM "good fit" criteria. The difference between NAC_{pre} and NAC_{post} is the Normalized Annual Savings (NAS).

$$NAS = NAC_{pre} - NAC_{post} \qquad (11)$$

We stress the fact that PRISM is a weather-normalizing tool which only corrects for differences in temperature between pre- and post-periods; PRISM doesn't account for the impact of humidity and occupancy schedule changes, but neither do most of the programs now commonly used.

CASE STUDY RESULTS

Table 1 presents general retrofits activity performed for the WAP. The retrofits basically include maintenance, modification or replacement of cooling and heating systems and envelope retrofits such as replacement of windows, replacement of doors, and insulation of attics.

1. Data received

The utility bills for a pre- & post-weatherization period were collected for 462 Texas WAP houses which underwent weatherization. Eleven of the 462 houses underwent retrofits that would decrease gas use, while the remaining houses underwent other electricity-conserving retrofits.

Next, a daily temperature file for each of 73 Texas cities during the entire billing period as well as for the last twelve years were obtained from the National Oceanic and Atmospheric Agency (NOAA). The long term temperature data were used for calculating CDD and HDD for different reference temperatures for the average year. The temperature data during utility billing periods were used with corresponding utility billing data to develop PRISM regression models. The NOAA daily temperature file for each city contains a pair of maximum and minimum temperature data for each day in a DOS-unreadable format. The advanced version of PRISM converts this to daily average temperature ((Tmax+Tmin)/2) in a DOS-readable format as required for running PRISM. However this is only possible if the NOAA temperature files have no missing data or other problems such as an incorrect year or month.

If the meter file is good, i.e., includes at least 12 monthly energy use and corresponding meter reading dates for each pre- and post-period, and the temperature file is complete, i.e., without missing data or any other problems, the PRISM software will do the rest of the analysis and produce the NAC, NAS and statistical parameters.

Unfortunately, common and even trivial problems and oversights existing in the utility bills and the temperature files can abort a PRISM run. Therefore the data quality problems must be investigated before performing PRISM analysis.

2. Types of data quality problems in utility bills

The common problems encountered with utility bills were:

1) no meter reading dates. 90 of 462 houses had this problem,

2) the bills were estimated, not read. We have been able to identify such cases from the utility bills which showed constant energy use for every month of the year, and
3) less than one year of data for pre- or post-retrofit periods.

Since the PRISM analysis accuracy is very sensitive to the accuracy of the utility bills, the houses with the above stated problems were rejected from our analysis data set. Appendix A briefly presents the findings of another study (Griffith et al., 1994) involving several residences in College Station which illustrate the sensitivity of PRISM models to even small data quality problems.

3. Types of data quality problems in the NOAA temperature files

The advanced version of the PRISM program accepts NOAA format weather files to perform energy savings analysis only if the NOAA weather files have no missing data or problems such as an incorrect month or year number. When the NOAA data have any problem, PRISM will abort. More than 60% of the NOAA weather files for the above 28 cities had these types of problems.

The common data quality problems in the NOAA temperature files are:

- missing temperature data.
- incorrect order of years or months.

The NOAA data can not be read and fixed without compiling the data file, and therefore, we had to resort to the following steps in order to resolve this problem:

1. The NOAA weather files were compiled using the NOAAFLPY.EXE program supplied by Princeton University.

2. The resultant ASCII files were checked for missing data, incorrect month or year number.

3. The problems in the ASCII file were adjusted as follows:

a) Missing data were filled in using data from the same dates from a previous year for missing data occurring for a period of several days or more which were used for calculating average year CDD & HDD.

b) Data from the handbook "Climatological Data" for Texas were used for missing data during the utility billing periods.

After investigating the data quality and resolving the fixable problems, 182 of 462 houses which included eleven gas weatherization houses and 171 electricity weatherization houses, had enough utility data and temperature data to run PRISM. Therefore, 11 gas weatherization and 171 electricity weatherization houses were accepted for PRISM analysis.

Nine of the eleven gas weatherization houses met PRISM criteria while 81 of 171 electricity houses met PRISM criteria. Thus we note that poor data quality led us to reject 80% of the houses from our analysis.

4. Recommendations

Based on the experience gained from the WAP analysis and other allied studies, we would like give the following recommendations to minimize data quality problems.

- Utility billing data must have at least twelve consecutive months of pre-weatherization and twelve consecutive months of post-weatherization data, and must have corresponding meter-reading dates.

- It is recommended that copies of original utility bills also be sent to the analysts.

FUTURE WORK ON ENERGY CONSUMPTION STUDIES

The State Energy Conservation Office (SECO) contracted with the Texas Department of Housing and Community Affairs (TDHCA) to implement the Weatherization Plus Program. Weatherization Plus provides for the weatherizing of dwellings containing eligible households whose incomes are greater than 125 percent, but not more than 175 percent of the current federal poverty income guidelines. Based upon 1990 census data, Texas has approximately 614,310 potentially eligible households. This population, often described as the "working poor", is not eligible for the Department of Energy (DOE) Weatherization Assistance for Low Income Persons Program (WAFLIPP). Although their income is too high for WAFLIPP, the income is still too low to afford energy conservation measures on the open market.

A second "Energy Consumption Study" is in progress by TDHCA Energy Assistance, to study 10% of the homes weatherized in the WAP+ Program. Data has been collected from Texas Energy Vendors by TDHCA with the use of a "Client Release Form" for 1,000 homes to analyze utility bills 12 months pre and 12 months post to retrofitting to determine the energy retrofit savings on weatherized single family dwellings.

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Appendix A. Case Study Results

In order to illustrate the effect of bad data, we shall briefly discuss results from another study done at College Station (Griffith et al., 1994). Eleven houses were selected as the sample for study. All these houses have gas heating and gas fired domestic hot water systems. Hence electricity is used solely for lighting, appliances and Air Conditioning (AC). Figure A1 depicts time plots of the monthly electricity use in the two houses of interest. As expected, they have an annual energy use cycle due to air conditioning use, with a minimum around January and a maximum around July. A few outliers (such as October and November use in house 9, H9) are also to be noted.

Of the eleven homes, House 8 (H8) and H9 did not fall into the region of acceptable PRISM fit as shown in Figure A2. Inquiry as to the reason for the poor fit led to the discovery that the occupants of H8 were on vacation for two-and-half weeks during July 1992. This accounted for the abnormally low consumption for this house in July. As a result, omitting the July consumption data from the PRISM run gives much better PRISM fit to the data as is shown from point 8 move to point 8a in Figure A2.

For H9, a very high consumption in October followed by a very low November consumption is observed (see Fig. A1). Investigation with College Station Utilities revealed that the October value was not a real reading but an estimation, while the November value was an actual meter reading. This type data quality problem can be adjusted by combining these two data points into a single two-month period point. Identifying and adjustment of estimated data have been added in advance version PRISM. By adjusting the estimated data for H9, PRISM fit level of H9 moves to point 9a from point 9 (see Fig. A2).

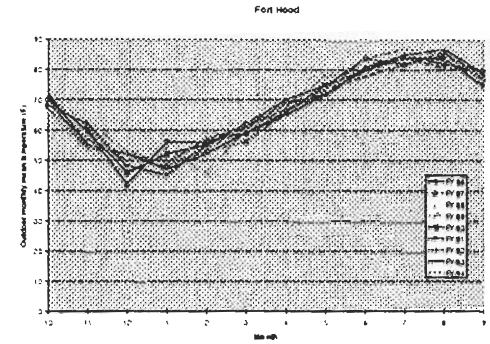

Figure 1. Temperature variation for past several years at the Army Base.

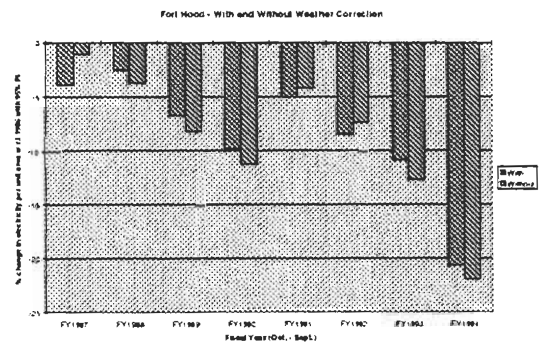

Figure 2. Comparison of Percentage savings for electricity with and without weather correction.

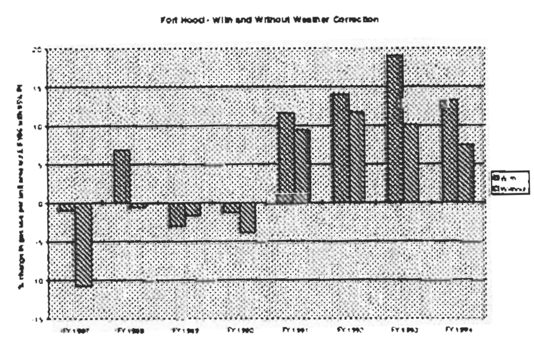

Figure 3. Comparison of percentage savings for gas use with and without weather correction.

Table 1. Summary of Retrofits on 78 WAP houses

CONTRACTOR	TOTAL	COOLING	HEATING			PRIMARY MEASURES				EWAP (Only)	SECONDARY MEASURES				
	NO. OF CLIENTS	A/C Unit	Natural Gas	Electric	Butane	Primary Windows	Replacement Doors	Water Heater Jacket	Attic Insulation	Replace Heat/ Cool System	Weatherstripping Doorsweeps/door shoes/ bottoms & thresholds	Replacement Glass	Pipe Insulation	Outlet Gaskets	Solar Screens
PANHANDLE	11	7	11	5		9	8		2		11	5	5	1	
WEST TX OPP	2	2	2			2	2		2		2			2	
EL PASO CAP	6	4	4	3	1	3	6	4	3		3	2	4	5	
CAUSE	1	1	1			1	1	1			1		1	1	
CAP TAYLOR	6	1	6			3	6		4		6				
SHELTERING ARMS	3	1	2	1		2	3	2	1		3		1	2	
EOAC	1		1			1	1		1		1		1	1	
HILL COUNTRY	1		1			1	1	1	1		1		1	1	
AUSTIN	1	1	1					1	1	Replace A/C	1		1	1	1
BRAZOS	2	2	1	1			1		1		1		2	1	1
CSI (Dallas)	36	19	31	9	1	25	25	4	15		34	10	18	27	
CSI	8	5	8	4		4	5	3	5		8	2	3	5	
Total	78	43	69	23	2	51	59	16	36	0	72	19	37	47	2
Percentage		56	90	30	3	66	77	21	47	0	94	25	48	61	3

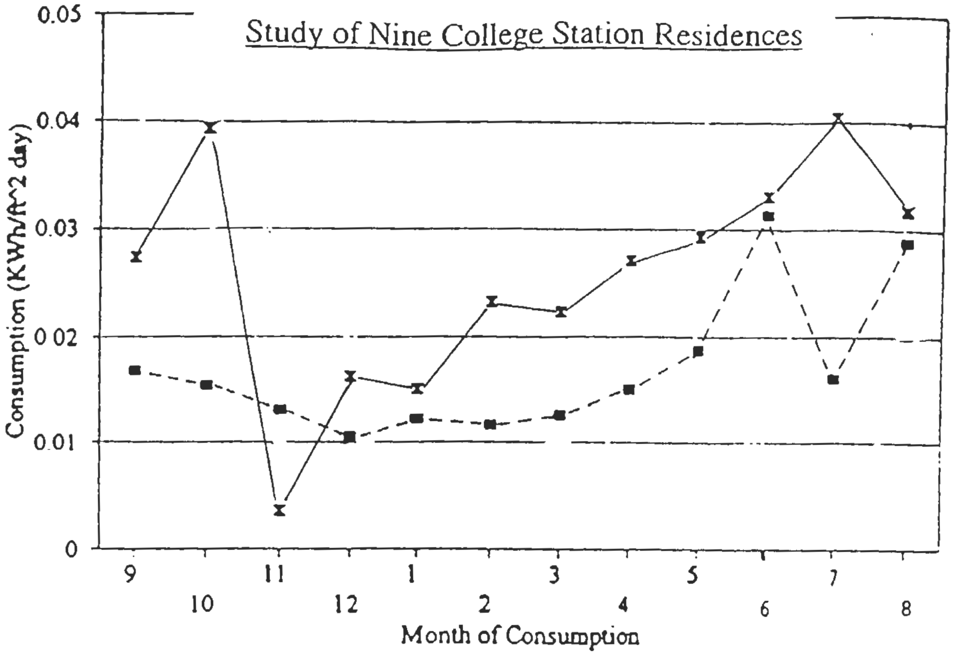

Figure A1. Time series plots of the monthly electricity use in two houses (H8 & H9) in College Station

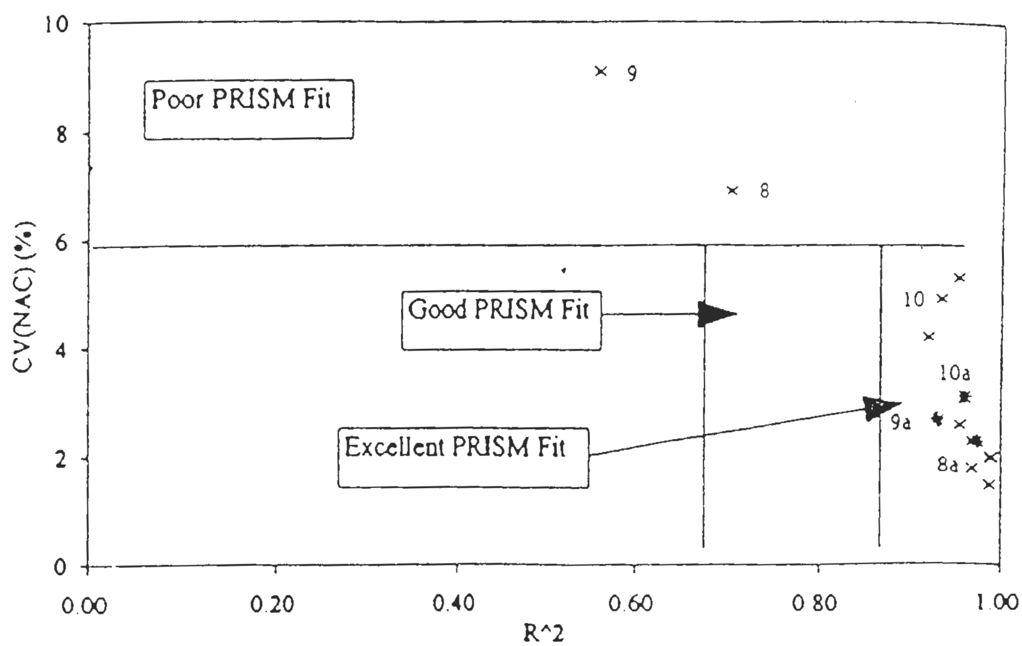

Figure A2. A plot of R^2 versus CV(NAC) to show regions of excellent, good, and poor PRISM fit for eleven houses. Alternate PRISM runs for houses 8, 9, and 10 are shown as astrices.