The Use of a Monthly Whole-Campus Energy Analysis for Evaluating a Third Party Energy Service Agreement

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Although sophisticated energy modeling procedures exist for evaluating energy savings from building energy conservation retrofits very few of these techniques are currently being used in everyday practice. In many cases third party energy services agreements rely on "negotiated" estimates to evaluate the energy savings. The calculation techniques are often wrapped into a binding legal agreement that is, in effect, the basis for which payments on the energy savings are made. Unfortunately, such negotiated calculation techniques can be almost impossible to verify (sometimes even proprietary), and, in some cases, may be inaccurately reporting the savings from an energy conservation retrofit.

This paper presents results from an evaluation of energy savings resulting from a $5 million energy services contract between an energy services contractor and a state university located in Central Texas. Savings were evaluated over a 57 month period using sliding, weather-normalized indices that were adjusted for square footage and student occupancy. Weather adjustments were performed with sliding PRISM, the Princeton Scorekeeping method using whole-campus data (Fels 1986). The results indicate several interesting features that should give some encouragement for the development of standardized methods for evaluating energy service agreements. First, the impact of the savings from VAV retrofits to 35 buildings can easily be seen over the noise that existed in the raw data due to price fluctuations, weather variations, and changes in student enrollment and conditioned area.

Second, since the sliding indices are based on PRISM, goodness-of-fit indicators were developed that allow one to determine how well the sliding indicators are working, and whether or not the savings rise above the confidence interval described by the goodness-of-fit. Careful inspection indicated that the sliding indicators revealed important features that were not evident in the raw data: for example, the impact of the substantial completion date on the savings calculations, and the ability to see how a mid-winter boiler failure decreased the energy savings from the energy services agreement.

Introduction

In 1987, a $5 million energy management program was started by the Prairie View A&M University to renovate the HVAC systems in over 35 buildings on campus. This program used a third party service arrangement between the university and energy service company. In order to assess the impact of a campus-wide guaranteed-savings energy management program, whole-campus energy usage indices were constructed for the period 1983 through 1991. These indices utilize the Princeton Scorekeeping Method (PRISM), a steady-state three parameter regression model (Fels 1986). The well documented PRISM method is the most commonly used method for evaluating before-after energy conservation retrofit savings in residences and small commercial buildings. The majority of the information required for the analysis was available at the university physical plant offices, with supplemental information obtained from the utility suppliers. Additional material concerning the analysis can be found in the report by Haberl et al. (1992).

Figure 1 illustrates the erratic nature of the monthly utility bills that the university pays. In 1991 the university consumed $2,016,000 worth of energy to provide services, of this $1,701,000 (84%) was spent on electricity, and the remaining $315,000 (16%) was spent on natural gas. In Figure 1 the total monthly utility bills, electric bills, and natural gas bills are shown for the period April 1988 through December 1991. Although certain patterns can be seen in these data (i.e., natural gas consumption increasing during the winter months) it is difficult to determine visually to what extent savings have occurred from the energy management program. Several large billing adjustments also existed in the utility cost data from December 1988 through February 1989 that were not reflected in the actual energy data.

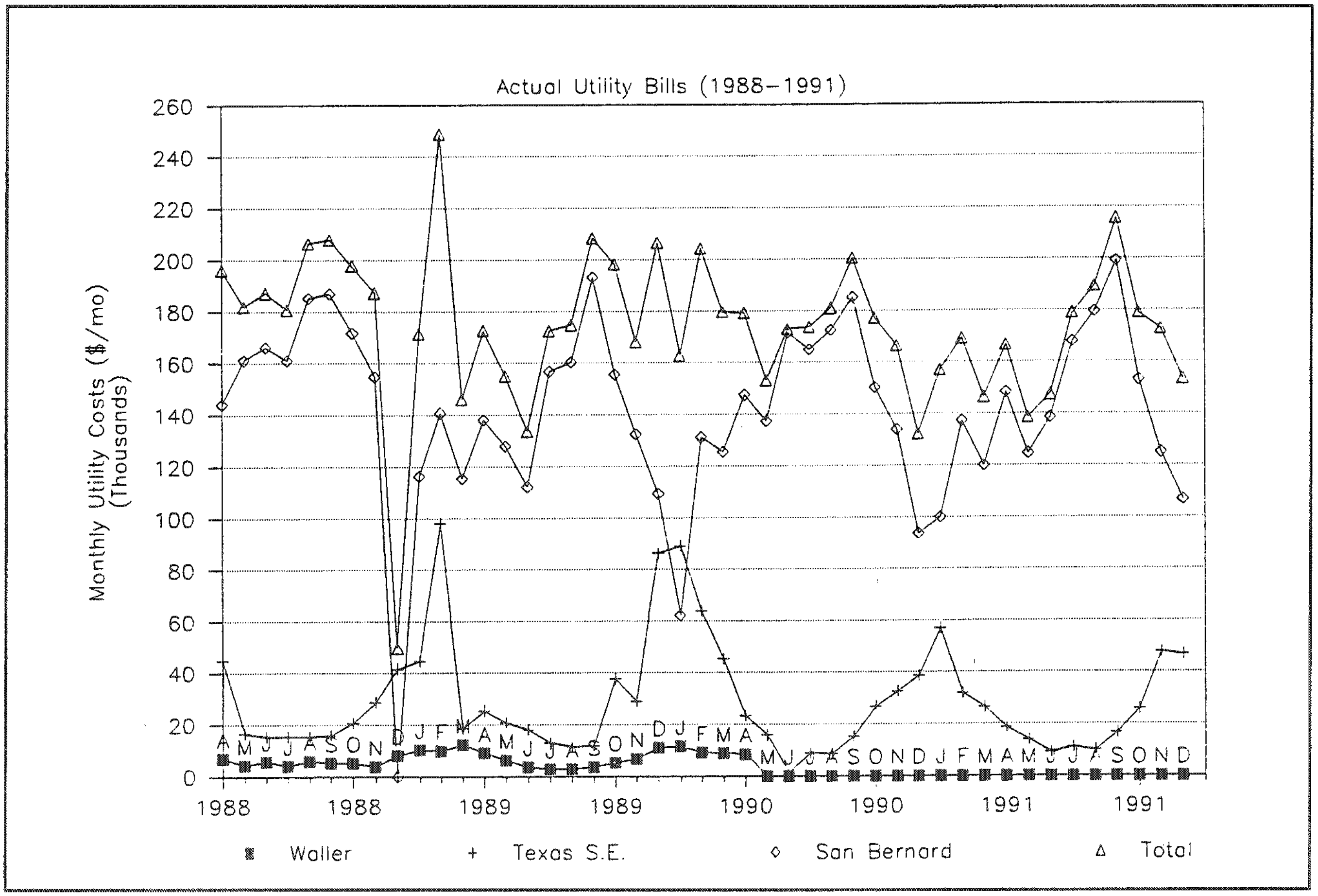

Figure 1. Actual Utility Bills for the Campus. The actual monthly utility bills for the campus are shown in this figure. In this figure the total monthly utility bills (triangle), electric bills (diamond), and natural gas bills (main supplier - plus symbol, and municipal supplier - filled square symbol) are shown for the period April 1988 through December 1991.

Natural Gas Consumption

Unadjusted natural gas consumption for the campus is shown in Figure 2 (GBtu per month - Btu x 10^9) from April 1983 through December 1991. The total campus natural gas consumption includes gas purchased from the primary supplier, and gas purchased from the secondary supplier. At one point the campus received natural gas from two suppliers. This arrangement was discontinued in August 1990.

As expected, the consumption of natural gas is strongly influenced by the prevailing weather conditions, usually having a peak consumption during the month of January and dropping to its lowest consumption during July or August. The highest consumption during this seven-year period occurred in December of 1989 when record-breaking cold temperatures were experienced.

Unadjusted natural gas use versus average monthly temperature is shown in Figure 3 for the period April 1983 through December 1991. The data labels represent the year the gas was consumed. A strong weather-dependent, linear relationship can be observed in these data with only a base-level, or non-weather-dependent consumption occurring at average ambient temperatures greater than about 80°F.

Several interesting features can also be seen in the unadjusted data. First, the extreme weather conditions experienced in December 1989 (shown as "90" in Figure 3 because the reading was recorded on January 1, 1990) were within 5°F of conditions in December 1983 ("84" in Figure 3), January 1984, January and February of 1985, and January 1988. However, it appears that in December 1989, the campus consumed significantly more natural gas--a possible indication of excessive natural gas

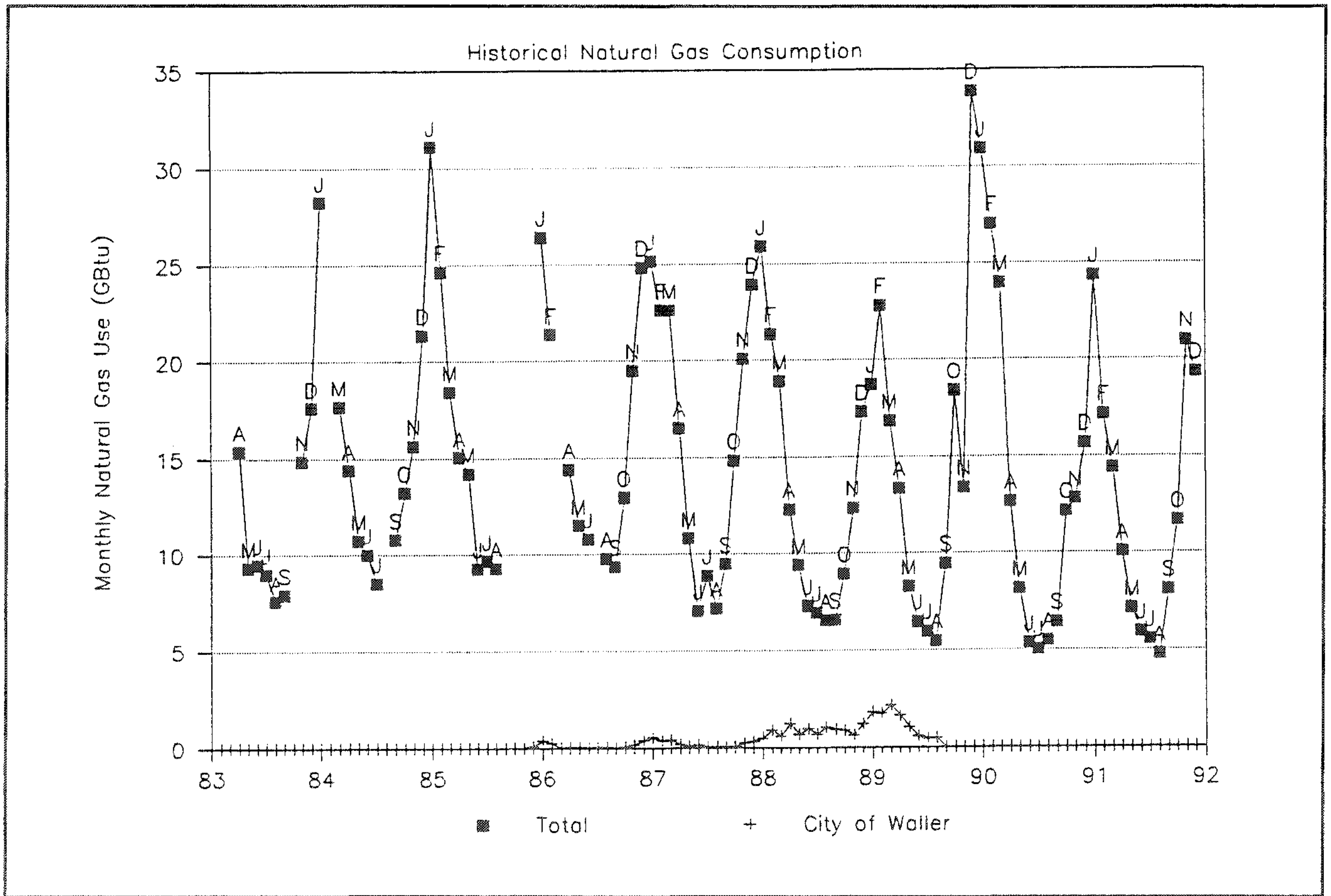

Figure 2. Historical Natural Gas Consumption. The unadjusted natural gas consumption (GBtu - billion Btu per month) is shown in this figure from April 1983 through December 1991. The total campus consumption (filled square symbol) includes gas purchased from the texas southeastern gas company, and gas purchased from the City of Waller (the plus symbol).

use during the winter of 1989-90. The abnormally high consumption for the following months (i.e., January, February and March 1990) also indicate excessive consumption. These months are the outliers labeled "90" that are considerably above the other months. Conversations with campus personnel indicated a problem with a steam leak in the main campus boiler that could not be repaired until the following spring.

Electricity Consumption

Unadjusted electricity consumption (kWh) is shown in Figure 4 for the period January 1983 through December 1991. In Figure 5 this same electricity use is displayed against average monthly temperatures. The electricity use for the campus can be characterized as having only a slight weather dependency, with a significant monthly variation that is related to scheduling and/or enrollment effects.

The largest electricity consumption occurs in September (versus August or July for similar commercial buildings)--due to the combined cooling-related and student-related electricity requirements. Similar September peaks have been seen before in other campus studies (Haberl et al. 1989). The lowest consumption occurs during the months of December and January--periods when the campus has its Christmas vacation. Another interesting feature is that February electricity use seems to always be larger than March electricity use--most likely due to the reduced energy use that occurs during the one-week spring vacation period which occurs in March.

Peak Electric Demand

The campus is billed for two different types of peak electric demand: non-coincident peak electric demand and coincident peak electric demand. The whole-campus electric peak demand (non-coincident demand) is recorded

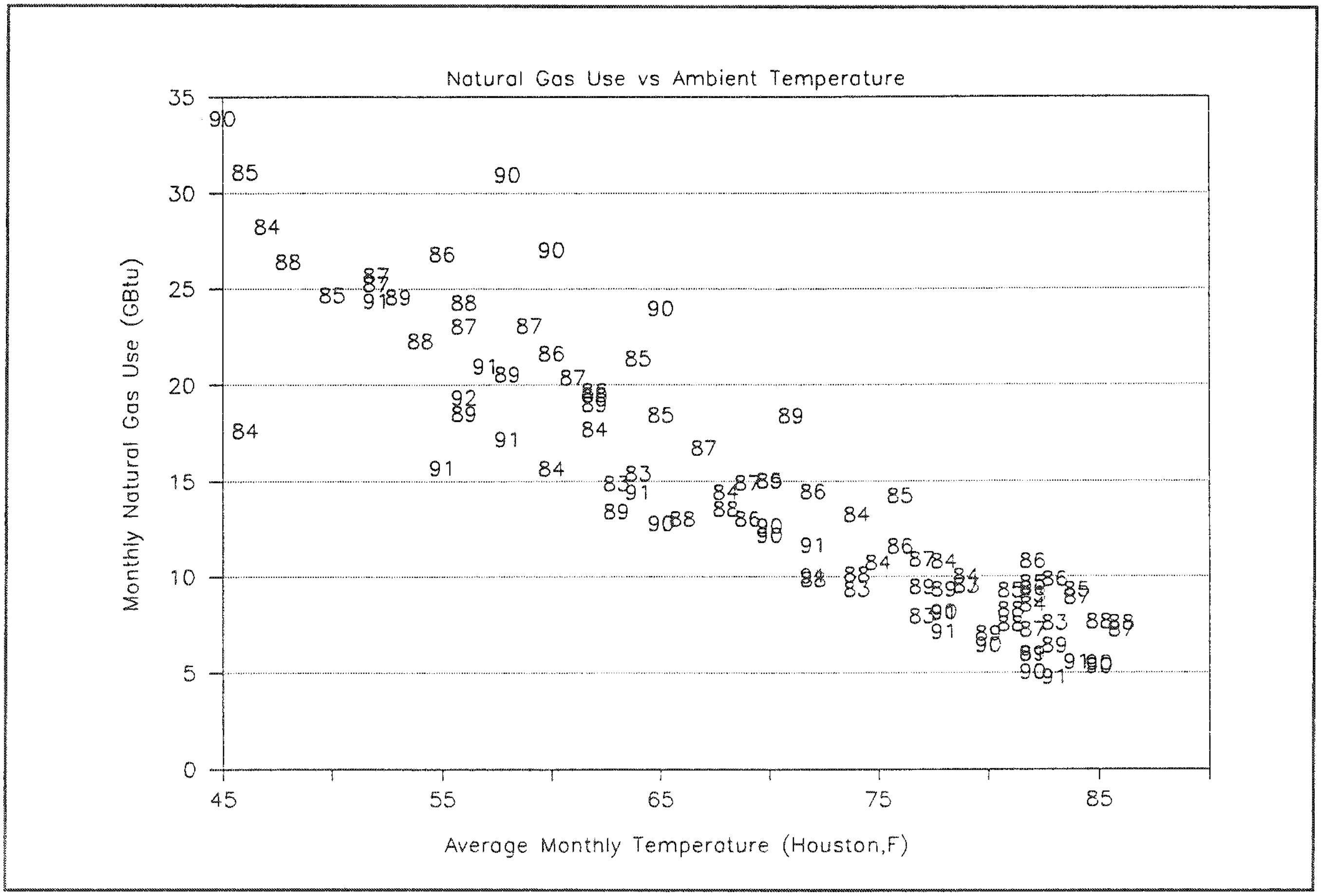

Figure 3. Natural Gas Use vs. Ambient Temperature. Unadjusted natural gas use versus average billing-period temperature is shown in this figure for the period April 1983 through December 1991. The data labels represent the year the gas was consumed.

by the electric utility company on a 15-minute interval using magnetic tapes that are transcribed for billing purposes once-per-month.

Non-coincident peak electric demand therefore represents the maximum, monthly 15-minute electric power levels for the entire campus. Coincident electric peak demand reflects the highest 15-minute whole-campus electric power requirements that occurred when the electric utility experienced their 15-minute peak demand. The campus is charged separately for both coincident and non-coincident peak electric demand.

Figures 6, 7 and 8 show the whole-campus coincident and non-coincident peak electric demand for the period January 1983 through April 1991. Figure 6 shows non-coincident peak electric demand and coincident peak electric demand in a time series. Figure 7 shows the non-coincident peak electric demand displayed against the average monthly temperature, and Figure 8 shows the coincident peak electric demand displayed against the average monthly temperature.

Several features can be clearly seen in the campus electric demand. First, in Figures 6 and 7, non-coincident peak demand varies much less from season to season than does coincident peak electric demand (Figure 8). Coincident peak electric demand seems to have a much stronger cooling-season component than does non-coincident peak electric demand.

In Figure 6 there are several trends in the electric demand. First, non-coincident peak electric demand increased steadily from 1983 through 1988 peaking at about 8 MW ($x10^6$) in the summer of 1988 and declined afterwards to a peak of 7.4 MW during the summer of 1991. Second, the cooling-season portion of the coincident peak electric demand also increased from 1983 to 1988 peaking at 7.1 MW during the summer of 1988 and declined afterward to a peak of 6.6 MW during the

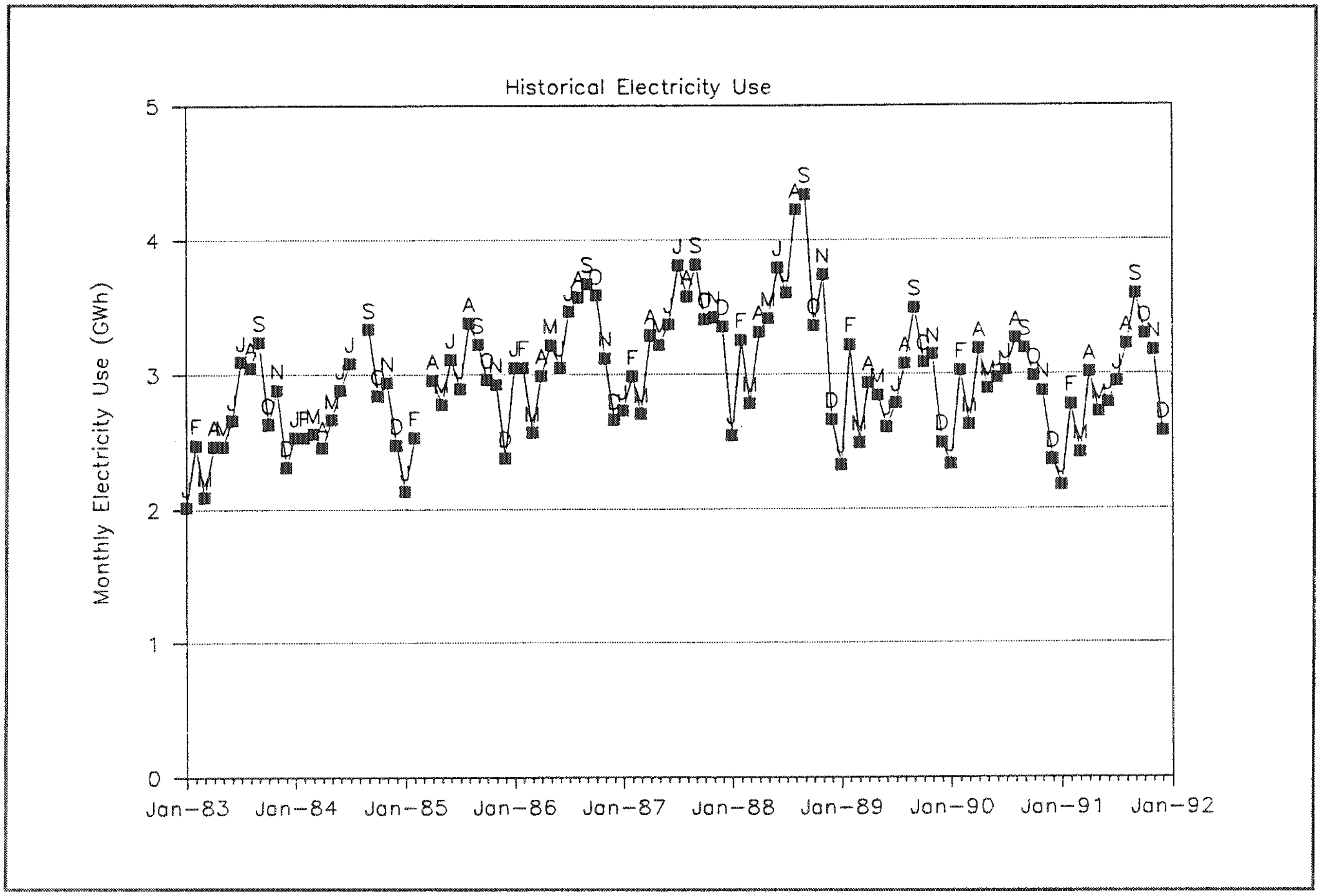

Figure 4. Historical Electricity Consumption (kWh). This figure shows unadjusted electricity usage (million kWh) for the campus during the period January 1983 through December 1991.

summer of 1991. Finally, the wintertime coincident peak demand "valley" decreased after 1988 from about 3.6 MW to 2.0 MW in 1991.

There is also another interesting feature that is evident in the coincident peak demand data in Figure 8. Specifically, 2 MW "step" that occurs in the peak demand at about 70°F. Conversations with the physical plant personnel indicate that this is traditionally the temperature at which the larger chillers are switched-on.

Tracking Energy Savings with the Normalized Consumption

We have found that campus operators have a need for concise, timely energy information (Haberl et al. 1989). Year-to-year comparisons of energy usage need to account for varying weather conditions, for additions to the conditioned floor area , and for changes in the student enrollment. Such annual indices require weather-normalization, and an adjustment for square footage of conditioned area for each major fuel. The agreement between the university and the service company also included a production factor-type adjustment for student enrollment. For the campus this meant one index each for electricity use (kWh), coincident electric demand (kW), non-coincident electric demand (kW), and natural gas usage.

A multi-step procedure for normalizing the energy usage of the campus was chosen. First, a model of the temperature dependence was assembled with Sliding PRISM - the Princeton Scorekeeping Method, a three-parameter steady-state model (Fels 1986). Sliding PRISM is PRISM applied to 12-month increments, sliding forward the estimation period one billing interval (usually one month) at a time. The next step was to divide the Normalized Annual Consumption (NAC) by the appropriate conditioned area for each fuel type, yielding a NAC/ft^2-1,000 students. Finally, the normalized indices were expressed using constant dollars. To complete the assessment of the guaranteed-savings contract the monthly differences

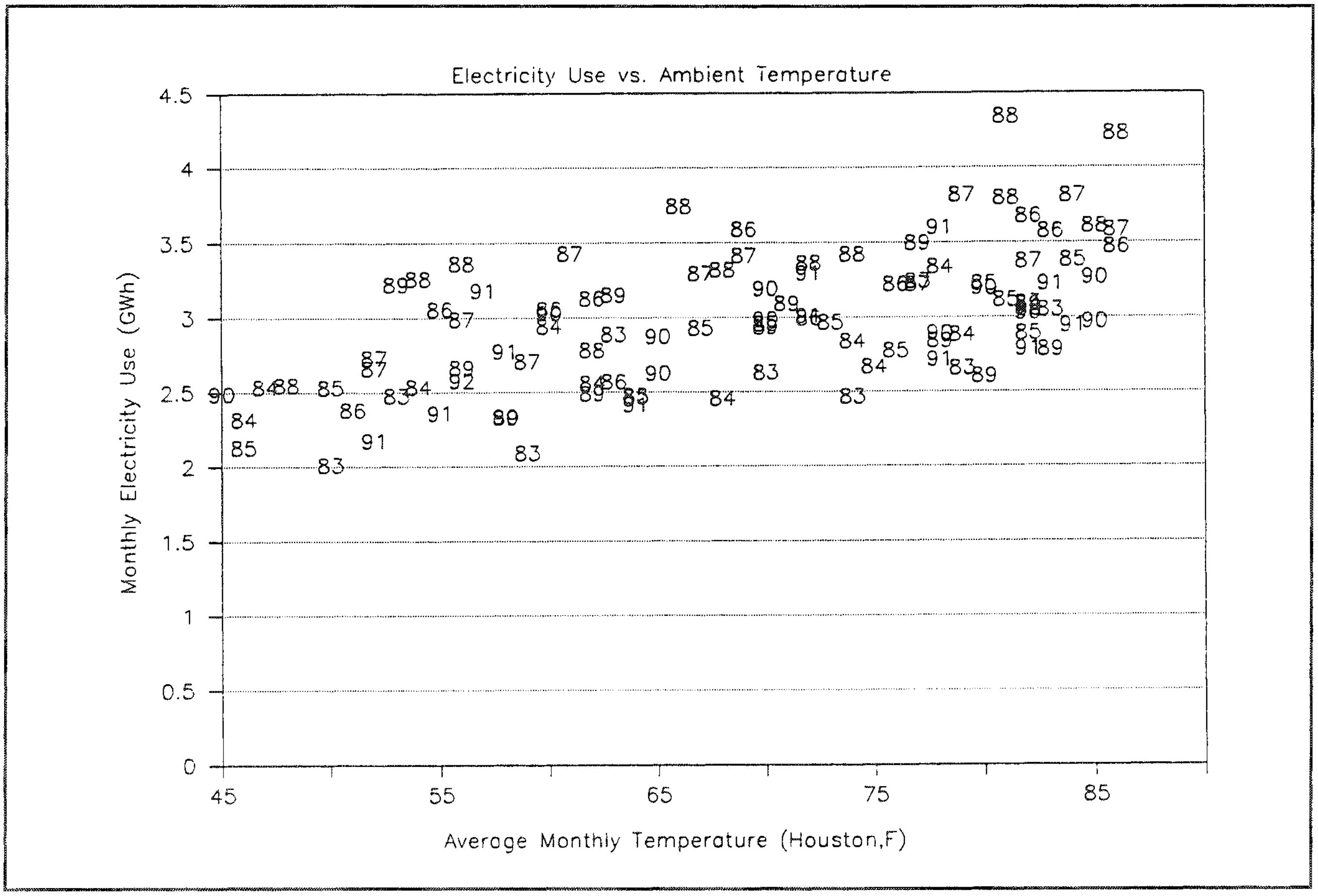

Figure 5. Electricity Use vs. Ambient Temperature. Unadjusted whole-campus electricity consumption is displayed against average billing-period temperature for the period January 1983 through December 1991.

between the normalized values (from the April 1987 start of the guaranteed-savings contract) were added through December 1991, and displayed as cumulative totals. The construction period represented the period between the contract start date and the date of the substantial completion.

Both electricity usage and natural gas usage were normalized for varying weather conditions using PRISM. PRISM regresses energy consumption against heating or cooling degree days (taken at the balance-point temperature which gives the best fit) and includes thorough goodness-of-fit statistics. For either heating (i.e., PRISM HO) or cooling (i.e., PRISM CO) data, the model yields a slope (fuel-use/degree-day), base-level consumption (fuel-use/day), and a balance point temperature (F). Such a model is composed of a base-level, or non-weather dependent consumption (a), the change-point, or balance point temperature (T_{bp}), a cooling slope (b_c), and an error term (e). In order to calculate a total normalized energy index for the entire campus it was necessary to analyze electricity use and natural gas use separately. To assess the variations in weather conditions for the campus 10 years of daily minimum-maximum temperatures were obtained from the National Weather Service (NWS 1991) for the Houston airport.

Twelve-month sliding indicators were also developed for the coincident peak electric demand, and non-coincident peak electric demand. Sliding indicators display a moving average of the previous 12-months of consumption. Sliding PRISM was applied to the electricity consumption (PRISM CO), and to the natural gas consumption (PRISM HO). A 12-month moving average was used for both coincident and non-coincident peak electric demand.

Next, the annual weather-normalized natural gas consumption was divided by the conditioned area for heating. The annual normalized electricity and electric demand values were divided by the conditioned area for electricity. Since the campus buildings may receive some combination of hot-water (generated by consuming natural gas), chilled

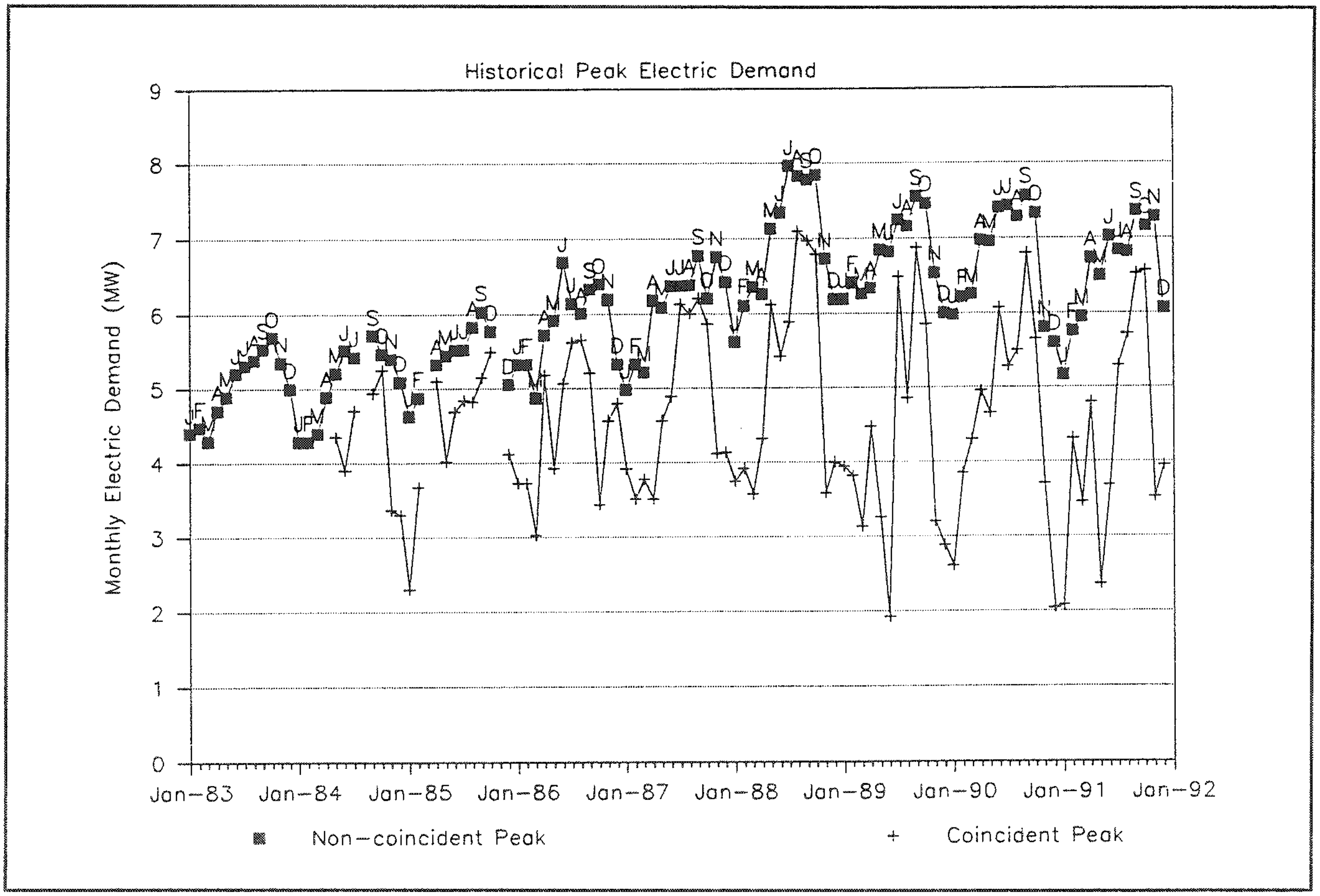

Figure 6. Historical Peak Electric Demand. This figure shows peak electric demand during the period January 1983 through December 1991. Values for non-coincident peak electric demand (square symbol) and coincident peak electric demand (plus symbol) are shown. The non-coincident peak electric demand represents the whole-campus electric demand peak. The coincident peak electric demand represents the whole-campus electric demand that occurred during the utility's peak electric demand.

water or electricity this involved a separate index for each fuel type. In Figure 9 the cumulative campus conditioned areas are shown for all buildings (1,944,248 ft^2): 97% of those buildings receive electricity (1,878,147 ft^2), 87% receive heating from the central plant (1,695,176 ft^2), and surprisingly only 73% receive cooling from the central plant (1,423,408 ft^2). It is interesting to note that even though the total campus square footage has doubled since 1970 the proportions of the buildings receiving electricity, steam and chilled water have remained about the same.

The next step in the normalization process was to express the energy consumption in terms of the number of students that were enrolled at the campus. In Figure 10 the historical campus enrollment by semester is shown. In this figure values are displayed for the monthly enrollment, and for a 12-month moving average. Natural gas consumption, electricity use and electric demand were each expressed as a consumption per 1,000 students using the moving average student enrollment figure.

The final adjustment to the consumption figures involved expressing the consumption in terms of constant dollars. Current costs for April 1990 were used for the constant dollar indices. The following values were used in the conversions: 1 kWh = 3413 Btu, 1 MCF = 1.09 MBtu, N.G. = $2.11 /MBtu, kWh = $0.034645/kWh, kW (coincident) = $4.46/Peak-kW, kW (non-coincident) = $2.75/Peak-kW. These cost figures were obtained from the campus utility suppliers.

Results

Figure 11 shows the results of a sliding PRISM analysis. PRISM HO was used for the whole-campus natural gas use (upper graph) and a sliding PRISM CO analysis

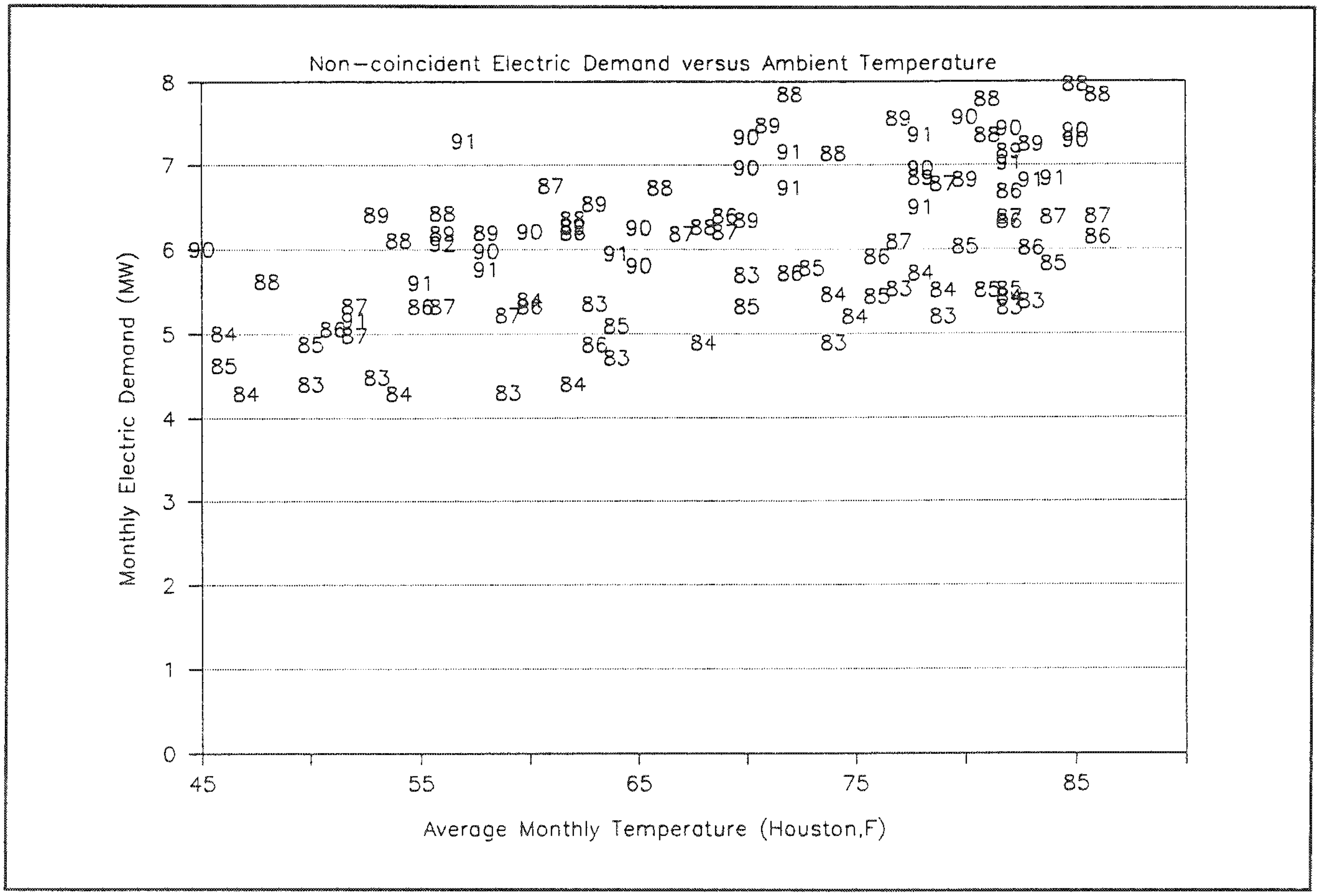

Figure 7. Non-Coincident Peak Electric Demand vs. Ambient Temperature. Non-coincident peak electric demand is displayed in this figure against the average billing-period temperature during the period January 1983 through December 1991. (NOTE: The exact day and date for the peak electric demands were not available. Hence the average monthly temperature was used for the x-axis).

(lower graph) for the whole-campus electricity use for the period January 1983 through December 1991. Values shown represent the Normalized Annual Consumption (NAC), the cooling and heating portion of the annual consumption, and the base-level portion of the of the annual consumption. The dashed lines surrounding the NAC represent the standard errors for the NAC. The inverted triangles represent the R^2. A 12-month moving average has also been indicated for discussion purposes.

The sliding PRISM HO analysis of the natural gas indicates that roughly 50% of the natural gas is heating related and 50% can be considered non-heating related or base level. Most of the increase during the 1990 period occurred from heating related usage as is evidenced by the rise in the heating fraction. PRISM HO also indicates that the natural gas consumption is well described (average $R^2 = 0.92 > 0.7$ and CV(NAC) is $0.04 < 0.06$) using the reliability criteria established by Reynolds and Fels (1988). A 25% decrease is evident from June of 1986 through June of 1989. Then, beginning in June 1989 (sliding indicators have a 6-month time lag) a 25% increase occurred and lasted through September 1990, followed by a 25% decrease that bottomed-out in March 1991. The 25% increase was due to the boiler failure that occurred during the 1989-90 winter.

The electricity consumption (which contains the cooling energy use) is only moderately described by PRISM CO. This is because of a weak temperature dependence and strong influence by other factors such as semester and non-semester periods. The average R^2 for the sliding PRISM CO analysis of the electricity is 43%, the average CV(NAC) is 0.04. Since October of 1988 a 19% decrease in the electricity use occurred.

For comparison a 12-month moving average has been displayed in both the natural gas and electricity graphs as

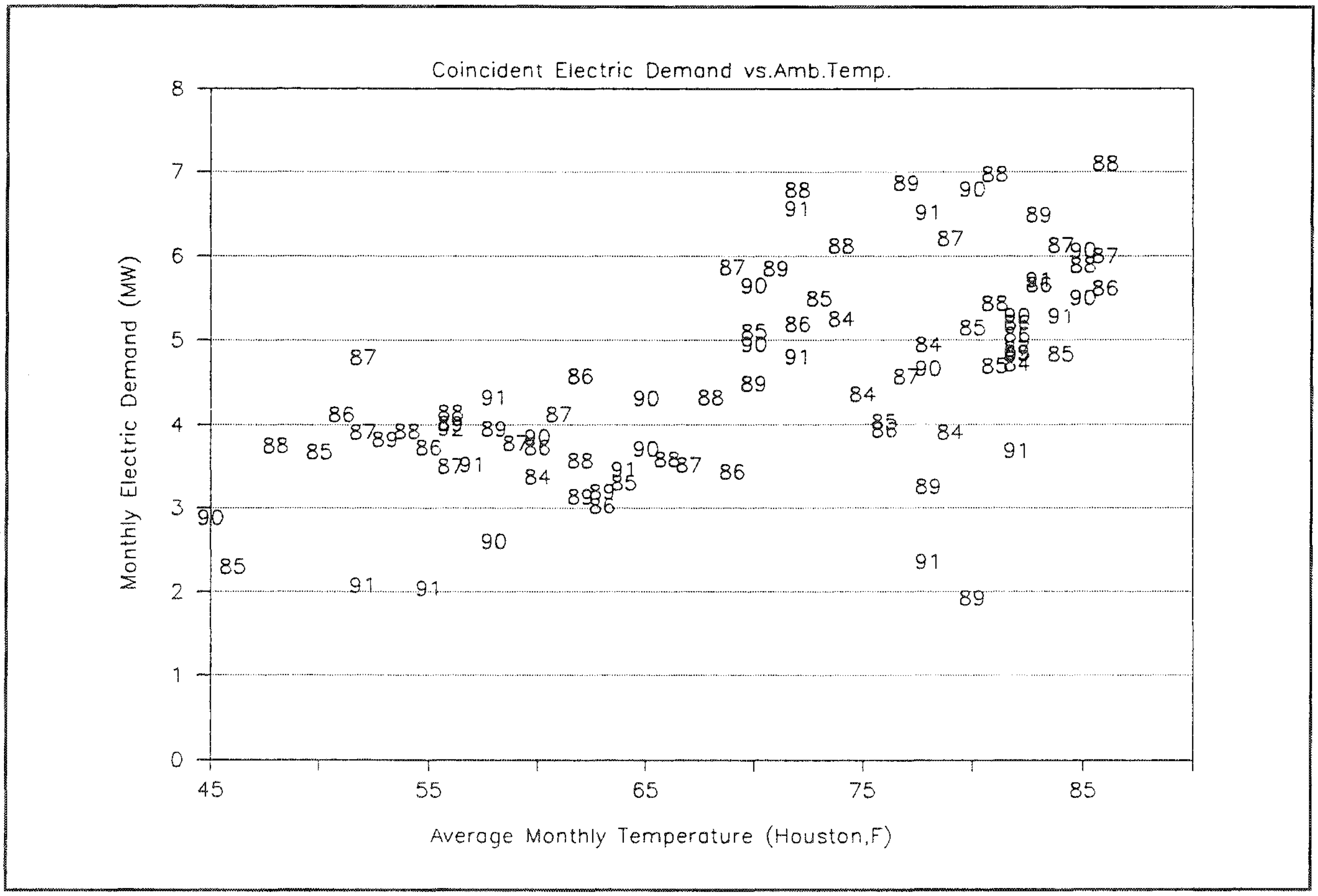

Figure 8. Coincident Peak Electric Demand vs. Ambient Temperature. Coincident peak electric demand is displayed in this figure against the average billing-period temperature for the period January 1983 through April 1991.

indicated. The moving average for the electricity use tracked the PRISM CO model very closely, remaining within the CV(NAC) boundary with the exception of two periods. In 1985 and 1986 the moving average fell below PRISM CO because of missing data. In October 1990 there was a large increase in PRISM's NAC and CV(NAC) and a corresponding decrease in the R^2-- indicating that the data for this period had virtually no weather dependence. During this period the moving average turned out to be the indicator of choice.

The 12-month moving average did not track the PRISM HO as closely as the PRISM CO for two reasons. First, there were missing data during the period from August 1983 through March 1986 which affects the moving average and not PRISM. Second, the since the campus natural gas use contains a stronger weather dependent component variations from one year's weather to the next show-up as slight differences between the moving average and PRISM. Hence, the tendency for the moving average to "wander" out of the CV(NAC) boundary. Since the PRISM HO model displayed a remarkable 92% average R^2 it was the preferred model.

Figure 12 displays weather and area normalized consumption expressed as 12-month sliding-average annual energy costs (\$/ft^2) for the period April 1987 through December 1991. Values are shown for the total energy use, electricity usage (kWh), natural gas consumption, coincident peak electric demand (kW), and the non-coincident peak demand (kW).

Figure 13 displays weather, area and enrollment normalized consumption expressed as 12-month sliding-average annual energy costs (\$/ft^2-1000 students) for the period April 1987 through December 1991. Values are shown for the total energy use, electricity usage (kWh), natural gas consumption, coincident peak electric demand (kW), and the non-coincident peak demand (kW).

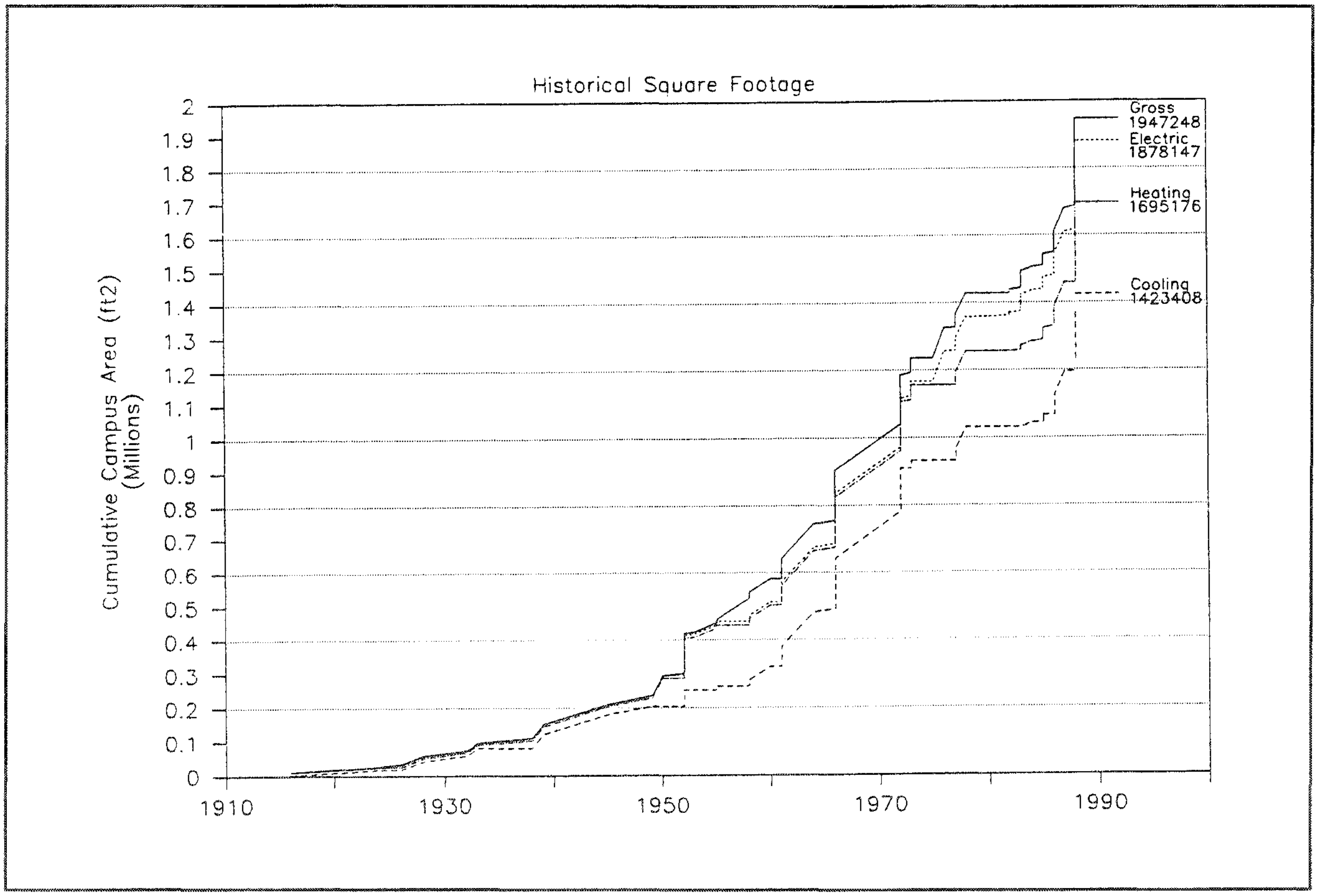

Figure 9. Cumulative Campus Square Footage (Heating, Cooling & Electric). This figure displays the campus growth from 1916 to 1991. Square footage is shown for all buildings (Gross), Those buildings receiving electricity (electricity), buildings receiving heating from the central plant (heating), and buildings that receive cooling from the central plant (cooling).

Figures 14 and 15 show the normalized energy savings for the campus. Figure 14 displays the estimated whole-campus energy savings from April 1987 to December 1991, displayed as a sliding monthly indicator (constant dollars). Values are shown for the total energy savings, electricity usage (kWh), natural gas consumption, coincident peak electric demand, the non-coincident peak demand. The target savings amount ($72,504) is also indicated. These values were calculated by "locking" the sliding indicators at the "substantial completion" date and summing the monthly accumulations for each index. The confidence interval for the total estimated savings represents two standard errors (one SE is about 13%). The total standard error represents the cumulative error from estimating the consumption from all the fuel types. For the electricity usage and the natural gas usage the standard error is the CV(NAC) PRISM value (i.e., the coefficient of variation of the normalized annual consumption). For the electric demands, and those periods where PRISM CO did not adequately explain the electricity use, the standard error is the standard deviation of the 12 months used to calculate the sliding average.

Discussion

Additional Features Revealed with the Sliding Indices

Whole-Campus Energy Savings. The decline in the monthly whole-campus energy savings may be due, in part, to the nature of the indices that were used to calculate the savings, in particular, the normalization by student enrollment. This is quite evident when one compares Figure 10, 12, and 13. In Figure 10, beginning with the Spring 1990 semester there was a marked decrease in the student enrollment--this has the effect of lowering the monthly savings because the number of students is declining. In Figure 12 one can clearly see that the total

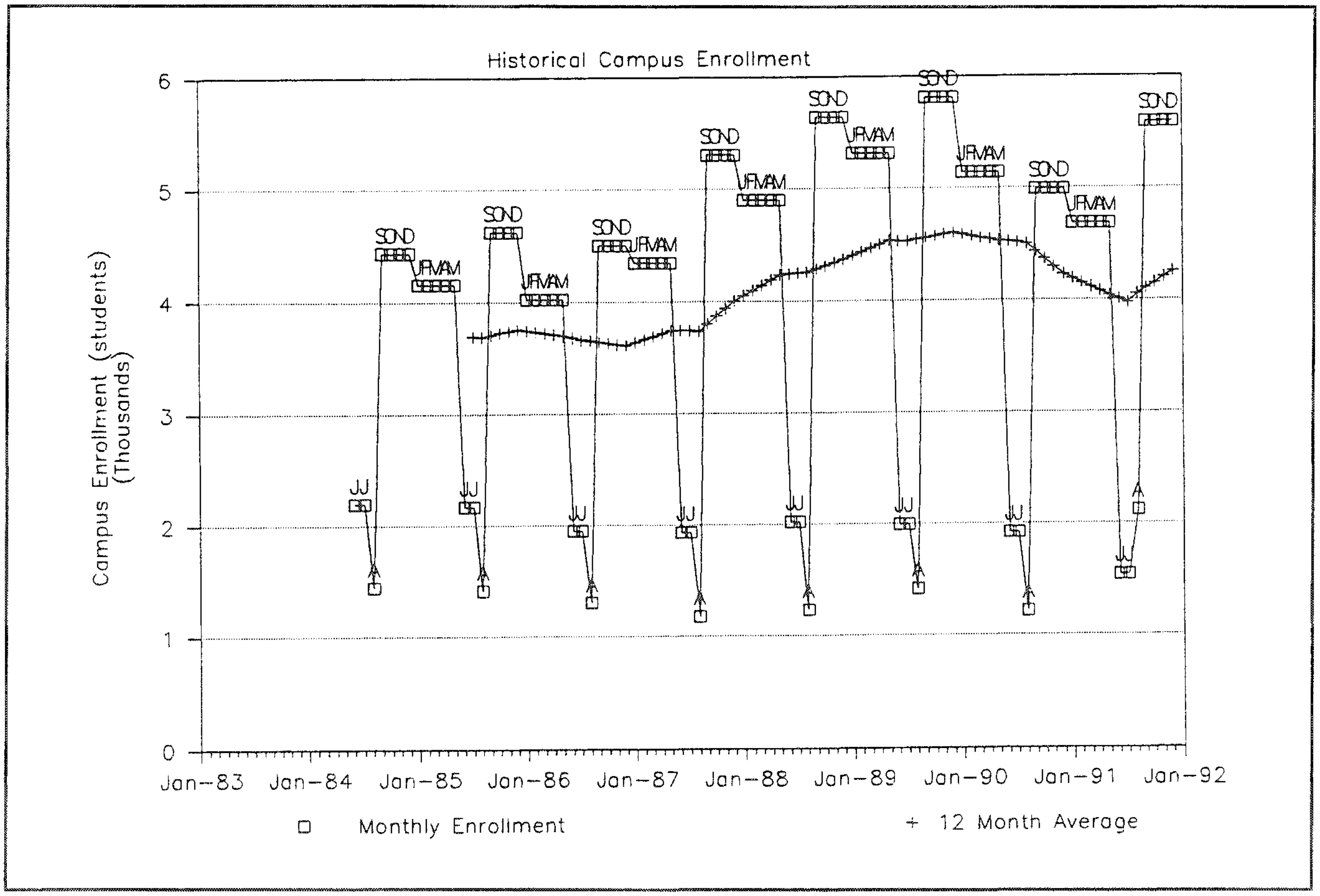

Figure 10. Historical Campus Enrollment by Semester. This figure displays annual campus student enrollment. Values are displayed for the monthly enrollment (square symbol), and for a 12-month moving average (+).

energy has actually reached a new low point in July 1991 ($1.05/sq ft), this effect is virtually canceled-out by the decreasing student enrollment (Figure 13). Since the normalization by student enrollment was negotiated in the original contract it was included in this analysis. A more rigorous statistical analysis may indicate that it is not a statistically significant contributor to the whole-campus energy use.

Electricity Use. In a similar fashion to the whole-campus energy use, the decline in the monthly electricity savings that began in December 1989 and continues through July 1991 may also be due, in part, to the nature of the indices that were used to calculate the savings, in particular, the normalization by student enrollment. In Figure 12 one can clearly see that the $\$/ft^2$ for electricity use stays flat after December 1989. This flat signal becomes overwhelmed by the drop in student enrollment when expressed as the negotiated $\$/ft^2$-student (Figure 13).

Natural Gas. As expected, natural gas use has a strong weather dependence. This can clearly be seen from the monthly consumption data. The highest peak use of natural gas occurred in December 1989. The natural gas use throughout the winter of 1989/90 appeared to be abnormally high. This effect can be clearly seen in both the $\$/ft^2$ (Figure 12) and $\$/ft^2$-student (Figure 13) indices beginning in November 1989 and lasts through most of 1990. This decline in natural gas savings significantly decreased the whole-campus savings during this period.

Projecting Savings into the Future

One of the requests from the facilities management was to determine if the entire project was going to save more or less energy than was negotiated. With sliding indicators in hand it is possible to project savings into the future by "locking" rates at the present and sliding the indices out into the future. Such estimates do not account for such uncertainties as changes in student enrollment, or additions or to the building stock. Figure 15 shows the

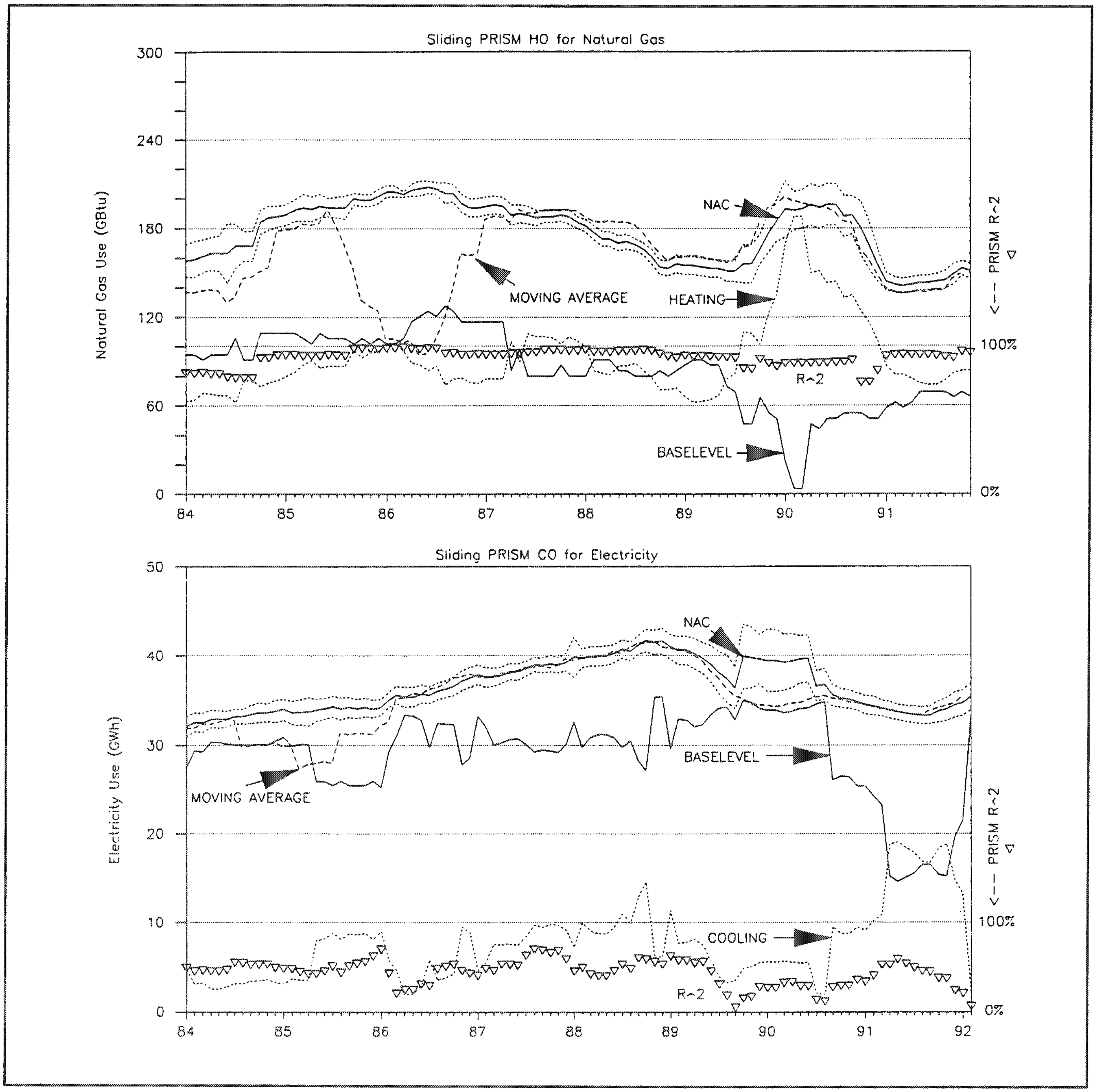

Figure 11. Sliding PRISM Analysis for Whole-Campus Natural Gas and Electricity Use. This figure shows the results of a sliding PRISM HO analysis for the whole-campus natural gas use (upper graph) and a sliding PRISM CO analysis (lower graph) for the whole-campus electricity use for the period January 1983 through December 1991. Values shown represent the Normalized Annual Consumption (NAC), the cooling and heating portion of the annual consumption, and the base-level portion of the annual consumption. The dashed lines surrounding the NAC represent the standard errors for the NAC. The inverted triangles represent the R^2. A 12-month moving average is also indicated. All dates represent the end-date of the slide.

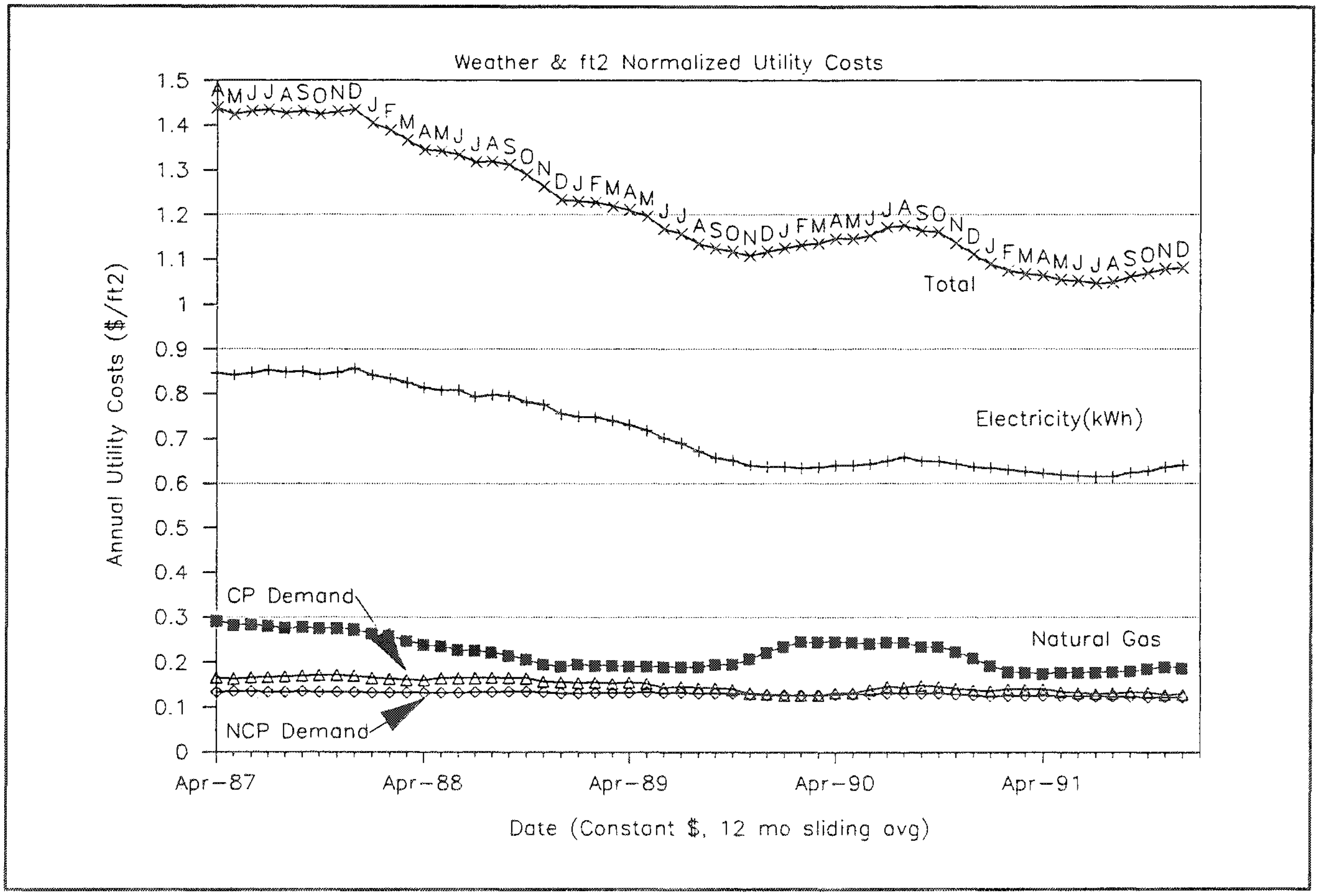

Figure 12. Weather Normalized Energy Costs Adjusted for Conditioned Area. This figure displays 12-month sliding-average annual energy costs ($/ft^2) for the period April 1987 through December 1991. Values are shown for the total energy use (x), electricity usage (kWh - the plus symbol), natural gas consumption (the square symbol), coincident peak electric demand (kW - the triangular symbol), and the non-coincident peak demand (kW - the diamond symbol). The electricity (kWh) and natural gas sliding averages have been weather normalized using a sliding PRISM analysis.

cumulative 5-year, whole-campus estimated utility cost savings from April 1987 to August 1993 (constant dollars). The confidence interval shown for the total savings represents two standard errors (one SE is about 13%). To project the savings the average savings rate that occurred from December 1991 were extended through August 1993, and added to the savings that occurred prior to the guaranteed savings (April 1987 to September 1988) for a total savings of $4,577,000 which is 109% of the guaranteed savings of $4,278,000. Without the $355,000 that accumulated prior to substantial completion the estimated savings is then $4,222,000 or 99% of the guaranteed savings of $4,278,000.

Summary

This paper has presented results from an evaluation of energy savings resulting from a $5 million energy services contract between an energy services contractor and a state university located in Central Texas, using sliding, weather-normalized indices that adjust for square footage and student occupancy. Such indices allow the impact of the savings from VAV retrofits to 35 buildings to be easily be seen over the noise that existed in the raw data. A mid-winter boiler failure which decreased the energy savings from the energy services agreement can also be seen.

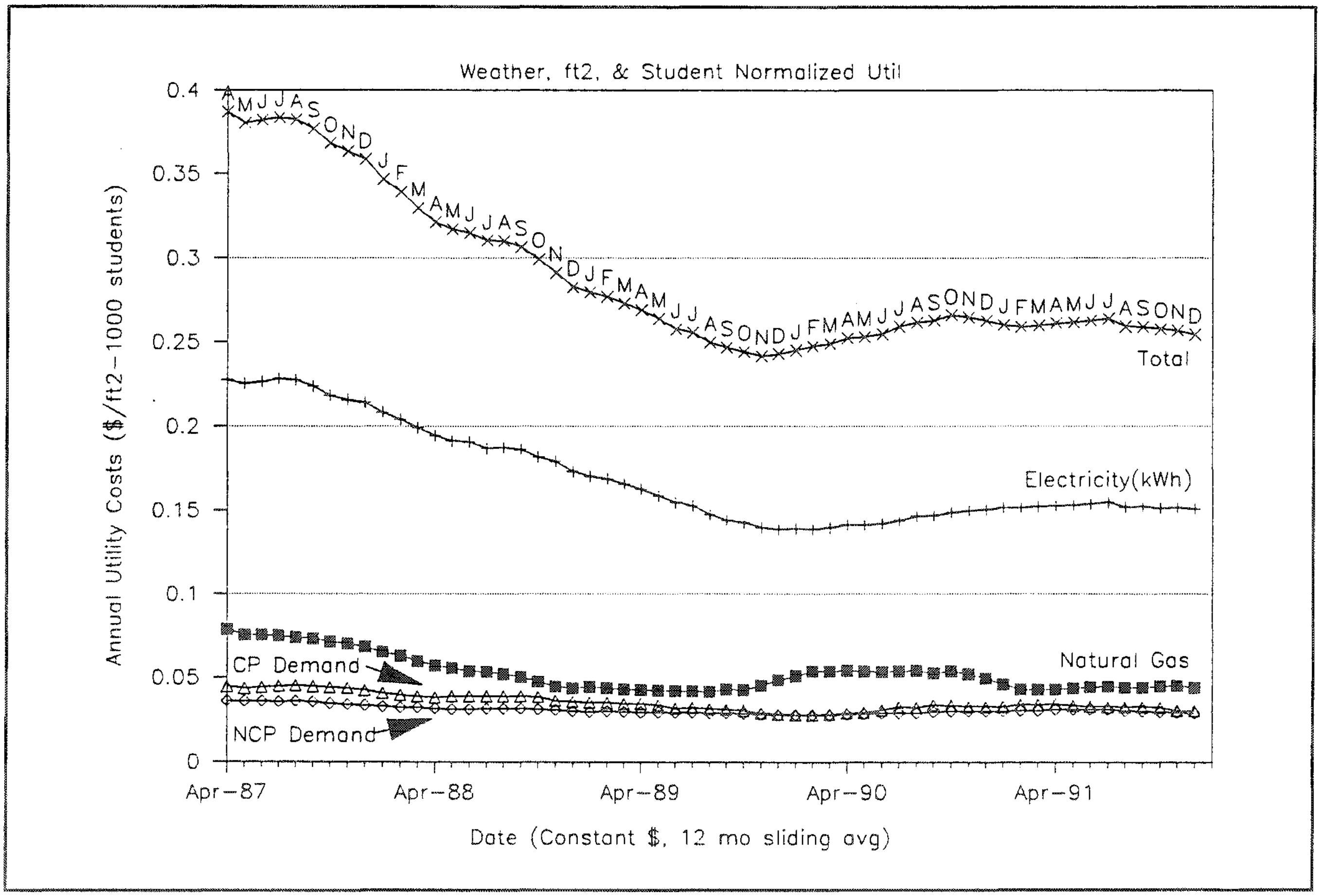

Figure 13. Weather Normalized Energy Costs Adjusted for Conditioned Area and Enrollment. This figure displays 12-month sliding-average annual energy costs ($/ft^2-student) for the period April 1987 through December 1991. Values are shown for the total energy use (x), electricity usage (kWh - the plus symbol), natural gas consumption (the square symbol), coincident peak electric demand (kW - the triangular symbol), and the non-coincident peak demand (kW - the diamond symbol).

Although sophisticated energy modeling procedures exist for evaluating energy savings from individual building energy conservation retrofits very few of these techniques are currently being used--usually because they are not understood by both parties to the contract. This paper gives strong evidence that simple, easy-to-understand, standardized procedures can be developed to track energy savings--even across 35 buildings. Unfortunately, due to litigious pressures when contracts fall into dispute, there is already a growing need for such standardized procedures.

Acknowledgments

The Energy Systems Laboratory at Texas A&M University would like to extend its thanks and appreciation to Prairie View A&M University and its staff for assistance in obtaining the utility and building data. Special thanks are due to the following people who provided assistance to the project: Mr. Kollye Kilpatrick, Mr. Gerald Kelley, and Ms. Linda Garette. Thanks also to Mr. Norman Ferguson of Johnson Controls; the City of Waller (natural gas billing data), the Texas Southeastern Gas Company, and the San Bernard Electric Cooperative. Dr. David Claridge and Dr. Dan Turner provided helpful review of the original summary report. Mr. Tarek Bou Sada also provided considerable assistance with the updated numbers.

This project was funded and supported by the State of Texas, Governor's Energy Office, as part of Texas A&M's Technical Assistance Contract with the Governor's Energy Office using oil overcharge funds. Further thanks are extended to the staff at the Governor's Energy Office for their support and comments, including Mr. Malcolm Verdict and Dr. Steve Jaeger.

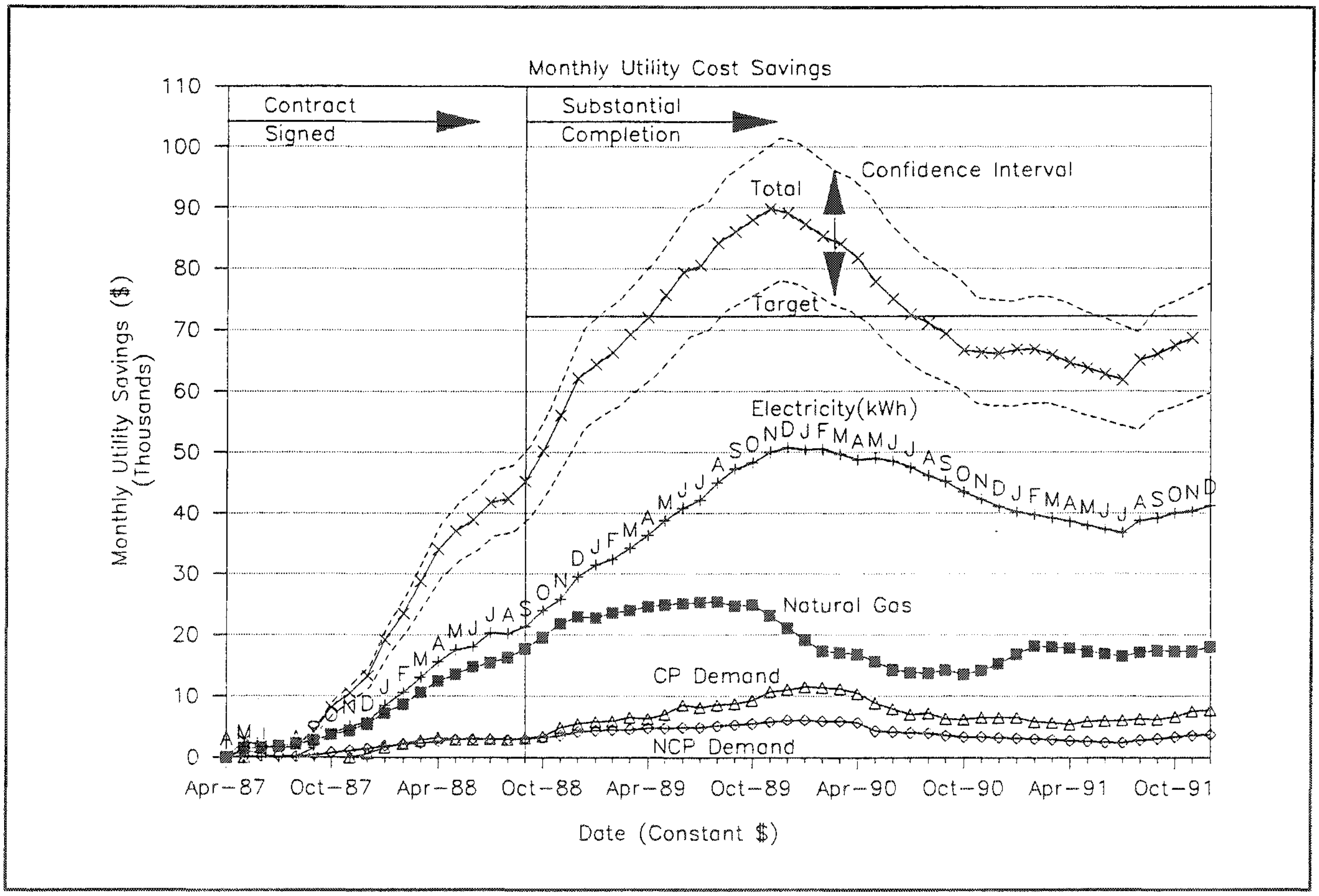

Figure 14. Monthly Whole-Campus Utility Cost Savings. This figure displays the estimated whole-campus energy savings from April 1987 to December 1991, displayed as a sliding monthly indicator (constant dollars). Values are shown for the total energy savings (X), electricity usage (kWh - the plus symbol), natural gas consumption (the square symbol), coincident peak electric demand (the triangular symbol), the non-coincident peak demand (the diamond symbol), and the target savings amount ($72,504). The confidence interval for the total estimated savings represents two standard errors (one SE is about 13%). All dates indicate the end-date of the slide.

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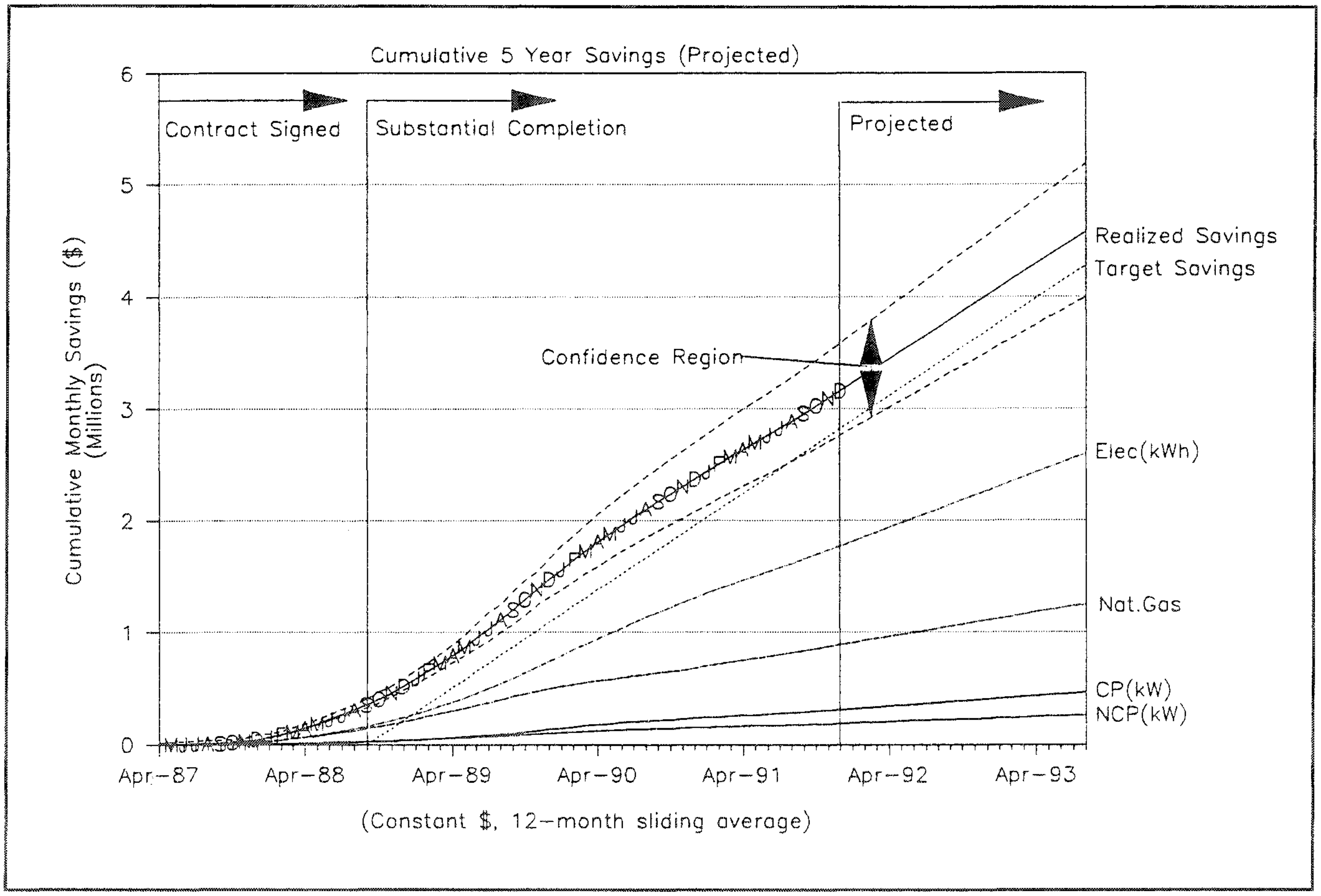

Figure 15. Estimated Cumulative 5-Year Whole-Campus Utility Cost Savings. This figure shows the cumulative 5-year, whole-campus estimated energy savings from April 1987 to August 1993 (constant dollars). The "realized" savings are based on an analysis of measured consumption through December 1991 and are projected thereafter. The "J, F, M..etc." data labels represent labels for the monthly consumption data. The confidence interval shown for the total savings represents two standard errors (one SE is about 13%).