ESL-TR-96/11-02

A Study of Diagnostic Pre-Screening Methods for Analyzing Energy Use of K-12 Public Schools

Summary Report

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Research sponsored by

The Office of Buildings and Community Systems
U. S. Department of Energy through Oak Ridge National Laboratory,
Oak Ridge, Tennessee 37831
Operated by Martin Marietta Energy Systems, Inc. for the
U. S. Department of Energy
under Contract No. DE-AC05-84OR41200

November 1996

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PREFACE

This report has been prepared for the Office of Buildings and Community Systems at the United States Department of Energy through the Existing Building Efficiency Research Program at Oak Ridge National Laboratory. The purpose of this report is to create and document the use of indices that can be used to characterize the energy operations at public schools monitored in the Texas LoanSTAR program. It utilizes monitoring procedures and data analysis routines and software developed for the Texas LoanSTAR program that are copyrighted for distribution in the public domain. Software mentioned in this report, and additional software used in the LoanSTAR program may be obtained by contacting the authors.

This report has been prepared by David Landman and Dr. Jeff Haberl and includes significant input from Dr. David Claridge and Dr. Agami Reddy.

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ABSTRACT

This report describes an investigation of energy use in primary and secondary public schools to identify potential energy cost reduction measures (ECRMs) and operation and maintenance opportunities (O&Ms) and then compare those ECRMs against annual, monthly, daily, and hourly indices to determine how well such indicators can guide the energy audit process. Eleven schools in Texas were identified for case studies. The results show that certain indices match what is recommended by on-site visits and actually provide additional information that is sometimes not identified by a site visit. As a result, these indices provide a useful means by which energy audit firms and building owners/administrators can identify those areas of a school that have the most potential for ECRMs and O&Ms prior to a site visit. These indices assist the energy auditor in performing more efficient energy analyses on schools. Each school in this report had been audited prior to this study and certain retrofits were completed between September 1991 and December 1993, the period in which the indices were developed. The sites were then reaudited to affirm the results from the previous audits and to discover new areas for energy savings. Indices created for this report are based on hourly, daily, monthly, and annual electricity and gas consumption. These indices utilize dry bulb temperature, whole building electricity, natural gas consumption, electric load factors, occupancy load factors, people load factors and monthly quartile plots.

EXECUTIVE SUMMARY

This report discusses indices created for analyzing primary and secondary public school energy use. The indices help an energy analyst identify areas for energy cost reduction measures (ECRMs) and operation and maintenance opportunities (O&Ms). It is a summary report which discusses how data were collected, how indices were created, and presents comparative results across sites. Additional school specific data for the eleven case study schools may be found in *Development of Prescreening Indices to Improve Energy Analysis of Educational Facilities* (Landman 1996).

The purpose of this study is to provide energy analysts with a standard methodology to analyze consumption data by creating indices based on climate conditions, electricity and natural gas consumption for various equipment and systems at each school as well as operation and occupancy profiles. A site visit was made to each school to supplement data collected from previous audits performed on the schools within the past few years as part of the LoanSTAR program. The intent of this study is to compare potential ECRMs and O&Ms against indicators and to see if the use of the indices could have improved the energy audit.

Information was gathered in the following manner. First hourly, daily, monthly, and annual electricity, natural gas and weather data were obtained from the LoanSTAR data base along with existing energy audit reports of the case study schools. Next, previously defined indices were tested and modified for use with schools, including work performed at the Princeton Shopping Center (Haberl and Komor 1989). Then new indices were developed to describe special characteristics for schools. Finally, this was followed by additional site visits to each school to confirm the findings and look for additional ECRMs.

The results of this study show that annual, monthly, daily, and hourly indices provided useful information about the schools' energy use characteristics. Annual indices provided comparative indications of gross energy use but do not indicate which energy consuming system is inefficient or if the building's operation schedule is to blame. Monthly indices were capable of providing comparative information about weather dependent energy use and non-weather dependent energy use

when semester and non-semester periods were considered including comparisons between both weather dependent and non-weather dependent energy consumption. However, monthly indices could only provide limited information about whether or not a building's operating schedule was to blame for high energy use. Daily indices were capable of showing weather dependent weekday/weekend use which provides helpful information about whether or not systems are being shut off on the weekends or during the summer. Hourly indices, as expected, provided detailed information about building operation, on/off schedules, and equipment operation. This information, supplemented by an on-site visit, verified the usefulness of these indices.

One of the surprising findings of this report is how well a three parameter cooling model fits the monthly data once it has been separated into semester and non-semester periods. This could mean that school districts, or state agencies, could screen large numbers of schools and determine which ones have inefficient cooling systems, base-level use and/or are being operated inefficiently in the summer when the schools are sparsely occupied. Comparisons of the parameters from the monthly three parameter model analysis to the daily weekday-weekend analysis (i.e. base-level, change-point, and weather dependent slope) shows significant differences in these parameters. This is in difference to previous reports that have attempted to assign physical significance to monthly parameters. The reason for this difference may be due to the fact that schools, such as the ones that were analyzed, tend to have significant differences in weekday versus weekend operation. One of the indices , the weekday daily base-level use, does appear to be well predicted by the monthly analysis during the school year periods.

Such a desktop tool can be a valuable tool in determining where to most effectively apply scarce energy conservation funds. The uncertainty of the monthly model (as measured by the CV(RMSE)) and R^2 also appears to be robust enough to be helpful to school administrators who need to statistically determine whether or not savings have occurred from energy conservation retrofits.

1.0 INTRODUCTION

The goal of this study is to use existing and newly developed indices to more efficiently identify energy cost reduction measures (ECRMs) at primary and secondary public schools. This is a summary report describing how data were collected, indices were created, results from site visits, and comparative conclusions.

2.0 METHODOLOGY

The first step in gathering information was to obtain monthly, daily, and hourly electricity and natural gas data from each school. Two years of data were obtained for the period September 1, 1991 through December 31, 1993 to ensure that annual aberrations in temperature and operation could be factored out. This information was obtained primarily from the LoanSTAR Monitoring and Analysis Program (MAP) (Claridge et al. 1994). The LoanSTAR MAP provided hourly, and in some cases 15 minute consumption data at each of the sites used as case studies in this report. Supplemental information was also obtained from monthly utility bills provided by the school districts and from site visits.

Step 2 was to obtain copies of any previous audits performed on the schools as part of the original LoanSTAR audit. After gathering as much data as possible the facilities manager at each location was contacted and a tour/audit of each school was performed. At each site the energy manager was questioned about HVAC equipment operation. The principal at each school was also contacted to confirm the school's occupancy (which may vary greatly on a daily basis) and information about equipment run times.

After gathering all consumption, equipment lists, operation schedules, and occupancy profiles, indices were developed to identify potential ECRMs and O&Ms. The first step was to utilize existing indices created in the Princeton shopping center report (Haberl and Komor 1989). The first index utilized was a monthly dry bulb temperature graph with minimum, min-max average, and maximum temperature for each month to determine peak and average weather influences. The second index utilized was monthly electric power levels. The third index consisted of monthly

Electric Load Factors (ELFs) and Occupancy Load Factor (OLFs). An additional index was created to provide additional meaning to the Occupancy Load Factor, which is called the People Load Factor (PLFs).

New indices investigated include PLFs, simple comparisons of annual electric and gas consumption versus gross square footage of each school, peak and average electric power levels versus peak and average min-max monthly temperatures. Empirical 1, 2, 3, and 4-parameter energy use models calculated using the EModel software (Kissock 1992) for monthly data based on data for all months, data for school year months only, and summer months. Daily power levels versus average daily temperatures were also investigated including those based on data for all days of the year, data for school year days only, and summer days. Daily 1, 2, 3, and 4-parameter models were also calculated.

The final step includes the comparison of ECRMs and O&Ms recommended by the indices with those determined by energy audits.

3.0 INDICES INVESTIGATED

Energy indices can give meaningful insight into how a building is being operated. The following section discusses different types of indices available. The first section discusses annual electricity and gas indices, which use the variation in energy consumption from 1992 to 1993 for each school. The next section is monthly electricity and gas indices, 1, 2, 3, and 4-parameter models, and box-whisker mean plots. The last section are the daily 3-parameter weekday and weekend models.

3.1 Annual Indices

Figure 3.1 shows the total annual electricity and natural gas consumption. Table 3.1 provides similar information in a tabular format. The top graph is annual electricity consumption, which measures the gross consumption at each school in kWh/yr. versus the gross conditioned area (square footage) at each school, which includes all heated or cooled space. The schools range in size from approximately 60,000 square feet to 260,000 square feet. Electricity consumption at the schools ranges from about 500,000 kWh/yr. to about 2,500,000 kWh/yr. The diamonds in Figure 3.1 represent available data for the 1992 calendar year. The filled squares represent available data for the 1993 calendar year. Several retrofits were completed at the schools from 1991 through 1993. These retrofits account for some of the changes from year to year. These retrofits are listed in Table 6.1 in Section 6.

The bottom graph, in Figure 3.1, shows annual natural gas consumption at each school in MMBtu/yr. (millions of Btu per year) versus the gross square footage of each school. Although natural gas is purchased in hundreds of cubic feet (ccf) per month, a conversion of 1030 Btu per ccf has been used uniformly for all schools based on discussions with natural gas companies in the region. The schools consumed between 100 MMBtu/yr. and 5,800 MMBtu/yr. The total site EUI for the schools varied from a low of 33,343 Btu/sf-yr for Parker Elementary School to a high of 78,820 Btu/sf-yr for Dunbar Middle School.

Figure 3.1: *Annual Consumption: Electricity and Gas Consumption for the eleven schools for 1992 and 1993.*

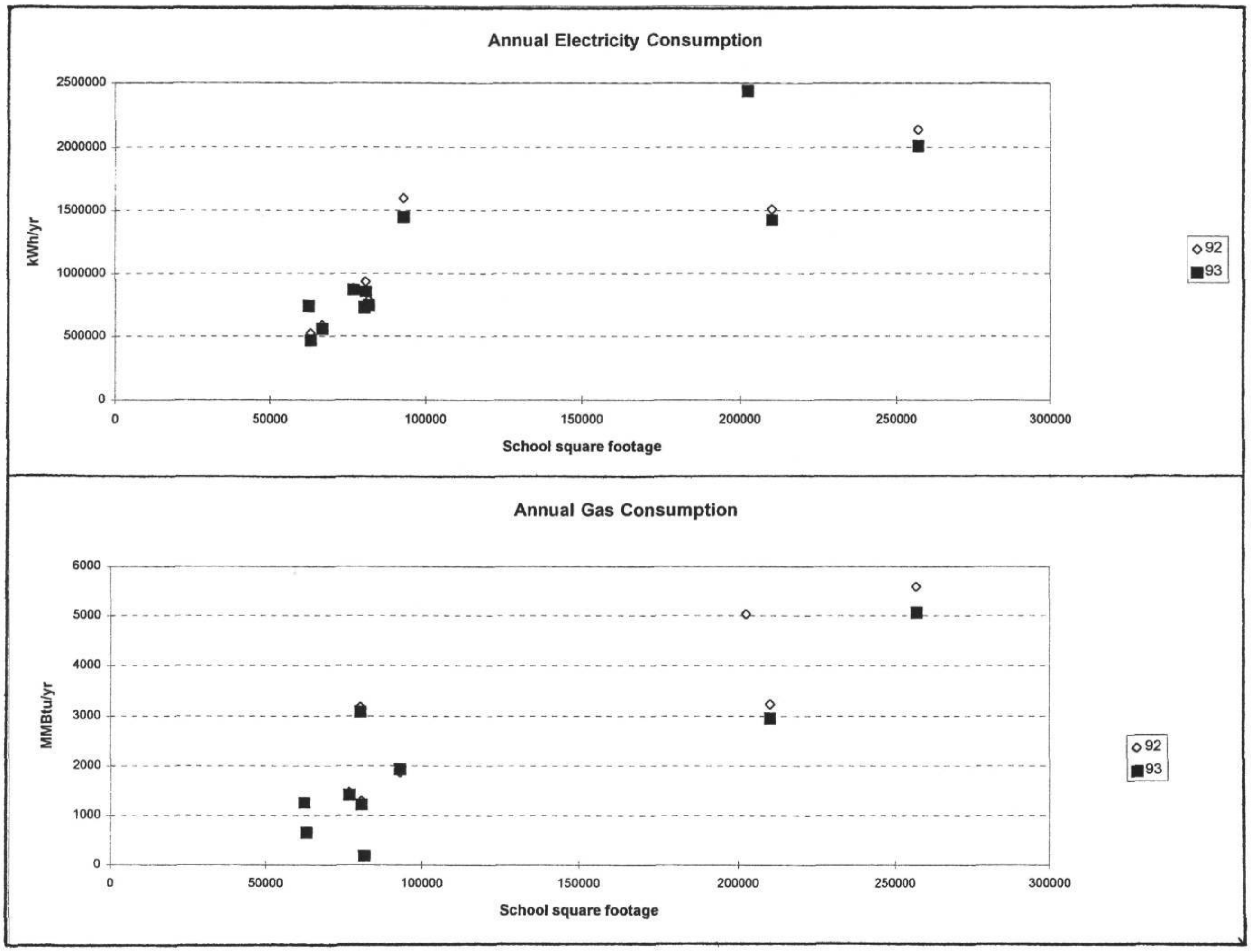


Table 3.1: *Annual electric and gas data*

School	Square Footage (sf)	Electricity kWh/yr. (92/93)	Natural Gas MMBtu/yr. (92/93)	Electricity W/sf (92/93)	Electricity Peak W/sf (92/93)	Natural Gas Btu/(hr-sf) (92/93)	Total Energy Consumption Btu/(yr.-sf) (92/93)
SHS	210,474	1,511,072 1,425,888	3,233 2,958	0.82 0.77	3.37 3.29	1.75 1.60	39,854 37,167
VHS	257,014	2,136,419 2,011,920	5,586 5,070	0.95 0.89	4.20 4.37	2.48 2.25	50,096 46,437
SES	62,400	743,568 742,677	1,261 1,261	1.36 1.36	4.25 5.38	2.31 2.38	60,862 60,814
DMS	92,884	1,598,637 1,449,609	1,867 1,934	1.96 1.78	5.84 6.90	2.29 2.38	78,820 74,073
NHS	202,515[1]	---- 2,439,513	5,031 ----	---- 1.39	4.78[2] 4.83	2.86 ----	---- ----
CMS	66,778	590,548 561,761	---- ----	1.01 .96	5.42 5.11	---- ----	---- ----
OES	80,400	866,504 730,417	3,176 3,086	1.23 1.04	5.46 6.34	4.51 4.38	76,272 69,376
WMS	80,769	934,406 855,630	1,295 1,221	1.32 1.21	5.84 8.44	1.83 1.73	55,503 51,260
PES	81,742	780,860 745,158	201 183	1.09 1.04	6.44 6.46	0.28 0.26	35,055 33,343
MES	76,798	883,268 871,888	1,471 1,418	1.31 1.3	7.68 8.22	2.19 2.11	58,399 57,195
RES	63,044	525,488 469,776	661 655	0.95 0.85	4.77 4.38	1.20 1.19	38,923 35,818

---- Data were unavailable or incomplete

[1] There is a separate building at Nacogdoches High School of about 20,000 sf in gross area which was not included in calculations due to lack of building electricity and natural gas metering.

[2] Data for Nacogdoches in 1992 only included 7 months of data.

Note: Peak values from utility bills were included even if 12 months of data shown were not available.

[3] Total energy consumption was calculated using a site conversion of 1 kWh = 3,412 Btu.

Note: Peak values from utility bills were included even if 12 months of data shown were not available.

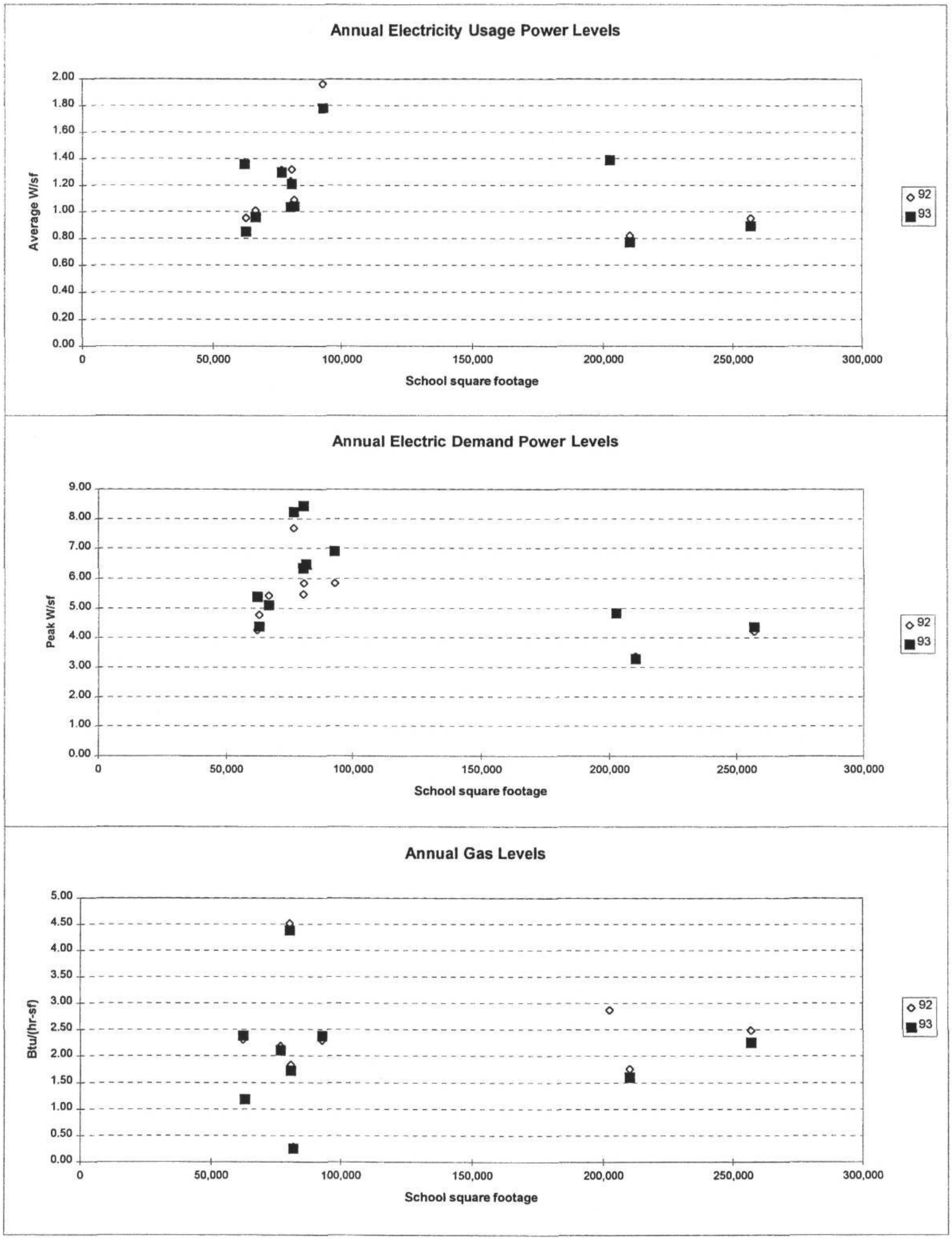
Figure 3.2 contains the annual power levels. The top graph shows average W/sf versus the school gross square footage. W/sf are computed by dividing the total kWh/h consumed per year by the number of hours in the year to get the average Watts. This is divided by the gross square footage of the building. The average W/sf ranged from about 0.5 W/sf to 2.0 W/sf.

The middle graph measures the peak W/sf versus the school gross square footage. W/sf are computed by taking the peak kWh for the entire year and dividing by the gross square footage of the building. Basically, this is similar to taking the peak reading for each month as utilities do for their bills. However, the highest monthly peak is selected for the annual peak.

In the case of Galveston (OES, WMS, PES, MES, RES), VA/sf were computed from the billed VA (not necessarily the peak VA) instead of using W/sf. These were then converted to W/sf using power factors ranging from 0.7817 to 0.9072, which were evaluated separately for each school. The peak W/sf ranged from about 3.5 W/sf to 9.5 W/sf.

The bottom graph measures the average gas consumption in Btu/(hr-sf) versus the gross square footage of each school. Btu/(hr-sf) is computed from the sum of cubic feet of natural gas consumed per hour multiplied by the conversion factor divided by the number of hours in the period. The annual natural gas consumption varies from about 0.25 Btu/(hr-sf) to about 4.5 Btu/(hr-sf). Chamberlain Middle School is not represented here due to fact that the natural gas meter for this school is for several buildings including Chamberlain Middle School. Chamberlain could not be separated from the other buildings for natural gas consumption data.

Figure 3.2: *Annual Power Levels: Average W/sf, Peak W/sf, and gas levels in BTU/(hr-sf) for 1992 and 1993.*



3.2 Monthly Indices

Figure 3.3a and 3.3b are monthly peak W/sf for consecutive months from September 1991 through December 1993. These are plotted versus the peak monthly dry bulb temperature recorded at National Weather Service Station in the following locations: Fort Worth, Victoria, and Lufkin. The exception is Galveston, where the NWS does not record weather data for about 5 hours during the night. Galveston temperature data from the LoanSTAR weather site was used instead. This temperature is recorded at the Texas A&M Galveston campus located less than 10 miles from the NWS weather station. The peak temperatures are generally between 70 F and 100 F with the exception of Fort Worth which has temperatures outside both bounds. Galveston tends to have a smaller grouping of temperatures due to the fact that it is a island and it has a more temperate climate than the other three locations. The peak W/sf is from about 2.5 to 7.0 W/sf in FWISD (Fort Worth Independent School District), 1.0 to 8.5 W/sf in GISD (Galveston Independent School District), 2.0 to 4.0 W/sf in VISD (Victoria Independent School District), and 0.8 to 5.0 W/sf for NISD (Nacogdoches Independent School District). Schools are labeled as follows:

School Initials:	School Name:	School District:	Weather Station:
SHS	Stroman High School	VISD	VCT
VHS	Victoria High School	VISD	VCT
SES	Sims Elementary School	FWISD	DFW
DMS	Dunbar Middle School	FWISD	DFW
NHS	Nacogdoches High School	NISD	LFK
CMS	Chamberlain Middle School	NISD	LFK
OES	Oppe Elementary School	GISD	GLS
WMS	Weis Middle School	GISD	GLS
PES	Parker Elementary School	GISD	GLS
MES	Morgan Elementary School	GISD	GLS
RES	Rosenberg Elementary School	GISD	GLS

Figure 3.3a: ***Monthly Peak Consumption*****:** *Demand in W/sf versus peak monthly temperatures for September 1991 through December 1993.*

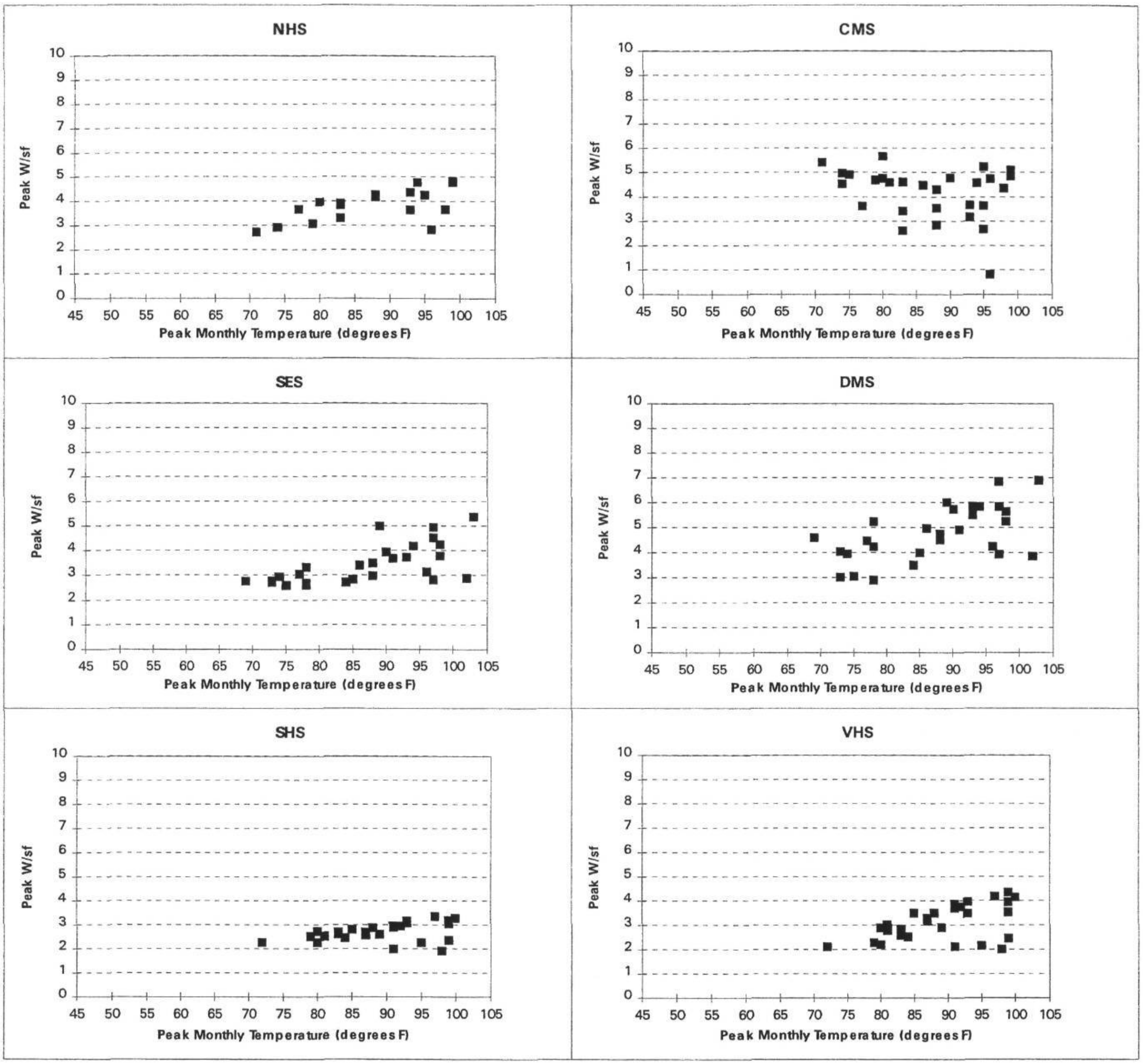
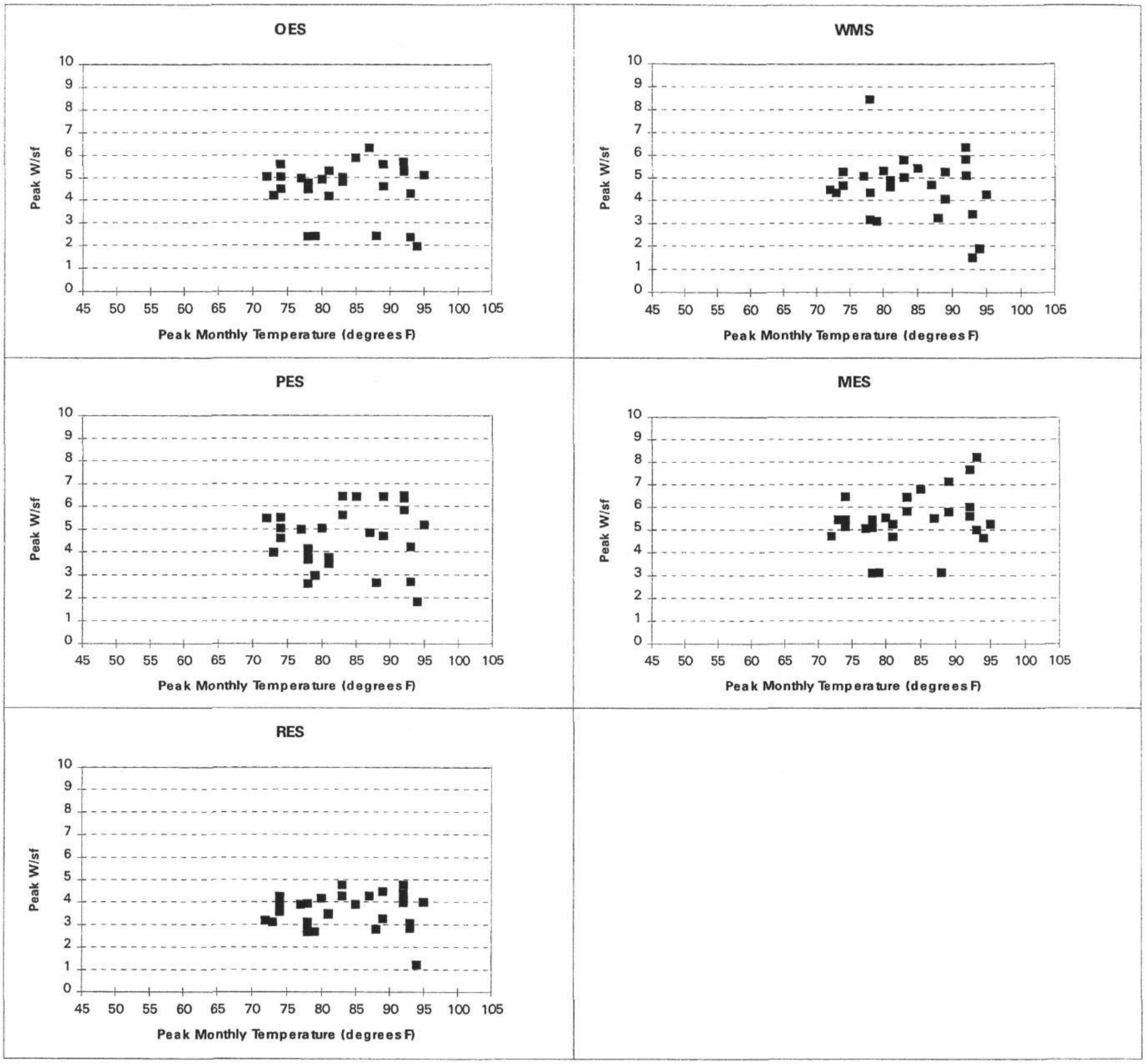


Figure 3.3b: *Monthly Peak Consumption: Demand in W/sf versus peak monthly temperatures for September 1991 through December 1993.*



Figures 3.4a and 3.4b show graphs of monthly average electricity consumption in W/sf for consecutive months from September 1991 through December 1993. These are plotted versus the average min-max monthly dry bulb temperature. Monthly min-max temperature represents the average value calculated from daily temperatures recorded by the National Weather Service (NWS) for each day and averaged for each month. For example, assume there are three days in a month. The peak temperatures for each day are 90 F, 94 F, and 100 F. The minimums are 70 F, 70F and 76 F. The average min-max for each day would be 80 F, 82 F, and 88 F. The average for that month would be 83.33 F. Again, these values were recorded at NWS stations in each location except for Galveston which used LoanSTAR temperatures recorded at the Texas A&M Galveston campus on Galveston island. Shown in Figures 4a and 4b, the average min-max temperatures were generally between 45 F and 90 F with the exceptions of Victoria and Galveston where average min-max temperatures over 52 F and Victoria does as well. The average W/sf is from about 1.0 to 3.0 W/sf in Fort Worth, 0.3 to 2.5 W/sf in Galveston, 0.5 to 1.5 W/sf in Victoria, and 0.25 to 2.25 W/sf for Nacogdoches.

Figure 3.4a: ***Monthly Ave Consumption****: W/sf versus min-max average monthly temperatures for September 1991 through December 1993.*

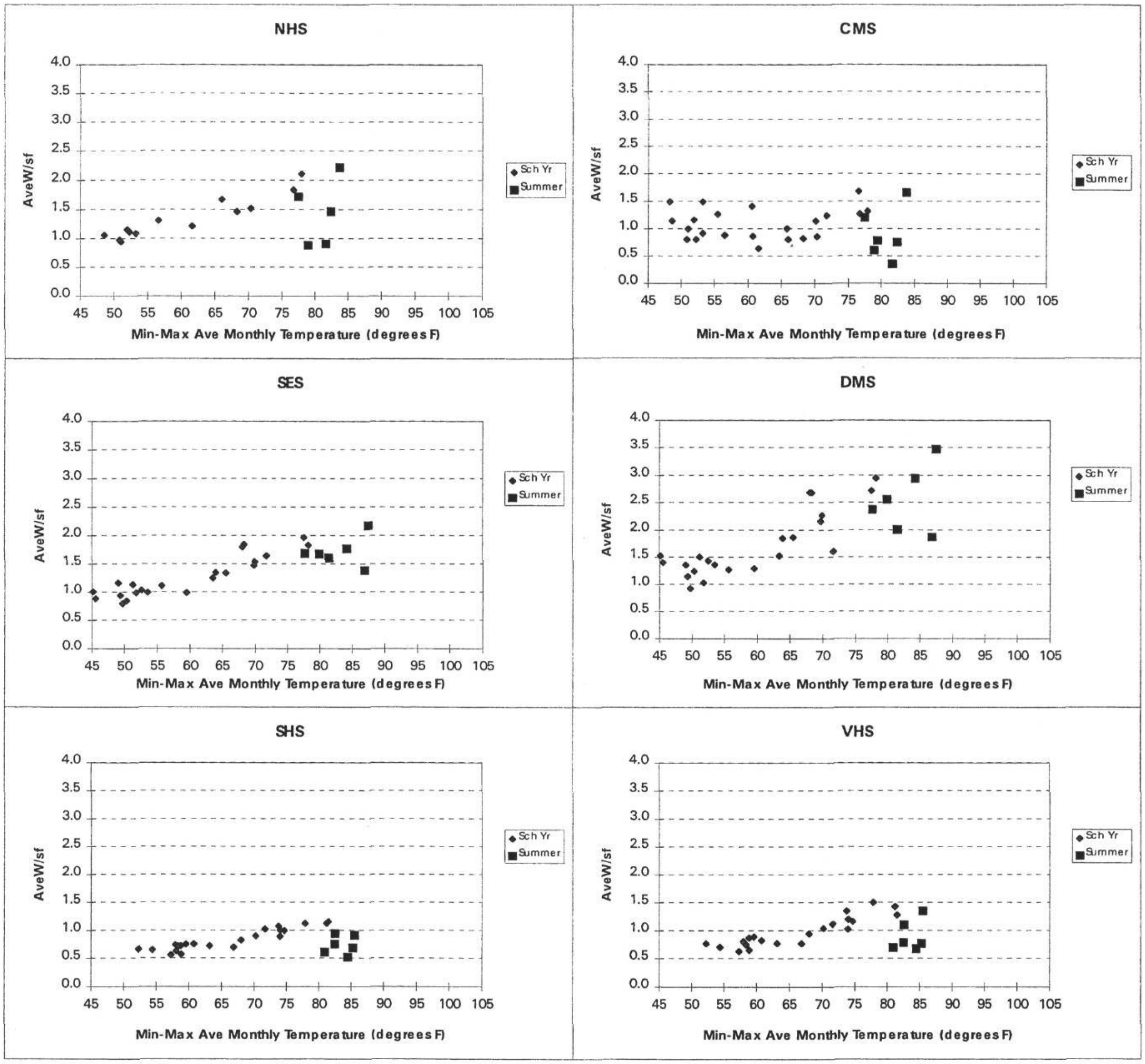
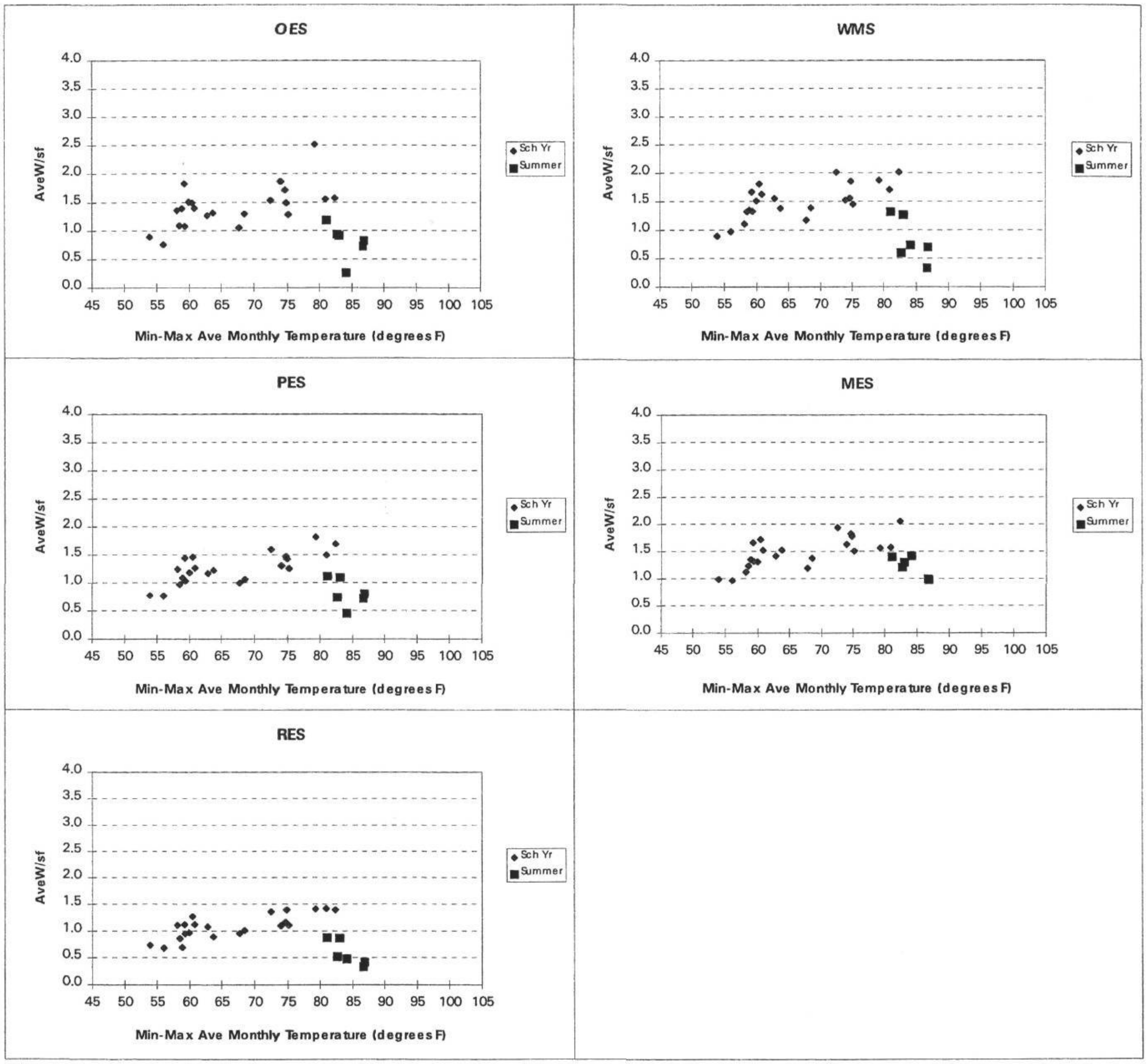


Figure 3.4b: *Monthly Ave Consumption: W/sf min-max average monthly temperatures for 1991 through December 1993*



Figures 3.5a and 3.5b show graphs of monthly average natural gas consumption in Btu/(hr-sf) for consecutive months from September 1991 through December 1993 with the corresponding 3-parameter change-point regression model. These are plotted versus the average min-max monthly dry bulb temperature. Again, these values were recorded at NWS Stations in each location except for Galveston which used LoanSTAR temperatures. The average min-max temperatures were generally between 45 F and 90 F during the time period analyzed at all four locations with a few exceptions. Victoria and Galveston which have no average min-max temperatures lower than 52 F. The average Btu/(hr-sf) is from 0.0 to 12.0 with the majority of the schools consuming under 9.0 Btu/(hr-sf) during the heating season and under 2.0 Btu/(hr-sf) during the summer time. Parker Elementary School consumes less than 2.0 Btu/(hr-sf) year round while Oppe Elementary School consumes greater than 10.0 Btu/(hr-sf) a few months of the year. The average natural gas consumption is approximately 3.5 Btu/(hr-sf)

Figure 3.5a: *Natural Gas Consumption: Btu/(hr-sf) versus min-max average monthly temperatures for September 1991 through December 1993.*

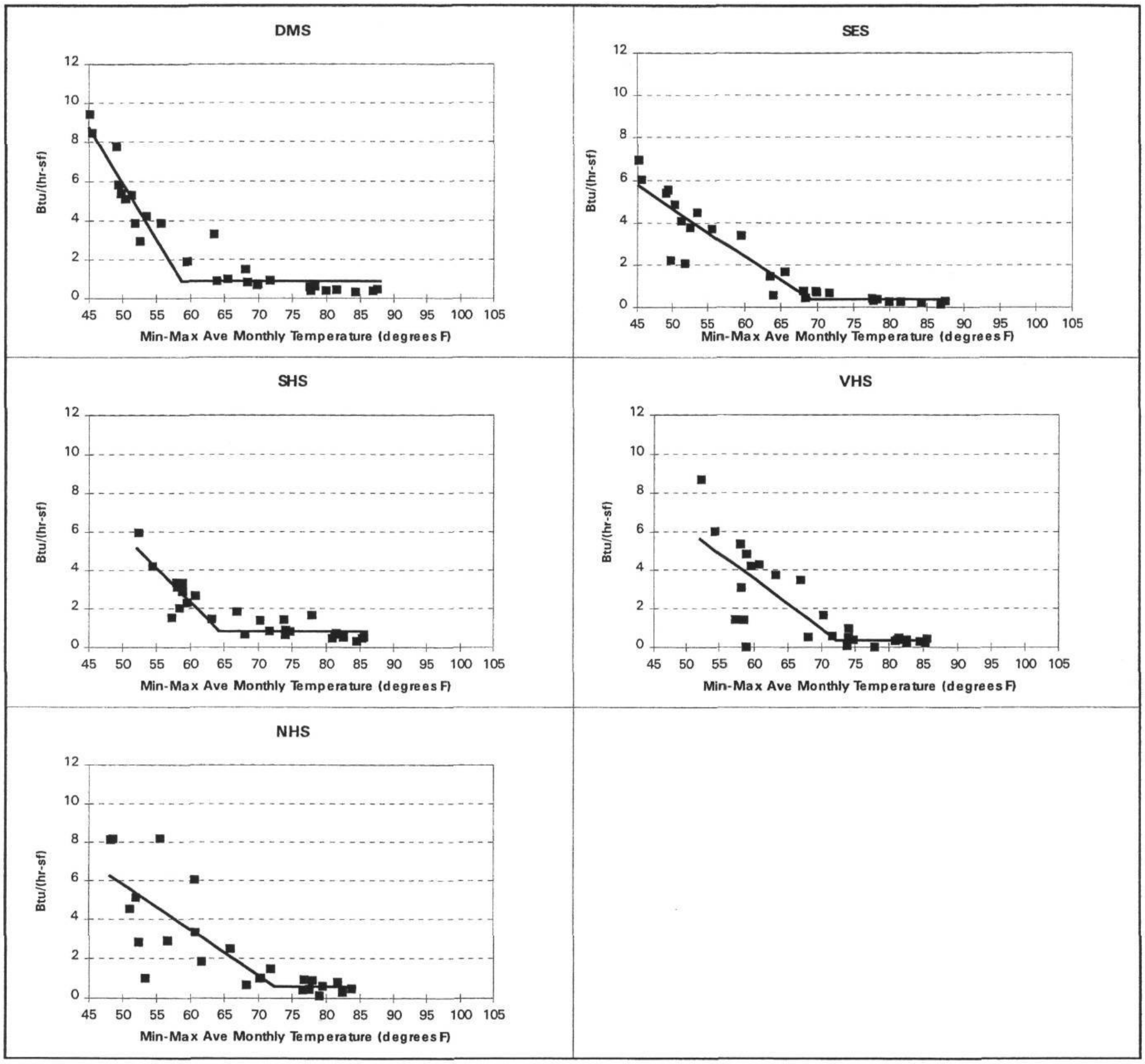


Figure 3.5b: *Natural Gas Consumption: Btu/(hr-sf) versus min-max average monthly temperatures for September 1991 through December 1993.*

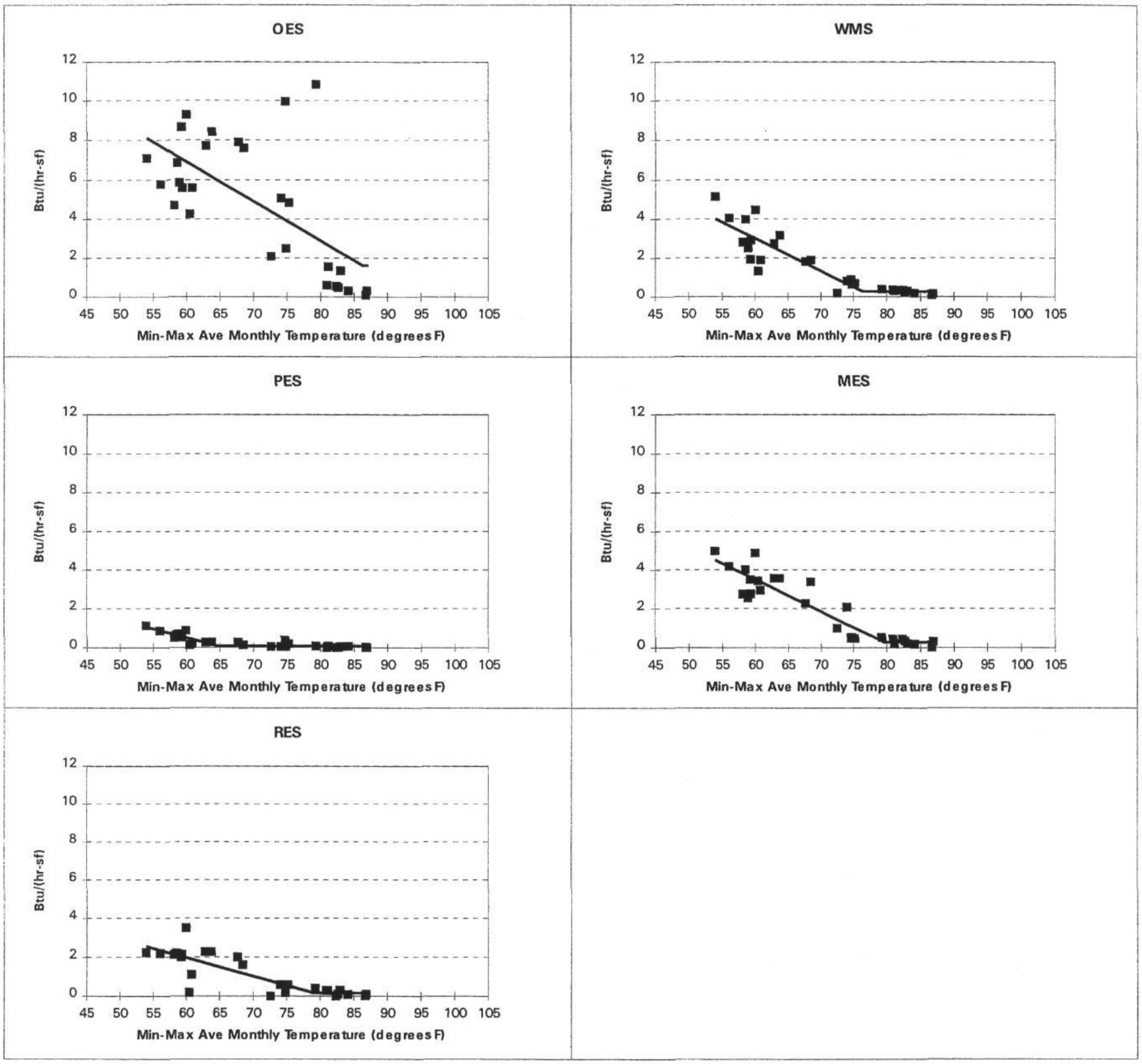


Figure 3.6 illustrates the 1, 2, 3, and 4-parameter empirical energy use models that were deemed appropriate for commercial building energy use (Kissock 1990). The upper left figure is a one-parameter model. The upper right figure is a two- parameter cooling model. The right and left figures in the middle are three-parameter cooling and heating models. The bottom right and left figures are four-parameter cooling and heating energy model. In general, the cooling-type 3-parameter models were used to model electricity use during the school year with a mean model for the summer use and 3-parameter heating-type models were used to model natural gas use. Additional information concerning model selection can be found in Landman (1996).

EModel Equations:

Mean Model:	$Eperiod = B_o$	Equation (a)
2-parameter Model:	$Eperiod = B_o + B_1(T)$	Equation (b)
3-parameter Heating Model:	$Eperiod = B_o + B_1 (B_2 - T)^+$	Equation (c)
3-parameter Cooling Model:	$Eperiod = B_o + B_1 (T - B_2)^+$	Equation (d)
4-parameter Heating Model:	$Eperiod = B_o + B_1 (B_3 - T)^+ - B_2(T - B_3)^+$	Equation (e)
4-parameter Cooling Model:	$Eperiod = B_o - B_1 (B_3 - T)^+ + B_2(T - B_3)^+$	Equation (f)

Figure 3.6: ***Energy Models****: Empirical energy use models appropriate for commercial building energy use a) one-parameter model, b) two-parameter model shown for cooling energy use, c) three-parameter heating energy use model, d) three parameter cooling energy use model, e) four-parameter heating energy use model and f) four parameter cooling energy use model.*

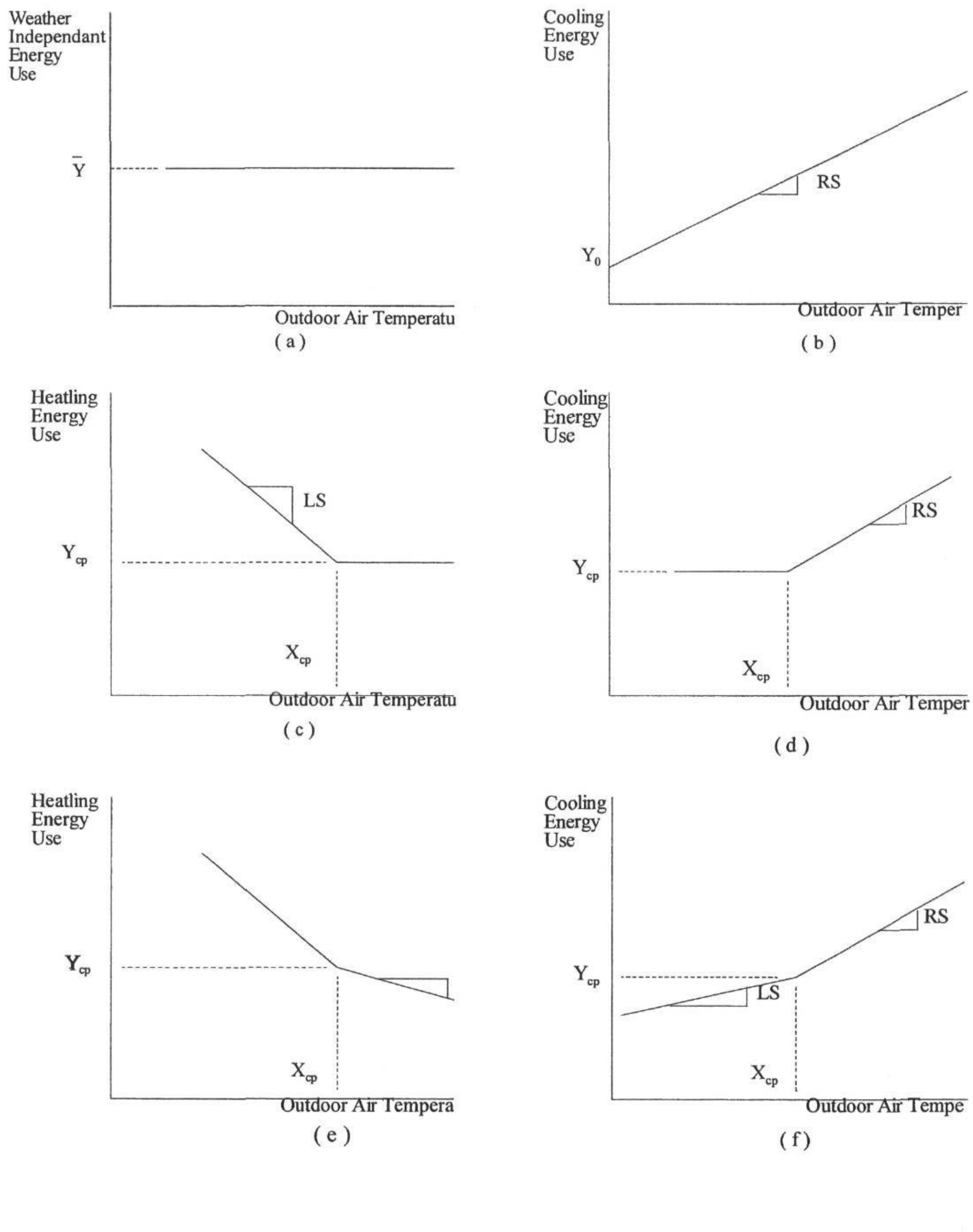
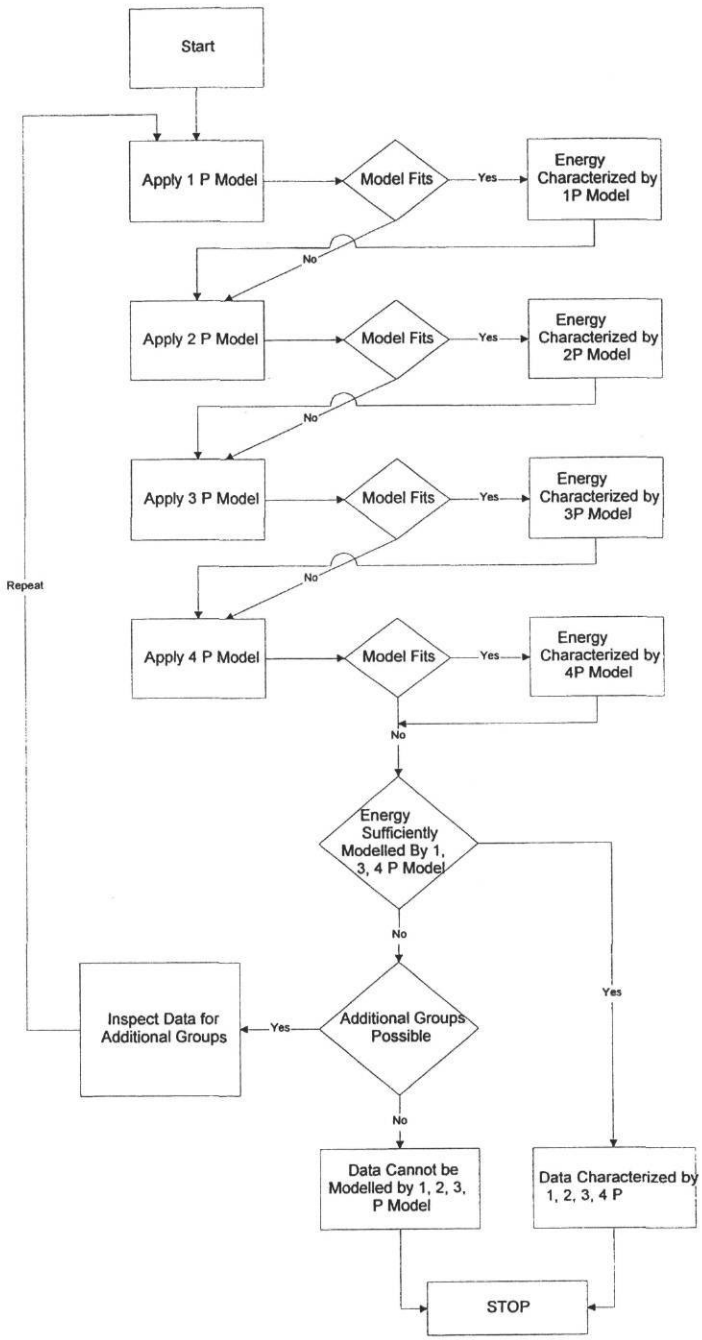


Figure 3.7 illustrates the procedure that was employed to select the appropriate 1, 2, 3, or 4-parameter model. This procedure has been adapted from the PRISM sieve developed by Reynolds and Fels (Reynolds and Fels 1988). It differs from the PRISM sieve in its use of 1, 2, 3, and 4-parameter models and by its ability to identify more than one model and allow for additional groupings to be performed.

Figure 3.7 : ***Flowchart for 1, 2, 3, 4-parameter Models***



For each of the buildings all of the models are applied first to all of the data being considered then to subsets of the data such as school year and non-school year months. A model is considered adequate if the $R^2 > 0.6$ and the CV(Std-Dev, RMSE) < 0.25 where:

EQUATIONS

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2} \qquad (1)$$

$$\text{CV(Std-Dev)} = 100\left(\frac{StdDev}{Ymean}\right) \qquad (2)$$

$$\text{CV(RMSE)} = 100\left(\frac{RSME}{Ymean}\right) \qquad (3)$$

$$\text{RMSE} = \left[\frac{\sum_{i=1}^{n}(y_i - \hat{y})^2}{n-p}\right]^{1/2} \qquad (4)$$

$$\text{Std-Dev} = \left[\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n-p}\right]^{1/2} \qquad (5)$$

y_i = individual power levels during the period

$\hat{y}$ = estimated value of y

$\bar{y}$ = average value of y

y_{mean} = the average value of all power levels

p = number of parameters in the model

n = number of variables

CV(RMSE) is the coefficient of variation of the Root Mean Square Error. It is a measure of the unbiased error of the model analyzed. This is computed from the square root of the MSE divided by

Ymean. RMSE is the Sum of the Square of the predicted errors divided by the degrees of freedom error (i.e. a measure of the deviation of the data from the model). Ymean is the average value of the power level.

CV(Std-Dev) is similar to CV(RMSE) but computed from the Std-Dev which is the standard error of the difference between mean values.

R^2 is the coefficient of determination. It measures the percent of variability in the data which is explained by the model (i.e. the measure of fit, vertical error). If $R^2 = 1.0$ all the variability in the consumption data is explained by the model. The degree to which R^2 is less than one tells us how much unexplained variability there is in the model. Variables such as weather and scheduling have large effects on the models fit. Numbers greater than 0.75 were considered adequate due to the large number of data analyzed. Numbers smaller than 0.75 may still be adequate for daily data, but were not considered in this report.

Reynolds and Fels (1990) performed a similar monthly analysis for homes using the PRInceton Scorekeeping Method (PRISM). They compared CV(NAC) to R^2. CV(NAC) equals the se(NAC)/NAC. NAC is the normalized annual consumption. CV(NAC) is not equal to CV(RMSE). Reynolds and Fels recommended a CV(NAC) less than 0.06 and R^2 greater than 0.9 and assigned a medium fit to data having the same CV(NAC) and R^2 greater than 0.7. According to Reynolds and Fels, models with CV(NAC) greater than 0.06 and R^2 less than 0.70 were deemed unreliable.

	R^2	CV(RMSE)	CV(NAC)
EModel Analysis	>0.60 acceptable	<0.25 acceptable	
PRISM Analysis	>0.70 medium fit >0.90 highly reliable		<0.06 reliable

R^2 values selected in this report are similar to those in Fels and Reynolds (1990). However, due to the difference in CV(NAC) and CV(RMSE) these two numbers cannot be directly compared. For this study, an R^2 of 60% and CV(RMSE) of less than 25% were considered acceptable.

Figures 3.8, 3.9, and 3.10 have been provided to illustrate the application of the 1, 2, 3, and 4-parameter models to monthly utility billing data from the Stroman High School (SHS) Table 3.2 provides tabular results of the same data shown in the figures. Clearly the 1, 2, and 3-parameter models provide increasingly better fits to the data. However, the four parameter model provides a physically more reasonable fit due to the inclusion of the partial-occupancy summer months. The models are applied to data for the school months in Figure 3.9, and to data for summer months in Figure 3.10.

Figure 3.8: *Monthly 1, 2, 3, and 4-parameter model fits for SHS using All Months: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are for September 1991 through December 1993.*

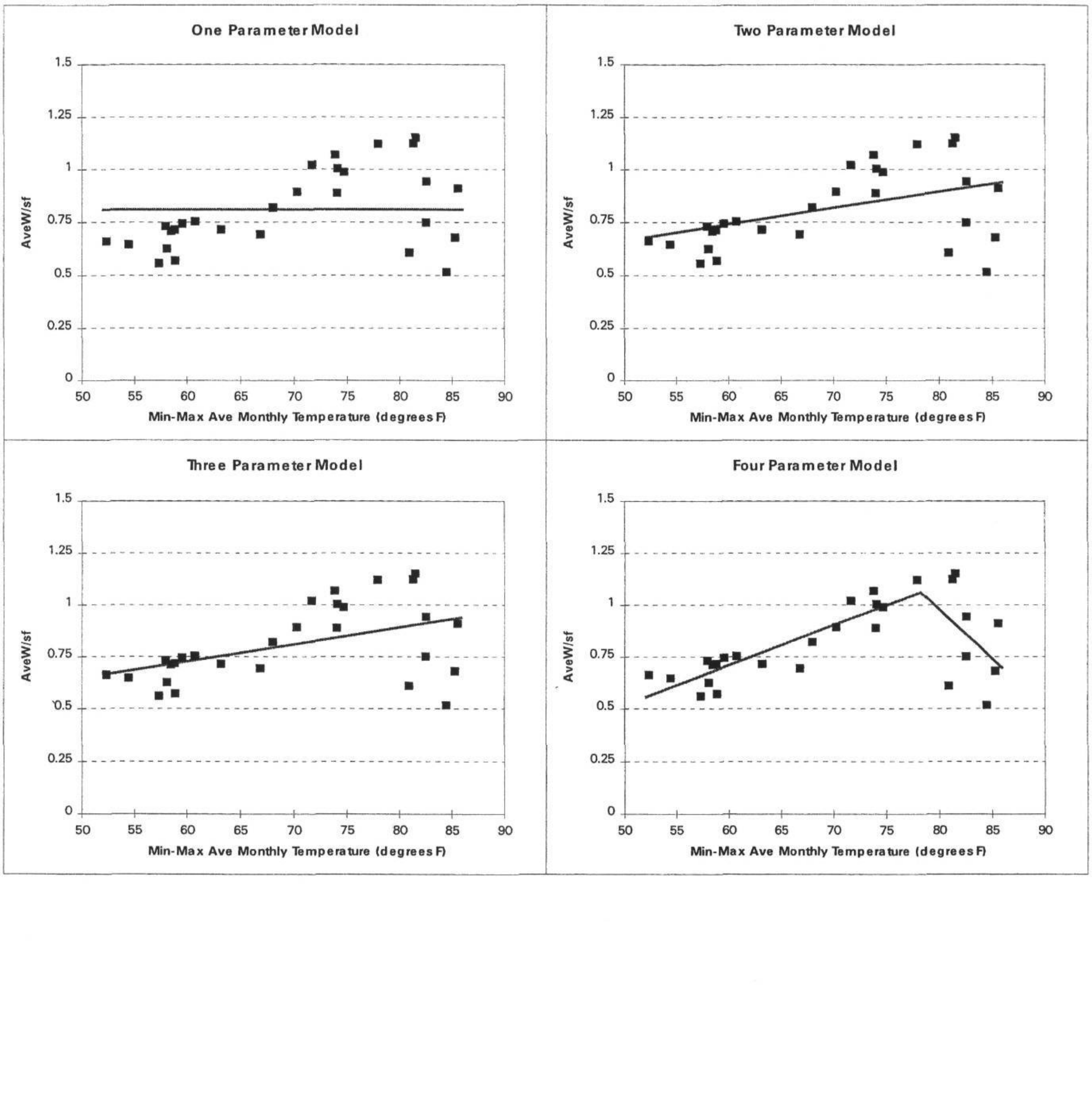


Figure 3.9: *Monthly 1, 2, 3, and 4-parameter model fits for SHS using School Months: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are school months for September 1991 through December 1993, not including June through August Months.*

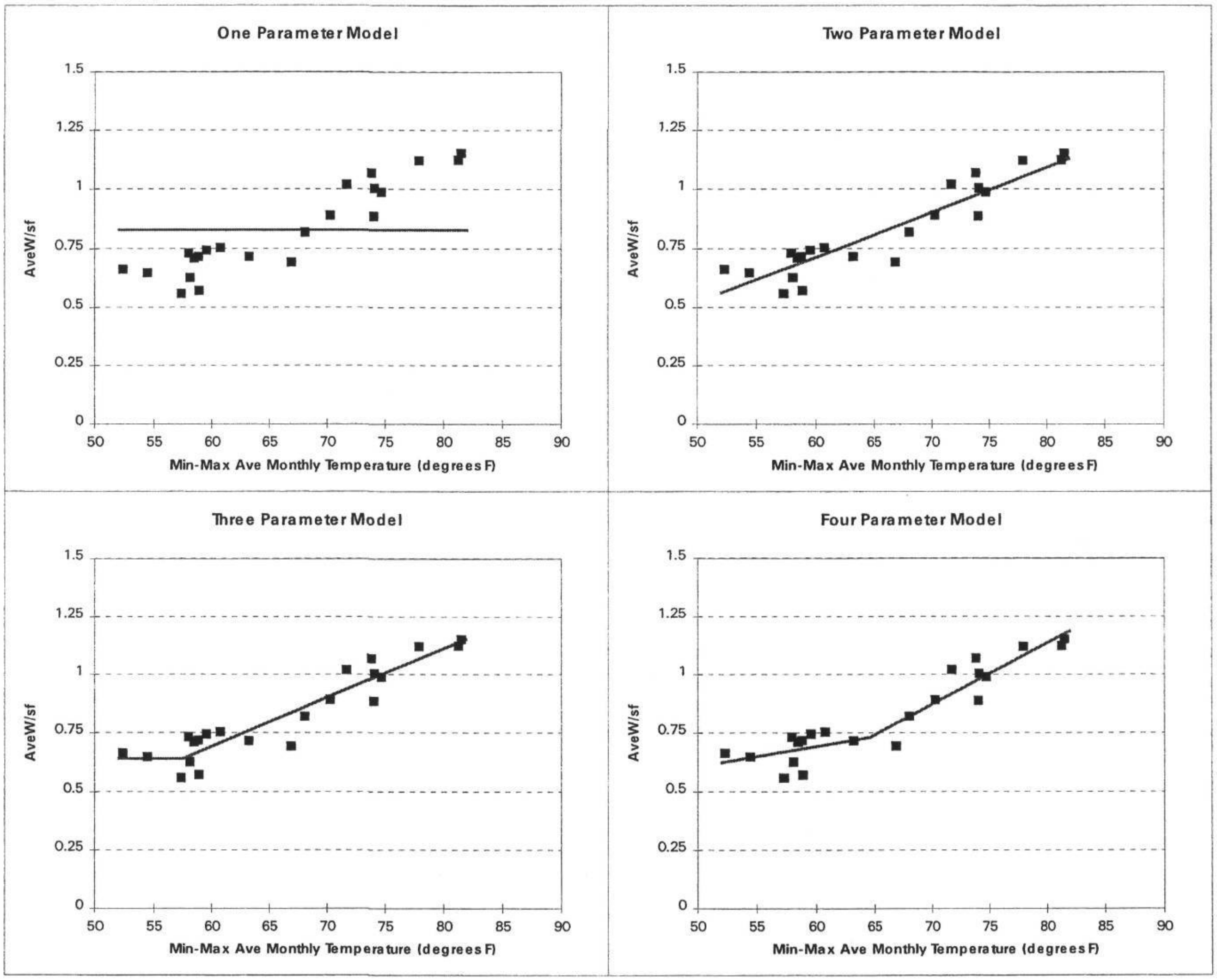


Figure 3.10: *Monthly 1, 2, 3, and 4-parameter model fits for SHS using Summer Months: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are summer months for September 1991 through December 1993 (June through August Months).*

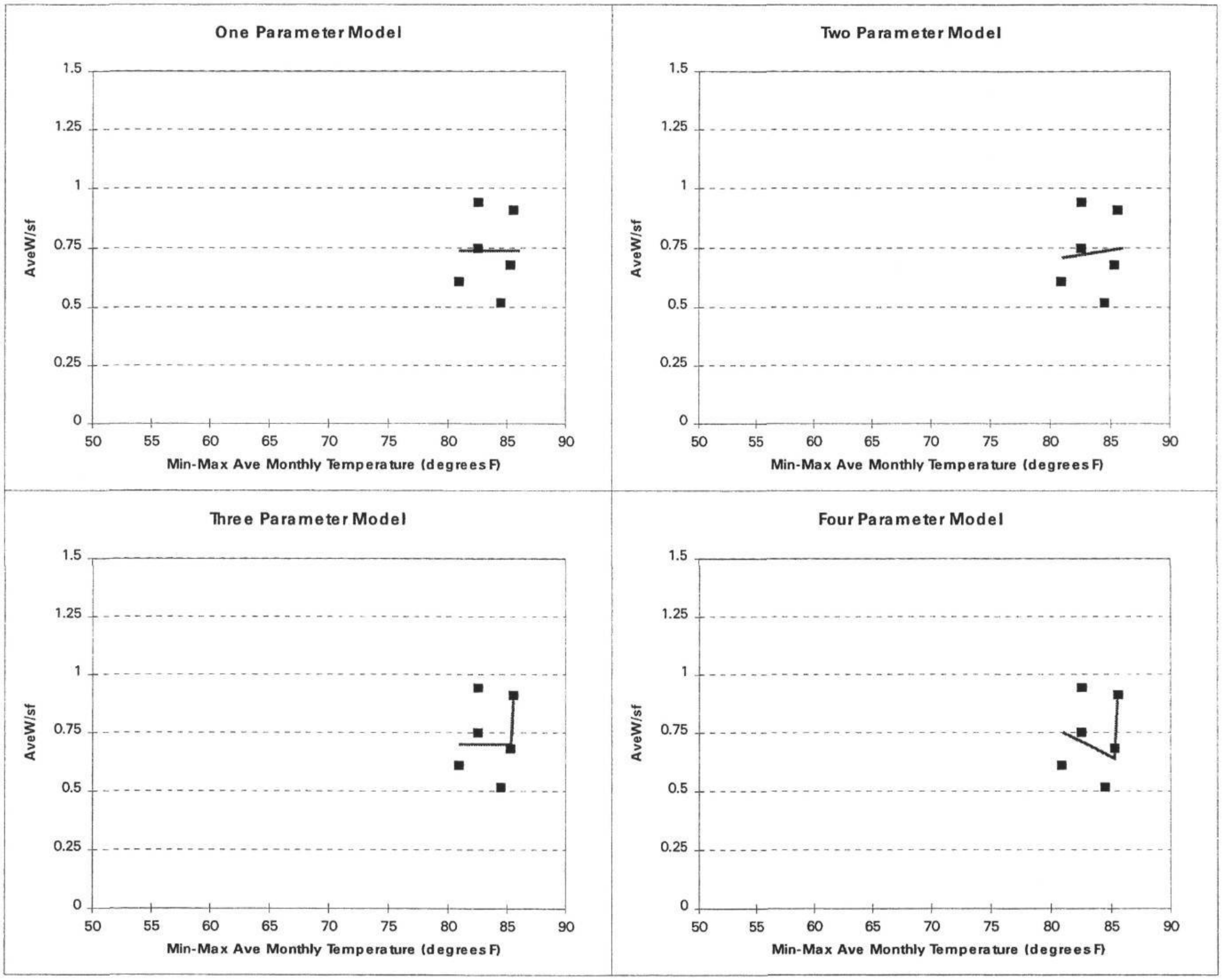


Table 3.2: *SHS 1, 2, 3, 4-parameter electric models.*

SHS	1P	2P	2P	3P	3P	4P	4P
	CV(Std-Dev)	R^2	CV(RMSE)	R^2	CV(RMSE)	R^2	CV(RMSE)
All Mos	0.23	0.23	0.206	0.23	0.206	0.54	0.162
School Yr. Mos	0.229	0.86	0.086	0.89	0.079	0.89	0.079
Non-Sch Yr. Mos	0.226	0.01	0.251	0.27	0.216	0.31	0.241

From the analysis it can be seen that none of the models provide a good fit to the data for all months. This is due to the outliers provided by the low energy consumption during the summer months. The fit improves for the 2-parameter, 3-parameter, and 4-parameter school year models once the summer months are separated. The 3-parameter and 4-parameter models show slightly improved R^2 and CV(RMSE) which are indicating their improved ability to fit the lower consumption months when temperatures are below 60-65 F. During the summer months significant scatter in the data produces low R^2 and CV(RMSE). The narrow 5 F average summer temperature range probably excludes the choice of anything other than a 1-parameter (or mean) model.

Figures 3.11, 3.12, and 3.13 illustrate the grouping of R^2 and CV(RMSE) across all eleven sites for all months (Figure 3.11), school months (Figure 3.12), and summer months (Figure 3.13). Table 3a, 3b, 3c present the same data in tabular format. Models that fit in the lower right quadrant (i.e. with boundaries of $R^2 >= 0.6$ and CV(RMSE) <= 0.25) are assumed to be suitably modeled. For the 1-parameter mean model, only CV(Std-Dev) <= 0.25 is shown. Clearly, only a few schools showed an adequate characterization with 1-parameter, 2-parameter, 3-parameter, or 4-parameter models using all months.

Figure 3.11: ***Monthly 1, 2, 3, and 4-parameter model fits for All Schools using All Months****: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are months for September 1991 through December 1993.*

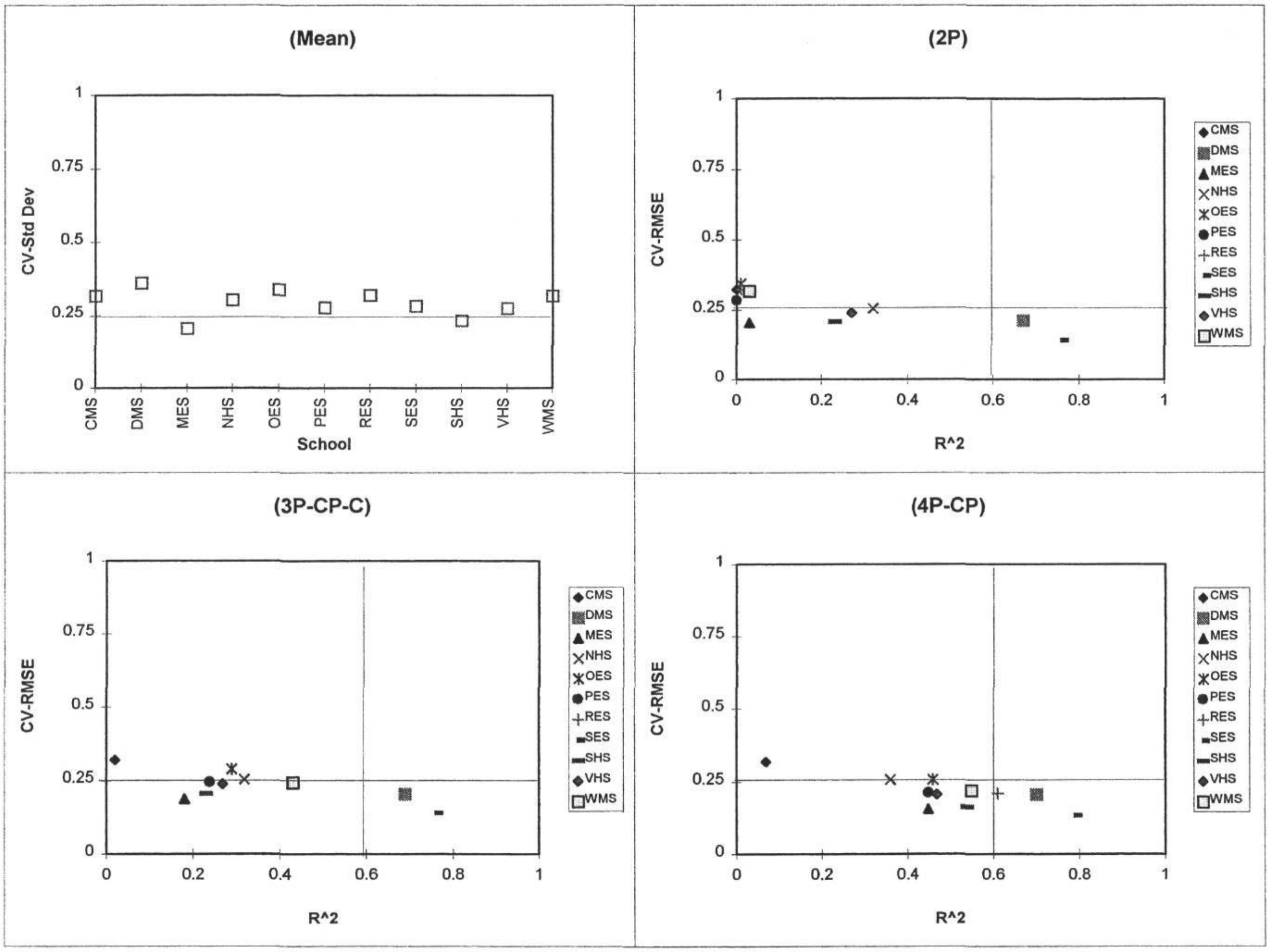


Table 3.3a: *1,2, 3, 4-parameter electric models for all eleven schools using data from all months.*

	1P		2 P		3P		4P	
		CV(Std-Dev)	R^2	CV(RMSE)	R^2	CV(RMSE)	R^2	CV(RMSE)
SHS		0.23	0.23	0.206	0.23	0.206	0.54	0.162
VHS		0.273	0.27	0.238	0.27	0.238	0.47	0.206
SES		0.282	0.76	0.141	0.76	0.14	0.79	0.133
DMS		0.36	0.67	0.211	0.69	0.205	0.7	0.206
NHS		0.301	0.32	0.255	0.32	0.255	0.36	0.257
CMS		0.315	0.0	0.321	0.02	0.319	0.07	0.316
OES		0.337	0.01	0.342	0.29	0.29	0.46	0.256
WMS		0.315	0.03	0.316	0.43	0.243	0.55	0.22
PES		0.277	0.0	0.282	0.24	0.246	0.45	0.213
MES		0.203	0.03	0.204	0.18	0.187	0.45	0.156
RES		0.319	0.01	0.323	0.43	0.246	0.61	0.209
Average		0.292	0.212	0.258	0.351	0.234	0.495	0.212

Figure 3.12: ***Monthly 1, 2, 3, and 4-parameter model fits for All Schools using School Months****: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are school months for September 1991 through December 1993, not including June through August Months.*

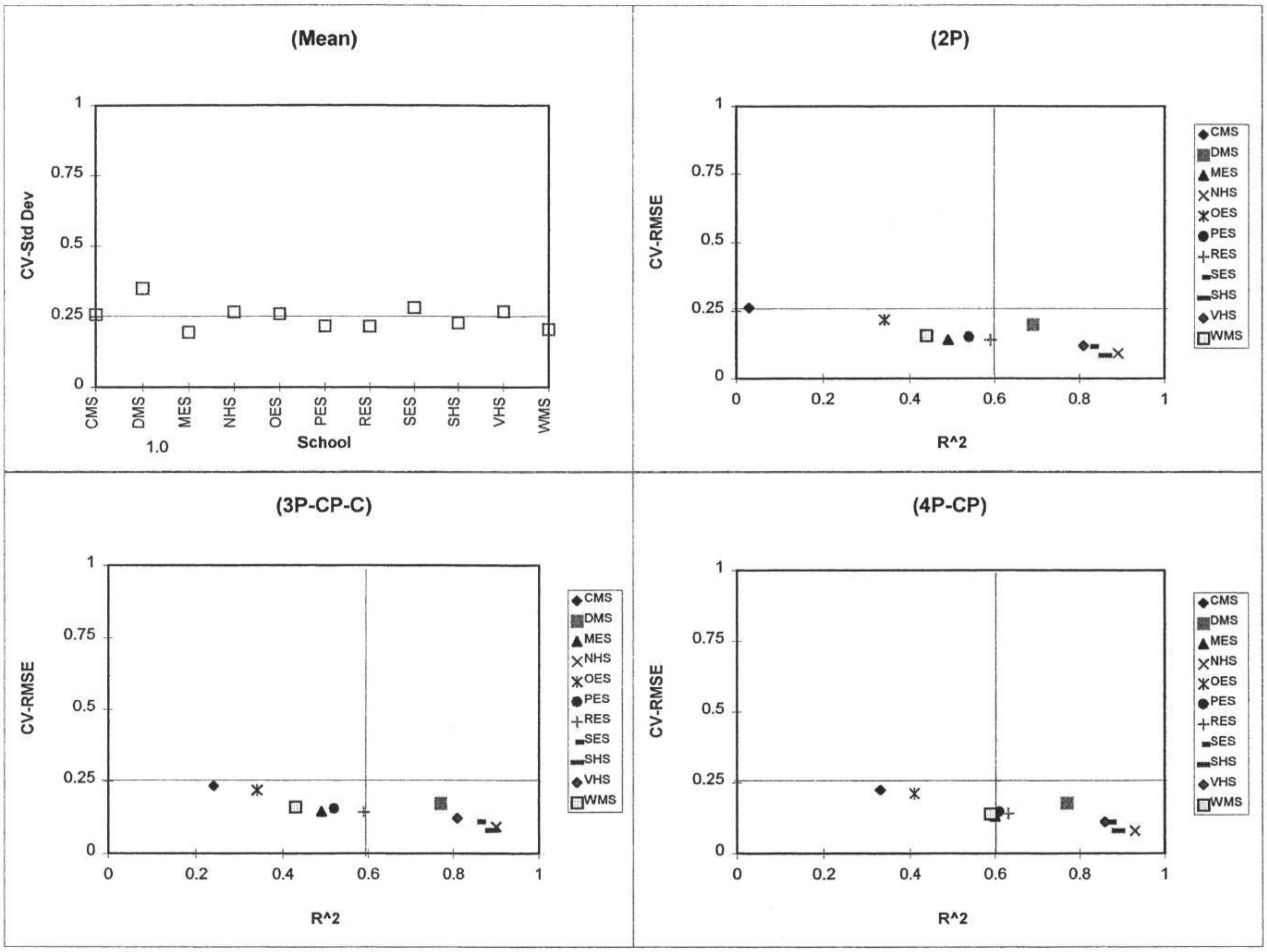


Table 3.3b: *1,2, 3, 4-parameter electric models for all eleven schools using data from school months only.*

	1P		2P		3P		4P	
		CV(Std-Dev)	R^2	CV(RMSE)	R^2	CV(RMSE)	R^2	CV(RMSE)
SHS		0.229	0.86	0.086	0.89	0.079	0.89	0.079
VHS		0.27	0.81	0.12	0.85	0.107	0.86	0.108
SES		0.284	0.83	0.119	0.86	0.108	0.87	0.109
DMS		0.35	0.69	0.198	0.77	0.172	0.77	0.176
NHS		0.268	0.89	0.093	0.9	0.091	0.93	0.078
CMS		0.258	0.03	0.26	0.24	0.231	0.33	0.222
OES		0.26	0.34	0.216	0.34	0.217	0.41	0.209
WMS		0.206	0.44	0.158	0.43	0.159	0.59	0.138
PES		0.219	0.54	0.153	0.52	0.155	0.61	0.144
MES		0.195	0.49	0.143	0.49	0.144	0.6	0.13
RES		0.216	0.59	0.142	0.59	0.142	0.63	0.139
Average		0.25	0.592	0.153	0.625	0.146	0.681	0.139

Figure 3.13: ***Monthly 1, 2, 3, and 4-parameter model fits for All Schools using Summer Months****: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are summer months for September 1991 through December 1993 (June through August Months).*

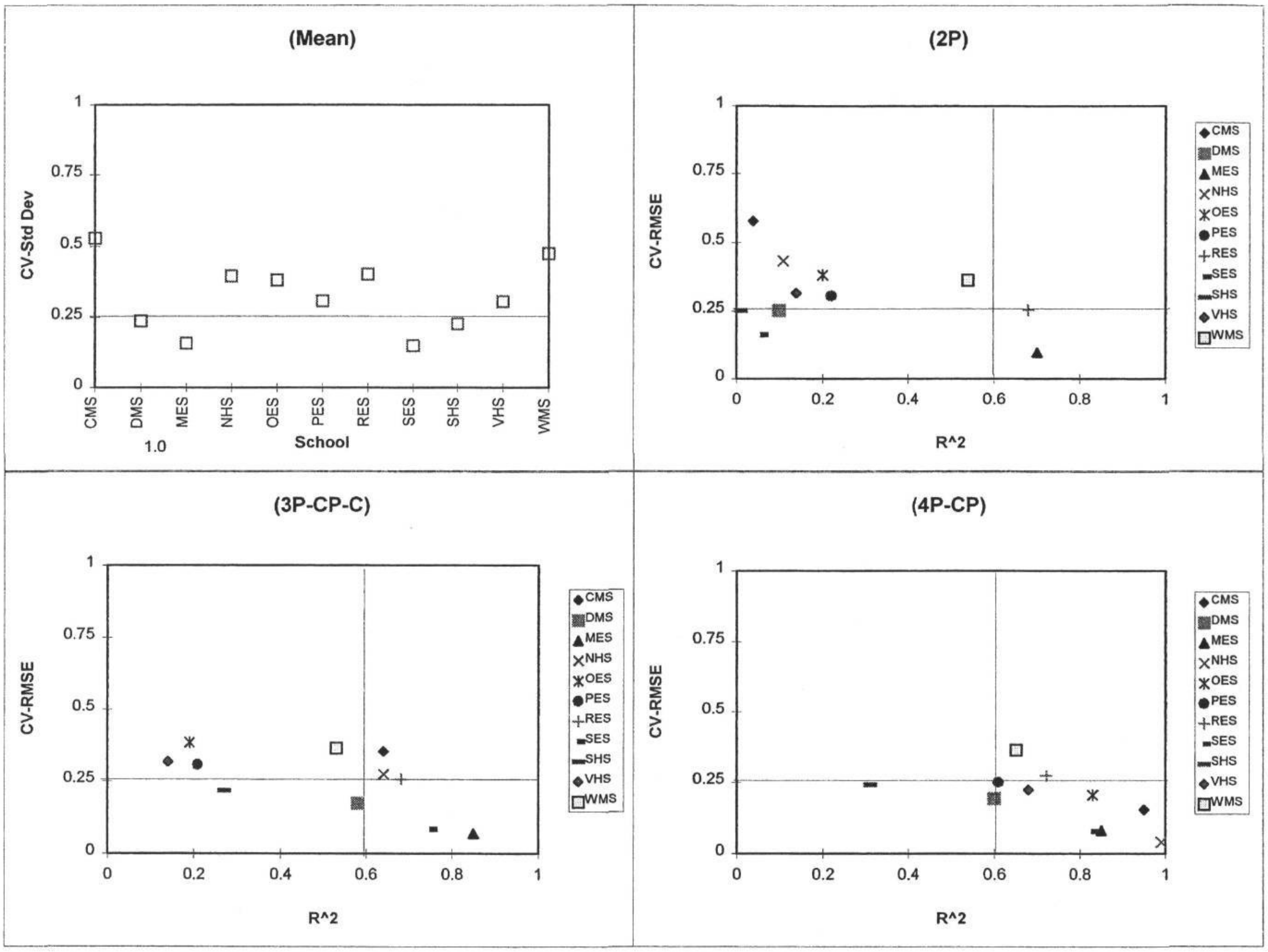


Table 3.3c: *1,2, 3, 4-parameter electric models for all eleven schools using data from summer months only*

	1P		2P		3P		4P	
		CV(Std-Dev)	R^2	CV(RMSE)	R^2	CV(RMSE)	R^2	CV(RMSE)
SHS		0.226	0.01	0.251	0.27	0.216	0.31	0.241
VHS		0.305	0.14	0.316	0.68	0.194	0.68	0.222
SES		0.15	0.06	0.162	0.75	0.084	0.83	0.079
DMS		0.231	0.1	0.251	0.58	0.171	0.6	0.193
NHS		0.396	0.11	0.431	0.64	0.273	0.99	0.04
CMS		0.527	0.04	0.576	0.64	0.352	0.95	0.152
OES		0.381	0.2	0.381	0.19	0.383	0.83	0.204
WMS		0.475	0.54	0.362	0.53	0.364	0.65	0.364
PES		0.308	0.22	0.304	0.21	0.305	0.61	0.25
MES		0.158	0.7	0.097	0.85	0.069	0.85	0.08
RES		0.403	0.68	0.254	0.68	0.256	0.72	0.275
Average		0.324	0.255	0.308	0.547	0.242	0.729	0.191

Table 3.4 presents the models selected for each school.

Table 3.4: ***Best Fitting Model***

Site	
SHS	3-parameter (School Months), 1-parameter Mean (Summer Months)
VHS	3-parameter (School Months), 1-parameter Mean (Summer Months)
SES	3-parameter (School Months), 1-parameter Mean (Summer Months)
DMS	3-parameter (School Months), 1-parameter Mean (Summer Months)
NHS	3-parameter (School Months), 1-parameter Mean (Summer Months)
CMS	3-parameter (School Months), 1-parameter Mean (Summer Months)
OES	3-parameter (School Months), 1-parameter Mean (Summer Months)
WMS	3-parameter (School Months), 1-parameter Mean (Summer Months)
PES	3-parameter (School Months), 1-parameter Mean (Summer Months)
MES	3-parameter (School Months), 1-parameter Mean (Summer Months)
RES	3-parameter (School Months), 1-parameter Mean (Summer Months)

The 3-parameter model was selected as the appropriate model during school months. The average R^2 value for school months was 0.625 as opposed to 0.351 for all monthly data. This ranged from a low of 0.24 for CMS to a high of 0.9 for NHS. The larger schools (i.e. High Schools) had the highest values for R^2. The average CV(RMSE) for school months was 0.146 versus 0.234 for all monthly data. The values for 3-parameter and 4-parameter models are almost identical. In many cases the 4-parameter models were slightly higher. However, 3-parameter models were chosen for all sites to allow for a comparison between school year base-level use and summer mean use. The 3-parameter model also provides an estimate of school year cooling energy use. In addition, when looking at the 4-parameter models graphically, several did not seem appropriate. Hence the 3-parameter model was selected as the best fit to describe monthly data during the school year.

For the summer months a 1-parameter mean model was selected for several reasons. First approximately 5^{o} F average temperature range did not provide a wide enough variation to statistically assess weather dependency. Second, visual inspection of the 2, 3, and 4-parameter models in many of the schools showed meaningless fits as indicated in Figure 3.10 even though the statistics indicated a good fit.

The final selection of models is shown in Figures 3.14a, 3.14b:

Figure 3.14a: ***Monthly Models: School Year and Summer***

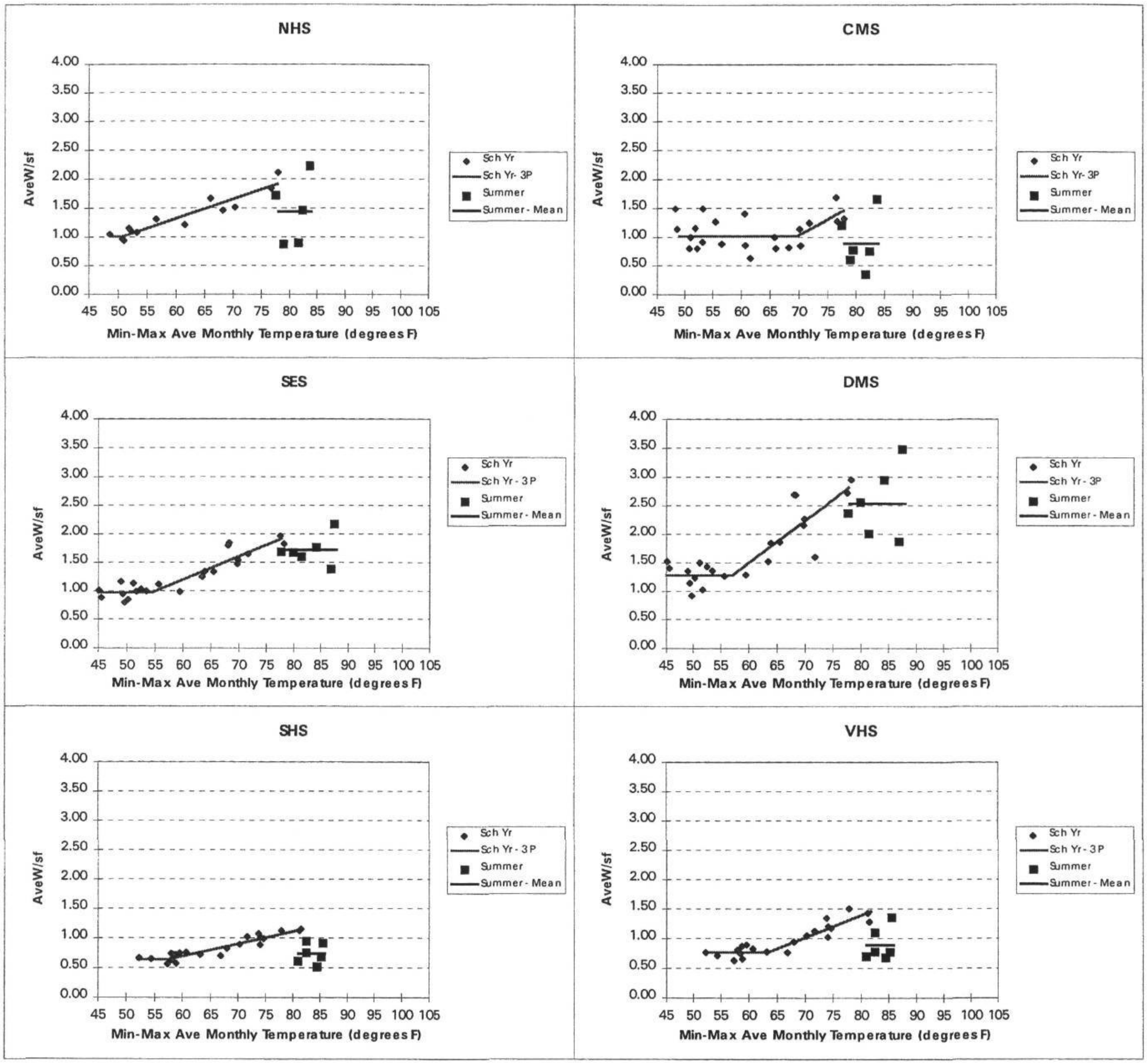
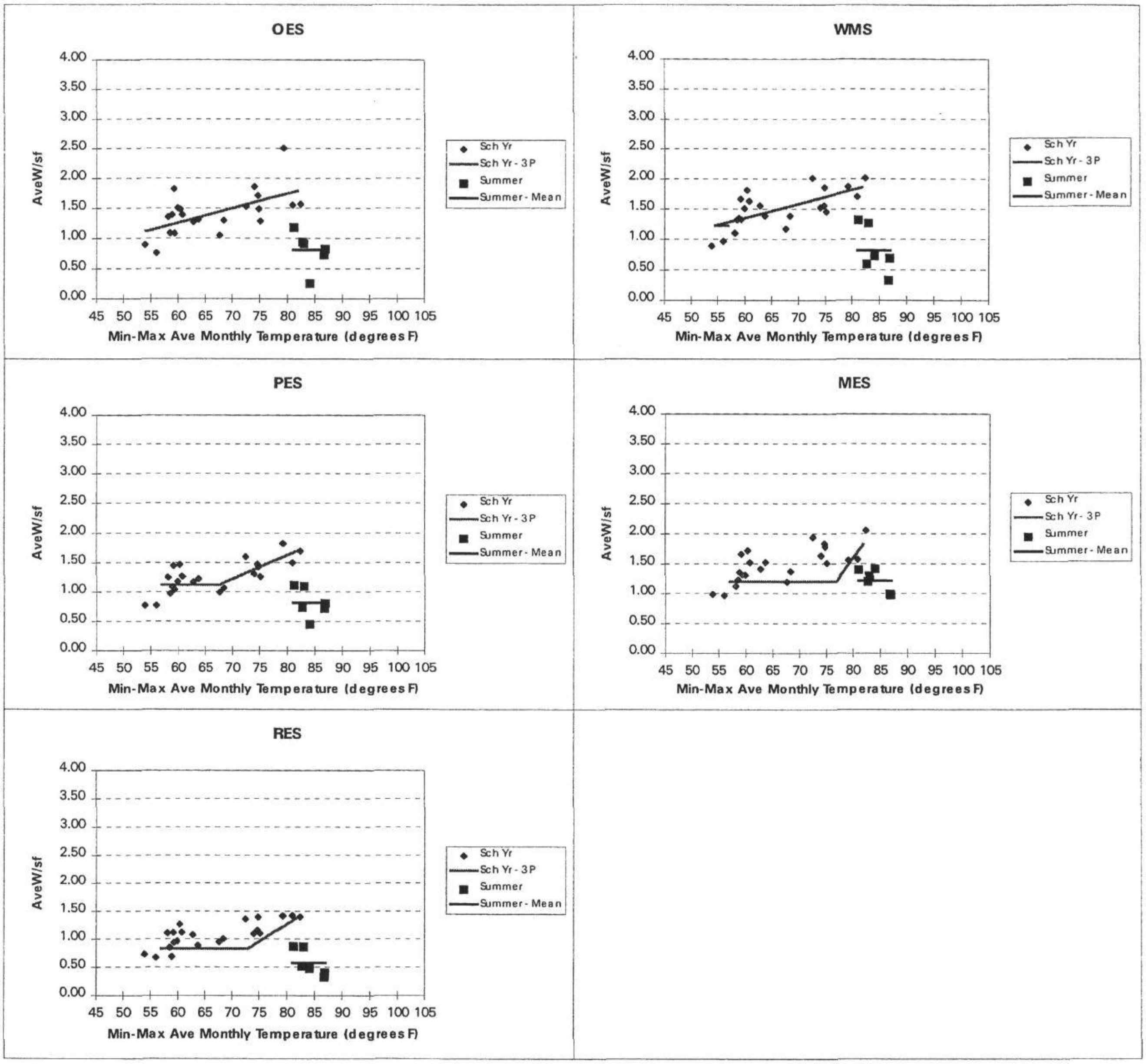


Figure 3.14b: ***Monthly Models***: School Year and Summer



Figures 3.15 through 3.19 are average monthly data for the following indices: whole-building electricity in W/sf (Figure 3.15), whole-building gas in Btu/(hr-sf) (Figure 3.16), Electric Load Factor (Figure 3.17), Occupancy Load Factor (Figure 3.18), and People Load Factor (Figure 3.19). Each of these figures shows the mean, median, 10th percentile, 25th percentile, 75th percentile, 90th percentile and extreme points for all of the schools in the following order:

Location on Box-Whisker Mean Plots:	School Initials:	School Name:
1	NHS	Nacogdoches High School
2	CMS	Chamberlain Middle School
3	SES	Sims Elementary School
4	DMS	Dunbar Middle School
5	VHS	Victoria High School
6	SHS	Stroman High School
7	OES	Oppe Elementary School
8	WMS	Weis Middle School
9	PES	Parker Elementary School
10	MES	Morgan Elementary School
11	RES	Rosenberg Elementary School

On Figure 3.15, the monthly average WBE shows the means vary from about 0.6 W/sf for CMS to 1.8 W/sf for DMS with monthly extremes from as low as 0.2 W/sf for CMS to as high as 3.5 W/sf for DMS. Most of the other schools have a mean between 1.0 W/sf and 1.5 W/sf.

Figure 3.16 shows the monthly average natural gas use with means that range from about 0.5 Btu/(hr-sf) for PES to about 5.0 Btu/(hr-sf) for OES with the majority in the 1 Btu/(hr-sf) to 2.5 Btu/(hr-sf). Extremes range from almost 0.0 Btu/(hr-sf) for a few of the schools to as high as 11.0 Btu/(hr-sf) for OES.

Figure 3.17 shows the monthly average ELFs with means that range from about 0.25 for several of the schools in Galveston to about 0.4 for both schools in Fort Worth, SES and DMS. The extreme ranges are from as low as 0.05 for OES to 0.75 for DMS with SES also very high.

Figure 3.18 shows the monthly average OLFs with means that range from about 0.3 for CMS to about 0.425 for both schools in Fort Worth, SES and DMS. The extreme ranges are from as low as about 0.2 for CMS to over 0.5 for DMS and SES.

Figure 3.19 shows the monthly average PLFs with means that range from about 0.18 for RES to about 0.22 for the larger schools, 3 high schools and CMS. The extreme ranges are from as low as almost 0.0 for all of the elementary schools to over 0.3 for the high schools and CMS.

Figure 3.15: *Monthly Average WBE: An aggregate monthly analysis for all 11 schools of their average monthly consumption in W/sf for September 1991 through December 1993.*

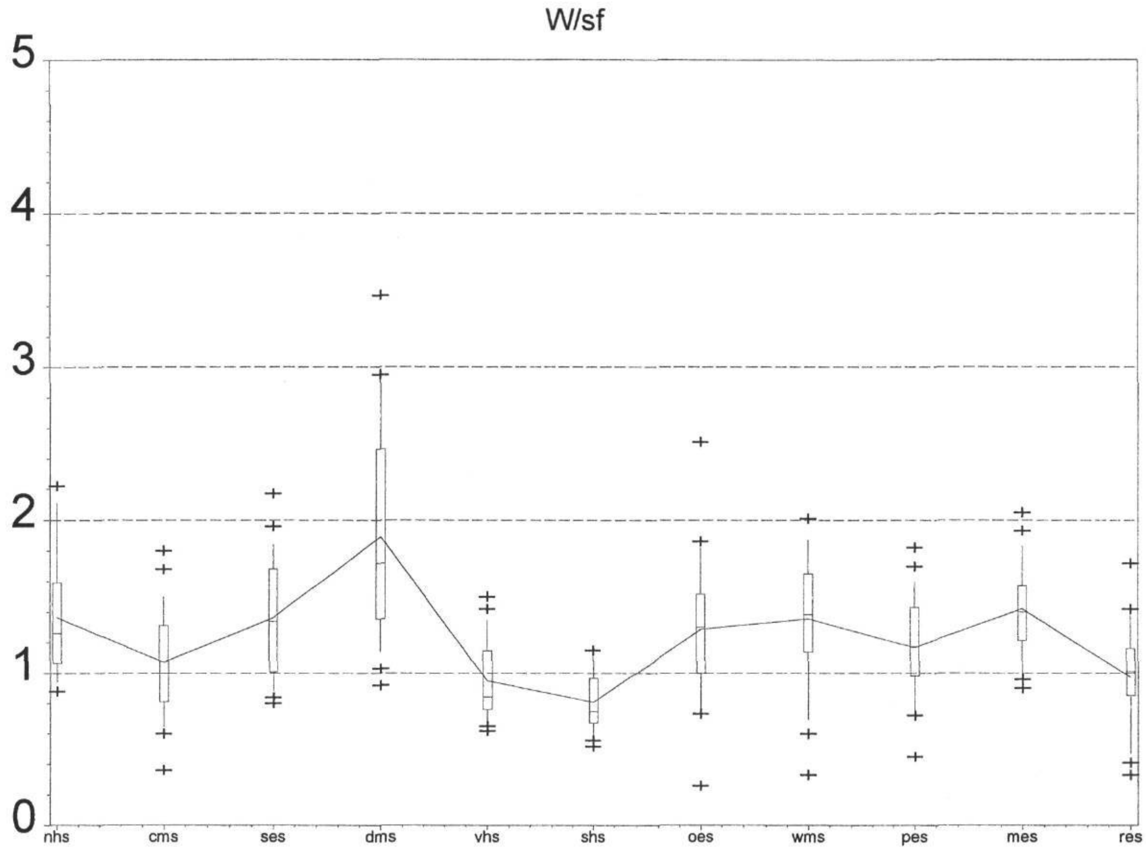


Table 3.5: *Monthly Average WBE: An aggregate monthly analysis for all 11 schools of their average monthly consumption in W/sf for September 1991 through December 1993.*

	NHS	CMS	SES	DMS	VHS	SHS	OES	WMS	PES	MES	RES
0th percentile	0.88	0.36	0.8	0.92	0.62	0.52	0.26	0.33	0.45	0.96	0.33
25th percentile	1.05	0.81	1.01	1.36	0.76	0.67	1.0	1.14	0.98	1.22	0.79
50th percentile	1.26	1.0	1.34	1.72	0.85	0.75	1.3	1.39	1.18	1.41	0.99
mean	1.37	1.07	1.36	1.89	0.95	0.81	1.29	1.36	1.17	1.42	0.97
75th percentile	1.67	1.31	1.68	2.46	1.15	0.97	1.52	1.65	1.43	1.6	1.14
100th percentile	2.22	1.8	2.17	3.47	1.5	1.15	2.51	2.01	1.82	2.05	1.42

Figure 3.16: ***Monthly Average Natural Gas:*** *An aggregate analysis for all 11 schools of their average natural gas consumption each month in Btu/(hr-sf) for September 1991 through December 1993.*

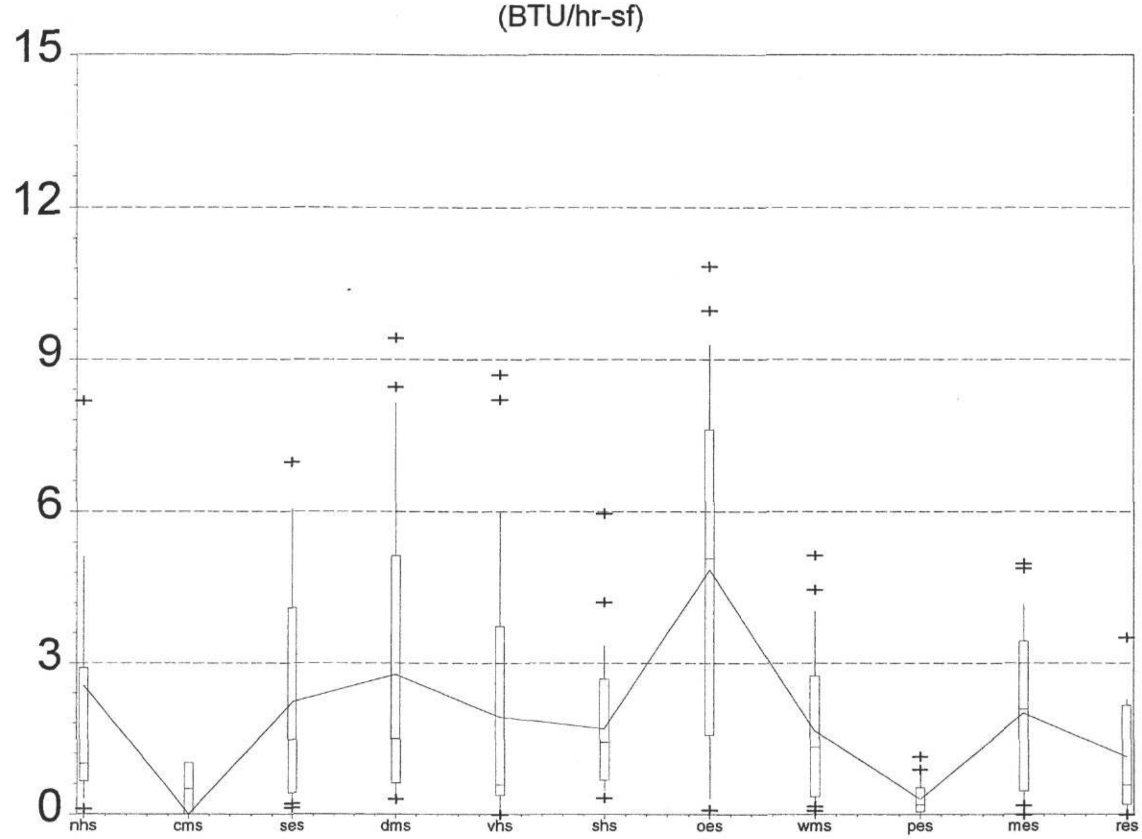


Table 3.6: *Monthly Average Natural Gas: An aggregate analysis for all 11 schools of their average natural gas consumption each month in Btu/(hr-sf) for September 1991 through December 1993.*

	NHS	CMS	SES	DMS	VHS	SHS	OES	WMS	PES	MES	RES
0th percentile	0.11	--------	0.13	0.3	0.0	0.32	0.09	0.08	0.0	0.0	0.0
25th percentile	0.65	--------	0.4	0.6	0.35	0.66	1.46	0.33	0.05	0.45	0.19
50th percentile	1.02	--------	1.12	1.24	0.56	1.41	5.34	1.12	0.16	2.18	0.58
mean	2.55	--------	2.22	2.77	1.93	1.69	4.86	1.65	0.29	2.0	1.12
75th percentile	3.33	--------	3.94	4.69	3.61	2.5	7.67	2.77	0.51	3.47	2.16
100th percentile	8.2	--------	6.96	9.43	8.7	5.96	10.84	5.14	1.14	4.98	3.51

Figure 3.17: *Monthly Average ELFs: An aggregate analysis for all 11 schools of their electric load factor for September 1991 through December 1993.*

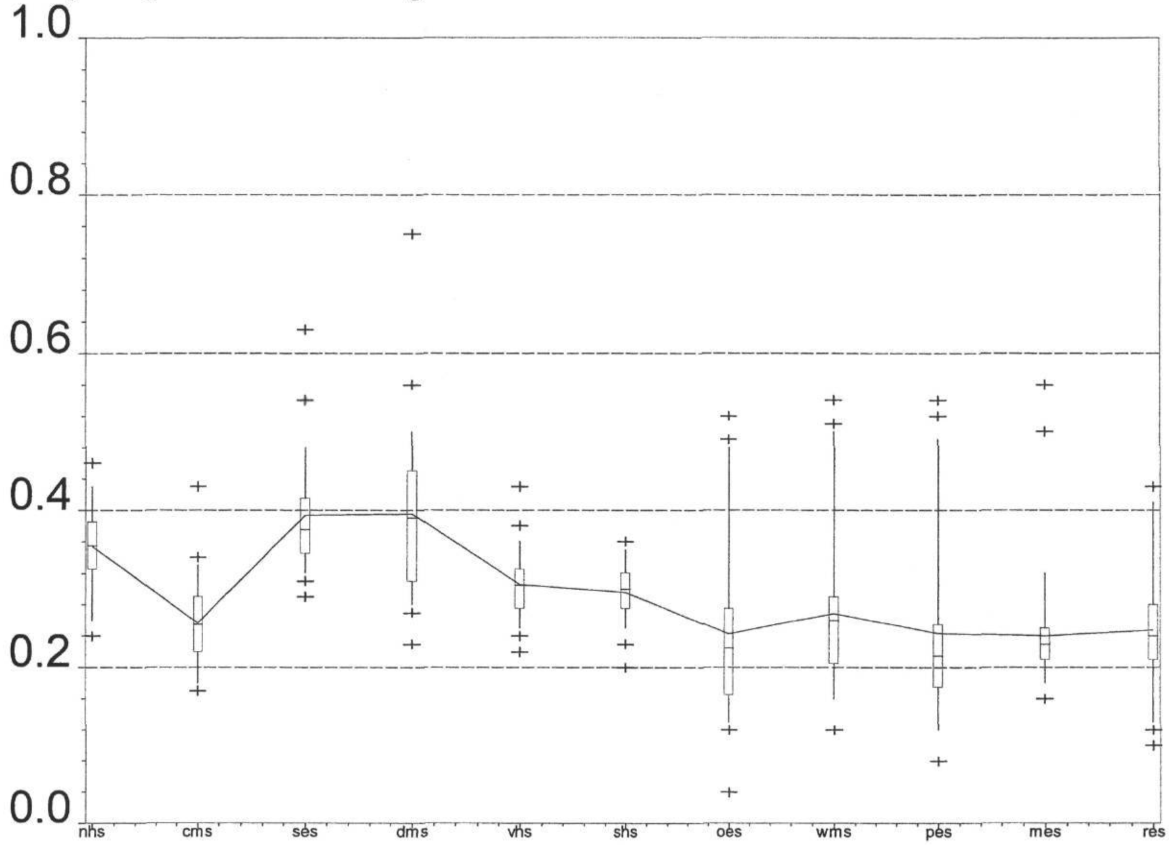


Table 3.7: *Monthly Average ELFs: An aggregate analysis for all 11 schools of their electric load factor for September 1991 through December 1993.*

	NHS	CMS	SES	DMS	VHS	SHS	OES	WMS	PES	MES	RES
0th percentile	0.24	0.17	0.29	0.23	0.22	0.2	0.04	0.12	0.08	0.16	0.1
25th percentile	0.32	0.22	0.35	0.31	0.28	0.28	0.17	0.21	0.18	0.21	0.21
50th percentile	0.36	0.26	0.39	0.39	0.31	0.3	0.23	0.26	0.22	0.23	0.24
mean	0.35	0.26	0.38	0.40	0.31	0.3	0.24	0.27	0.24	0.24	0.25
75th percentile	0.39	0.29	0.42	0.45	0.33	0.32	0.28	0.29	0.26	0.25	0.28
100th percentile	0.46	0.43	0.63	0.75	0.43	0.36	0.52	0.54	0.54	0.56	0.43

Figure 3.18: *Monthly Average OLFs: An aggregate analysis for all 11 schools of their occupancy load factor for September 1991 through December 1993.*

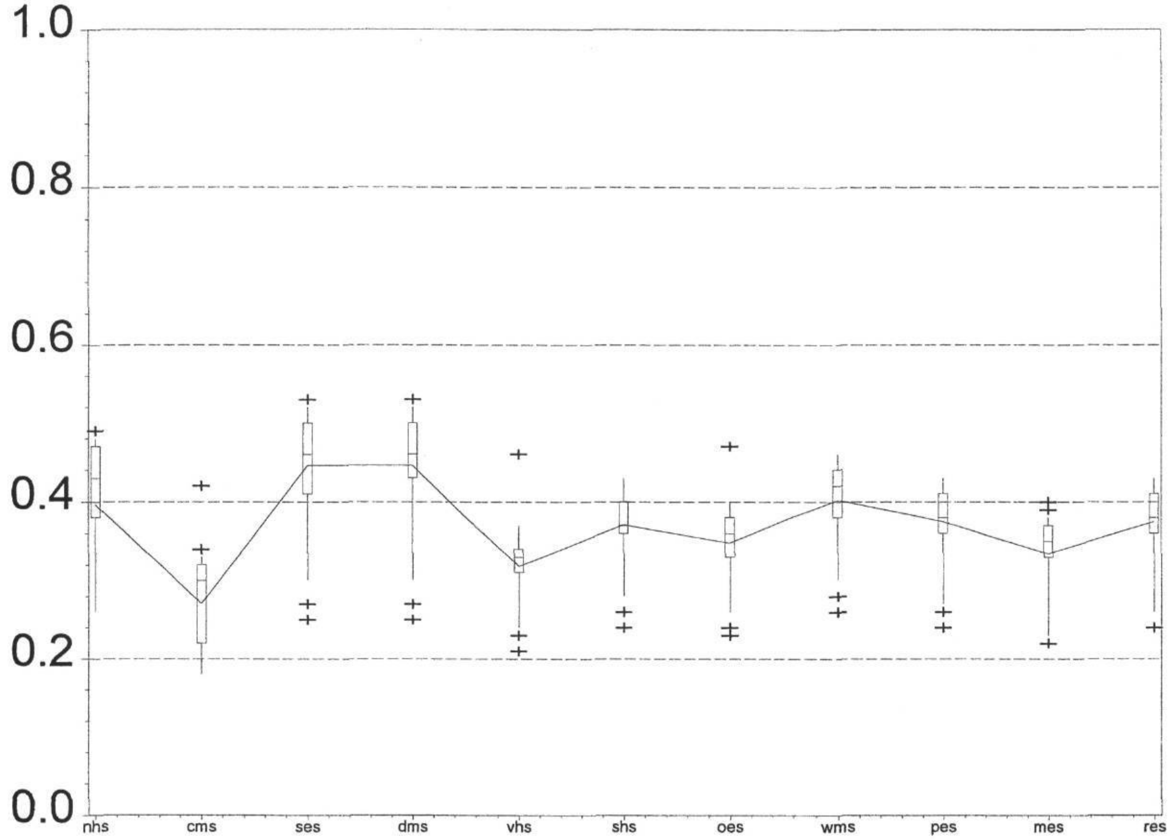


Table 3.8: *Monthly Average OLFs: An aggregate analysis for all 11 schools of their occupancy load factor for September 1991 through December 1993.*

	NHS	CMS	SES	DMS	VHS	SHS	OES	WMS	PES	MES	RES
0th percentile	0.26	0.18	0.25	0.25	0.21	0.24	0.23	0.26	0.24	0.22	0.24
25th percentile	0.35	0.22	0.43	0.43	0.31	0.36	0.33	0.38	0.36	0.33	0.36
50th percentile	0.43	0.3	0.47	0.47	0.33	0.38	0.36	0.42	0.39	0.35	0.39
mean	0.40	0.27	0.45	0.45	0.32	0.37	0.35	0.40	0.38	0.33	0.38
75th percentile	0.47	0.32	0.5	0.5	0.34	0.4	0.38	0.44	0.41	0.37	0.41
100th percentile	0.49	0.34	0.53	0.53	0.37	0.43	0.4	0.46	0.43	0.4	0.43

Figure 3.19: *Monthly Average PLFs: An aggregate analysis for all 11 schools of their people load factor for September 1991 through December 1993.*

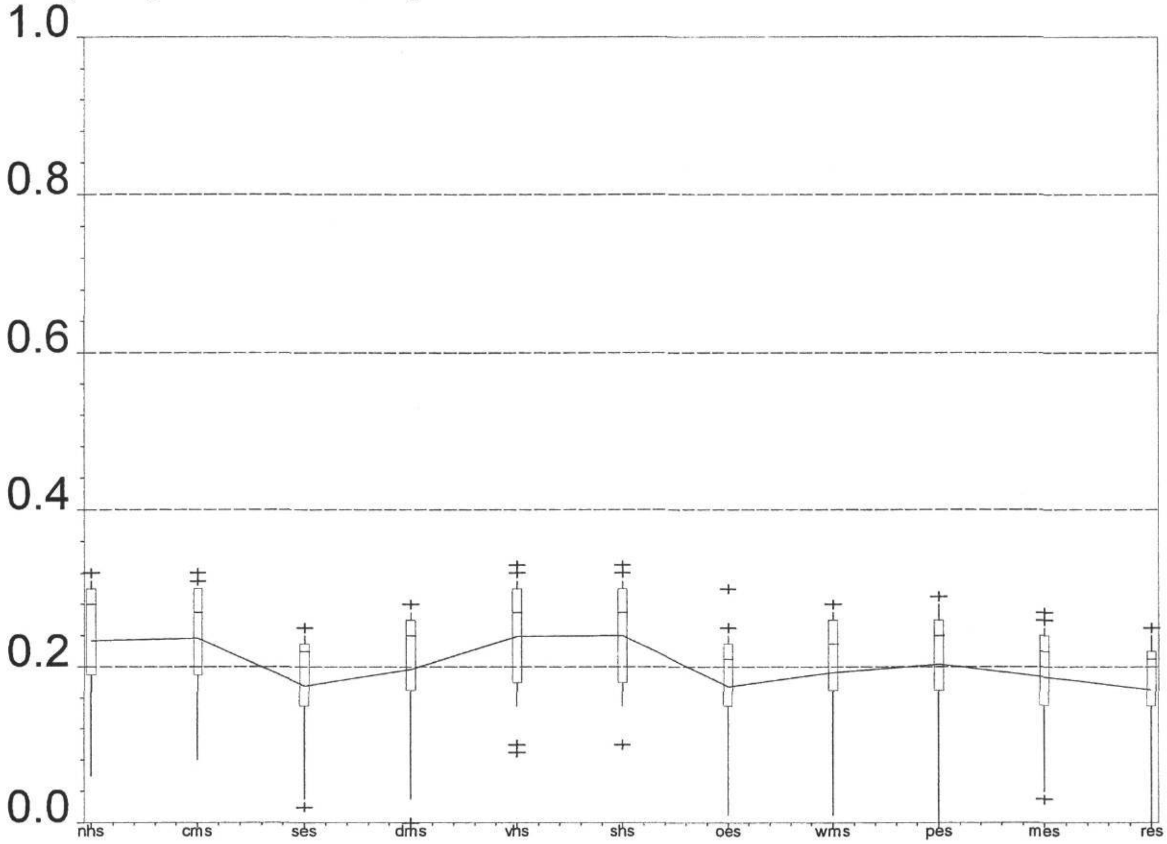


Table 3.9: *Monthly Average PLFs: An aggregate analysis for all 11 schools of their people load factor for September 1991 through December 1993.*

	NHS	CMS	SES	DMS	VHS	SHS	OES	WMS	PES	MES	RES
0th percentile	0.06	0.08	0.02	0.0	0.09	0.1	0.01	0.01	0.0	0.03	0.0
25th percentile	0.19	0.19	0.15	0.16	0.18	0.18	0.15	0.17	0.18	0.16	0.15
50th percentile	0.28	0.28	0.18	0.24	0.27	0.27	0.21	0.23	0.24	0.22	0.21
mean	0.23	0.24	0.22	0.20	0.24	0.24	0.18	0.19	0.20	0.19	0.17
75th percentile	0.3	0.3	0.24	0.26	0.3	0.3	0.23	0.26	0.27	0.24	0.23
100th percentile	0.32	0.32	0.25	0.27	0.33	0.33	0.25	0.28	0.29	0.27	0.25

3.3 Daily Indices

Figures 3.20a and 3.20b, and 3.21a and 3.21b show total daily electricity consumption (W/sf) versus average daily temperatures from the NWS (LoanSTAR site for Galveston) with separate symbols to show the data by weekday (filled symbols) or weekend (unfilled symbols). The first of these plots (Figure 3.20) has all days during the school year minus all vacations including: all summer days, vacations, Labor Day, 2 or 3 days for Thanksgiving, 2 weeks for Christmas, Martin Luther King Day, and 1 or 2 days for Easter. Half days were not considered vacation days. The second set of plots (Figure 3.21) shows only summer vacation days with the 4th of July being the only day not included since it was a weekday holiday.

In Figures 3.20a and 3.20b a line representing the 3-parameter models has been superimposed on the weekday data, and a line representing a 1-parameter mean model has been superimposed on the weekend data. The choice of a 3-parameter model for weekdays and a 1-parameter mean model for weekends was consistent with the models chosen for the monthly analysis. The weekday and weekend data for the summer months were modeled with a mean model.

Figure 3.20a: ***Daily Consumption for School Days**: Electricity grouped by weekday and weekend for all school days, from the middle of August through the middle of May, monitored as part of the LoanSTAR Program from September 1991 through December 1993.*

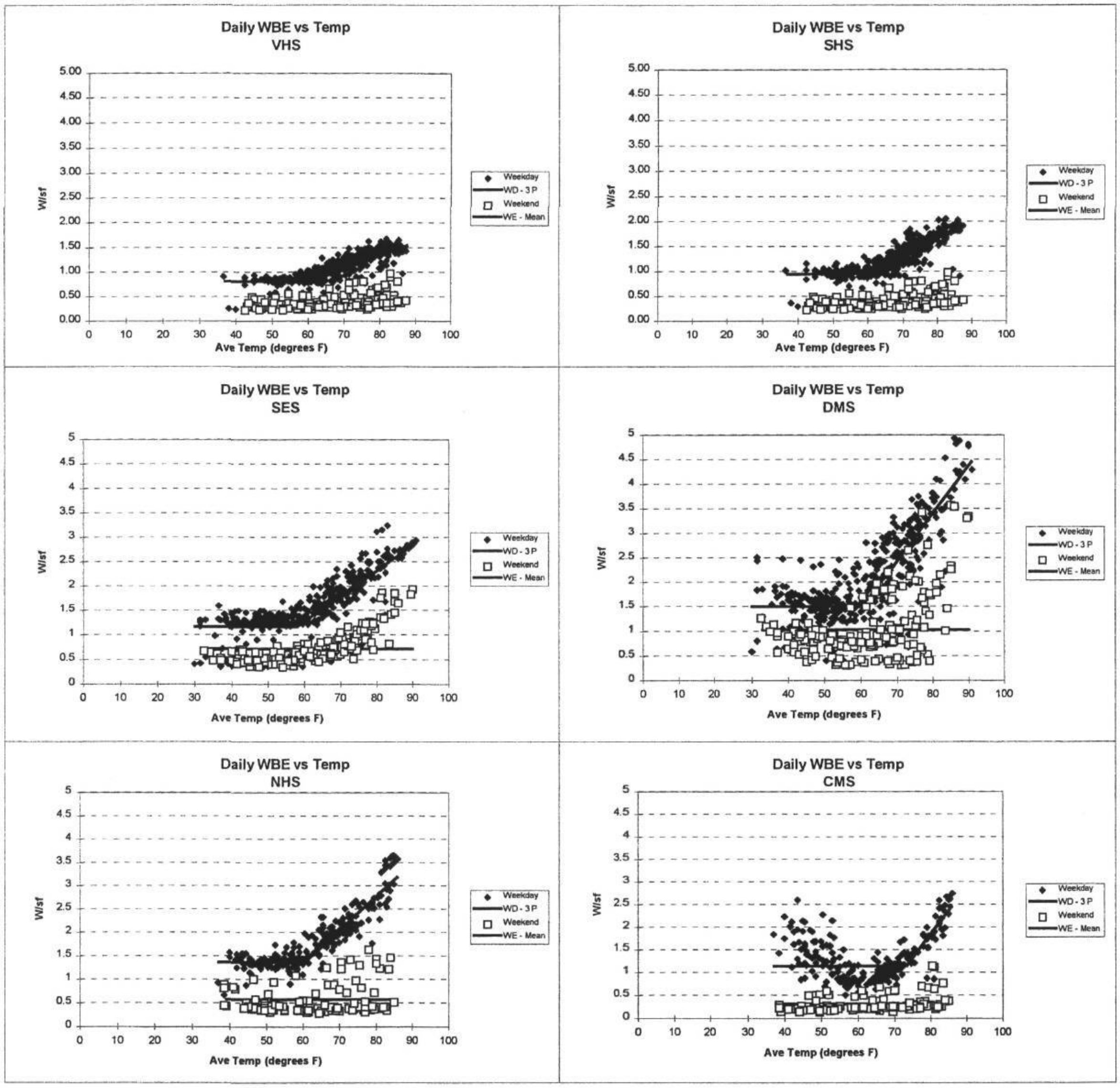


Figure 3.20b: ***Daily Consumption for School Days****: Electricity grouped by weekday and weekend for all school days, from the middle of August through the middle of May, monitored as part of the LoanSTAR Program from September 1991 through December 1993.*

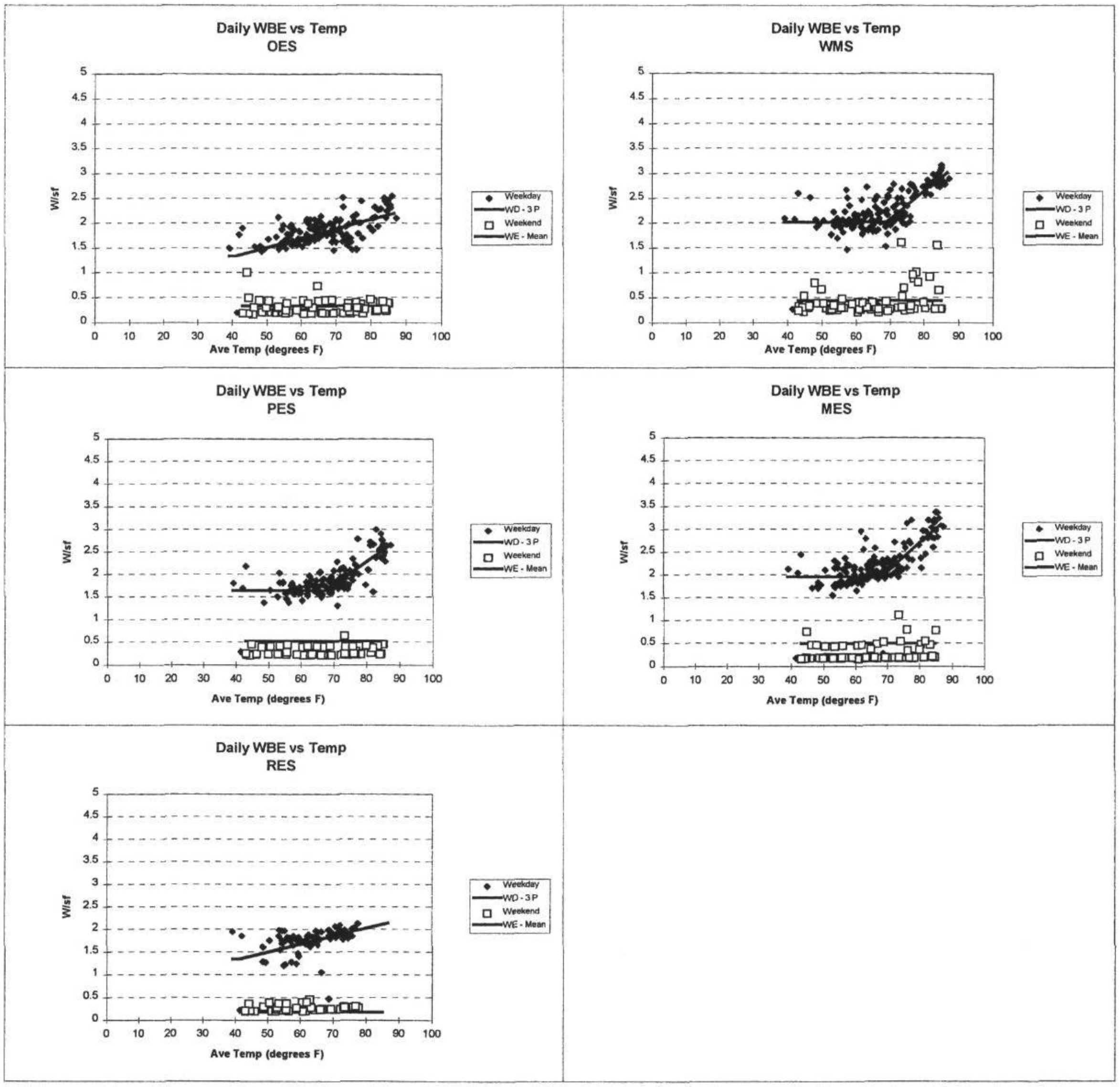


Figure 3.21a: ***Daily Consumption for Summer Days***: *Electricity grouped by weekday and weekend for all summer days, middle of May through middle of August, monitored as part of the LoanSTAR Program from September 1991 through December 1993.*

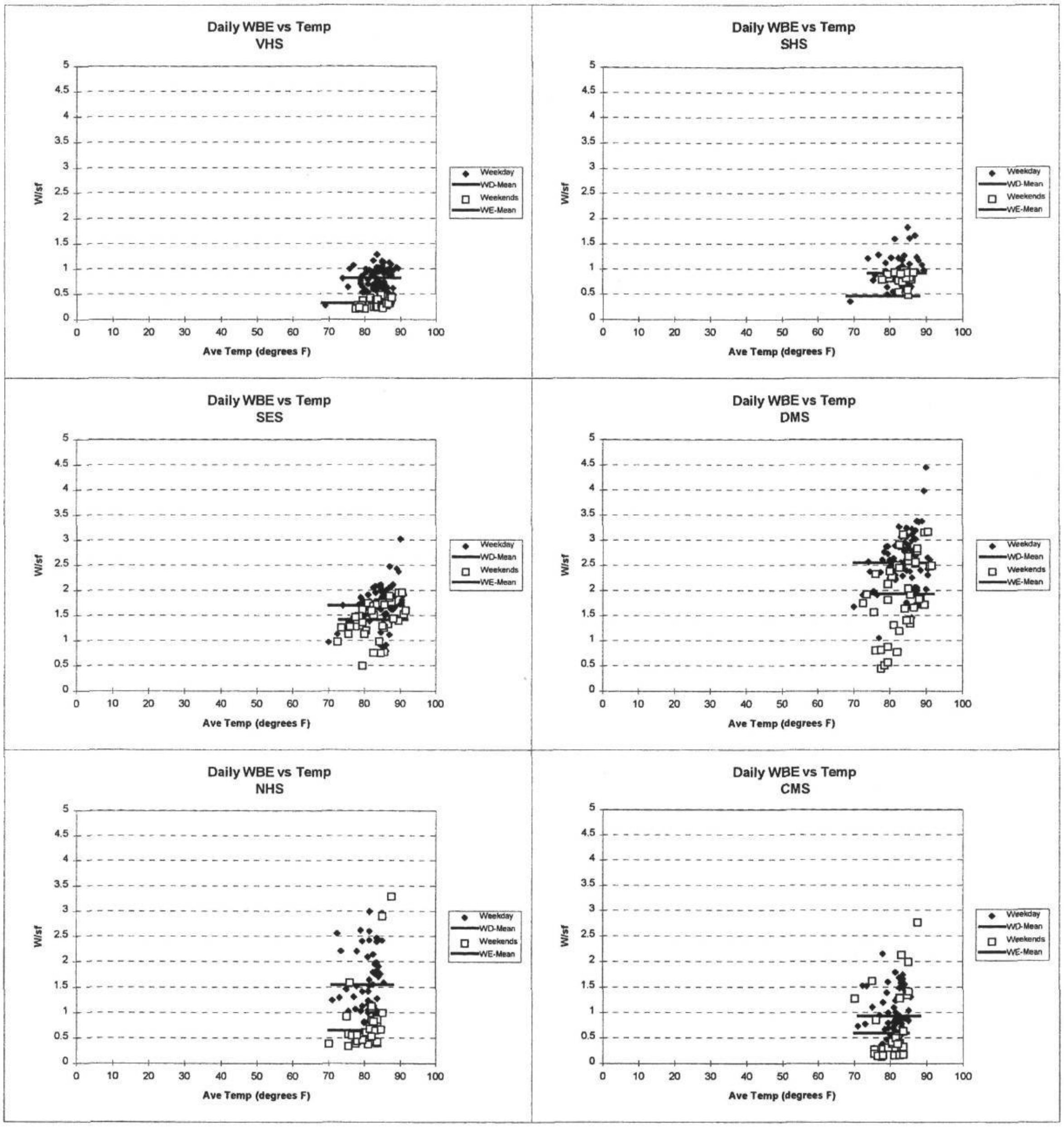
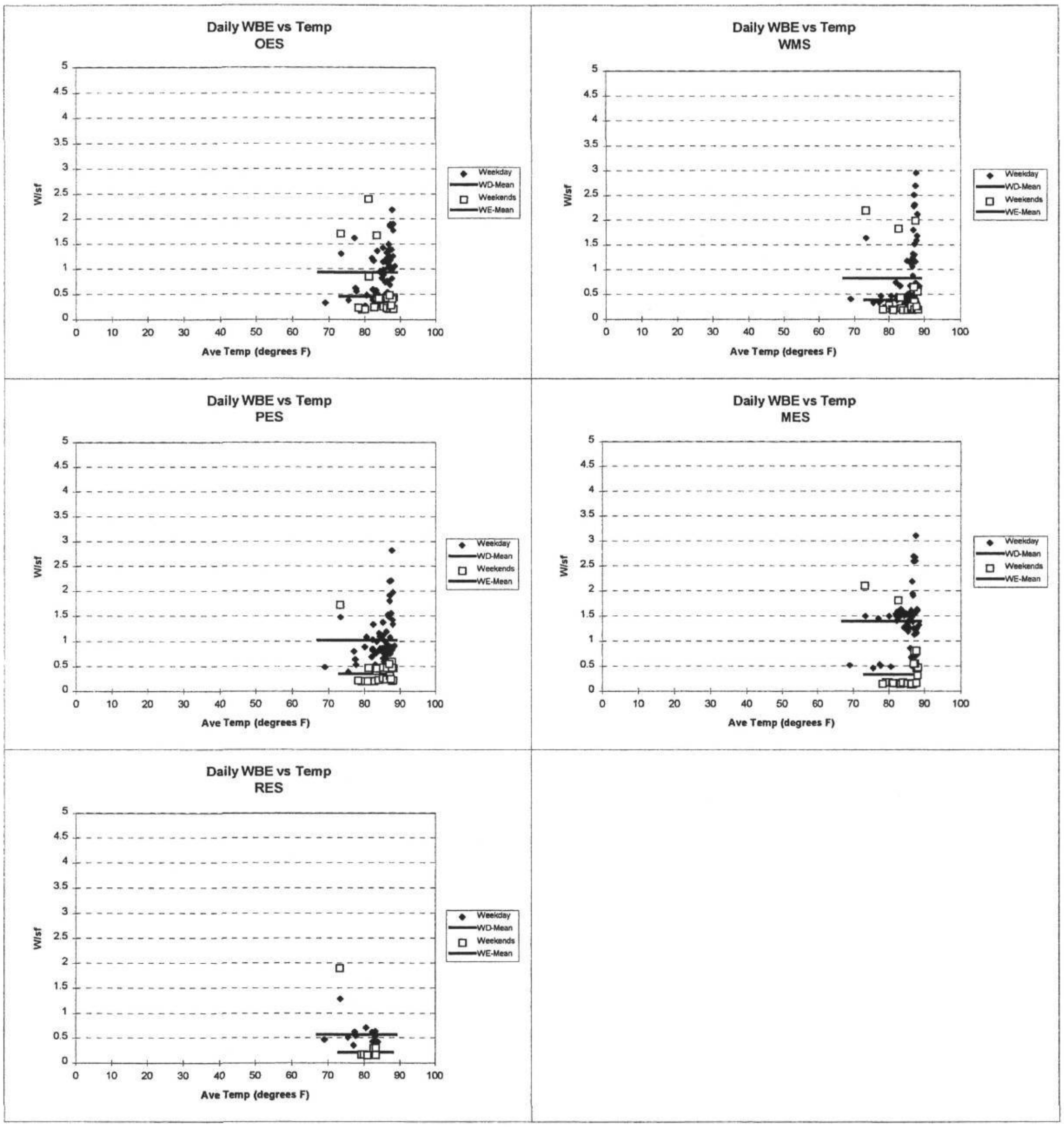


Figure 3.21b: ***Daily Consumption for Summer Days****: Electricity grouped by weekday and weekend for all summer days, middle of May through middle of August, monitored as part of the LoanSTAR Program from September 1991 through December 1993.*



3.4 Summary

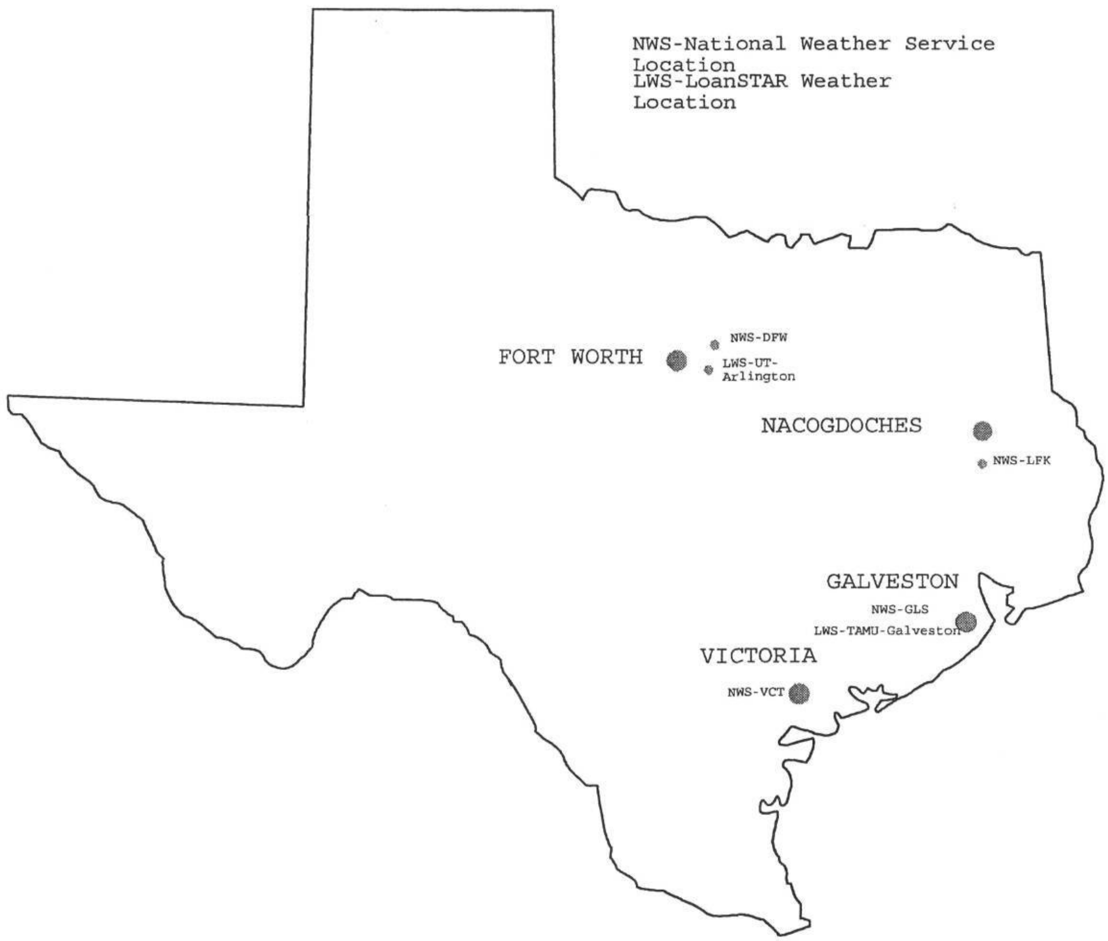
This section of the report has presented the basic indices that are used in this study, including: annual, monthly, and daily indices. The annual indices consist of simple single point comparisons for each school for each of the primary energy types being consumed by the schools, namely electricity use, electric demand, and natural gas use. In each case, these annual indices were assembled from monthly utility billing data from the 1992 and 1993 study period. In general, the annual indices were found to be useful in identifying the high energy consuming schools but provided only limited insight into why the school was over-consuming when compared to similar schools.

The monthly utility indices considered peak electric demand, electricity use and natural gas use for each school normalized by square footage. In order to begin to unravel the weather dependency of each of the schools, 1, 2, 3, and 4-parameter regression models were investigated to determine which models most appropriately fit the energy use data for all of the schools and provided the most useful index. An interquartile analysis was also found to be useful.

In the case of the natural gas use, a simple 3-parameter change-point heating model which used all 28 months of data analyzed was the model of choice. For the electricity use data it was necessary to first separate the data into school year and summer months. These data were then modeled with a 3-parameter change-point cooling model for school year months and a 1-parameter mean model for summer months. As will be shown in the following chapters, these 3-parameter change-point models begin to provide additional information about which systems are over-consuming at each of the schools.

Daily data were also investigated with the idea that in the future schools may begin to have hourly data available from data loggers on Energy Management Systems that could be used to analyze daily data energy use against average daily weather data. The same 3-parameter change-point models were investigated with the daily data and it was determined that the daily data could yield additional information about weather dependent weekday/weekend use.

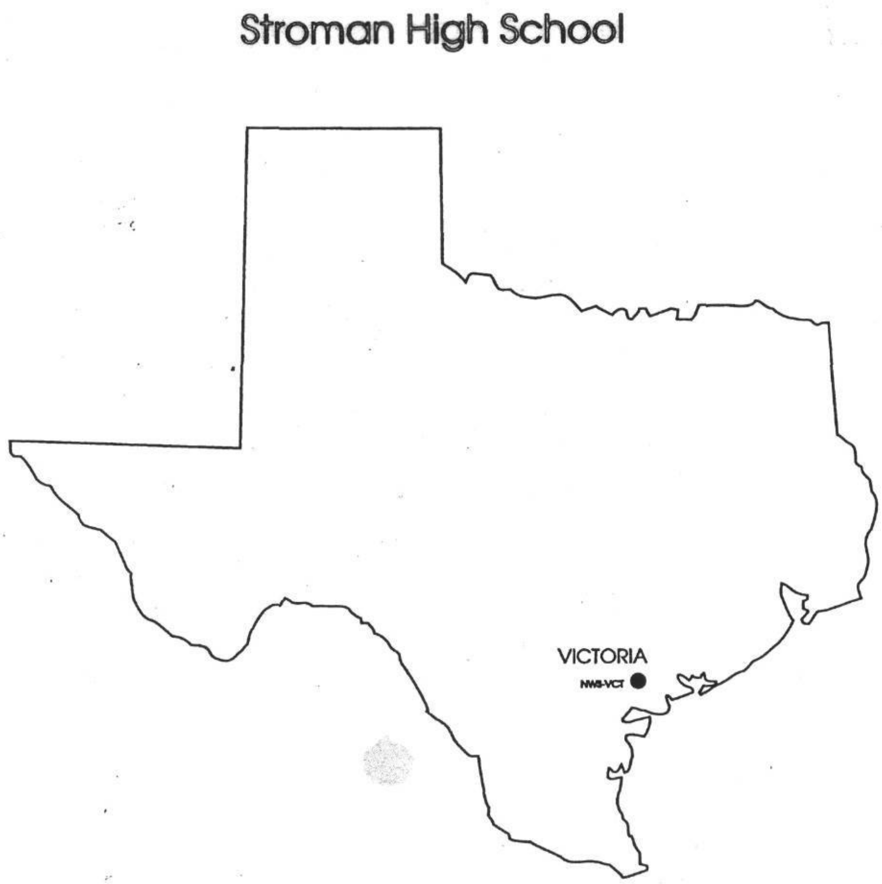
4.0 SCHOOL DESCRIPTIONS

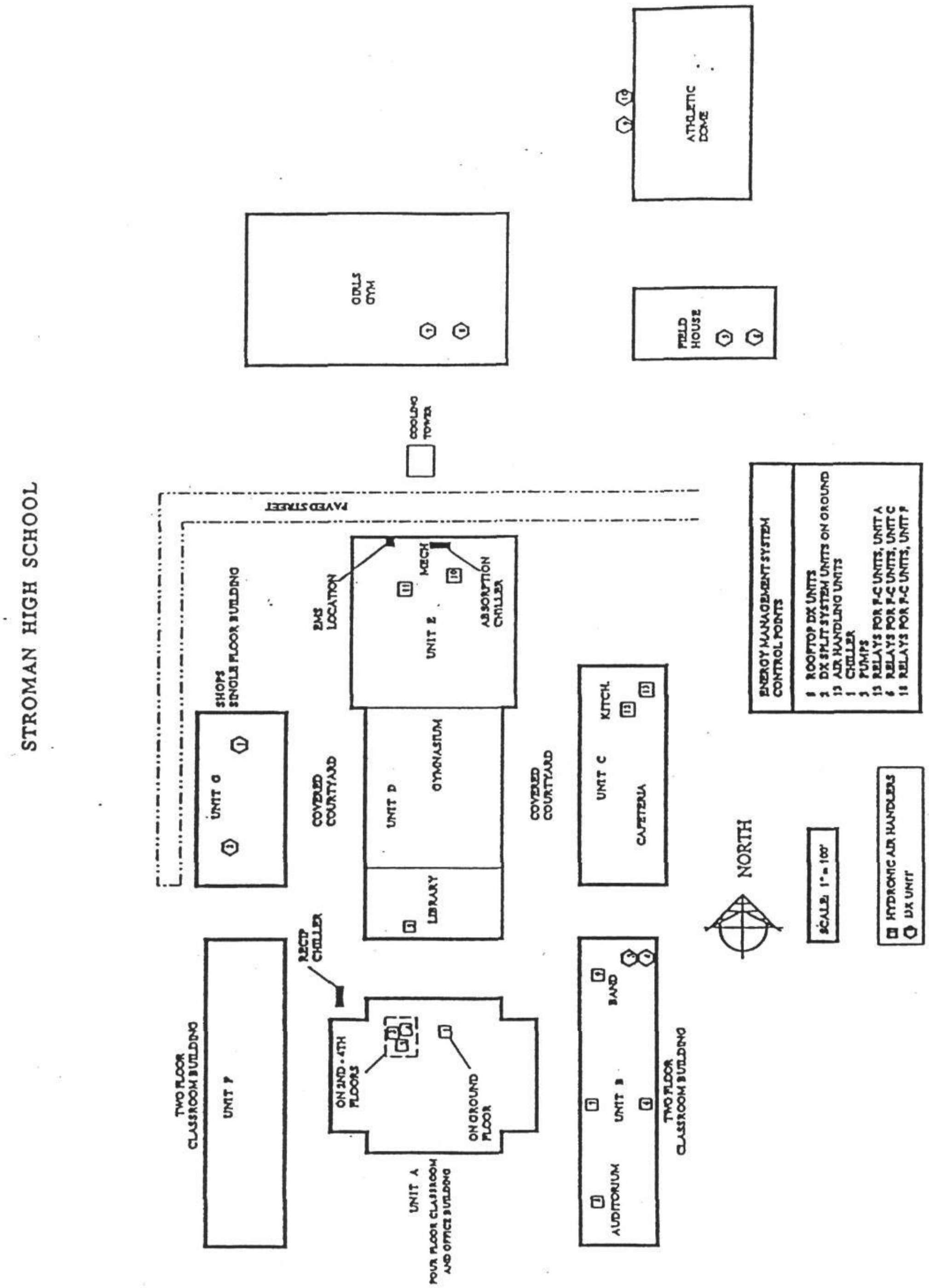


4.0 School Descriptions

In this section the pertinent information about each of the schools is presented, including: a physical description of the layout of each school, the major HVAC systems in each school, and basic occupancy and control schedules in use. In several of the schools information is provided about energy conservation retrofits including what the retrofit was and the date at which the retrofit occurred. For each site the basic monthly data is also displayed in a consistent format across sites to allow for visual comparisons using juxtaposed time series graphs that display energy use as power levels along with information about scheduling and average ambient conditions.

4.1 Stroman High School (SHS)




STROMAN HIGH SCHOOL
ATHLETIC DOME
GIRLS GYM
FIELD HOUSE
COOLING TOWER
PAVED STREET
SHOPS SINGLE FLOOR BUILDING
UNIT G
COVERED COURTYARD
EMS LOCATION
MECH
ABSORPTION CHILLER
UNIT E
UNIT D
GYMNASIUM
LIBRARY
UNIT C
KITCH.
CAFETERIA
COVERED COURTYARD
NORTH
ENERGY MANAGEMENT SYSTEM CONTROL POINTS
HYDRONIC AIR HANDLERS
DX UNIT
RECIP CHILLER
TWO FLOOR CLASSROOM BUILDING
UNIT F
ON 2ND + 4TH FLOORS
ON GROUND FLOOR
UNIT A
FOUR FLOOR CLASSROOM AND OFFICE BUILDING
BAND
UNIT B
AUDITORIUM
TWO FLOOR CLASSROOM BUILDING

4.1 Stroman High School (SHS)

Stroman High School is located in Victoria, TX. It consists of nine separate buildings with a total floor area of 210,414 square feet. Classrooms are heated and cooled by individual 2-pipe hydronic fan coil units. The first floor is heated/cooled by an air handler, and there are separate air handlers on floors two through four to supply conditioned outside air to each floor. The two story Unit B contains the auditorium, choir room, band room, and drafting classrooms. It is heated/cooled by air handlers, though the band hall has direct expansion cooling as well, operating whenever the hydronic air handler does not provide cooling, in order to prevent humidity problems. Unit C is a single story, and it contains the cafeteria and kitchen. It is heated/cooled by hydronic fan-coil units (six in the cafeteria, two in the kitchen). Unit D and E are in one contiguous building, a two story structure containing the library, gymnasium, locker rooms, and the main mechanical room. HVAC is provided by hydronic air handler in the library, and heating/ventilation units in the remaining athletic facilities. Unit F is a two story containing the science classrooms. It is heated and cooled by hydronic fan-coil units. Unit G is a single story shops building containing several pieces of electrical equipment from band saws to drills. It is heated and cooled by direct expansion units with gas furnaces. Chilled water and hot water for units A-G are provided by a 460 ton electric chiller and a 5.05 million Btu gas-fired steam boiler. Auxiliary equipment includes a 50 horsepower chilled water pump, 40 horsepower condenser water pump, 30 horsepower cooling tower fan, and a 20 horsepower hot water pump.

There are also three athletic buildings just north of the main buildings that house the girls' gym, the field house, and the "athletic dome", in which weight training takes place. All three buildings are heated/cooled by direct expansion units with gas furnaces.

Air distribution is primarily through single duct multi-zone systems providing cooling temperatures are in the 75 F range and heating temperatures are in the range of 70-72 F. Heating is turned-off completely as are air-handling systems during the evenings. Control is maintained from a central location through a Carrier EMCS.

The school is operated from the middle of August through the middle of May with approximately 1,529 students and 145 faculty and staff. The maximum school occupancy is from approximately 8:00 a.m. until 4:00 p.m. However, the building is occupied for much longer periods including weekends and summers. Stroman and Victoria High School alternate as the primary location for summer school. Stroman was the site during the summer of 1993. Large quartz lamps are used to light the tennis courts in the evenings. These are shut off at 11:00 PM. Electricity is purchased from Central Power and Light Company, natural gas from ENTEX Gas Company.

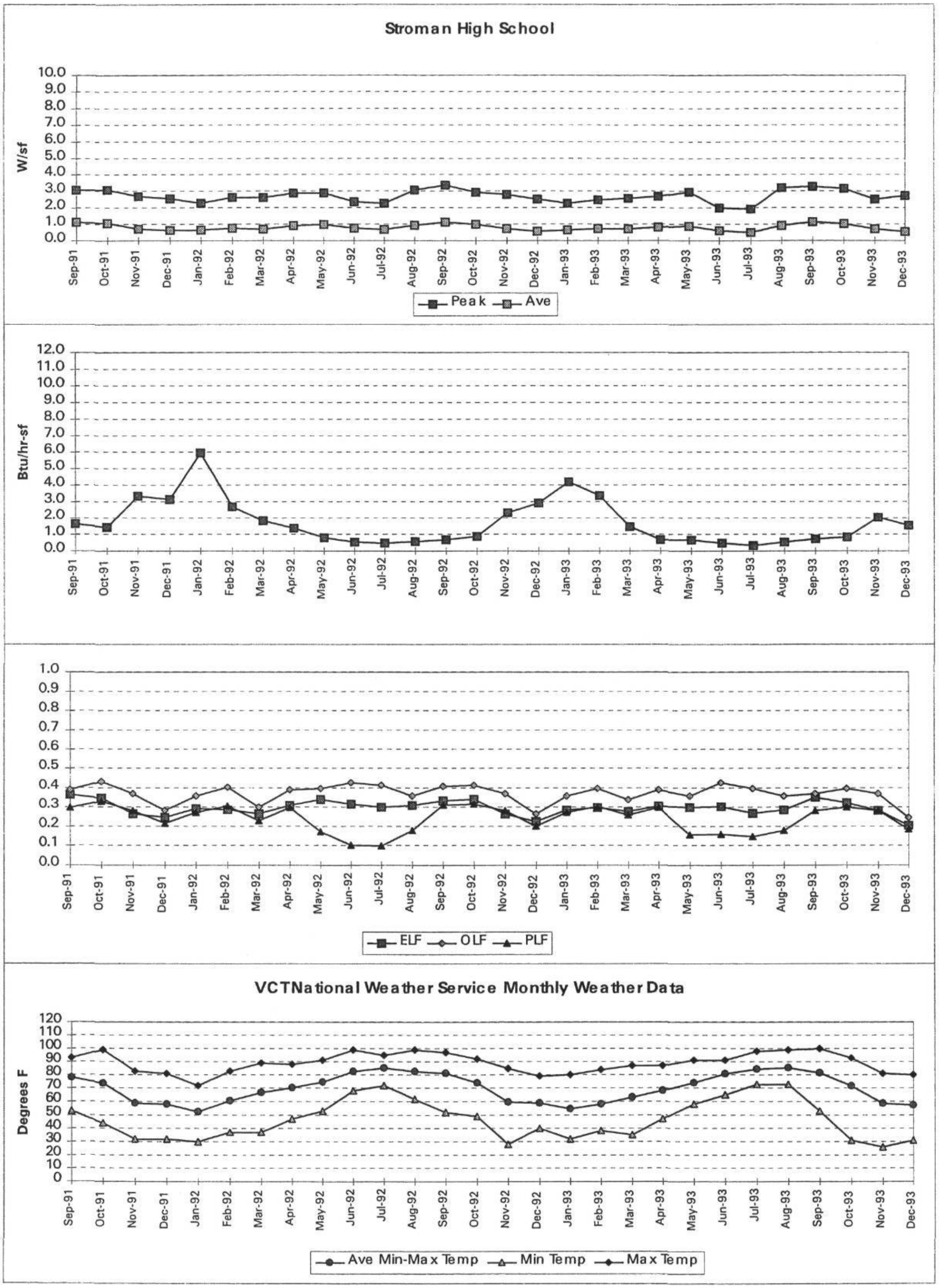
The following Energy Conservation Retrofit Measures (ECRMs) were installed at SHS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

Retrofits	Date Competed
•Install EMS	Aug. 1991
•Replace Absorption Chiller with HE electric chiller	Aug. 1991
•Rewire Hallway lighting for reduced usage during high natural lighting and low occupancy periods	Aug. 1991
•Replace single speed 20 horsepower HW pump with new 2-speed motor, and use EMCS	Aug. 1991

All retrofits were completed prior to data collected for analysis in this report. Hence, these retrofits are shown in all energy consumption data analyzed.

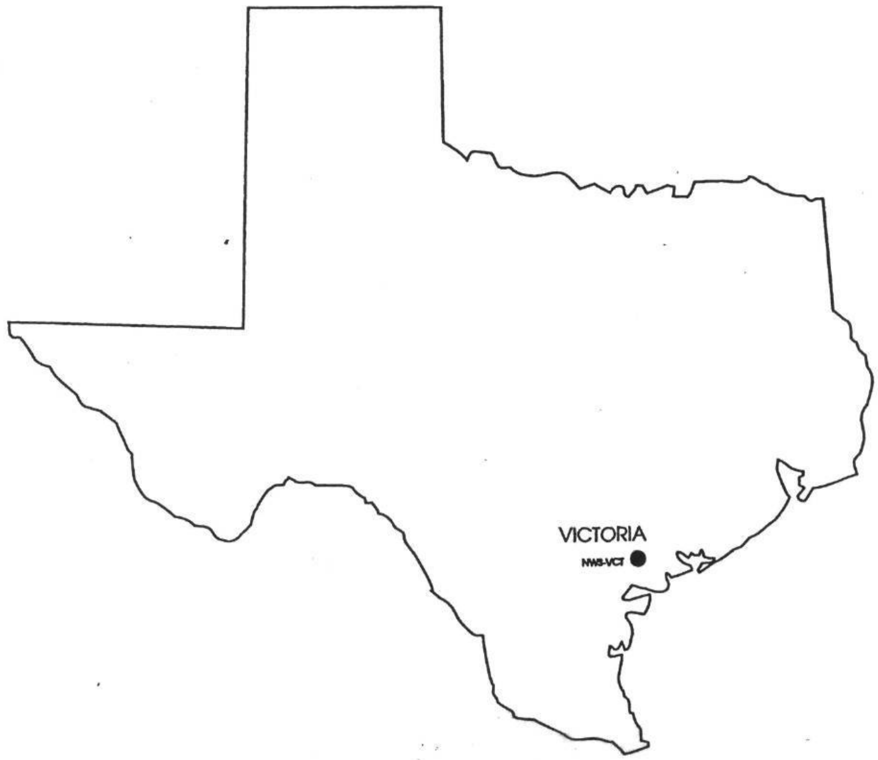
On the following page is Figure 4.1, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for SHS. SHS has a relatively flat power levels for both peak electric (the upper line) and monthly average consumption (the lower line) during the entire year. Natural Gas use appears to have declined from year to year. There also appears to be good gas shut down in the summer time. Lastly, PLF drops off significantly in the summer time while ELF and OLF do not indicating a potential to shut off some electrical systems in the summer time.

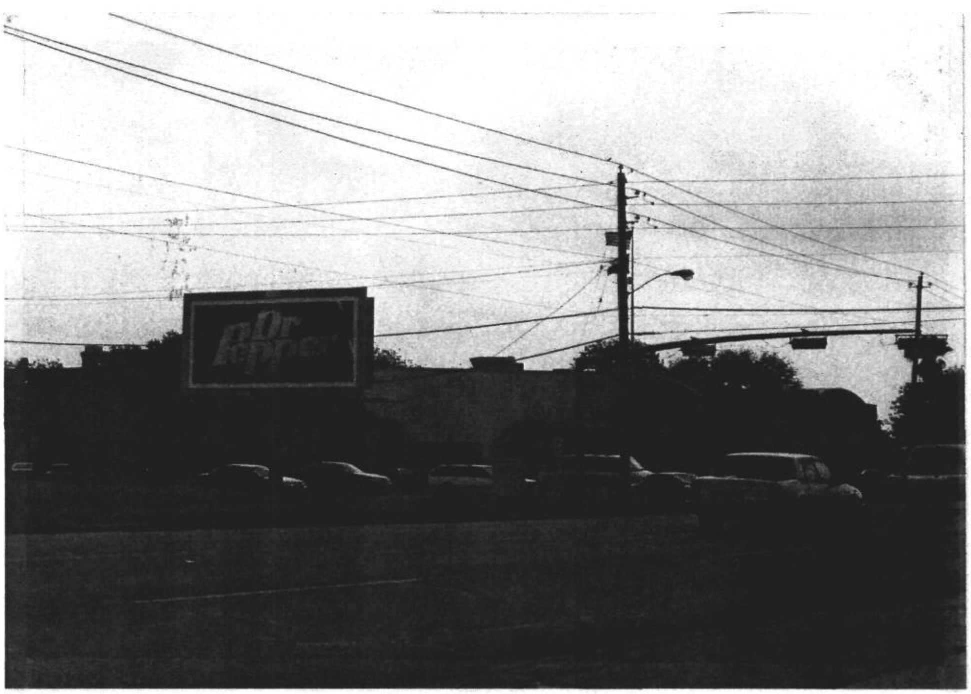
Figure 4.1: ***Monthly Data for SHS***: *Electric, Natural Gas, ELF, OLF, PLF, and weather data*

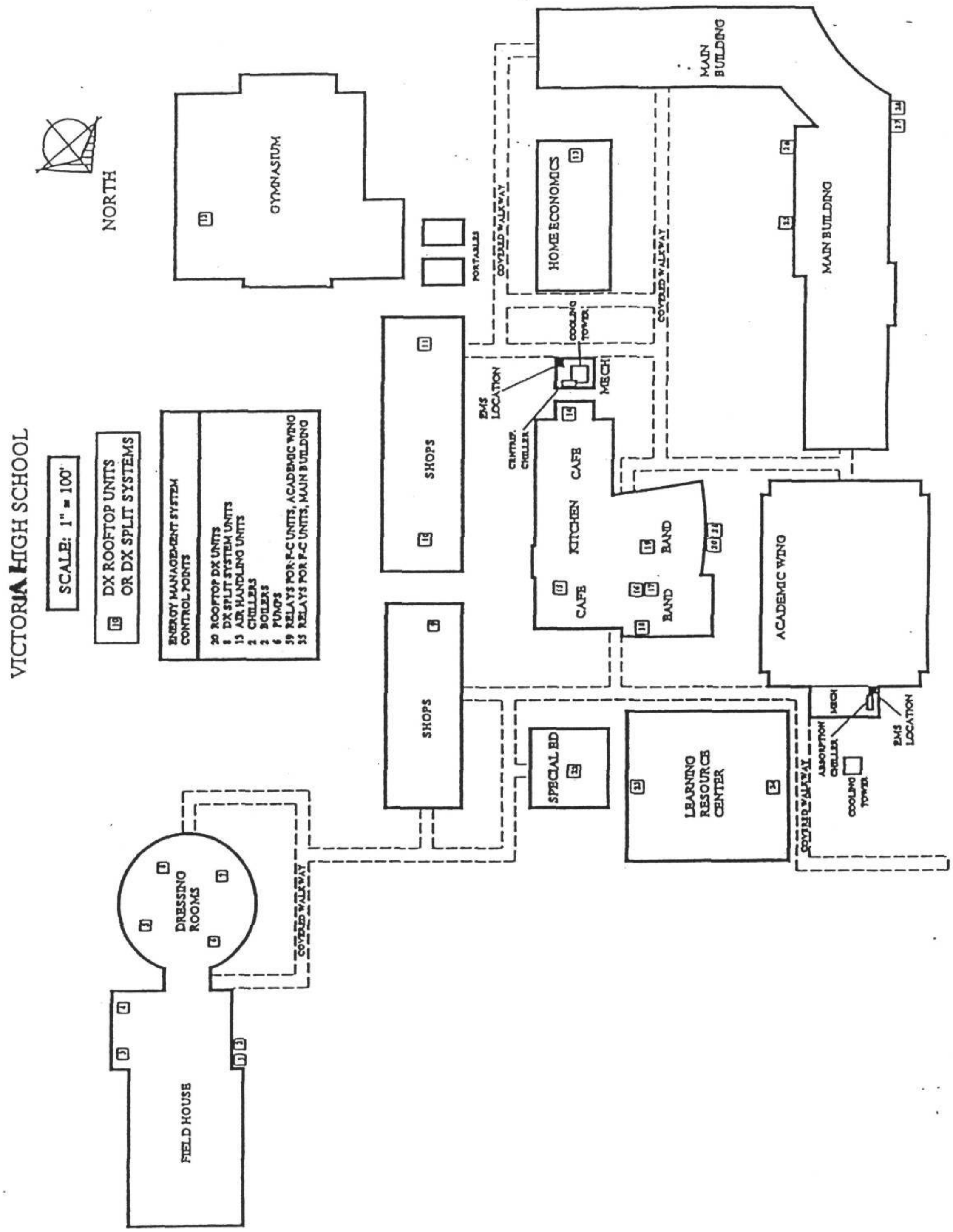


4.2 Victoria High School (VHS)

Victoria High School






VICTORIA HIGH SCHOOL
SCALE: 1" = 100'
DX ROOFTOP UNITS OR DX SPLIT SYSTEMS
ENERGY MANAGEMENT SYSTEM CONTROL POINTS
20 ROOFTOP DX UNITS
8 DX SPLIT SYSTEM UNITS
13 AIR HANDLING UNITS
2 CHILLERS
2 BOILERS
6 PUMPS
59 RELAYS FOR F-C UNITS, ACADEMIC WING
33 RELAYS FOR F-C UNITS, MAIN BUILDING
NORTH
GYMNASIUM
PORTABLES
COVERED WALKWAY
HOME ECONOMICS
MAIN BUILDING
SHOPS
EMS LOCATION
CENTRIF. CHILLER
COOLING TOWER
MECH
KITCHEN
CAFE
BAND
ACADEMIC WING
SPECIAL ED
LEARNING RESOURCE CENTER
ABSORPTION CHILLER
DRESSING ROOMS
FIELD HOUSE

4.2 Victoria High School (VHS)

Victoria High School is located in Victoria, TX. It consists of ten buildings with a total floor area of 257,014 square feet. The two largest buildings are the Main Building and the Academic Wing. Both of these buildings are two story, brick, slab on grade construction, with a flat roof. Both buildings are served by hydronic fan-coil units. The chiller serving the Main Building is a 192 ton centrifugal chiller, with 25 horsepower chilled water and condenser pumps, and a 15 horsepower cooling tower fan. The chiller serving the Academic Wing is a 182 ton chiller with 20 horsepower chilled water and 15 horsepower condenser water pumps and a 20 horsepower cooling tower fan.

The eight remaining buildings are all single story, served by rooftop units with direct expansion cooling and gas heating. These buildings include a field house/dressing room, two shops building, a gymnasium, special education building, learning resource center, home economics building, and a multipurpose building with kitchen, cafeteria, band hall, and choir rooms.

Air distribution is primarily through single-duct air-handling systems providing cooling. Setpoint temperatures for cooling are in the 75 F range, and heating temperatures are in the 70-72 F range. Heating and air-handling systems are turned-off completely during the evening and are maintained from a central location through a Carrier EMCS.

The school is operated from the middle of August through the middle of May with approximately 2,135 students and 228 faculty and staff. The maximum school occupancy is from approximately 8:00 a.m. until 4:00 p.m. However, the building is occupied for much longer periods including weekends and summers. Stroman and Victoria High School alternate as the primary location for summer school. Victoria was the site during the summer of 1992. Electricity is purchased from Central Power and Light Company, natural gas from ENTEX Gas Company.

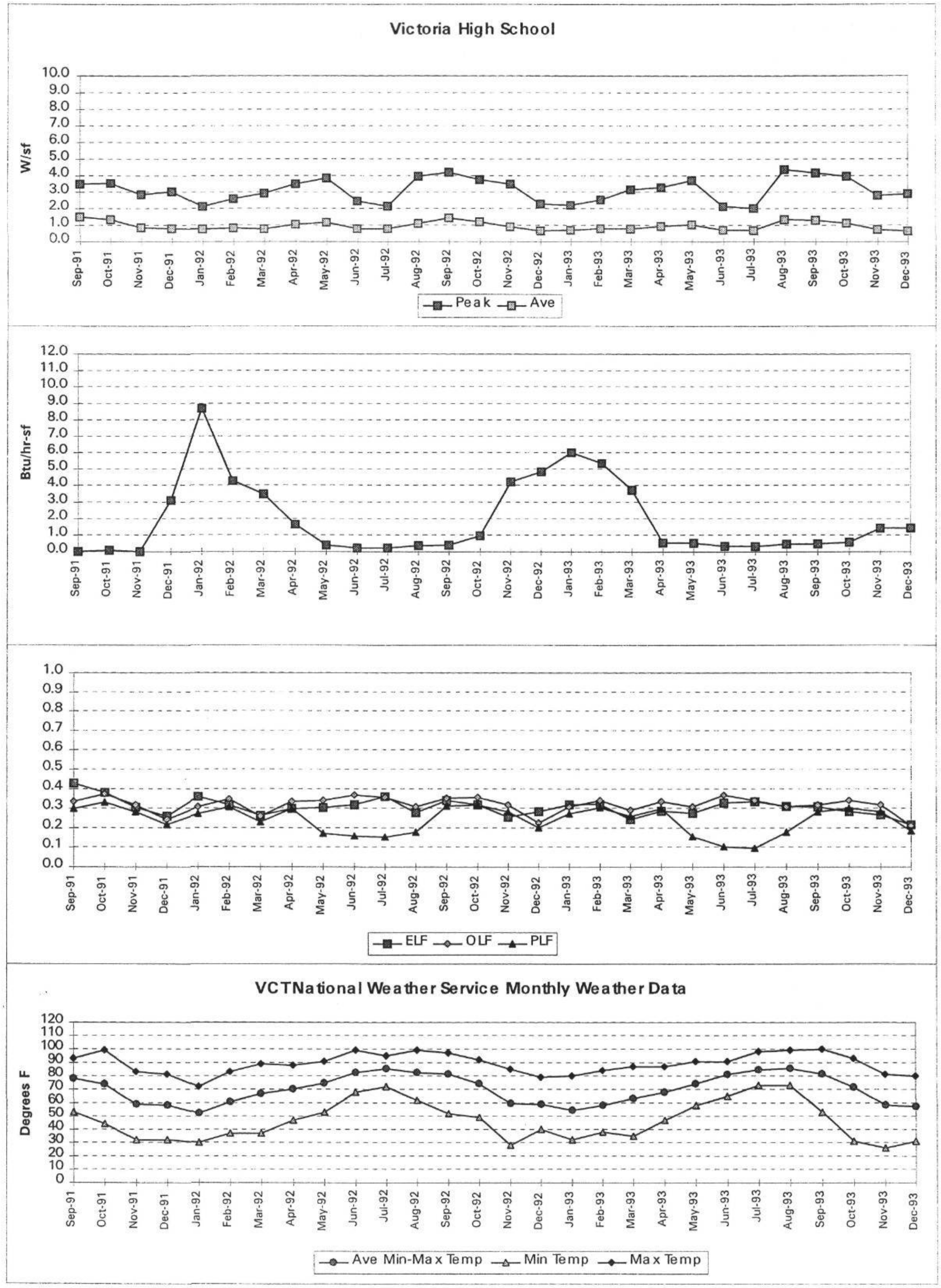
The following ECRMs were installed at VHS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

Retrofits	Date Competed
•Install EMS	Aug. 1991
•Replace Absorption Chiller	Aug. 1991

All retrofits were completed prior to data collected for analysis in this report.

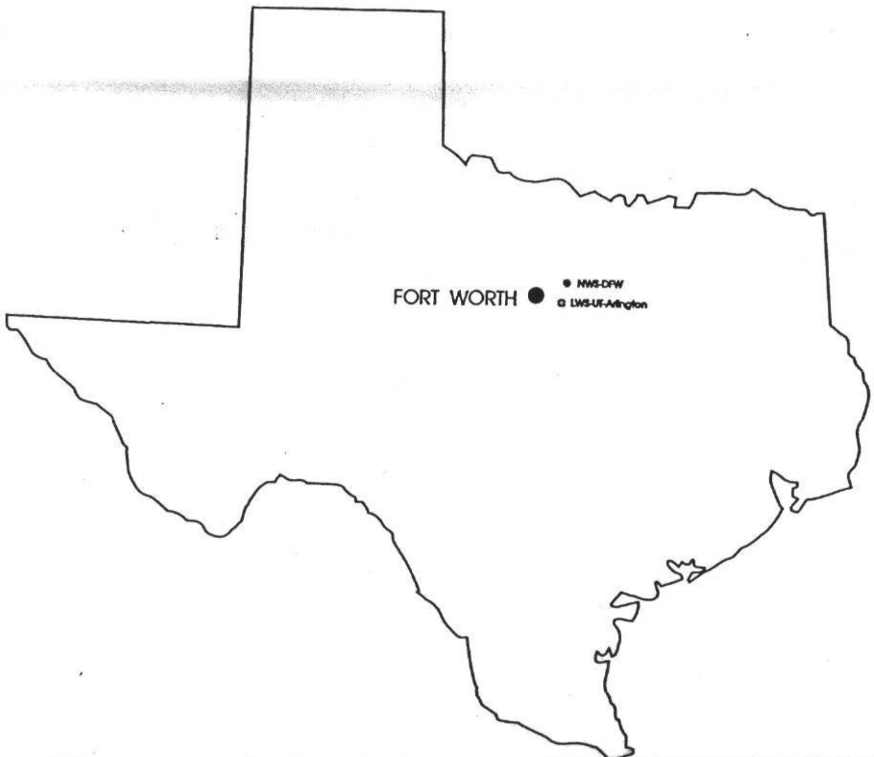
On the following page is Figure 4.2, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for VHS. VHS has a slightly higher peak W/sf than SHS. The peak electric is the upper line and monthly average consumption is the lower line. Natural Gas use appears to have declined from year to year. There also appears to be good gas shut down in the summer time. ELF, OLF, and PLF match very well throughout most of the year except the summer time. Lastly, PLF drops off significantly in the summer time while ELF and OLF do not indicating a potential to shut off some electrical systems in the summer time

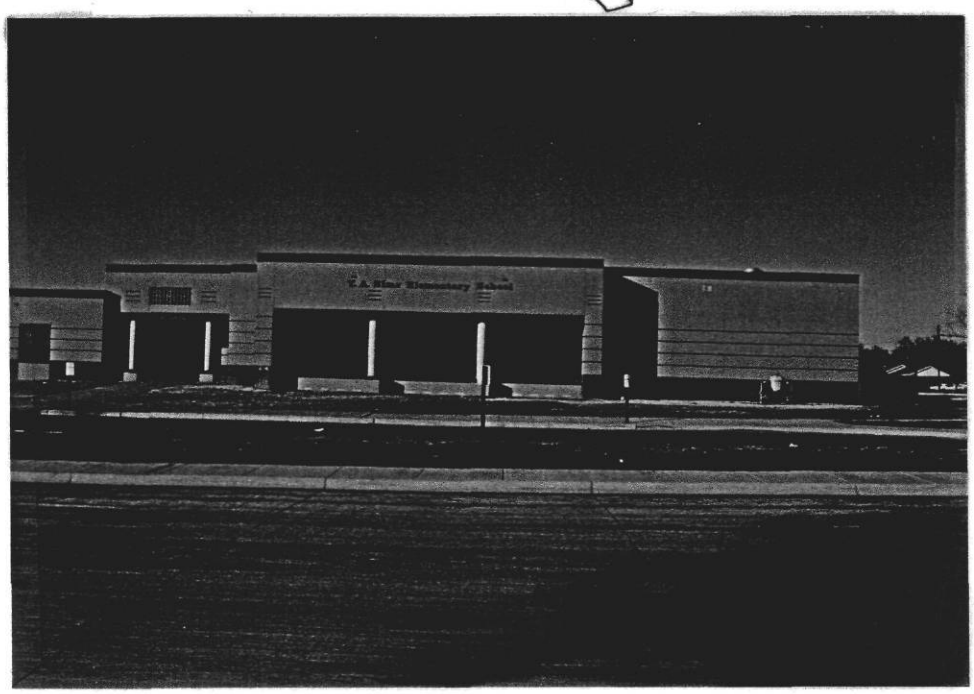
Figure 4.2: *Monthly Data for VHS: Electric, Natural Gas, ELF, OLF, PLF, and weather data*

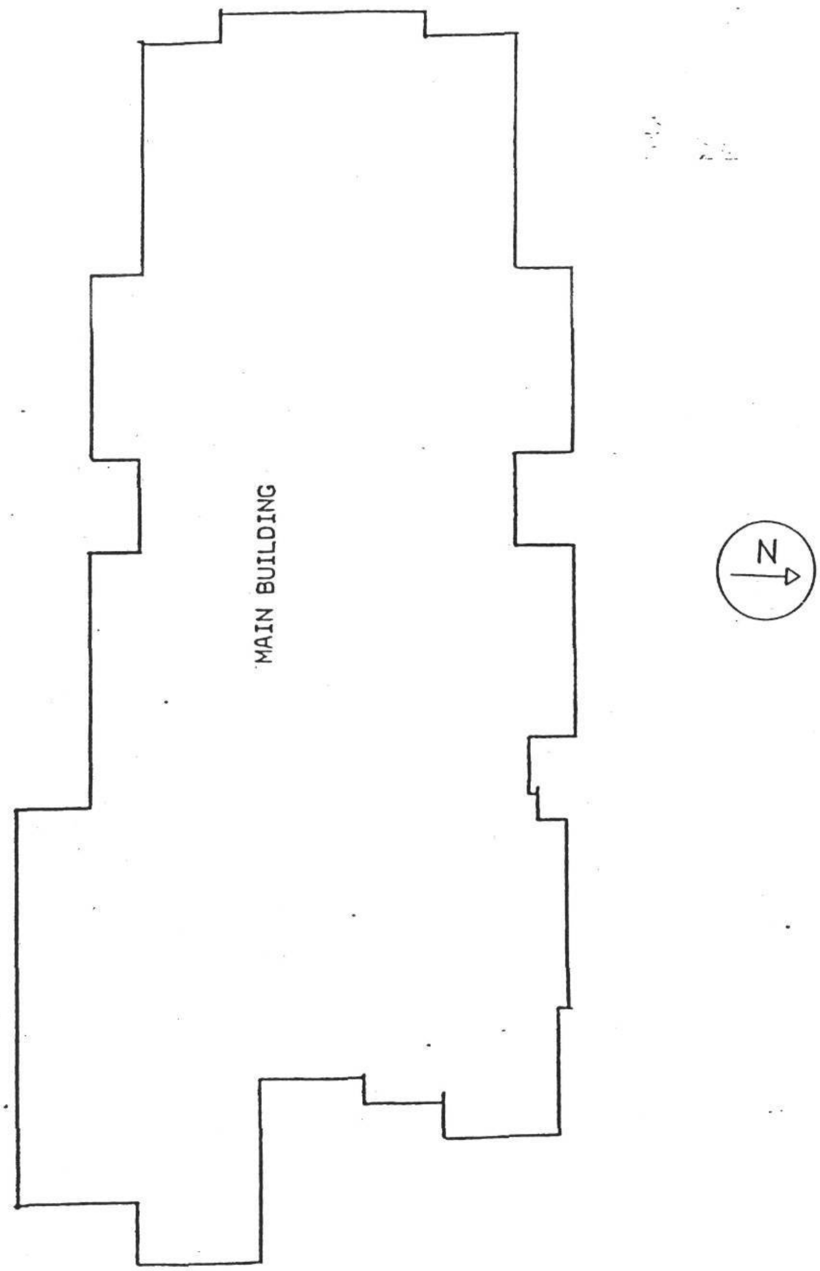


4.3 Sims Elementary School (SES)

T.A. Sims Elementary School






MAIN BUILDING
N

4.3 Sims Elementary School (SES)

Sims Elementary school is located in Fort Worth, TX It is a single story concrete building with single-pane tinted, operable windows. Sims is 62,400 square feet There are approximately 54 rooftop units of various sizes that provide both heating and cooling throughout the building.

The school is operated from August through May with approximately 862 students and 50 faculty and staff. The maximum school occupancy is from approximately 7:00 a.m. until 3:00 p.m. The building has a lower occupancy during the weekend. There are also three summer sessions of three weeks duration each during the morning in the summer time with only approximately 10% of the students and staff present. Electricity is purchased from Texas Utilities Electric Company and natural gas from Lone Star Gas Company.

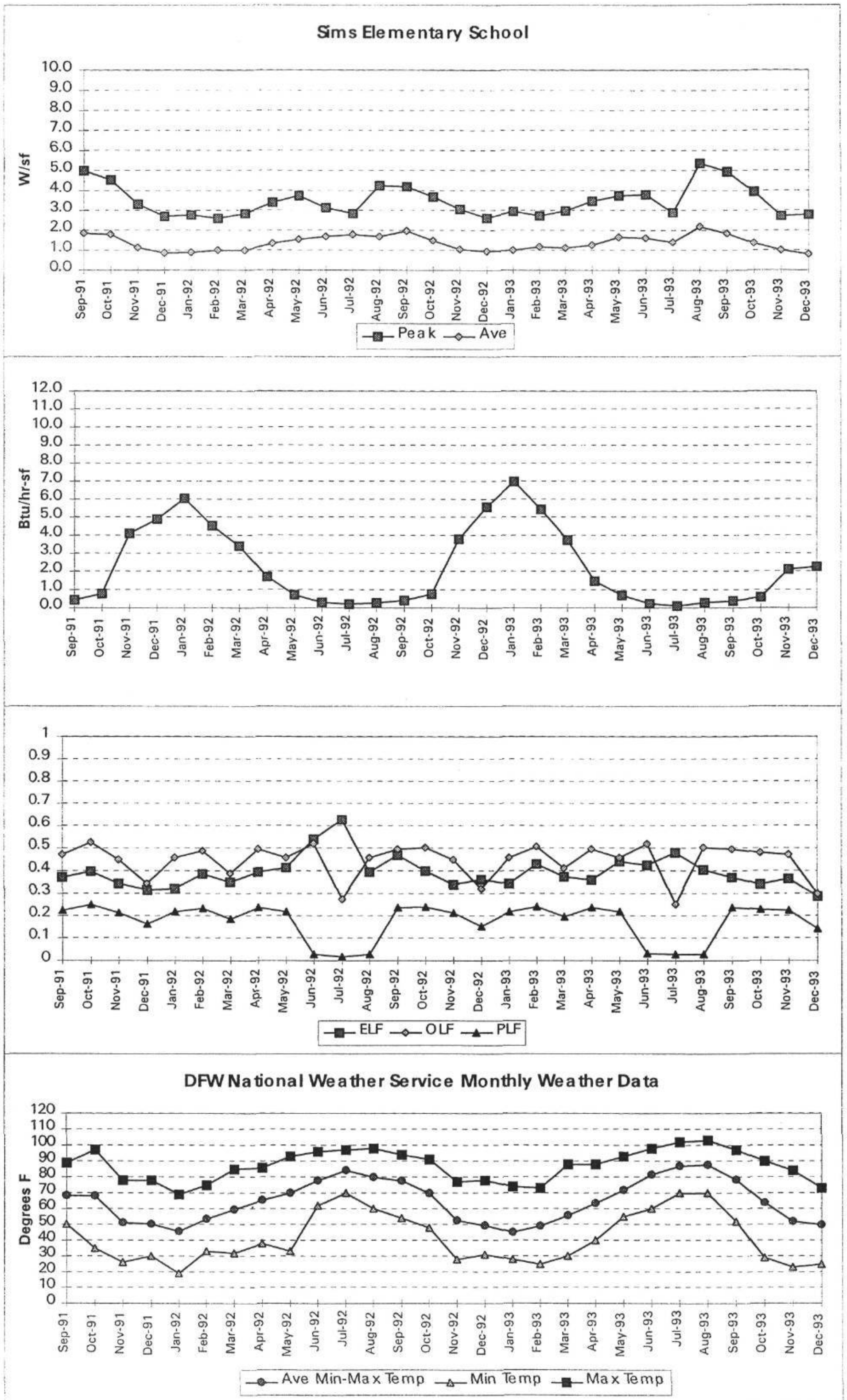
The following ECRM was installed at SES with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

Retrofits	Date Competed
•Convert 2x4 to 1x4 fl	Nov. 1991

The retrofit was completed in November 1991 and the data analyzed for this report started in September 1991. Therefore there may be a slight drop-off in electricity power levels due to the retrofits from December 1991 through December 1993.

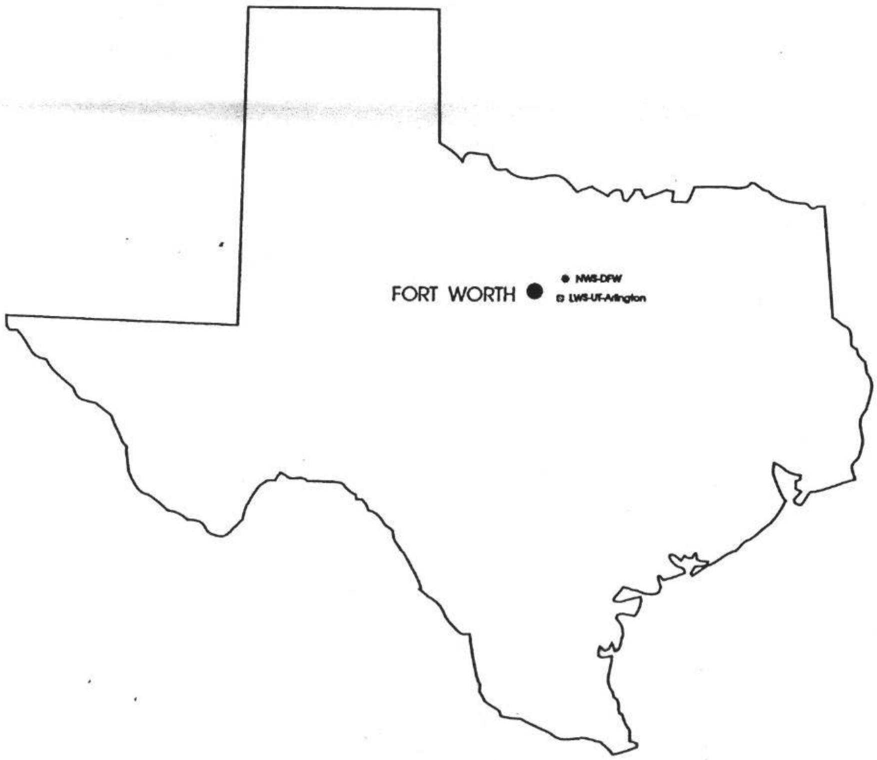
On the following page is Figure 4.3, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for SES. The peak electric demand fluctuates from just below 3 W/sf to 5 W/sf. There also appears to be good gas shut down in the summer time. Lastly, PLF drops off significantly in the summer time while ELF actually increases indicating significant potential to shut off some electrical systems in the summer time

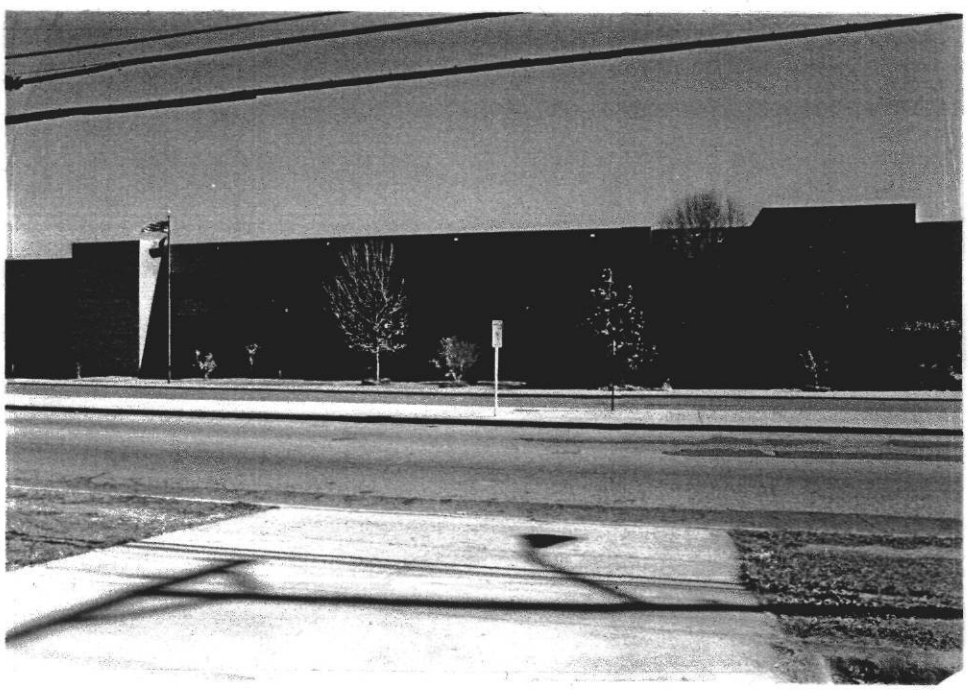
Figure 4.3: *Monthly Data for SES: Electric, Natural Gas, ELF, OLF, PLF, and weather data*

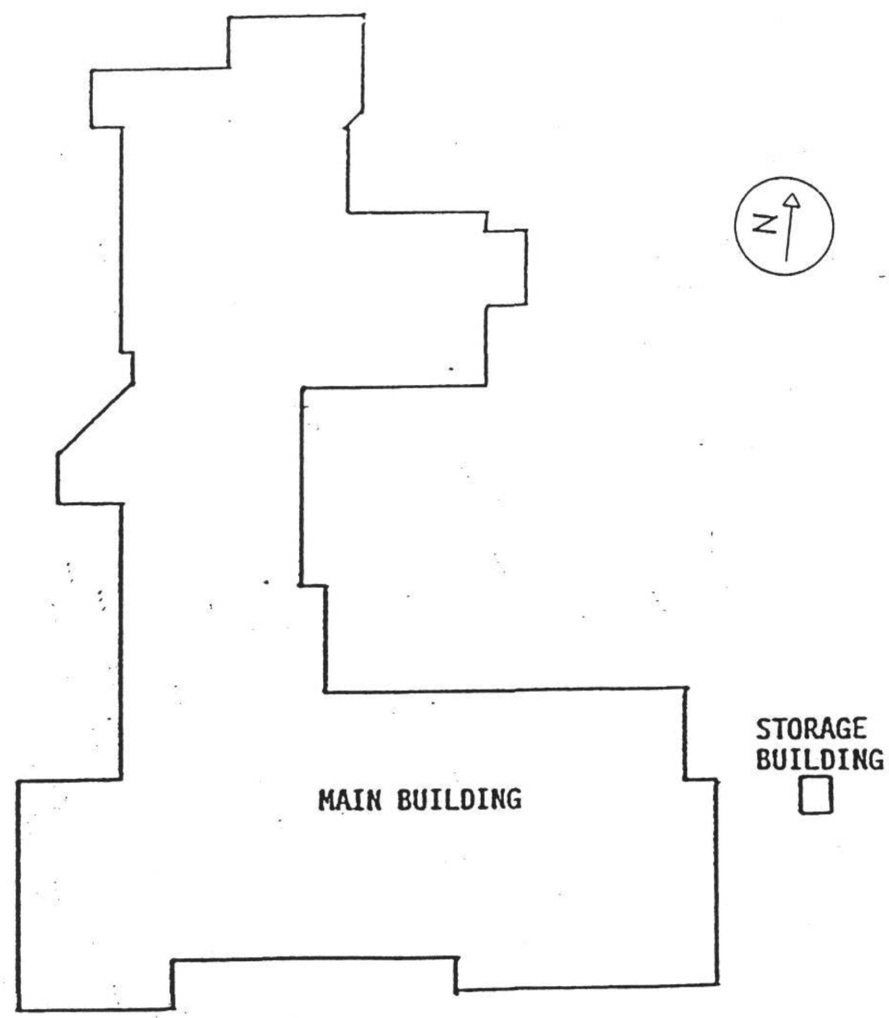


4.4 Dunbar Middle School (DMS)

Dunbar Middle School






N
STORAGE
BUILDING
MAIN BUILDING

4.4 Dunbar Middle School (DMS)

Dunbar Middle School is located in Fort Worth, TX. There are three buildings; the main building which is two stories and contains 92,884 square feet in gross conditioned area. An activities buildings contains 6,128 square feet and is heated but not cooled. There is also a portable building that is both heated and cooled. The main building has a brick exterior with a cinderblock interior wall. The main building is heated by a 2,520 MBtu/hr centralized sectional steam boiler and cooled with two 110 ton chillers and air handing units. The activities building has gas-fired unit heaters, while the portable building has a packaged electric unit for heating and cooling.

The school is operated from August through May with approximately 774 students and 85 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:00 p.m. There is some usage on the weekends and afternoons for sporting events in the Fall, not as much in the Spring. There is also a ten day summer school session starting the end of July that operates during the morning. Electricity is purchased from Texas Utilities Electric Company and natural gas from Lone Star Gas Company.

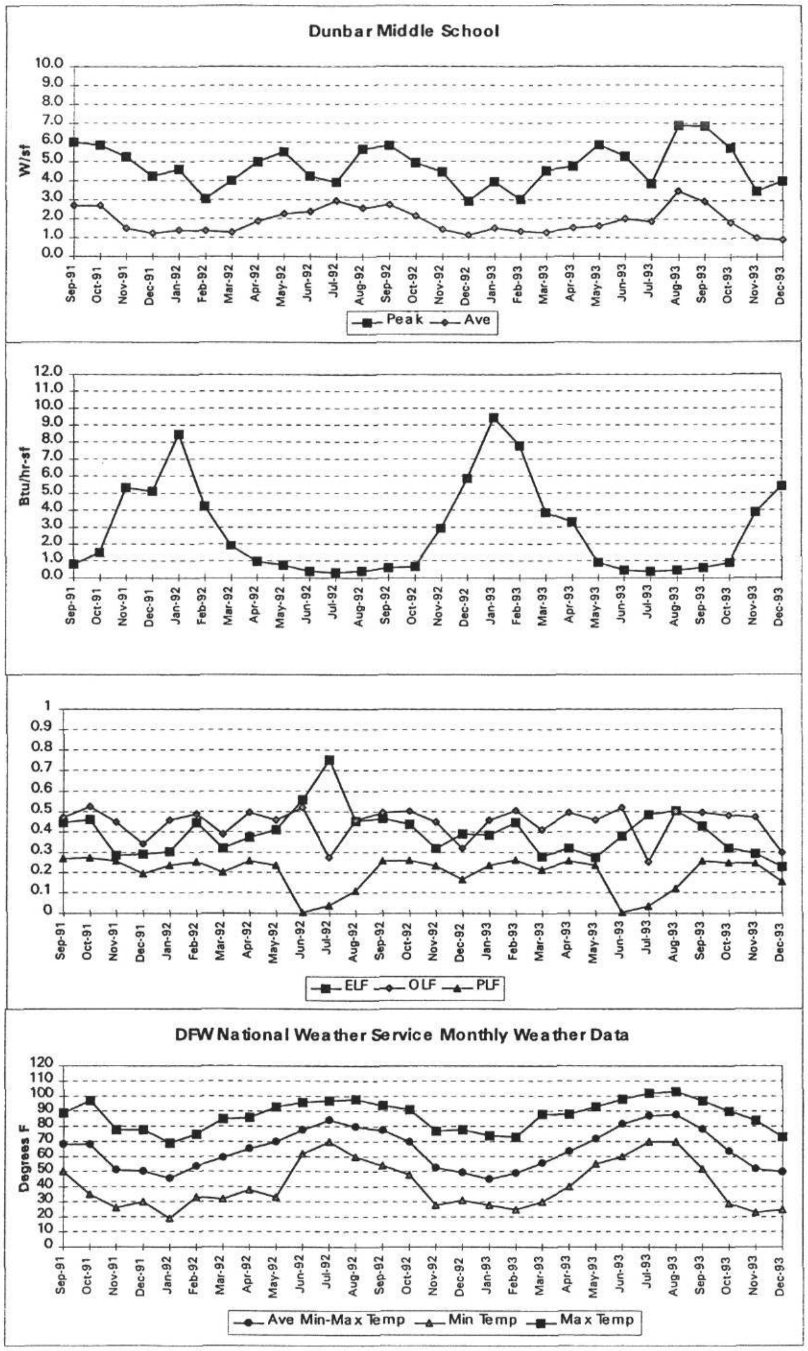
The following ECRM was installed at DMS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

Retrofits	Date Competed
•Convert 2x4 to 1x4 fl	Nov. 1991

The retrofit was completed in November 1991 and the data analyzed for this report started in September 1991. Therefore there many be a slight drop-off in electricity power levels due to the retrofits from December 1991 through December 1993.

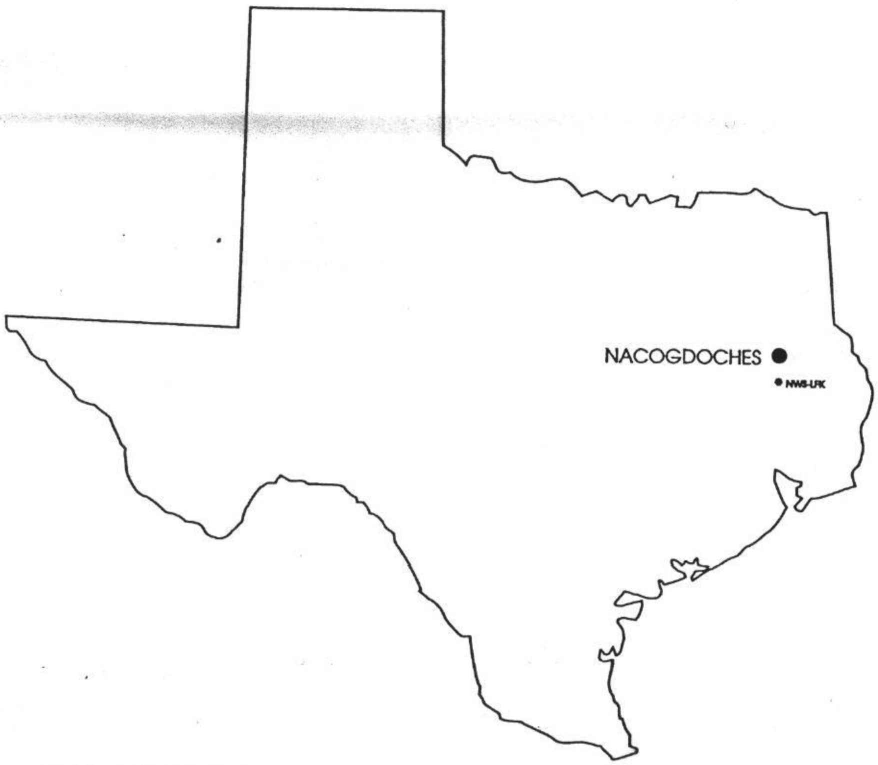
On the following page is Figure 4.4, which shows the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for DMS. Electric use in the summer time is very high, about 3.0 W/sf. Also, the peak electric demand is very erratic, fluctuating from just below 3.0 W/sf to 7.0 W/sf. There does appear to be good gas shut down in the summer time, about 0.5 Btu/(hr-sf). Lastly, PLF drops off significantly in the summer time while ELF actually increases indicating significant potential to shut off some electrical systems in the summer time.

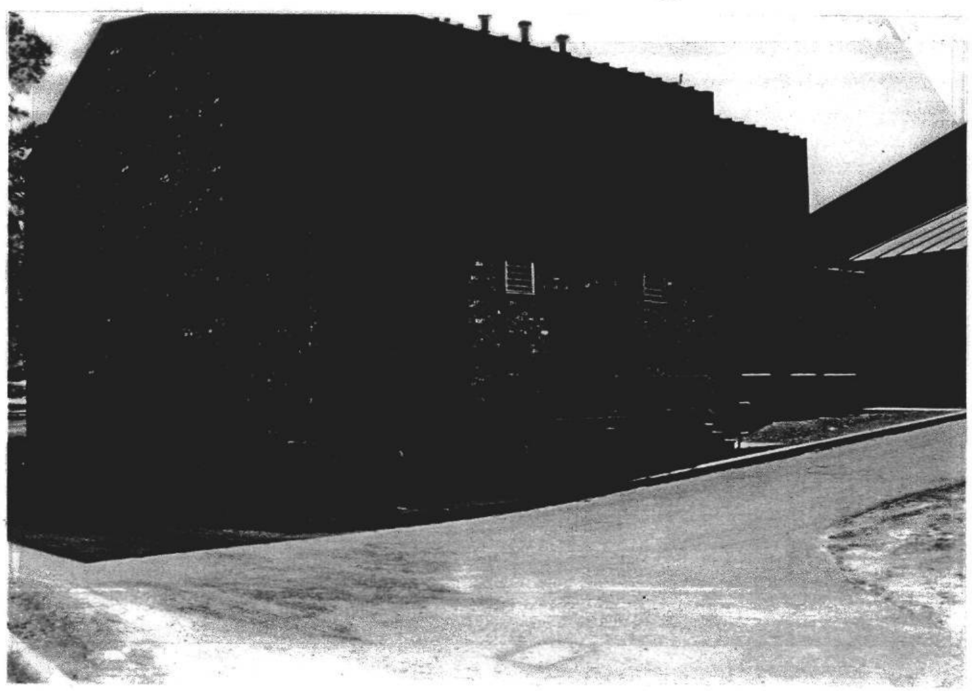
Figure 4.4: ***Monthly Data for DMS****: Electric, Natural Gas, ELF, OLF, PLF, and weather data*

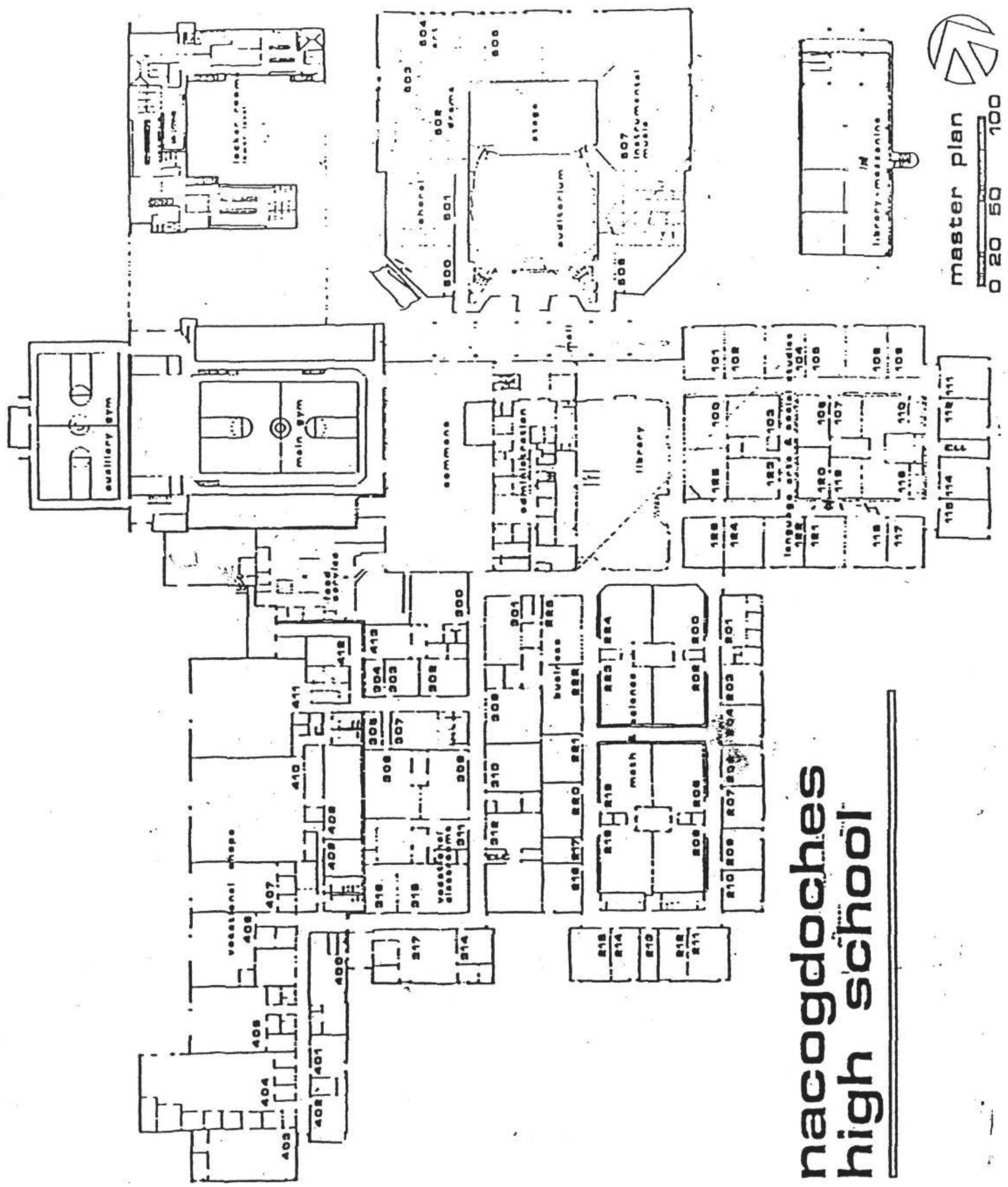


4.5 Nacogdoches High School (NHS)

Nacogdoches High School






nacogdoches
high school
master plan
0 20 50 100
main gym
auxiliary gym
commons
library
auditorium
stage
vocational shops

4.5 Nacogdoches High School (NHS)

Nacogdoches High School is located in the Nacogdoches Independent School District in northeastern Texas. It contains 206,750 square feet of space in three main buildings. The main building composes all but the band hall and the 600 wing of school. The 600 wing is used for summer school in order to try to shut-off most of the school. In the Band wing, cooling units are maintained year-round to reduce the humidity from damaging any of the instruments. The main heating system is a new 6 million Btu/hr modular boiler system installed for the 1993 heating season. The main cooling system are four chillers providing 548 tons of cooling. The band wing is heated by three 120,000 Btu/hr forced warm air furnaces in the band hall and a 20 ton roof top unit provides heating and cooling for the old band hall located in the same building. Twenty-two constant volume air handing units provide heating and cooling for the main building during the day.

The school is operated from August through May with approximately 1,800 students and 160 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:30 p.m. However, the building is occupied for much longer periods with afternoon and weekend activities as well as summer school. Electric service is purchased from Texas Utilities Electric Company and natural gas from ENTEX Gas Company

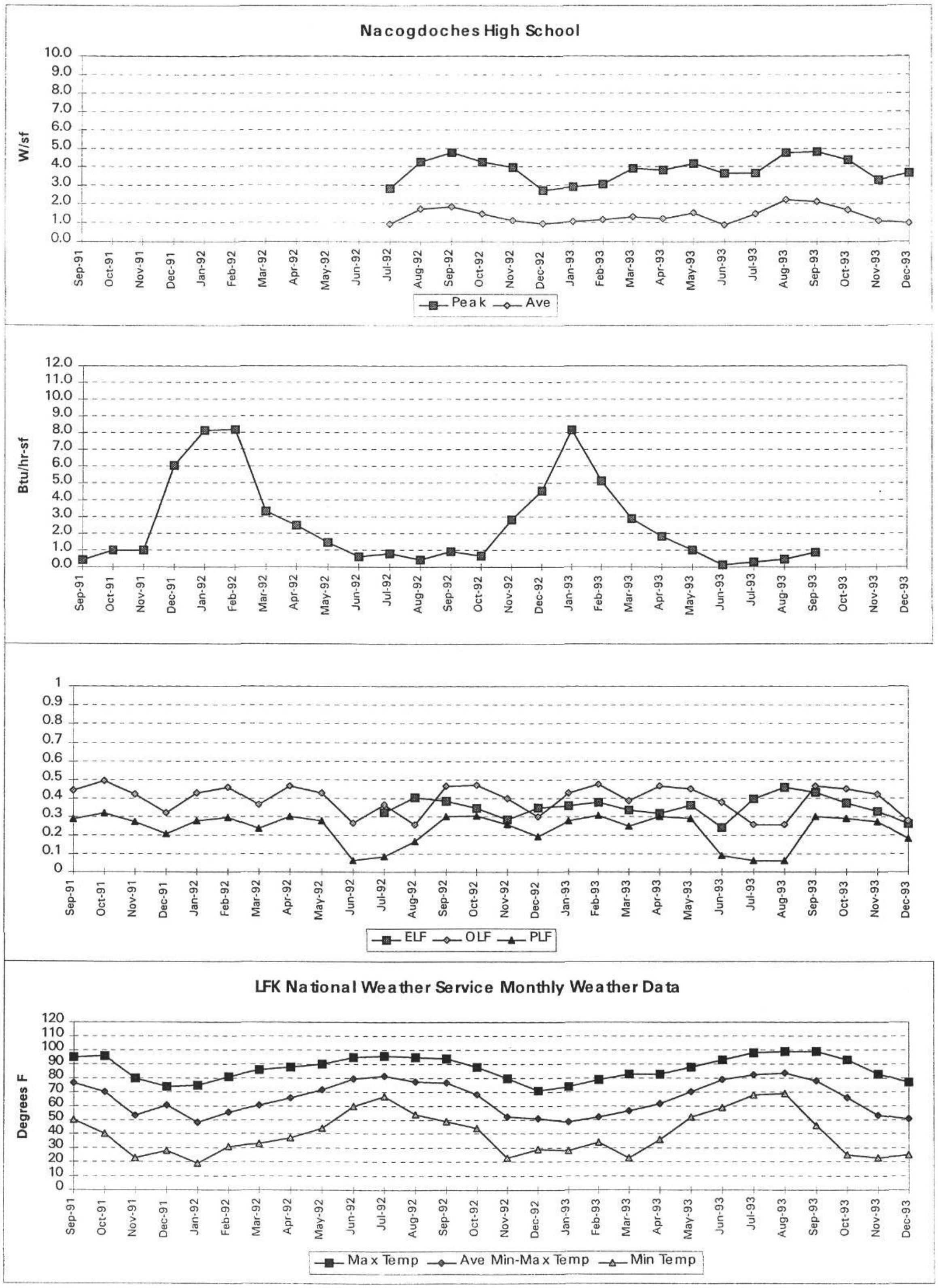
The following ECRMs were installed at NHS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

Retrofits	Date Competed
•Install EMS	Oct. 1992
•Fixture Relamping	Oct. 1992
•Convert to Gas Heating	Not Completed
•Increase Cooling Capacity	Oct. 1992

The retrofits were completed in October 1992 and the data analyzed for this report started in September 1991. Therefore there are probably going to be slight variations in both electricity and natural gas power levels due to the retrofits.

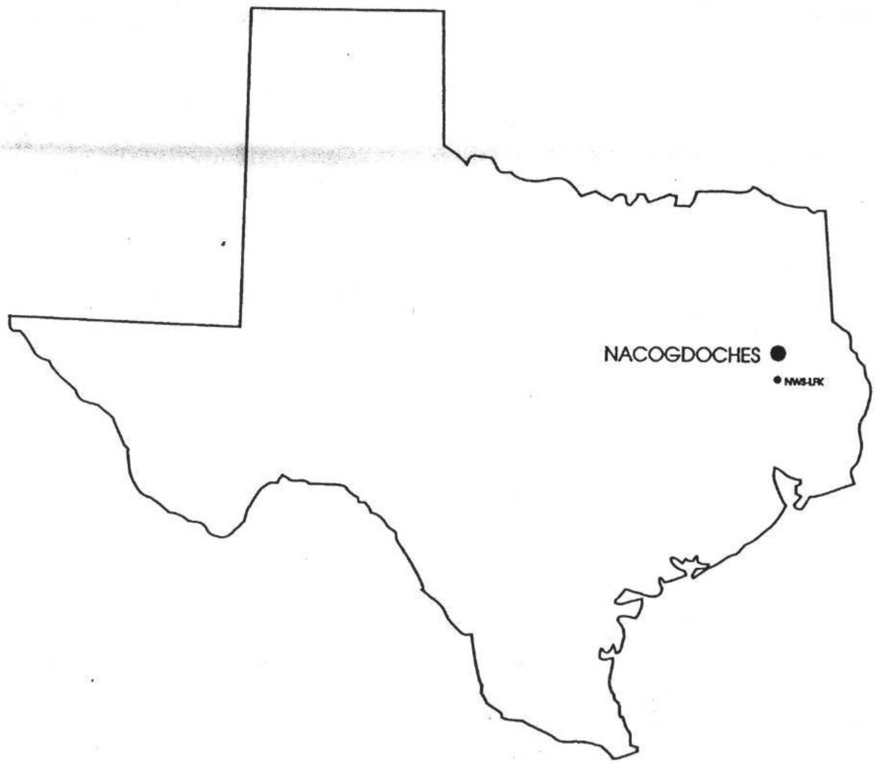
On the following page is Figure 4.5, which shows the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for NHS. The electric demand (the upper line) and monthly average consumption (lower line) increase with the start of school and decrease during the summer time and months with long vacation. Lastly, PLF drops off significantly in the summer time while ELF and OLF do not indicating a potential to shut down some electrical systems in the summer time

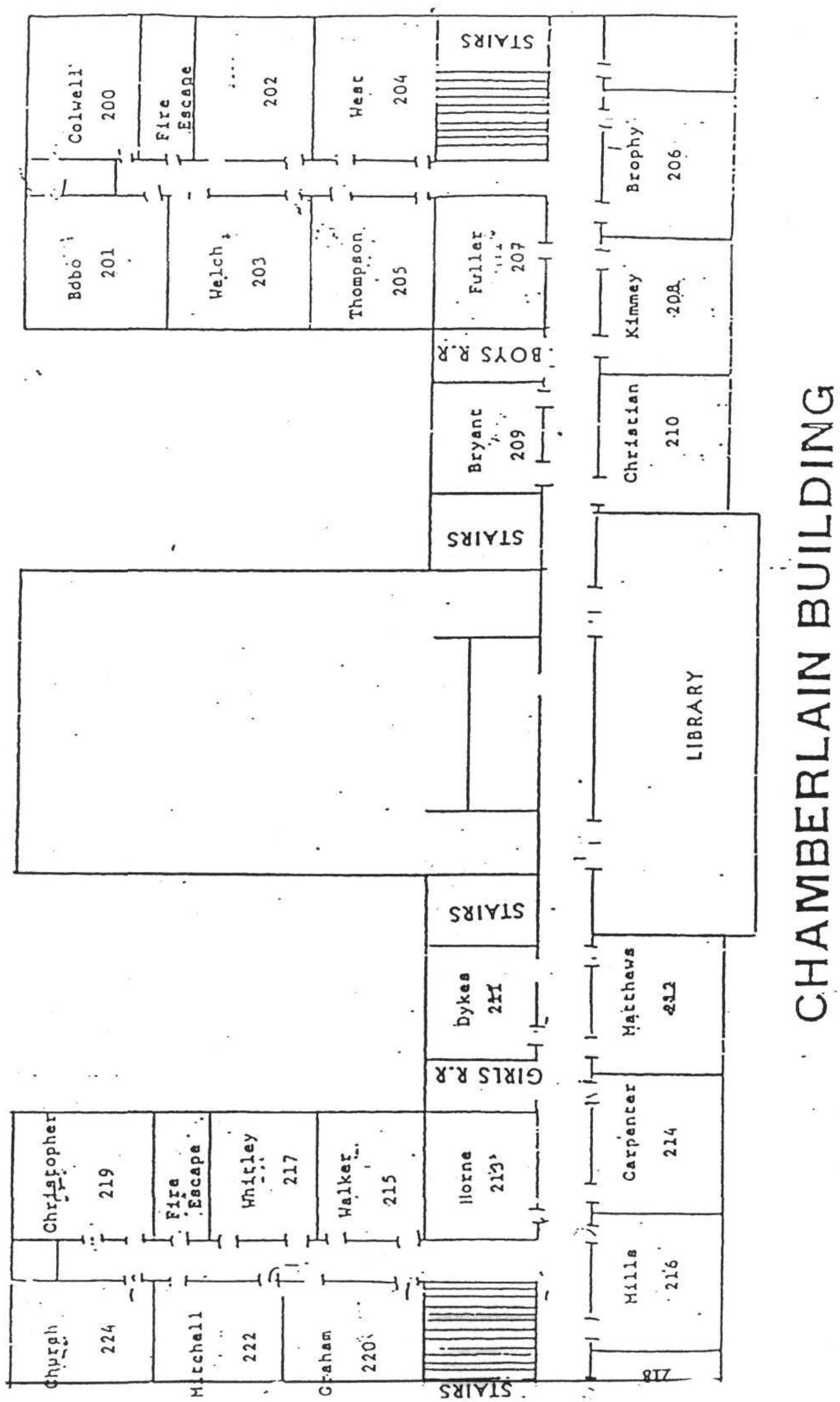
Figure 4.5: *Monthly Data for NHS: Electric, Natural Gas, ELF, OLF, PLF, and weather data*



4.6 Chamberlain Middle School (CMS)

Chamberlain Middle School




CHAMBERLAIN BUILDING
Colwell 200
Fire Escape
202
West 204
STAIRS
Brophy 206
Bdbo 201
Welch 203
Thompson 205
Fuller 207
Kimmey 208
BOYS R.R
Bryant 209
Christian 210
STAIRS
LIBRARY
STAIRS
Dykes 211
Matthews 212
GIRLS R.R
Christopher 219
Fire Escape
Whitley 217
Walker 215
Horne 213
Carpenter 214
Hills 216
Church 224
Mitchell 222
Graham 220
STAIRS
218

4.6 Chamberlain Middle School (CMS)

Chamberlain Middle School is located in Nacogdoches, TX. It is single building on the T.J. Rusk campus. It is a two story brick structure with 66,778 square feet. There are classrooms, a cafeteria, an auditorium and offices at Chamberlain. There is no gymnasium in this building; it is located elsewhere on the T.J. Rusk campus. This is the only school of the eleven which does not cook meals at this facility. Instead they are cooked elsewhere and only preheated in the kitchen prior to serving. Chamberlain is also the only one of the eleven schools to have electricity as a primary heating source in a non-portable building. The first floor is cooled by 106 tons of split systems with thirty-four AHUs with electric heating located in each classroom. There is a 10 horsepower pump to circulate the water. The remainder of the building is heated and cooled by rooftop units with a heating capacity of 2.85 million Btu/hr and cooling capacity of 90 tons.

The school is operated from August through May with approximately 1,480 students and 300 faculty and staff. The maximum school occupancy is from approximately 8:00 a.m. until 4:00 p.m. There is little usage during the weekend and some usage during the summer. Electric service is purchased from Texas Utilities Electric Company and natural gas from ENTEX Gas Company.

The following ECRMs were installed at CMS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

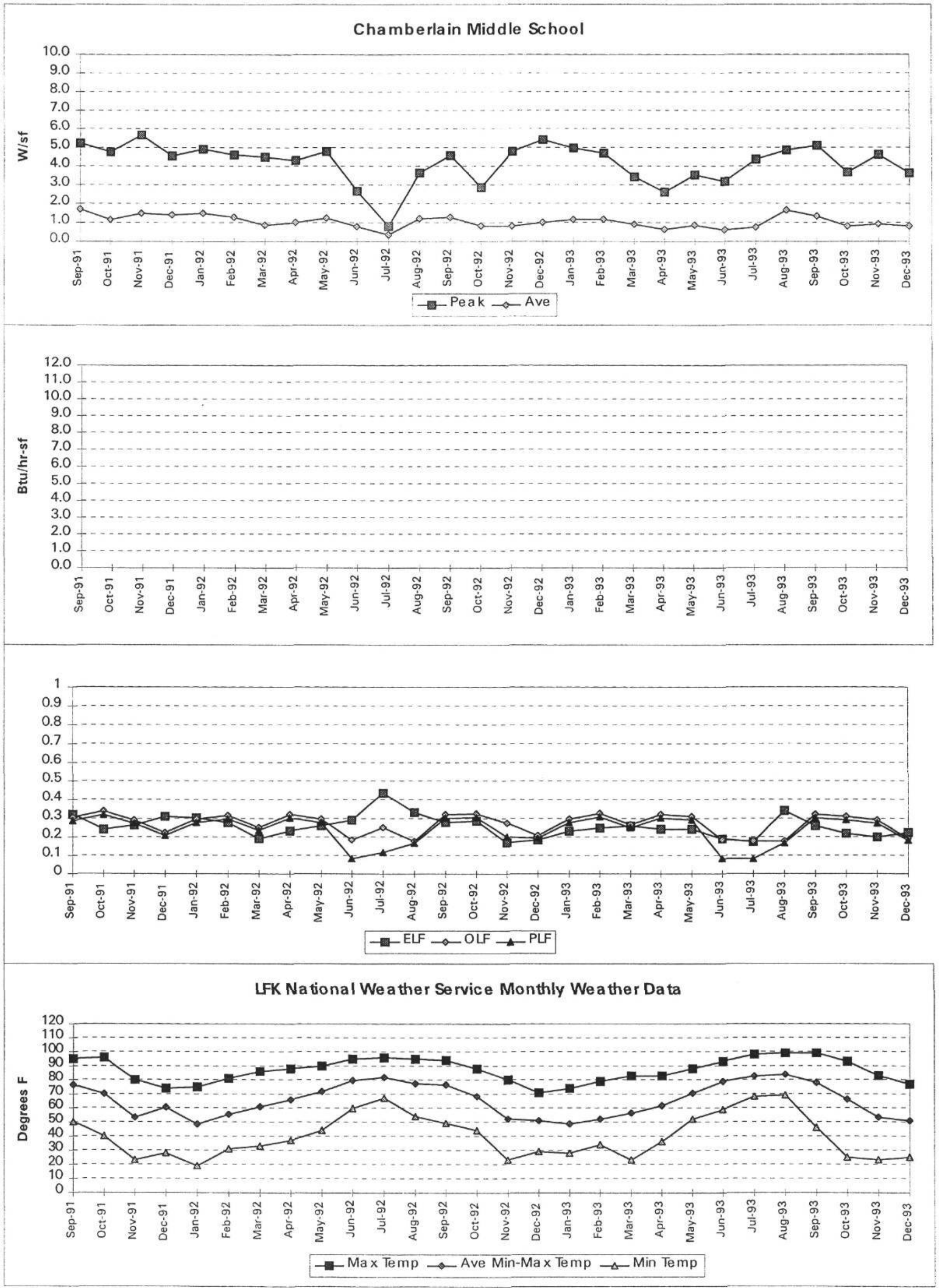
Retrofits	Date Competed
•Install EMS	Oct. 1992
•Install Gas heating on 1st floor to replace electric heating	Not Completed
•Fixture Relamping	Oct. 1992

The retrofits were completed in October 1992 and the data analyzed for this report started in September 1991. Therefore there are probably going to be slight variations in both electricity and natural gas power levels due to the retrofits.

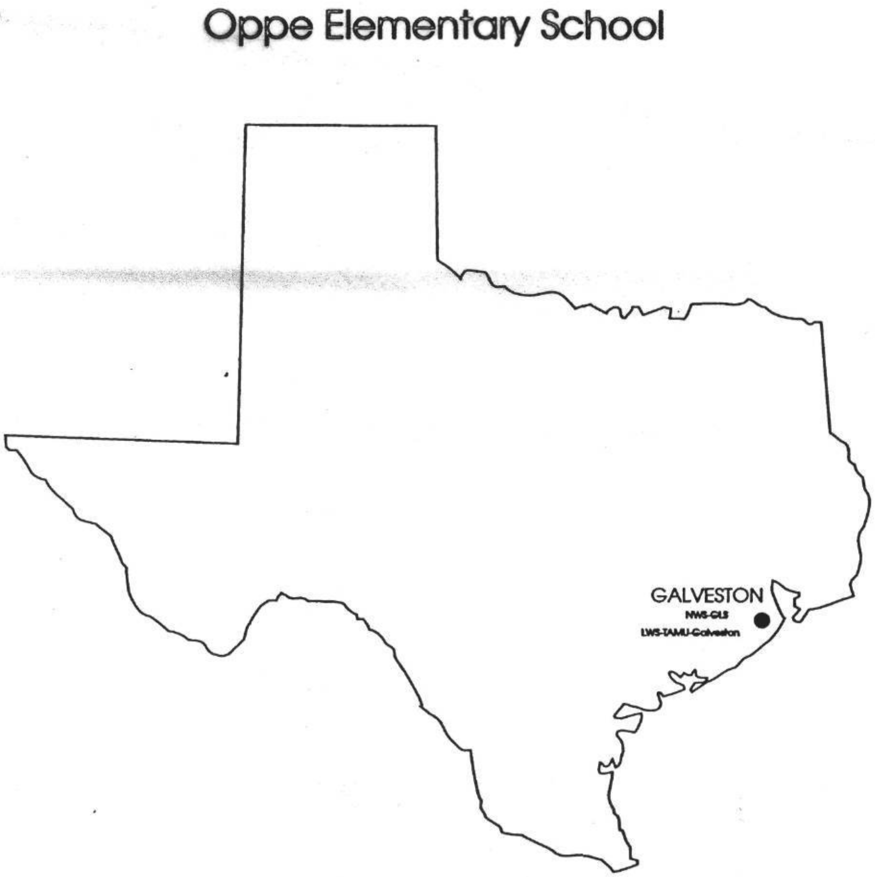
On the following page is Figure 4.6, showing the monthly electric, ELF, OLF, PLF, and weather related data for CMS. CMS has a high peak demand (the upper line) in both winter and summer. However, electric consumption (lower line) doesn't fluctuate very much from summer to winter.

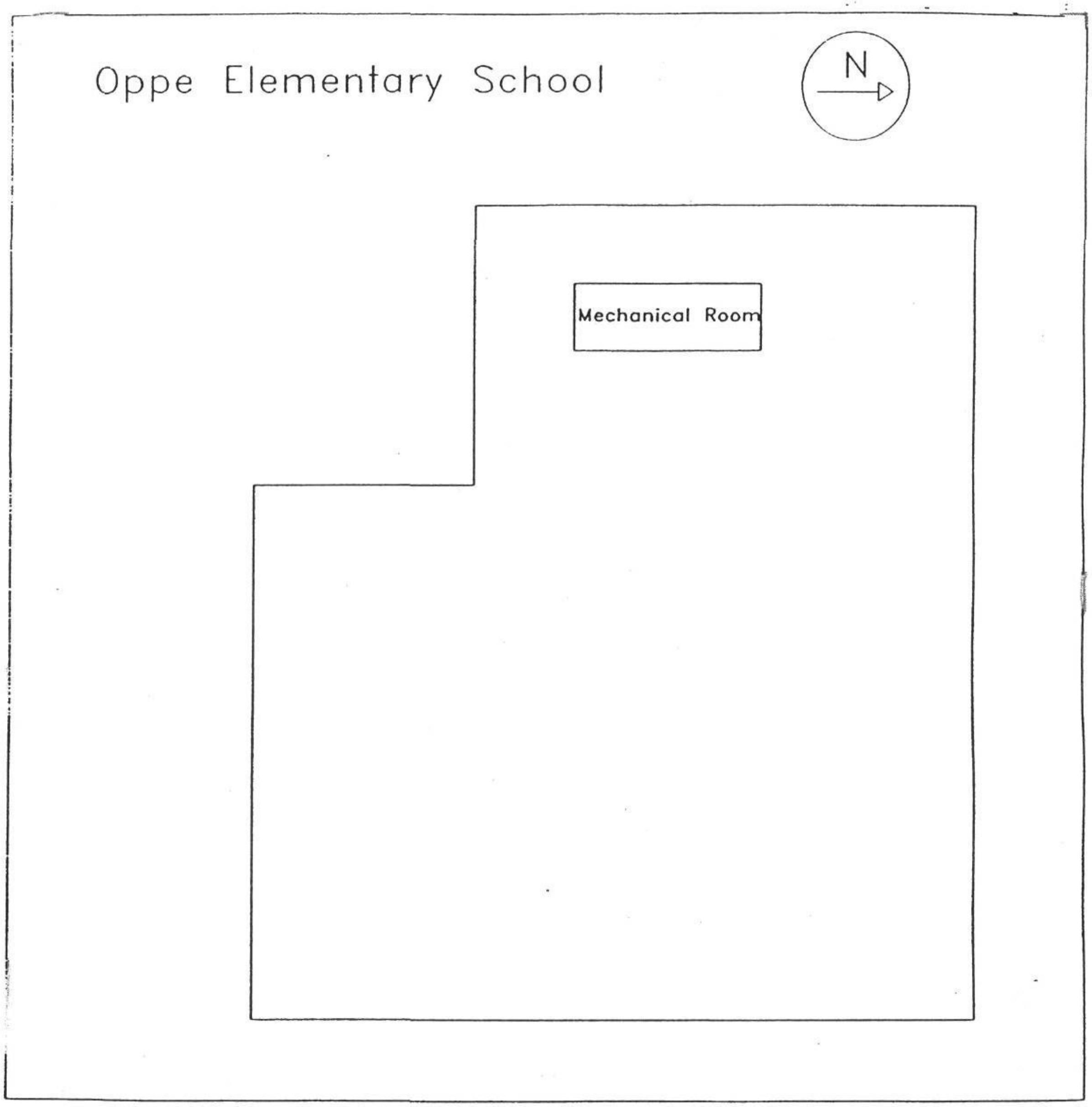
Lastly, CMS had a reasonably low PLF and ELF in the summer of 1993 indicating good shut down of equipment.

Figure 4.6: ***Monthly Data for CMS***: *Electric, Natural Gas, ELF, OLF, PLF, and weather data*



4.7 Oppe Elementary School (OES)




Oppe Elementary School
N
Mechanical Room

4.7 Oppe Elementary School (OES)

Oppe Elementary School is located in Galveston, TX. It is a single story prefabricated concrete panel construction with small energy efficient windows. It has a total floor area of 80,400 square feet with a kitchen, cafeteria, gymnasium, library, and classrooms. Cooling is provided by a 190 ton single reciprocating air-cooled chiller with cool storage. Heating is primarily provided by a 2.3 million Btu/hr gas-fired hot water boiler. There are also 6 small heat pumps. Air flow is from fan-coil units for each classroom and by AHUs in the library, gymnasium, kitchen, and cafeteria. This school also has humidity control in the summer time. The controls cause simultaneous heating and cooling which cycle throughout the year with reheat coils. Office areas are served by heat pumps. An ice thermal storage system was installed in 1993. A separate chiller was added to generate ice at night to be utilized between the hours of 1:00 p.m. and 4:00 p.m. At this time the other chillers are shut off.

The school is operated from August through May with approximately 624 students and 70 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:30 p.m. However the building is occupied for much longer periods of time in the office area and for the custodians. There is very little weekend and summer use at Oppe Elementary School.

Electric service is purchased from Houston Lighting & Power Company and natural gas from Southern Union Gas Company.

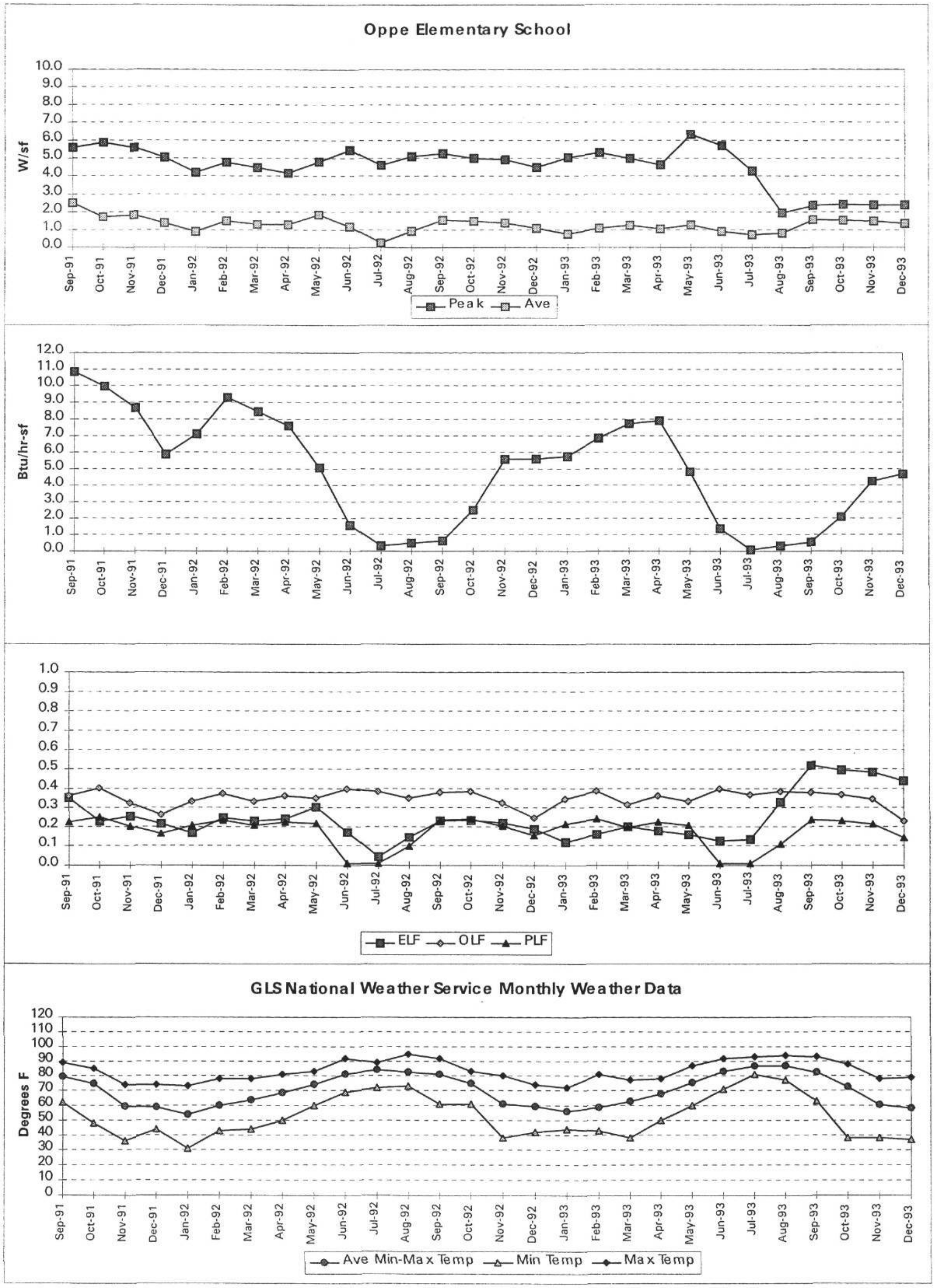
The following ECRM was installed at OES with the corresponding date reflecting the month the installation of the retrofit was completed:

Retrofit	Date Competed
•Install Thermal Storage System	May 1993

The retrofit was completed in May 1993 and the data analyzed for this report started in September 1991. There is a drop off in the electric demand power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 p.m. when the thermal storage is being used, hence the peak electric power level reflects a measurement of the peak electric readings during the 1 to 4 p.m. period in the afternoon for the month rather than the peak for all 24 hours during the month.

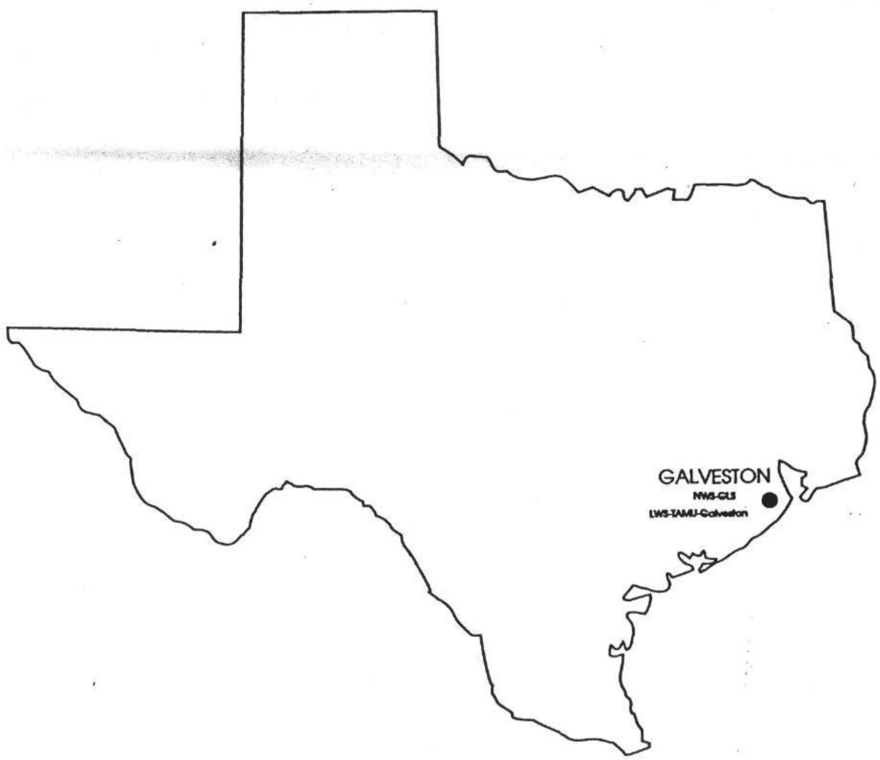
On the following page is Figure 4.7, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for OES. Also, thermal storage was installed at the school in August of 1993. Beginning in August of 1993 peak demand was measured between 1 and 4 p.m. and is not necessarily the true peak from August 1993 to the present. Natural gas use was very high in the Fall of 1991. Lastly, PLF and ELF are reasonably low during the summer.

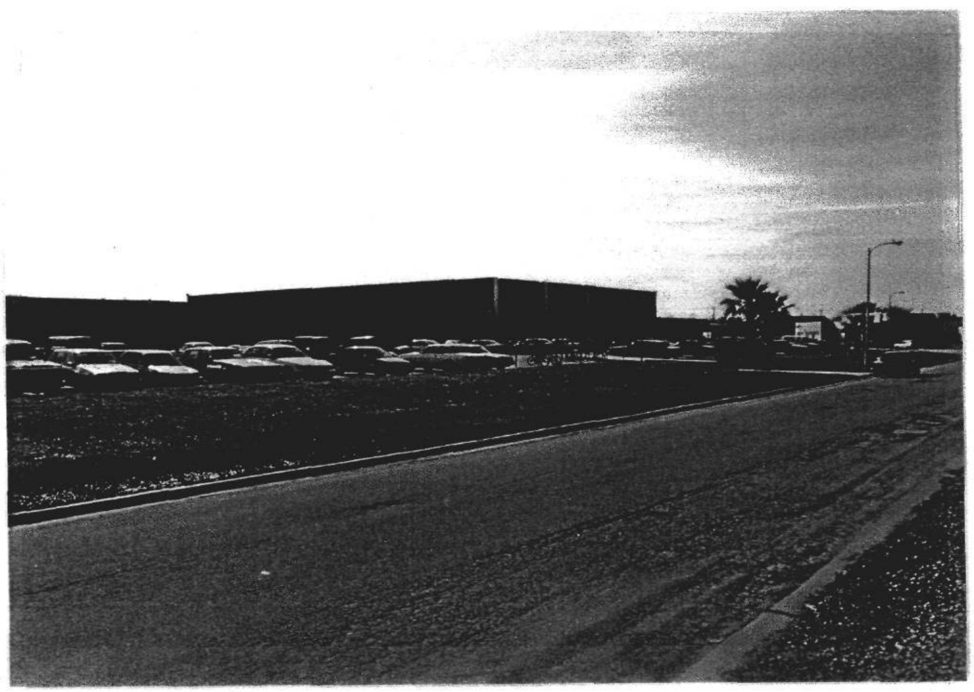
Figure 4.7: ***Monthly Data for OES****: Electric, Natural Gas, ELF, OLF, PLF, and weather data*

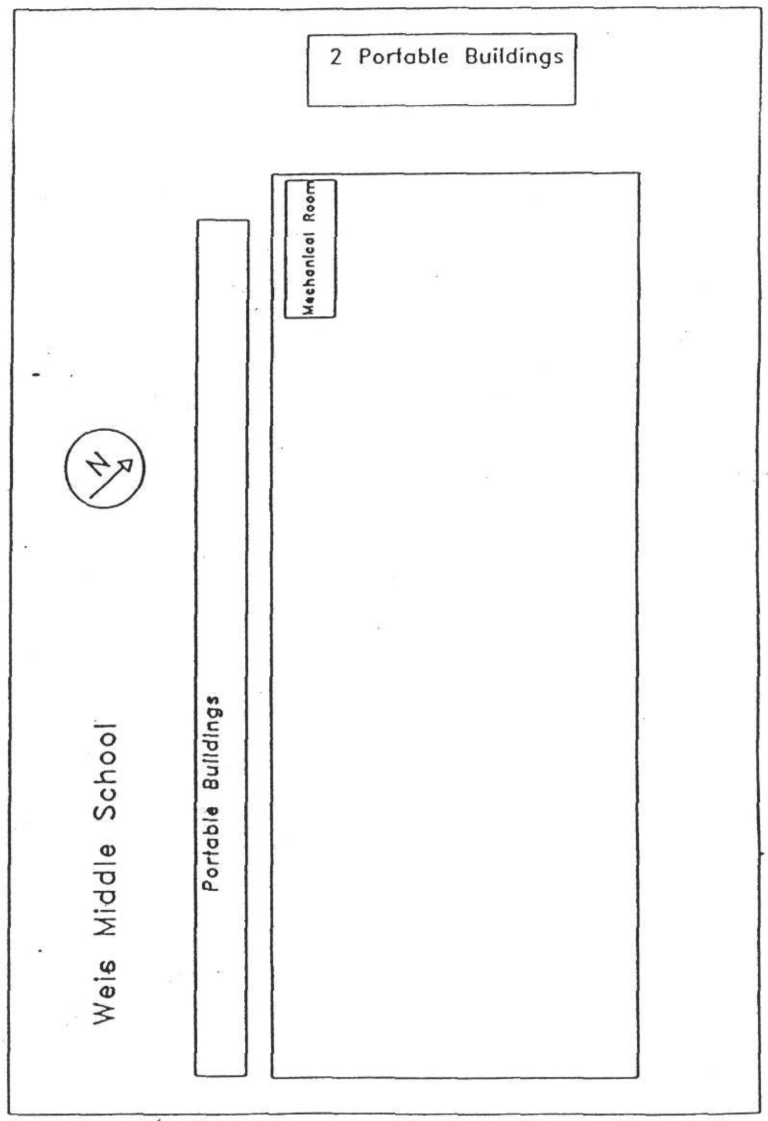


4.8 Weis Middle School (WMS)

Weis Middle School






2 Portable Buildings
Mechanical Room
Portable Buildings
Weis Middle School
N

4.8 Weis Middle School (WMS)

Weis Middle School is located in Galveston, TX. It is a single story prefabricated concrete panel type construction with small energy efficient windows. It has a total floor area of 80,769 square feet with a kitchen, cafeteria, gymnasium, library, and classrooms. There are also several portable buildings in use at Weis. However, they are on a separate electric meter and are not included in this analysis. Cooling is provided by two 140 ton reciprocating air-cooled chiller with cool storage. Heating is provided by a 3.25 million Btu/hr gas-fired hot water boiler. Air flow is from fan-coil units for each classroom and by AHUs in the library, gymnasium, kitchen, and cafeteria. This school also has humidity control in the summer time. The controls cause simultaneous heating and cooling which cycle throughout the year with reheat coils. An ice thermal storage system was installed in 1993. A separate chiller was added to generate ice at night to be utilized between the hours of 1:00 p.m. and 4:00 p.m. At this time the other chillers are shut off.

The school is operated from August through May with approximately 827 students and 80 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:30 p.m. However the building is occupied for much longer periods of time for afternoon activities and Saturday morning activities Except for the office area the school is closed during the summer time.

Electric service is purchased from Houston Lighting & Power Company and natural gas from Southern Union Gas Company.

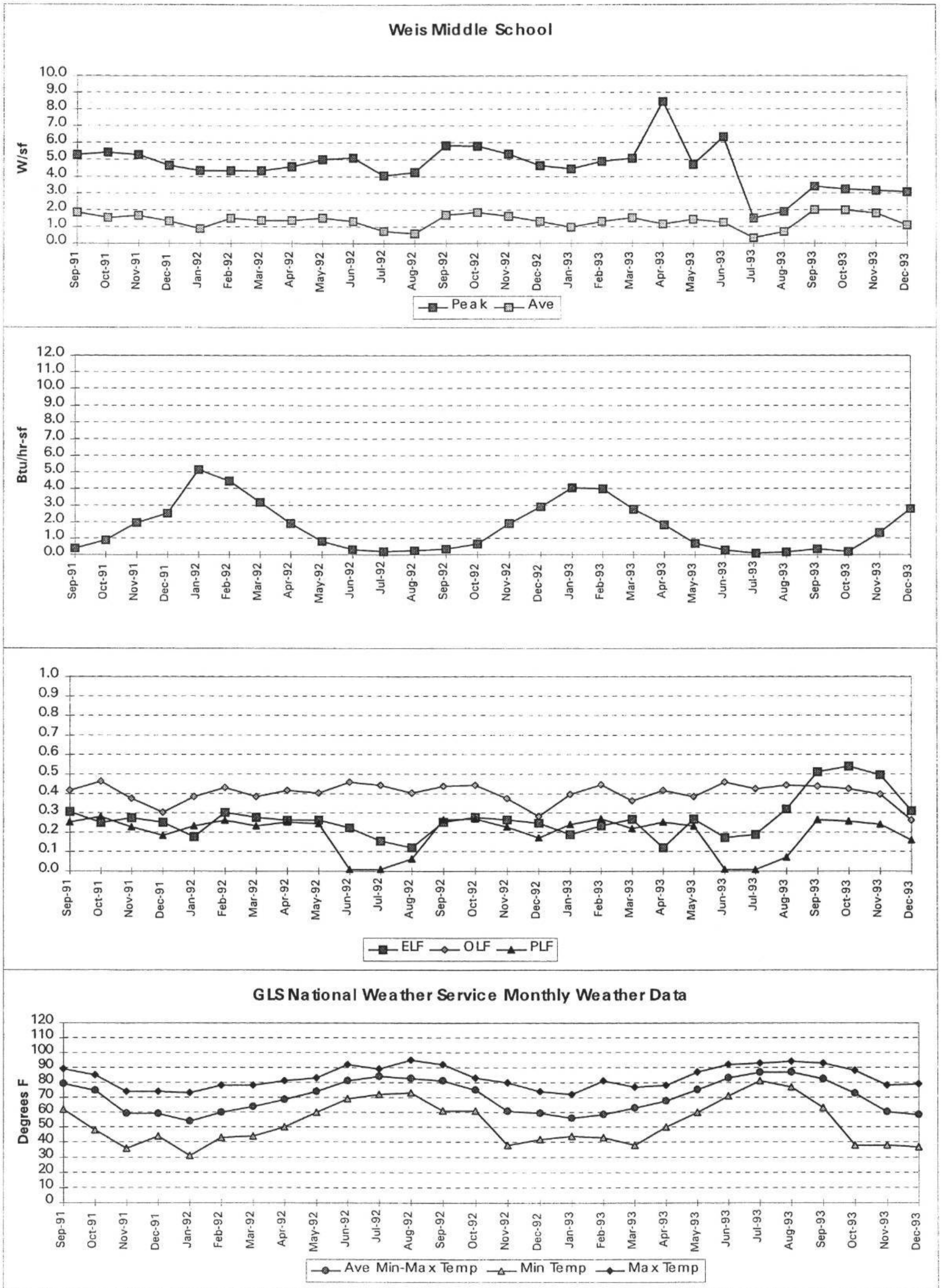
The following ECRM was installed at WMS with the corresponding date reflecting the month the installation of the retrofit was completed:

Retrofit	Date Competed
•Install Thermal Storage System	May 1993

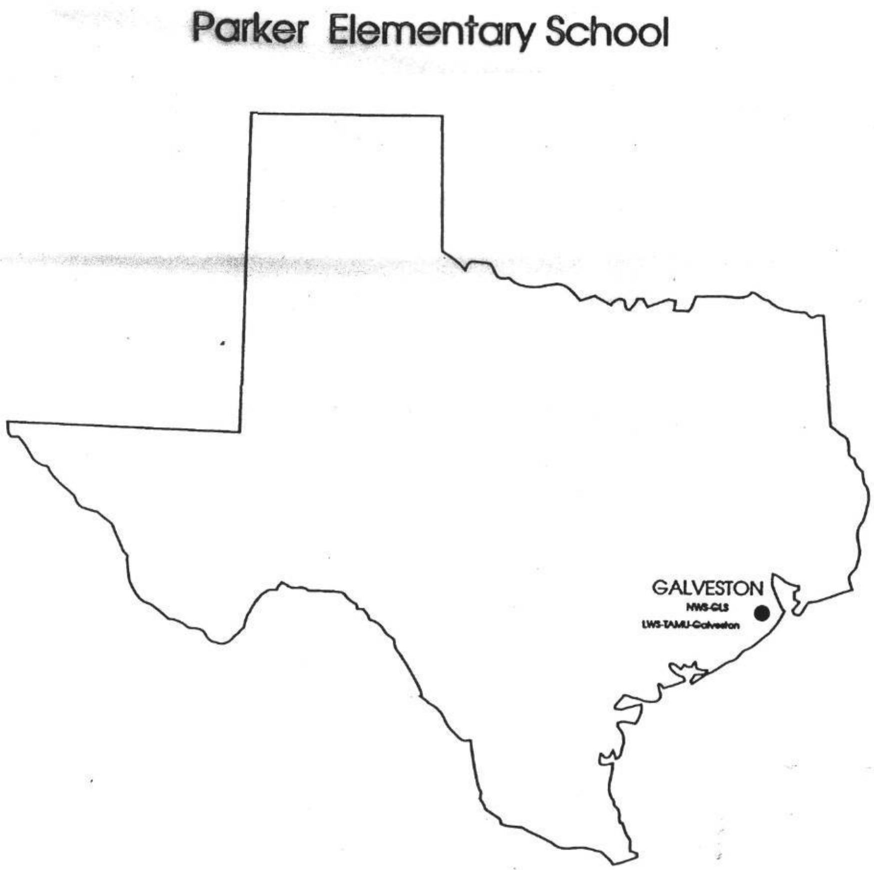
The retrofit was completed in May 1993 and the data analyzed for this report started in September 1991. There is a drop off in the electricity power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 p.m. when the thermal storage is being used, hence the peak power level became a measurement of the peak electricity readings during the afternoon for the month rather than the peak for all hours during the month.

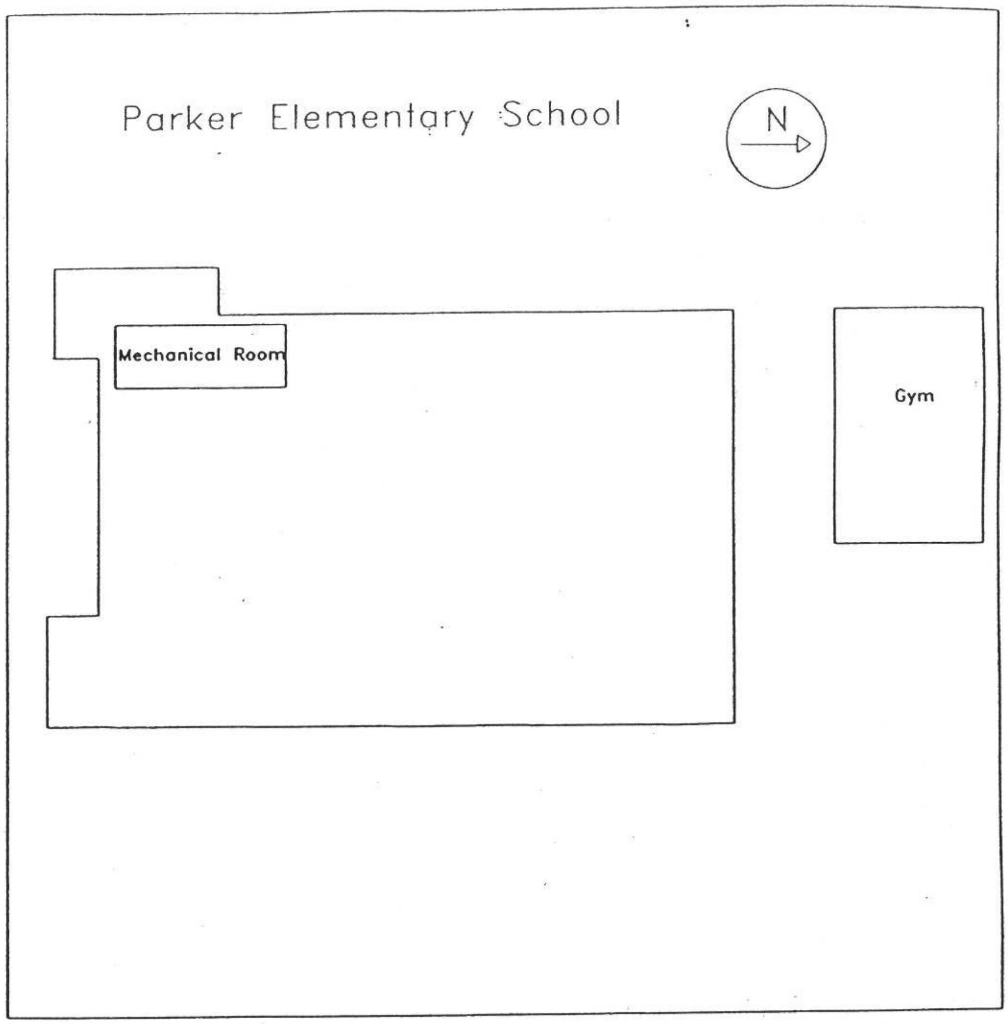
On the following page is Figure 4.8, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for WMS. Also, thermal storage was installed at the school in August of 1993. Consequently, peak demand was measured between 1 and 4 p.m., not necessarily the true peak from August 1993 to the present. Also, natural gas use is normal. Lastly, PLF and ELF are reasonably low during the summer.

Figure 4.8: ***Monthly Data for WMS****: Electric, Natural Gas, ELF, OLF, PLF, and weather data*



4.9 Parker Elementary School (PES)




Parker Elementary School
N
Mechanical Room
Gym

4.9 Parker Elementary School (PES)

Parker Elementary School is located in Galveston, TX. It is a single story building with tilt-wall concrete panel construction. It has a total floor area of 81,742 square feet with a kitchen, cafeteria, library, and classrooms. Cooling is provided by a three 80 ton reciprocating air-cooled chillers and four 15 ton split systems. The building has two mechanical penthouses with several multi-zone units. Each of these units serves several classrooms. Each zone of these multi-zone units is equipped with reheat coils. Heating is provided by a 3.25 million Btu/hr gas-fired hot water boiler which remains off during the cooling season. This school has a detached gymnasium, which is heated and cooled. An ice thermal storage system was installed in 1993. A separate chiller was added to generate ice at night to be utilized between the hours of 1:00 p.m. and 4:00 p.m. At this time the other chillers are shut off.

The school is operated from August through May with approximately 609 students and 60 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:30 p.m. However the building is occupied for much longer periods of time in the office area and for the custodians. There is very little weekend and summer use at Parker Elementary School. Electric service is purchased from Houston Lighting & Power Company and natural gas from Southern Union Gas Company.

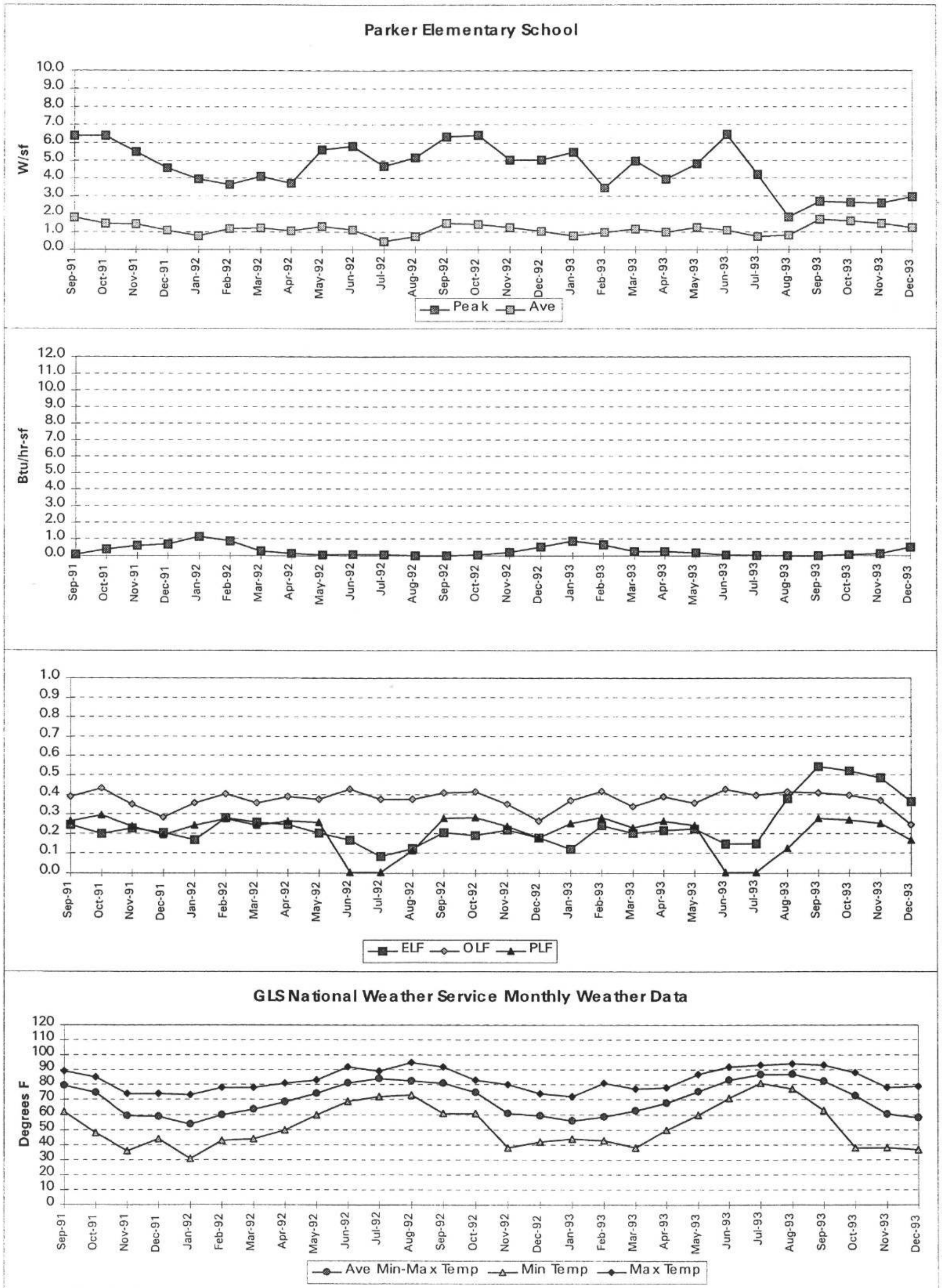
The following ECRM was installed at PES with the corresponding date reflecting the month the installation of the retrofit was completed:

Retrofit	Date Competed
•Install Thermal Storage System	May 1993

The retrofit was completed in May 1993 and the data analyzed for this report started in September 1991. There is a drop off in the electric demand power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 p.m. when the thermal storage is being used, hence the peak power level became a measurement of the peak electricity readings during the afternoon for the month rather than the peak for all hours during the month.

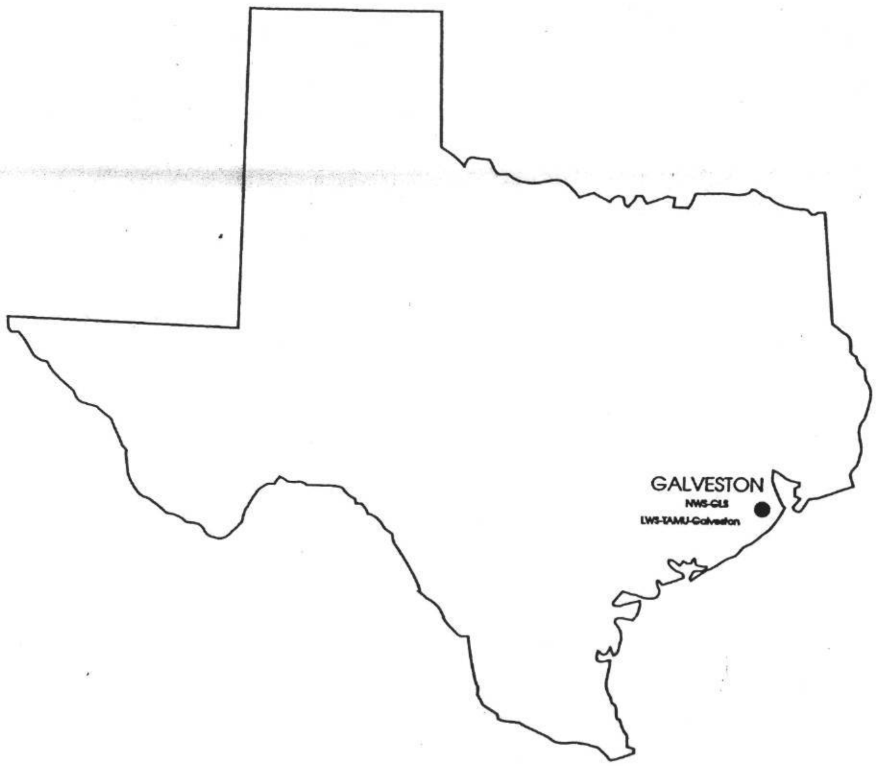
On the following page is Figure 4.9, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for PES. Also, thermal storage was installed at the school in August of 1993. Consequently, peak demand was measured between 1 and 4 p.m., not necessarily the true peak from August 1993 to the present. Also, natural gas use is very low year round. Lastly, PLF and ELF are reasonably low during the summer.

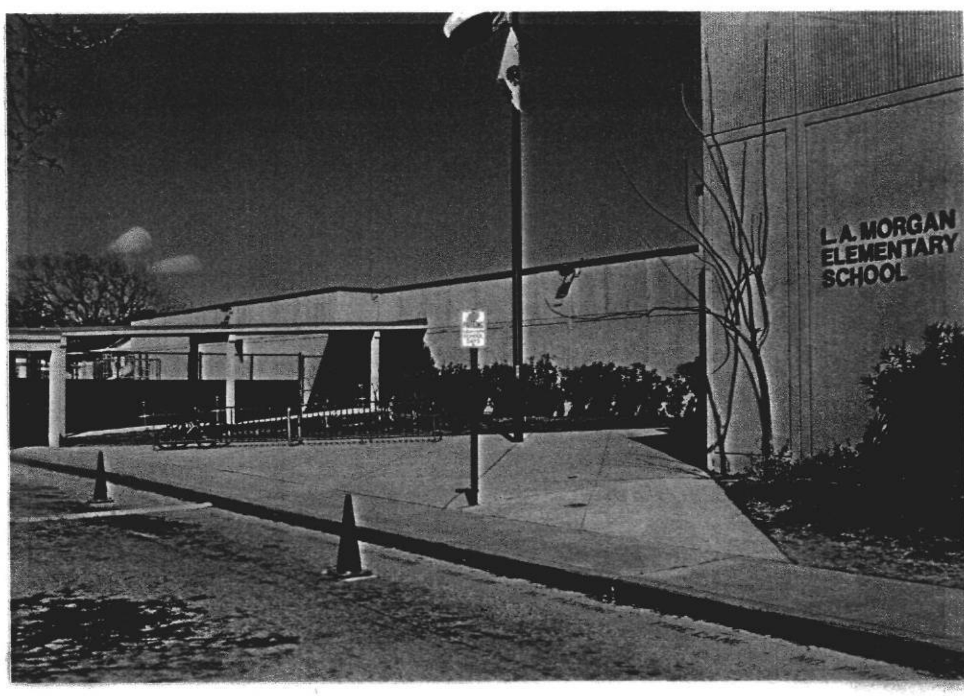
Figure 4.9: *Monthly Data for PES: Electric, Natural Gas, ELF, OLF, PLF, and weather data*

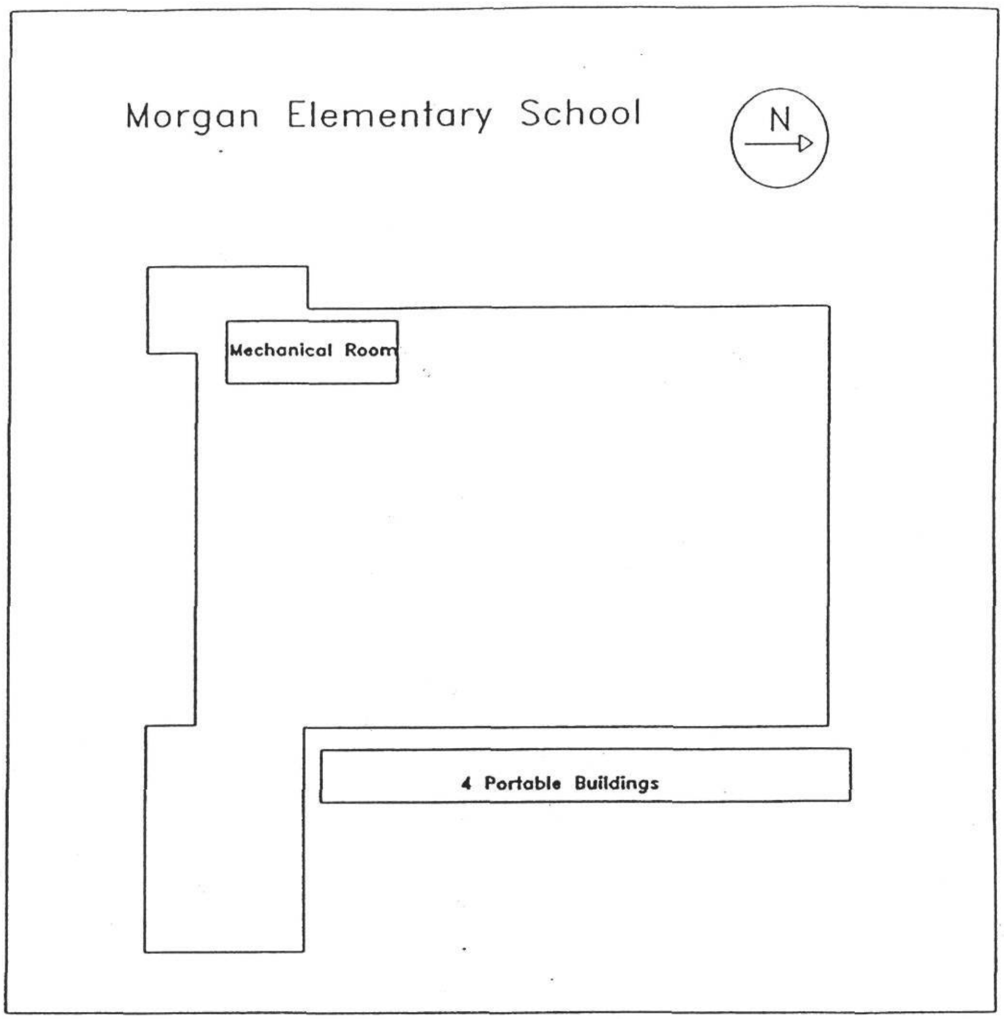


4.10 Morgan Elementary School (MES)

Morgan Elementary School






Morgan Elementary School
N
Mechanical Room
4 Portable Buildings

4.10 Morgan Elementary School (MES)

Morgan Elementary School is located in Galveston, TX. It is a single story building with tilt-wall concrete panel construction. It has a total floor area of 76,798 square feet with a kitchen, cafeteria, library, and classrooms. Cooling is provided by a three 80 ton reciprocating air-cooled chillers and four 15 ton split systems. Morgan is similar to Parker. It has two mechanical penthouses with several multi-zone units. Each of these units serves several classrooms. Each zone of these multi-zone units is equipped with reheat coils. Heating is provided by a 3.25 million Btu/hr gas-fired hot water boiler which remains off during the cooling season. This school has an attached gymnasium, and a portable building with four classrooms conditioned by wall hung DX package units with electric heaters. An ice thermal storage system was installed in 1993. A separate chiller was added to generate ice at night to be utilized between the hours of 1:00 p.m. and 4:00 p.m. At this time the other chillers are shut off.

The school is operated from August through May with approximately 555 students and 70 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:30 p.m. However, the building is occupied for much longer periods of time. There is afternoon tutoring until 6:00. In the summer time there is school starting in the middle of June during the mornings. This elementary schools gets significantly more usage throughout the entire year than the other ones located in Galveston. Electric service is purchased from Houston Lighting & Power Company and natural gas from Southern Union Gas Company.

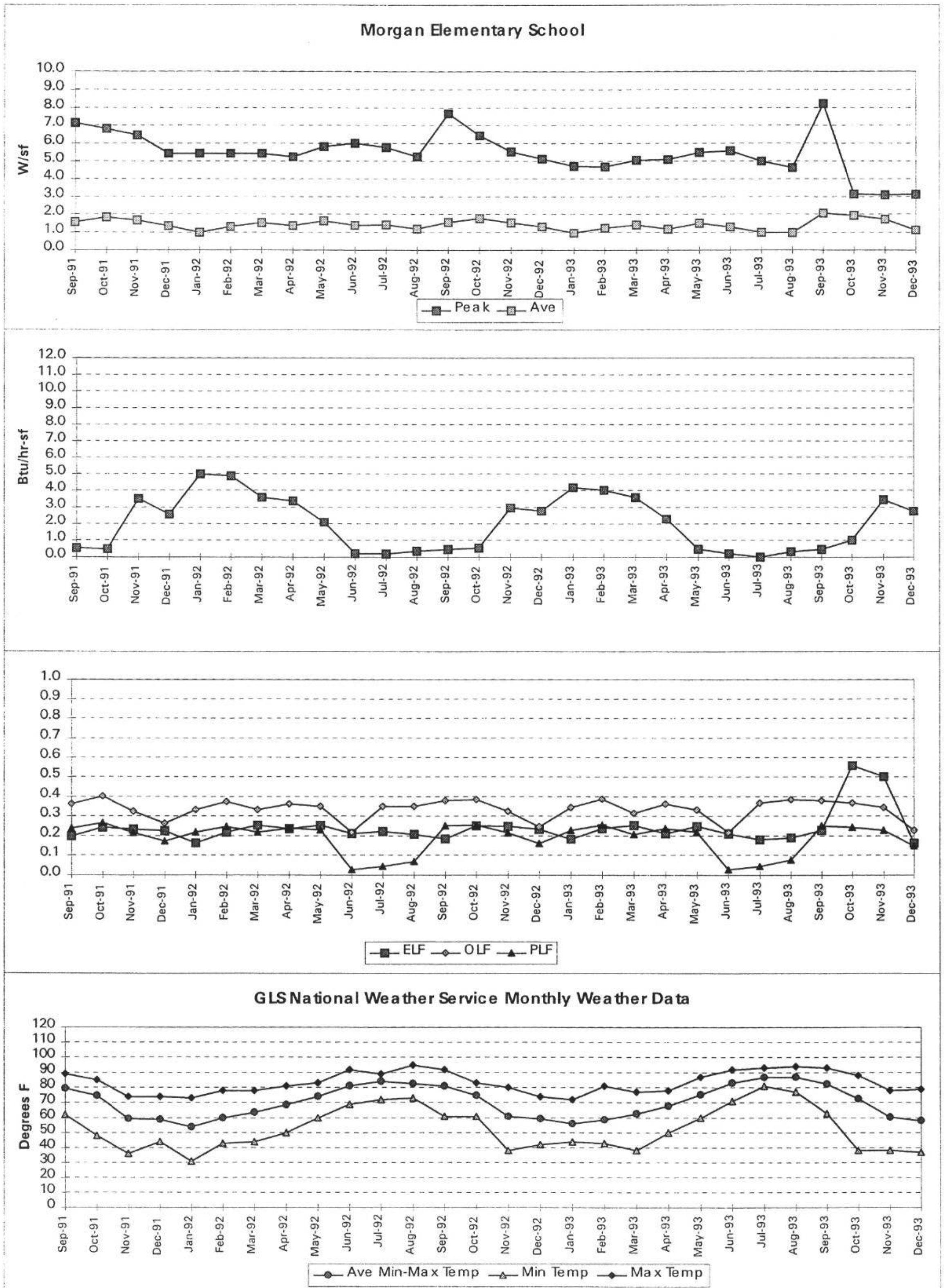
The following ECRM was installed at MES with the corresponding date reflecting the month the installation of the retrofit was completed:

Retrofit	Date Competed
•Install Thermal Storage System	June 1993

The retrofit was completed in May 1993 and the data analyzed for this report started in September 1991. There is a drop off in the electricity power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 p.m. when the thermal storage is being used, hence the peak power level became a measurement of the peak electricity readings during the afternoon for the month rather than the peak for all hours during the month.

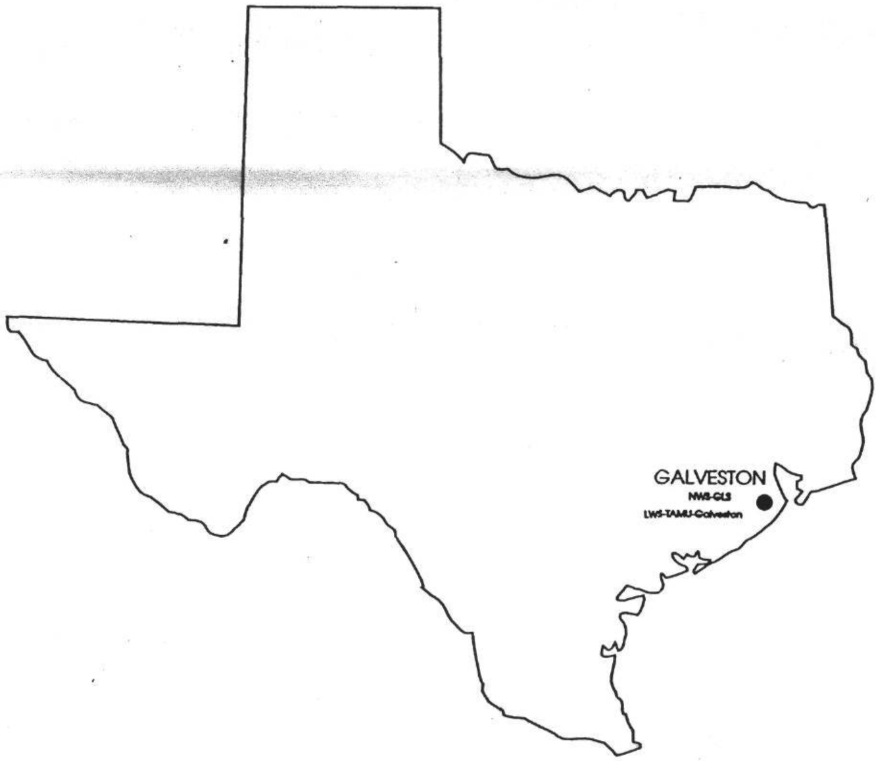
On the following page is Figure 4.10, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for MES. Also, thermal storage was installed at the school in August of 1993. Consequently, peak demand was measured between 1 and 4 p.m., not necessarily the true peak from August 1993 to the present. Also, natural gas use is normal. Lastly, PLF and ELF are reasonably low during the summer.

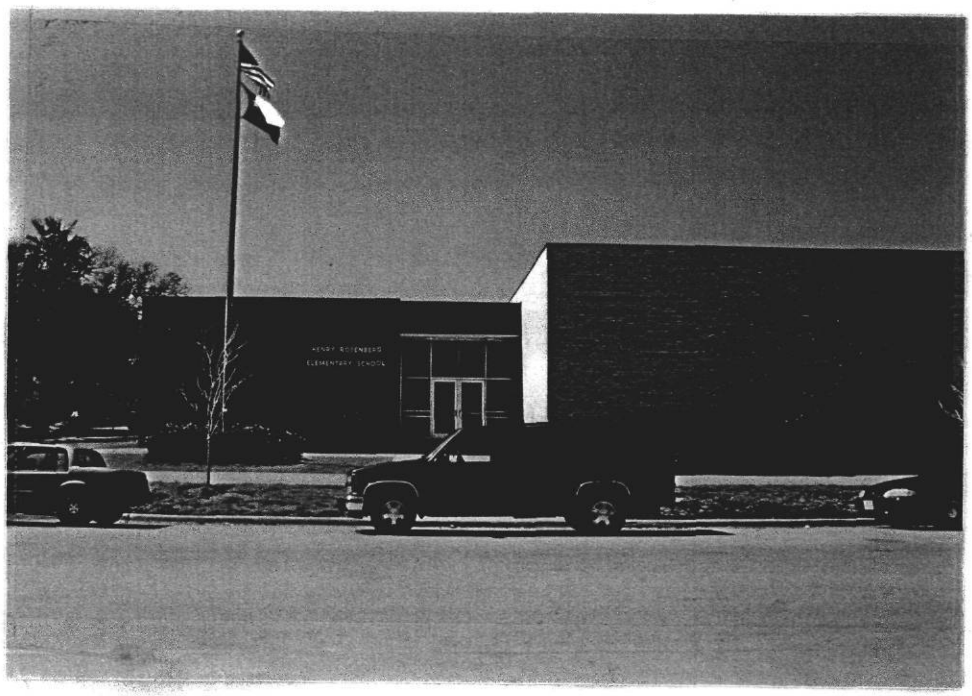
Figure 4.10: *Monthly Data for MES: Electric, Natural Gas, ELF, OLF, PLF, and weather data*

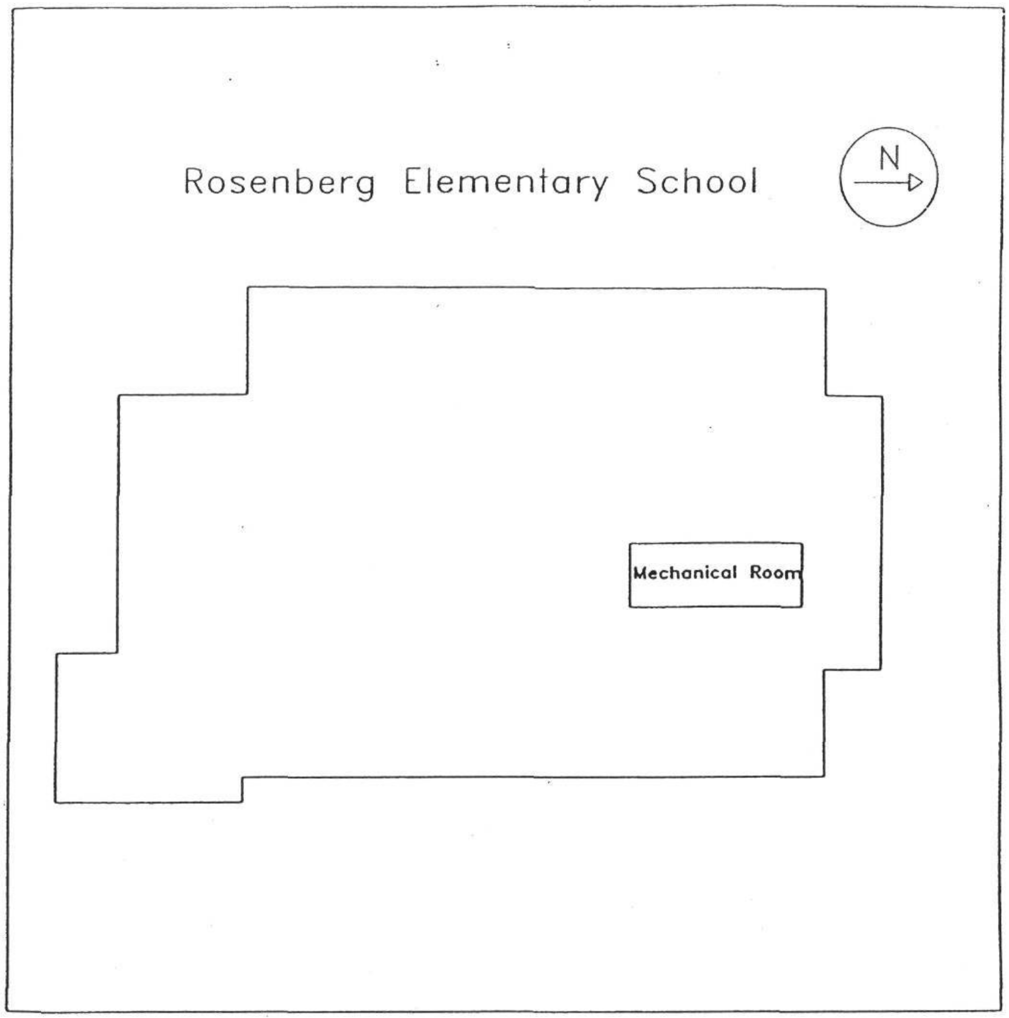


4.11 Rosenberg Elementary School (RES)

Rosenberg Elementary School






Rosenberg Elementary School
N
Mechanical Room

4.11 Rosenberg Elementary School (RES)

Rosenberg Elementary School is located in Galveston, TX. It is a single story brick structure. It has a total floor area of 63,044 square feet with a kitchen, cafeteria, gymnasium, library, and classrooms. Cooling is provided by a two 80 ton reciprocating water-cooled chillers with cool storage and four 5 ton split systems. Heating is provided by three 1.25 million Btu/hr gas-fired hot water boilers. The boilers remain off during the cooling season. Two 15 horsepower multi-zone units are serving the classrooms. The office gymnasium and library have dedicated DX coil units with a dedicated gas-fired boiler for heating. Cooling is maintained during the summertime to counteract humidity problems. An ice thermal storage system was installed in 1993. A separate chiller was added to generate ice at night to be utilized between the hours of 1:00 p.m. and 4:00 p.m. At this time the other chillers are shut off.

The school is operated from August through May with approximately 609 students and 60 faculty and staff. The maximum school occupancy is from approximately 7:30 a.m. until 3:30 p.m. However, the building is occupied for much longer periods of time in the office area and for the custodians. There is very little weekend and summer use at Rosenberg Elementary School. Electric service is purchased from Houston Lighting & Power Company and natural gas from Southern Union Gas Company.

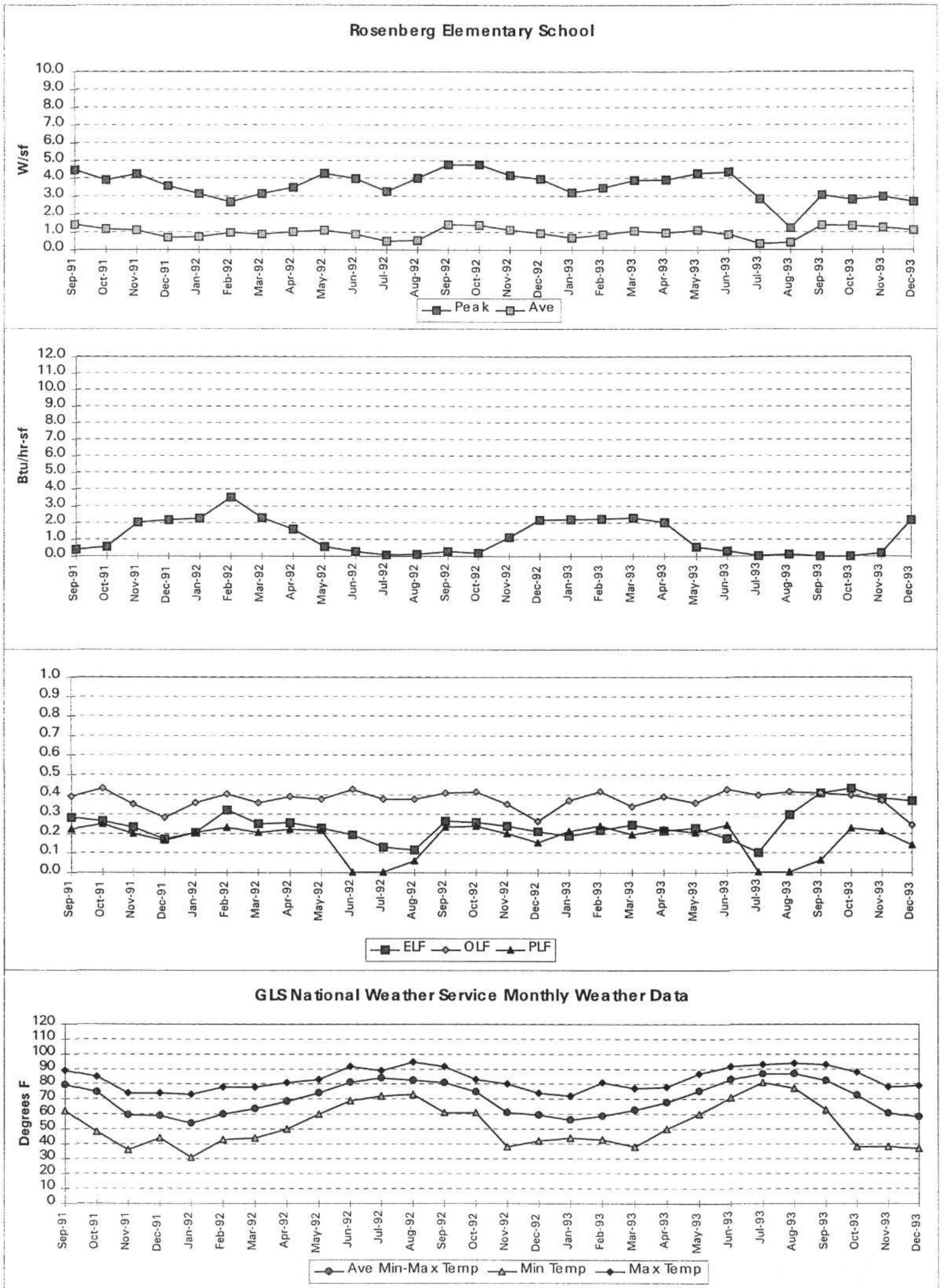
The following ECRM was installed at RES with the corresponding date reflecting the month the installation of the retrofit was completed:

Retrofit	Date Competed
•Install Thermal Storage System	June 1993

The retrofit was completed in May 1993 and the data analyzed for this report started in September 1991. There is a drop off in the electricity power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 p.m. when the thermal storage is being used, hence the peak power level became a measurement of the peak electricity readings during the afternoon for the month rather than the peak for all hours during the month.

On the following page is Figure 4.11, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for RES. Also, thermal storage was installed at the school in August of 1993. Consequently, peak demand was measured between 1 and 4 p.m., not necessarily the true peak from August 1993 to the present. Also, natural gas use is low in the summer and moderate during the winter. Lastly, PLF and ELF are reasonably low during the summer.

Figure 4.11: *Monthly Data for RES: Electric, Natural Gas, ELF, OLF, PLF, and weather data*



5.0 RESULTS

This section summarizes the results of the application of the annual, monthly, and daily indices. The results are organized into the following sections: first annual results, second monthly, and lastly daily results are presented for all eleven schools. Each results section is broken down into general results for that index then school specific results.

5.1 Annual Results

Table 5.1a: *Annual whole-building electric and natural gas index*

School	Peak Electric Demand (W/sf)	Electricity Consumption (W/sf)	Natural Gas Consumption (Btu/(hr-sf)
CMS	5.68	0.98	N/A
DMS	6.90	1.87	2.34
MES	8.22	1.30	2.15
NHS	4.83	1.39	2.86
OES	6.34	1.13	4.45
PES	6.46	1.07	0.27
RES	4.77	0.90	1.19
SES	5.38	1.36	2.35
SHS	3.37	0.8	1.68
VHS	4.37	0.92	2.37
WMS	8.44	1.26	1.78
Average (W/sf)	5.89	1.18	2.14

5.1.1 General

In general, annual energy indices allow for gross comparison of energy use in schools from year to year. Expressing the energy use per unit area of conditioned space allows for comparisons to be made among similar schools which are using the same fuel types for the same purposes. If a suitable average value can be developed then schools can be ranked as being above or below the group average for the specific fuel type under analysis. For the schools in this analysis, this included a comparison of the peak annual monthly demand using a demand power level (i.e. W/sf), a comparison of electricity consumption using power levels (i.e. W/sf) and an analysis of natural gas consumption (Btu/hr-sf).

5.1.1.1 Power Factor Correction

For the eleven schools analyzed in this study, the annual indices provided pertinent data that could have been used to develop a rough ranking of their comparative energy use. With the exception of peak demand electric power levels, the annual indices allowed for a good comparison across schools. Unfortunately, since monthly utility billing data were used for these indices, the units for a direct comparison, peak power levels could not be directly compared. This is because In five of the schools, all located in Galveston, peak electric load is measured in Volt-Amp, or kVA, whereas in the six other schools analyzed, the peak electric demand was measured in kW. Therefore, data from these schools had to be adjusted before they could be compared.

Figure 5.1: *kW versus kVA for all five Galveston*

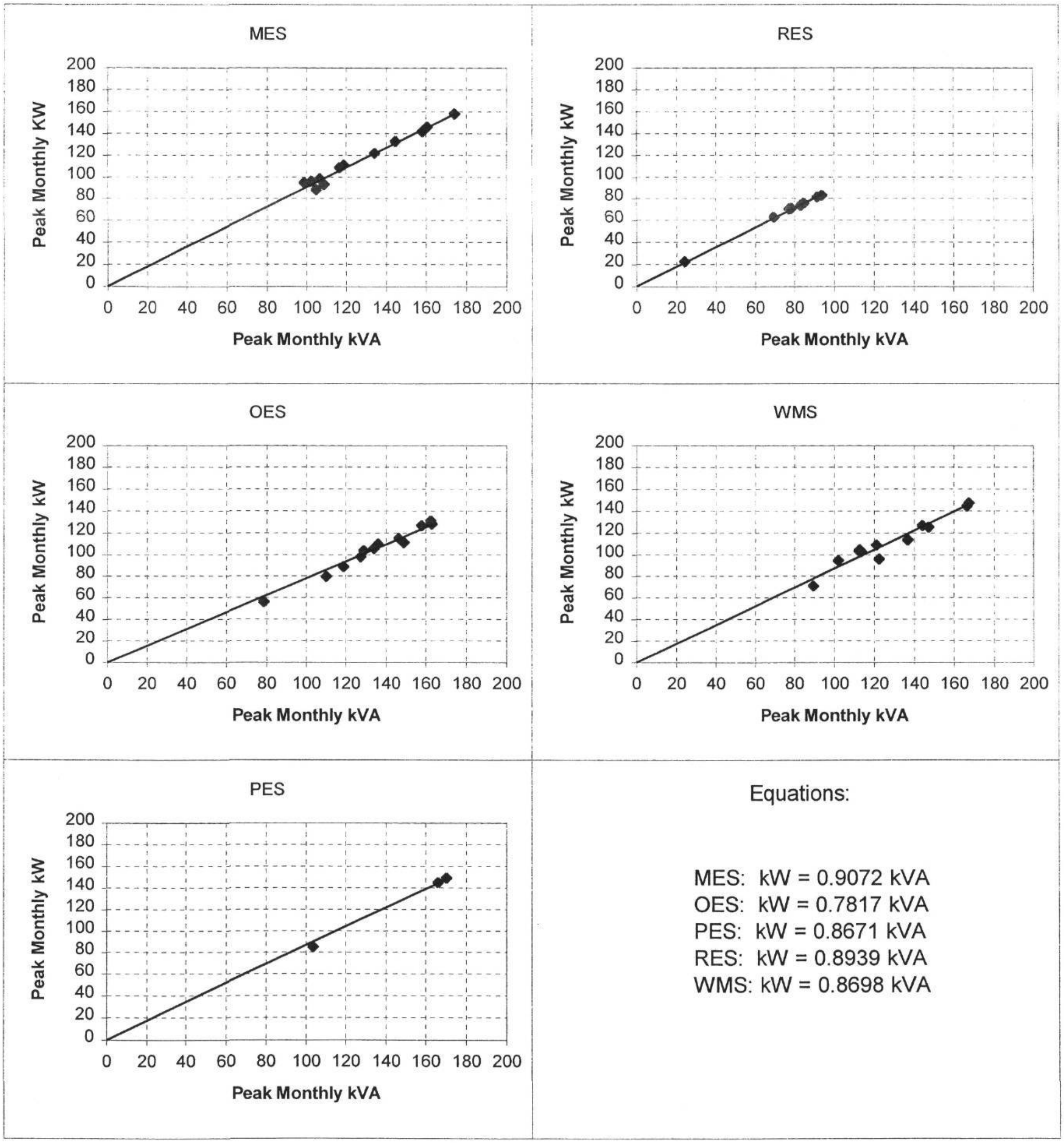


Figure 5.1 shows that the relationship between peak 15 minute kVA and kW (as measured by 15 minute LoanSTAR data in kWh) varies greatly from month to month. Even though the average

VA/sf tended to be about 1.7 times the average W/sf, an analysis of parallel kVA and kWh measures using utility loggers and LoanSTAR loggers revealed that kVA and kWh varied depending on the amount and type of equipment operating. This is to be expected since kVA and kWh basically differ by the power factor for a given site, and power factor varies significantly from winter periods when loads are composed of lights, receptacles and AHUs to periods during the summer when the peak is dominated by chiller loads.

Therefore, VA/sf was converted to W/sf. Peak W/sf varied from 47% above the average peak demand of 5.89 W/sf to about 47% below this value with all of the larger schools below the average value and most of the smaller schools above this value.

Electric use per conditioned area varied by 32% from an average of 1.18 W/sf. Natural gas varied by 88% of the average Btu/(hr-sf) of 2.14. This greater variation in gas use is somewhat expected since some schools only use gas for DHW and space-heating purposes while other schools use gas for cooking, DHW, and space-heating.

5.1.2 School Specific

For each school, the annual indices can be used to begin to describe how their energy use compares to other schools. In this section the annual indices are used to generate a helpful statement to the potential energy auditor.

Chamberlain Middle School (CMS)

CMS has a peak demand of 5.68 W/sf close to the average peak demand of 5.89 W/sf. Monthly indices would indicate additional information such as whether or not this is occurring in the winter or summer. The electricity consumption is 0.98 W/sf, slightly below the average consumption of 1.18 W/sf. This would tend to indicate that the building is a low energy consumer when compared to the other schools in the study. Natural gas data were not available for CMS.

Dunbar Middle School (DMS)

DMS has a 17% above average peak demand of 6.90 W/sf. This indicates possible oversizing of equipment. Monthly indices would indicate additional information. Electricity consumption of 1.87 W/sf is 58.5 % above average. This indicates that the HVAC systems and/or lighting are inefficient at the school when compared to the 1.18 W/sf average for the other eleven schools. Natural gas consumption is 9% above average, which does not indicate an immediate problem.

Morgan Elementary School (MES)

MES has a very high peak demand of 8.22 W/sf, which is 40% higher than the 5.65 W/sf average for all schools. This indicates possible oversized equipment. Electricity consumption of 1.3 W/sf is 10% above average. Natural gas consumption is average at 2.14 Btu/(hr-sf).

Nacogdoches High School (NHS)

NHS has a very low peak demand of 4.83 W/sf. This is 18% below the 5.89 W/sf average. NHS also has an 18% higher than average electricity consumption of 1.39 W/sf, which may be indicating a slight excess use of HVAC equipment. Natural gas consumption is 33% higher than average at 2.86 Btu/(hr-sf). Both the natural gas and electricity indices seem to indicate possible overuse of equipment during the year, possibly during holidays as well. Monthly and daily indices should reveal additional useful information.

Oppe Elementary School (OES)

OES has a high peak demand of 6.34 W/sf. This indicates possible oversizing of equipment. Monthly indices would indicate additional information. Electricity consumption of 1.13 W/sf is slightly below average. Natural gas consumption of 4.45 Btu/(hr-sf) is approximately double the average use of 2.14 Btu/(hr-sf), a clear indication of excess use. However, one will need to look at monthly indices to determine if the use is related to heating or other uses.

Parker Elementary School (PES)

PES has a peak demand of 6.46 W/sf, only 10% above average. Electricity consumption of 1.07 W/sf is slightly below average. Natural gas consumption is 0.27 Btu/(hr-sf) approximately 87.4% below the average use which may be indicating that gas may only used for cooking or non-heating related end-uses.

Rosenberg Elementary School (RES)

RES has a peak demand of 4.77 W/sf, 19% below the average. Electricity consumption of 0.9 W/sf is a approximately 24% below average indicating less usage of equipment, possibly no summer school. Monthly indices will help to confirm this. Natural gas consumption is 1.19 Btu/(hr-sf) approximately 44% below average indicating the potential of a broken boiler or heating other than by natural gas.

Sims Elementary School (SES)

SES has a peak demand of 5.38 W/sf, 9% below average. Electricity consumption of 1.36 W/sf is slightly above average. Natural gas consumption is 10% above average. All three indices would indicate that SES is an average consumer and does not have any immediate areas that stand out as excessive energy consumption.

Stroman High School (SHS)

SHS is a low consumer of energy. The peak demand is 3.33 W/sf is the lowest of the group. Electricity consumption is 0.8 W/sf or 32.2% below average. The natural gas consumption is 1.68 Btu/(hr-sf), 21.5 % below average. This may indicate that SHS is a more efficient energy consumer or that the school is not used for part of the year.

Victoria High School (VHS)

VHS is also a low electricity consumer. The peak demand power level is 4.37 W/sf, second lowest of the group and below average. The electricity consumption is 0.92 W/sf, 22% below average. However, the natural gas consumption is 2.37 Btu/(hr-sf), slightly above average.

Weis Middle School (WMS)

WMS has a high peak demand of 8.44 W/sf, 43% above average. Electricity consumption of 1.26 W/sf is slightly above average. Natural gas consumption is 1.78 Btu/(hr-sf), approximately 17% below average.

Table 5.1b: *Annual Whole Building Electric and natural gas index*

School	Peak W/sf	Ave W/sf	Btu/(hr-sf)
CMS	Medium	Low	------------
DMS	High	High	Medium
MES	High	High	Medium
NHS	Low	High	High
OES	Medium	Medium	High
PES	Medium	Medium	Low
RES	Low	Low	Low
SES	Medium	Medium	Medium
SHS	Low	Low	Low
VHS	Medium	Low	Medium
WMS	High	Medium	Low
Average	5.89	1.18	2.14

Table 5.1a can be further reduced to a simplified high, medium, low type of table that could facilitate an easier decision making process as shown in Table 5.1b. For a value to be considered low it must be less than the average value minus 25% of the average value. For a value to be considered high, it must be greater than the average plus 25% of the average value.

5.2 Monthly Results

Twenty eight months of data from September 1991 through December 1993 were analyzed for each school. The results are presented in tabular form in the following tables. A description of the indices is provided below:

Peak demand WBE with Std-Dev	This is peak electric demand for the months analyzed (Sept-May for school years, June-July for summer months). The value is in W/sf. The standard deviation is in parentheses. At OES, WMS, PES, MES, and RES has been calculated from kVA described in section 5.1.1.1
Ave WBE with Std-Dev	This is the average electricity consumption for the months analyzed (Sept-May for school years, June-July for summers). The value is in W/sf. The standard deviation is in parentheses.
Base-level WBE with CV-RMSE	This is the base-level consumption, excluding cooling, for school year months, determined using a three parameter change-point model. The value is in W/sf. The CV(RMSE) for this parameter is included in parentheses.
Cooling Slope	This is the measure of the slope of the weather dependent portion of the 3-parameter model.
Change-point temperature	The temperature in degrees F where cooling begins determined by a 3-parameter change-point analysis.
R^2	Coefficient of determination
Whole Model CV-RMSE	Coefficient of variation of the root mean square error

Table 5.2: *Monthly school year WBE results*

School	Peak demand WBE with Std-Dev in (W/sf)	Ave WBE with Std-Dev in (W/sf)	Base Level WBE with CV-RMSE in (W/sf)	Cooling Slope with CV-RMSE in (W/sf)	Change-Point Temp. in (Degrees F)	% Cooling	R^2	Whole Model CV-RMSE
CMS	5.68 (0.80)	1.09 (0.28)	1.03 (0.06)	0.05 (0.02)	69.65	------------	0.24	0.23
DMS	6.86 (1.08)	1.72 (0.60)	1.30 (0.08)	0.07 (0.01)	57.10	29	0.77	0.17
MES	8.22 (1.33)	1.48 (0.29)	1.20 (0.08)	0.02 (0.01)	54.52	8.5	0.49	0.14
NHS	4.83 (0.68)	1.34 (0.36)	1.02 (0.05)	0.03 (0.00)	51.00	31	0.90	0.09
OES	6.34 (1.16)	1.42 (0.37)	1.12 (0.11)	0.25 (0.01)	54.52	17	0.34	0.22
PES	6.44 (1.27)	1.26 (0.27)	1.13 (0.05)	0.04 (0.01)	67.61	20	0.52	0.16
RES	4.77 (0.66)	1.08 (0.23)	0.83 (0.06)	0.02 (0.00)	54.52	28	0.59	0.14
SES	4.98 (0.75)	1.27 (0.36)	0.98 (0.04)	0.04 (0.00)	54.45	28	0.86	0.11
SHS	3.37 (0.30)	0.83 (0.19)	0.64 (0.02)	0.02 (0.00)	57.58	37	0.89	0.08
VHS	4.20 (0.62)	0.96 (0.26)	0.76 (0.03)	0.04 (0.00)	63.41	13	0.85	0.11
WMS	8.44 (1.14)	1.50 (0.31)	1.22 (0.09)	0.02 (0.01)	54.52	27	0.43	0.16
Average	5.83 (0.89)	1.27 (0.32)	1.02 (0.03)	0.05 (0.01)	62.78	24	0.63	0.15

note: % cooling was not included for Chamberlain Middle School because it is the only building of the group with electric heating as well as electric cooling.

Table 5.3: *Monthly summer(June-Aug.) WBE results*

School	Peak demand WBE with Std-Dev in (W/sf)	Ave WBE with Std-Dev in (W/sf)	Whole Model CV-RMSE
CMS	4.86 (1.43)	0.89 (0.47)	0.53
DMS	6.90 (1.19)	2.54 (0.60)	0.24
MES	6.01 (0.51)	1.21 (0.19)	0.16
NHS	4.78 (0.73)	1.44 (0.57)	0.40
OES	5.70 (1.36)	0.81 (0.31)	0.38
PES	6.46 (1.61)	0.82 (0.25)	0.31
RES	4.38 (1.15)	0.58 (0.23)	0.40
SES	5.38 (0.99)	1.72 (0.26)	0.15
SHS	3.20 (0.54)	0.74 (0.17)	0.15
VHS	4.37 (1.04)	0.89 (0.27)	0.31
WMS	6.34 (1.86)	0.82 (0.39)	0.48
Average	5.31 (1.13)	1.13 (0.34)	0.32

Table 5.4: *Monthly ELF, OLF, and PLF results for all months*

School	ELF	OLF	PLF
CMS	0.27	0.4	0.19
DMS	0.24	0.33	0.19
MES	0.30	0.37	0.24
NHS	0.24	0.35	0.18
OES	0.24	0.37	0.20
PES	0.35	0.40	0.23
RES	0.30	0.32	0.24
SES	0.26	0.27	0.24
SHS	0.25	0.37	0.17
VHS	0.39	0.44	0.17
WMS	0.4	0.44	0.20
Average	0.29	0.37	0.20

Table 5.5: *Monthly natural gas results for all months*

School	Base Level Natural Gas with CV-RMSE (Btu/hr-sf)	Heating Slope with CV-RMSE (Btu/hr-sf)	Change-point Temperature (Degrees F)	Whole Model CV-RMSE
CMS	N/A	N/A	N/A	N/A
DMS	0.89 (0.19)	-0.57 (0.03)	58.73	0.29
MES	0.27 (0.18)	-0.16 (0.01)	79.64	0.31
NHS	0.57 (0.44)	-0.23 (0.04)	72.38	0.62
OES	1.63 (0.90)	-0.20 (0.05)	86.23	0.54
PES	0.09 (0.03)	-0.09 (0.01)	64.49	0.49
RES	0.17 (0.16)	-0.10 (0.01)	78.98	0.51
SES	0.38 (0.21)	-0.23 (0.02)	68.89	0.36
SHS	0.84 (0.13)	-0.35 (0.03)	64.29	0.34
VHS	0.37 (0.35)	-0.26 (0.04)	72.26	0.73
WMS	0.28 (0.18)	-0.17 (0.02)	76.35	0.40
Average	0.55 (0.277)	-0.24 (0.025)	72.23	0.46

5.2.1 General

Monthly indices are considered in this section. Previously it was shown that an average annual index could be useful in identifying high energy consumers according to their maximum peak electric load (W/sf), average annual electricity use (W/sf), and annual natural gas use (Btu/(hr-sf)). In this next section we take a look at what additional information can be provided within the analysis of monthly data.

5.2.1.1 Quartile Analysis

To begin with, we look at some simple statistics that were calculated with the monthly data. Figures 3.15 to 3.19, which were previously presented, illustrate the results of this analysis. Figure 3.15 shows the results of a monthly aggregate analysis across all schools. For each school in Figure 3.15 a box-whisker mean symbol is used to indicate the results of the statistical analysis. Each plus symbol indicates outliers which are less than 10th percentile or greater than the 90th percentile. The distance between the top and bottom of the vertical line represents the range from the 10th to the 90th percentile. The box indicates the range between the 25th and 75th percentile. The hash mark in the box is the 50th percentile or median value, and the line connecting all schools together connects the mean value for each school.

The statistical quartile analysis of monthly data provides additional information that allows for further insight into how the schools are performing. First, with the exception of DMS and RES, the data points falling below the 10th percentile usually represent the summer months when many of the schools have reduced operating schedules. For those schools where these data points represent summer months, the variation between these lower outliers and the 25th percentile seems to represent the extent to which the schools are shutting down during the summer and how many months the shut down lasts (i.e. whether or not there is one or more outliers).

In the case of DMS and RES, two different stories emerge. First, at DMS the lower consumption months occur during the winter months. This is due to the fact that significant amounts of air conditioning are used all summer long. At RES the lower consumption months occur during the summer and winter which would seem to indicate that a similar shut down practice is applied for both periods.

The second feature worth noting about the quartile plots, with the exception of DMS, is that the data points falling above the 90th percentile occur during the school year. To some extent this is to be expected since those points represent the months in early fall when there is a significant air conditioning load.

The third feature worth noting is that the 25th percentile almost always equals the school year base-level consumption calculated with a three parameter change-point model such as PRISM or EModel. This may turn out to be a very noteworthy feature of such an analysis. If the school year base-level can be calculated with a simple 25th percentile, then the school year consumption can be subdivided into heating, cooling, and base-level consumption without having to run a three parameter change-point analysis. This is a very helpful finding since it shows that useful weather-dependent trends can be gleaned from the monthly data without having to assemble daily weather data for each site required by the 3-parameter change-point models. Further analysis may be needed across a broader ranger of climates to verify if this feature is applicable to other areas of the U.S.

Figure 3.16 shows the results of the quartile analysis for the natural gas used by ten of the eleven schools (CMS has electric heating on one floor and natural gas heating on the other that is not separately metered and consequently was not included in this analysis). Monthly average natural gas is a good indicator of Btu/(sf-mo). This quartile analysis of natural gas use also provides useful insight into how the building is using gas for heating and non-heating purposes.

In each of the ten case study schools, the 25th percentile tends to be a good proxy indicator for the base-level gas use. Additional analysis will be needed to determine if this statistic is useful for schools located in other climate regions.

Figure 3.17 shows the results of the quartile analysis of the Electric Load Factor (ELF) for the eleven schools. ELF is a good indicator of electric diversity at the schools. The maximum value and the 90th percentile usually indicate September and October usage for schools. The minimum and 10th percentile generally indicates summer usage for schools without any summer school. WBE & ELF tend to be linearly related as indicated in Figure 5.2.

Figure 5.2: ***WBE versus ELF***

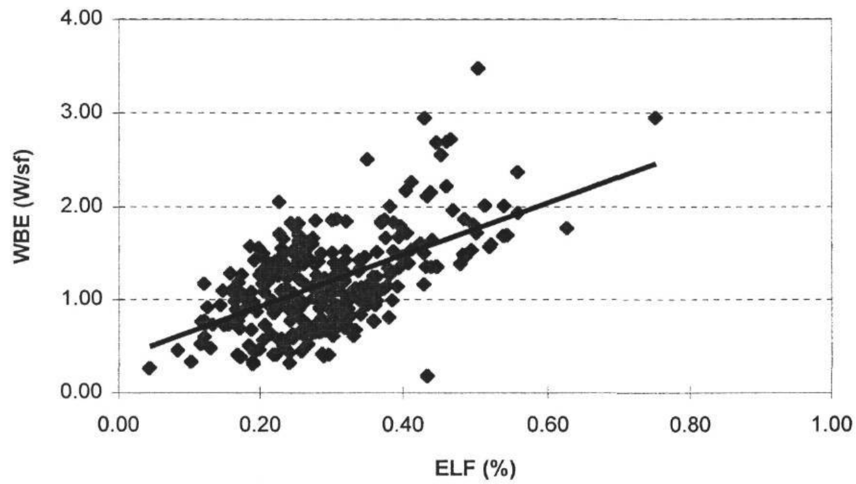


Figure 3.18 shows the results of the quartile analysis for the Occupancy Load Factor (OLF) for the eleven schools. The 10th percentile of the OLF generally indicates months with significant vacation periods, with the minimum usually occurring in June or July. OLF is also consistently higher than PLF (see Figure 3.19), an indication that HVAC systems and lighting are being turned on for custodial purposes prior to the arrival of staff and students and well after staff and students leave. Minimum PLF values indicate summer vacation. VHS and SHS have school almost year round, hence their minimum PLF values are much higher than other schools.

5.2.1.2 3-Parameter Change-Point Analysis

To improve the insight into a school's reason for high or low energy usage it is necessary to create temperature related models. However, in order to accomplish this, it is best to separate all months into two groups: school months and summer months. Consequently, seasonal and operational changes my be compared with the results of other indices such as monthly electric power levels, ELF, OLF, and PLF. A good monthly 3-parameter change -point model is defined as having a CV(RMSE) < 0.25 and an $R^2 > 0.6$. (i.e. having low scatter and being highly weather dependent).

The models selected had a 3-parameter fit for the school year, and a 1-parameter mean model during the summer months. About half the schools fit into this criteria during the school year. All have CV(RMSE) < 0.25. This indicates that all schools had low levels of scatter. However, six of the schools (elementary and middle schools) have $R^2 < 0.6$, indicating schools are more weather dependent than others during the school year. Also, for summer months there was indication that a 2 or 3-parameter model may provide a better statistical fit to the data. Additional analysis of data would be required to verify this. A 3-parameter model of the electricity use fits the data from most of the schools very well during the school year. There is clear indication of cooling in schools, starting at approximately 63 F. A base electricity consumption level of approximately 1.0 W/sf was the average for all of the schools. The average electricity usage during the school year months for all schools was approximately 1.27 W/sf. Also, on average, cooling was approximately 24% of the electric load during the school year for all eleven schools based on the 3-parameter models.

For all of the schools the average peak whole-building electric demand was 5.83 W/sf during the school year (Table 5.2) and 5.31 during the summer months (Table 5.3) indicating that at least once during the summer months, most of the buildings were fully occupied (i.e., the lights in all the classrooms were on) and cooling systems were fully engaged. The average whole-building electricity was 1.27 W/sf during the school year and 1.13 W/sf during the summer months (Table 5.3) indicating that electricity declined during the summer months when the buildings are less occupied.

The % cooling is defined by taking the base-level whole building electric usage multiplied by the number of days in the school year. This value is then subtracted from the total whole building electric usage to define the % cooling.

5.2.2 School Specific

Chamberlain Middle School (CMS)

During the school year CMS has an average peak demand of 5.68 W/sf. However, the values seem to be highest during both the heating and cooling season indicating the possibility of electric heating. The WBE consumption of 1.09 W/sf is approximately 14% below average during the school year. The ELF, OLF, and PLF are very similar during the school year suggesting fewer afterschool activities. Natural gas usage was not measured at the individual building on this campus. Hence it is not commented on.

During the summer time CMS has a peak demand of 4.86 W/sf, slightly below average. The WBE consumption of 0.89 W/sf is approximately 21% below average. This suggests little or no unusual activity during the summer time such as large summer school programs. The ELF is approximately 0.35 during the summertime compared to an OLF of 0.22 and a PLF of 0.12, indicating that, even though the school is already below average, there is still room for improvement on energy consumption during the summer time. Certain systems may be left on beyond occupied hours.

Dunbar Middle School (DMS)

During the school year DMS has an above average 6.86 W/sf peak demand which is 18% above average. The WBE consumption is 1.72 W/sf, or 35% above average, indicating that systems are left on beyond occupied hours. Comparing ELF with OLF and PLF during the school year, there is a large difference. The OLF is actually higher than the ELF during the year, 37% higher on average, primarily in the summer time. However, the PLF is approximately 21% below the ELF indicating that systems are being used in rooms not occupied. This is especially noticeable in the summer time. Approximately 29% of the electricity provides cooling during the school year. Natural gas use at DMS is approximately twice normal. However, the error associated with the value is fairly high.

During the summer time DMS has a peak demand of 6.90 W/sf, about the same as during the school year. indicating systems used during the school year are not shut off in the summer time. The summer WBE consumption is 2.54 W/sf more than twice the average value and higher the consumption during the school year. Also, ELF is twice the value of the OLF and more than 4 times the value of the PLF. These results indicates that although some systems are shut off in the summer time, the ones left on are being used significantly beyond what is required at the school.

Morgan Elementary School (MES)

Morgan Elementary School has a peak demand of 8.22 W/sf, second highest of the schools. This indicates the possibility of oversized equipment or additional equipment at MES not found at other schools. The WBE consumption is 1.48 W/sf during the school year, approximately 17% above average, indicating a equipment may be used beyond the hours of operation and has potential for O&M measures. Comparing the ELF with OLF and PLF shows a good match during the school year, suggesting efficient operation of equipment. Approximately 8.5% of the electricity provides cooling during the school year, a low number. Air Conditioning equipment size should be checked as a result. Natural gas use at MES is approximately one half of average.

During the summer time the peak demand is reduced by approximately 27% to 6.01 W/sf indicating systems are shut off in the summer time. The WBE consumption of 1.21 W/sf in the summer time versus 1.48 W/sf during the school year is further indication that the energy consumption is being reduced when the school is not occupied.

Nacogdoches High School (NHS)

Nacogdoches High School has a below average peak demand of 4.83 W/sf during the school year and a slightly above average WBE consumption of 1.34 W/sf. Both indices match the school's scheduling very well, increasing when students begin school and decreasing when there are long holidays. ELF fluctuates with OLF; however, PLF is always lower than ELF indicating there may be room to reduce energy consumption during non-occupied hours. Approximately 31% of the electricity provides cooling during the school year. Natural gas use at NHS is approximately average with an error associated with it close to acceptable.

During the summer time both peak demand and WBE consumption are approximately equal to during the school year period indicating a potential to reduce consumption during the summer months. Also, the ELF is still much higher than the PLF during the summer time indicating there is additional potential to reduce consumption.

Oppe Elementary School (OES)

Oppe Elementary School has a peak demand of 6.34 W/sf and WBE consumption of 1.42 W/sf. Both are approximately average. Although OLF is usually higher than ELF, both ELF and PLF match well throughout the year with the exception of the Fall of 1993. Systems should be checked for change of operating schedule during the Fall of 1993 compared with previous years. Approximately 17% of the electricity provides cooling during the school year. Natural gas consumption was high during the fall of 1991, and more than three times the base-level average of 0.55 Btu/(hr-sf) indicating possible problems with boiler operation. ELF, OLF, and PLF are average throughout the year.

During the summer time the peak demand only drops 10%, indicating that at least once during the summer months all systems were turned on. However, WBE consumption is reduced by approximately 43% indicating that the system may be oversized for summer usage. The PLF is much lower than the ELF during the summer time.

Parker Elementary School (PES)

During the school year Parker Elementary School has a peak demand of 6.44 W/sf and WBE consumption of 1.26 W/sf. Both are about average. Although OLF is usually higher than ELF, both ELF and PLF match well throughout the year with the exception of the fall of 1993. Systems should be checked for change of operating schedule for the fall of 1993 compared with previous years. In fact, this is the time that thermal storage was installed at the school, affecting equipment scheduling. Approximately 20% of the electricity provides cooling during the school year. Natural gas consumption is unusually low during the entire period analyzed, 84% below average. By analyzing the fluctuation of the natural gas consumption there does appear to be heating during the winter time but at unusually low levels. This suggests that there is an additional source of heating with a fuel other than natural gas or electricity.

During the summer time the peak demand remains almost the same as during the school year, indicating that systems are not shut off. WBE consumption is reduced by approximately 35% indicating that the system may be oversized for summer usage. The PLF is much lower than the ELF during the summer time.

Rosenberg Elementary School (RES)

During the school year Rosenberg Elementary School has a peak demand of 4.77 W/sf and WBE electricity consumption of 1.08 W/sf. Both are slightly below average. Although OLF is usually higher than ELF, both ELF and PLF match well throughout the year with the exception of fall of 1993. Systems should be checked for change of operating schedule for the fall of 1993 compared with previous years. The base-level consumption is approximately average at 1.34 W/sf compared with an overall average of 1.66 W/sf, and the cooling load during the school year is approximately 28% of the WBE electricity consumption. Natural gas consumption is about half the average.

During the summer time the peak demand is reduced by only 8% while the WBE consumption is reduced by approximately 46% indicating that cooling systems may be oversized for summer usage. The PLF is much lower than the ELF during the summertime. This helps verify the conclusion.

Sims Elementary School (SES)

During the school year SES has a 14% above average 4.98 W/sf peak demand and an average WBE consumption of 1.37 W/sf. Comparing ELF with OLF and PLF during the school year there is a large difference. The OLF is actually higher than the ELF during the year. However, the PLF is more than 30% lower than the ELF on average. This indicates that systems are being used in rooms that are not occupied, and it is especially noticeable in the summer time. Approximately 28% of the electricity provides cooling during the school year. Natural gas use at SES is approximately one third normal. However, the error associated with the value is fairly high.

During the summer time SES has an average peak demand of 5.38 W/sf and a 52% above average WBE consumption during the summer was 1.72 W/sf. The peak demand value is 18% higher during the summer time than school months, and the average WBE consumption is 35% increase. This combined with the ELF being twice as high as the OLF and more than 4 times the value of the PLF indicates that although some systems are shut off in the summer time, the ones left on are being used significantly beyond what is required at the school.

Stroman High School (SHS)

Stroman High School has a very low 3.37 W/sf peak demand during school year months, as well as a low WBE consumption of 0.83 W/sf, approximately 35% below average. Both match scheduling very well, increasing when student begin school and decreasing when there are long holidays. Although OLF is usually higher than ELF, both ELF and PLF match well throughout the year except the summer time. Approximately 37% of the electricity provides cooling during the school year, highest of the schools. This suggests overuse of the chillers. Natural gas use at NHS is above average. However, the error associated with it is high.

During the summer time both peak demand and WBE consumption are reduced by 5% and 11% respectively, indicating a slight reduction of equipment used and hours equipment is operated during the summer time. However, the ELF is still much higher than the PLF during the summer time indicating there is additional potential to reduce consumption.

Victoria High School (VHS)

Victoria High School has a very low 4.20 W/sf peak demand during the school year. It also has a low WBE consumption of 0.96 W/sf, approximately 26% below average. Both match scheduling very well, increasing when students begin the school year and decreasing when there are long holidays. ELF, OLF and PLF match well throughout the year except the summer time. Indicating equipment is turned-off when the building is not occupied. Approximately 13% of the electricity provides cooling during the school year. Natural gas use at VHS is below average. However, the error associated with it is high. Also, natural gas consumption during the winter of 91/92 has a much higher peak demand than the winter of 92/93 even though weather patterns were similar. Therefore, the boiler should be checked for changes to its operation or entire system replacement.

During the summer time both peak demand and WBE consumption are reduced by 4% and 7% respectively, indicating a slight reduction of equipment used and hours equipment is operated during the summer time. However, the ELF is still much higher than the PLF during the summer time indicating there is additional potential to reduce consumption.

Weis Middle School (WMS)

Weis Middle School has a peak demand of 8.44 W/sf, highest of the schools. This indicates the possibility of oversized equipment or additional equipment not found at other schools. The WBE consumption is 1.50 W/sf during the school year, approximately 31% above average, indicating a potential of overusing equipment. Comparing the ELF with OLF and PLF there seems to be a good match during the school year indicating there is probably not much over use. Approximately 27% of the electricity provides cooling during the school year. Natural gas use at WMS is approximately half of average.

During the summer time the peak demand reduces 25% and WBE consumption reduces by approximately 25% indicating energy consumption reduction in the summer time. However, the ELF is still much higher than the PLF during the summer time indicating there is additional potential to reduce consumption.

5.3 Daily Results

Table 5.6: *Daily WBE-school year, weekday results*

School	*Weekday* Ave WBE with Std-Dev (W/sf)	*Weekday* Base Level WBE with CV-RMSE (W/sf)	*Weekday* Cooling Slope with CV-RMSE (W/sf)	*Weekday* Change-point Temp (Degrees F)	R^2	*Weekday* Whole Model CV-RMSE
CMS	1.32 (0.51)	1.14 (0.03)	0.10 (0.01)	73.26	0.46	0.29
DMS	2.19 (0.84)	1.50 (0.06)	0.10 (0.00)	60.5	0.70	0.24
MES	2.18 (0.46)	1.97 (0.03)	0.06 (0.00)	68.10	0.50	0.16
NHS	1.87 (0.62)	1.36 (0.02)	0.07 (0.00)	60.52	0.82	0.14
OES	1.82 (0.29)	1.34 (0.06)	0.02 (0.00)	41.18	0.34	0.15
PES	1.92 (0.39)	1.65 (0.03)	0.05 (0.00)	68.10	0.53	0.16
RES	1.76 (0.21)	1.35 (0.09)	0.02 (0.00)	41.57	0.19	0.18
SES	1.66 (0.49)	1.17 (0.02)	0.05 (0.00)	58.06	0.65	0.21
SHS	1.28 (0.35)	0.95 (0.01)	0.04 (0.00)	59.96	0.77	0.13
VHS	1.09 (0.27)	0.81 (0.01)	0.02 (0.00)	56.90	0.69	0.13
WMS	2.20 (0.37)	2.02 (0.03)	0.06 (0.00)	69.06	0.45	0.15
Average	1.75 (0.44)	1.39 (0.058)	0.054 (0.003)	59.746	0.555	0.176

Table 5.7: *Daily WBE-school year, weekend results*

School	*Weekend* Ave WBE (W/sf)	*Weekend* Whole Model CV-RMSE
CMS	0.31	0.57
DMS	1.03	0.61
MES	0.29	0.65
NHS	0.57	0.56
OES	0.30	0.47
PES	0.31	0.32
RES	0.28	0.25
SES	0.72	0.46
SHS	0.43	0.41
VHS	0.40	0.37
WMS	0.41	0.67
Average	0.459	0.486

Table 5.8: *Daily WBE-summer results*

School	*Weekday* Ave WBE (W/sf)	*Weekday* Whole Model CV-RMSE	*Weekend* Ave WBE with Std-Dev (W/sf)	*Weekend* Ave WBE (W/sf)	*Weekend* Whole Model CV-RMSE
CMS	0.94	0.59	0.60 (0.52)	0.60	0.87
DMS	2.55	0.2	1.91 (0.76)	1.93	0.39
MES	1.39	0.41	0.30 (0.37)	0.33	1.12
NHS	1.56	0.44	0.65 (0.28)	0.65	0.44
OES	0.94	0.54	0.46 (0.51)	0.46	1.07
PES	1.03	0.47	0.32 (0.11)	0.35	0.39
RES	0.57	0.42	0.21 (0.07)	0.21	0.34
SES	1.70	0.21	1.43 (0.33)	1.42	0.23
SHS	0.92	0.27	0.47 (0.12)	0.46	0.25
VHS	0.82	0.23	0.33 (0.07)	0.32	0.21
WMS	0.83	0.82	0.32 (0.34)	0.39	1.18
Average	1.205	0.416	0.63 (0.32)	0.647	0.591

5.3.1 General

This section considers daily indices. In the previous section it was shown that grouping monthly indices into school year and summer periods reveals more information about how seasons affect a school's operation and consequently provides additional information to identify high energy consumers. In this next section we take a look at what additional information can be provided within the analysis of daily data and the ability to further separate data into weekday and weekend models based on scheduling as well as weather related data.

5.3.1.2 Weekday/Weekend School Year Days

While creating daily school year models, subtracting the weekend data from the analysis has a significant affect on results when compared to monthly analyses that include weekend results. The average base electric consumption increases approximately 32%, ranging from a low of 15% for DMS to a high of over 50%. Although a 1-parameter model is used for weekend data, there is indication that a 3-parameter model may be as good a fit. This can be clearly seen in Figures 3.20a and 3.20b. There is a significant difference between weekday and weekend usage. A 1-parameter mean model is most useful for the summer use for both weekday and weekend models due to the narrow temperature band. However, at some of the schools a 3-parameter model from the school year fits. The summer data possibly indicating significant changes of school operation throughout the summer time.

With a daily model is easier to point out the cooling and non-cooling electrical usage at a school as well as the weekday and weekend usage. Also, removing holidays from weekday school year data there is a noticeable 36% increase in the WBE base-level and an average 11% drop in CV-RMSE in weekday school year data with holidays removed from the data versus weekday school year data with holidays included in the data. This indicates the complexity of modeling a school because of all the different types of schedules throughout the calendar year. Also of note, when modeling weekday electricity versus monthly electricity, (both using the school year data) it is significant that base-level energy consumption increases by approximately 34% indicating that the weekends consumption plays an integral role in modeling a school's consumption. Weekend data varies greatly from school to school, indicating the differences in occupancy at each school.

5.3.2 School Specific

Chamberlain Middle School (CMS)

During the school year Chamberlain Middle School has a weekday base electricity consumption of 1.14 W/sf. However, the CV-RMSE is 0.29, the highest of these schools. The profile (see Figure 3.20a,b) suggests a 4 parameter model may be a better fit. Electricity consumption drops significantly on the weekend, indicating systems are being shut off when not in use. During the summer time the same can be said. There is a 36% drop in electricity consumption versus school year days indicating that school systems are not in use when the building in not occupied. All daily electricity consumption values are below the averages.

Dunbar Middle School (DMS)

During the school year Dunbar Middle School has a weekday base electricity consumption of 1.5 W/sf. Electricity consumption does not drop significantly on the weekend. DMS has a electricity consumption of 1.03 W/sf on the weekend, a value more than twice average. This is indication that systems are being left on all the time. The same is true during the summer time. The weekday electricity consumption is 2.55 W/sf, more than twice the average, and the weekend electricity consumption is 1.93 W/sf, three times the average. Both are indications that the school has systems on well beyond hours suggested by the PLF.

Morgan Elementary School (MES)

During the school year Morgan Elementary School has a weekday base electricity consumption of 1.97 W/sf, significantly higher than average, suggesting possible overuse of systems at night. The weekend electricity consumption of 0.29 W/sf is significantly below average suggesting little activity at the school on the weekend. During the summer time the weekday electricity consumption reduces to 1.39 W/sf and increases to 1.12 W/sf on the weekend. This suggests the school has less use in the summer time, but the school is still being used throughout the entire week. The PLF is lower during the summer time. Therefore, weekend usage of systems may be excessive in the summer.

Nacogdoches High School (NHS)

During the school year Nacogdoches High School has a weekday base electricity consumption of 1.36 W/sf, approximately average. Electricity consumption drops significantly (58%) on the weekend, indicating systems are being shut off when not in use. During the summer time the same can be said, indicating that school systems are not in use when the building in not occupied.

Oppe Elementary School (OES)

During the school year Oppe Elementary School has a weekday base electricity consumption of 1.34 W/sf, approximately average. The weekend electricity consumption of 0.30 W/sf is significantly below average suggesting little activity at the school on the weekend. During the summer time the weekday electricity consumption reduces to 0.94 W/sf and 0.46 W/sf on the weekend. This suggests the school has significantly less use in the summer time, and as a result systems are shut off when not in use.

Parker Elementary School (PES)

During the school year Parker Elementary School has a weekday base electricity consumption of 1.65 W/sf, slightly above average. The weekend electricity consumption of 0.31 W/sf is significantly below average suggesting little activity at the school on the weekend. During the summer time the weekday electricity consumption reduces to 1.03 W/sf and 0.35 W/sf on the weekend. This suggests the school has significantly less use in the summer time, and as a result systems are shut off when not in use.

Rosenberg Elementary School (RES)

During the school year Rosenberg Elementary School has a weekday base electricity consumption of 1.35 W/sf, approximately average. The weekend electricity consumption of 0.28 W/sf is significantly below average suggesting little activity at the school on the weekend. During the summer time the weekday electricity consumption reduces to 0.57 W/sf and 0.21 W/sf on the weekend. Both values are far below average suggesting the school is shut down for most of the summer.

Sims Elementary School (SES)

During the school year Sims Elementary School has a weekday base electricity consumption of 1.17 W/sf, which is about average. Electricity consumption does not drop significantly on the weekend. SES has an average electricity consumption of 0.72 W/sf on the weekend approximately 57 % above average. This is indication that systems are being left on all the time. The same is true during the summer time. The weekday electricity consumption is 1.70 W/sf, larger than the average during the school year indicating that HVAC systems are not being shut off when the building is not being used. The weekend electricity consumption is 1.42 W/sf, more than double the average. Both are indications that the school has systems on well beyond hours suggested by the PLF.

Stroman High School (SHS)

During the school year Stroman High School has a weekday base consumption of 0.95 W/sf, second lowest value and well below average. Electric consumption drops significantly (more than 50%) on the weekend, indicating systems are being shut off when not in use. During the summer time the same can be said indicating that school systems are not in use when the building in not occupied. This is a lower consumer of electricity.

Victoria High School (VHS)

During the school year Victoria High School has a weekday base electricity consumption of 0.81 W/sf, the lowest value and well below average. Electricity consumption drops significantly (more than 50%) on the weekend, indicating systems are being shut off when not in use. During the summer time the same can be said indicating that school systems are not in use when the building in not occupied. This is a lower consumer of electricity.

Weis Middle School (WMS)

During the school year Weis Middle School has an weekday base electricity consumption of 2.02 W/sf, significantly higher than average, suggesting that systems are left on at night during the weekday. However, the weekend electricity consumption is 0.41 W/sf, slightly below average and much lower than during the week. This suggests that the school gets minimal usage during the weekend. During the summer time the weekday electricity consumption reduces to 0.83 W/sf and 0.39 W/sf on the weekend. This suggests the school has significantly less use in the summer time, and as a result systems are shut off when not in use.

5.4 Summary

This section of the report has traced through the information that is available to the building analyst at the annual, monthly, and daily time frames. In almost every case, the refinement of the suggestions improved, as expected. However, several features are worth noting. First, the base-level use, calculated with a monthly 3-parameter model during the school year seems to be a good indicator or occupied period weather independent energy use. This monthly baseline holds up well against the daily baseline in comparison to significant changes in the slope and change-point parameter as one moves from monthly to daily data.

Second, comparing the monthly base-level use during the school year against the mean use of the summer period provides a good indicator of whether or not systems are being left on during unoccupied periods.

Third, knowing the base-level use from the school year 3-parameter model allows one to calculate the proportions of the energy use that are weather dependent and weather independent. This allows for a refined comparison of cooling systems.

Fourth, the 25th percentile of a monthly quartile analysis is a remarkably robust parameter and seems to be consistently indicating the base-level use.

Finally, a simple x-y plotting of the monthly and daily data versus temperature provides a very good visual clue as well as helping to confirm the model choices.

6.0 AUDIT RECOMMENDATIONS

The following table lists the ECRMs recommended by four different energy audit companies who performed audits on these schools between 1990 and 1992. Dates listed on this table indicate the ECRM was approved and completed during that month. Recommendations varied for each school district due to different energy audit companies. In the Fort Worth Independent School District (ISD) (Carter & Burgess, Inc. 1990), lighting was converted from 2 lamp fixtures to 1 lamp fixtures. In Victoria ISD (ACR Engineering, Inc. 1990), new control systems (EMCS) were recommended. After installation, both Stroman and Victoria High Schools had significant control over HVAC systems as well as lighting. Additionally, rewiring of hall lighting at Stroman was recommended. At both Victoria ISD High Schools, the natural gas absorption chillers were replaced with electric chillers. In Nacogdoches ISD, both Nacogdoches High School and Chamberlain Middle School had EMCS systems installed for greater control of HVAC and hallway lighting (Kinsman and Associates, 1991). Another common recommendation from the audit reports was refixturing with high efficiency fluorescent lamps. One recommendation not implemented was replacing the electric heating units on the first floor with gas units at Chamberlain Middle School. In Galveston ISD (Yandell & Hiller, 1992), all five elementary schools had thermal cool storage systems recommended that were installed in 1993.

O&Ms were made primarily in aggregate for schools and are thus shown with the O&M recommendations made from this study.

Table 6.1: *Retrofits performed on each school and date completed*

School	Retrofits	Date Competed
Sims E.S.	•Convert 2x4 to 1x4 fl	Nov. 1991
Dunbar M.S.	•Convert 2x4 to 1x4 fl	Nov. 1991
Stroman H.S.	•Install EMS	Aug. 1991
	•Replace Absorption Chiller with HE electric chiller	Aug. 1991
	•Rewire Hallway lighting for reduced usage during high natural lighting and low occupancy periods	Aug. 1991
	•Replace single speed 20 horsepower HW pump with new 2-speed motor, and use EMCS	
Victoria H.S.	•Install EMS	Aug. 1991
	•Replace Absorption Chiller	Aug. 1991
Nacogdoches H.S.	•Install EMS	Oct. 1992
	•Fixture Relamping	Oct. 1992
	•Convert to Gas Heating	Oct. 1992
	•Increase Cooling Capacity	Oct. 1992
Chamberlain M.S..	•Install EMS	Oct. 1992
	•Install Gas heating on 1st floor to replace electric heating	
	•Fixture Relamping	Oct. 1992
Oppe E.S.	•Install Thermal Storage System	May 1993
Weis M.S.	•Install Thermal Storage System	May 1993
Parker E.S.	•Install Thermal Storage System	May 1993
Morgan E.S.	•Install Thermal Storage System	Jun. 1993
Rosenberg E.S.	•Install Thermal Storage System	Jun. 1993

7.0 SITE VISIT RECOMMENDATIONS

7.1 ECRMs

After collecting all the annual, monthly, daily, and hourly information needed to create the indices, and reading the audit reports already prepared, site visits confirmed and revealed any additional ECRMs and O&Ms not already suggested by the indices and prior energy audits. The following areas showed promise for additional ECRMs:

The energy managers at some of the larger schools explained that a lot of zones were conditioned during periods of low occupancy. Nacogdoches High School in particular has summer school in the 600 wing, a separate zone on the overall system. The idea of only using the 600 wing was to allow the main building of the school to be shut down except for the office area. However, the library gets used in the summer time and is not zoned separately. As a result a large percent of the main building's zones remain on during the summer time to allow use of the library. A solution for this and at other large schools is to rezone areas for more control during times of lower occupancy.

Another area that should be further investigated is converting CAV systems to VAV systems for night and summer energy savings. The larger schools have better control than the smaller ones. In both Nacogdoches ISD and Victoria ISD, there is enough control to shut down most systems at night. However, in the summertime there is a lot of partial activity in the buildings. In the smaller schools, Galveston ISD, systems remain on during the summer time to prevent humidity problems. This occurs even during zero occupancy periods. This is also of concern in band rooms at the larger schools. VAV conversion should be explored as an alternative in all schools.

Lighting systems at the schools varied from standard 40 watt fluorescent lamps to high efficiency 34 watt 4 foot fluorescent lamps. At Galveston ISD, which was supposed to have all 34 watt lamps, there was a mixture of 34 watt and 40 watt lamps. This was probably due to the fact that there was still a large supply of 40 watt lamps remaining in storage. To remedy the situation and save energy in the future 32 Watt T8 lamps with electronic ballasts and tandem wiring were recommended wherever possible. This prevents any possibility of reverting back to 40 Watt lamps and with the combinations of electronic ballasts, already replaced at some of these schools, the lighting quality should be improved. Lighting quality is very important in education and needs to be taken into consideration when replacing lighting, T8 lighting systems provide comparable lighting levels and color rendition.

At Stroman High School a new hot water boiler was recommended and replaced a few years ago to allow shut off of the main boiler during the summer time. Also recommended at the High Schools is replacing the boilers with new modular boilers better able to handle the heating demand. This had just been done been completed at Nacogdoches High School for the 1993 heating season.

The following table lists recommend ECRMs:

Table 7.1: *ECRMs recommended from site visit*

ECRMs	SES	DMS	SHS	VHS	NHS	CMS	OES	WMS	PES	MES	RES
•Retrofit F40 std and HE lamps with T8 lighting w/ electronic ballasts and tandem wiring	X	X	X	X	X	X	X	X	X	X	X
•Rezone			X		X	X					
•Convert CAV to VAV							X	X	X	X	X
•Install new boiler				X							

7.2 O&Ms

General O&Ms suggested were to maintain better control of windows. Seal windows if necessary. Typically windows are opened if possible rather than adjusting or in addition to adjusting a thermostat to maintain certain room temperatures. The older schools in Victoria ISD and Nacogdoches ISD are especially susceptible to this.

Fort Worth ISD schools had poor control of HVAC systems in the past few years. Systems were left on at night and on the weekends. New EMCS systems need to be installed and in fact have just been completed at Sims Elementary school by the end of the summer in 1994. As a result there should be better control of temperatures at night and on the weekends.

Separate DHW tanks were recommended at most of the schools in Galveston to allow shut off of the boilers during the summer time. All schools in Galveston have separate DHW tanks and one, Parker even has separate storage tanks for DHW.

Refrigeration plays a large role at all schools except for Chamberlain. Each school has one or two walk-in coolers and freezers as well as several reach in coolers and soda machines. For walk-in coolers/freezers, plastic strips should be used to limit the amount of cool air loss and these boxes should remain as full as possible to possibly allow the shut down of some of the reach in boxes.

Cooking also uses a tremendous amount of electricity. Electric ovens and fryers can increase demand by 10 kW or more each. They should always be shut off when not in use and used at minimum required heating levels for cooking. All electrical equipment should be shut off when not in use if possible. This also applies to lighting and computers which may consume 0.1 W/sf

The following table shows all potential O&Ms (some of these were recommended in the audit reports, but in general, not site specific):

Table 7.2 *O&Ms recommended*

O&M Measures	SES	DMS	SHS	VHS	NHS	CMS	OES	WMS	PES	MES	RES
Building Envelope											
•Install Weather-stripping						X					
•Replace Caulking						X					
Heating System											
•Lower T-stats during occ and unocc periods	X	X	X	X	X	X	X	X	X	X	X
•Adjust outside reset temp											
Cooling System											
•Raise Thermostat during	X	X									
occ and unocc periods											
•Clean evaporator and	X	X	X	X	X	X	X	X	X	X	X
condenser coils											
•Adjust outside reset temp											
HVAC Distribution System											
•Replace Faulty Steam Traps											
•Shut off fans and pumps when not in use	X	X	X	X	X	X					
Domestic Hot Water											
•Hot water temp reset									X		
•Turn off on weekends											
•Separate kitchen DHW tank from main tank (boiler) to reduce main DHW temp.			X					X		X	X
Cooking											
•Keep coolers at warmest temps	X	X	X	X	X	X	X	X	X	X	X
•Keep coolers closed, install plastic strips on Walk-in boxes	X	X	X	X	X		X	X	X	X	X
•Turn off equipment when not used	X	X	X	X	X	X	X	X	X	X	X
Lighting System											
•Turn off when not in use	X	X	X	X	X	X	X	X	X	X	X
•Delamp & disconnect ballasts											
•Photocells in well lit rooms								X			
•Motion Sensors											
Power Factor Correction							X	X	X	X	X

8.0 CONCLUSIONS

Eleven schools in this case study, six elementary schools, two middle schools, and three high schools have been investigated for whether or not special indices could reveal useful information about their energy use. They are located in four different locations around Texas with fairly similar but different weather patterns throughout the year. However, all seemed to have some common conclusions result from this analysis. Certain indices revealed a great deal of information about the electrical and gas consumption at schools and how they are operated. This information, supplemented by an on-site visit, verified the usefulness of these indices.

Annual consumption data shows a clear trend that with increased size (square footage) of a school one should expect the electric and gas consumption to increase proportionally. If not, there is probably something wrong with the operation of the equipment and should be pursued at an energy audit. The other possibility is that there is some additional equipment or a lack of equipment at the specific school in question. Regardless of which, this identifies for an energy analyst an area to concentrate on when looking for potential ECRMs at the visit. When normalizing annual data on a per square footage basis, information becomes less clear. From the eleven schools studied in this report there does not seem to be a clear trend. Energy use varies on a normalized basis.

When correlating monthly data to dry bulb temperature, there is a clear trend towards increased electrical usage and increased temperature for both peak demand and average data, with a dip at the highest temperatures due to summer activity. This is also a useful index because both monthly electricity and weather data are typically readily available in most locations and can be simulated easily. This index is clearly seen across all types of schools in all four locations even though dry bulb temperatures and equipment usage varied at all schools.

Even more revealing is grouping monthly data into school year and non school year blocks (summer). When one fits a statistical model to the normalized consumption data versus the average dry bulb temperature, one sees that a three-parameter cooling model or a four-parameter model (better fit) describes how much of the electrical consumption is used for cooling, and consequently what the baseline electrical consumption is with a reasonable amount of accuracy. However, it is important to divide the monthly data into school year and summer data prior to the analysis.

When looking at monthly data for more than a single year (something not always available but important to reveal operating trends), one sees how weather patterns or change of operating schedules affect normalized electrical and gas consumption at schools. At both Fort Worth schools it was evident that operations were atypical when comparing electricity and gas consumption to the other schools on a monthly basis. The monthly data also revealed that CMS had a slightly different pattern than the other schools, high electricity consumption at both high and low temperatures. Hence, electrical heating was identified something that may be overlooked at a site visit if there is a combination of both electric and gas heating. As a result, potential fuel switching to natural gas heating was suggested as an ECRM after the site visit.

Monthly ELFs, OLFs, and PLFs show how well the hours of operation for the equipment match the hours that the building is occupied. From discussions with the energy managers of each district as well as talking with the principals at each school a clear pattern was determined. Occupancy at schools was usually higher than the equipment usage. However, the amount of people (PLFs) occupying the building at off peak demand hours was only a fraction of the number of people occupying the building during peak demand times. Equipment shut off did not necessarily reflect these changes due to inability to properly control zoning of the buildings. The more zones a building had, the better the control, and hence, the better the match between ELFs and PLFs. This was especially seen during summer times.

Although not always available, daily data is very helpful in determining building operation. Aberrations normally smoothed out over an entire month can be seen more clearly with daily data. Weekday and weekend grouping was even more revealing. This data helped confirm what interviews with building managers revealed approximately school operations. On weekends that schools had functions, electric power levels rose for those days as well as for weekday with higher than usual afternoon activities. This index was useful for smaller schools, especially elementary schools, which get minimal usage outside of the normal school day. In these schools it was particularly useful in identifying unplanned evening and weekend usage at the schools and whether controls were being properly utilized, something that was not occurring at DMS and SES.

The following things can be said about comparing what the recommendations from the indices indicate versus what the recommendations from the audit reports indicated.

Chamberlain Middle School (CMS)

At Chamberlain Middle School the indices indicated a fairly average energy consuming school. However, it also did indicate the possibility or electric heating at the school. The audit for CMS recommended replacing electric heating of the first floor with gas heating. In this case the indices verified what was discovered from an on-site audit at the school.

Dunbar Middle School (DMS)

At Dunbar Middle School the indices indicated that systems were being run continuously throughout the school year and summer. However, the audit for DMS only recommended a lighting retrofit and other "standard" or cookbook items that did not indicate that further attention needed to be focused on why the HVAC systems ran continuously and whether or not they could be shut-off. Clearly, the indices could have provided useful information at this school.

Morgan Elementary School (MES)

At Morgan Elementary School the indices indicated that systems may be oversized for school year demand and are being operated longer than at other schools. However, the audit for MES only recommended thermal storage and other "standard" or cookbook items that did not indicate that further attention needed to be focused on why the systems may be oversized and running more hours during the school year. Clearly, the indices could have provided useful information at this school.

Nacogdoches High School (NHS)

At Nacogdoches High School the indices indicated a relatively low energy consuming school. The audit for NHS had recommended an EMS among a few other changes. The indices were calculated after the audit recommendations were installed and this can clearly be seen in the audits.

Oppe Elementary School (OES)

At Oppe Elementary School the indices indicated a potential problem with natural gas consumption. However, the audit for OES only recommended thermal storage and other "standard" or cookbook items that did not indicate that further attention needed to be focused on natural gas consumption. Clearly, the indices could have provided useful information at this school.

Parker Elementary School (PES)

At Parker Elementary School the indices indicated a very low natural gas consuming school. However, the audit for PES only recommended thermal storage and other "standard" or cookbook items that did not indicate that further attention needed to be focused on natural gas consumption and natural gas equipment. Clearly, the indices could have provided useful information at this school.

Rosenberg Elementary School (RES)

At Rosenberg Elementary School the indices indicated a low energy consuming school and has a low occupancy during the summer months. However, the audit for RES recommended thermal storage and other "standard" or cookbook items, while there may have been better recommendations or other schools where thermal storage might have been more applicable.

Sims Elementary School (SES)

At Sims Elementary School the indices indicated that systems operations and sizing are about average during the school year weekdays, but on weekends and during the summer, the systems were not being shut off. The audit for SES only recommended a lighting retrofit and other "standard" or cookbook items that did not indicate that further attention needed to be focused on why the HVAC systems ran continuously during periods of low building occupancy and whether or not they could be shut-off. Clearly, the indices could have provided useful information at this school.

Stroman High School (SHS)

At Stroman High School the indices indicated a low energy consuming school. Audit recommendations basically reflect this by recommending an EMS and rewiring of lighting to decrease energy consumption slightly.

Victoria High School (VHS)

At Victoria High School the indices indicated a low energy consuming school. Audit recommendations basically reflect this by recommending an EMS to decrease energy consumption slightly.

Weis Middle School (WMS)

At Weis Middle School the indices indicated that systems are oversized and overrun. The audit for WMS only recommended thermal storage and other "standard" or cookbook items that did not indicate that further attention needed to be focused on why the HVAC systems ran continuously and whether or not they could be shut-off. Clearly, the indices could have provided useful information at this school.

9.0 RECOMMENDATIONS

Recommendations are as follows: Obtain as much information as possible prior to auditing a school. Annual and monthly data is readily available and should be obtained for at least two years. If possible obtain daily data as well, especially for smaller schools. It reveals a great deal of useful information about the school. Talk with both the energy manager and the principal of the school. That way one obtains both the HVAC operation and people occupancy schedule of the school. If the schedules do not match, the control of equipment should be inspected. Finally, plan a visit of the school to confirm findings. That way one knows exactly which areas to target for ECRMs.

10.0 REFERENCES

Abbas, M. 1993. Development of graphical indices for building energy data. Master's Thesis, Texas A&M University, College Station, TX, Energy Systems Laboratory Report No. ESL-TH-93/12-02.

ACR Engineering, Inc. Austin, TX, Energy Cost Reduction Analysis of Victoria Independent School District, October 1990.

Carter & Burgess, Inc. Engineers-Planners-Surveyors, Fort Worth, TX, An Evaluation of RFP #90-040 prepared for: The Fort Worth Independent School District, December 1990.

Fels, M.F. and Reynolds, C.L. 1990. "Now That I've Run PRISM, What Do I Do With the Results? Home Energy October 1990, pp. 27-34.

Haberl, J.S. and P.S. Komor. 1989. Investigating an analytical basis for improving commercial energy audits: Early results from a New Jersey mall. *Thermal Performance of the Exterior Envelopes of Buildings IV*. ASHRAE. Atlanta, GA.

Hadley, D.L 1993. Daily variations in HVAC system electrical energy consumption in response to different weather conditions. Energy and Buildings. 19: 235-247.

Kinsman, and Associates, Richardson, TX, Energy Cost Reduction Analysis of Nacogdoches Independent School District, September 1991.

Landman, D. 1996. "Development of Pre-screening Indices to Improve Energy Analysis of Public K-12 Schools", *Masters Thesis*, ESL-TH-xx/xx-xx. Department of Mechanical Engineering, Texas A&M University, College Station, TX.

Verdict, M., J. Haberl, D. Claridge, D. O'Neal, W. Heffington, D. Turner, "Monitoring $98 Million Energy Efficiency Retrofits: The Texas LoanSTAR Program," Proceedings of the ACEEE 1990. Summer Study on Energy Efficiency in Buildings, American Council for an Energy Efficiency Economy, Washington, D.C. (August) 1990

Yandell & Hiller Inc. Fort Worth, TX, Energy Cost Reduction Analysis of Galveston Independent School District, April 1992

11.0 ACKNOWLEDGMENTS

Contributions to this report by the following people are acknowledged: Mustafa Abbas, Anna Baranowski, Tarek Bou-Saada

This project was conducted by the Energy Systems Laboratory, Department of Mechanical Engineering, Texas A&M University, under subcontract with Oak Ridge National Laboratory as part of the U. S. Department of Energy's Existing Building Research Program.

Portions of this work would not have been possible without support from the Texas LoanSTAR program through the Texas State Energy Conservation Office, and funding through Texas ERAP project #227.

Special thanks are also due to Mike MacDonald, the Oak Ridge project manager, and Mr. Ernest Freeman at the USDOE.

12.0 APPENDIX

Table 12.1: *Summary Table: information collected at each school and the indices*

SITE	School Site Name	Area Sq-ft.	Site Description	Audit Report	Uitlity Monthly Electric Bills	Loan STAR Hourly Electric	Uitilty Monthly Natural Gas Bills	LoanSTAR Hourly Natural Gas	Utility Monthly Water Bills	Daily Weather Data	School Map	Site Visit Date
SHS	Stroman High School	210,474	X	X		9/91-Pres		9/91-Pres		11/91-Pres	X	4/25/94
VHS	Victoria High School	257,014	X	X		9/91-Pres		9/91-Pres		11/91-Pres	X	4/25/94
SIM	Sims Elementary School	62,400	X	X	1/91-Pres	9/91-Pres	1/93-Pres	9/91-Pres		11/91-Pres	X	1/20/94
DMS	Dunbar Middle School	92,884	X	X	1/91-Pres	9/91-Pres	1/93-Pres	9/91-Pres		11/91-Pres	X	3/25/94
NHS	Nacogdoches High School	202,615*	X	X	1/91-Pres*	7/92-Pres	1/91-Pres*	9/91-Pres	1/91-Pres	7/92-Pres	X	3/25/94
CMS	Chamberlain Middle School	66,778	X	X	1/91-Pres*	7/92-Pres		N/A	1/91-Pres	7/92-Pres	X	2/27/94
OES	Oppe Elementary School	80,400	X	X	8/91-Pres*	1/93-Pres*	8/91-Pres*	N/A		12/92-Pres	X	2/27/94
WMS	Weis Middle School	80,769	X	X	8/91-Pres*	1/93-Pres*	8/91-Pres*	N/A		12/92-Pres	X	2/27/94
PES	Parker Elementary School	81,742	X	X	8/91-Pres*	1/93-Pres*	8/91-Pres*	N/A		12/92-Pres	X	2/27/94
MES	Morgan Elementary School	76,798	X	X	8/91-Pres*	1/93-Pres*	8/91-Pres*	N/A		12/92-Pres	X	2/27/94
RES	Rosenberg Elementary School	63,044	X	X	8/91-Pres*	1/93-Pres*	8/91-Pres*	N/A		12/92-Pres	X	2/27/94
TOTAL		1,072,303										

Summary Information

SITE	School Site Name	Indices Tested (M)ontly, (Y)early, (D)aily, (H)ourly											
		Ave. Power Levels (W/sf)	Peak Power Levels (W/sf)	Gas Levels {Btu (hr-sf)}	Energy Consumption (kWh/yr)	Natural Gas (mmBtu/yr)	Average WBE (W/sf)	Average WB heat {Btu (hr-sf)}	ELF OLF PLF	Peak W/sf vs. Peak Temp	Ave. W/sf vs. Ave. Temp	Emodel Fit for (All Months, School Year, Summers)	WBE vs. Temp (All Days, School Days, Summer Days)
SHS	Stroman High School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
VHS	Victoria High School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
SIM	Sims Elementary School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
DMS	Dunbar Middle School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
NHS	Nacogdoches High School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
CMS	Chamberlain Middle School	A	A	A	A	A	A		A	M (by dist.)	M (by dist.)	M	D
OES	Oppe Elementary School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
WMS	Weis Middle School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
PES	Parker Elementary School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
MES	Morgan Elementary School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D
RES	Rosenberg Elementary School	A	A	A	A	A	A	A	A	M (by dist.)	M (by dist.)	M	D

Appendix Information

SITE	School Site Name	Indices Tested (M)ontly, (Y)early, (D)aily, (H)ourly									
		Electric Consump. & Demand (W/sf) *GISD Demand (VA/sf)	Natural Gas Consumption	ELF OLF PLF	NWS Temp (LoanSTAR weather site for GISD)	WBE {Daytype and 3d} (W/sf)	WB heat {Daytype and 3d} (W/sf)	Lighting {Daytype and 3d} (W/sf)	Chillers {Daytype and 3d} (W/sf)	Chiller Eiff {Daytype and 3d} (kW/toa)	Chiller {Daytype and 3d} {Btu/(hr-sf)}
SHS	Stroman High School	M	M	M	M	H	H		H	H	H
VHS	Victoria High School	M	M	M	M	H	H		H	H	H
SIM	Sims Elementary School	M	M	M	M	H	H	H			
DMS	Dunbar Middle School	M	M	M	M	H	H	H			
NHS	Nacogdoches High School	M	M	M	M	H	H	H	H		
CMS	Chamberlain Middle School	M		M	M	H		H			
OES	Oppe Elementary School	M	M	M	M	H			H		
WMS	Weis Middle School	M	M	M	M	H			H		
PES	Parker Elementary School	M	M	M	M	H			H		
MES	Morgan Elementary School	M	M	M	M	H			H		
RES	Rosenberg Elementary School	M	M	M	M	H			H		

SITE	School Site Name	Information Table	Map	Monitoring Diagrams	Weekly IPN Plots	MECR Information
SHS	Stroman High School	X	X	X	X	X
VHS	Victoria High School	X	X	X	X	X
SIM	Sims Elementary School	X	X	X	X	X
DMS	Dunbar Middle School	X	X	X	X	X
NHS	Nacogdoches High School	X	X	X	X	X
CMS	Chamberlain Middle School	X	X	X	X	X
OES	Oppe Elementary School	X	X	X	X	X
WMS	Weis Middle School	X	X	X	X	X
PES	Parker Elementary School	X	X	X	X	X
MES	Morgan Elementary School	X	X	X	X	X
RES	Rosenberg Elementary School	X	X	X	X	X