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Preliminary Study of Advanced Diagnostic Prescreening Methods

Volume 1:
Summary

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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). This report then compares 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 recommendations of on-site visits and actually provide additional information that is sometimes not identified by a site visit. As a result, these indices can assist energy audit firms and building owners/administrators with identifying those areas of a school that have the most potential for ECRMs and O&Ms prior to a site visit. These indices help the energy auditor to perform 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 confirm 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, and people load factors.

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 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. 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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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 Facilites* (Landman 1996).

The purpose of this study is to provide energy analysts with a 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 relative 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. 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.

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. baselevel, 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 baselevel 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 program 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. Other indices investigated include a 24 hour weather-daytype graphs used for the analysis of power levels including gas consumption, lighting use, and chiller use.

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

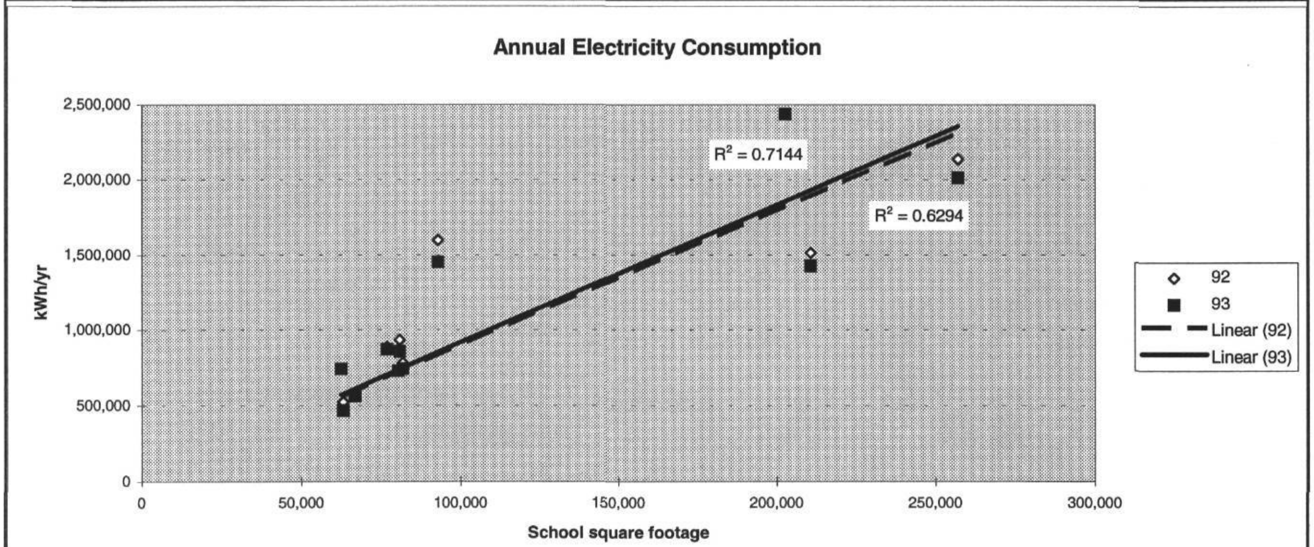
Energy indices tell alot about how a building is operating. The following section discusses different types of indices available. The first section is annual electricity and gas indices, dealing with variation in energy consumption from 1992 to 1993. The next section is monthly electricity and gas indices, 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 1 shows the total annual electricity and natural gas consumption. 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 1 represent available data for the 1992 calendar year. The filled squares represent available data for the 1993 calendar year. The diagonal line has been added to provide a general sense of the difference between the 1992 and 1993 consumption years. 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 13 in Section 6.0, Audit recommendations.

The bottom graph 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.

Figure 1: *Annual Consumption*: Electricity and Gas Consumption for the eleven schools for 1992 and 1993.



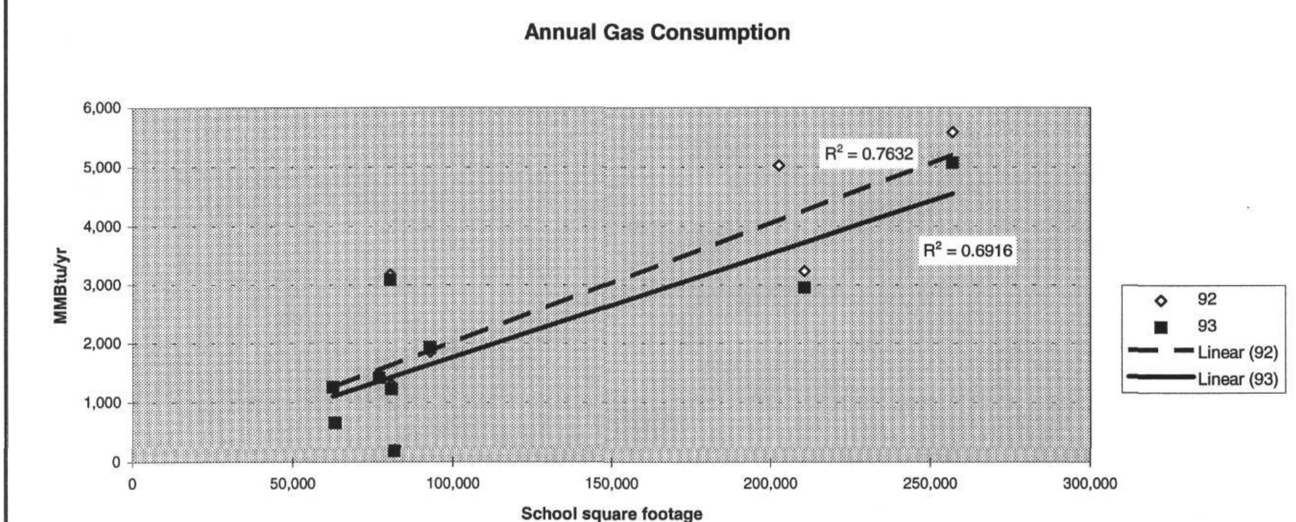


Table 1: Annual electric and gas data

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

---- Data was 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.

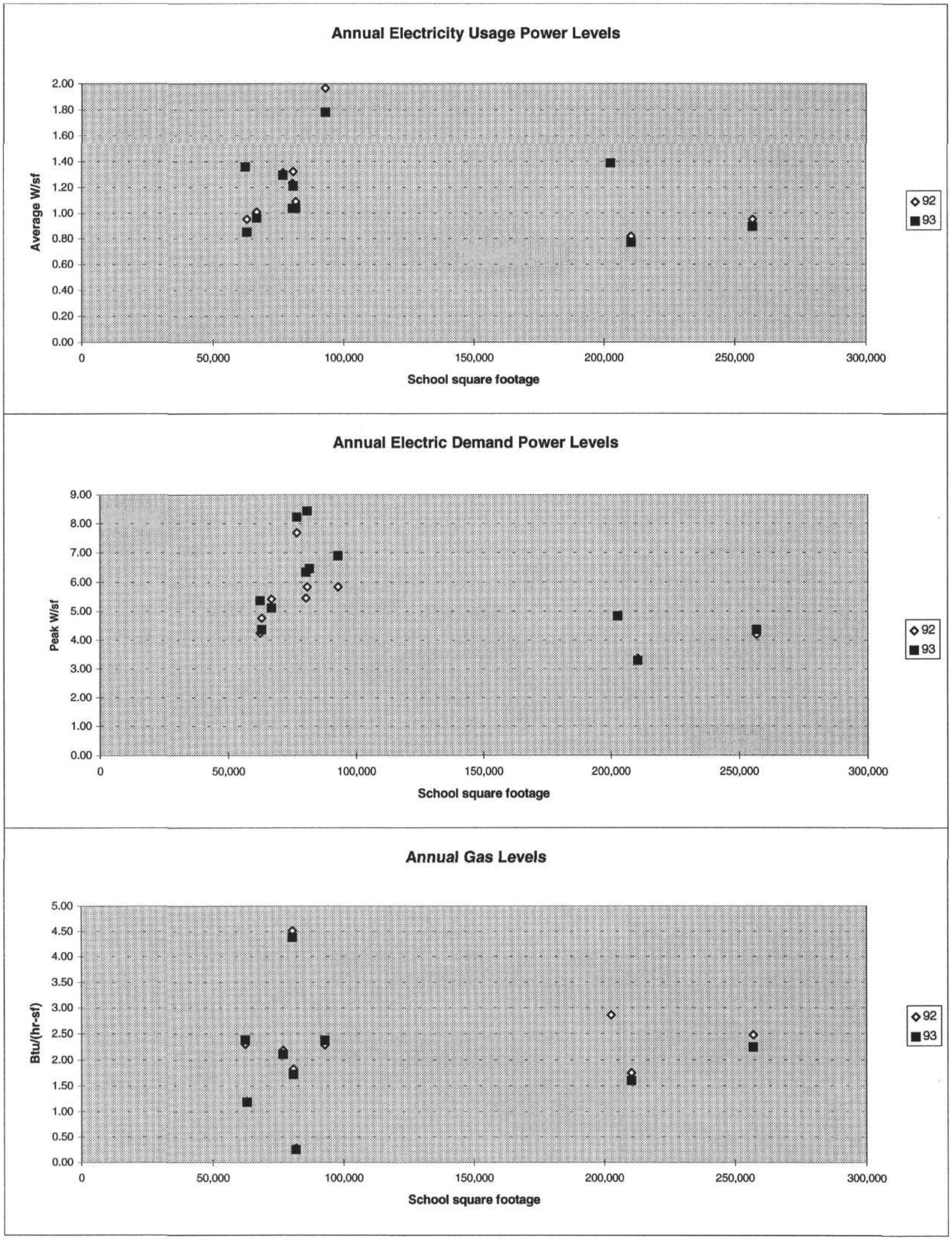
Figure 2 is the annual power levels. The top graph is Average W/sf versus the school gross square footage. W/sf are computed by dividing the total kWh/h consumed per year by the number of hours in the year to get the average Watts. This is divided by the gross square footage of the building. The average 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 usiing power factors ranging from 0.7817 to 0.9072.. 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.

Figure 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 3a and 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 from the LoanSTAR weather site was then 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 more temperate temperatures 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 3a: ***Monthly Peak Consumption*****: Demand in W/sf versus peak monthly temperatures for September 1991 through December 1993.**

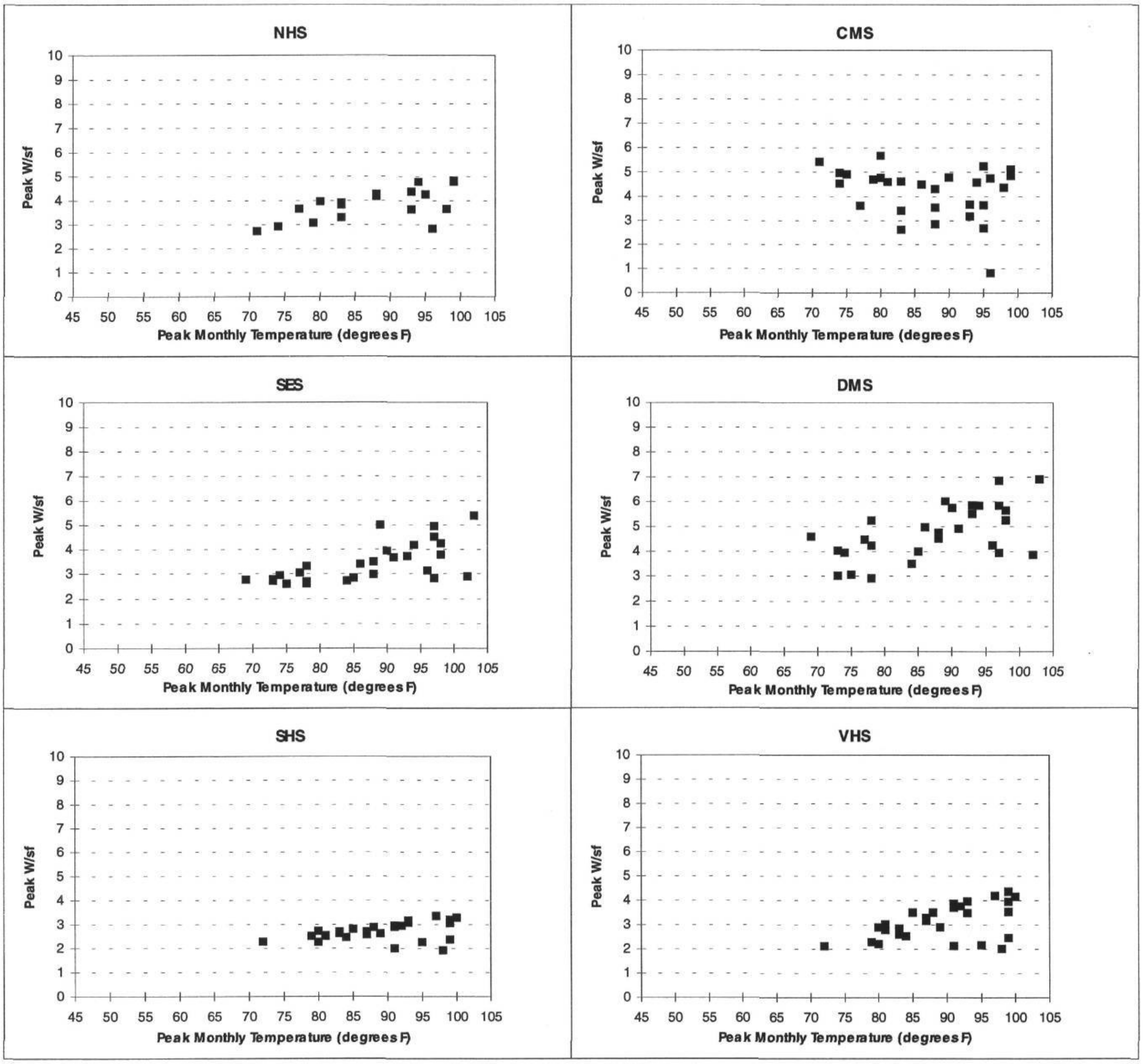
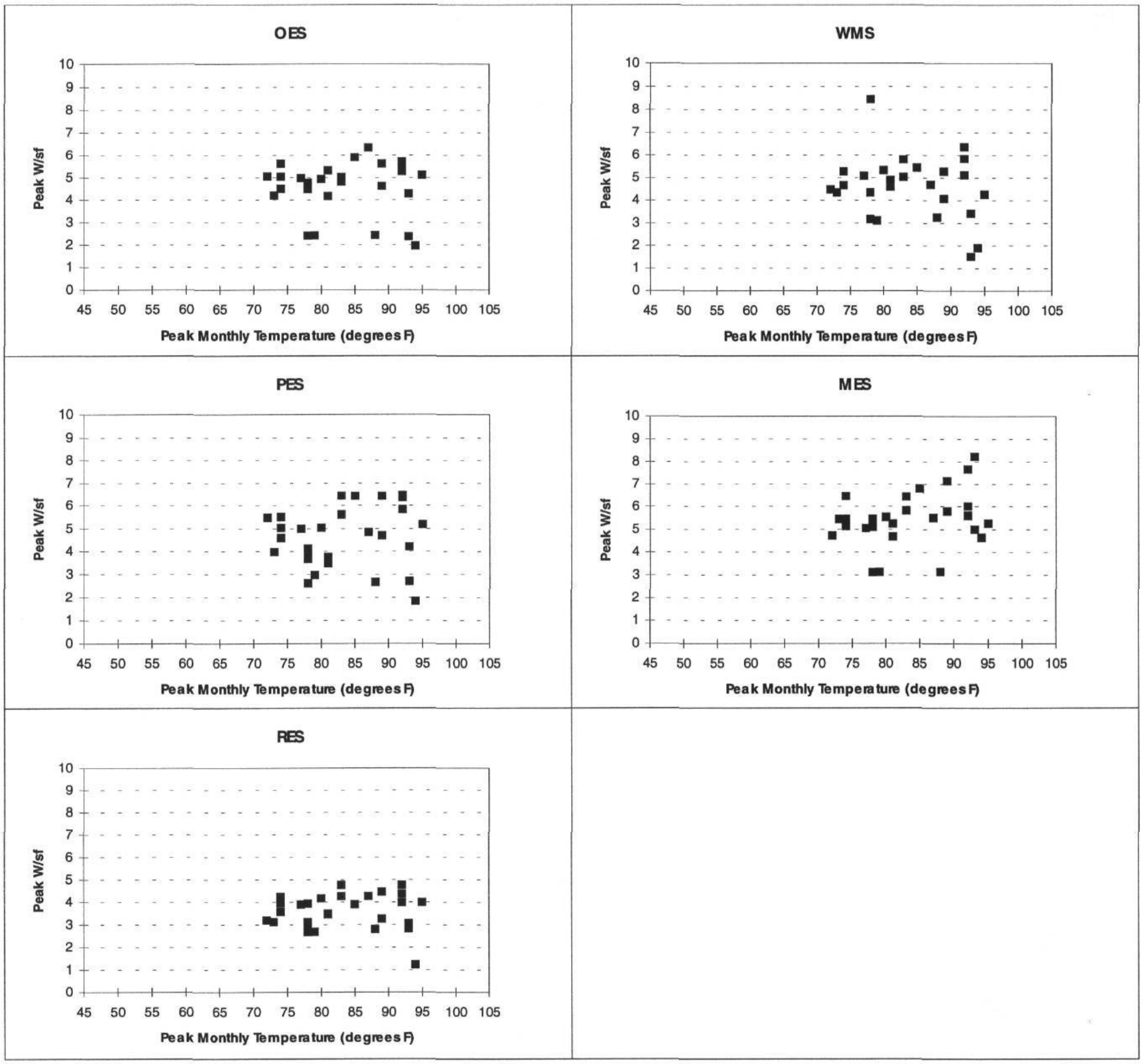


Figure 3b: ***Monthly Peak Consumption*****: Demand in W/sf versus peak monthly temperatures for September 1991 through December 1993.**



Figures 4a and 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 4a: ***Monthly Ave Consumption*****: W/sf versus min-max average monthly temperatures for September 1991 through December 1993.**

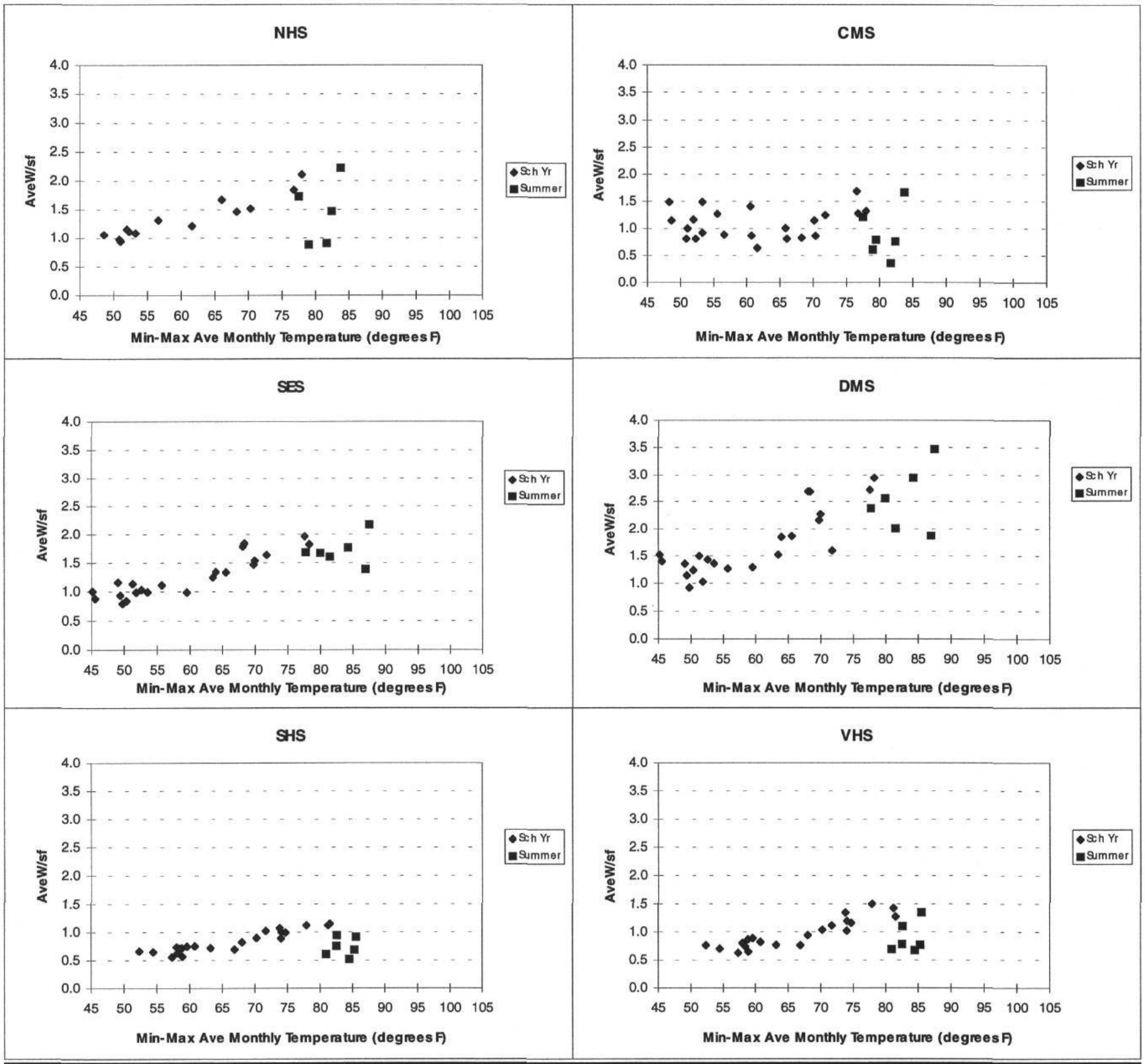
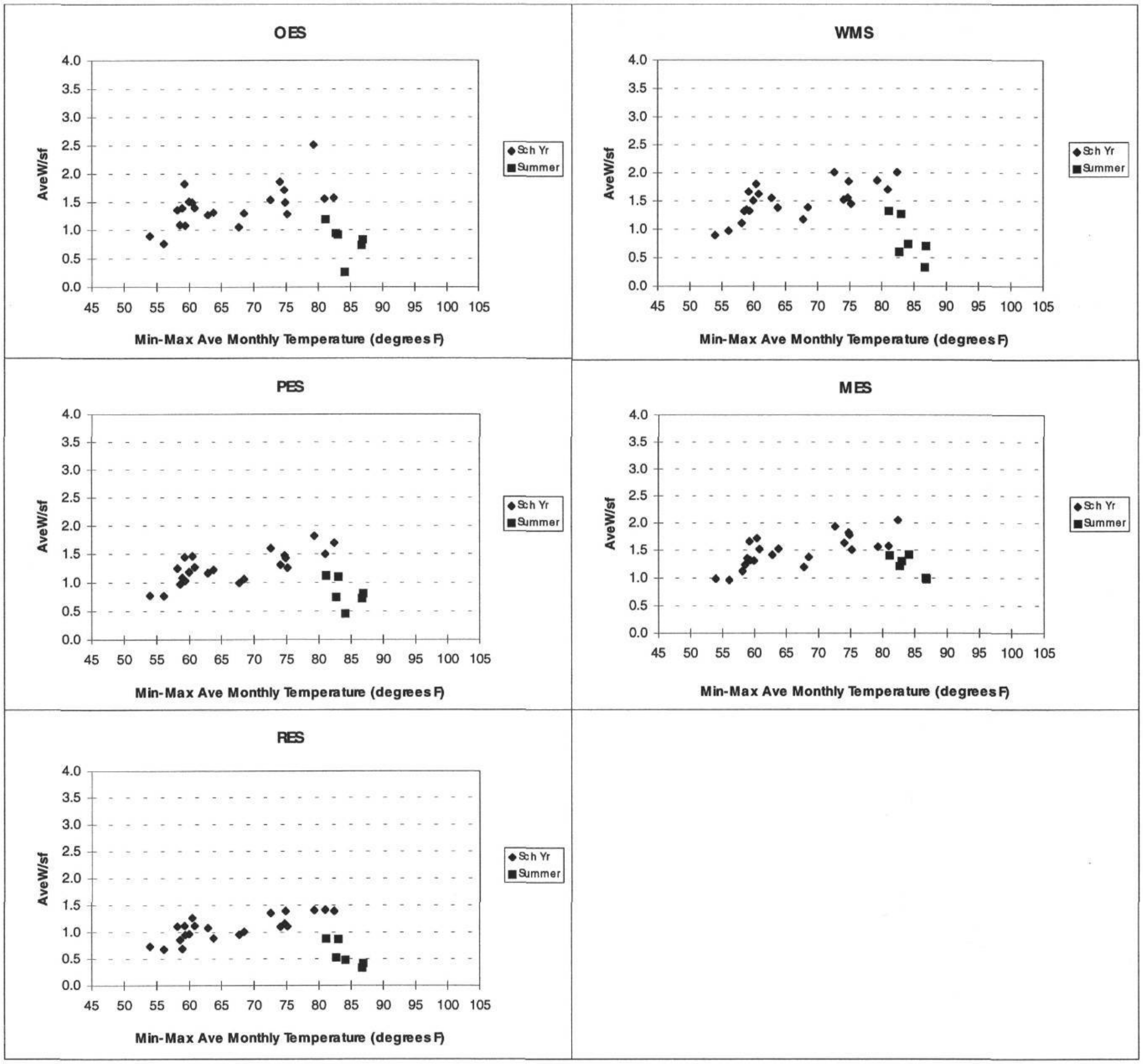


Figure 4b: ***Monthly Ave Consumption*: W/sf min-max average monthly temperatures for 1991 through December 1993**



Figures 5a and 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 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 loactions 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 5a: ***Natural Gas Consumption*****: Btu/(hr-sf) versus min-max average monthly temperatures for September 1991 through December 1993.**

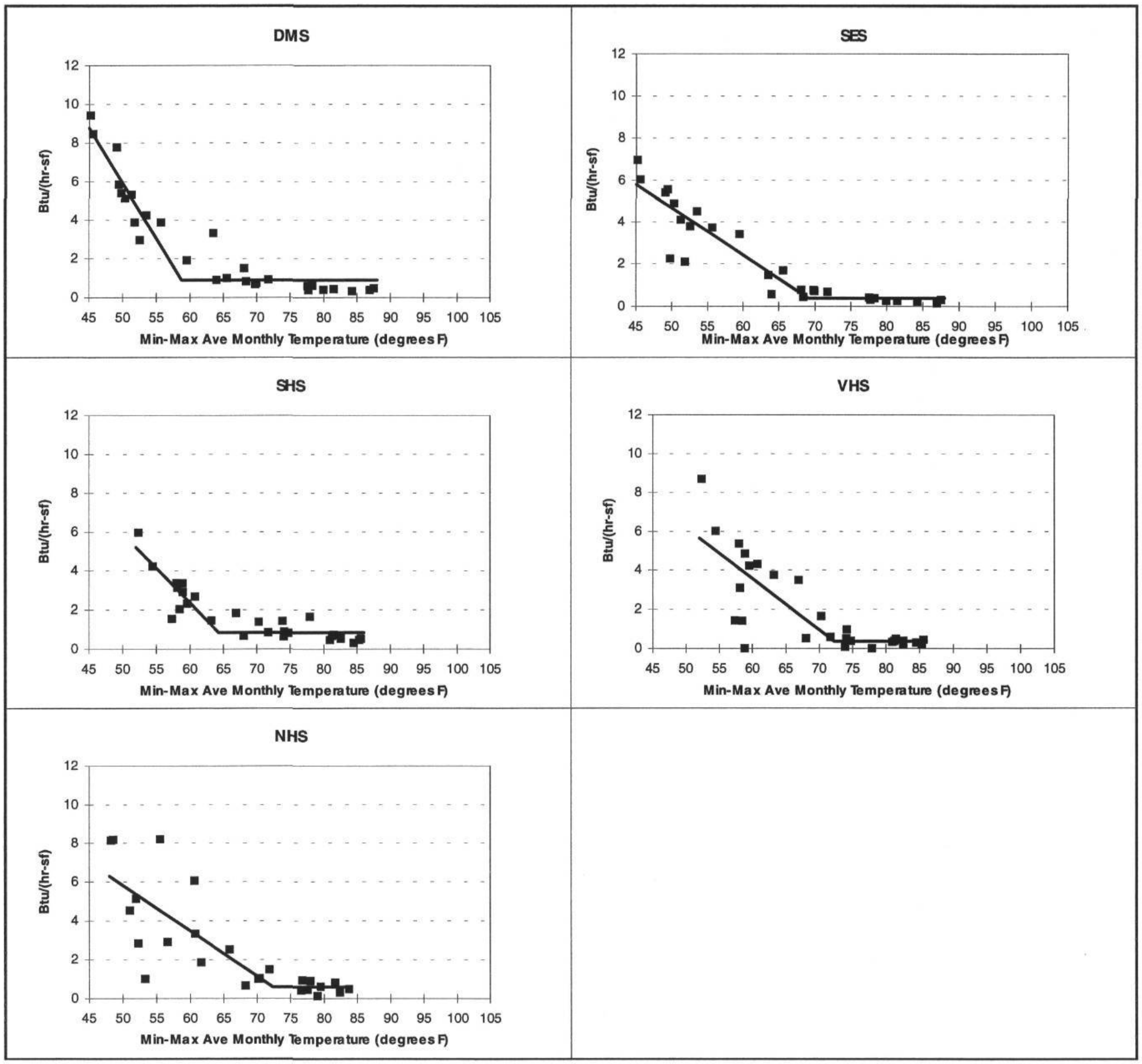


Figure 5b: ***Natural Gas Consumption*****: Btu/(hr-sf) versus min-max average monthly temperatures for September 1991 through December 1993.**

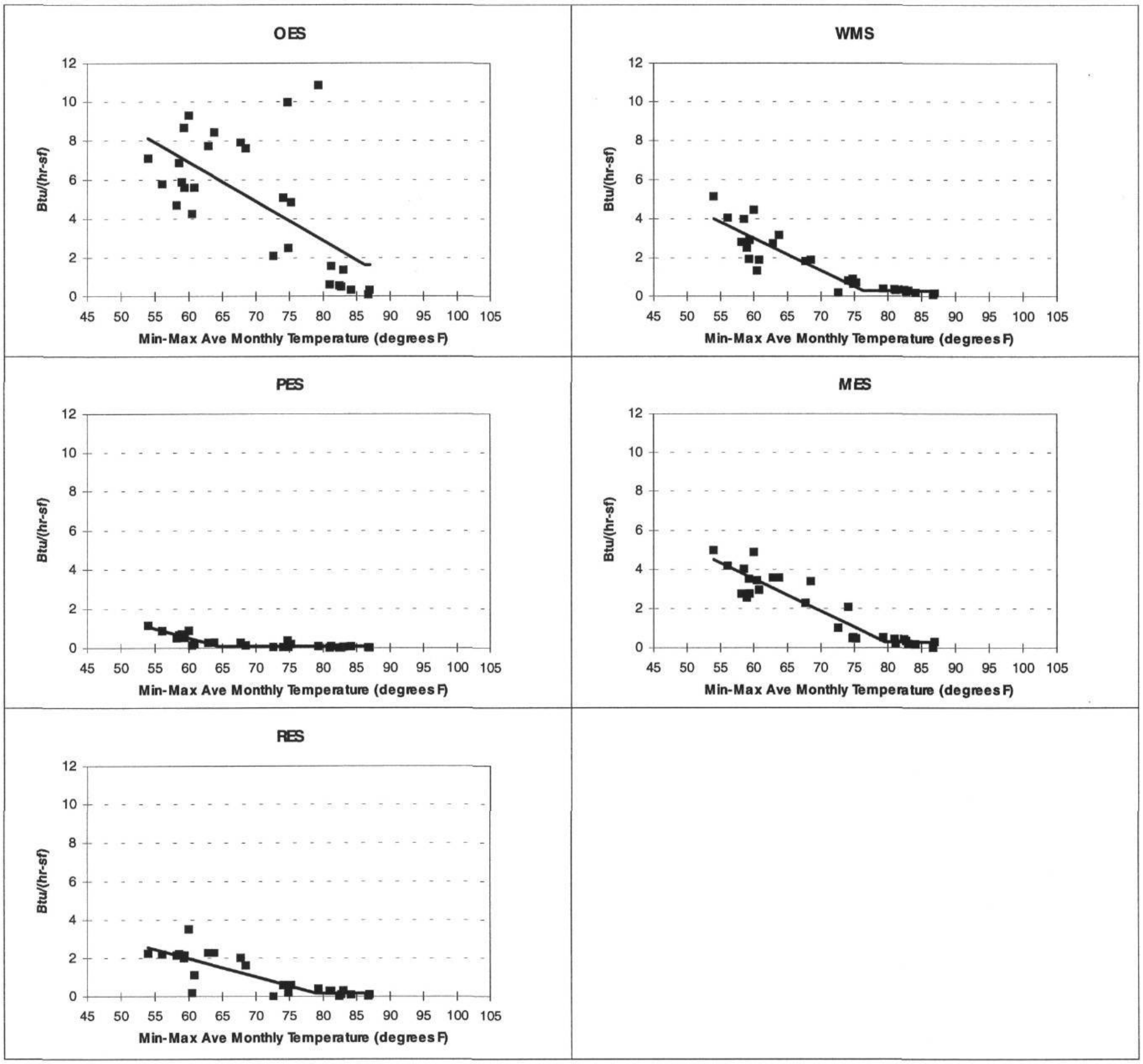


Figure 6 illustrates the 1, 2, 3, and 4 parameter empirical energy use models that were deemed appropriate for commercial building energy use (Kissock 1990). The upper left figure is a one-parameter model. The upper right figure is a two- parameter cooling model. The right and left figures in the middle 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.

Emodel Equations:

Mean Model:	Eperiod = Bo	Equation (a)
2 Parameter Model:	Eperiod = Bo +B1(T)	Equation (b)
3 Parameter Heating Model:	Eperiod = Bo + B1(B2 - T)+	Equation (c)
3 Parameter Cooling Model:	Eperiod = Bo + B1(T - B2)+	Equation (d)
4 Parameter Heating Model:	Eperiod = Bo + B1(B3 - T)+ - B2(T - B3)+	Equation (e)
4 Parameter Cooling Model:	Eperiod = Bo - B1(B3 - T)+ + B2(T - B3)+	Equation (f)

Figure 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.

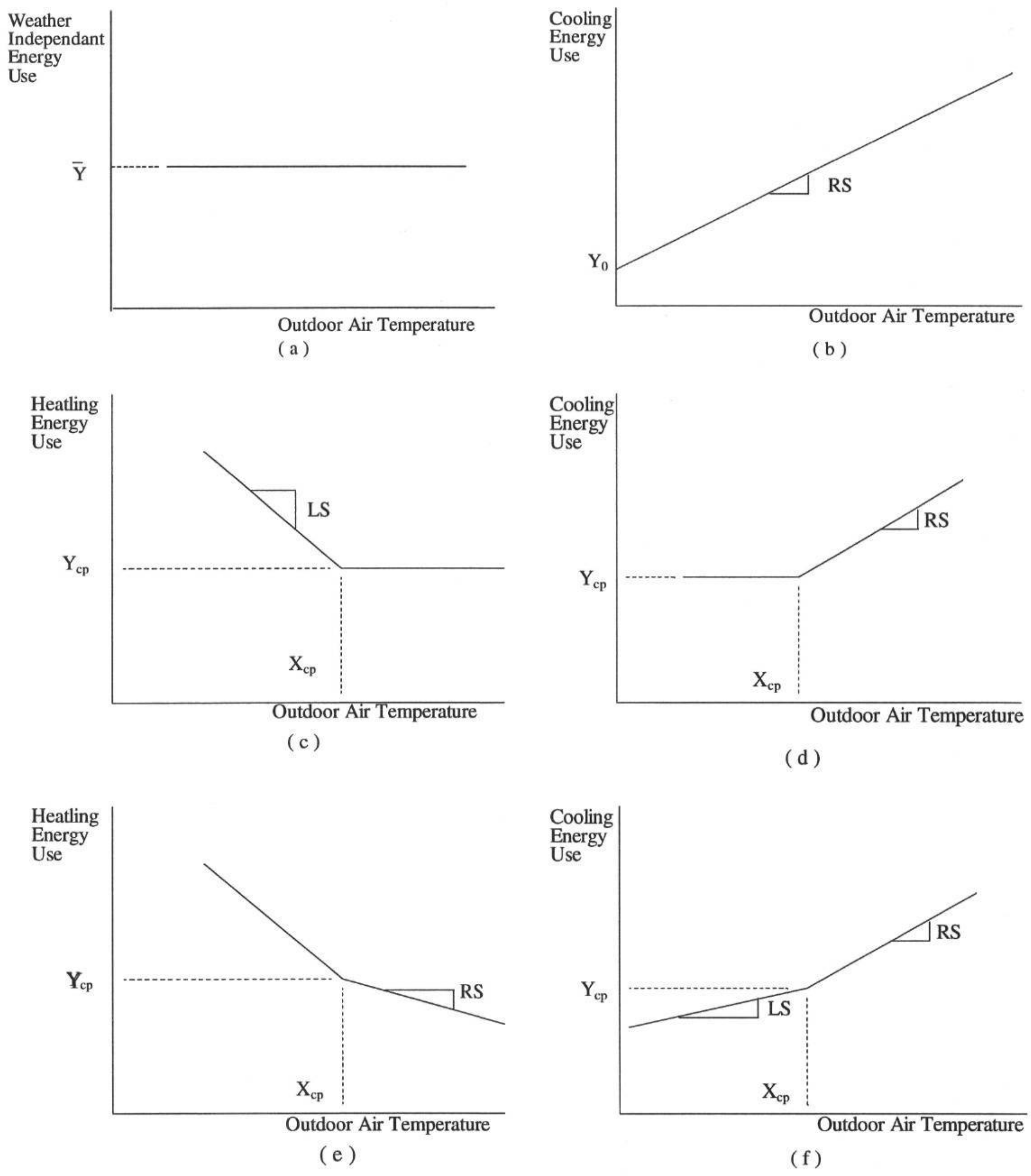
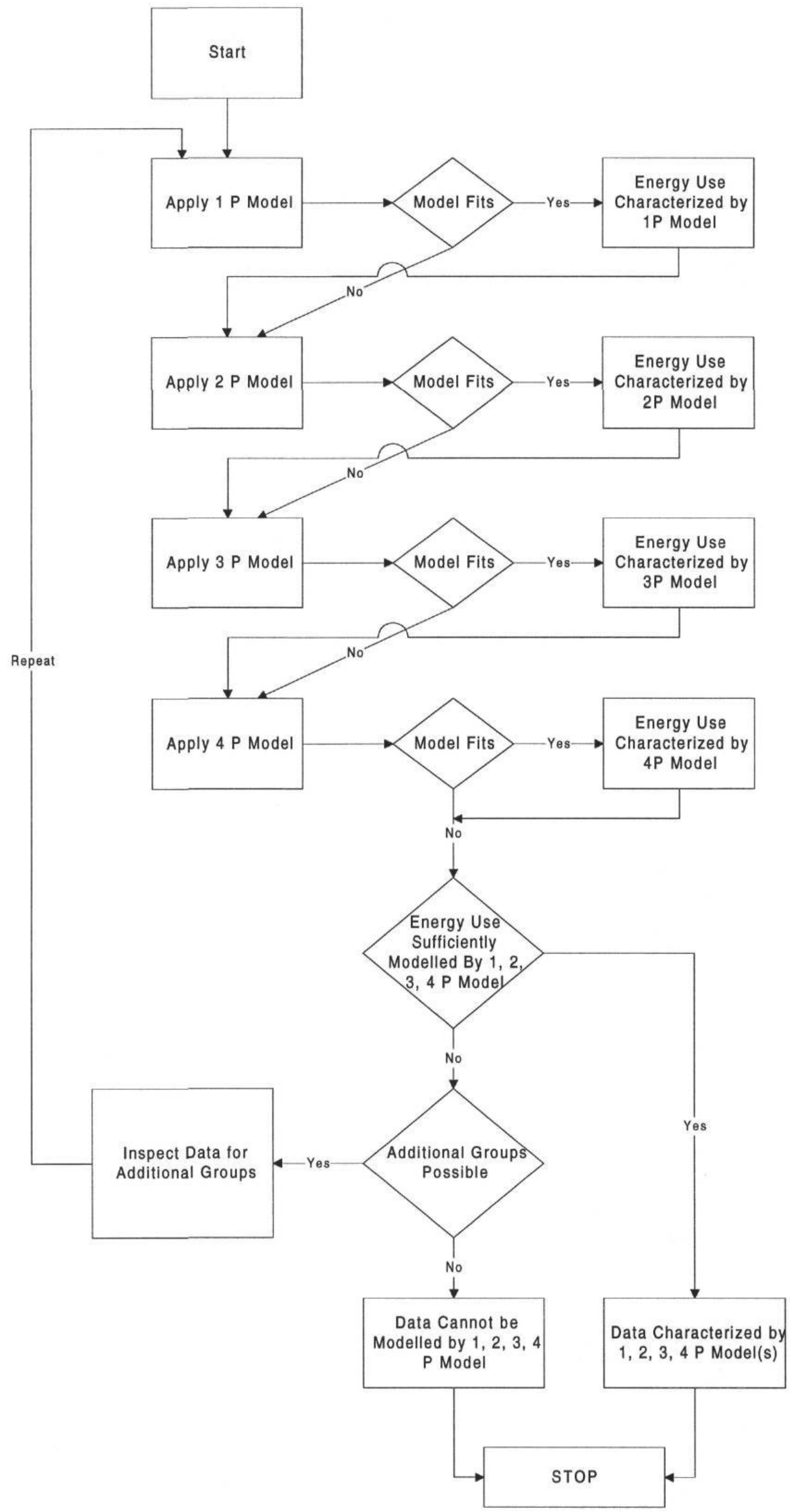


Figure 7 illustrates the procedure that was employed to select the appropriate 1, 2, 3, or 4 parameter model. This procedure has been adapted from the PRISM sieve developed by Reynolds and Fels (Reynolds and Fels 1988). It differs from the PRISM sieve in its use of 1, 2, 3, and 4 parameter models and by its ability to identify more than one model and allow for additional groupings to be performed.

Figure 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

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

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

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

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

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

y_i = individual power levels during the period (6)

$\hat{y}$ = estimated value of y (7)

$\bar{y}$ = average value of y (8)

y_{mean} = the average value of all power levels (9)

p = number of parameters in the model (10)

n = number of variables (11)

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 Emodel. 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. 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.

Figures 8, 9, and 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 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 school month data in Figure 9, and data for summer months in Figure 10.

Figure 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.**

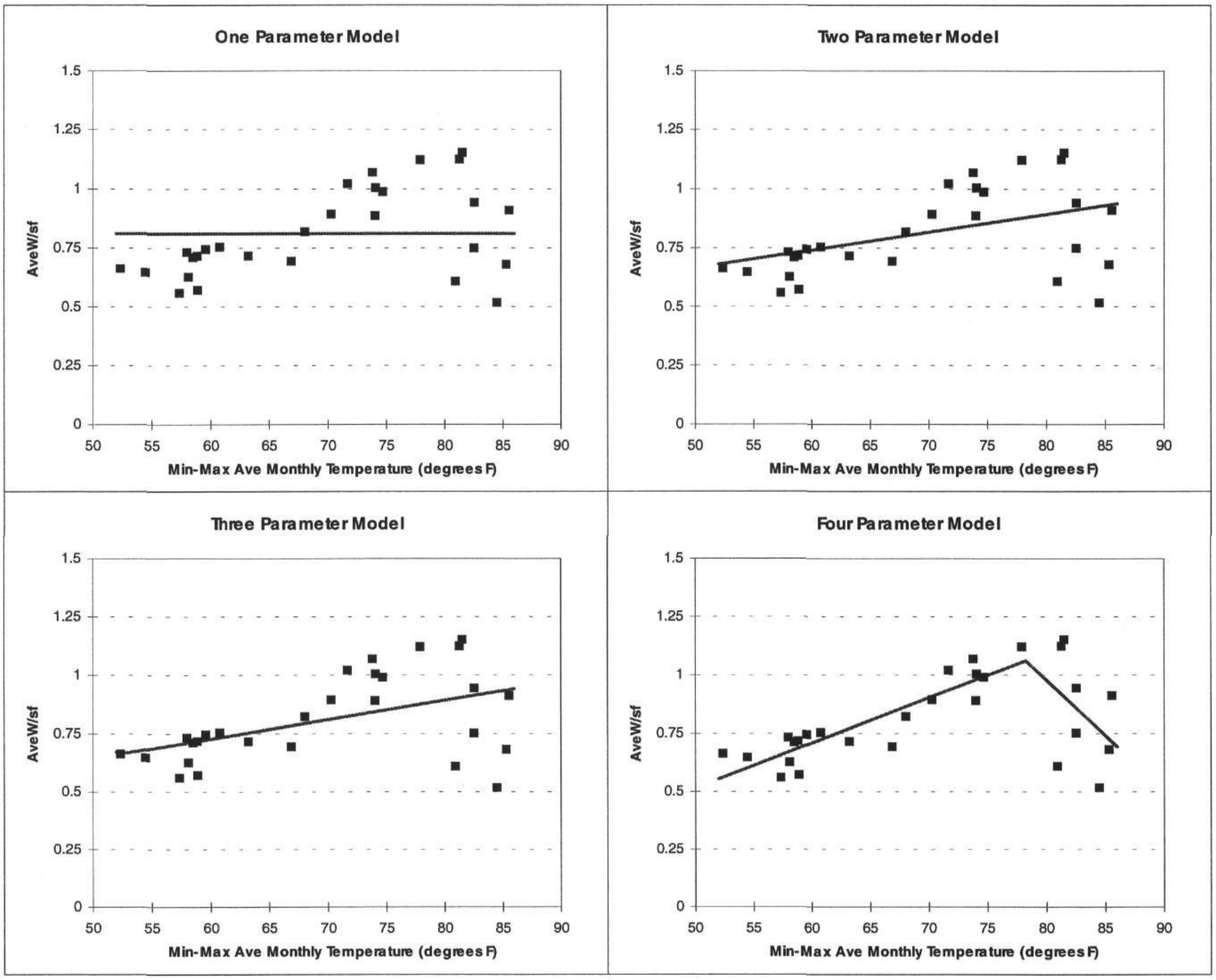


Figure 9: ***Monthly 1, 2, 3, and 4 parameter model fits for SHS using School Months*****: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are school months for September 1991 through December 1993, not including June through August Months.**

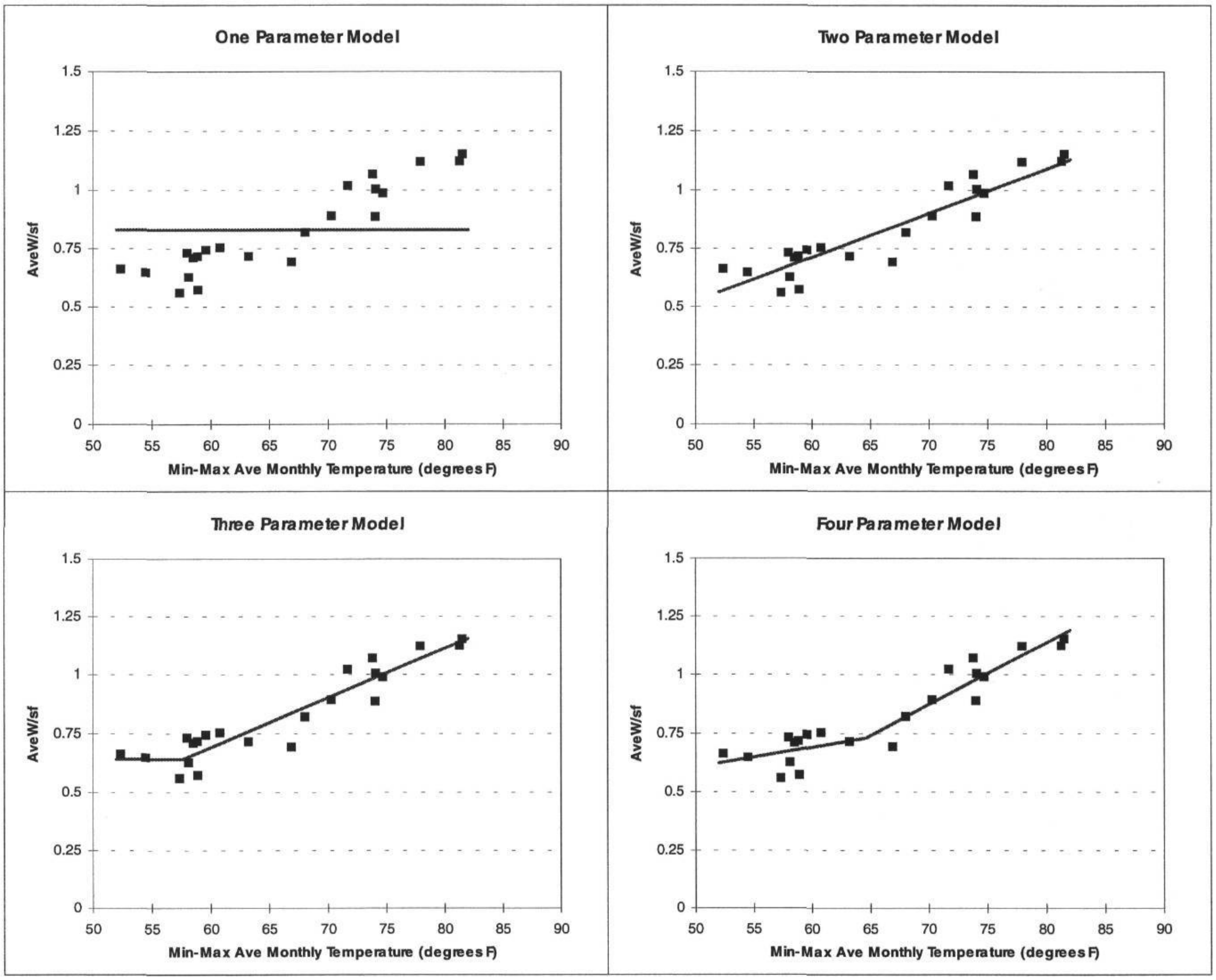


Figure 10: ***Monthly 1, 2, 3, and 4 parameter model fits for SHS using Summer Months*****: A one-parameter model is in the upper left corner, a two-parameter model is in the upper right corner, a three parameter cooling energy use model is in the lower left corner, and a four parameter cooling energy use model in the lower right corner. Data shown are summer months for September 1991 through December 1993 (June through August Months).**

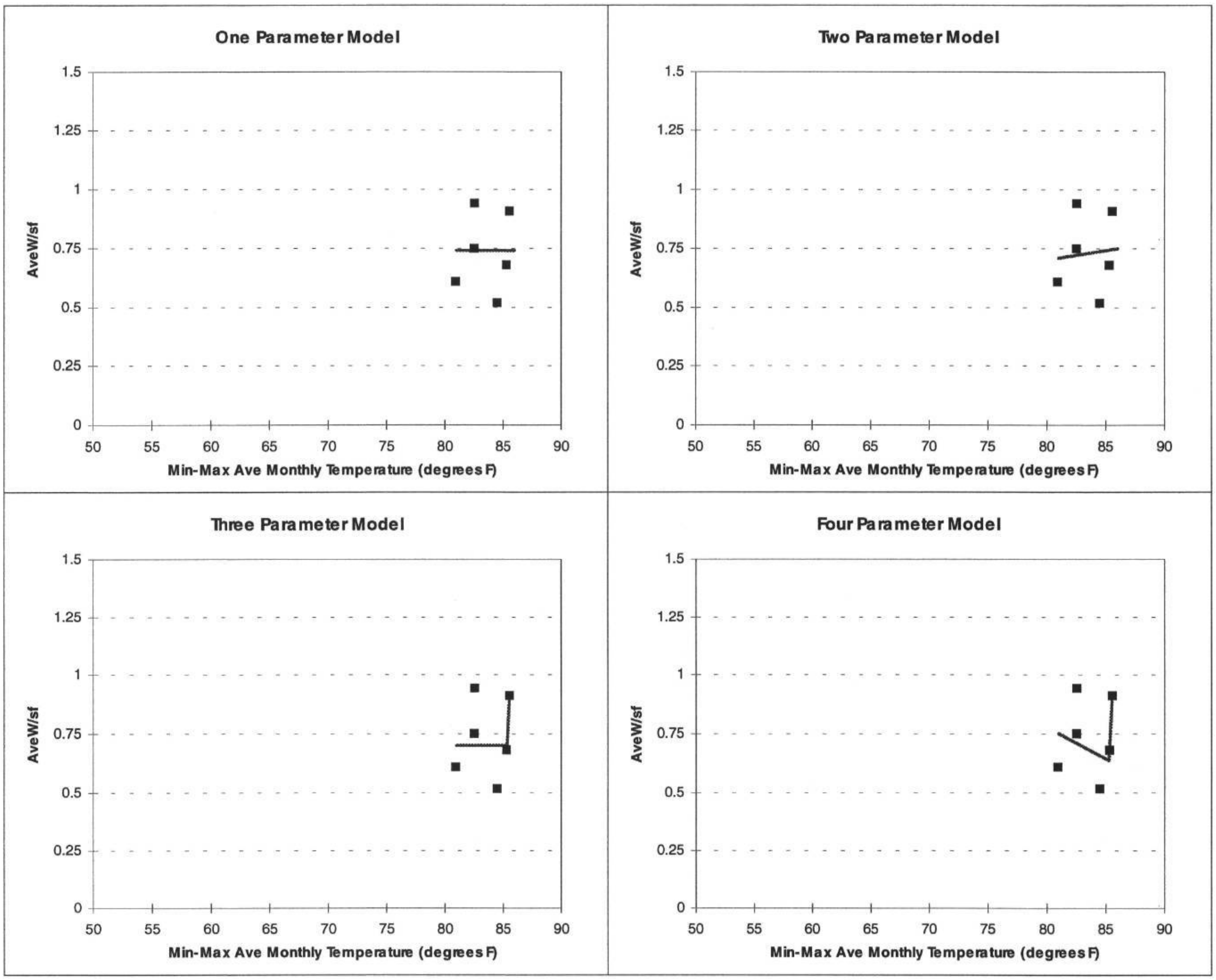


Table 2: SHS 1, 2, 3, 4 parameter electric models

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 false signal provided by the low energy consumption during the summer months. The fit improves for the 2 parameter, 3 parameter, and 4 parameter models once the summer months are separated. The 3 parameter and 4 parameter models show slightly improved R^2 and CV(RMSE) whihc 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 11, 12, and 13 illustrate the grouping of R^2 and CV(RMSE) across all eleven sites for all months (Figure 11), School Months (Figure 12), and Summer Months (Figure 13). Table 3a, 3b, 3c present the same data in tabular format. According to Reynolds and Fels (1990) models that provide a fit in the lower right quadrant (i.e. with boundaries of $R^2 >= 0.6$ and CV(RMSE) <= 0.25) are suitably modelled. 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 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.**

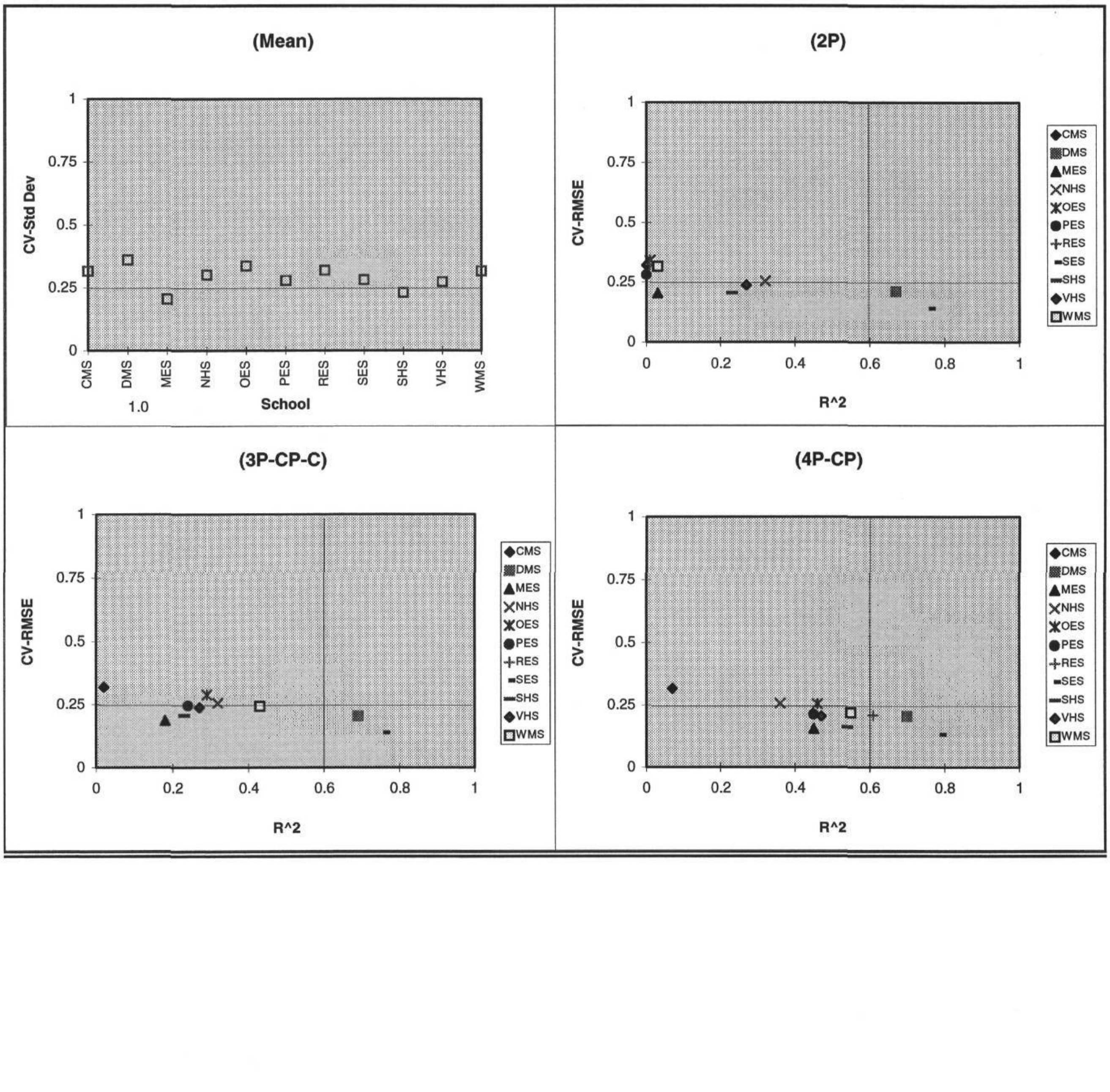


Table 3a: 1,2, 3, 4 parameter electric models for all eleven schools using data from all months

	1P		2P		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 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.**

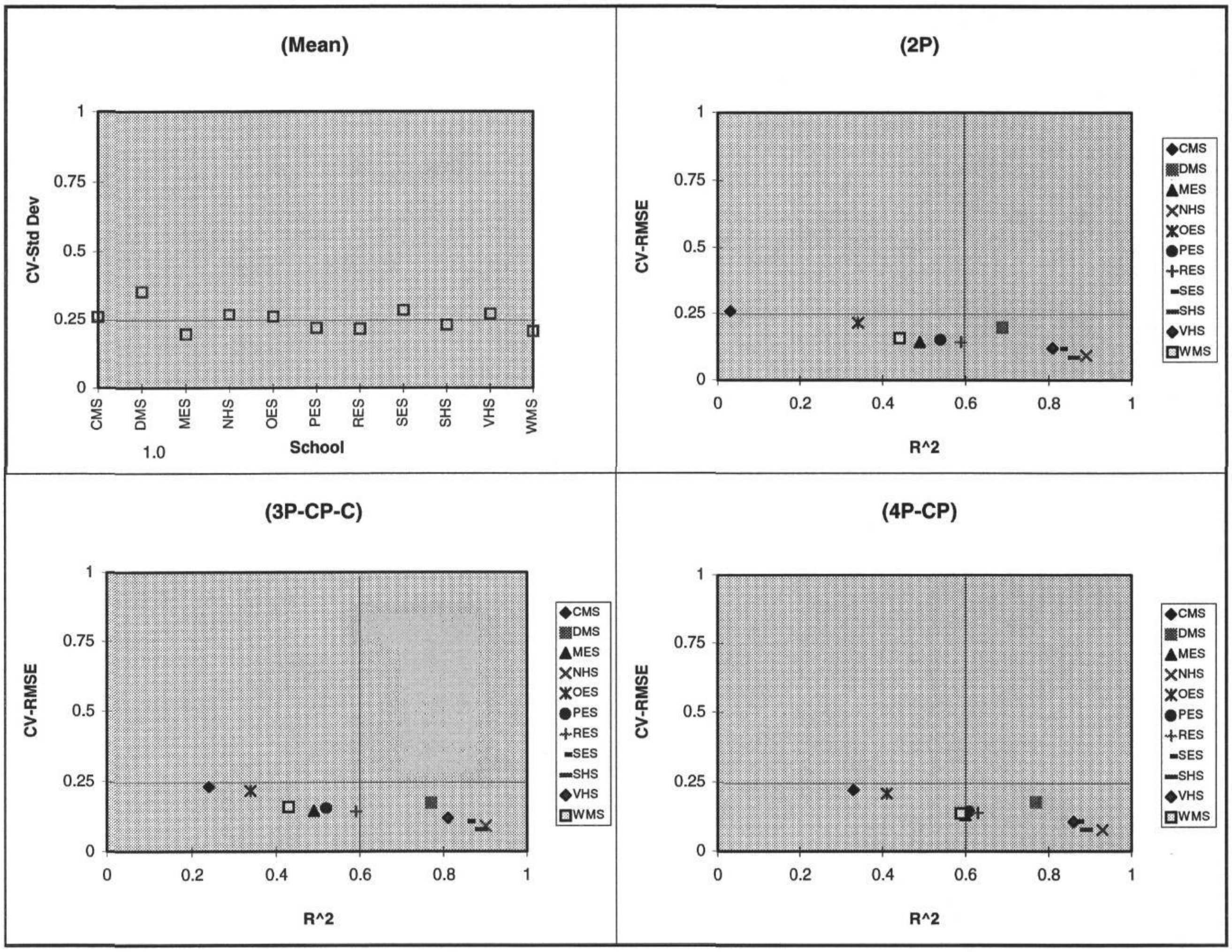


Table 3b: 1,2, 3, 4 parameter electric models for all eleven schools using data from school months only

	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 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).**

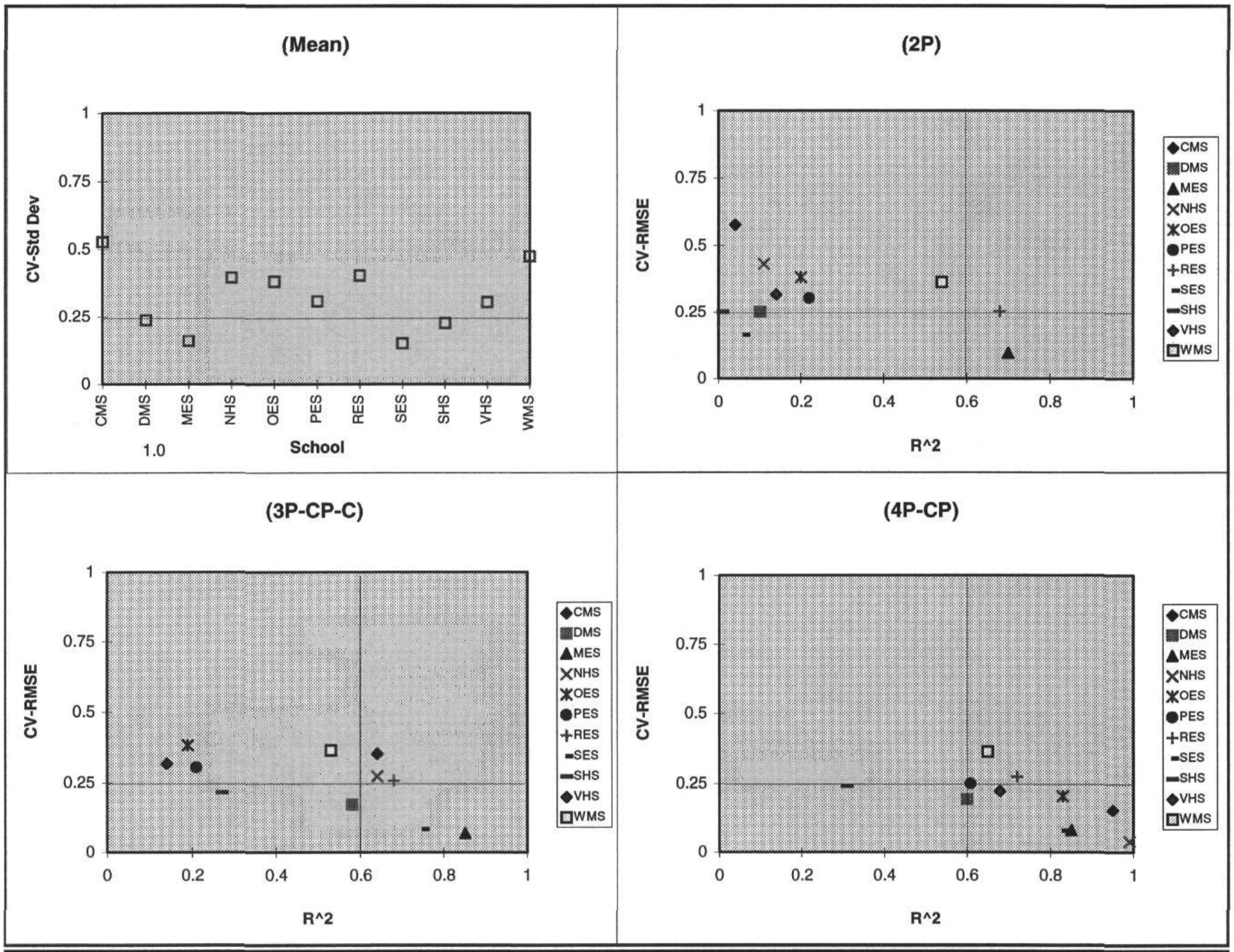


Table 3c: 1,2, 3, 4 parameter electric models for all eleven schools using data from summer months only

	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 4 presents the models selected for each school.

Table 4: Best Fitting Model

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

The final selection of models is shown in Figures 14a, 14b:

Figure 14a: ***Monthly Models*** **:**
School Year and Summer

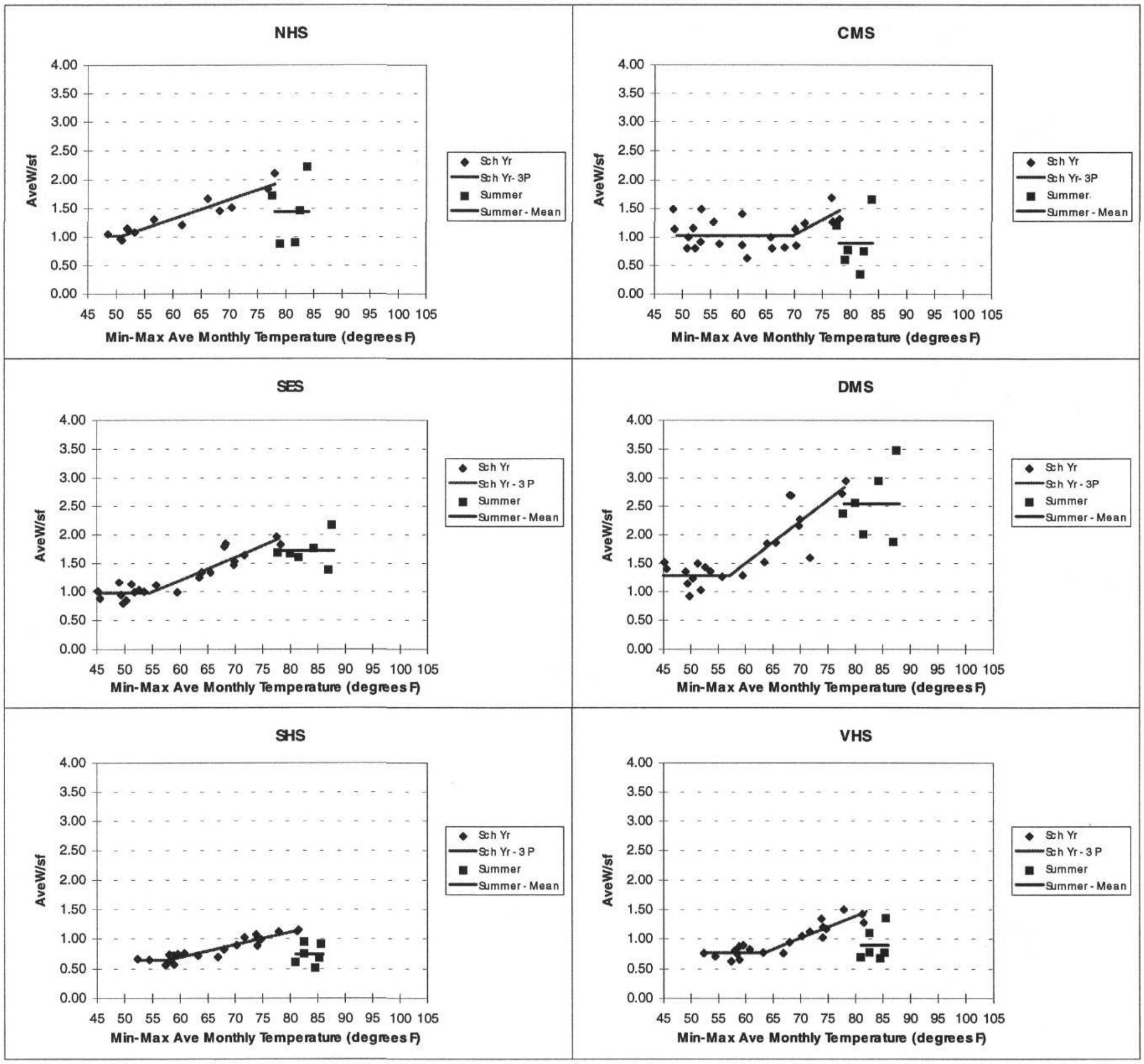
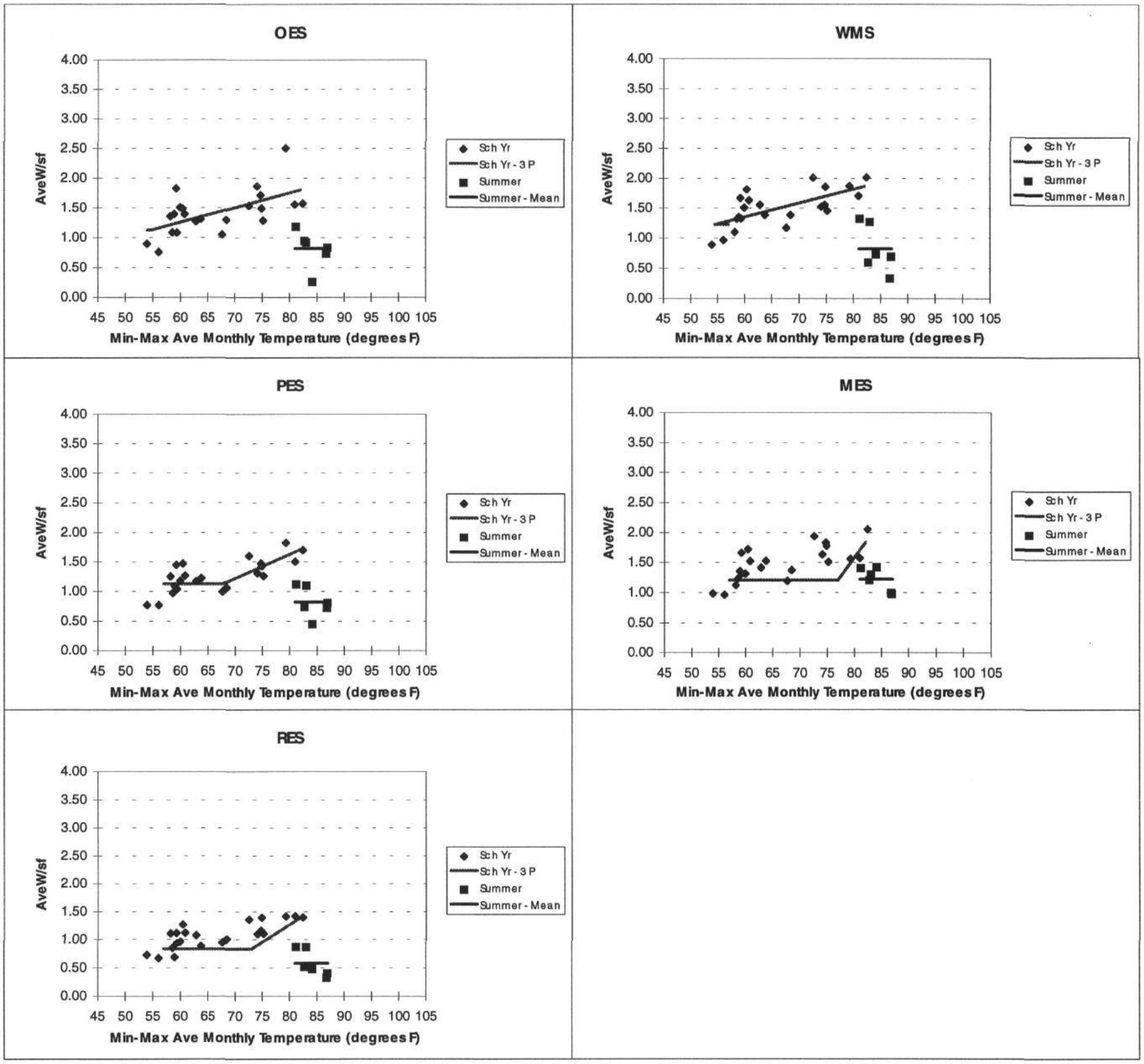


Figure 14b: ***Monthly Models*** **:**
School Year and Summer



Figures 15 through 19 are average monthly data for the following indices: whole-building electricity in W/sf (Figure 15), whole-building gas in Btu/(hr-sf) (Figure 16), Electric Load Factor (Figure 17), Occupancy Load Factor (Figure 18), and People Load Factor (Figure 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:

1	2	3	4	5	6	7	8	9	10	11
NHS	CMS	SES	DMS	VHS	SHS	OES	WMS	PES	MES	RES

On Figure 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 15: ***Monthly Average WBE:*** **An aggregate monthly analysis for all 11 schools of their average consumption each month 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 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 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.**

	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 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 17: ***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 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 18: ***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 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.

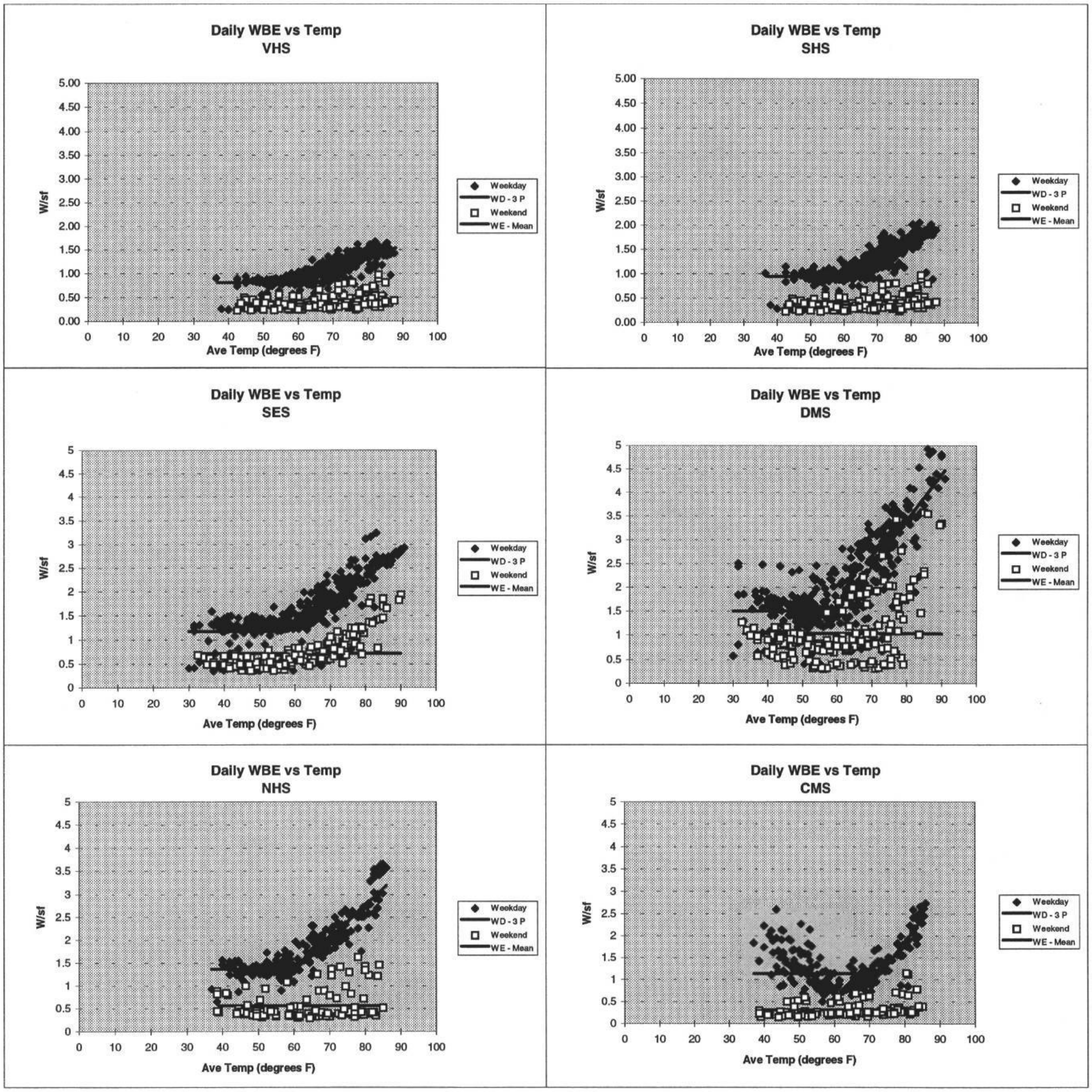
Figure 19: ***Monthly Average PLFs:*** **An aggregate analysis for all 11 schools of their people load factor for September 1991 through December 1993.**

	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

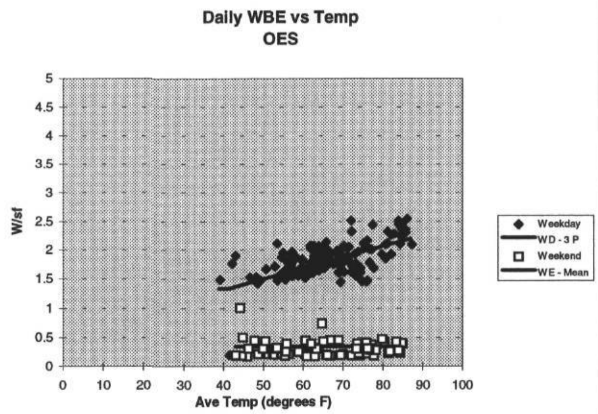
3.3 Daily Indices

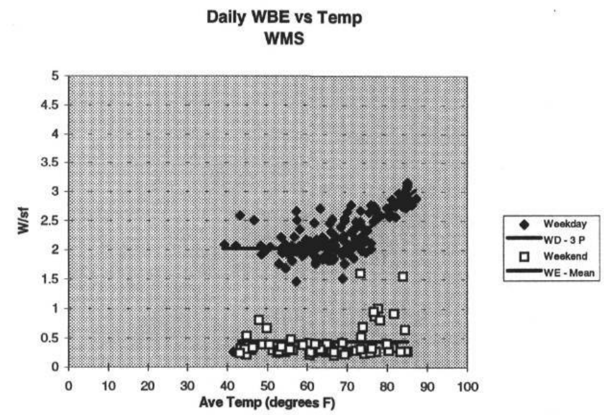
Figures 20a and 20b, and 21a and 21b show total daily electricity consumption (W/sf) versus average daily temperatures from the NWS (LoanSTAR site for Galveston) with separate symbols to show the data by weekday (filled symbols) or weekend (unfilled symbols). The first of these plots (Figure 20) has 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 21) shows only summer vacation days with the 4th of July being the only day not included since it was a weekday holiday.

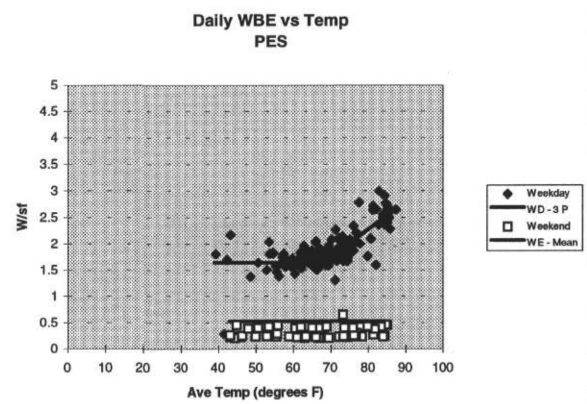
Figure 20a: ***Daily Consumption for School Days*****:**
Electricity grouped by weekday and weekend for all school days, from the middle of August through the middle of May, monitored as part of the LoanSTAR Program from September 1991 through December 1993.

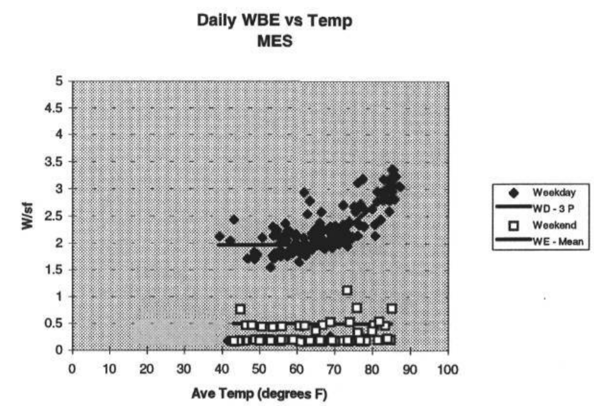


Daily Consumption for School Days: **Electricity grouped by weekday and weekend for all school days, from the middle of August through the middle of May, monitored as part of the LoanSTAR Program from September 1991 through December 1993.**









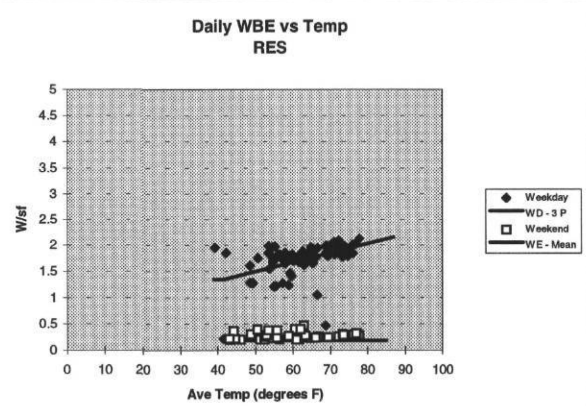


Figure 21a: ***Daily Consumption for Summer Days*****: Electricity grouped by weekday and weekend for all summer days, middle of May through middle of August, monitored as part of the LoanSTAR Program from September 1991 through December 1993.**

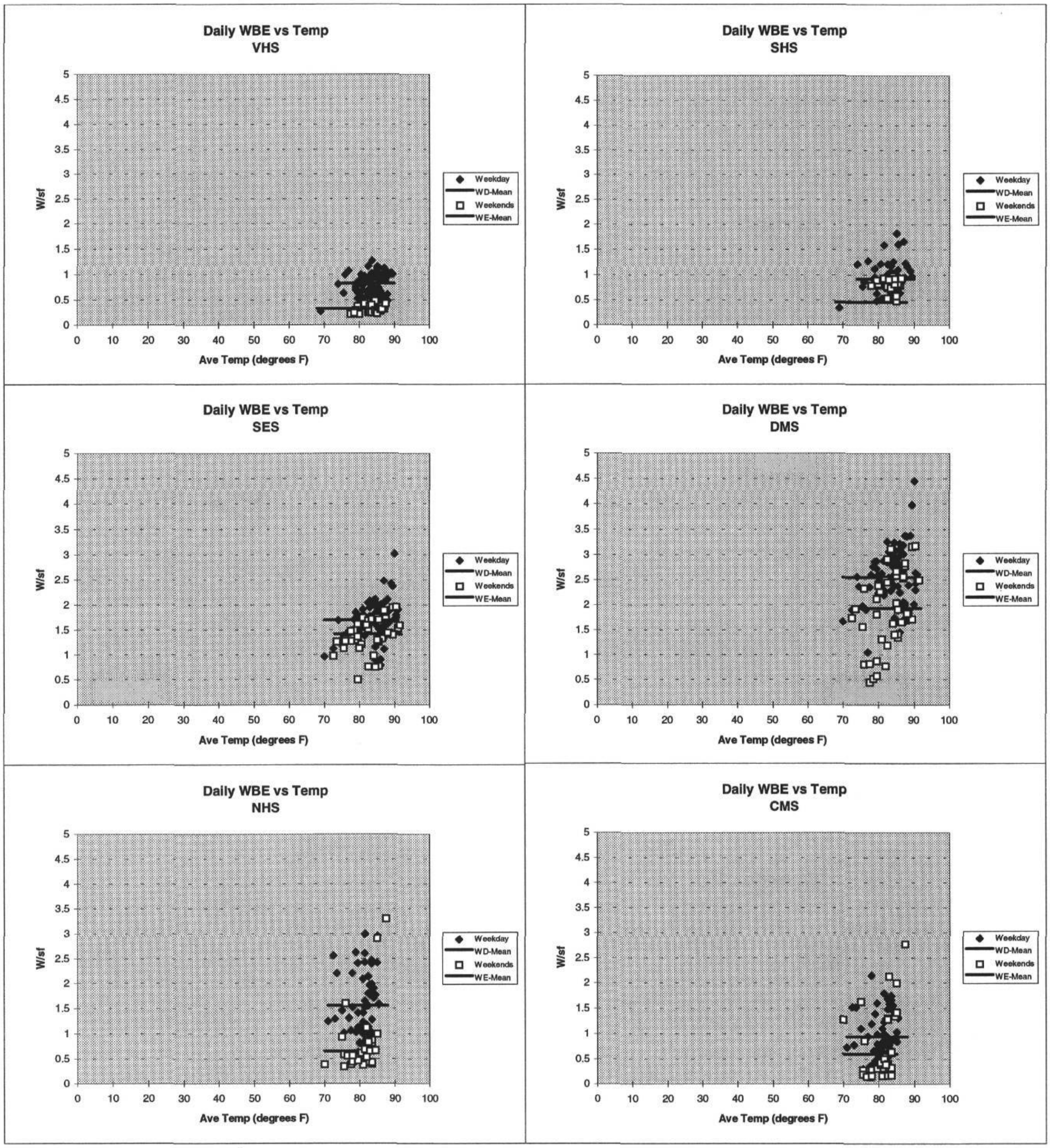
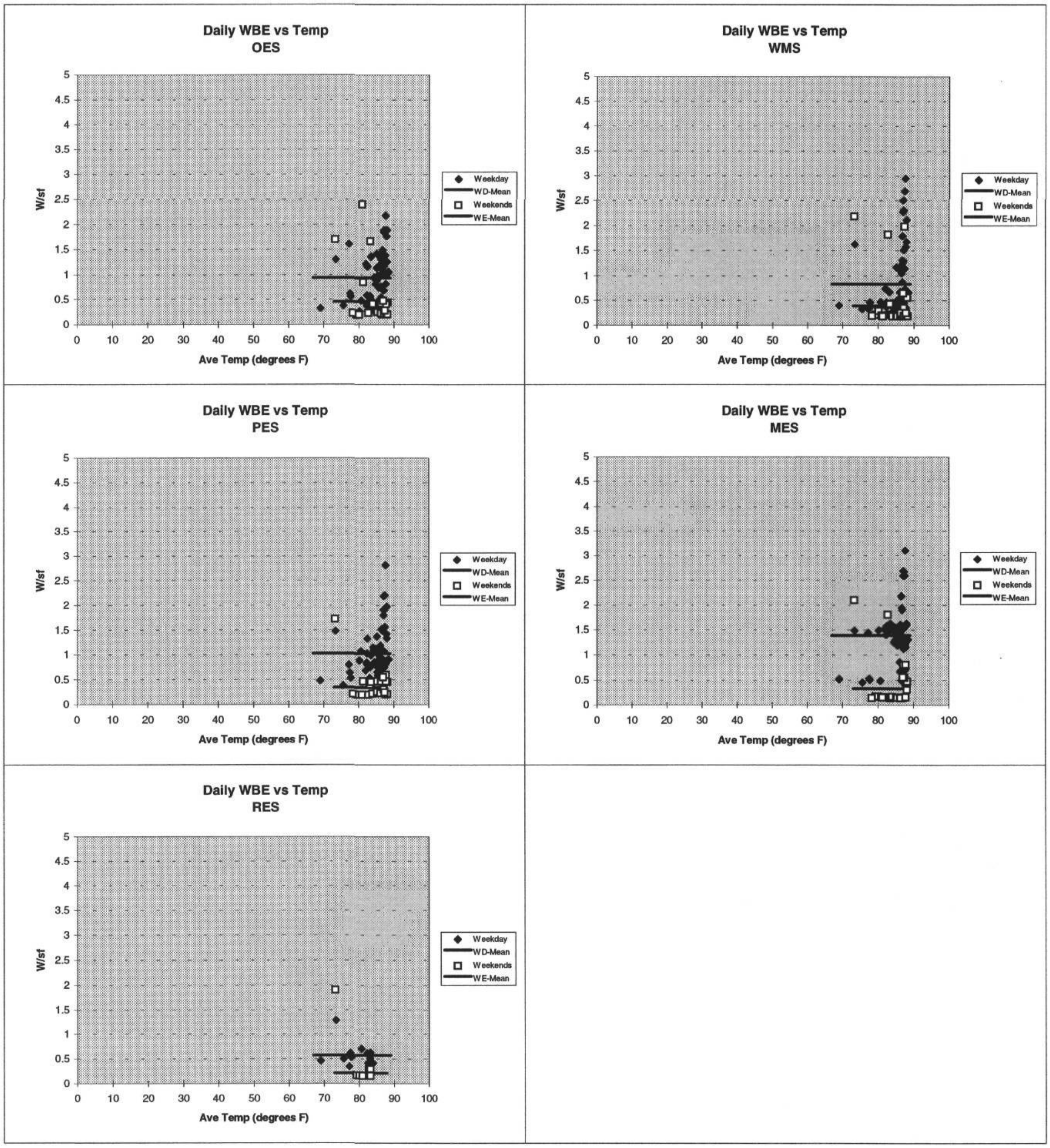
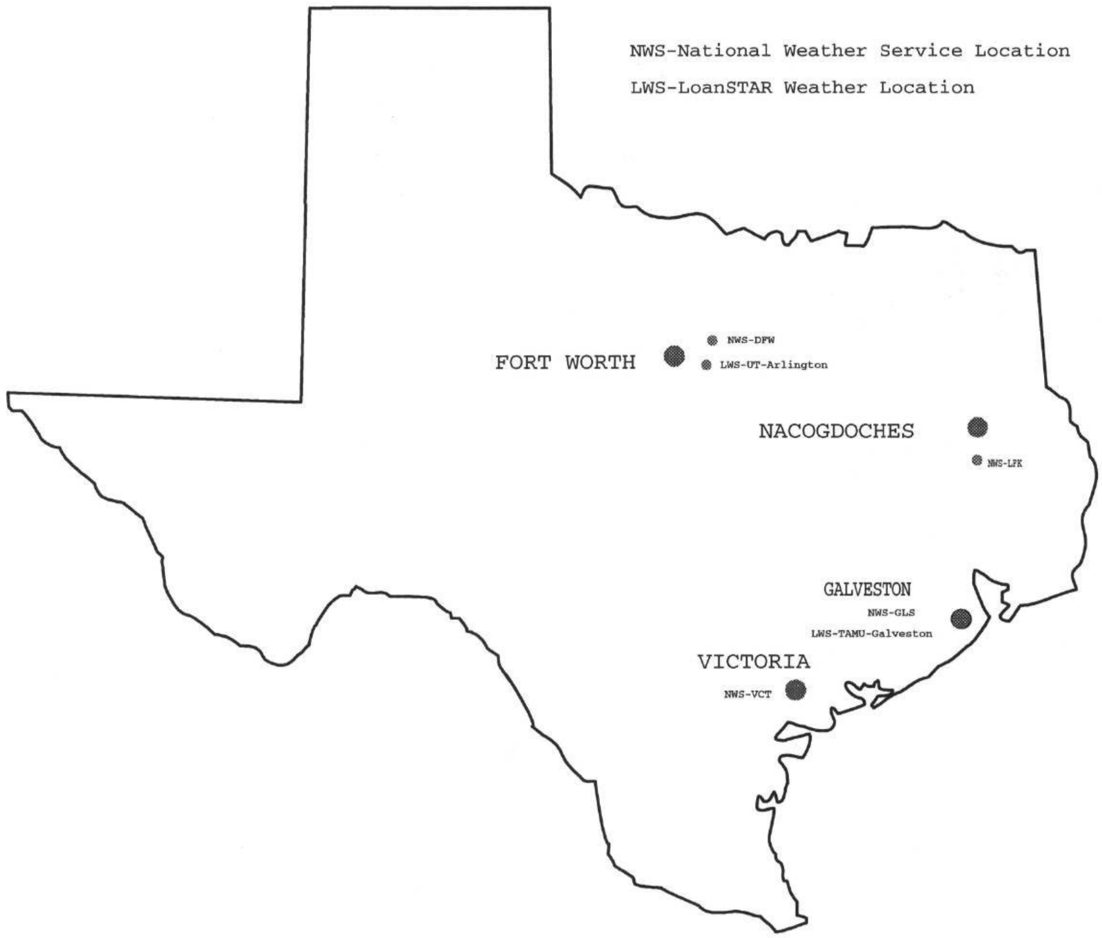


Figure 21b: ***Daily Consumption for Summer Days*****:**
Electricity grouped by weekday and weekend for all summer days, middle of May through middle of August, monitored as part of the LoanSTAR Program from September 1991 through December 1993.



4.0 SCHOOL DESCRIPTIONS



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 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 waster 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 furnace.

Air distribution is primarily through single duct multi-zone systems providing cooling temperatures in the range of 75 F and heating within the ranger 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 1529 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. These are shut off at 11:00 PM. Electricity is purchased from Central Power and Light Company, natural gas from ENTEX Gas Company.

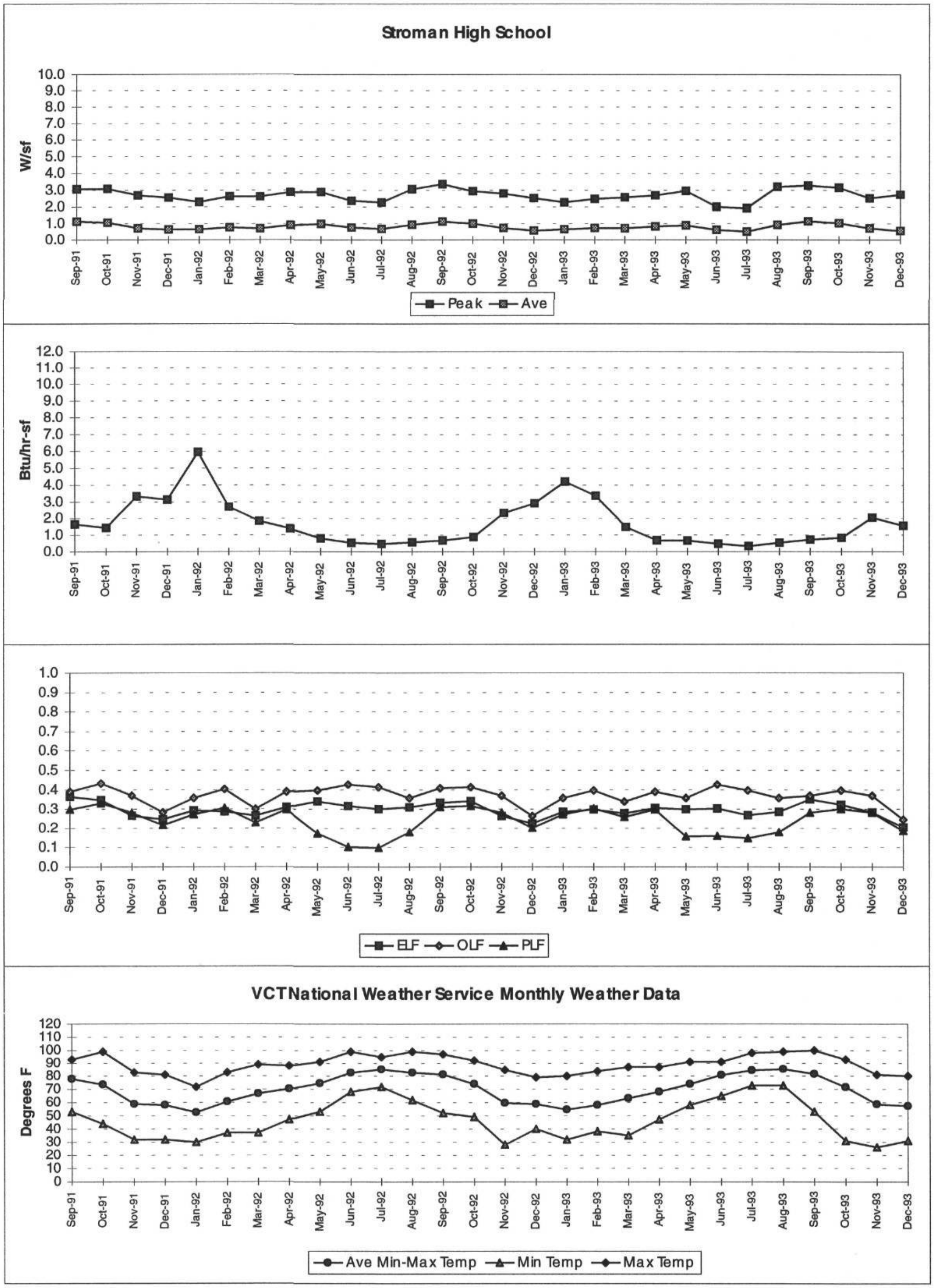
The following ECROs were installed at SHS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

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 22, 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 22: ***Monthly Data for SHS*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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 range of 75 F and heating within the range of 70-72 F. 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 2135 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.

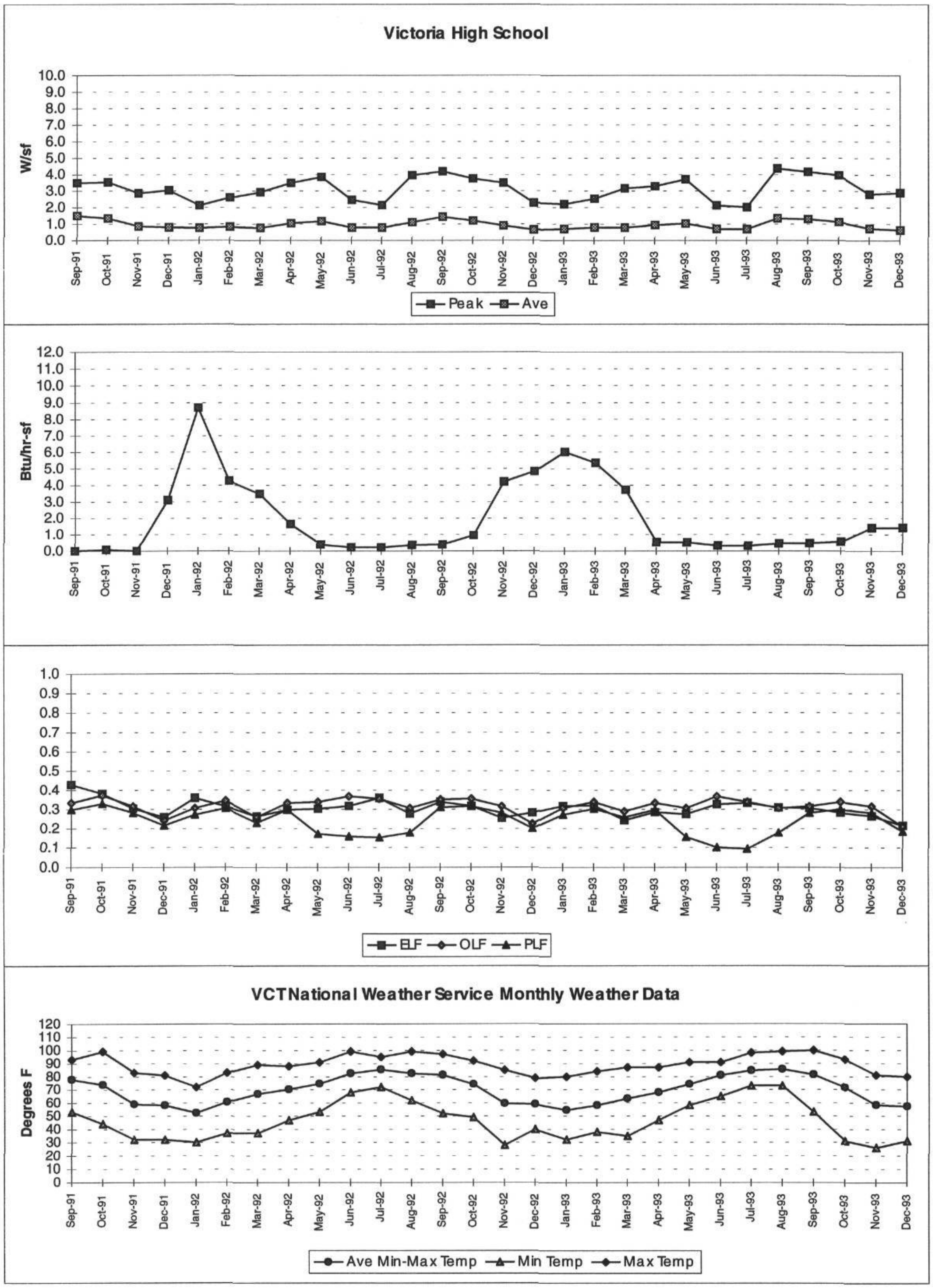
The following ECROs were installed at VHS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

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. Hence, these retrofits are shown in all energy consumption data analyzed.

On the following page is Figure 23, 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 23: ***Monthly Data for VHS*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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.

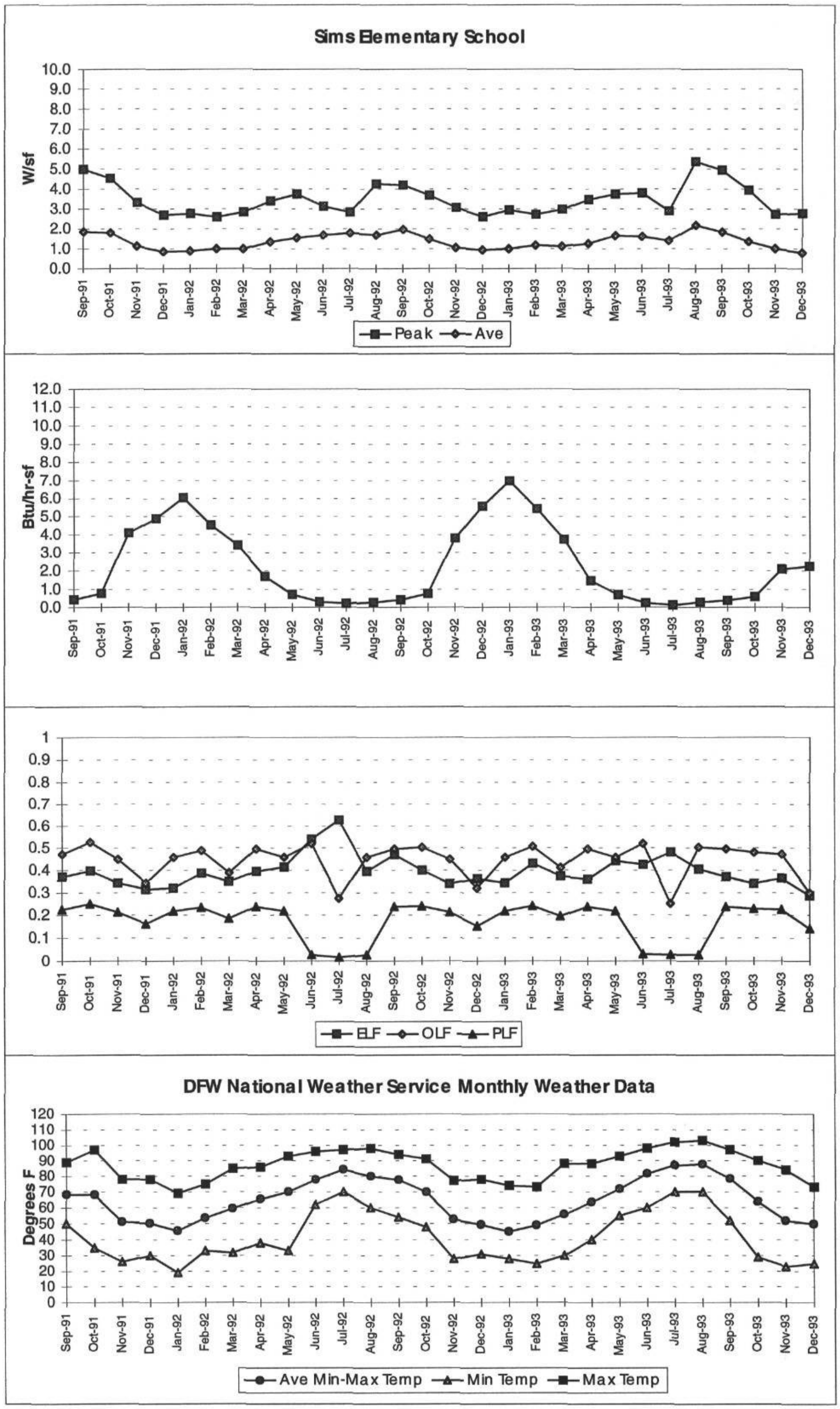
The following ECRO was installed at SES with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

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 many be a slight dropoff in electricity power levels due to the retrofits from December 1991 through December 1993.

On the following page is Figure 24, 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 24: ***Monthly Data for SES*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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.

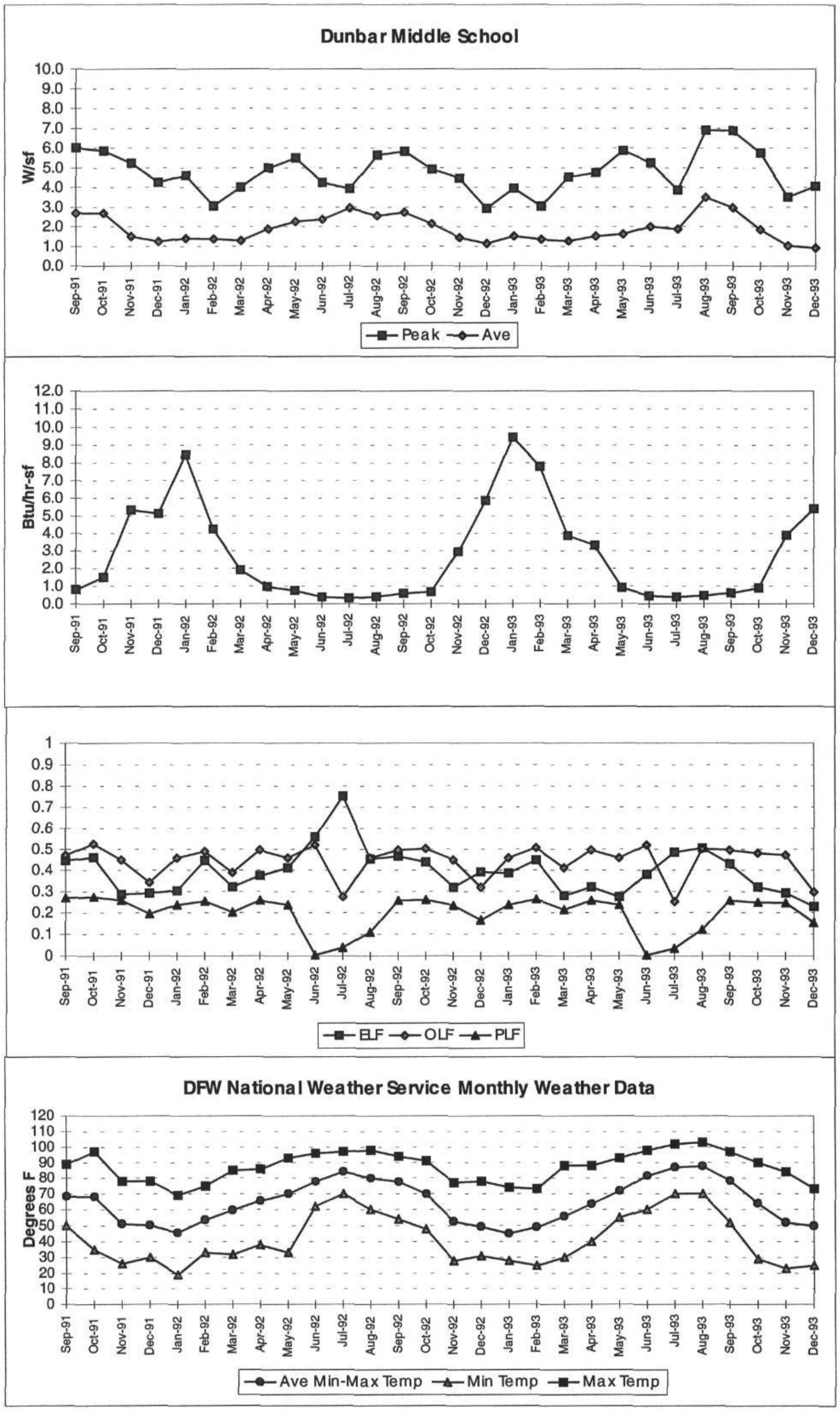
The following ECRO was installed at DMS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

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 dropoff in electricity power levels due to the retrofits from December 1991 through December 1993.

On the following page is Figure 25, 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 25: ***Monthly Data for DMS*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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 schools in order to try 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 6,000,000 million Btu/hr modular boiler system installed for the 1993 heating season. 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. 22 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 1800 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

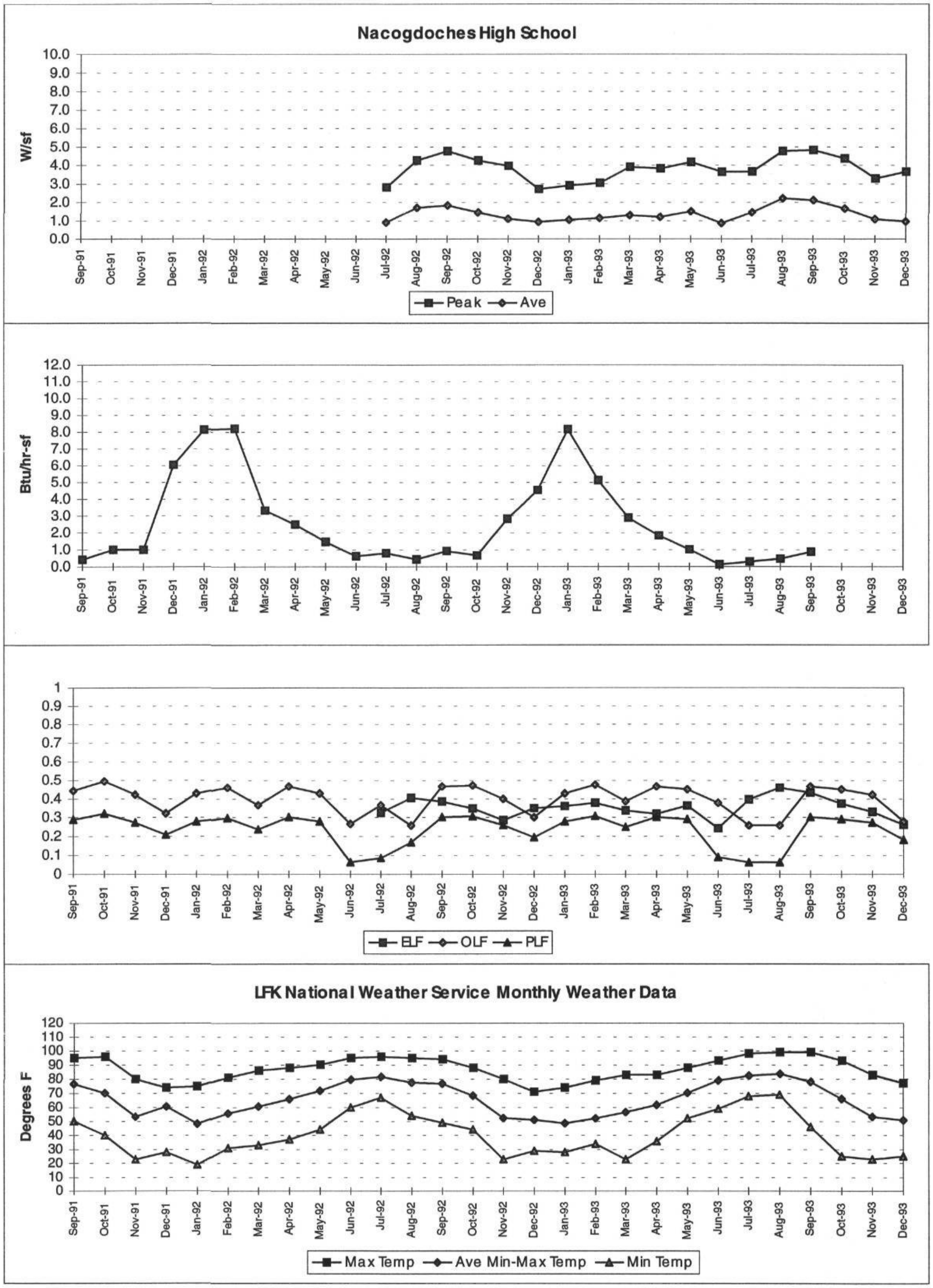
The following ECROs were installed at NHS with the corresponding date reflecting the month the installation of the retrofit was completed or blank if the retrofit was not performed:

Retrofits	Date Competed
•Install EMS	Oct 1992
•Fixture Relamping	Oct 1992
•Convert to Gas Heating	
•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 26, 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 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 26: ***Monthly Data for NHS*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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 a 120 horsepower electric chiller with 34 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 and split systems.

The school is operated from August through May with approximately 1480 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 ECROs 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:

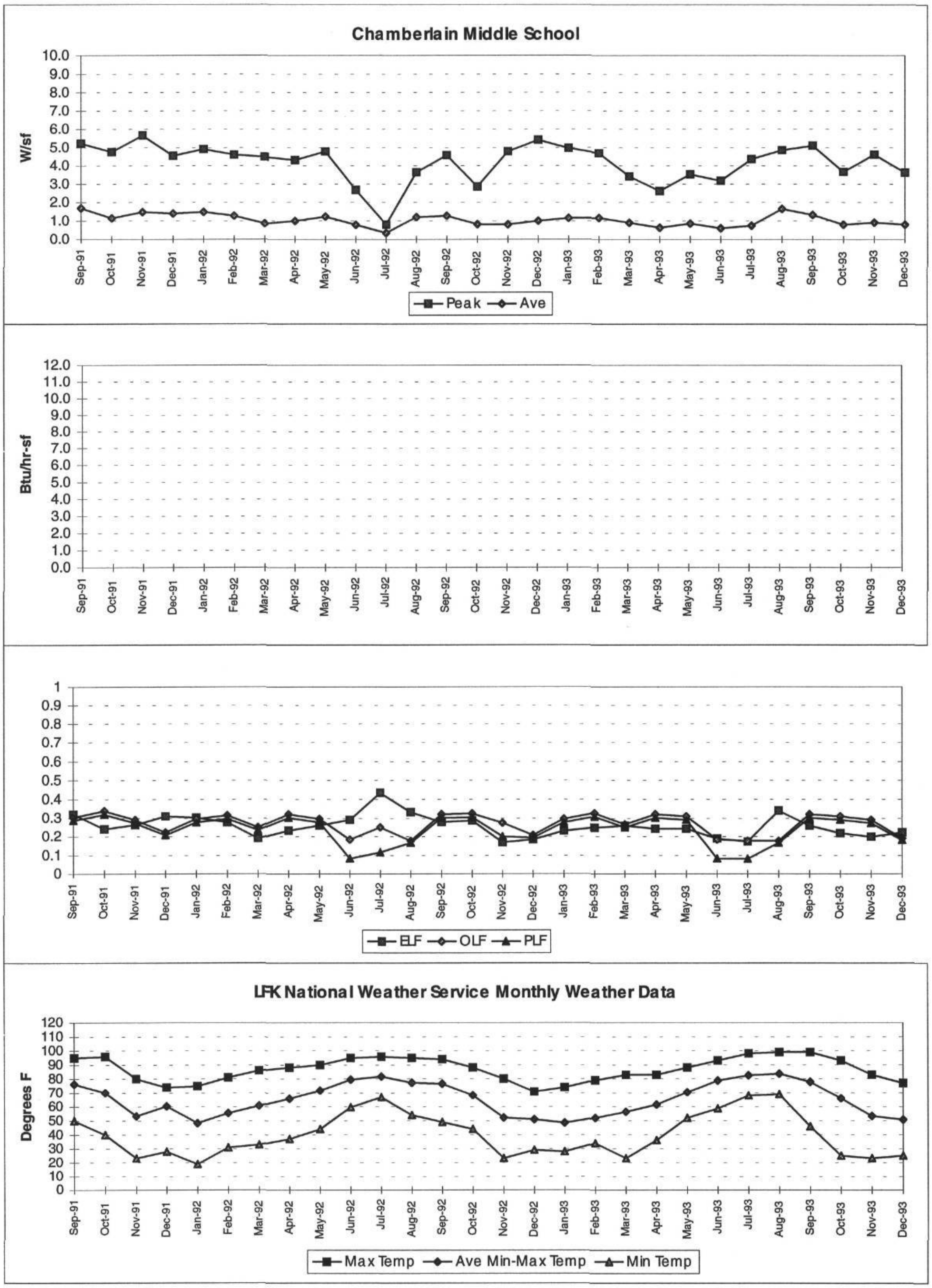
Retrofits	Date Competed
•Install EMS	Oct 1992
•Install Gas heating on 1st floor to replace electric heating	
•Fixture Relamping	Oct 1992

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 27, 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 27: ***Monthly Data for CMS*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



4.7 Oppe Elementary School (OES)

Oppe Elementary 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 80,400 square feet with a kitchen, cafeteria, gymnasium, library, and classrooms. Cooling is provided by a single reciprocating air-cooled chiller with cool storage. Heating is provided by a 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. 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.

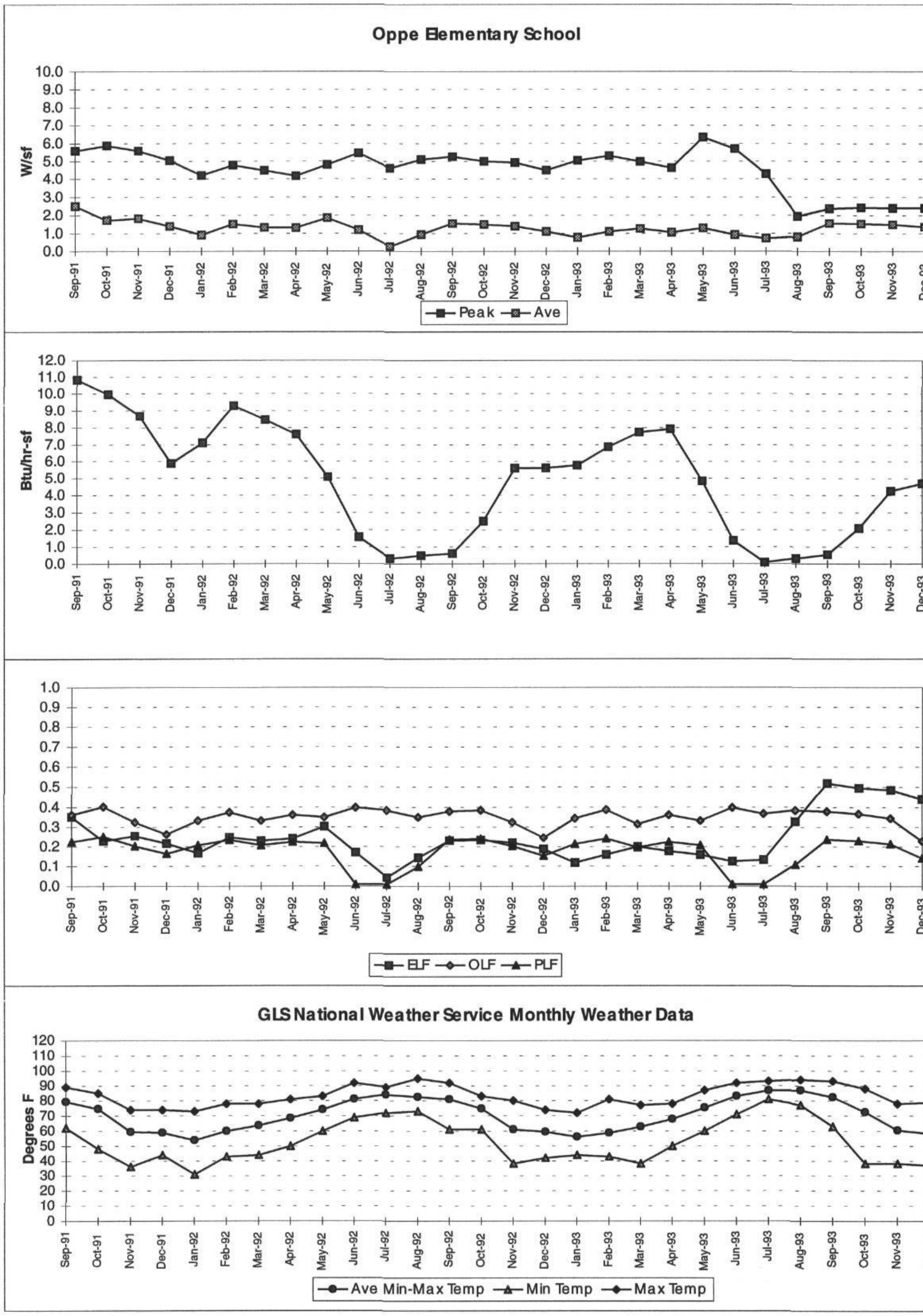
The following ECRO was installed at OES with the corresponding date reflecting the month the installation of the retrofit was completed:

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 electricity power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 pm when the thermal storage is being used, hence the peak power level became a measurement of the peak electricty readings during the afternoon for the month rather than the peak for all hours during the month.

On the following page is Figure 28, 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. 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 was very high in the Fall of 1991. and during summer time and months with long vacation. Lastly, PLF and ELF are reasonably low during the summer.

Figure 28: ***Monthly Data for OES*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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 a single reciprocating air cooled chiller with cool storage. Heating is provided by a 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. The building HVAC has simultaneous heating and cooling. which cycle throughout the year to maintain low humidity levels. 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.

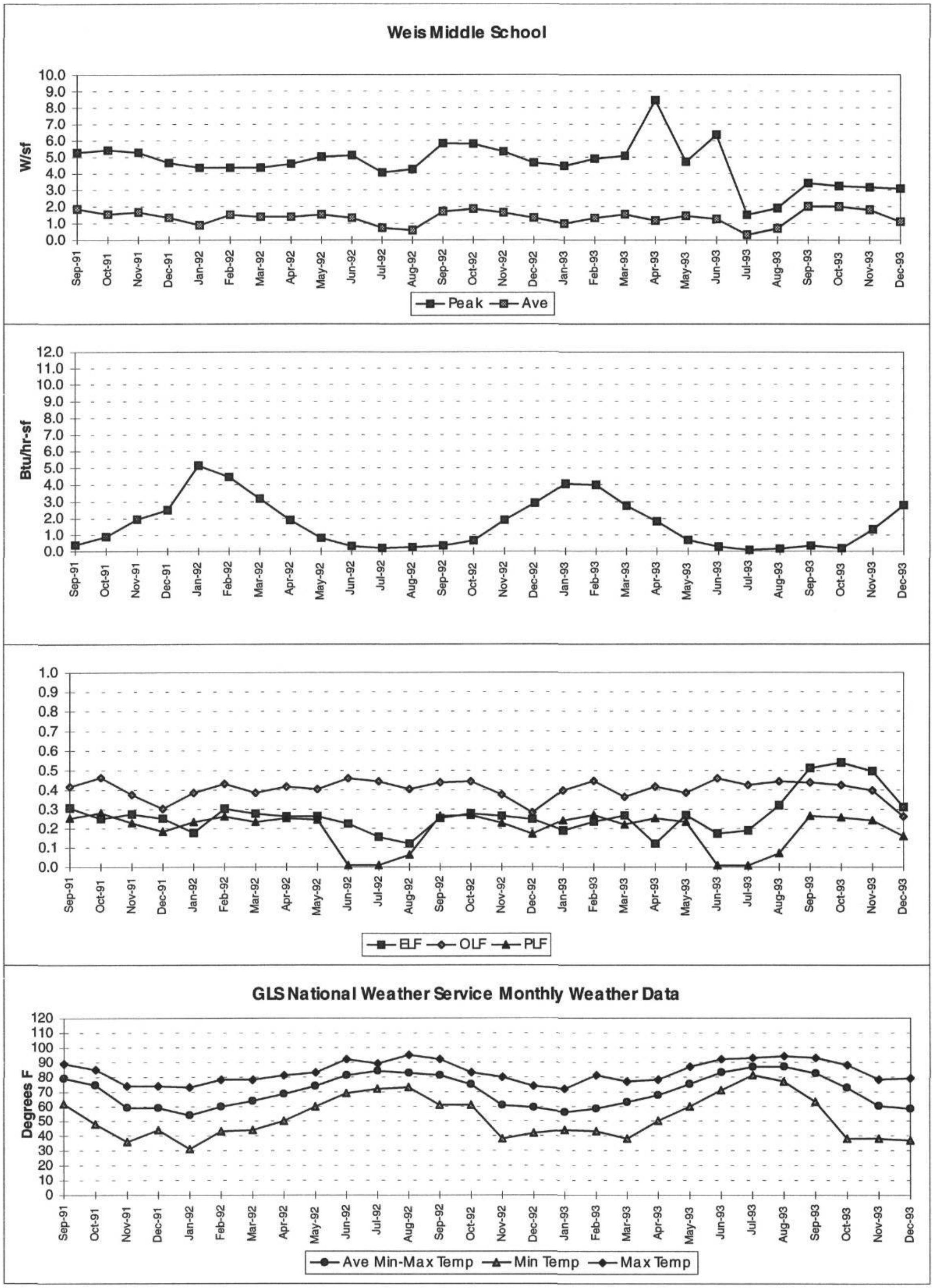
The following ECRO was installed at WMS with the corresponding date reflecting the month the installation of the retrofit was completed:

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 pm when the thermal storage is being used, hence the peak power level became a measurement of the peak electricty readings during the afternoon for the month rather than the peak for all hours during the month.

On the following page is Figure 29, showing the monthly electric, natural gas, ELF, OLF, PLF, and weather related data for WMS. The electric demand (the upper line) is measured in VA/sf, not W/sf like the monthly average consumption (lower line). 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 29: ***Monthly Data for WMS*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



4.9 Parker Elementary School (PES)

Parker Elementary School is located in Galveston, TX. It is a single story building with tilt wall 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 reciprocating air-cooled chillers. 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 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.

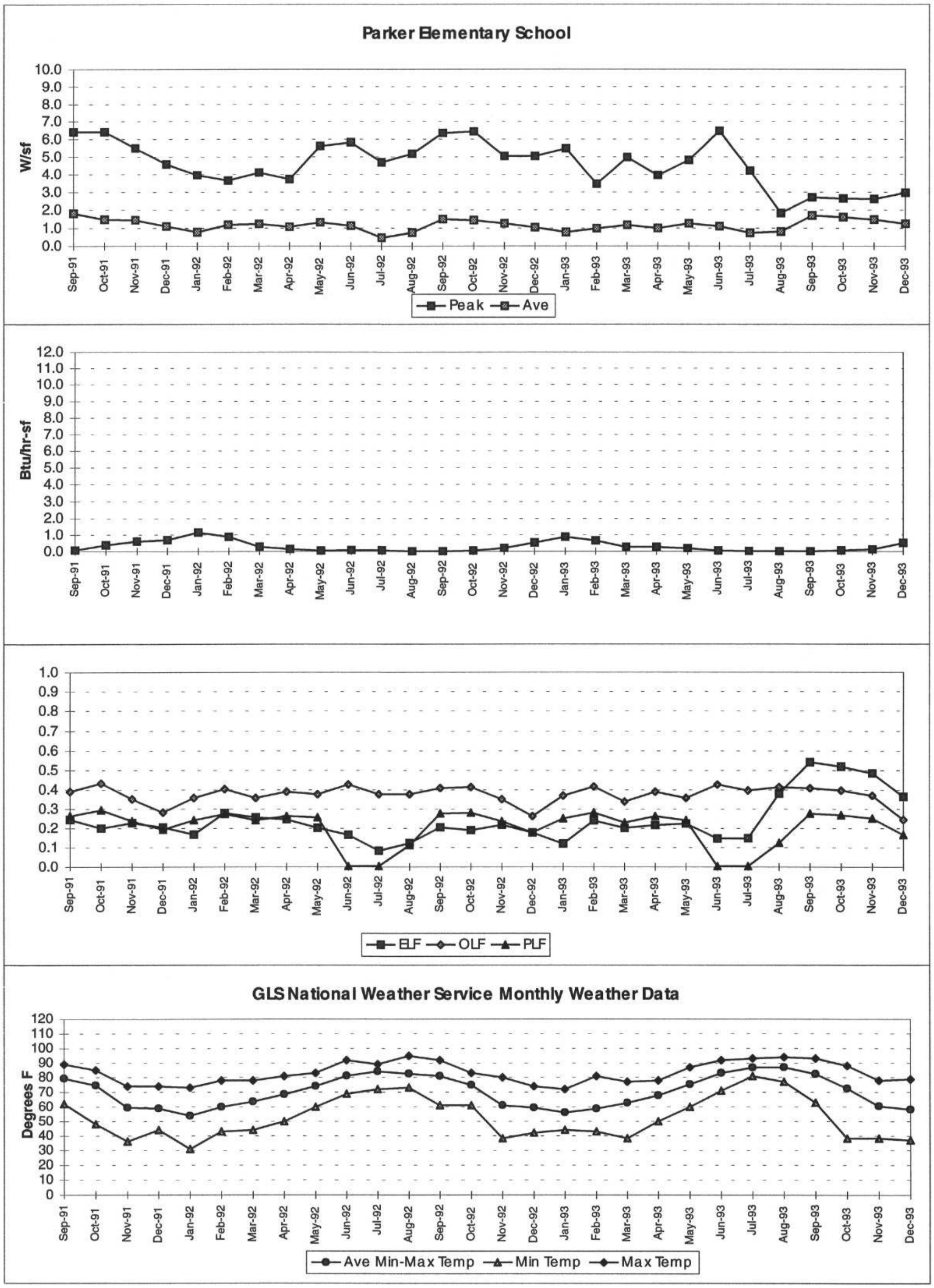
The following ECRO was installed at PES with the corresponding date reflecting the month the installation of the retrofit was completed:

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 electricity power levels due to this retrofit. The local utility reads peak electricity between 1 and 4 pm when the thermal storage is being used, hence the peak power level became a measurement of the peak electricty readings during the afternoon for the month rather than the peak for all hours during the month.

On the following page is Figure 30, 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 30: ***Monthly Data for PES*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



4.10 Morgan Elementary School (MES)

Morgan Elementary School is located in Galveston, TX. It is a single story with tilt wall construction building. It has a total floor area of 76,798 square feet with a kitchen, cafeteria, library, and classrooms. Cooling is provided by a three reciprocating air-cooled chillers. 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 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.

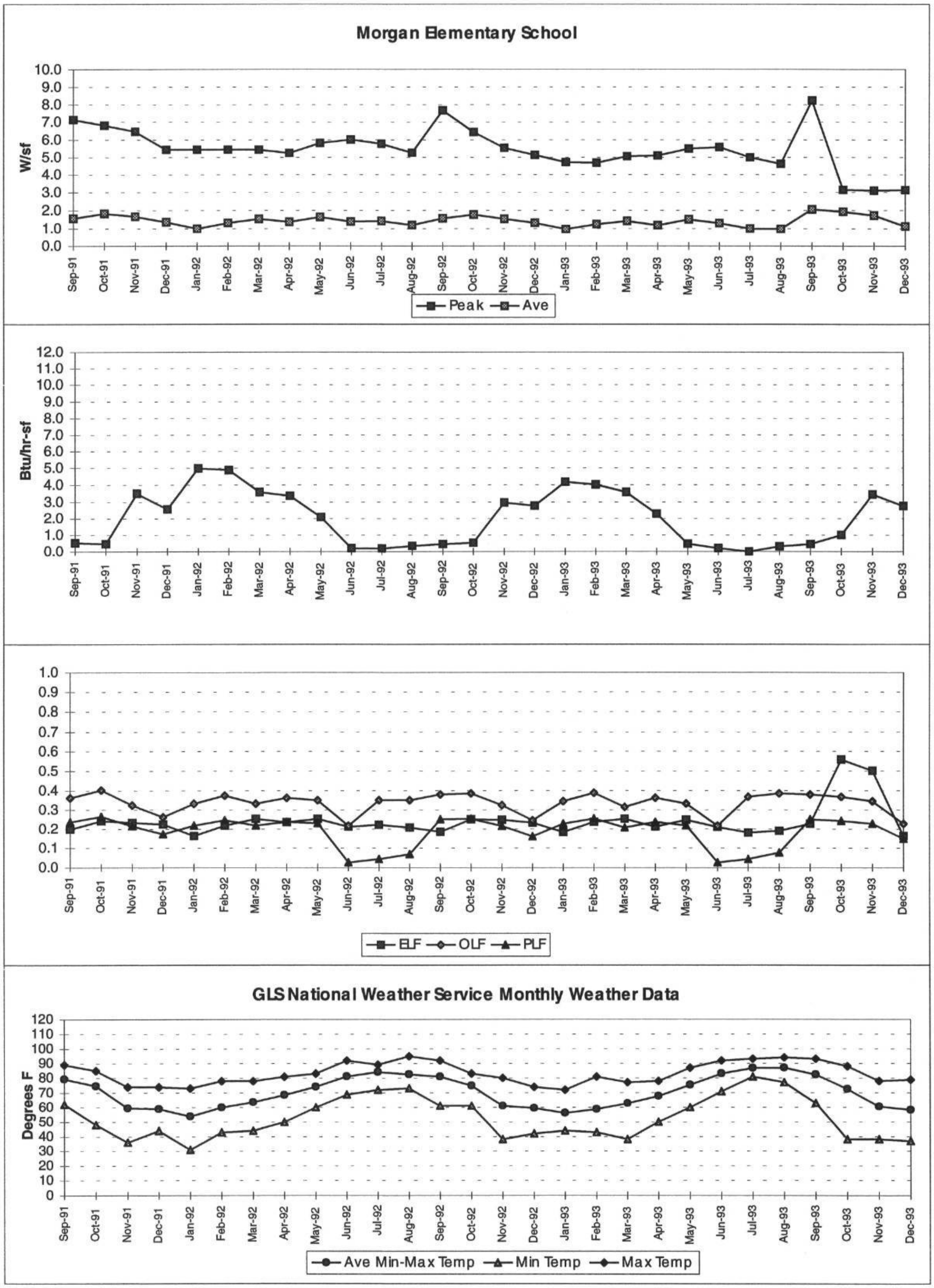
The following ECRO was installed at MES with the corresponding date reflecting the month the installation of the retrofit was completed:

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 pm when the thermal storage is being used, hence the peak power level became a measurement of the peak electricty readings during the afternoon for the month rather than the peak for all hours during the month.

On the following page is Figure 31, 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 31: ***Monthly Data for MES*****: Electric, Natural Gas, ELF, OLF, PLF, and weather data**



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 reciprocating water-cooled chillers with cool storage. Heating is provided by 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.

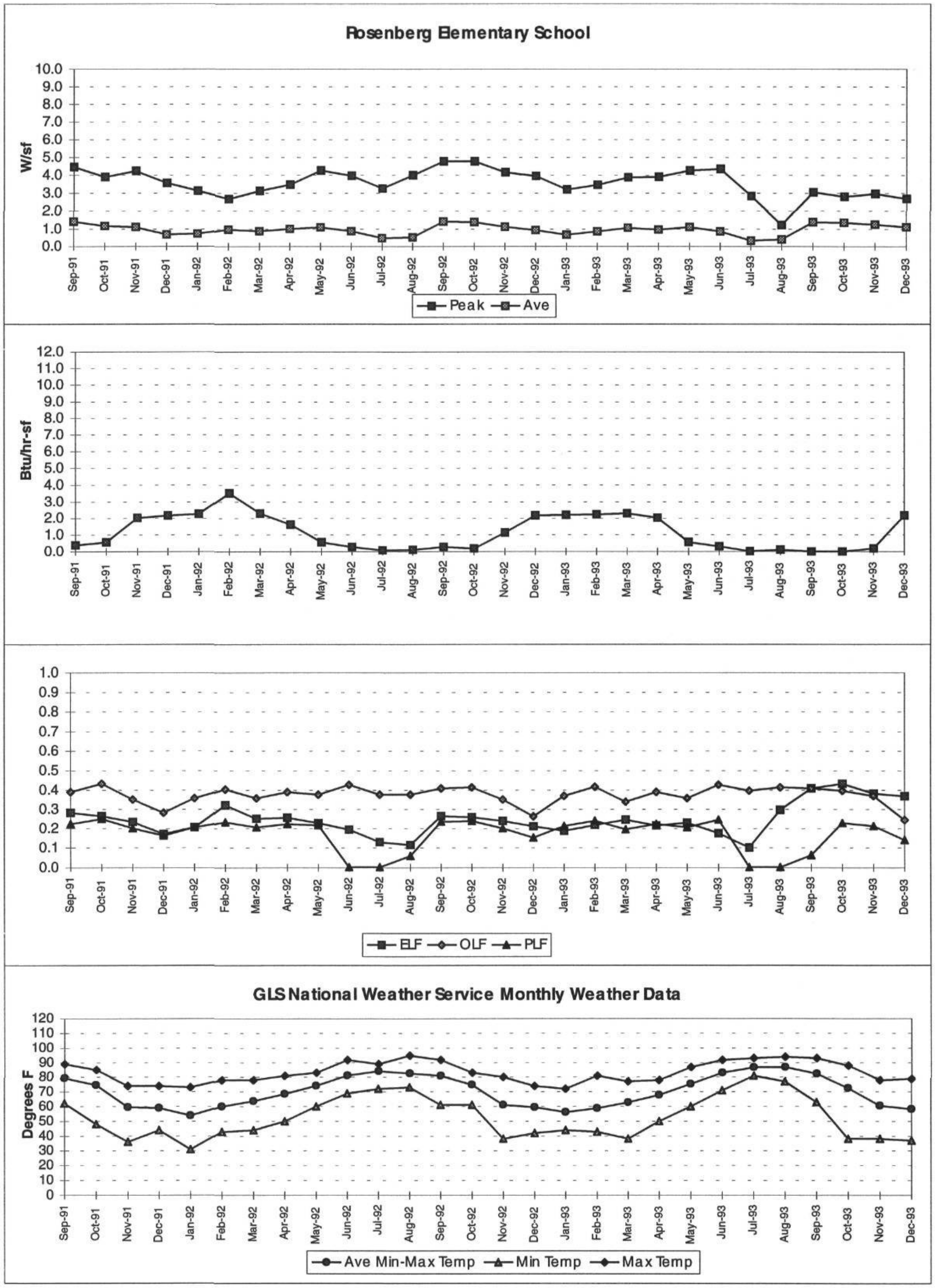
The following ECRO was installed at RES with the corresponding date reflecting the month the installation of the retrofit was completed:

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 pm when the thermal storage is being used, hence the peak power level became a measurement of the peak electricty readings during the afternoon for the month rather than the peak for all hours during the month.

On the following page is Figure 32, 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 32: ***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 5a: 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

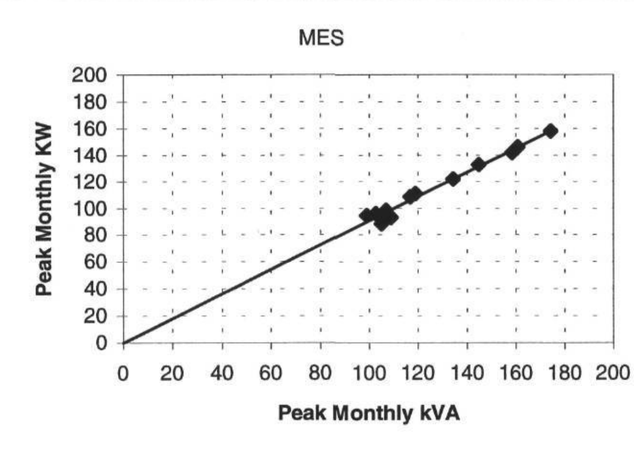
5.1.1 General

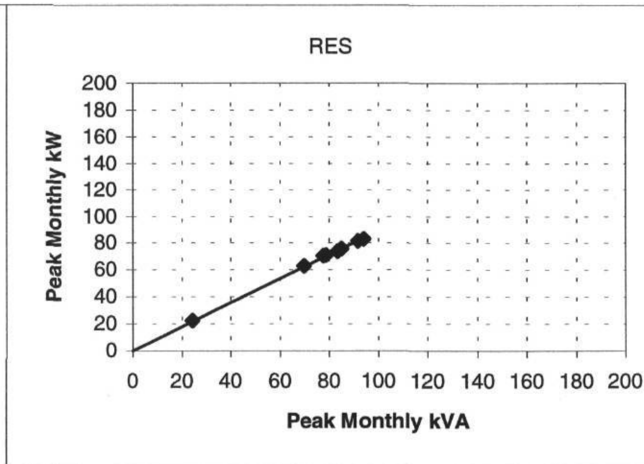
In general, annual energy indices allow for gross comparison of energy use in schools from year to year. Expressing the energy use per unit area of conditioned space allows for comparisons to be made among similar schools which are using the same fuel types for the same purposes. If a suitable average 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).

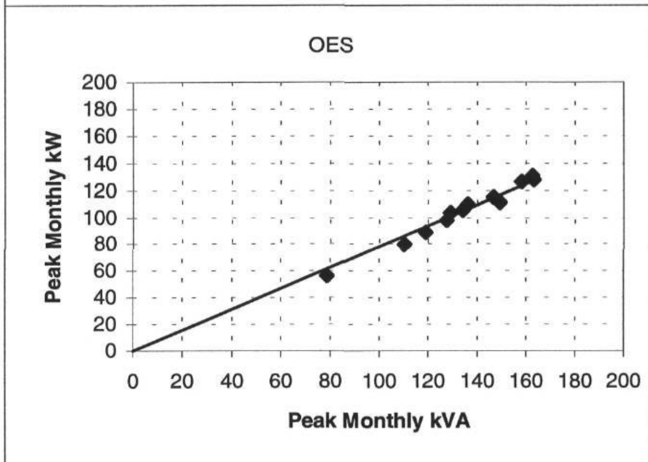
5.1.1.1 Power Factor Correction

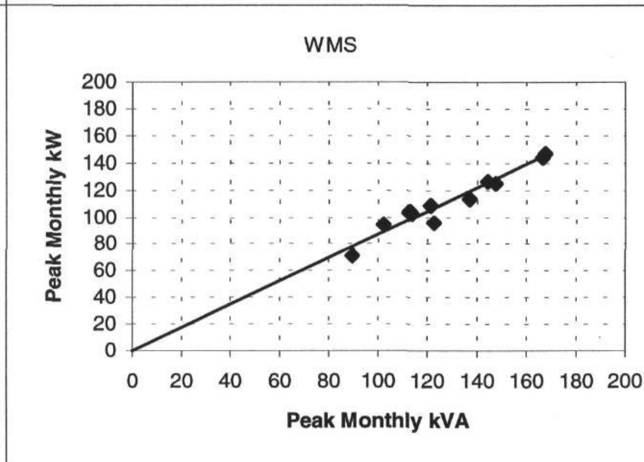
For the eleven schools analyzed in this study, the annual indices provided pertinent data that could have been used to develop a rough ranking of their comparative energy use. With the exception of peak demand electric power levels, the annual indices allowed for a good comparison across schools. Unfortunately,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

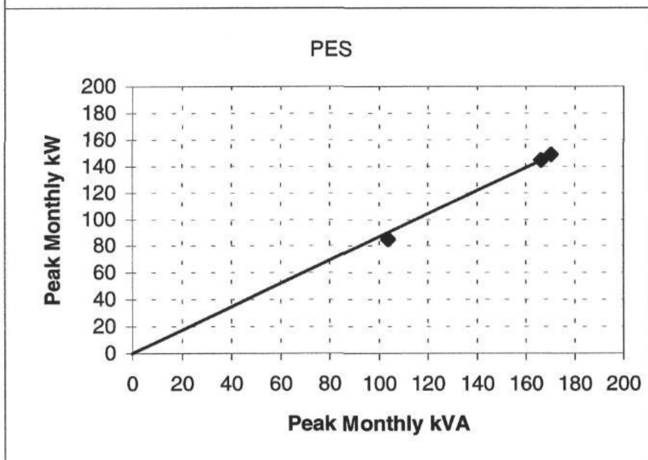
Figure 33: *kW versus kVA* for all five Galveston schools for Spring/Fall months (March, April, May, September, October, November), Summer months (June, July, August), and Winter months (December, January, February)











Equations:

MES: kW = 0.9072 kVA
OES: kW = 0.7817 kVA
PES: kW = 0.8671 kVA
RES: kW = 0.8939 kVA
WMS: kW = 0.8698 kVA

Figure 33 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.

Therfore, 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.

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. Natural gas data was not available for CMS.

DMS has an above average (i.e. 17%) 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 innefficient at the school when compared to the 1.18 W/sf average for the other eleven schools. Natural gas consumption is slightly (i.e. 9%) above average.

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 slightly (i.e. 10%) above average. Natural gas consumption is average at 2.14 Btu/(hr-sf).

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 a higher than average (i.e. 18%) electricity consumption of 1.39 W/sf, which may be indicating a slight excess use of HVAC equipment. Natural gas consumption is higher than average (33%) too, 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. Monthly and daily indices should reveal additional useful information.

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.

PES has a peak demand of 6.46 W/sf, 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.

RES has a peak demand of 4.77 W/sf, 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 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.

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.

SHS is a low consumer of energy. The peak demand is 3.33 W/sf, lowest of the group and well below average. Electricity consumption is 0.8 W/sf, 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.

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.

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 5b: 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 5a 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 5b.

5.2 Monthly Results

Twenty eight months from September 1991 through December 1993 were analyzed. The results are presented in tabular form. Some key meanings are expressed below to help follow the Tables

Peak demand WBE with std-dev	This is peak demand for months analyzed (Sept-May for school years, June-July for summers). The value is in W/sf . The standard deviation is in parentheses.
Ave WBE with std-dev	This is average electricity consumption for 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 when doing a three parameter model on Emodel. The value is in W/sf. The CV(RMSE) for this parameter is included.
Cooling Slope	This measure the slope of the angle in a 3 parameter model from the change point temperature to the maximum recorded temperature.
Change Point temperature	The temperature in degree F where cooling begins, determined by a 3 parameter analysis.
R^2	Coefficient of determination
Whole Model CV-RMSE	Coefficient of variation of the root mean square error

Table 6: 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 Temperature in (Degrees F)	R^2	Whole Model CV-RMSE
CMS	5.68 (0.80)	1.02 (0.28)	1.03 (0.06)	0.05 (0.02)	69.65	0.24	0.23
DMS	6.90 (1.08)	1.84 (0.60)	1.30 (0.08)	0.07 (0.01)	57.10	0.77	0.17
MES	8.22 (1.26)	1.60 (0.29)	1.20 (0.08)	0.02 (0.01)	54.52	0.49	0.14
NHS	4.83 (0.68)	1.48 (0.36)	1.02 (0.05)	0.03 (0.00)	51.00	0.90	0.09
OES	6.34 (1.23)	1.35 (0.37)	1.12 (0.11)	0.25 (0.01)	54.52	0.34	0.22
PES	6.46 (1.37)	1.42 (0.27)	1.13 (0.05)	0.04 (0.01)	67.61	0.52	0.16
RES	4.77 (0.82)	1.28 (0.23)	0.83 (0.06)	0.02 (0.00)	54.52	0.59	0.14
SES	5.38 (0.75)	1.37 (0.36)	0.98 (0.04)	0.04 (0.00)	54.45	0.86	0.11
SHS	3.37 (0.30)	1.02 (0.19)	0.64 (0.02)	0.02 (0.00)	57.58	0.89	0.08
VHS	4.37 (0.62)	0.87 (0.26)	0.76 (0.03)	0.04 (0.00)	63.41	0.85	0.11
WMS	8.44 (1.42)	1.66 (0.31)	1.22 (0.09)	0.02 (0.01)	54.52	0.43	0.16
Average	5.89 (0.94)	1.36 (0.32)	1.02 (0.03)	0.05 (0.01)	62.78	0.63	0.15

Table 7: Monthly summer(June-Aug) WBE results

School	Peak demand WBE with std-dev in (W/sf)	Ave WBE with std-dev in (W/sf)	Base Level WBE in (W/sf)	Whole Model CV-RMSE
CMS	4.36 (1.43)	0.82 (0.47)	0.89	0.53
DMS	5.25 (1.19)	2.35 (0.60)	2.54	0.24
MES	6.01 (0.51)	1.07 (0.19)	1.22	0.16
NHS	3.66 (0.73)	1.27 (0.57)	1.44	0.40
OES	5.70 (1.36)	0.79 (0.31)	0.81	0.38
PES	6.44 (1.61)	0.82 (0.25)	0.82	0.31
RES	4.38 (1.15)	0.40 (0.23)	0.58	0.40
SES	3.78 (0.99)	1.61 (0.26)	1.72	0.15
SHS	2.38 (0.54)	0.78 (0.17)	0.74	0.15
VHS	2.45 (1.04)	0.67 (0.27)	0.89	0.31
WMS	6.34 (1.86)	0.66 (0.39)	0.82	0.48
Average	5.62 (1.13)	1.02 (0.39)	1.13	0.32

Table 8: Monthly ELF, OLF, and PLF results

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 9: Monthly natural gas results

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 next 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. To begin with, we look at some simple statistics that were calculated with the monthly data. Figures 15 to 19, which were previously presented, illustrate the results of this analysis. Figure 15 shows the results of a monthly aggregate analysis across all schools. For each school in Figure 15 a box-whisker mean symbol is used to indicate the results of the statistical analysis. Each plus symbol (whiskers) indicates outliers, within the 10th percentile and greater than 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 75th 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 outlier).

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 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 analysis. 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 16 shows the results of the interquartile 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 interquartile 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. Fitting a 3 parameter model to the schools indicates a heating trend. There is a clear trend to heating at lower temperatures and a base natural gas consumption during the summer time, primarily indicating domestic hot water consumption.

Figure 17 shows the results of the interquartile analysis for the ELF for the eleven schools. ELF is a good indicator of diversity at the schools. The maximum value and the 90th percentile usually indicate September and October usage for schools without much summer usage and July and August for schools that do. The minimum and 10th percentile generally indicates summer usage for schools without any summer school.

WBE & ELF tend to be linearly related:

Figure 34: ***WBE versus ELF***

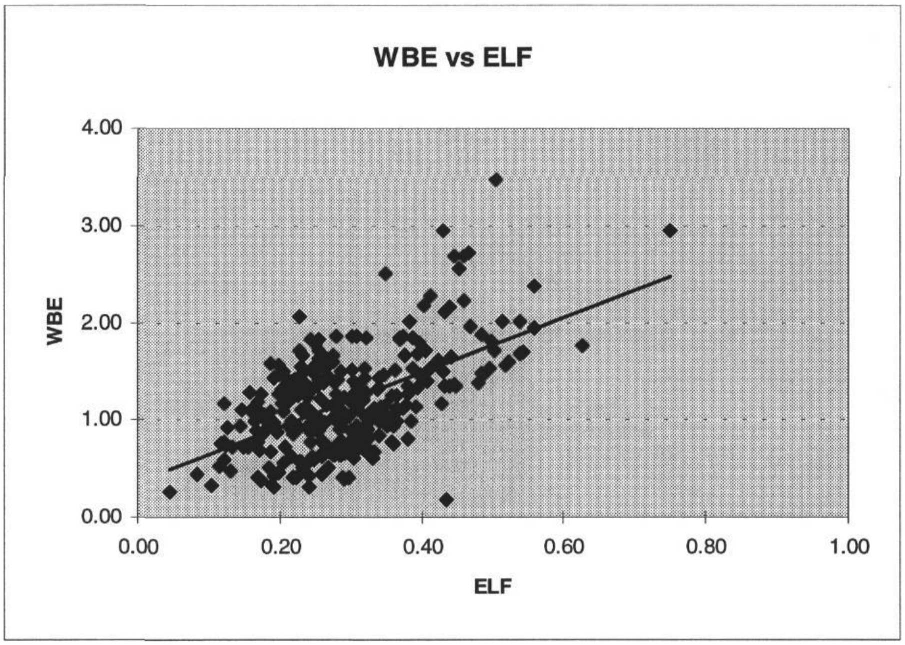


Figure 18 shows the results of the interquartile analysis for the OLF for the eleven schools. OLF 10th percentile generally indicates months where there has been significant vacation with the minimum usually occurring in June or July. OLF is also consistently higher than PLF (see Figure 19), an indication that custodial workers are in the school during different hours than teachers, students and staff. Minimum PLF values indicate summer vacation for staff. VHS and SHS have school almost year round, hence their minimum PLF values are much higher than other schools.

To improve results when creating temperature related models, 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 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 fit during the summer time. 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 be a better fit. Additional months of data would be required to verify this. A 3 parameter model fits most of the schools during the school year well. There is clear indication of cooling in schools, starting at approximately 63 F and a base electricity consumption level of approximately 1.0 W/sf. There is an increase in electricity consumption as temperature increases. The average electricity usage during the all school year months for all schools was approximately 1.4 W/sf. Therefore, on average, cooling was approximately 24% of the electric load during the school year for all eleven schools based on the 3 parameter models.

5.2.2 School Specific

Chamberlain Middle School

During the school year CMS has a peak demand of 5.68 W/sf, slightly below average. However, the values seem to be highest during both the heating and cooling season indicating the possibility of electric heating. The WBE consumption is approximately 25% below average during the school indicating fewer afterschool and weekend activities. The ELF, OLF, and PLF are very similar during the school year suggesting that the previous assumption of little afterschool activities is true. 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 4.36 W/sf, slightly below average. The WBE consumption is approximately 25% 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 there is room for improvement on energy consumption during the summer time. Certain systems may be left on beyond occupied hours.

Dunbar Middle School

During the school year DMS has an above average 6.90 W/sf peak demand. The WBE consumption is 1.9 W/sf, 36% 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 5.69 W/sf, about 14% lower than during the school year, indicating some of the systems used during the school year are shut off in the summer time. The summer WBE consumption is 2.35 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

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 1.6 W/sf during the school year, approximately 18% 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 half of average. However, the error associated with the value is fairly high.

During the summer time the peak demand reduces approximately 27% to 6.01 W/sf indicating systems are shut off in the summer time. WBE consumption of 1.07 W/sf in the summer time versus 1.60 W/sf during the school year is further indication of energy consumption reduction when the school is not occupied.

Nacogdoches High School

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 1.39 W/sf. Both match 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 reduced by 24% and 14% respectively, indicating a 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.

Oppe Elementary School

Oppe Elementary School has a peak demand of 6.34 W/sf and WBE consumption of 1.5 W/sf. Both 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 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 systems are not shut off during semester breaks. However, WBE consumption is reduced by approximately 41% indicating that the system may be oversized for summer usage. The PLF is much lower than the ELF during the summer time. This helps verify the conclusion.

Parker Elementary School

During the school year Parker Elementary School has a peak demand of 6.46 W/sf and WBE consumption of 1.42 W/sf. Both are slightly above 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. 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 42% indicating that the system may be oversized for summer usage. The PLF is much lower than the ELF during the summer time. This helps verify the conclusion.

Rosenberg Elementary School

During the school year Rosenberg Elementary School has a peak demand of 4.77 W/sf and WBE electricity consumption of 1.28 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 and WBE consumption are both reduced by approximately 25% indicating that the system 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

During the school year SES has an average 5.38 W/sf peak demand and 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 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 a peak demand of 3.78 W/sf and an average WBE consumption during the summer was 1.61 W/sf. The peak demand value is lower during the summer time, but the average is actually a 17.5% 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

Stroman High School has a very low 3.37 W/sf peak demand during the school years, as well as a low WBE consumption of 1.02 W/sf, approximately 33% 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 29% and 24% respectively, indicating a 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

Victoria High School has a very low 4.37 W/sf peak demand during the school year. It also has a low WBE consumption of 0.87 W/sf, approximately 36% below average. Both match scheduling very well, increasing when student begin school 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 44% and 23% respectively, indicating a 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

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 1.66 W/sf during the school year, approximately 16% 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. However, the error associated with the value is fairly high.

During the summer time both the peak demand and WBE consumption reduce by approximately 25% indicating equipment of 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 10: 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 11: Daily WBE-school year, weekend results

School	*Weekend* Ave WBE with std-dev (W/sf)	*Weekend* Base Level WBE (W/sf)	*Weekend* Whole Model CV-RMSE
CMS	0.31 (0.18)	0.31	0.57
DMS	1.04 (0.63)	1.03	0.61
MES	0.27 (0.17)	0.29	0.65
NHS	0.57 (0.31)	0.57	0.56
OES	0.28 (0.13)	0.30	0.47
PES	0.29 (0.09)	0.31	0.32
RES	0.27 (0.06)	0.28	0.25
SES	0.72 (0.33)	0.72	0.46
SHS	0.43 (0.18)	0.43	0.41
VHS	0.39 (0.14)	0.40	0.37
WMS	0.40 (0.28)	0.41	0.67
Average	0.45 (0.23)	0.459	0.486

Table 12: Daily WBE-summer results

School	*Weekday* Ave WBE with std-dev (W/sf)	*Weekday* Base Level WBE (W/sf)	*Weekday* Whole Model CV-RMSE	*Weekend* Ave WBE with std-dev (W/sf)	*Weekend* Base Level WBE (W/sf)	*Weekend* Whole Model CV-RMSE
CMS	0.91 (0.52)	0.94	0.59	0.60 (0.52)	0.60	0.87
DMS	2.53 (0.46)	2.55	0.2	1.91 (0.76)	1.93	0.39
MES	1.38 (0.51)	1.39	0.41	0.30 (0.37)	0.33	1.12
NHS	1.53 (0.65)	1.56	0.44	0.65 (0.28)	0.65	0.44
OES	0.93 (0.48)	0.94	0.54	0.46 (0.51)	0.46	1.07
PES	1.02 (0.42)	1.03	0.47	0.32 (0.11)	0.35	0.39
RES	0.48 (0.15)	0.57	0.42	0.21 (0.07)	0.21	0.34
SES	1.69 (0.31)	1.70	0.21	1.43 (0.33)	1.42	0.23
SHS	0.92 (0.24)	0.92	0.27	0.47 (0.12)	0.46	0.25
VHS	0.82 (0.19)	0.82	0.23	0.33 (0.07)	0.32	0.21
WMS	0.80 (0.62)	0.83	0.82	0.32 (0.34)	0.39	1.18
Average	1.18 (0.41)	1.205	0.416	0.63 (0.32)	0.647	0.591

5.3.1 General

This next section considers daily indices. In the previous section it was shown that breaking up monthly indices into school year and summer periods reveals more information about how seasons affect a schools 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. While creating daily school year models, taking the weekend data out of the analysis has a significant affect of 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. 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, taking out 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. 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

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 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 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

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 average, and the weekend electricity consumption is 1.93 W/sf, three times average. Both are indications that the school has systems on well beyond hours suggested by the PLF.

Morgan Elementary School

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 being used throughout the entire week. The PLF is lower during the summer time. Therefore, weekend usage of systems may be excessive.

Nacogdoches High School

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

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

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

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

During the school year Sims Elementary School has a weekday base electricity consumption of 1.17 W/sf. 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

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

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

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.

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 13: 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 14: 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 15: 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 occ and unocc periods	X	X									
•Clean evaporator and condenser coils	X	X	X	X	X	X	X	X	X	X	X
•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 identified in this case study, six elementary schools, two middle schools, and three high schools. 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 approximately 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 or 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 curve 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 break up the monthly data into school year and summer data for a good fit.

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.

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 approximately 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 controls of equipment should be looked at. Finally plan a visit of the school to confirm findings. That way one knows exactly which areas to target for ECRMs.

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12.0 APPENDIX

Table 16: *Sumary Table*: information collected at each school and the indices