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DEVELOPMENT OF BASELINE MONTHLY UTILITY MODELS, STABILIZATION OF DATA LOGGING ENVIRONMENT AND DEVELOPMENT OF METERING PLAN AND SHOPPING LIST FOR FORT HOOD, TEXAS

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GENERAL ABSTRACT

This report has been prepared for the United States Army Construction Engineering Research Laboratories (CERL) located at Champaign, IL. The report describes the work performed by the Energy Systems Laboratory (ESL) of Texas A&M University System at Ft. Hood army base in Texas. The project at Ft. Hood was divided into three major Tasks:

Task A: Development of Baseline Monthly Utility Models for Ft. Hood
Task B: Provide Stable Data Logging at Ft. Hood
Task C: Provide Metering Plan and Shopping List of Necessary Data Points at Ft. Hood to Meter and Monitor Energy Use

The report is divided into three main parts representing the three tasks of the project. The objectives of Task A are to develop baseline monthly models of (i) electricity use, (ii) electricity demand, (iii) gas use, and (iv) water use both at the whole-base level and at the three cantonment area-level for Fort Hood, Texas and illustrate their use as screening tools for detecting changes in future utility bills and also to track/evaluate the extent to which the Presidential Executive Order mandating 30% decrease in energy utility bills from 1986 to 2005 is being met. This task also evaluates two different types of energy modeling software- PRISM and EModel- in order to ascertain which is more appropriate of baseline modeling of large installations.

The objectives of Task B are to provide a stable data logging environment, and inspection and archiving of data coming from five existing data loggers at the base. This task also included the installation of a weather station (temperature, humidity and solar sensors) at the west substation, and the installation of the ESL's Monitor software for use by the Energy Office at the base. The objective of Task C is to provide a metering plan and shopping list of necessary data points to provide CERL with energy measurements capability at Ft. Hood.

For Task A, 1990 has been selected as the baseline year to illustrate the predictive capability of the models. Model coefficients at the cantonment area-level for all years from 1989 to 1993 are presented. Relevant equations for computing the 95% prediction intervals of the regression models are given. The use of the equations are illustrated using measured data over the period 1989-1993. At the base-wide level, electricity use, electric demand, gas use and water use models have been developed for each year between 1987 and 1993. The extend to which energy

and water use has declined from 1987 to 1993 has also been determined. It was found that electricity use increased by 4.7% whereas demand has decreased by 1.8%, gas decreased by 20.4% and water use decreased by 15.5%. Two different types of energy modeling softwares were evaluated, PRISM and EModel, and it was found that EModel gave more accurate modeling results than PRISM, and therefore EModel was used in the analysis.

For Task B, a weather station that includes temperature, humidity and solar sensors was installed at the west substation of Ft. Hood. Weekly inspection plots of electricity use at the main substation of Ft. Hood has been developed using equipment and data polling and archiving routines at the ESL. The inspection plots are delivered weekly to Ft. Hood Energy Office and CERL. To provide on screen visualization of real-time energy consumption data collected by the data loggers, the ESL installed Monitor, a software developed at the ESL, to be used by Ft. Hood Energy Office personnel.

The ESL is in the process of developing a software package of PC routines (PollHood) that will enable the personnel at the energy office to poll the data from the five data loggers at the base and to generate weekly inspection plots. The ESL will also install a cellular phone at the west substation to facilitate communications with the data loggers there.

For Task C, the ESL has prepared a shopping list and metering and monitoring plan of necessary data point to monitor energy use at 25 power plants at different locations on the base. The proposed system will cost about $1,075,537 and it could be installed in about 12 months. The system would include all necessary software, and hardware for polling and archiving the data.

TABLE OF CONTENTS

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TASK A

DEVELOPMENT OF BASELINE MONTHLY UTILITY MODELS FOR FT. HOOD, TEXAS

TASK A: ABSTRACT

The objectives of Task A were to develop baseline monthly models of (i) electricity use, (ii) electricity demand, (iii) gas use, and (iv) water use for the three cantonment areas of Fort Hood, TX and illustrate their use as screening tools for detecting changes in future utility bills and also to track/evaluate the extent to which the Presidential Executive Order mandating 30% decrease in energy utility bills from 1986 to 2005 is being met. 1990 has been selected as our baseline year to illustrate the predictive capability of the models. Model coefficients at the cantonment area-level for all years from 1989 to 1993 are also presented in this report. Since ascertaining the uncertainty of our predictions is very important for meaningful evaluations, we have also presented the relevant equations for computing the 95% prediction intervals of the regression models and illustrated their use with measured data over the period 1989 - 1993. Certain salient features of the models are also highlighted, like the effect of a FM load management program initiated to reduce electricity demand by residential air-conditioner cycling.

At the base-wide level, electricity use, electricity demand, gas use and water use models have also been developed for each year between 1987 and 1993. The extent to which energy and water use has declined from 1987 to 1993 has also been determined. With changes normalized by conditioned building area, we find that from 1987 to 1993, (i) electricity use increased by 4.7%, (ii) demand decreased by 1.8%, (iii) gas decreased by 20.4%, and (iv) water use decreased by 15.5%. This study also evaluated two different types of energy modeling software- the Princeton Scorekeeping method (PRISM) (Fels 1986) and EModel (Kissock 1994)- in order to ascertain which is more appropriate for baseline modeling of large installations such as Fort Hood. It was found that the EModel software developed by the Energy Systems Laboratory to model baseline energy use in commercial buildings has more flexibility to handle different types of linear, single-variate change-point models. EModel also gave more accurate modeling results. Hence EModel software was used to develop all the models presented in this report.

TASK A: LIST OF TABLES

TASK A: List of figures

TASK A: EXECUTIVE SUMMARY

The objectives of Task A are to develop baseline models of (i) electricity use, (ii) electricity demand, (iii) gas use, and (iv) water use both at the whole-installation level and for the three cantonment areas of Fort Hood, TX and illustrate their use as screening tools for detecting changes in future energy use. These baseline models will also be used to track/evaluate the extent to which the Presidential Executive Order 12902 mandating 30% decrease in energy consumption in all DoD installations from 1985 to 2005 is being met. The report, developed primarily for use by USACERL and the Energy Office at Fort Hood, also contains explanations of how to use these models. Further, the report includes spreadsheet models on baseline development, in the event that future circumstances dictate that another year than the one chosen in this study be used as the baseline year.

A certain amount of effort has been placed in narrowly defining the scope of this project because of the amount of monitored data that is available. Since models developed for Fort Hood through the Model Energy Installation Program (MEIP) initiative are intended to be easily extrapolated to DoD-wide use, USACERL decided it would be best to develop monthly-level models using readily available monthly utility bill data. Further it was decided that disaggregation of electricity use, electrical demand, natural gas use and water use beyond the three cantonment-area-wide level was not required in this study. Utility data for 1985 was not readily available, and hence this study limited itself to essentially the period 1987 to 1993.

In 1991, the Energy Office at Fort Hood instituted a very successful demand shedding initiative via frequency modulated (FM) cycling of residential air conditioning units. Because of the USACERL and the Fort Hood Energy Office requested a baseline of Fort Hood sometime prior to 1991 as a means of further validating the effects of the demand shedding effort. Hence the year 1990 was chosen for baseline model development. Finally, it was felt that since Fort Hood is experiencing (and has experienced) changes in population as well as total square footage of buildings over the years, the influence of these two variables should also be included in the study.

USACERL sent monthly utility data in electronic form to the Energy Systems Laboratory (ESL). USACERL also informed ESL that this utility-type data was exactly on a calendar month basis. Therefore, the start and end of the utility bill readings dates were assumed to be the first and last day respectively of each calendar month.

This study also evaluated two different types of energy modeling software- PRISM and EModel - in order to ascertain which is more appropriate for baseline modeling of large DoD installations. It was determined that in most cases EModel out-performed PRISM, and even in the few cases where it did not, the difference was very small. Hence the EModel software was adopted for all subsequent analyses in this report.

Altogether, this report presents 10 baseline models for 1990 at the cantonment area level. The water use model for the North cantonment area has very poor predictive capabilities and therefore we do not recommend that it be used. Three other models, namely (i) electricity use by the North substation, (ii) gas use in the Main and West cantonment areas combined, and (iii) gas use in the North cantonment area, are to be used with caution. In an effort to improve these models we have investigated the use of the base population as an additional variable in the model. Unfortunately, we could not find any improvements by incorporating this variable and so it was decided that the effect of year-to-year population changes and building square footage changes be used simply to normalize the tota' energy use values (a procedure widely adopted in most studies to date).

Once baseline models have been developed, it is possible to use them as screening tools by comparing the forecasted levels with actual energy use. Effect from changes in the weather from year-to-year (more accurately, outdoor temperature) on the energy use are explicitly accounted for by the baseline model forecasts. The method used to calculate the 95% prediction intervals of the 3-P model are also fully described in the report. We have used our 1990 baseline models to forecast into the future up to 1993 and also backcast into the past until 1989. For the Main substation electricity demand, Fig.1 clearly indicates the benefit of the DSM program since we see a substantial reduction from March 1991. Because of the ratchet clause on the peak electric demand, the billed peaks in winter are also lower from 1991-92 onwards. It is only during Sept-Oct. 1993 that demand seems to have crept up again. A computer disk containing six spreadsheets (in Excel) have also been delivered to USACERL which would be useful for projecting 1990 baseline models into the future and generating the 95% prediction intervals.

At the whole-installation level, this report presents, for each of the four consumption channels (electricity use, electricity demand, natural gas use, water use), models for each year from 1987 to 1993. The 1987 models have been used to determine whether energy and water use efficiency has increased over the years till 1993. This type of analysis capability is crucial if one wishes to ascertain the extent to which the Presidential Executive Order has been met. The percentage changes in energy and water use normalized by building conditioned area are shown in Fig.2 along with their 95% prediction intervals. A positive percentage change implies that energy (or water) use has increased, and vice versa. We note from Fig.2 that from 1987 to 1993, (i) electricity use has increased by 4.7%, (ii) demand has decreased by 1.8%, (iii) gas has decreased by 20.4%, and (iv) water use has decreased by 15.5%.

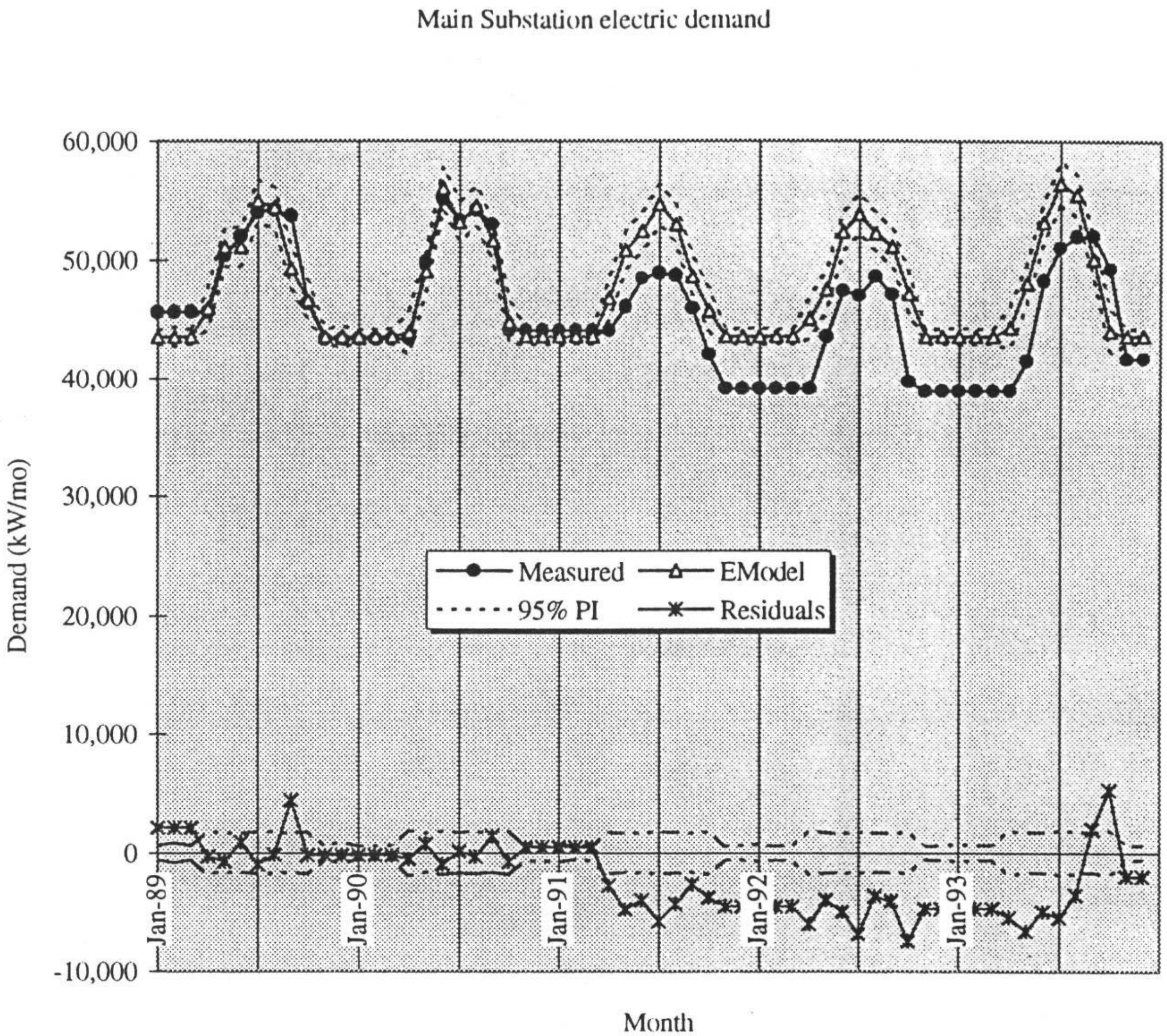


Fig. 1 Predictive ability of 1990 baseline 3-P regression model for Main Substation electric demand. Prediction intervals for the model as well as for the residuals are shown

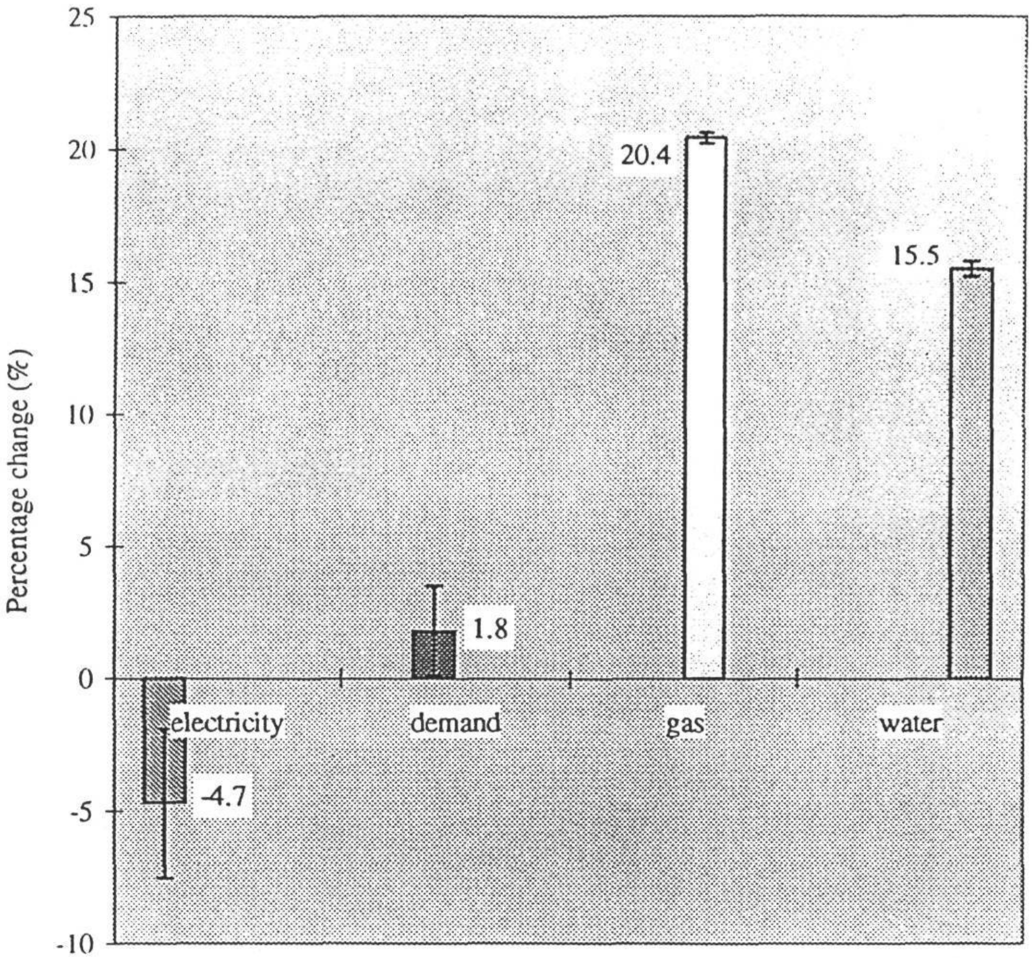


Fig. 2 Percentage change in annual energy use and water use from 1987 to 1993 normalized by total conditioned building area. Negative change indicates an increase in use and vice versa. 95% confidence intervals for the % change are also shown.

1.0 Background

Presidential Executive order 12902 states that all federal facilities shall reduce energy consumption and utility costs by 30% from 1985 levels by the year 2005 (Chalifoux et al., 1996). Subsequently the Army Corps of Engineers of the United States Construction Engineering Research Laboratories (USACERL) at Champaign, IL instituted the Model Energy Installation Program (MEIP). The MEIP is a 5-year pilot project to investigate the feasibility of instituting energy efficiency on an installation-wide (i.e., base-wide) scale in the United States Army. One of the basic intents was to meet the mandate of the above Executive Order in 5 years by reducing the energy consumption and utility bills by 30% at Fort Hood, Texas, taking 1993 as the baseline year.

2.0 Objectives and Scope of Task A

The objectives of Task A are to develop baseline monthly models of (i) electricity use, (ii) electricity demand, (iii) gas use, and (iv) water use for the three cantonment areas of Fort Hood, TX and illustrate their use as screening tools for detecting changes in future utility bills. These baseline models will also be used to track/evaluate the extent to which the Executive Order mandating 30% decrease in energy consumption is being met. In order to accomplish this it was also necessary to evaluate two different types of energy modeling software- PRISM (Fels et al., 1995) and EModel (Kissock et al. 1994)- in order to ascertain which is more appropriate for baseline modeling of lar... Department of Defense (DoD) installations.

A certain amount of effort has been placed in narrowly defining the scope of this project because extensive monitored data is available. For example, hourly data for several years for more than 20 electric feeders is available. The primary objective was to develop baseline models capable of evaluating the extent to which energy conservation measures at Fort Hood are reducing energy consumption and thereby meeting the target set by the Executive Order. Since models developed for Fort Hood through the MEIP initiative are intended to be easily extrapolated to DoD-wide use, USACERL decided it would be best to develop monthly-level models. Such data is readily available for DoD installations, while hourly or daily data are not.

USACERL directed that disaggregation of electricity use, electrical demand, natural gas use and water use beyond the cantonment-area level was not required in this study. Disaggregation of Fort Hood total electricity use into its component end uses (e.g. cooling, fans, pumps, lights, plug loads, etc.) is currently underway through another research contract. Further, it was felt that, since Fort Hood is experiencing (and has experienced) changes in population as well as total square footage of buildings over the years, the influence of these two variables should be studied as well.

Finally, regarding the issue of which year to use for baseline model development, three choices were available. Since the Executive Order set the goal based on year 1985, one should have chosen this year as the baseline year. However, utility data for 1985 was not readily available. Since obtaining the data would have postponed the completion of this study, USACERL decided to use a later year. The second choice was to choose year 1993 (the first year of the MEIP effort) as the baseline year, as done in the CERL report (Chalifoux et al., 1996). In 1991, the Energy Office at Fort Hood instituted a very successful demand shedding initiative via frequency modulated (FM) cycling of residential air conditioning units (the "FM Load Management System"). USACERL and the Fort Hood Energy Office wanted to baseline Fort Hood energy use sometime previous to 1991 as a means of further validating the effects of the demand shedding effort. Hence it was decided to use 1990 data for baseline model development at the cantonment-level and for subsequent screening purposes in this study. However, cantonment-level models for individual years between 1989 to 1993 would be presented in the event that future circumstances dictate that a year other than 1990 be used as the baseline. At the whole installation-level, it was decided that models for all individual years from 1987 to 1993 be developed and reported in this study. This would allow, if necessary, the same type of flexibility as that offered by the cantonment-level models.

3.0 Previous Studies

There has been extensive data gathering and analyses work done at Fort Hood over the years. A comprehensive report on Fort Hood Utility and services data has been prepared (USACERL, 1993). Historical energy consumption data from as far back as 1983 is available for electricity, gas and other services. Complete details about the electrical distribution, water distribution and storage, sewage treatment, gas distribution, air conditioning and refrigeration equipment, and chiller and boiler equipment are also available. The various building categories and types and statistics relating to each of these are also documented.

The MEIP is a multi-faceted endeavor with efforts ranging from technology assessments to technical training to resident energy education. The focus during the first year was to commission numerous consultants to perform well-defined base-wide studies of the major building mechanical and electrical technologies and to determine specific energy retrofit technologies that would result in maximum energy savings. During the second year, a computer program called Building Use Categorization and Scale-up (BUCS) system was developed that allows for the empirical and systematic selection of prototype buildings for auditing and/or computer modeling purposes with the objective of projecting probable energy usage of the whole installation from the audited subset. Project funding was also applied for and received during the second year of the MEIP. The third year, which is currently underway, involves continuing training programs for Fort Hood maintenance personnel and assisting Fort Hood in implementing various retrofits identified during the first two years of the METP. It is in the framework of this research objective that the current project with Energy Systems Laboratory (ESL) of the Texas Engineering Experiment Station (TEES) at Texas A&M University was initiated.

Lister et al.(1996) have determined energy conservation opportunities and associated cost savings for the military family housing neighborhoods at Fort Hood, estimated to account for 25% of the total annual energy consumption. A collaborative design process under the direction of a multi-disciplinary team has proposed design alternatives of prototypical energy efficient residential units that would have the least environmental impact and still provide pleasant living conditions (Deal and Adams, 1996). Studies aimed at disaggregating, by end use, the specific electric feeders at Fort Hood have also been performed in an effort to more accurately identify energy conservation of specific processes such as space cooling, air-handling units, fans, cold and hot water pumps, cooking, lighting, etc. (Akbari and Konopacki, 1995; Konopacki et al., 1995).

4.0 Data used for the analysis

The various types of utility use and associated cost figures of the three cantonment areas of Fort Hood were sent to ESL by USACERL in electronic form. These are summarized in Table 4.1. USACERL informed ESL that utility reading dates are not exactly known but are close to within 2-3 days of the first day of the calendar month. Therefore, the start and end of the utility bill readings dates were assumed to be the first and last day respectively of each month. Though the data were from October 1986 to June 1995, USACERL decided to start with January 1989, due to reasons explained in section 2.0. To perform weather corrections to the energy and water use, the ESL required daily values of outdoor dry-bulb temperature at Fort Hood. The closest meteorological station was Temple, TX only 30 miles away, and so ESL acquired relevant outdoor temperature data for Temple from the National Weather Service. However, readily-available weather data for Temple, Texas covered only through May 1994. In view of the objectives of this study and with concurrence from the USACERL Project Manager, it was decided to limit the present analysis at the cantonment area level from January 1989 to December 1993 data only. However, at the whole installation level, regression models for each calendar year from 1987 to 1993 would be identified for each of the four channels so that one could determine the decline in the amount of energy use and water use over the years.

Note that the degree-day information (CDD and HDD in Table 4.1) is not directly relevant to our current study since these are to a fixed base of 65 ^{0}F. As described below, all our analyses will be performed based on a variant of the variable-base degree day method as currently recommended in the professional literature (ASHRAE, 1993). Per direction of the USACERL Project Manager, the sewage data were not analyzed.

Time series plots of the monthly electricity use, electricity demand, gas use and water use are shown in Figs. 4.1, 4.2 and 4.3 for the Main, West and North substations. Note that since both Main and West have common meters for gas and water, the combined usage is plotted in Fig.4.1, while Fig.4.2 does not contain time series plots for both of these quantities. We note that on the whole the plots depict consistent annual patterns and little variation over the years. Notable exceptions are the electricity consumption in 1993 for West and North cantonment areas as well as water use in Main and North cantonment areas for the same year. We notice from all three figures, that electric use (consisting mainly of lighting, equipment and chillers) also seems to show small increases during the winter months leading us to suspect electric heating applications such as heat pumps or electric strip heating in a substantial portion of the buildings.

The decrease in demand from 1991 (when the DSM load shedding program was activated) is very clear for the Main cantonment area (Fig.4.1) though a slight take-back in 1992 and 1993 for all three cantonment areas is evident. This take-back effect is especially marked for the West cantonment area.

Figure 4.4 depicts the average monthly outdoor temperatures in Temple during 1989 to 1993. We note that the weather during these years seems to be remarkably consistent over the years though certain monthly excursions from the overall annual pattern can be noted. Except for the months of January and June, temperature data for 1990, our baseline year, seems to be fairly characteristic. Monthly mean daily values at Temple, TX from 1987 to 1993 are shown in Table 4.2 (NOAA Climatological Data).

Table 4.1 also contains population data on a monthly basis. We were informed that these data may not be as accurate as other types of data since it is estimated by several individuals on the army base who were responsible for certain sections of the base. The general tendency of variation can be seen in Fig. 4.5. On a daily basis, the population seems to have been between 40,000 and 45,000. There are no marked seasonal patterns and the population seems to have decreased from 1988 to 1992 and again increased abruptly in 1993 (see Fig.4.6). The annual population for the year 1990 is lower by about 5% as compared to 1989 and 1993, and higher by about 5% as compared to 1992.

Table 4.3 shows how the floor areas of permanent, semi-permanent and temporary buildings has changed on an annual basis from 1985 to 1995. Following discussions with USACERL and the Fort Hood Energy Office, it was decided that the sum of permanent and semi-permanent floor space would best reflect the total building area of the base that is mechanically cooled. Hence this value should be used for normalizing annual energy consumption values. How the cooled area changes from year to year from 1987 to 1993 is shown in Fig.4.7. We note that during the years 1987 to 1993, building area has been increasing steadily. From 1987 to 1993, building area seems to have increased by about 9%.

Table 4.1 Summary of data received

	Electricity	Gas	Water	Sewage	Population	CDD&HDD
Cantonment area	Use (kWh/mo) Demand (kW/mo) Cost ($/mo)	Use (Mcf/mo) Cost ($/mo)	Use (Gallons/mo) Cost ($/mo)	Purchased (Gallons/mo) Cost ($/mo)	(Persons/mo)	
Main	10/86----6/95	10/86----6/95	10/86----6/95	10/86---6/95	10/86---4/95	10/86---5/95
West	10/86----6/95					
North	10/86----6/95	10/86----6/95	5/88----5/95			

Table 4.2 Average monthly temperatures for Temple,TX from 1987 to 1993 in °F (*NOAA, Climatological Data*)

	1987	1988	1989	1990	1991	1992	1993
Jan	43.61	41.94	49.61	50.23	42.06	43.32	43.16
Feb	49.68	45.45	40.36	53.29	52.21	50.93	46.82
Mar	52.32	55.65	57.06	56.61	59.06	58.97	55.03
Apr	62.93	64.23	66.77	63.00	68.20	65.13	63.77
May	72.32	71.32	76.06	72.32	75.58	69.61	70.61
Jun	77.63	79.07	76.13	85.10	78.47	78.40	79.93
Jul	81.94	81.90	83.16	79.87	82.55	81.16	85.90
Aug	83.68	84.10	82.10	82.32	79.48	78.23	84.13
Sep	74.23	76.57	72.83	77.00	71.50	76.20	74.30
Oct	67.29	66.68	67.94	64.68	66.32	68.94	63.13
Nov	54.27	57.97	56.57	57.40	50.13	51.67	49.83
Dec	45.06	47.61	38.55	43.06	46.90	48.10	48.10

Table 4.3 Floor areas of permanent, semi-permanent and temporary buildings at Fort Hood from 1985 to 1995

	Building Square Footage				Number of Buildings			
Date	Perm	Semi-Perm	Temp	Total	Perm	Semi-Perm	Temp	Total
FY85	19076118	516260	3754858	23347236	3435	186	989	4610
FY86	19412248	551011	3687907	23651166	3457	210	933	4600
FY87	19750052	657087	3574331	23981470	3515	250	885	4650
FY88	20209828	699621	3494175	24403624	3560	268	868	4696
FY89	20670893	707098	3489014	24867005	3574	278	865	4717
FY90	20784257	737716	3481281	25003254	3586	286	863	4735
FY91	21017941	754916	3209401	24982258	3594	300	806	4700
FY92	21417400	773437	3095011	25285848	3601	328	773	4702
FY93	21468761	802527	2968409	25239697	3609	358	743	4710
FY94	21561898	919514	2892002	25373414	3618	407	716	4741
FY95	21972982	1029014	2692311	25694307	3620	460	669	4749

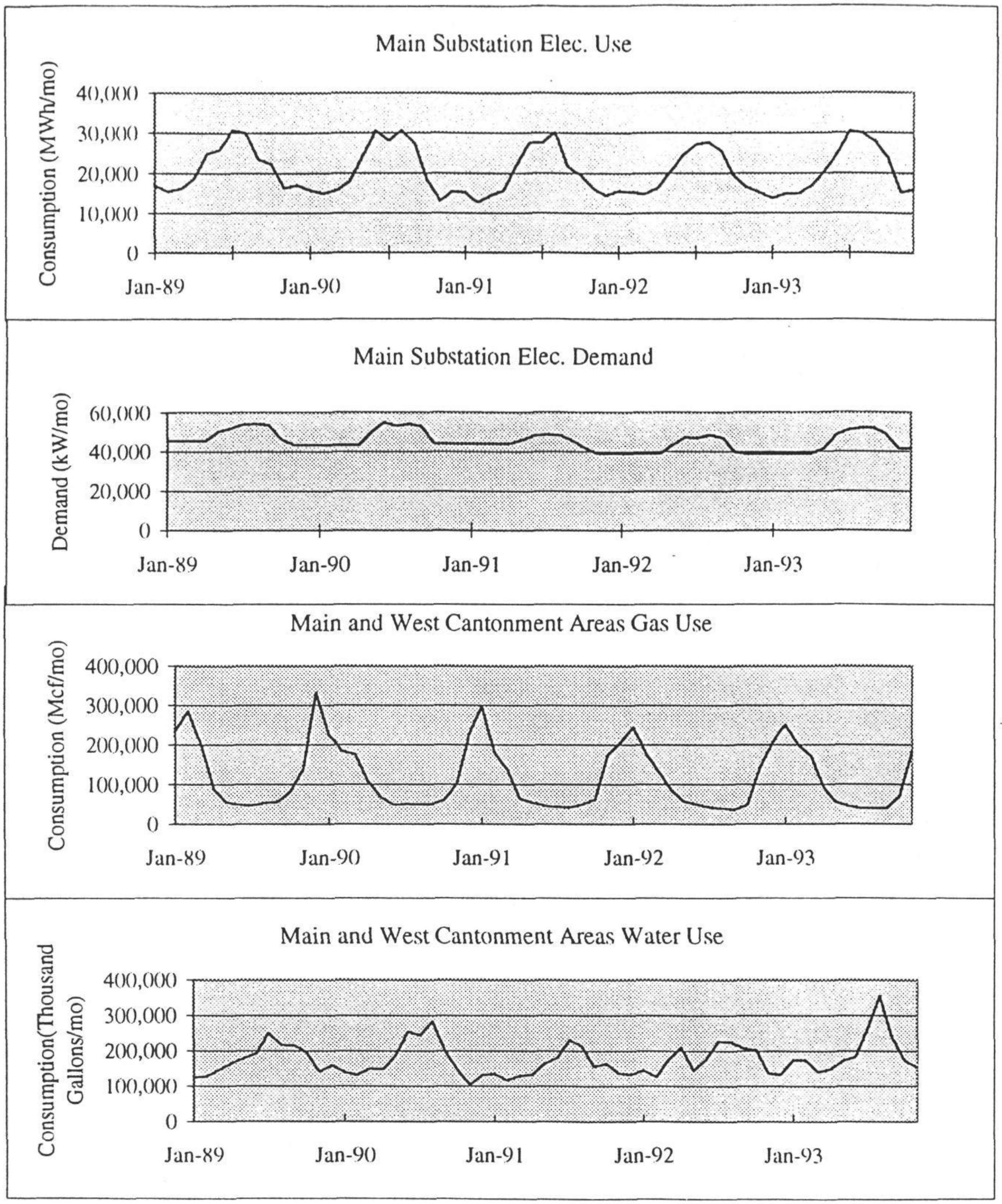


Fig.4.1 Time series graphs for Fort Hood Main Substation (serving Main Fort Hood cantonment area only) and Gas and Water use for Main and West cantonment areas since these have common gas and water meters.

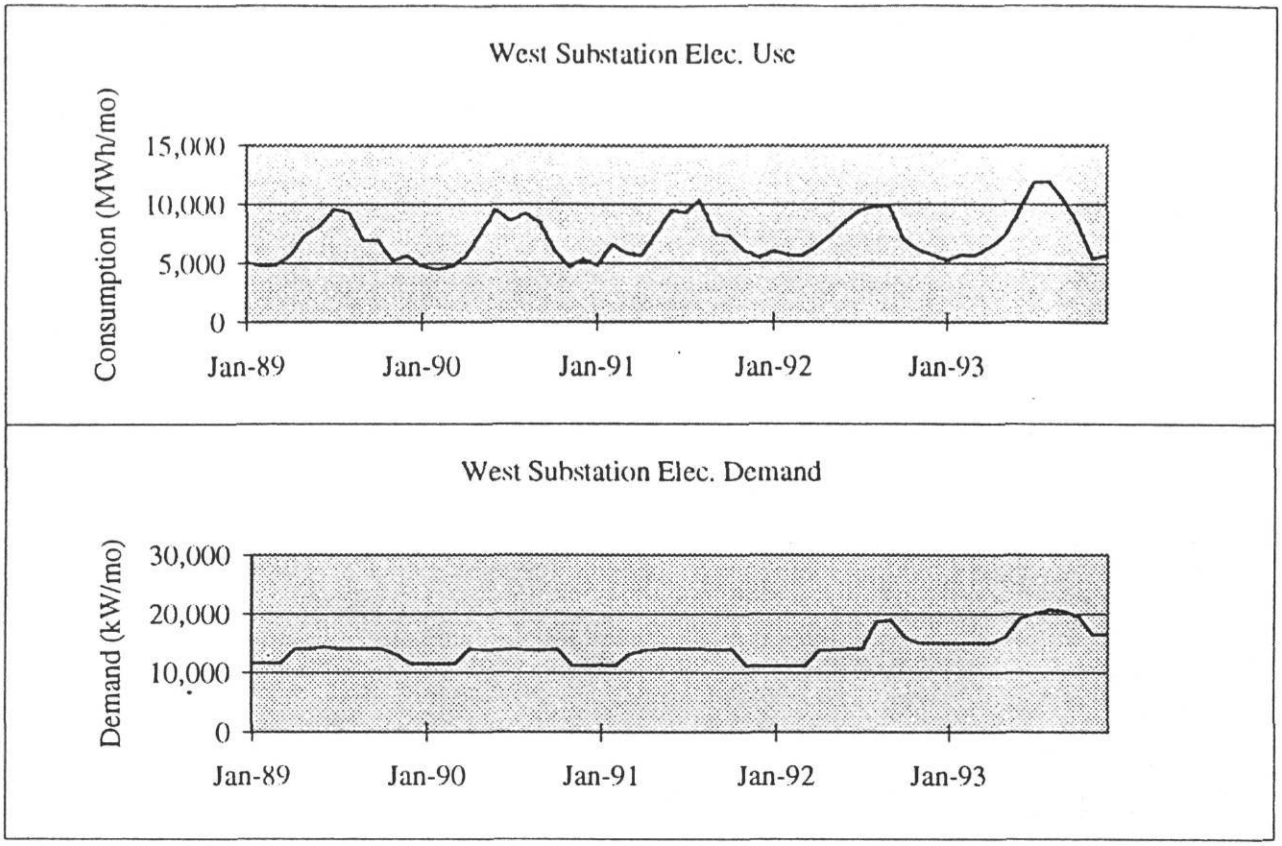


Fig.4.2 Time series graphs fot Fort Hood West Substation

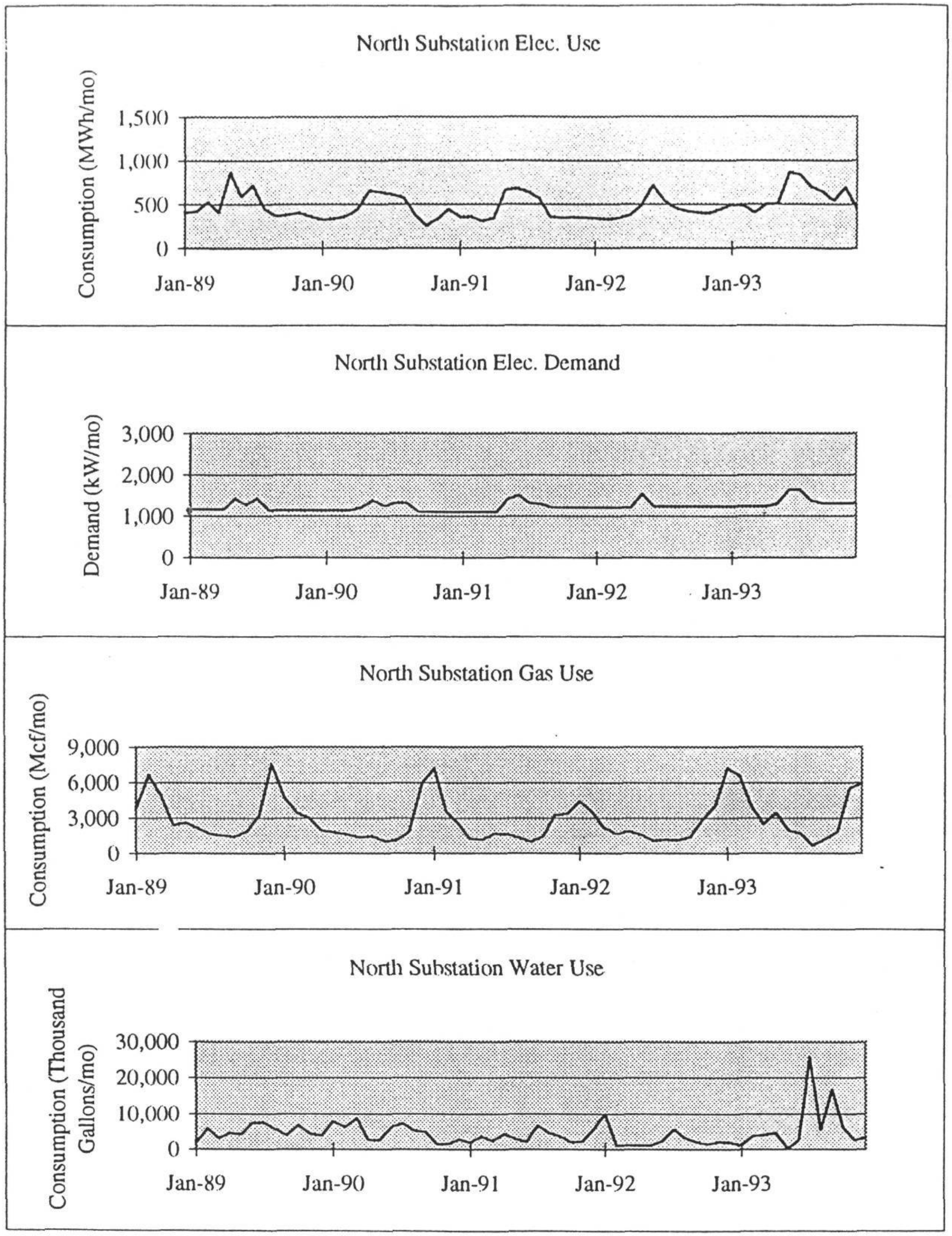


Fig. 4.3 Time series graphs for Fort Hood North Substation and Gas and Water use for North cantonment area.

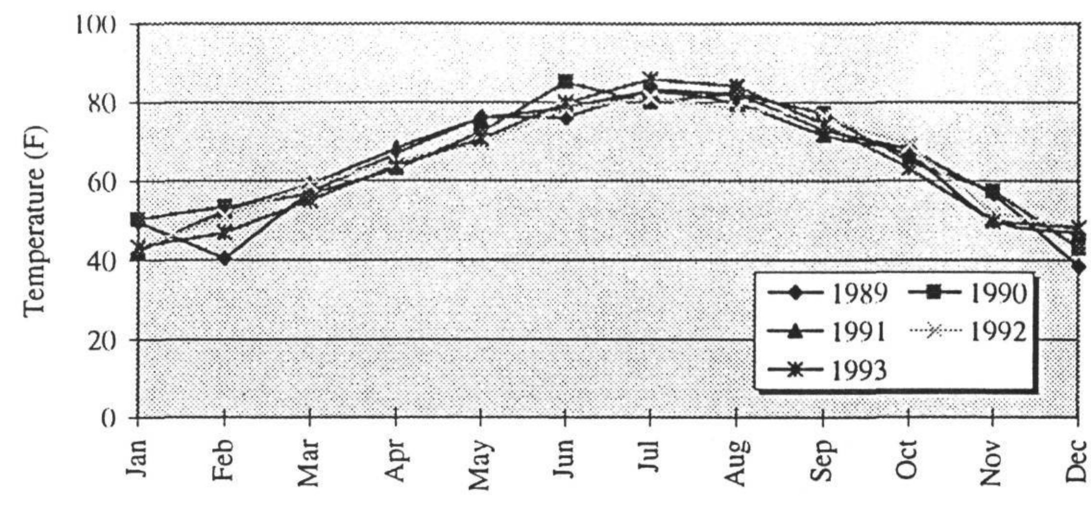


Fig. 4.4 Average monthly temperatures at Temple,TX from 1989 to 1993

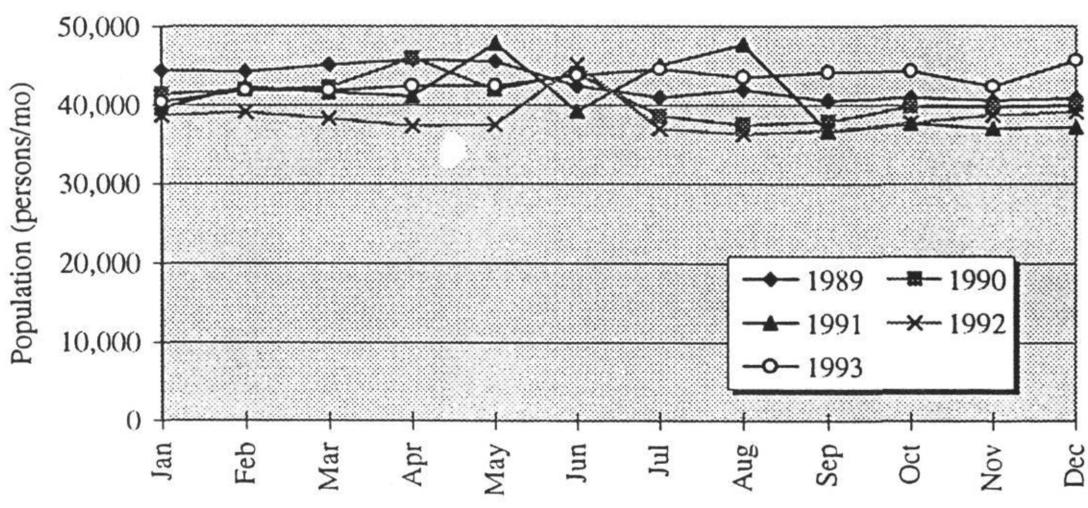


Fig. 4.5 Population of Fort Hood from 1989 to 1993

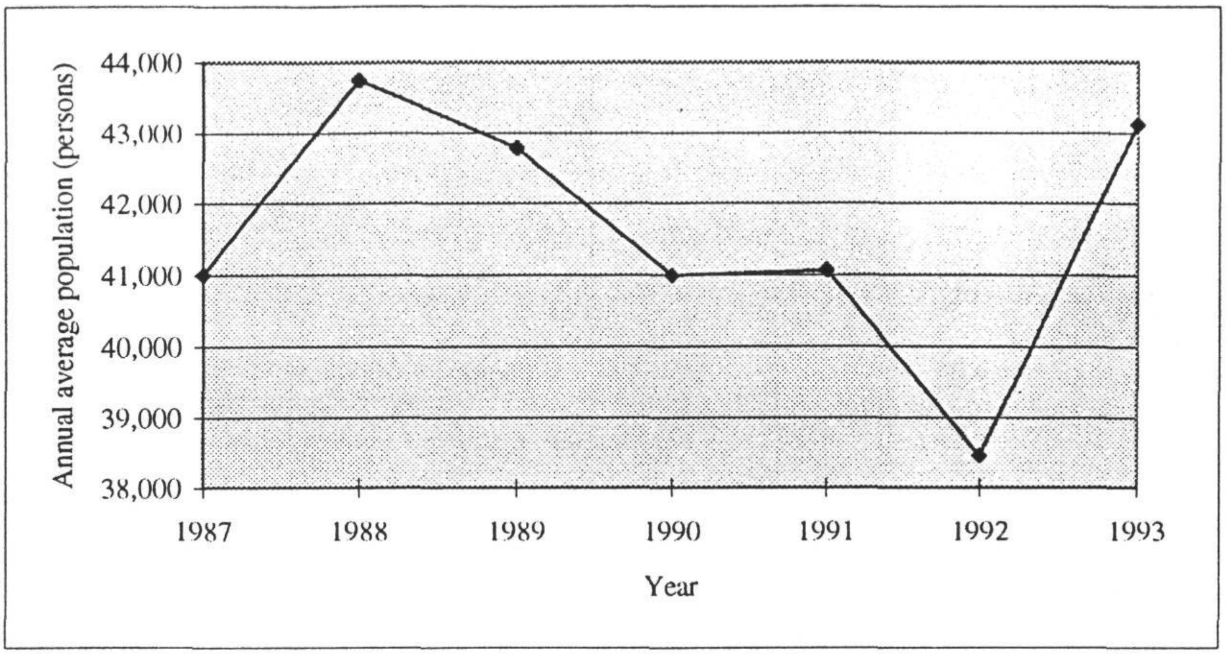


Fig 4.6 Changes in annual average population of Fort Hood from 1987 to 1993

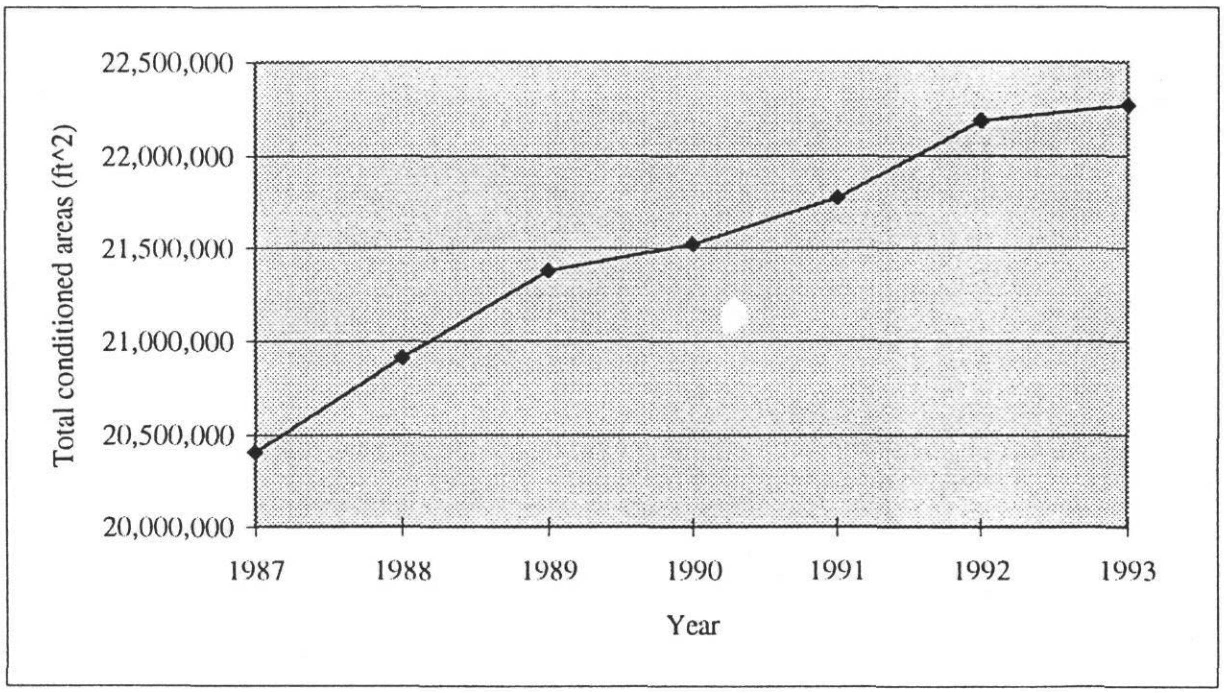


Fig. 4.7 Changes in total conditioned area(taken as the sum of permanent and semi-permanent buildings shown in Table 4.3) of Fort Hood from 1987 to 1993

5.0 Mathematical Basis of Regression Models

5.1 Pertinent background

An important aspect in identifying statistical models of baseline energy use is the choice of the functional form and that of the independent (or regressor) variables. Extensive studies in the past (for example, see Fels, 1986; or Reddy et al., 1994) have clearly indicated that the outdoor dry-bulb temperature is the most important regressor variable, especially at monthly time scales. Classical linear functions are usually not appropriate because of the presence of functional discontinuities, called "change points". Figure 5.1 shows the various types of single variable (SV) models that have been used to model energy use in commercial and residential buildings (Reddy et al., 1994). One should note how the shape of the functions can be captured by progressively introducing more parameters. A widely adopted convention is to refer to a single variable model with, say, three parameters as a 3-P SV model. This study will limit itself to SV models only (except for when we shall investigate whether addition of other variables, e.g. population, into the model leads to an improvement). Consequently the term SV will not be explicitly mentioned in the rest of this report.

The criteria used to select the most appropriate model is to maximize the goodness-of-fit using the simplest model or combination of models (Draper and Smith,1981). Although several measures of a model's goodness-of-fit are available, we prefer to use the coefficient of determination (R^2) and the coefficient of variation of the root mean square error (CV-RMSE). Though the two measures are related, both are useful indices. When model R^2 is very high or very low, the CV-RMSE may be a more appropriate measure to study. As a rough indication, models with $R^2 > 0.7$ and CV-RMSE < 8% can be considered "good" models.

R^2 can be interpreted as the fraction of the variation in the dependent variable Y (in this study: electricity use, electricity demand, gas use and water use) that is explained by the model. It has a maximum value of 1.0. A value of, say, $R^2 = 0.9$ would indicate that 90% of the variation in Y is explained by the model, thus leaving only 10% of the variation in Y unexplained.

Root Mean Square Error (RMSE) is a measure of the deviation of the data from the model, while CV-RMSE is a non-dimensional measure that is found by dividing RMSE by the mean value of Y. It is usually presented as a percentage. Hence, say, a value of 5% would indicate that the variation in Y not explained by the regression model is only 5% of the mean value of Y. RMSE can be calculated as follows:

$$RMSE = \left[\frac{\sum_{i=1}^{n} (Y_i - \hat{Y})^2}{n-p}\right]^{1/2} \tag{5.1}$$

where $\hat{Y}$ is the value of Y predicted by the regression model, n the number of observations and p is the number of model parameters. Since most of the models in this study are regression models with three parameters, p=3 for most of the models investigated in this study. (In the case of PRISM HC models, p=5).

Another important statistical measure is the standard error (SE) which is a measure of how accurately the regression model is able to identify the individual model coefficients (Draper and Smith, 1981). Each coefficient has a SE associated with it, and the smaller the measure, the more confidence you can place on the regression coefficient. Most statistical regression programs always present the SE of the model coefficients along with the output and one does not have to compute this statistic separately. In this report, we shall always present, in conjunction with the regression coefficients, the SE of the coefficients also.

5.2 Degree day method and PRISM 3-P model

The Princeton Scorekeeping Method (PRISM) (Fels, 1986) and the associated computer software (Fels et al., 1995) is widely used for determining energy savings in conservation programs. It is based on the steady-state energy balance of a residence operated as a one-zone building. Though it has been applied to commercial and institutional buildings and also to whole campus level (Haberl, 1992), it is most suitable for shell-dominated buildings such as residences and small commercial buildings wherein energy use is not strongly influenced by the non-linear behavior exhibited by chillers, refrigerators and boilers. PRISM uses the readily-available data of whole-house consumption based on utility billing data and average daily outdoor temperature data from the closest weather station (for the period being studied as well as long-term periods for the calculation of variable degree days) to determine a weather adjusted index of consumption, the Normalized Annual Consumption (NAC). NAC is analogous to the miles-per-gallon rating for automobiles. The NAC represents annual energy consumption during a year of average weather conditions. Total energy savings due to the implementation of energy conserving measures is then derived as the difference in the NACs for the periods before and after retrofit implementation.

The functional form of the PRISM models are:

- for electricity use, electricity demand and water use (uses which increase with outdoor temperature T):

$$Y = \alpha + \beta_c * DD(\tau_c) \tag{5.2}$$

- for gas use (which increases with decreasing T):

$$Y = \alpha + \beta_h * DD(\tau_h) \tag{5.3}$$

-for electricity use that increases with both increase and decrease in T (say, heat pumps)

$$Y = \alpha + \beta_h * DD(\tau_h) + \beta_c * DD(\tau_c) \tag{5.4}$$

where

DD (τ) are the degree-days to the base τ, and the subscripts c and h stand for cooling and heating respectively. Note that eqs. (5.2) and (5.3) represent a model with three regression parameters, i.e, a 3-P model, while eq.(5.4) represents a 5-P model.

The latest version of the PRISM software (Fels et al., 1995) is fairly user friendly and is run from a Microsoft Windows environment. It directly gives R^2 values of the models fitted. However, it only calculates the CV-RMSE of the NAC value and not of the individual model identified from the 12 utility bill readings that characterize the year under study. Hence we are forced to calculate the CV-RMSE separately in a spreadsheet for each year in the framework of the present study.

It must also be pointed out that in order to remove variations in the number of days during each billing period (utility meters are usually not read on exactly the same day each month but may vary by a couple of days), PRISM divides the utility bill energy use by the actual number of days during that billing period. Hence the dependent variable Y in eqs.(5.2) - (5.4) are monthly mean daily values and not monthly total values.

5.3 Simple 3-P regression model (use of EModel)

EModel (Kissock et al., 1994) is a tool for the analysis of building energy use data that is especially useful for analyzing hourly or daily data for commercial buildings. It can also be used for monthly data analysis provided the user performs certain data pre-processing steps to calculate average billing period temperature from daily data. EModel integrates the previously laborious tasks of data processing, graphing and modeling in a user-friendly, Microsoft Windows environment. It's easy-to-use features can quickly determine baseline energy consumption. It allows one to edit data files and create new columns of data. Variables can also be plotted as time series data, as relational (XY) plots and as histograms. EModel can apply the following models to data sets: mean, simple linear regression, multiple linear regression, 3 and 4 parameter change-point regression and bin fit.

The functional form of the model most appropriate for the monthly data being analyzed in this study is as follows:

- for electricity use, electricity demand and water use (uses which increase with outdoor temperature T):

$$Y = Y_{cp} + RS * (T - X_{cp})^+ \qquad (5.5)$$

- for gas use (which increases with decreasing T):

$$Y = Y_{cp} + LS * (T - X_{cp})^+ \qquad (5.6)$$

where

$(\ )^+$ is a mathematical symbolism which denotes that the term within the brackets should be set to zero if it is negative. Y_{cp} is the temperature independent energy use, RS the right-hand slope, LS the left hand slope (the values of this coefficient should always be negative), and X_{cp} the change point outdoor temperature. Because Y is a monthly sum of daily values, T should be taken as the monthly mean daily outdoor temperature value. Thus, unlike PRISM where daily mean T for individual days should be known, here one needs to be given monthly mean T values only. Also, EModel while performing a regression with 12 data points representing one year's worth of utility bills automatically presents the user with both R^2 and CV-RMSE of the particular year.

Finally, comparison of PRISM and EModel regression models and coefficients is more easily done if energy consumption used in EModel is also divided by the number of days in the billing period. The variable Y in eqs.(5.5) and (5.6) is then the monthly mean daily energy (and water) use value instead of the monthly total value.

5.4 Generation of 95% uncertainty bands for individual months

The baseline models developed from one year (in this study, year 1990 has been chosen) can be used to predict weather-adjusted monthly energy and water use into the future (or even into the past). Comparison of these projected values with actual monthly use values would provide a means of ascertaining whether actual use has changed as compared to this baseline. Regression-based model predictions invariably have a certain amount of uncertainty, and for the model to be useful as a screening tool, we should be able to ascribe uncertainty bounds to our predictions. The most commonly used convention of fixing these bounds is by computing the 95% uncertainty bands or 95% prediction interval (PI). Physically, this means that if $\hat{Y}$ is the value predicted by the model, then 95 out of 100 times, the next measured value of Y will be between ($\hat{Y}$+PI) and ($\hat{Y}$-PI). (For a simple linear model (i.e., a 2-P SV model), PI for predicting Y for a given X_0 (i.e., for a given month) is well known (Draper and Smith, 1981):

$$PI = t(1-\frac{\alpha}{2}, n-p).RMSE.\sqrt{1+\frac{1}{n}+\frac{(X_0-\bar{X})^2}{\sum_{i=1}^{n}(X_i-\bar{X})^2}} \tag{5.7}$$

where t - the t-statistic evaluated at ($1-\alpha/2$, n-p)

α -significance level (which for 95% confidence bands is equal to 0.05)

n - number of observations (in this study equal to 12 since utility bills for a year are used)

p - number of parameters in the model

RMSE - root mean square, defined by eq.(5.1)

X_0 - individual independent variable (in this study, the outdoor dry-bulb temperature)

$\bar{X}$ - mean value of X_i (in our case, mean annual value of the outdoor temperature during model identification, i.e., for the baseline year).

For a 3-P model with n = 12, ($1-\alpha/2$, n-p) from statistical tables (Draper and Smith, 1981) is equal to 2.262. Note that for the PRISM model, X is the variable degree-day (DD), while for the 3-P model using EModel, X is the mean daily outdoor temperature during the billing period.

Predicting PIs for change point SV models such as PRISM and EModel 3-P is very complex and is not to be found in textbooks. Simply calculating the PIs for a 3-P model using eq.(5.7) would lead to an over-estimation especiall, for the baseline portion of the fit (i.e., for the months when energy use is independent of outdoor temperature). Our baseline model would then be a rather ineffective screening tool. Though not strictly accurate in the statistical sense, we propose that PIs for 3-P models be determined separately for each of the two segments of the model (Hebert and Ruch, 1995). Let n_1 and n_2 be the number of months in the year which respectively fall in the baselevel portion and in the linear portion of the model. (Note that $n_1 + n_2 = 12$). Then, we suggest that RMSE and $\bar{X}$ be calculated separately for each portion. Then, for the model predictions falling on the base portion of the model, we shall use

$$PI_1 = t(1-\frac{\alpha}{2}, n-p). RMSE_1. \sqrt{1+\frac{1}{n}+\frac{(X_0-\bar{X}_1)^2}{\sum_{i=1}^{n_1}(X_i-\bar{X}_1)^2}} \tag{5.8}$$

and, for the linear portion of the model

$$PI_2 = t(1-\frac{\alpha}{2}, n-p). RMSE_2. \sqrt{1+\frac{1}{n}+\frac{(X_0-\bar{X}_2)^2}{\sum_{i=1}^{n_2}(X_i-\bar{X}_2)^2}} \tag{5.9}$$

Note that the value of t will still correspond to n-p = 9 degrees of freedom (n=12, p=3) and that $RMSE_1$ and $RMSE_2$ will be determined using eq.(5.1) with n=12 (and not with n_1 and n_2 respectively). Such a procedure gives more realistic PIs over the entire range of the model and has a certain amount of statistical basis as well (Hebert and Ruch, 1995). Graphically, the two PIs for the 3-P model appear as a band that narrows during the baselevel months (i.e., winter months for electricity and water, and summer months for natural gas) and expands during the months when energy use is linearly related to an outdoor temperature difference above the change point.

5.5 Generation of 95% uncertainty bands on an annual basis

The previous section presented relevant equations for calculatin~ PIs on an individual monthly basis which is appropriate if the baseline models are used as screening tools for detecting month-to-month variations. These equations cannot be used to track year-to-year changes in energy and water use which is one of the objectives of this study. For this purpose, the annual total energy (and water) use along with an estimate of the amount of confidence one can place on these values needs to determined. The total use is easily determined: the twelve monthly use values are simply added together. However, the 95% PIs for this annual energy use value cannot be determined by simply adding the PIs of the individual twelve months since this would lead to a gross over-prediction.

For a simple linear model (i.e., a 2-P SV model), Draper and Smith (1981) give the equation for PI of a sum of m number of individual points (m=12 if annual energy use values are sought):

$$PI = t(1-\frac{\alpha}{2}, n-p).RMSE.\sqrt{m+\frac{m}{n}+\frac{\sum_{o=1}^{m}(X_0-\bar{X})^2}{\sum_{i=1}^{n}(X_i-\bar{X})^2}} \tag{5.10}$$

As mentioned earlier in section 5.4, the corresponding equations to calculate PI of 3-P change point models are not available. Following a similar development as adopted earlier for monthly predictions, the annual PI can be determined from the following:

$$PI = t(1-\frac{\alpha}{2}, n-p).[RMSE_1.\sqrt{m_1+\frac{m_1}{n}+\frac{\sum_{o=1}^{m_1}(X_0-\bar{X}_1)^2}{\sum_{i=1}^{n_1}(X_i-\bar{X}_1)^2}}$$

$$+RMSE_2.\sqrt{m_2+\frac{m_2}{n}+\frac{\sum_{o=1}^{m_2}(X_0-\bar{X}_1)^2}{\sum_{i=1}^{n_1}(X_i-\bar{X}_1)^2}}] \tag{5.11}$$

where m_1 and m_2 are the number of months that fall on the baselevel and on the linear porti n of the model line respectively.

Equation (5.11) is rather cumbersome to use, and we suggest that the following simplified equation be used instead:

$$PI = t(1-\frac{\alpha}{2}, n-p).RMSE.\sqrt{m+\frac{m}{n}} \tag{5.12}$$

In this study where annual predictions are determined by using a monthly baseline model, m=12. The above equation simplifies to

$$PI = t(1-\frac{\alpha}{2}, n-p).RMSE.\sqrt{13} \tag{5.13}$$

We have used eq.(5.13) in determining the 95% PI of the annual energy (and water) use predicted by our baseline monthly models.

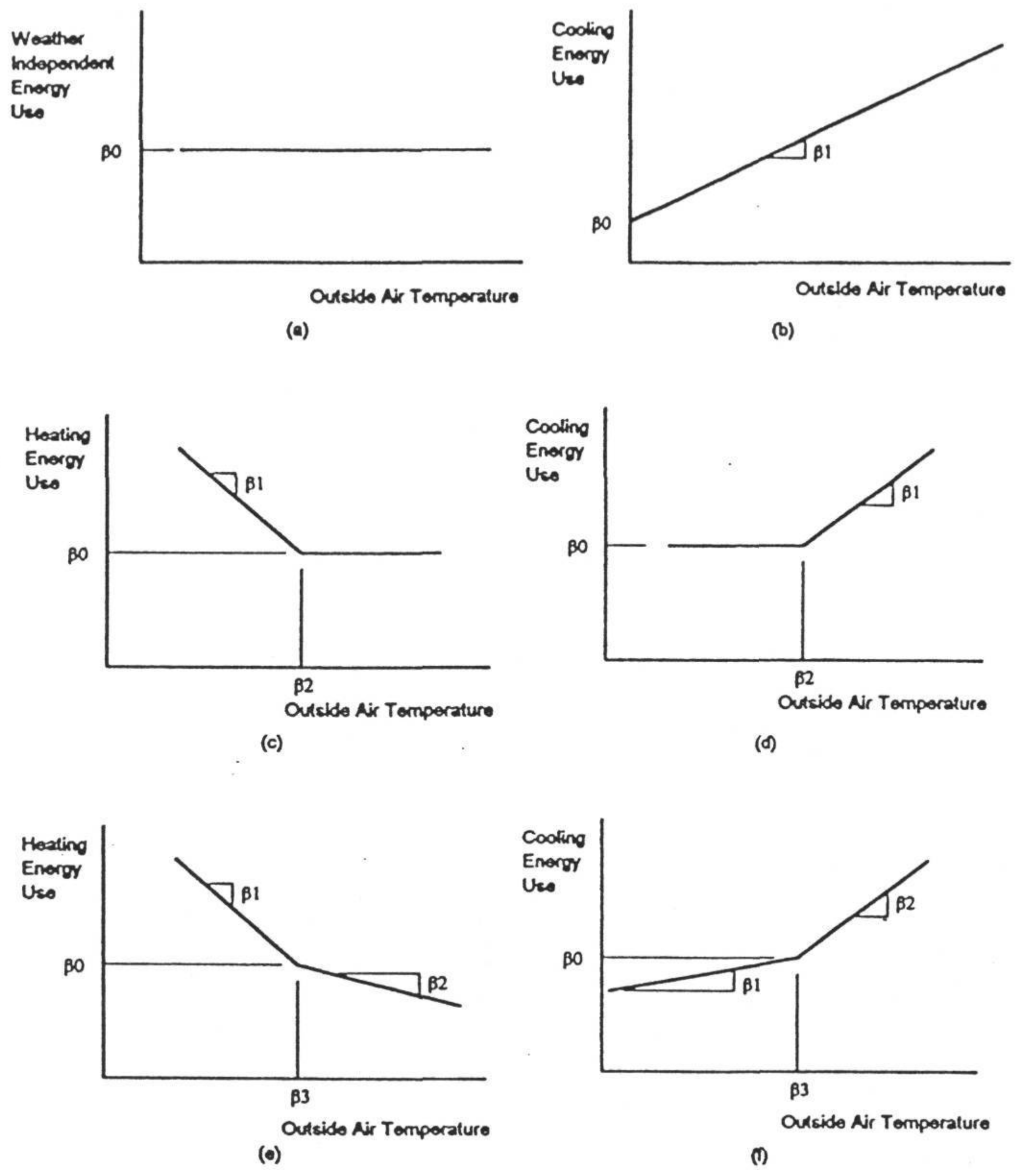


Fig. 5.1 Empirical SV energy use models appropriate for commercial building energy use: (a) one-parameter model, (b) two-parameter model shown for cooling energy use, (c) three-parameter heating energy use model, (d) three-parameter cooling energy use model, (e) four-parameter heating energy use model, and (f) four-parameter cooling energy use model.

6.0 Baseline Modeling

The main objective of the modeling effort is to develop models for the baseline year 1990 for energy and water use. Instead of limiting ourselves to this year alone, we have also identified models for the years ranging from 1989 to 1993 in an effort to study, (i) how well the models fit the data over the years, and (ii) the extent to which the model coefficients vary from year to year. Another objective of this study was to determine which of the two energy modeling software, PRISM or EModel, is more accurate for our particular purpose. The model coefficients and the associated standard errors along with the statistical indices R^2 and CV-RMSE which describe the goodness-of-fit of the models identified by PRISM and EModel, are shown for individual years in Tables 6.1 to 6.4 for the Main substation.

As an aside, we found from inspecting the data sent to us that one entry (corresponding to October 1991) was repeated twice. Whether this was an error or a real occurrence was evaluated by developing models, (i) with the extra entry as is, and (ii) by removing the particular entry. How the model statistical indices improve drastically when this correction is made can be seen from Tables (b) of Tables 6.1 to 6.4. This is an indirect justification that the entry is erroneous, and subsequent modeling effort has taken this aspect into consideration.

Table 6.1 presents results for electricity use at the Main substation. Since we detected a small weather dependent use in winter (see Fig.4.1), we evaluated both the 5-P PRISM heating and cooling (HC) model and the PRISM cooling only (CO) models. We note from Table 6.1a that though the R^2 values are high, the HC model coefficients have high standard errors, and are hence unreliable. Thus, we can safely discard this model.

On inspecting Tables 6.1b and 6.1c, we note that the models identified are generally very good ($R^2 > 0.9$ and CV-RMSE < 10%) with stable coefficients that are more or less consistent over the years. Also, it seems that the EModel 3-P model out-performs the PRISM model, generally yielding lower CV-RMSE and higher R^2 values. Similar conclusions can also be drawn from Table 6.2 which assembles the results of modeling the electricity demand for the Main substation.

We have evaluated PRISM HC and PRISM heating only (HO) models for gas and water uses at Main and West cantonment areas combined. Generally these models are poorer than for electricity use and demand studied above. The results shown in Table 6.3 lead us to conclude that PRISM HO model is better for modeling gas use than the PRISM HC model, while from Table 6.4 we note that the PRISM CO model is the best among the three PRISM models evaluated for water use. However, even here, the EModel 3-P models seems to have the edge over the PRISM models.

A clearer visual comparison is provided by Fig.6.1 which assembles the CV-RMSE values for all four channels, for all years and for all the models presented in Tables 6.1 to 6.4. We notice that in most cases EModel performs better than PRISM, and even in the few cases where it did not, the difference was very small. The reason for this phenomenon is unclear and could be partly due to the fact that PRISM is more sensitive than EModel to the 2-3 day discrepancy between utility read dates for electricity and calendar month periods. We have made contact with PRISM's author and are discussing these discrepancies to determine exactly why the difference would be so large in such side-by-side test. Therefore, for the moment it seems that EModel has the upper hand for modeling energy and water consumption of DoD installations. For this report we have decided to adopt EModel results for all subsequent analyses.

How the individual monthly observations for our baseline year 1990 scatter along the EModel regression lines are shown in Figs. 6.2 to 6.5 for the four channels of data modeled. The distinct change point behavior of the data points is clearly seen. The fact that demand is less influenced by outdoor temperature than the other three energy use channels should also be noted. In Fig.6.2, we note that five points fall on the baselevel portion of the change point model line and seven points fall on the linear portion. In this case, $n_1 = 5$ and $n_2 = 7$ should be used to determine the 95% PI from eq.(5.7).

The 3-P change point model results identified by EModel for electricity use and demand at the Fort Hood West substation are shown in Tables 6.5 and 6.6. The electricity use models are excellent except for year 1991 when the FM load shedding program was initiated. The demand models have low R^2, but this is due to demand models having a low slope (see Fig.6.3) and is not a major statistical limitation. Only for the year 1992 is the model poor since the CV-RMSE is over 15%. Other model results, namely (i) electricity use for the North substation, (ii) electricity demand for the North substation, (iii) gas use for the North cantonment area, and (iv) water use for the North cantonment area are shown in Tables 6.7-6.10 respectively. Except for water use models which are inexplicably poor (i.e., there is considerable noise in the data that is not predicted by the 3-P model), all other models are generally good though not as good as those of the Main cantonment area. The reason for the models faring poorly for North Fort Hood is not very surprising if one recalls the fact that this cantonment area has a variable population during the year, with several training programs scheduled during the summer months and a low winter occupancy.

Figure 6.6 shows a XY plot of the R^2 and CV-RMSE of the 10 baseline models for 1990. The water use model for North campus is very poor and therefore we do not recommend that it be used. Three other models, namely (i) electricity use by the North substation, (ii) gas use in the Main and West cantonments, and (iii) gas use in the North cantonment, are to be used with caution (CV-RMSE > 10%). In an effort to improve these models we have investigated the use of the base population as an additional variable in the model. Unfortunately, we could not find any improvement by doing so. This is illustrated in Figure 6.7 where we note the lack of any clear relation between the residuals of the gas model for Main and West cantonment and base population.

At the installation-wide level, 3-P change point models for each of the four channels for each year from 1987 to 1993 have been developed as shown in Tables 6.11 - 6.14. As explained earlier, these models have been calculated using a monthly mean daily basis. For monthly total energy use, the model predictions should be multiplied by the number of days in the month. The

R^2, RMSE and CV-RMSE values are also shown. The RMSE values are needed to determine 95% PIs for annual energy use (see eq.5.13).

Table 6.1 Model coefficients(and standard errors) and goodness-of-fit statistical indices for Fort Hood Main substation electricity use

Table 6.1a PRISM HC models

Heating and Cooling (HC)							
Year	α (MWh/day)	βh (MWh/°F-day)	τh (°F)	βc (MWh/°F-day)	τc (°F)	R^2	CV-RMSE
1989	487±88	2±19	64±71	27±7	64±4	0.97	5.3%
1990	420±111	5±23	58±52	23±5	58±6	0.97	6.9%
1991	451±51	25±65	42±14	30±9	65±4	0.92	10.8%
1992	462±95	3±24	63±65	25±8	63±5	0.95	6.8%
1993	477±303	0±28	55±-9	17±6	54±24	0.87	13.6%

Table 6.1b PRISM CO models

Cooling Only (CO)					
Year	α (MWh/day)	βc (MWh/°F-day)	τc (°F)	R^2	CV-RMSE
1989	531.1±17	27.3±5	66.0±3	0.97	4.8%
1990	475.6±28	24.1±4	61.3±4	0.97	6.4%
1991	475.4±31	30.1±8	65.9±4	0.91 0.82*	9.9%
1992	501.4±20	26.2±5	65.2±4	0.95 0.57*	6.1%
1993	475.1±59	16.3±5	54.5±9	0.87 0.38*	12.0%

Note: Numbers with '*' were calculated using the data as supplied to us. All other numbers were determined by removing one entry (corresponding to Oct.1991) which we deduced to have been erroneously repeated twice.

Table 6.1c 3-P change point regression models using EModel

EModel					
Year	Ycp (MWh/day)	RS (MWh/°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	540±10	20±1	60.9	0.98	3.5%
1990	492±12	20±1	58.2	0.98	4.5%
1991	483±25	25±3	63.1	0.90	9.9%
1992	510±13	23±2	63.8	0.96	5.2%
1993	496±32	15±2	54.3	0.87	11.5%

Table 6.2 Model coefficients(and standard errors) and goodness-of-fit statistical indices for Fort Hood Main substation electricity demand

Table 6.2a PRISM HC models

Heating and Cooling (HC)							
Year	α (kW/day)	βh (kW/°F-day)	τh (°F)	βc (kW/°F-day)	τc (°F)	R^2	CV-RMSE
1989	1428±156	5±12	55±-9	17±11	62±18	0.65	6.4%
1990	1424±199	1±9	66±622	22±14	66±7	0.89	4.2%
1991	1439±84	-7±11	55±-9	15±28	71±21	0.52	6.7%
1992	1289±57	-1±8	55±-9	24±13	68±7	0.85	4.6%
1993	1282±443	4±41	55±-9	13±9	55±44	0.64	9.2%

Table 6.2b PRISM CO models

Cooling Only (CO)					
Year	α (kW/day)	βc (kW/°F-day)	τc (°F)	R^2	CV-RMSE
1989	1487.0±45	21.8±14	69.0±8	0.64	5.7%
1990	1430.2±33	21.5±8	66.0±7	0.89	3.7%
1991	1395.6±42	16.3±18	69.0±13	0.47 0.51*	6.1%
1992	1277.6±28	22.6±9	66.6±5	0.85 0.63*	4.1%
1993	1314.2±72	12.6±8	56.0±17	0.63 0.17*	8.2%

Note: Numbers with '*' were calculated using the data as supplied to us. All other numbers were determined by removing one entry (corresponding to Oct.1991) which we deduced to have been erroneously repeated twice.

Table 6.2c 3-P change point regression models using EModel

EModel					
Year	Ycp (kW/mo)	RS (kW/°F)	Xcp (°F)	R^2	CV-RMSE
1989	44750±649	495±62	62.6	0.86	3.4%
1990	43571±264	548±23	62.4	0.98	1.5%
1991	42022±706	401±77	63.9	0.73	4.1%
1992	39002±443	599±53	64.5	0.93	2.7%
1993	40084±1347	381±83	55.2	0.68	7.5%

Table 6.3 Model coefficients(and standard errors) and goodness-of-fit statistical indices for Fort Hood Main and West cantonment areas gas use

Table 6.3a PRISM HC models

	Heating and Cooling (HC)						
Year	α (Mcf/day)	βh (Mcf /°F-day)	τh (°F)	βc (Mcf /°F-day)	τc (°F)	R^2	CV-RMSE
1989	1450±935	318±40	68.1±5.3	10±80	69.0±-9	0.99	12.0%
1990	1088±1648	256±58	71.0±9.1	53±181	73.0±0	0.91	24.5%
1991	763±1312	289±45	70.0±7.1	65±132	70.0±-9	0.97	16.4%
1992	740±1730	242±23	72.1±8.5	89±241	73.0±-9	0.98	12.1%
1993	2944±532	3850±1851	39.1±2.9	-132±60	70.0±1	0.91	25.9%

Table 6.3b PRISM HO models

Heating Only (HO)					
Year	α (Mcf /day)	βh (Mcf /°F-day)	τh (°F)	R^2	CV-RMSE
1989	1547.3±234	318.0±35	67.8±3	0.99	10.6%
1990	1487.5±404	250.4±59	69.7±5	0.90	21.9%
1991	1373.4±272	299.8±43	67.1±3	0.97 0.74*	14.8%
1992	1297.2±210	244.55±25	69.5±2	0.98 0.54*	11.1%
1993	1272.9±235	274.7±42	67.5±3	0.98 0.59*	12.3%

Note: Numbers with '*' were calculated using the data as supplied to us. All other numbers were determined by removing one entry (corresponding to Oct.1991) which we deduced to have been erroneously repeated twice.

Table 6.3c 3-P change point regression models using EModel

EModel					
Year	Ycp (Mcf /day)	LS (Mcf /°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	1734±169	-277±11	70.7	0.98	10.1%
1990	1755±294	-259±26	68.3	0.91	20.4%
1991	1514±204	-259±16	69.6	0.97	14.5%
1992	1366±180	-232±13	70.6	0.97	13.4%
1993	1442±217	-266±17	68.0	0.96	14.5%

Table 6.4 Model coefficients(and standard errors) and goodness-of-fit statistical indices for Fort Hood Main and West cantonment areas water use

Table 6.4a PRISM HC models

Heating and Cooling (HC)							
Year	α (10^3 Gallons/day)	βh (10^3 Gallons/°F-day)	τh (°F)	βc (10^3 Gallons/°F-day)	τc (°F)	R^2	CV-RMSE
1989	3218±1352	2195±2260	19±8	105±67	43±2	0.86	10.1%
1990	4499±823	-7±46	68±-9	296±107	70±6	0.93	10.5%
1991	4118±427	111±3661	43±29	230±255	69±7	0.92	7.8%
1992	6495±405	-85±27	71±-9	4763±0	85±9	0.67	15.2%
1993	5020±2970	9262±0	28±14	379±222	73±2	0.72	21.2%

Table 6.4b PRISM CO models

Cooling Only (CO)					
Year	α (10^3 Gallons /day)	βc (10^3 Gallons /°F-day)	τc (°F)	R^2	CV-RMSE
1989	4581.4±326	147.9±63	63.0±8	0.81	10.3%
1990	4373.2±262	289.0±89	68.7±5	0.93	9.2%
1991	4348.0±152	324.3±115	73.0±3	0.91 0.85*	7.0%
1992	3853.8±3961	75.1±32	39.0±65	0.65 0.29*	13.8%
1993	5358.4±447	470.9±323	76.0±6	0.70 0.18*	19.3%

Note: Numbers with '*' were calculated using the data as supplied to us. All other numbers were determined by removing one entry (corresponding to Oct.1991) which we deduced to have been erroneously repeated twice.

Table 6.4c PRISM HO models

Heating Only (HO)					
Year	α (10^3 Gallons /day)	βh (10^3 Gallons /°F-day)	τh (°F)	R^2	CV-RMSE
1989	7707±462	-66±14	93±-9	0.69	13.3%
1990	8840±542	-119±19	91±-9	0.80	15.7%
1991	6689±393	-65±15	88±-9	0.67	13.8%
1992	7505±465	-73±17	88±-9	0.64	13.9%
1993	8755±891	-92±30	90±-9	0.49	25.0%

Table 6.4d 3-P change point regression models using EModel

EModel					
Year	Ycp (10^3 Gallons /day)	RS (10^3 Gallons /°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	4595±237	103±15	55.5	0.82	9.5%
1990	4490±190	232±21	65.8	0.93	9.0%
1991	4449±141	216±25	69.6	0.88	7.7%
1992	4498±360	78±18	48.6	0.66	12.9%
1993	5228±416	241±52	68.0	0.68	18.7%

Table 6.5 3-P change point regression models using EModel for Fort Hood West substation electricity use.

EModel					
Year	Ycp (MWh/day)	RS (MWh/°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	169.5±5.1	6.6±0.5	62.6	0.95	5.8%
1990	158.2±2.8	5.7±0.2	57.4	0.99	3.3%
1991	190.5±11.2	7.1±1.2	63.9	0.77	12.2%
1992	192.3±6.8	7.1±0.7	62.3	0.91	7.1%
1993	183.8±11.1	6.6±0.7	56.0	0.90	10.9%

Table 6.6 3-P change point regression models using EModel for Fort Hood West substation electricity demand.

EModel					
Year	Ycp (kW/mo)	RS (kW/°F)	Xcp (°F)	R^2	CV-RMSE
1989	11552.5±277.9	75.4±11.2	43.9	0.82	4.0%
1990	11186.0±386.2	80.9±16.2	45.6	0.71	5.6%
1991	11341.6±254.2	90.5±11.6	47.0	0.86	3.9%
1992	12866.9±898.6	174.5±74.7	59.2	0.35	15.2%
1993	15580.5±597.9	160.3±37.0	55.2	0.65	8.5%

Table 6.7 3-P change point regression models using EModel for Fort Hood North substation electricity use.

EModel					
Year	Ycp (MWh/day)	RS (MWh/°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	13.9±1.6	0.47±0.21	67.1	0.35	26.3%
1990	12.1±1.1	0.43±0.11	64.9	0.59	20.3%
1991	11.4±0.8	0.78±0.11	68.0	0.82	14.4%
1992	12.2±1.0	0.37±0.12	63.8	0.51	18.4%
1993	16.9±1.1	0.58±0.14	68.0	0.62	16.6%

Table 6.8 3-P change point regression models using EModel for Fort Hood North substation electricity demand.

EModel					
Year	Ycp (kW/mo)	RS (kW/°F)	Xcp (°F)	R^2	CV-RMSE
1989	1148.5±33.8	11.5±4.5	67.1	0.40	7.7%
1990	1123.2±33.1	5.9±2.1	55.7	0.45	6.7%
1991	1144.8±33.1	15.2±3.8	64.7	0.61	7.0%
1992	1224.9±52.0	1.4±2.2	44.1	0.04	7.6%
1993	1266.7±29.7	18.2±3.9	68.8	0.68	6.3%

Table 6.9 3-P change point regression models using EModel for Fort Hood North cantonment area gas use.

EModel					
Year	Ycp (Mcf/day)	RS (Mcf/°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	61.3±8.5	-5.8±0.6	68.0	0.90	21.2%
1990	48.2±4.5	-8.2±0.6	61.6	0.94	15.9%
1991	44.1±8.2	-7.6±1.0	61.5	0.86	28.6%
1992	44.3±3.5	-4.2±0.3	66.8	0.95	12.8%
1993	58.3±9.1	-8.6±0.9	64.6	0.91	20.5%

Table 6.10 3-P change point regression models using EModel for Fort Hood North cantonment area water use.

EModel					
Year	Ycp (10^3 Gallons/day)	RS (10^3 Gallons /°F-day)	Xcp (°F)	R^2	CV-RMSE
1989	128.4±21.1	3.2±1.5	57.3	0.32	31.2%
1990	139.2±28.5	6.0±5.4	72.5	0.11	52.9%
1991	102.3±12.1	28.3±10.0	78.5	0.44	34.2%
1992	80.5±24.7	43.0±37.6	78.9	0.12	92.3%
1993	150.6±43.8	398.0±88.9	84.2	0.67	70.1%

Table 6.11 3-P change point regression models using EModel for Fort Hood whole-base electricity use

EModel						
Year	Ycp (MWh/day)	RS (MWh/°F-day)	Xcp (°F)	R^2	RMSE (MWh/day)	CV-RMSE
1987	640.0±14.6	28.7±1.3	61.2	0.98	37.35	4.4%
1988	653.3±18.8	30.9±1.7	62.2	0.97	48.57	5.5%
1989	725.1±13.5	27.5±1.2	61.7	0.98	33.56	3.6%
1990	662.5±13.8	26.4±0.98	58.2	0.99	34.69	3.8%
1991	682.6±34.1	31.9±3.5	63.1	0.89	85.90	9.6%
1992	711.6±18.9	30.0±2.0	63.0	0.96	48.04	5.3%
1993	699.3±42.5	22.5±2.6	55.2	0.88	105.24	11.0%

Table 6.12 3-P change point regression models using EModel for Fort Hood whole-base electricity demand

EModel						
Year	Ycp (kW/mo)	RS (kW/°F)	Xcp (°F)	R^2	RMSE (kW/mo)	CV-RMSE
1987	57842.6±544.6	736.1±80.7	68.5	0.89	1527.14	2.5%
1988	57245.8±901.8	762.6±90.5	63.9	0.88	2393.67	3.9%
1989	57731.2±647.2	500.1±47.5	58.2	0.92	1553.60	2.5%
1990	56115.2±255.9	558.5±18.1	58.2	0.99	641.85	1.0%
1991	53754.4±805.2	326.8±41.7	50.2	0.86	1729.97	2.9%
1992	52867.1±1098.9	694.4±105.4	61.5	0.81	2730.05	4.7%
1993	56905.3±1943.7	550.0±120.2	55.2	0.68	4816.23	7.6%

Table 6.13 3-P change point regression models using EModel for Fort Hood whole-base gas use

EModel						
Year	Ycp (Mcf/day)	RS (Mcf/°F-day)	Xcp (°F)	R^2	RMSE (Mcf/day)	CV-RMSE
1987	1719.2±117.8	-284.6±8.7	69.3	0.99	300.23	7.0%
1988	1729.5±171.7	-349.0±15.7	65.5	0.98	470.54	11.6%
1989	1791.1±174.3	-282.7±11.4	70.7	0.98	462.65	10.1%
1990	1794.1±297.0	-264.8±26.7	68.3	0.91	761.42	20.2%
1991	1608.0±198.8	-273.4±15.8	68.8	0.97	530.98	14.0%
1992	1431.5±137.6	-231.9±10.3	70.6	0.98	353.46	10.0%
1993	1470.2±153.5	-259.9±11.4	68.8	0.98	383.84	9.9%

Table 6.14 3-P change point regression models using EModel for Fort Hood whole-base water use

EModel						
Year	Ycp (10^3 Gallons/day)	RS (10^3 Gallons /°F-day)	Xcp (°F)	R^2	RMSE (10^3 Gallons/day)	CV-RMSE
1987	5479.9±291.3	2202.2±286.3	80.5	0.86	932.32	14.7%
1988	4855.6±291.5	125.9±18.5	55.4	0.82	688.27	10.9%
1989	4721.3±244.5	105.6±15.7	55.5	0.82	564.67	9.5%
1990	4642.7±198.8	248.2±22.9	66.6	0.92	545.81	9.2%
1991	4650.8±133.2	347.2±38.8	73.6	0.89	392.55	7.4%
1992	4662.1±353.7	80.1±18.7	50.1	0.65	757.47	12.9%
1993	5339.7±420.1	261.8±52.4	68.0	0.71	1194.34	18.3%

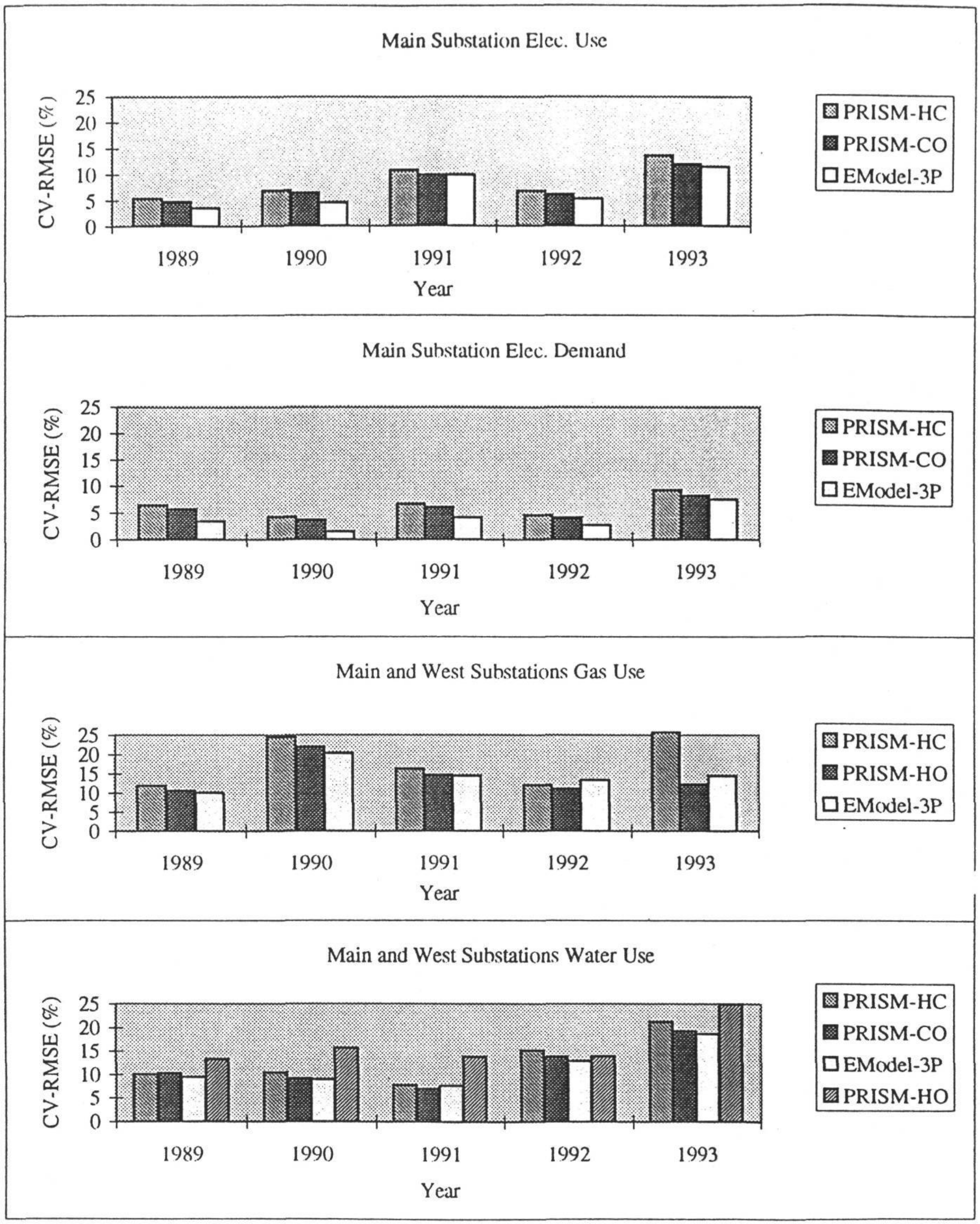


Fig. 6.1 Comparison of CV-RMSE of different models evaluated

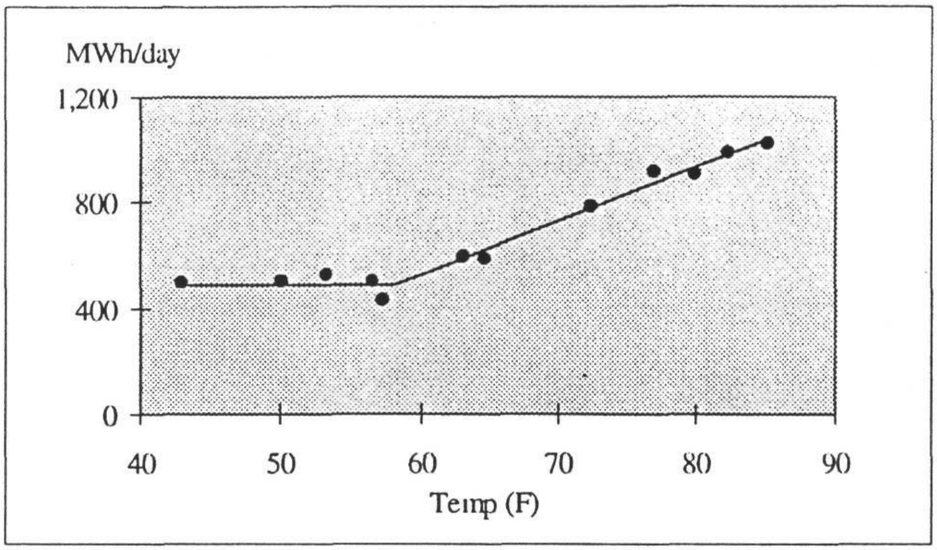


Fig. 6.2 EModel 3-P change point model and data points for Main substation electricity use for 1990

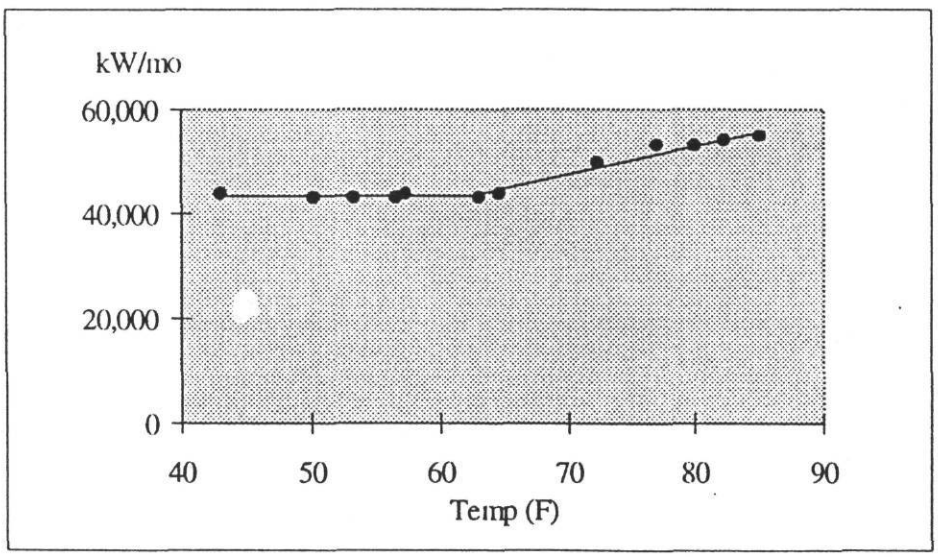


Fig. 6.3 EModel 3-P change point model and data points for Main substation demand for 1990

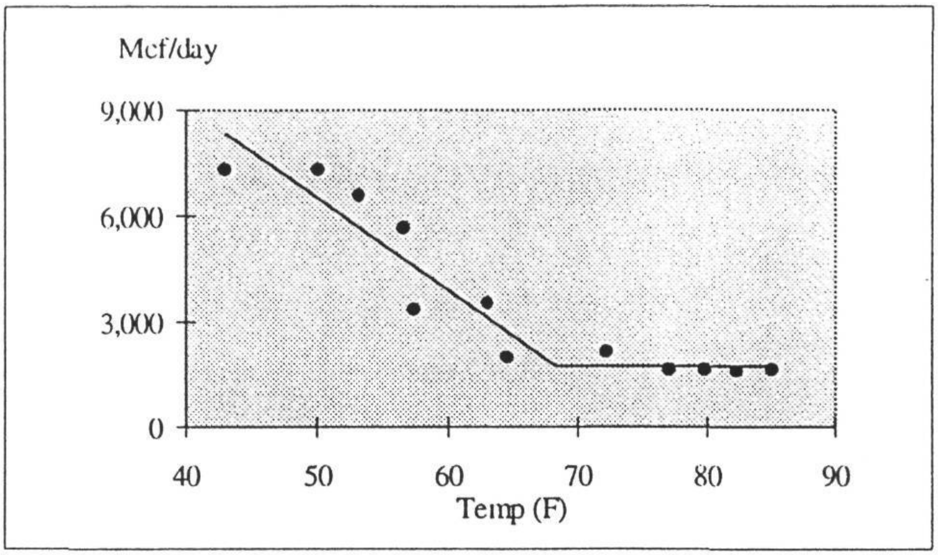


Fig. 6.4 EModel 3-P change point model and data points for Main and West cantonment areas gas use for 1990

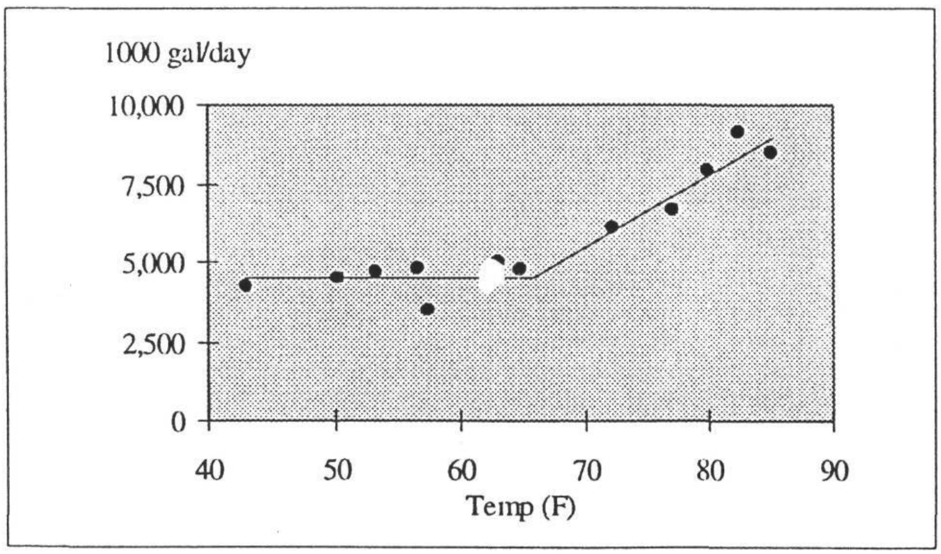
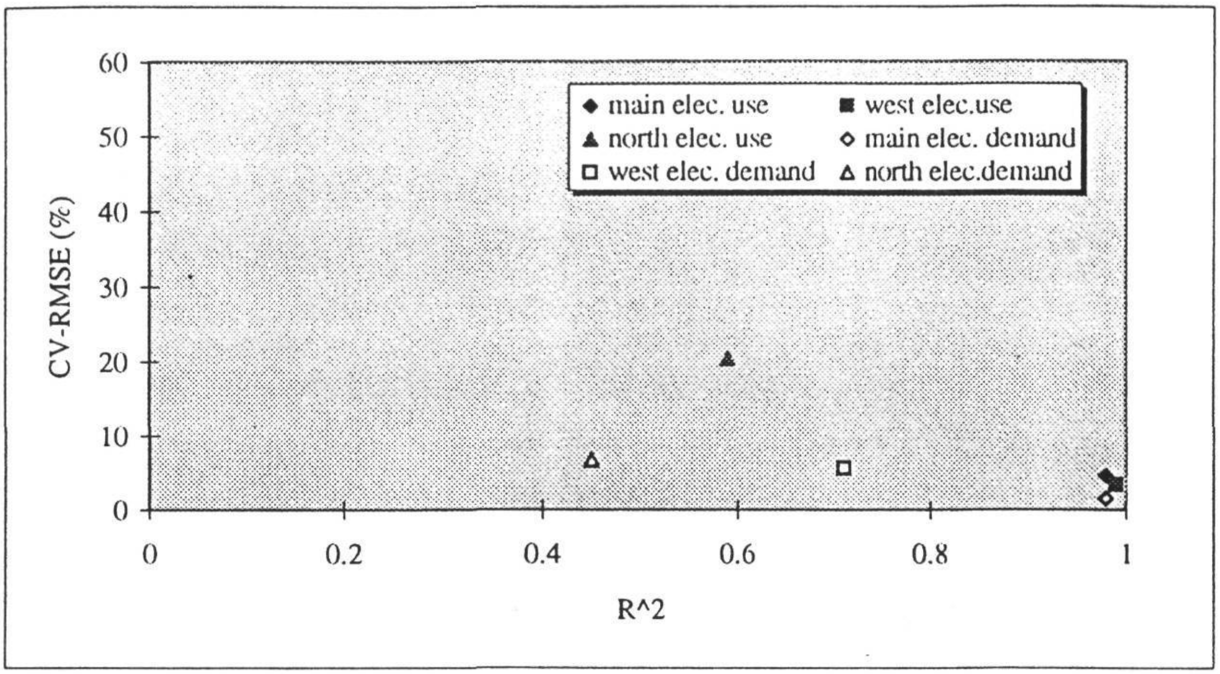


Fig. 6.5 EModel 3-P change point model and data points for Main and West cantonment areas water use for 1990



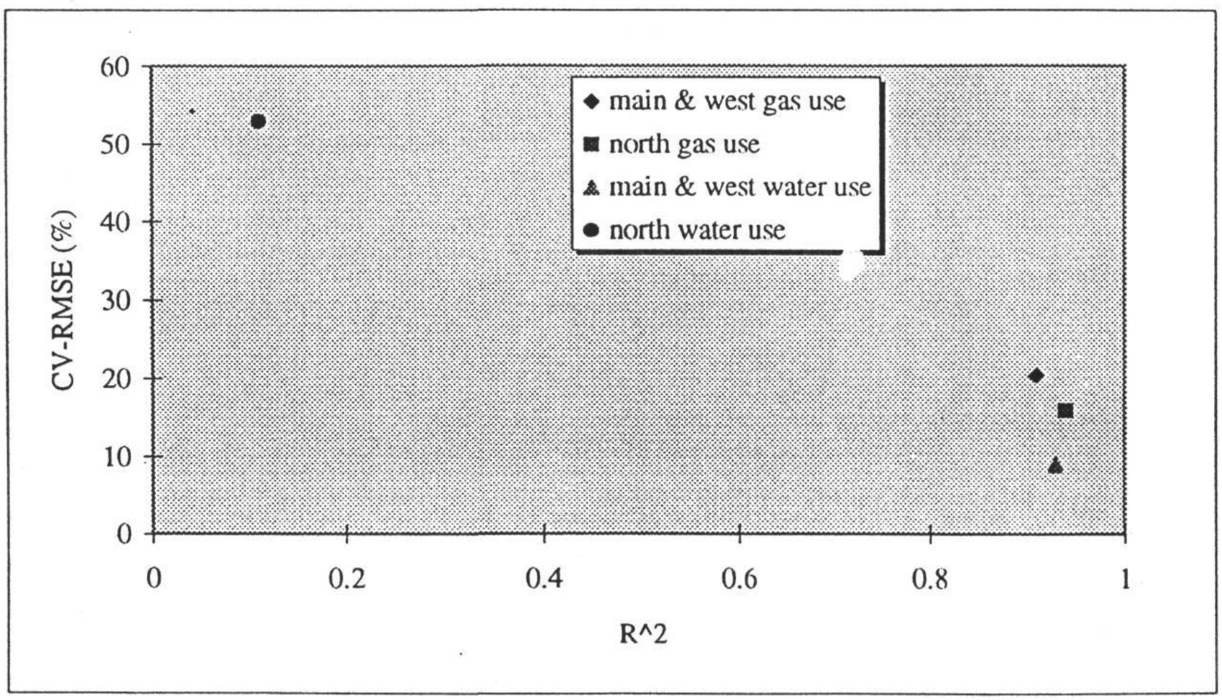


Fig. 6.6 R^2 and CV-RMSE of baseline models proposed for 1990

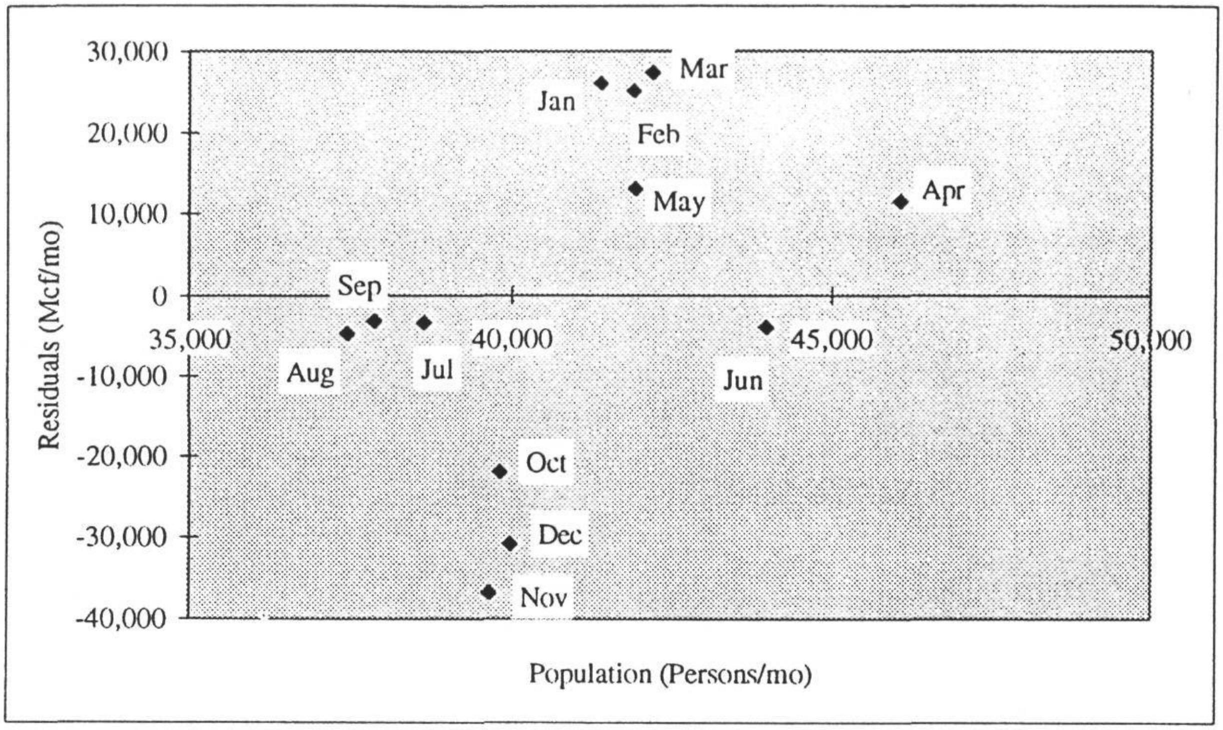


Fig. 6.7 Plot of 3-P model residuals of Main and West cantonment areas gas use for 1990 versus population. No correlation between both variables can be detected indicating that adding population in the model as an additional variable will not improve the fit.

7.0 Use of Baseline Models for Screening

Once baseline models have been developed, it is possible to use them as screening tools by comparing forecast levels with actual energy use. Effect of changes in weather from year-to-year (more accurately, outdoor temperature) on the energy use is explicitly accounted for by the baseline model forecasts. Deviations from expectations must be studied to determine whether known extraneous changes have contributed to this variation (for example, changes in population, square footage,...) or whether these changes are a result of energy efficiency measures or DSM programs that have been initiated. How the PIs of the model are to be calculated have been described in section 5.4. We have used our 1990 baseline models to forecast into the future up to 1993 and also backcast into the past until 1989.

Figures 7.1 to 7.6 depict the extent to which the monthly energy use utility bills are bounded by the PIs of the 1990 baseline model. For clearer visualization, we have also shown the residuals (residual = measured value minus model predicted value) along with the PIs. If, say, the utility bill data for a month fall below the lower 95% PI, one can safely affirm that energy use during that month has decreased as compared to model predictions. Salient observations from each figure are reported below:

(i) Main substation electricity use.

We note that on the whole, the observed energy use is bounded by the PIs of the 1990 baseline model (see Fig.7.1). Inspection of the residual plots reveal that there are certain periods, namely April, May and July of 1991, April-July of 1992, May-July 1993 where the observed energy use is definitely lower than that baseline model-predicted values (as a result of initiating the FM Load Management System). Energy use during Sept-Oct. 1993 is higher.

This spring time lag in electricity use may be due in part to a seasonal influence which has been observed at other facilities with significant amounts of buried chilled water distribution systems.

(ii) Main substation electricity demand.

Figure 7.2 clearly indicates the benefit of the DSM program since we see a substantial reduction from March 1991. Because of the ratchet clause on the peak demand, the billed peaks in winter are also lower from 1991-92 onwards. It is only during Sept-Oct. 1993 that demand seems to have crept up again, which has also raised the wintertime rate as well.

(iii) Main and West cantonments gas use.

Inspection of Fig.7.3 indicates that a small reduction in gas use during the summer months of 1992 and 1993 took place even though the baseline model was not very good and the PIs are relatively wide. A small seasonal trend can also be seen in these data which corresponds to a lag in heating energy use in the fall which would indicate that buried heating pipes are less affected by the ground in the fall when the summer's heat still remains in the ground.

(iv) Main and West cantonments water use.

Though the model has a CV-RMSE of less than 10%, the PIs are relatively wide (see Fig.7.4). Despite this there are a number of instances where observations fell outside the PIs. Clearly, in the case of Ft. Hood's water use another variable such as monthly precipitation may need to be evaluated in conjunction with temperature.

(v) West substation electricity use.

A major change seems to have occurred in this substation (see Fig.7.5). Electricity use from 1991 onwards seems to have increased significantly with the observed values mostly outside the PI range. A physical cause should be ascertained for this behavior. Energy use during the summer months of 1993 is almost 20% higher than previous use.

(vi) North cantonment gas.

During the first half of 1993, observed gas use has increased significantly (see Fig.7.6) while being generally consistent for the other periods. A small seasonal trend can also be observed in these data.

In Appendix A we have provided a list of the Excel spreadsheets that were used to generate the plots shown in Figs. 6.1-6.6. These programs are also provided on a diskette so that Fort Hood personnel can use our 1990 baseline models for generating similar plots for 1994 and onwards. In the event that future circumstances dictate a year other than 1990 be used as the baseline model new models will need to be developed and then the same programs can be used with minor modifications.

The whole-installation baseline models can be used to determine whether energy and water use efficiency has increased over the years. This type of analysis capability is crucial if one wishes to ascertain the extent to which the Executive Order 12902 has been met. Using monthly mean daily temperature data for 1993, the 1987 models have been used as the baseline models to predict 1993 energy and water use and compare them with measured values. Table 7.1 depicts the annual values of electricity use, electricity demand, gas use and water use for the entire installation, in terms of uncorrected use, use normalized by conditioned building square footage and use normalized by population. The changes in annual consumption, computed as the differences between model values and measured values, are also shown. The percentage changes are also included. Note that a negative change indicates an increase in energy use, and vice versa. We note from Table 7.1 and Fig. 7.7, that consumption normalized by conditioned area shows the following behavior from 1987 to 1993: (i) electricity use has increased by 4.7%, (ii) demand has decreased by 1.8%, (iii) gas has decreased by 20.4%, and (iv) water use has decreased by 15.5%.

The uncertainty, i.e., the 95% PIs of these changes have also been computed following eq.(5.13) and are shown in Table 7.1 and Fig.7.7. We note that these PIs are relatively small, 2.8% for electricity use, 1.7% for electricity demand, 0.2% for gas use and 0.3% for water use. Hence we can place a certain amount of confidence in our model's ability to show that normalized energy and water use for Fort Hood has changed from 1987 to 1993.

8.0 Summary of Models

The final baseline 3-P models identified from 1990 data are shown in Table 8.1. We have also included in the table the model coefficients for the entire installation of Fort Hood for electricity use, electricity demand, gas use and water use. As expected, the models at this level are better than those for each of the three cantonment areas separately because of the fact that aggregate energy use values usually behave more consistently than disaggregated ones. Though all four models have $R^2 > 0.90$, the gas model has a rather high CV-RMSE value (greater than 20%). The reason for this behavior is unclear and merits further investigation.

Main Substation electricity use

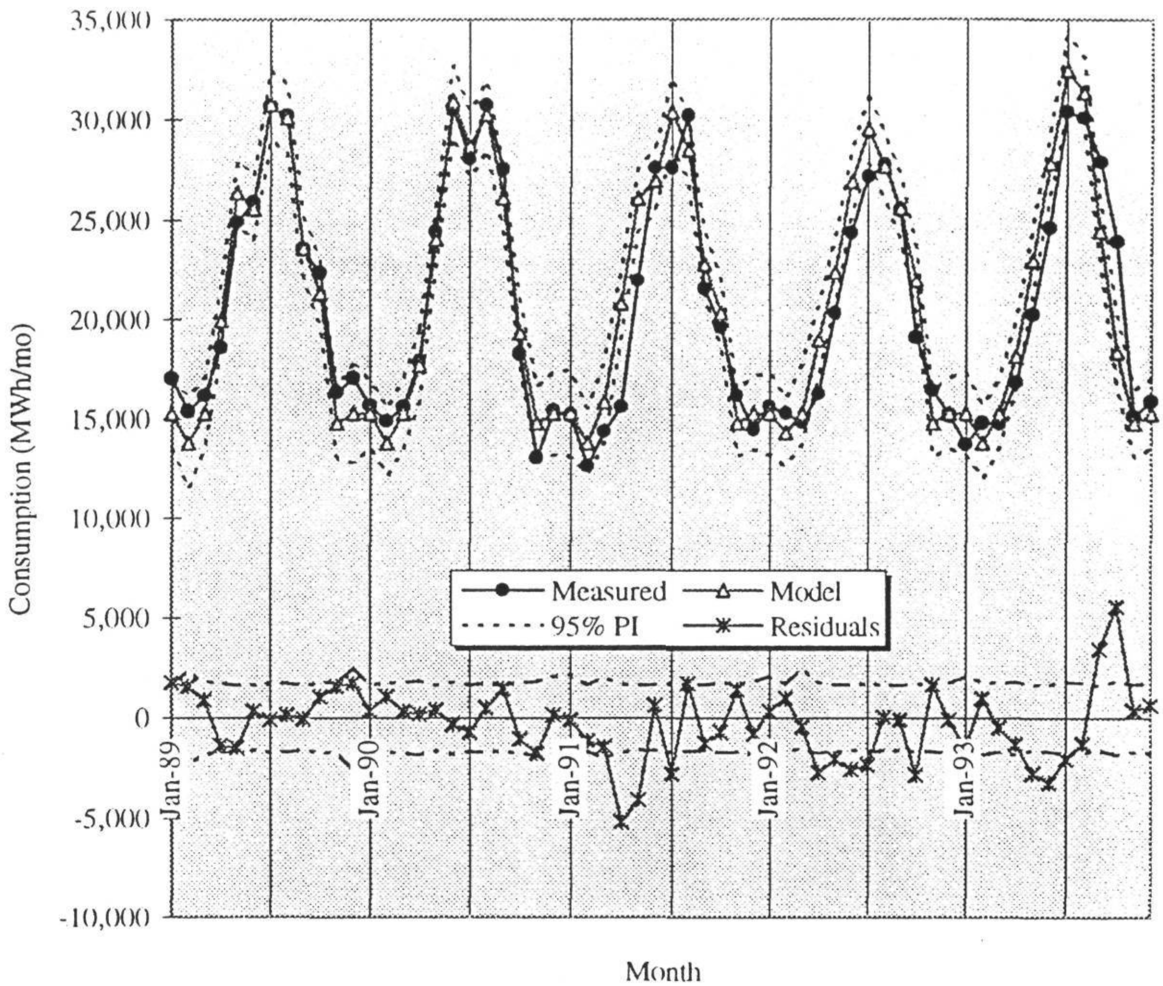


Fig. 7.1 Predictive ability of 1990 baseline 3-P regression model for Main Substation electricity use. 95% prediction intervals for the model as well as for the residuals are shown.

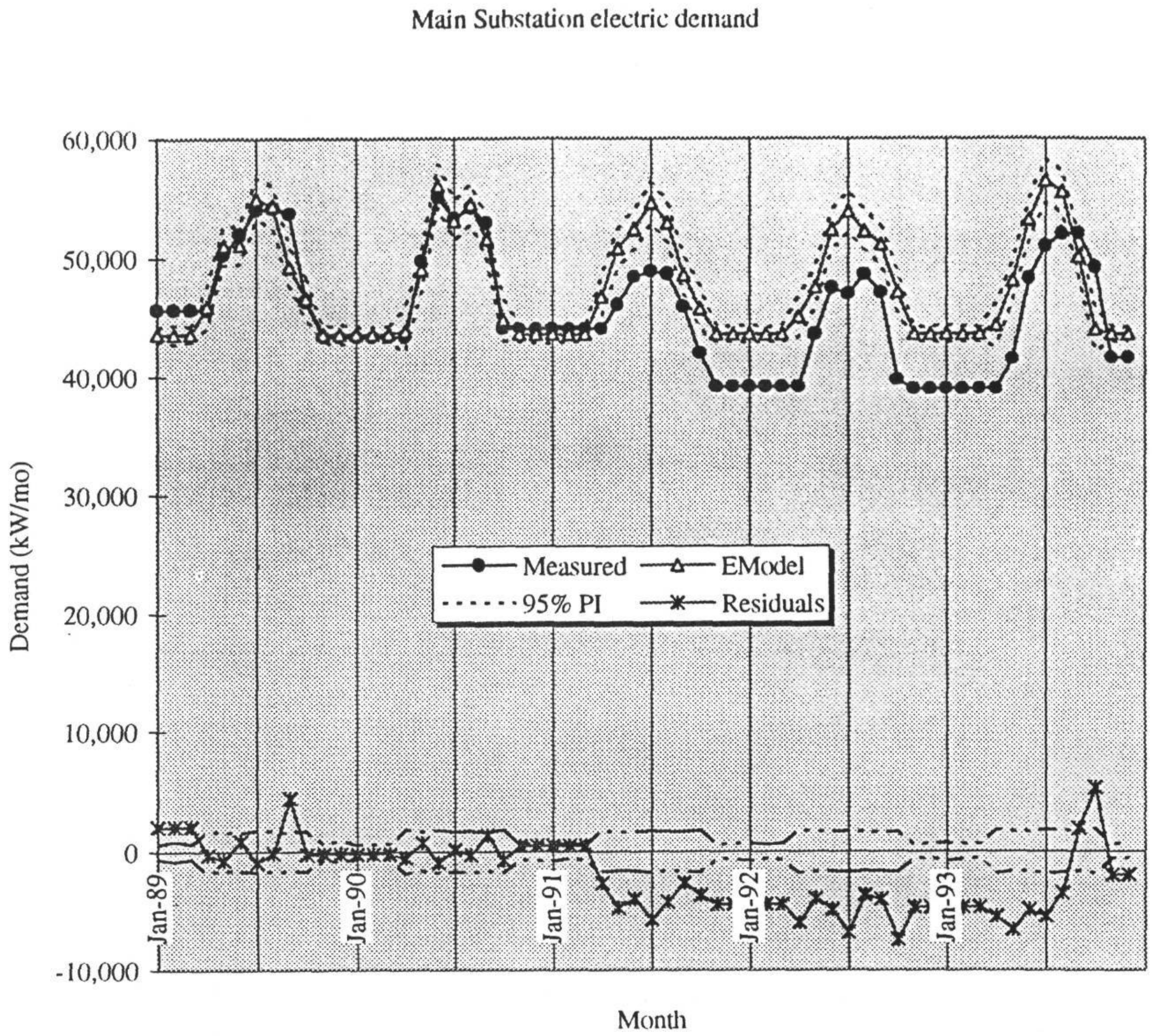


Fig. 7.2 Predictive ability of 1990 baseline 3-P regression model for Main Substation electric demand. Prediction intervals for the model as well as for the residuals are shown

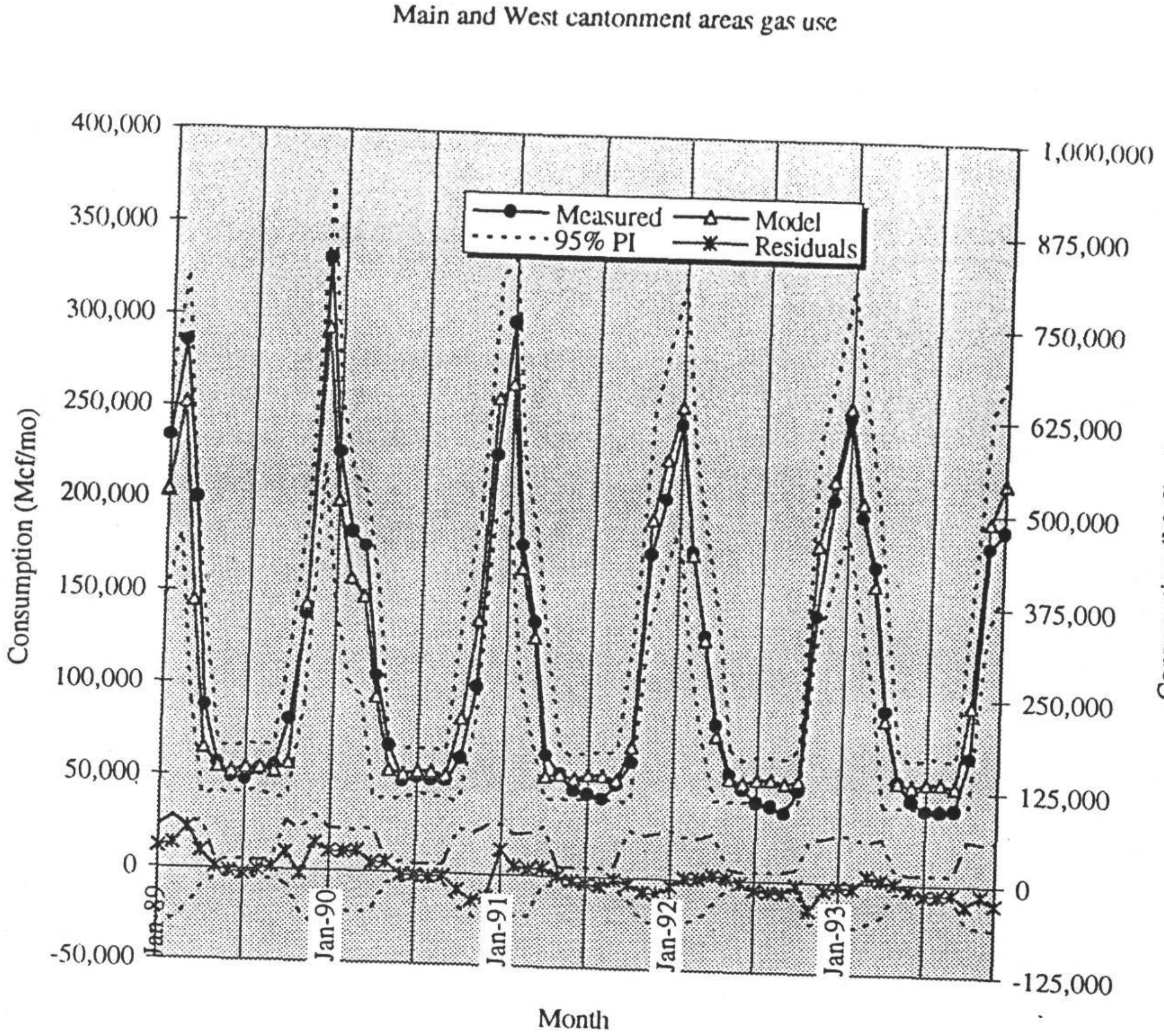


Fig. 7.3 Predictive ability of 1990 baseline 3-P model for Main and West cantonment areas gas use. 95% prediction intervals for the model as well as for the residuals are shown

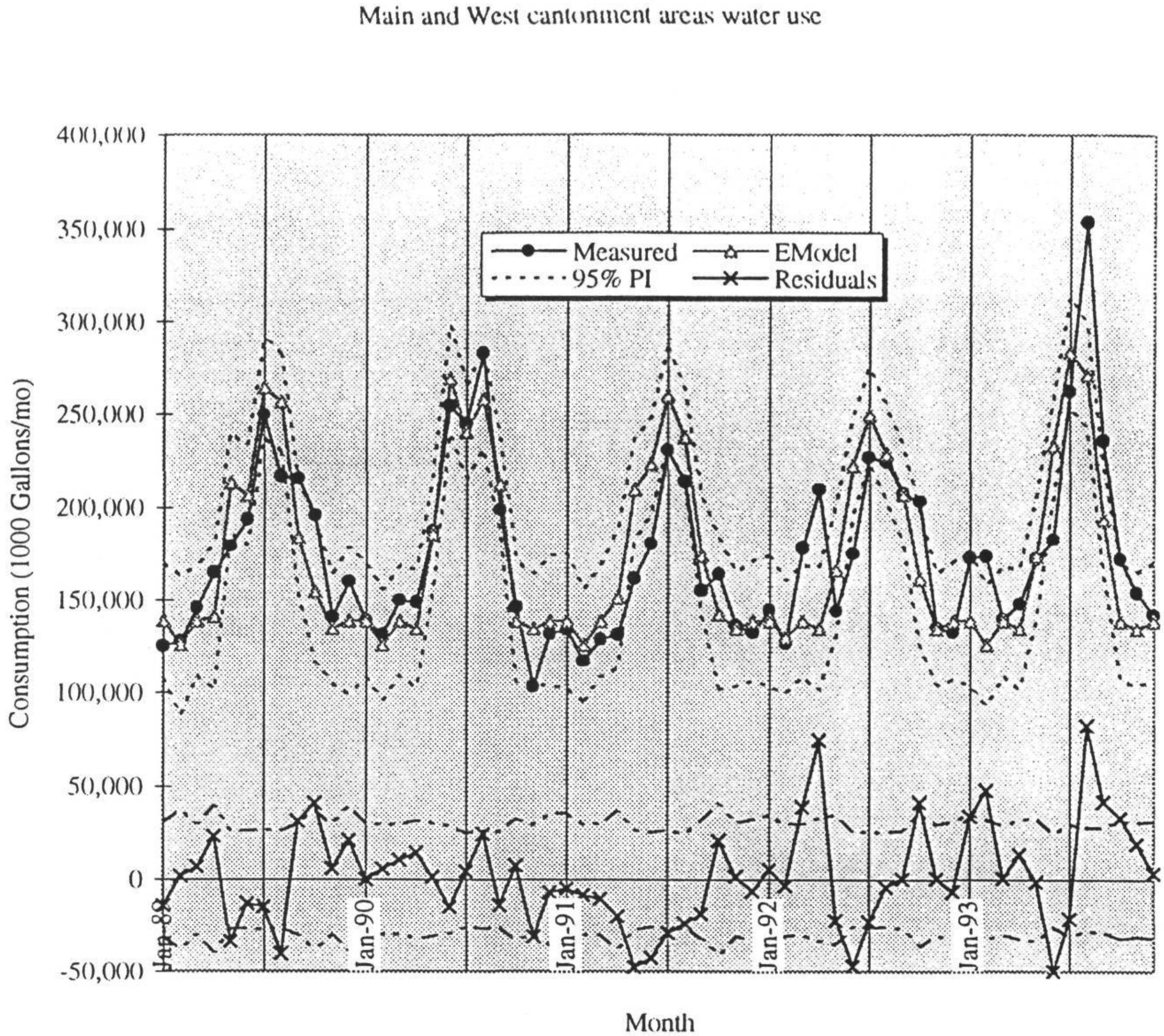


Fig.7.4 Predictive ability of 1990 baseline 3-P regression model for Main and West cantonment areas water use. 95% prediction intervals for the model as well as for the residuals are shown.

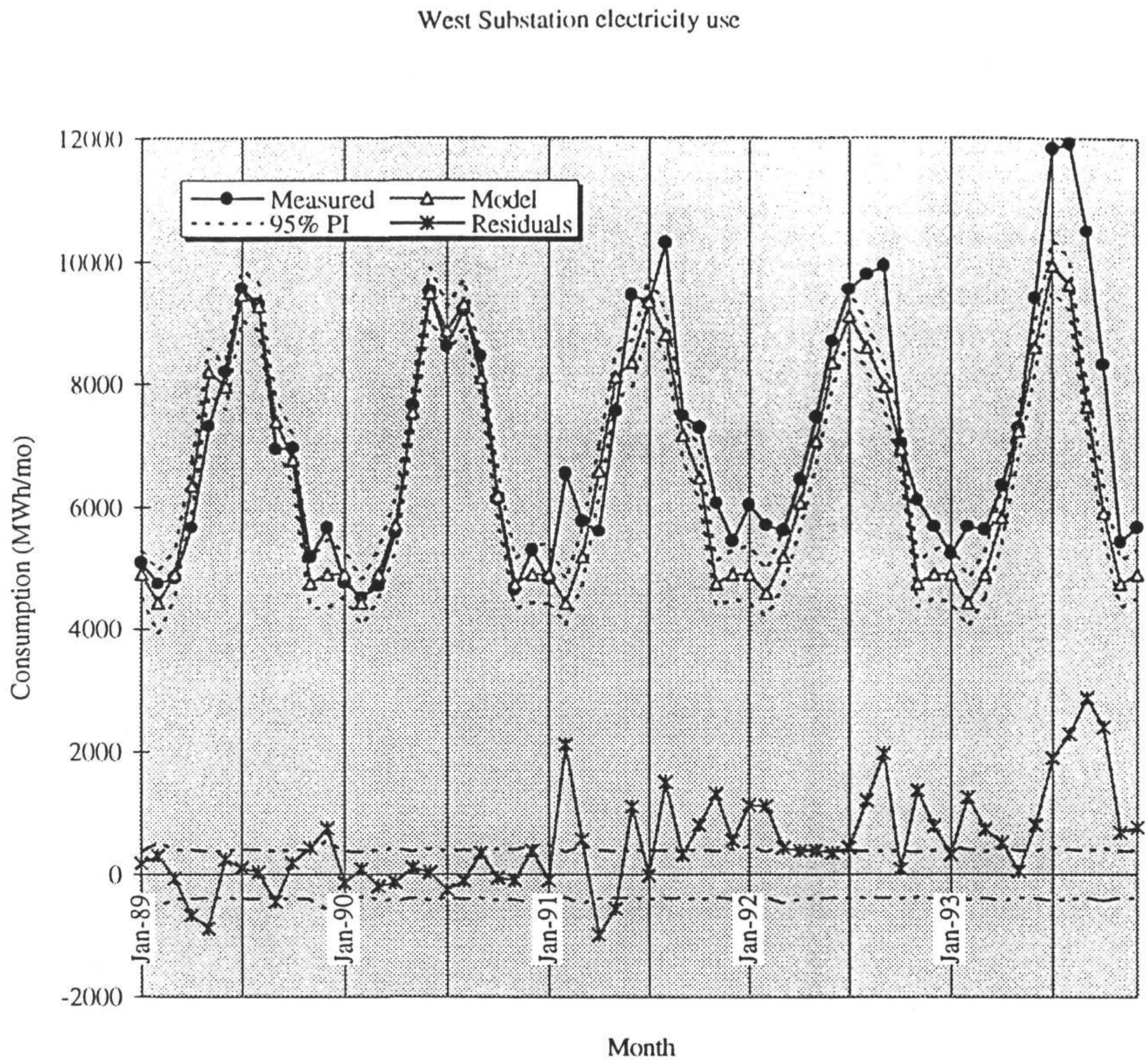


Fig. 7.5 Predictive ability of 1990 baseline 3-P regression model for West Substation electricity use. 95% prediction intervals for the model as well as for the residuals are shown

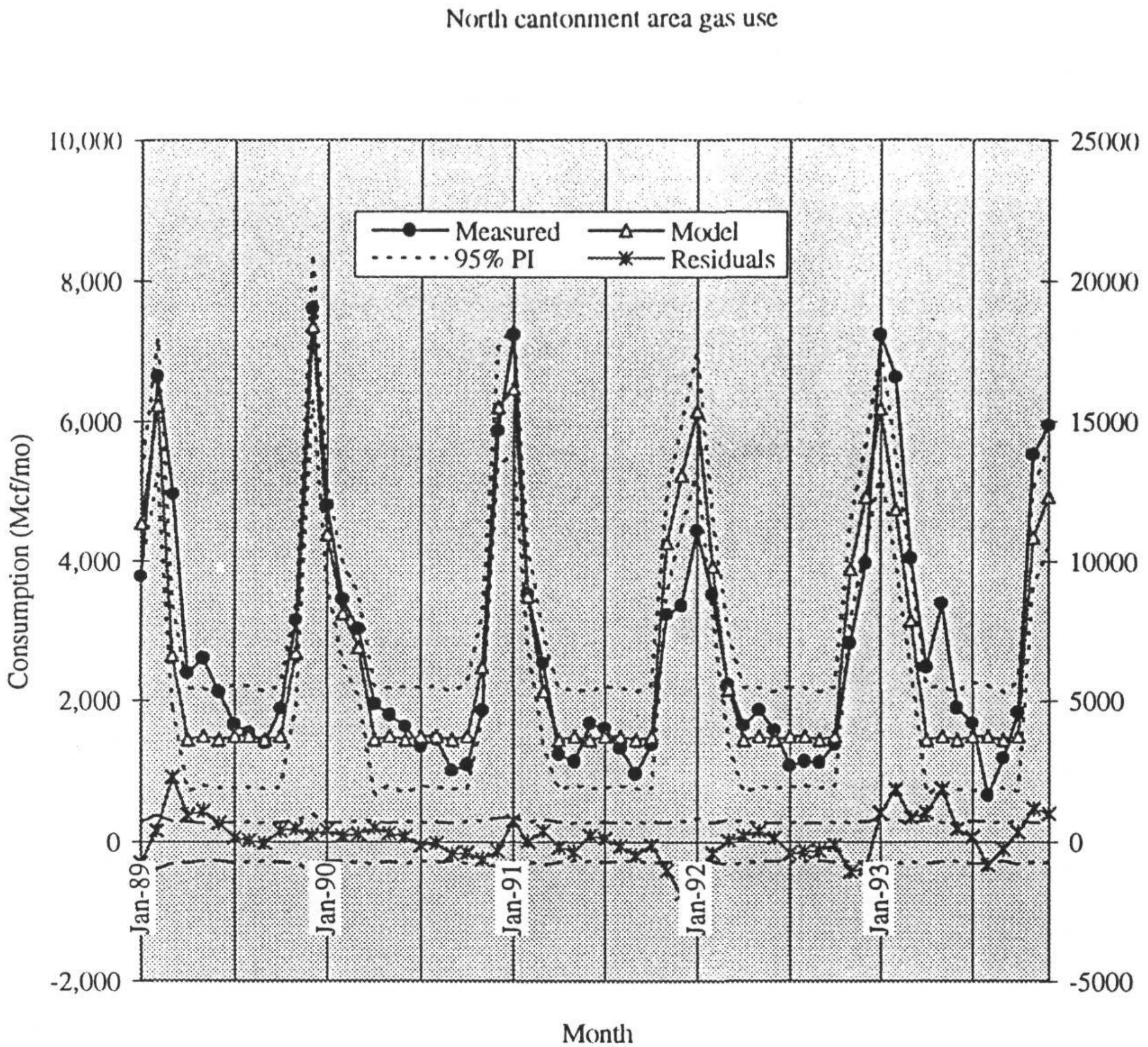


Fig. 7.6 Predictive ability of 1990 baseline 3-P model for North cantonment area gas use. 95% prediction intervals for the model as well as for the residuals are shown

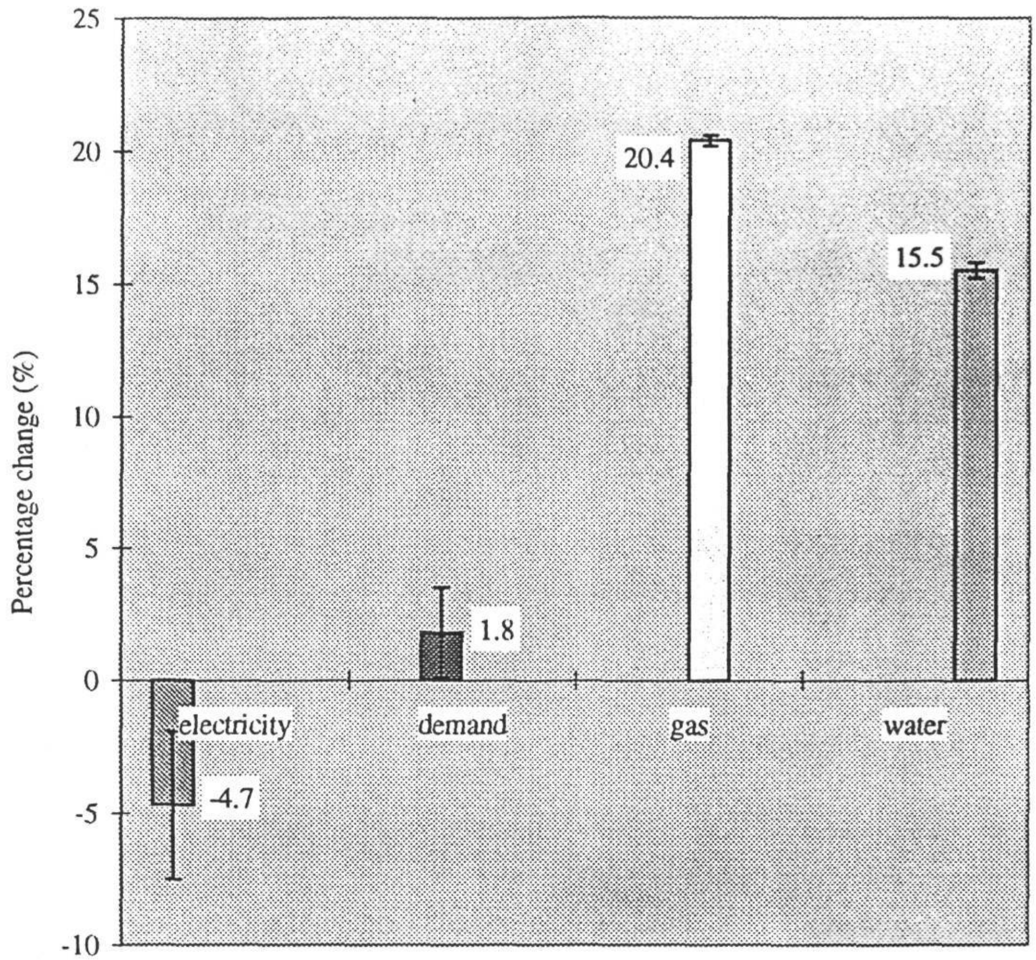


Fig. 7.7 Percentage change in annual energy use and water use from 1987 to 1993 normalized by total conditioned building area. Negative change indicates an increase in use and vice versa. 95% confidence intervals for the % change are also shown.

Table 7.1 Changes in annual energy and water use for Fort Hood from 1987 to 1993. The 1987 model has been used as the baseline model to predict 1993 energy and water consumption. T, ,e have been normalized by total building area and by base population. Percentage changes defined as [(Model value-Measured)/Measured] are also shown. Note that a negative change indicates an increase in use and vice versa. The 95% PIs of the percentage changes are also shown.

	Unnormalized 1993 use					
	Predicted from 1987 model	Measured	Change (model-measured)	95% PI of change	% change	95% PI of % change
Electricity use (MWh/yr)	315,545	348,390	-32,845	9,139	-9.4%	2.6%
Electricity demand (kW/yr)	732,855	757,453	-24,598	12,455	-3.2%	1.6%
Gas use (Mcf/yr)	1,618,014	1,414,665	203,349	2,449	14.4%	0.2%
Water use (1000 Gallons/yr)	2,620,876	2,388,590	232,286	7,604	9.7%	0.3%
	1993 use normalized by building area					
	Predicted from 1987 model	Measured	Change (model-measured)	95% PI of change	% change	95% PI of % change
Electricity use (MWh/yr-ft^2)	0.013	0.014	-0.001	0.0004	-4.7%	2.8%
Electricity demand (kW/yr-ft^2)	0.031	0.030	0.001	0.0005	1.8%	1.7%
Gas use (Mcf/yr-ft^2)	0.067	0.056	0.011	0.0001	20.4%	0.2%
Water use (1000 Gallons/yr-ft^2)	0.109	0.095	0.015	0.0003	15.5%	0.3%
	1993 use normalized by population					
	Predicted from 1987 model	Measured	Change (model-measured)	95% PI of change	% change	95% PI of % change
Electricity use (MWh/yr-person)	7.688	8.080	-0.392	0.223	-4.8%	2.8%
Electricity demand (kW/yr-person)	17.855	17.566	0.289	0.303	1.6%	1.7%
Gas use (Mcf/yr-person)	39.421	32.808	6.614	0.060	20.2%	0.2%
Water use (1000 Gallons/yr-person)	63.855	55.394	8.461	0.185	15.3%	0.3%

Table 8.1 Final 1990 Baseline 3-P Model coefficients and Goodness-of-fit Indices

Whole Base

	Ycp	Slope	Xcp	R^2	CV-RMSE
Elec.	662 MWh/day	26 MWh/°F-day	58.2 °F	0.99	3.80%
Demand	56,115 kW/mo	559 kW/°F-mo	58.2 °F	0.99	1%
Gas	1,794 Mcf/day	-265 Mcf/°F-day	68.3 °F	0.91	20.20%
Water	$4{,}643\times10^3$ Gallons/day	248×10^3 Gallons /°F-day	66.6 °F	0.92	9.20%

Main

	Ycp	Slope	Xcp	R^2	CV-RMSE
Elec.	492 MWh/day	20 MWh/°F-day	58.2 °F	0.98	4.5%
Demand	43,571 kW/mo	548 kW/°F-mo	62.4 °F	0.98	1.5%
Gas	1,755 Mcf/day	-259 Mcf/°F-day	68.3 °F	0.91	20.4%
Water	$4{,}490\times10^3$ Gallons/day	232×10^3 Gallons /°F-day	65.8 °F	0.93	9.0%

West

	Ycp	Slope	Xcp	R^2	CV-RMSE
Elec.	158 MWh/day	6 MWh/°F-day	57.4 °F	0.99	3.3%
Demand	11,186 kW/mo	81 kW/°F-mo	45.6 °F	0.71	5.6%

North

	Ycp	Slope	Xcp	R^2	CV-RMSE
Elec.	12 MWh/day	0.43 MWh/°F-day	64.9 °F	0.59	20.3%
Demand	1,123 kW/mo	6 kW/°F-mo	55.7 °F	0.45	6.7%
Gas	48 Mcf/day	-8 Mcf/°F-day	61.6 °F	0.94	15.9%
Water	139×10^3 Gallons/day	6×10^3 Gallons /°F-day	72.5 °F	0.11	52.9%

Nomenclature

LS	left slope of a multiple slope model
m	number of model predicted values that are summed
n	number of observations in the model
n_1	number of observations on the base portion of the curve
n_2	number of observations on the variable portion of the curve
R^2	coefficient of determination
RS	right slope of a multiple slope model
T	outdoor dry-bulb temperature
X	independent or regressor variable
Xcp	X change-point of a multiple slope model
Y	dependent variable (electricity use, demand, gas use and water use)
Ycp	Y change point of a multiple slope model
$\hat{Y}$	model-predicted value of Y

<u>Greek</u>

α	intercept or base energy use of the PRISM model
β_c	slope for the PRISM cooling model
β_h	slope for the PRISM heating model
τ_c	base temperature for the PRISM cooling model
τ_h	base temperature for the PRISM heating model

<u>Acronyms</u>

CDD	cooling degree days
CO	PRISM cooling-only model
CV-RMSE	coefficient of variation of the root mean square error
DD	degree days
EModel	Software developed by Energy Systems Laboratory to perform change point regressions
HC	PRISM heating and cooling model
HDD	heating degree days
HO	PRISM heating only model
PI	prediction intervals
PRISM	Princeton Scorekeeping Method and software
RMSE	root mean square error
SE	standard error
SV	single variate model

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Appendix A: List of spreadsheets (in Excel) that have been developed during this project which would be useful for projecting the 1990 cantonment area-level baseline models into the future and generating 95% prediction intervals.

Spreadsheet A1: For Main substation electricity use (see Fig. 7.1)

Spreadsheet A2: For Main substation electricity demand (see Fig. 7.2)

Spreadsheet A3: For gas use of Main and West cantonment areas (see Fig. 7.3)

Spreadsheet A4: For water use of Main and West cantonments areas (see Fig. 7.4)

Spreadsheet A5: For West substation electricity use (see Fig. 7.5)

Spreadsheet A6: For gas use of North cantonment area (see Fig. 7.6)

(A disk containing the above programs is attached).

TASK B

PROVIDE STABLE DATA LOGGING AT FT. HOOD

TASK B: EXECUTIVE SUMMARY

The purpose of this task is to provide a stable data logging environment, inspection and archiving of data from existing data loggers at the main and west substations at Ft. Hood. The ESL has installed a new weather station at west Ft. Hood substation, generated weekly inspection plots for the feeders at main Ft. Hood substation, and will develop PollHood to poll the data from all the data loggers at the base and generate weekly inspection plots for all the feeders at the main and west substations.

The existing monitoring process at Ft. Hood consists of data collection at the main and west substations. There are three Synergistic data loggers at the main substation that monitor energy use from 15 active feeders. Hourly data is transferred via telephone line to Ft. Hood Energy Office. At the west substation, two data loggers are used to collects data from six active feeders. No phone communications are available at the west substation. Personnel from the energy office travel to the west substation, download the hourly data using a laptop computer, and then view the data at the energy office. The energy office at Ft. Hood have accomplished a commendable work using the FM-based Demand Side Management (DSM) system for load shedding. Savings estimated at $1 million out of $25 million annual utility bill at Ft. Hood have been accomplished through using the load shedding program.

Although the present system is very effective it is also very time consuming and can be easily upset by manual error. For example, no phone communication is available with the loggers at the west substation and the personnel at the energy office can view only one logger at a time with the Parset software In addition, as mentioned above, data from the west substation must be downloaded manually on-site using a laptop computer. The personnel at the energy office must then determine the load shedding schedule for the day, enters the new shedding schedule into the Scientific Atlanta System and then recheck the Synergistics loggers to see that the program has taken effect.

MODIFICATIONS TO EXISTING MONITORING SYSTEM

a- Installing New Weather Station at the West Substation

ESL personnel installed calibrated temperature-humidity and solar sensors at the west substation on 9/6/1995. The Licor solar sensor and the solid state temperature-humidity sensor were calibrated at the ESL-Riverside Campus. Connections to the data loggers were also made. The weather station will provide weather data in the Killeen/Temple area that can be used to develop inspection plots for Ft. Hood and can also be used for the LoanSTAR program.

b- Install a Cellular Phone at the West Substation for Data Communication

The ESL provided information on a cellular phone that can be used for data communication between the data loggers at the west substation and Ft. Hood energy office. The use of the cellular phone will reduce the current effort of Ft. Hood energy office personnel in downloading the data from the west substation.

c- Provide On Screen Visualization (Monitor)

The ESL personnel installed Monitor Version 1.2 on one of Ft. Hood energy office computers. Monitor Version 1.2 (developed by the ESL) is a MS Windows application that allow the user to view real-time energy consumption data collected by a Synergistic logger. The data can be displayed on a rolling scroll chart, speedometer or VU meter. Many channels of data can be viewed simultaneously, and the format of the meters and charts can be customized by changing the fonts and by manipulating axis labels and ranges. Monitor provides on-line, context-sensitive help.

d- Provide PollHood to Download Hourly Data and Generate Weekly Inspection Plots

NOTE: This part of the project is awaiting the purchase and installation of a cellular phone on the west substation. The phone will be used for communications with the two data loggers at west Ft. Hood. However, this task is in the development process.

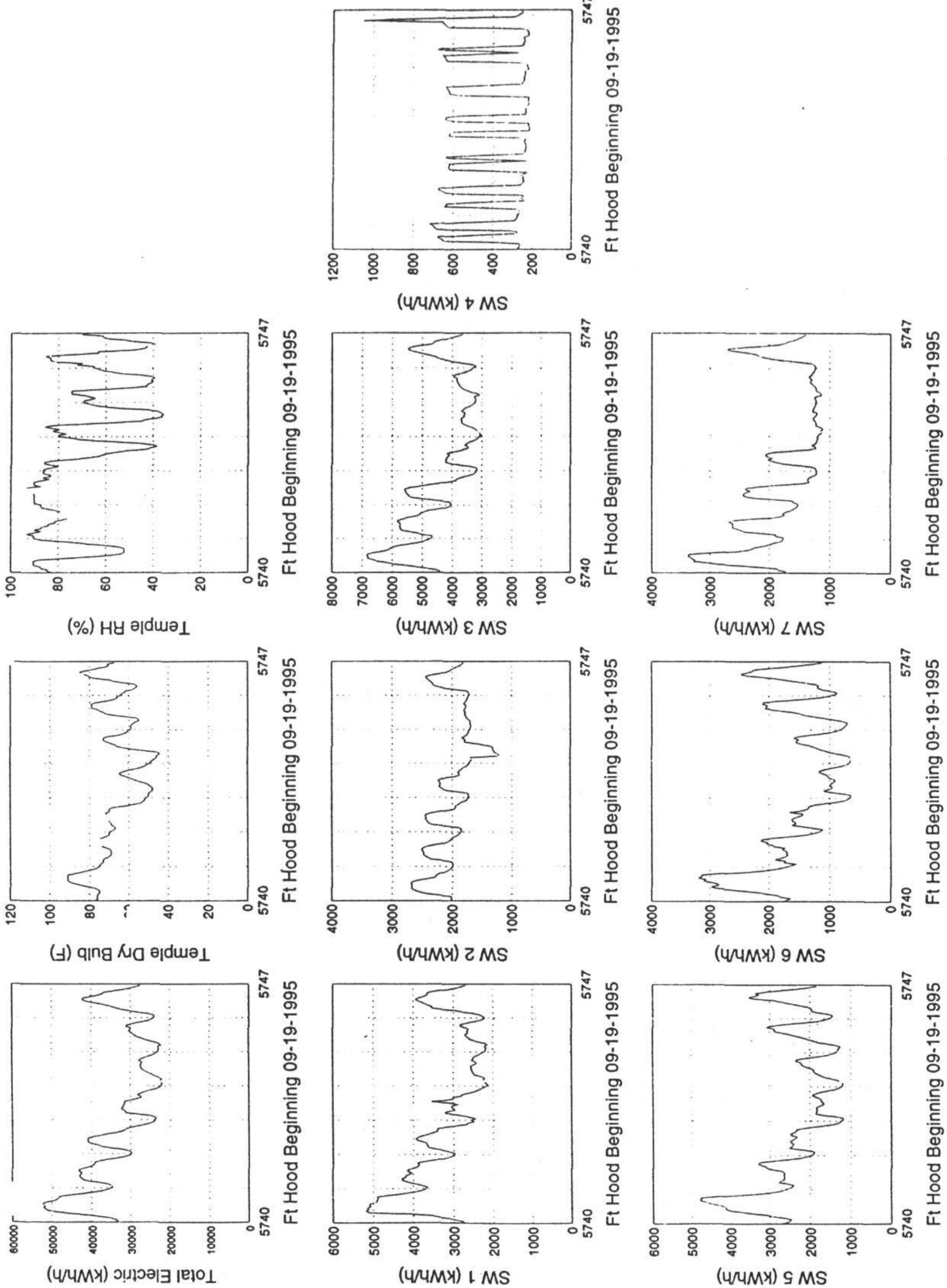
Currently, the ESL is producing weekly inspection plots for the data loggers at the main substation using ESL equipment and computer routines (see Appendix B1 for sample inspection plots). The inspection plots show the total electricity consumption (kWh/h) as well as the main substation individual feeders electricity consumption. Also shown are the daily temperature and relative humidity from the Temple weather data available at the ESL.

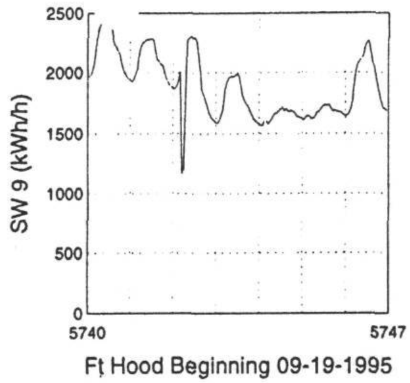
The objective of this part of the Fort Hood project is to create an automated polling and inspection plot creation process similar to the standard ESL weekly plot pages. It is not possible to use the current weekly inspection plot routines used by the ESL because they are implemented on a Unix server, and we need a version that is based on a PC running DOS so the personnel at Fort Hood Energy Office can create the plots themselves.

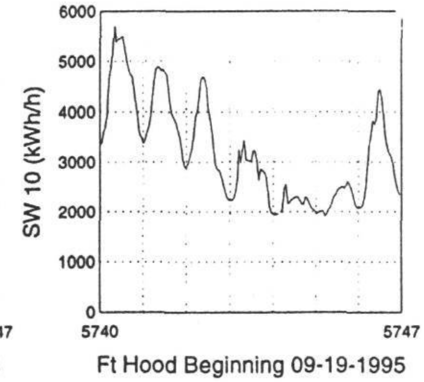
The DOS based routines for creating the Main inspection pages from the raw Synergistic output have been completed. The West station inspection page is currently being worked on and the data from the West site is still being manually downloaded. The task after the West plot pages are created is to develop and test the routines required to call all 5 loggers. A flow chart detailing the plot creation process is shown in Appendix B1.

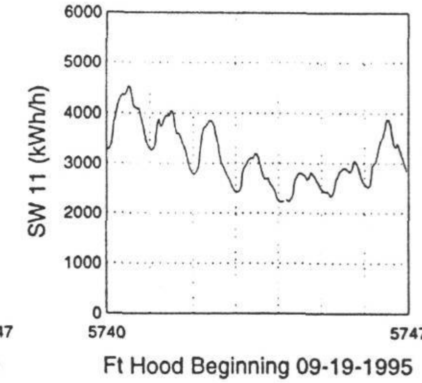
APPENDIX B1

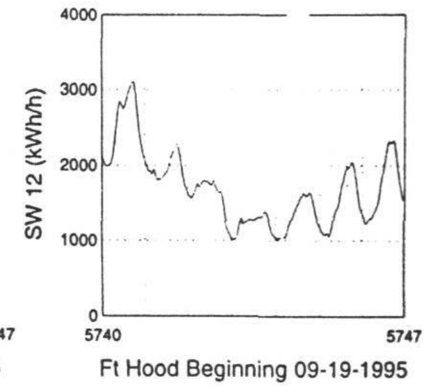
SAMPLE INSPECTION PLOTS FOR MAIN FT. HOOD SUBSTATION

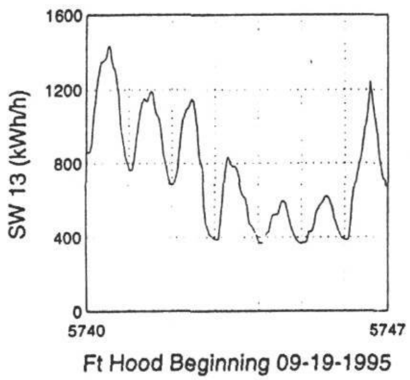

Total Electric (kWh/h)
Temple Dry Bulb (F)
Temple RH (%)
SW 1 (kWh/h)
SW 2 (kWh/h)
SW 3 (kWh/h)
SW 4 (kWh/h)
SW 5 (kWh/h)
SW 6 (kWh/h)
SW 7 (kWh/h)
Ft Hood Beginning 09-19-1995
5740
5747

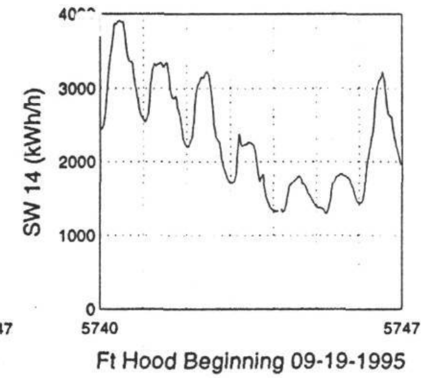

SW 9 (kWh/h)
2500
2000
1500
1000
500
0
5740
5747
Ft Hood Beginning 09-19-1995

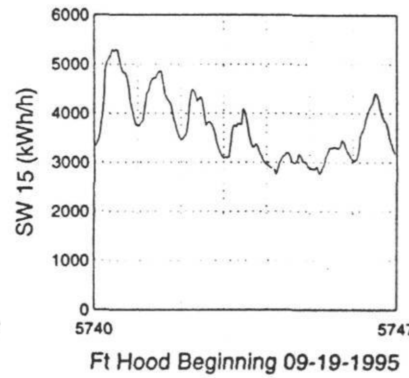

SW 10 (kWh/h)
6000
5000
4000
3000
2000
1000
0
5740
5747
Ft Hood Beginning 09-19-1995

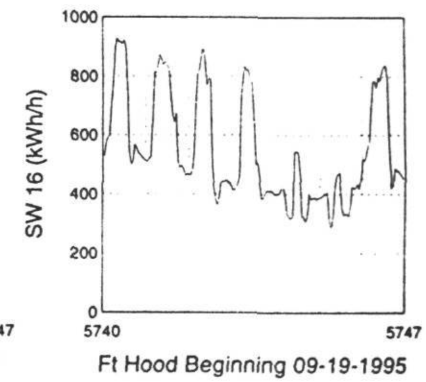

SW 11 (kWh/h)
6000
5000
4000
3000
2000
1000
0
5740
5747
Ft Hood Beginning 09-19-1995

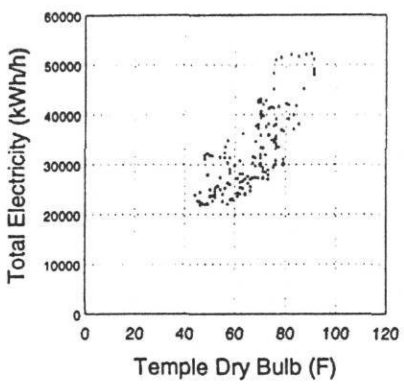

SW 12 (kWh/h)
4000
3000
2000
1000
0
5740
5747
Ft Hood Beginning 09-19-1995

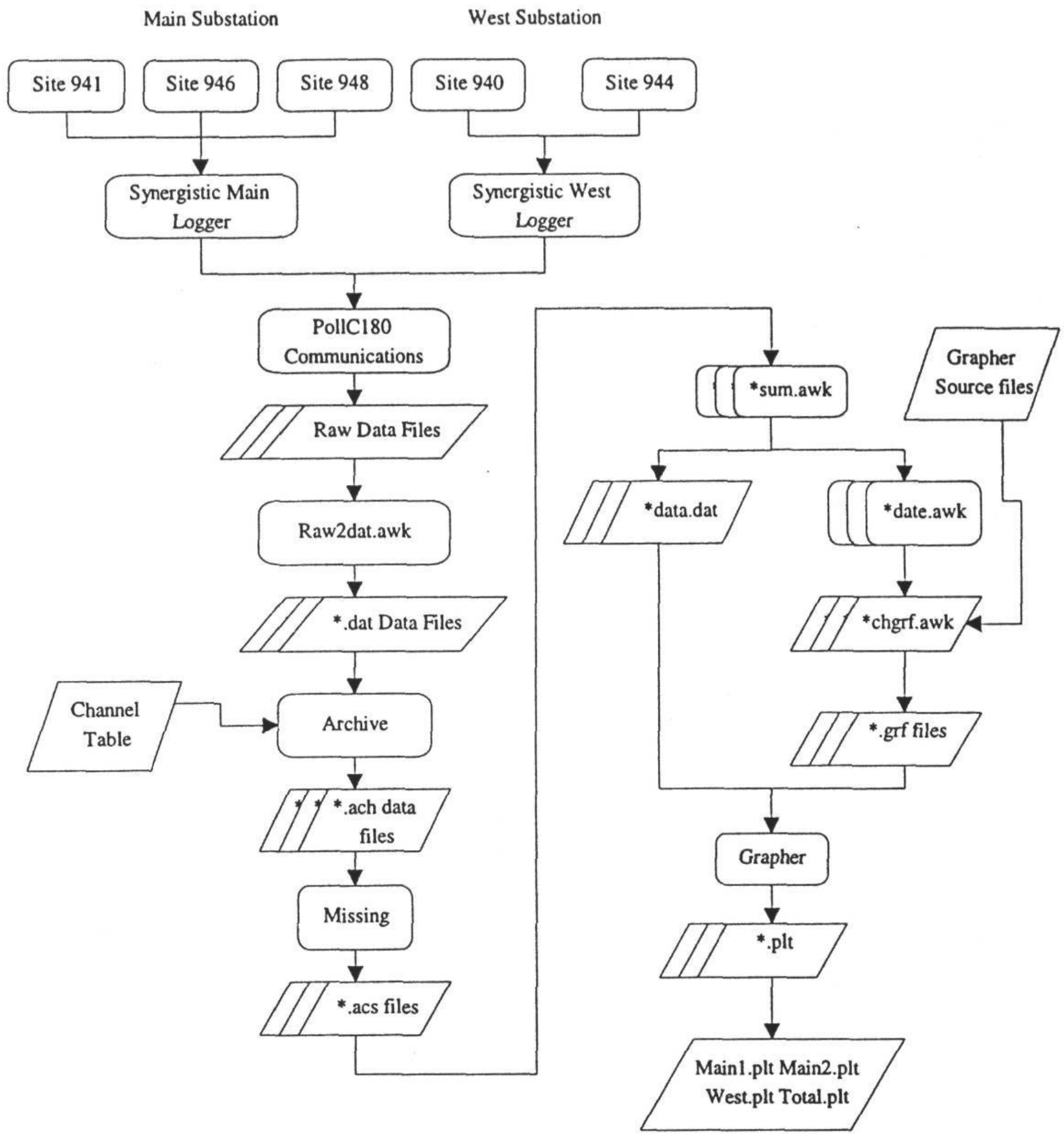

SW 13 (kWh/h)
1600
1200
800
400
0
5740
5747
Ft Hood Beginning 09-19-1995


SW 14 (kWh/h)
3000
2000
1000
0
5740
5747
Ft Hood Beginning 09-19-1995


SW 15 (kWh/h)
6000
5000
4000
3000
2000
1000
0
5740
5747
Ft Hood Beginning 09-19-1995


SW 16 (kWh/h)
1000
800
600
400
200
0
5740
5747
Ft Hood Beginning 09-19-1995


Total Electricity (kWh/h)
60000
50000
40000
30000
20000
10000
0
0
20
40
60
80
100
120
Temple Dry Bulb (F)



Flowchart for polling and processing Fort Hood Loggers

TASK C

PROVIDE METERING PLAN AND SHOPPING LIST OF NECESSARY DATA POINTS AT FT. HOOD TO METER AND MONITOR ENERGY USE

TASK C: EXECUTIVE SUMMARY

The purpose of this preliminary engineering survey of the Ft. Hood power plant facilities is to determine the cost and the level of effort necessary to establish a LoanSTAR-type monitoring capability for Ft. Hood energy use.

The monitoring points contained in this report are subject to verification during the Detailed Design Task. Final cost estimates will be submitted upon completion of the Detailed Design Budget.

Existing Monitoring Capability

At the present time the power plants at Ft. Hood do not have monitoring of chilled water, hot water, steam, natural gas or total plant electricity consumption. In order for the Ft. Hood Energy Office staff to effectively analyze savings from energy retrofits, a multi-logger data acquisition system is recommended based on systems that are installed in the Texas LoanSTAR energy conservation program. The sensors from such a system could also be used by the planned Ft. Hood Utility Control System (UCS).

The proposed system will cost at most ($1,075,537) and could be installed in about 12 months. Such a system would include all necessary software, and hardware for polling and archiving the data.

Data Analysis Options

Since the recommended monitoring system will utilize software developed for the Texas LoanSTAR program by the ESL, it is recommended that Ft. Hood consider utilizing ESL's analysis procedures on the data to be collected from the power plants at Ft. Hood (see Task A).

INTRODUCTION

The Texas LoanSTAR Monitoring and Analysis Program (MAP) is responsible for monitoring energy conservation retrofits at various sites throughout Texas. An important part of this program is gathering pertinent energy consumption and weather data for a site to determine the effectiveness of the retrofit projects. For this purpose, LoanSTAR researchers have installed dedicated data loggers at over 260 retrofit sites. These loggers are designed specifically to collect energy and/or weather data from the appropriate sensors, store the data locally, and transmit the data via telephone modem when polled by a centralized data archive facility, a task they perform quite well.

The purpose of this shopping list report is to determine an estimated cost of material and labor necessary to install a monitoring system for 25 power plants at Ft. Hood to meter and monitor energy use at the base. This report contains two sections. The first section contains a summary of labor and material costs to monitor energy use at Ft. Hood including end-use measurements at 25 power plants. The second section details the cost of materials and labor to monitor the 25 individual power plants.

MONITORING Ft. HOOD

This preliminary monitoring plan defines a point list and approximate costs for monitoring the end-use energy use at Ft. Hood, and includes plans for 25 power plants located at the base. Figure C1 shows a sketch of the base with the approximate location of each plant. The number of chillers and boilers for each plant is shown in Table C1. Sketches are provided for each power plant that show the equipment to be monitored in each plant together with the recommended monitoring points. The basic monitoring system for each plant consists of a data logger that is capable of monitoring the following loads as needed:

- Whole-plant electricity
- Chiller electricity
- Chilled water thermal production
- Condenser water and chilled water temperatures
- Whole-plant natural gas
- Steam pressure (for steam boilers)
- Steam temperature (for steam boilers)
- Condensate flow rate (for steam boilers)
- Condensate temperature (for steam boilers)
- Hot water thermal production and temperature (for hot water boilers)

Such system can be installed in about 12 months, and would include all necessary software, and hard ware for polling and archiving the data. The estimated cost of the system is $1,075,537.

Table C1- Summary of Cost Estimate for Monitoring 25 Power Plants at Ft. Hood.

Map ID#	Bldg #	# of Chillers	# of Boilers	Cost Estimate	NOTES
P1	410	2	1 (HW)	$ 26,870	
P2	1001	4	2 (HW)	$ 29,070	
P3	5764	1	1(S)	$ 30,020	
P4	5792	1	1(S)	$ 30,020	
P5	7050	2	1(S)	$ 30,370	
P6	7051	2	1(S)	$ 30,370	
P7	10006	2	2(S)	$ 30,370	
P8	14020	1	1 (S)	$ 30,020	To be rebuilt in 1996
P9	21002	1	2 (S)	$ 30,020	
P10	23001	1(AIR)	2(S)	$ 30,020	
P11	27004	1	2 (S)	$ 30,020	
P12	28000	2	1 (HW)	$ 26,870	
P13	29005	2	2 (S)	$ 30,370	
P14	31008	1	2 (S)	$ 30,020	
P15	34008	1	2 (S)	$ 30,020	
P16	36000	3	3 (S)	$ 37,920	
P17	36006	1	2 (S)	$ 30,020	
P18	36009	1	1 (S)	$ 30,020	
P19	39015	2	2 (S)	$ 30,370	
P20	39043	2	2 (HW)	$ 28,370	
P21	41003	1	2 (S)	$ 30,020	
P22	50001	1	1(HW)	$ 28,020	
P23	50004	3	1(HW)	$ 28,020	
P24	87018	2	2 (S)	$ 30,370	
P25	91014	1(AIR)	1(HW)	$ 28,020	
	Sub-Total Equipment & Installation			$ 745,600	
	10% Detailed Metering Plan			$ 74,560	
	Sub-Total (see Table C2)			$ 255,377	Personnel,Travel, Analysis
	Total			$ 1,075,537	

NOTES:

HW = Boilers provide hot water for space heating.
S = Boilers provide low pressure steam for space heating, and/or domestic water heating.
AIR = Chiller with air-cooled condenser.

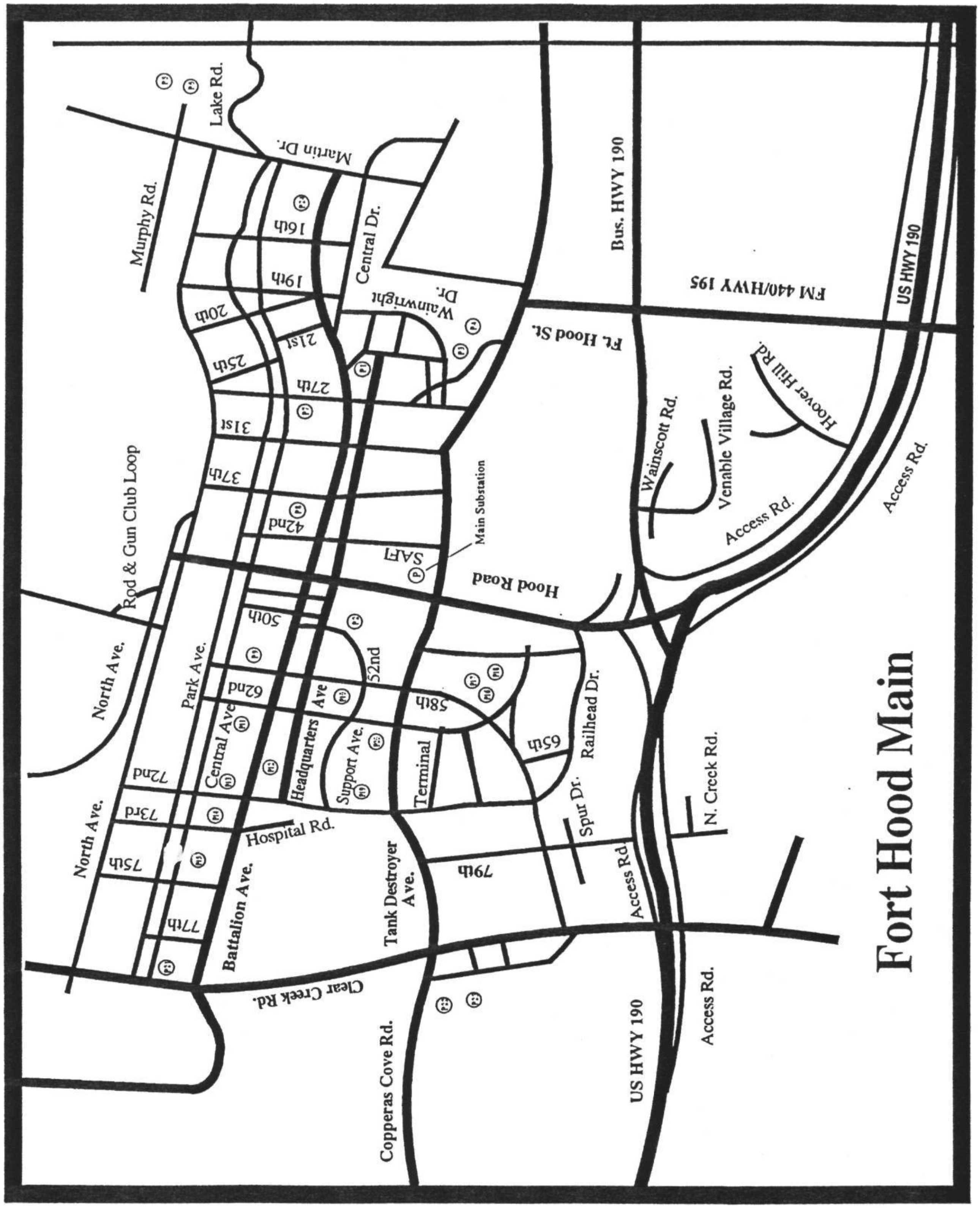
Table C2: **BUDGET DETAIL**
Ft. Hood Eng. Survey

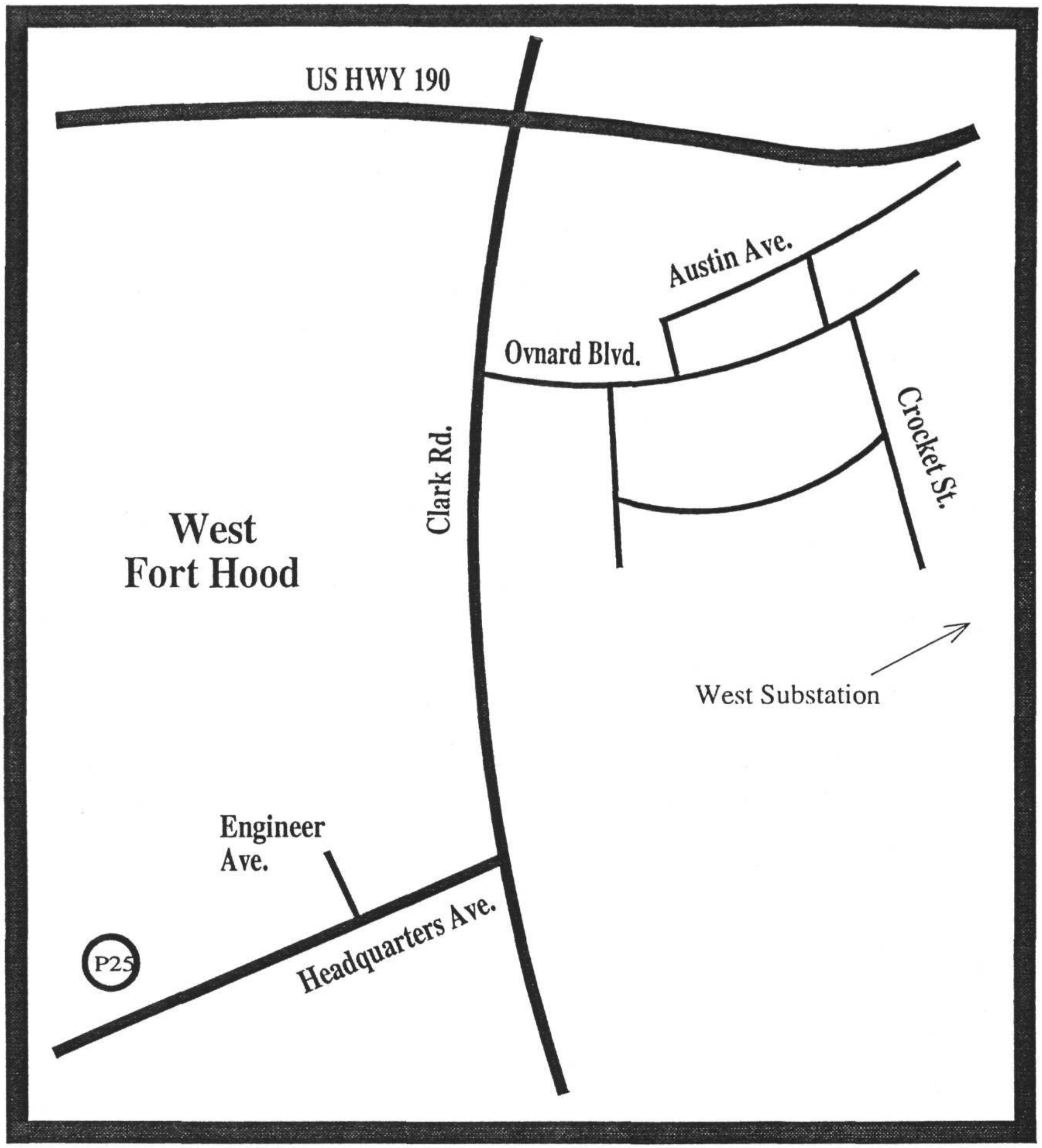
DRAFT

		Rate/Mo						Year 1
A.	**FACULTY**							
	Supervisor	$5,000		6.00	P-Mos per year			$30,000
							Total Senior Personnel	$30,000
B.	**STAFF/STUDENTS**							
	Record & Report	$3,500	@	7.00	P-Mos per year			$24,500
	Set-Up Recording	$3,500	@	6.00	P-Mos per year			$21,000
	Staff - To Be Named		@	0.00	P-Mos per year			$0
	Secretary		@	0.00	P-Mos per year			$0
	Baseline Analysis (2 Grad Students)	$1,000	@	12.00	P-Mos per year			$24,000
	Undergraduates		@	0.00	P-Mos per year			$0
							Total Other Personnel	$69,500
							Total Salaries and Wages	**$99,500**
C.	**Fringe Benefits**							
	1. Faculty and Staff at					23%		$17,365
	2. Students at					15%		$3,600
							Total Fringe Benefits	**$20,965**
D.	**Group Insurance****							
	Supervisor	Yr 1		6.00	P-Mos	@	$363 per month	$2,178
	Record & Report	Yr 1		7.00	P-Mos	@	$363 per month	$2,541
	Set-Up Recording	Yr 1		6.00	P-Mos	@	$363 per month	$2,178
	Staff - To Be Named	Yr 1		0.00	P-Mos	@	$363 per month	$0
	Secretary	Yr 1		0.00	P-Mos	@	$363 per month	$0
	Baseline Analysis (2 Grad Students)	Yr 1		24.00	P-Mos	@	$363 per month	$8,712
							Total Group Insurance	**$15,609**
							Total Salaries, Wages, Fringe Benefits & Group Insurance	**$136,074**
E.	**Permanent Equipment**							
	(Type in information)							
							Total Permanent Equipment	**$5,000**
F.	**Travel**							
	1. Domestic Travel							$36,600
	2. Foreign Travel							$0
	3. Consultant Travel							$0
							Total Travel	**$36,600**

Table C2 (Continued)

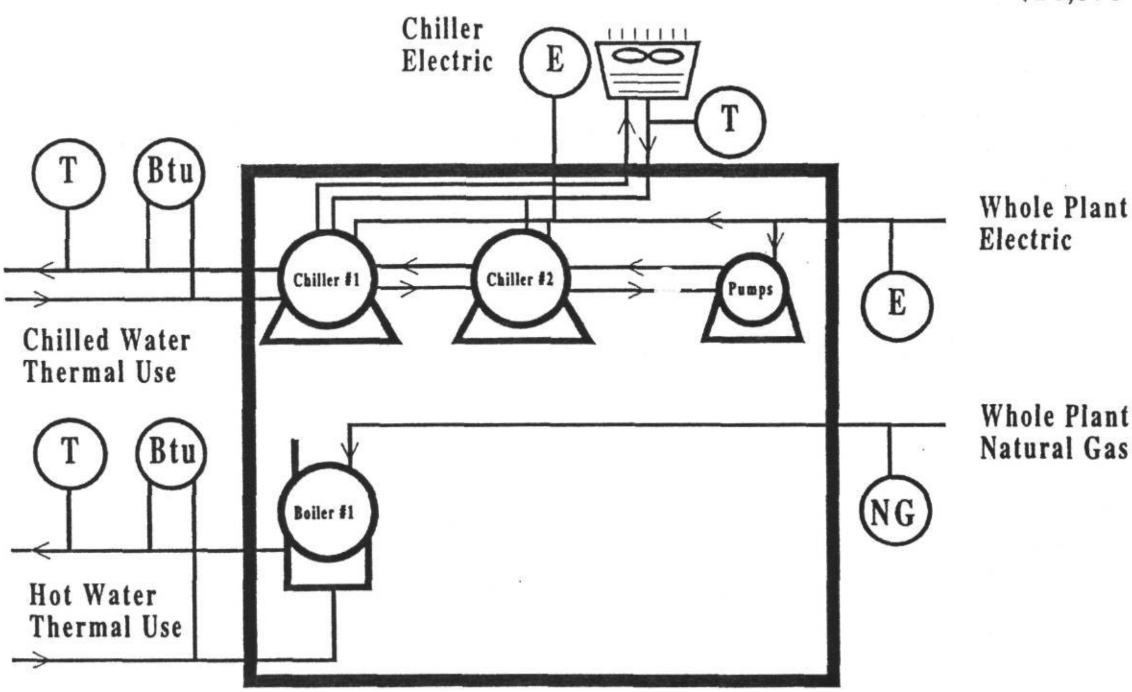
G.	**Other Direct Costs** - Included in MTDC		
	1. Consultants (travel costs included in Travel Section)		$0
	2. Telephone, Fax, Airborne		$0
	3. Publication/Page Charges, Photocopying		$0
	4. Materials & Lab Supplies		$0
	5. Computer Software		$0
	6. Computer Connect Charges		$0
	7. Office Supplies		$0
	8. Lab Equipment under $500		$0
	9. Rental/Equipment Use Fees		$0
	10. Other		$0
		Total Other Direct Costs - *Included in MTDC*	**$0**
H.	**Other Direct Costs** - *Not included in MTDC*		
	1. Sub-Recipient	(See attached)	$0
	2. Computer Charges		$0
	3. Participant Support Costs		$0
	4. Student Stipends		$0
		Total Other Direct Costs - *Not Included in MTDC*	**$0**
I.	**Modified Total Direct Costs** (MTDC)		**$172,674**
J.	**Total Direct Costs**		**$177,674**
K.	**Indirect Costs**		
	Rate negotiated with the DHHS	45.0% MTDC	**$77,703**
L.	**Total Project Costs**		**$255,377**


Fort Hood Main
Lake Rd.
Murphy Rd.
Martin Dr.
16th
19th
20th
21st
25th
27th
31st
37th
42nd
50th
52nd
58th
62nd
65th
72nd
73rd
75th
77th
79th
Central Dr.
Wainwright Dr.
Bus. HWY 190
FM 440/HWY 195
US HWY 190
Ft. Hood St.
Hoover Hill Rd.
Venable Village Rd.
Wainscott Rd.
Access Rd.
Main Substation
SAFT
Hood Road
Rod & Gun Club Loop
North Ave.
Park Ave.
Central Ave.
Headquarters Ave
Support Ave.
Terminal
Railhead Dr.
Spur Dr.
N. Creek Rd.
Hospital Rd.
Battalion Ave.
Tank Destroyer Ave.
Clear Creek Rd.
Copperas Cove Rd.


US HWY 190
Austin Ave.
Ovnard Blvd.
Crocket St.
Clark Rd.
West
Fort Hood
West Substation
Engineer
Ave.
Headquarters Ave.
P25

Monitoring Proposal for Ft. Hood: PLANT (P1)

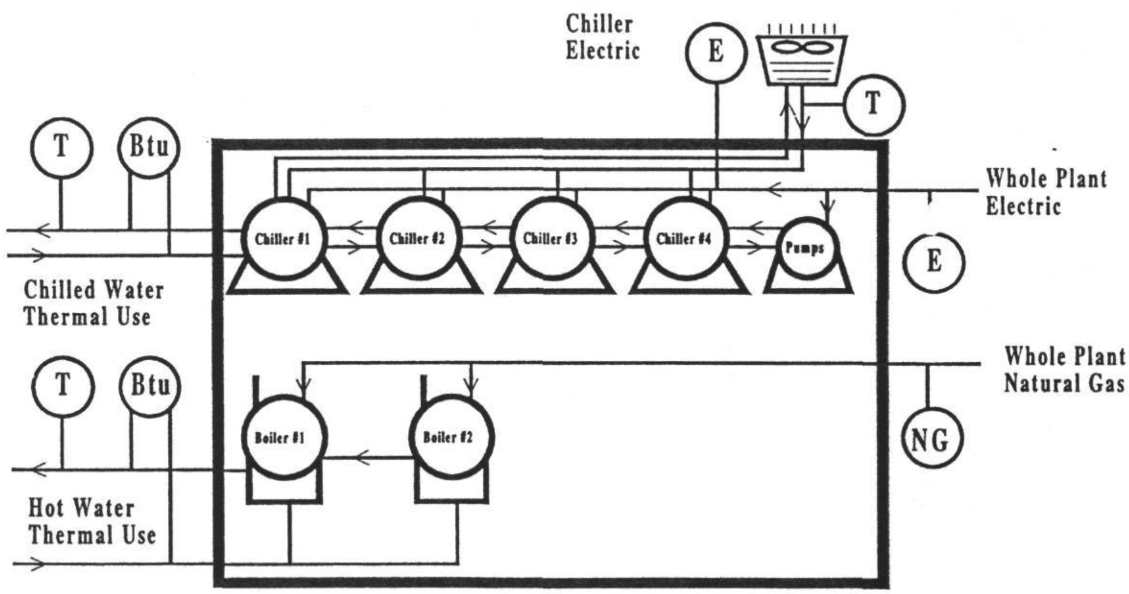
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
410	Whole-Building Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$1,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				2	$1,000
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu			1		$3,000
	Logger Channels	1	7	3	4	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$26,870



Bldg 410

Monitoring Proposal for Ft. Hood: (P2)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
1001	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chiller #3 Electric		2			$350
	Chiller #4 Electric		2			$350
	Chilled Water Temperature				2	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu			1		$3,000
	Logger Channels	1	11	3	4	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$29,070

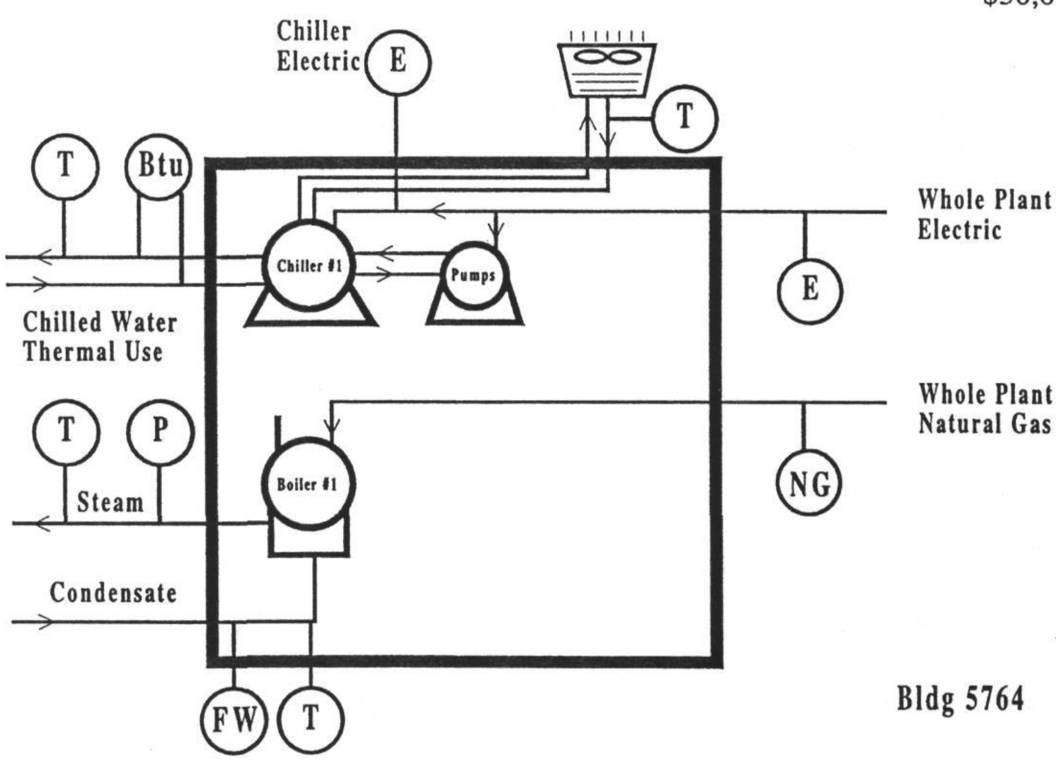


Bldg 1001

Monitoring Proposal for Ft. Hood: (P3)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
5764	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	-------	---------	------	------	------------	
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

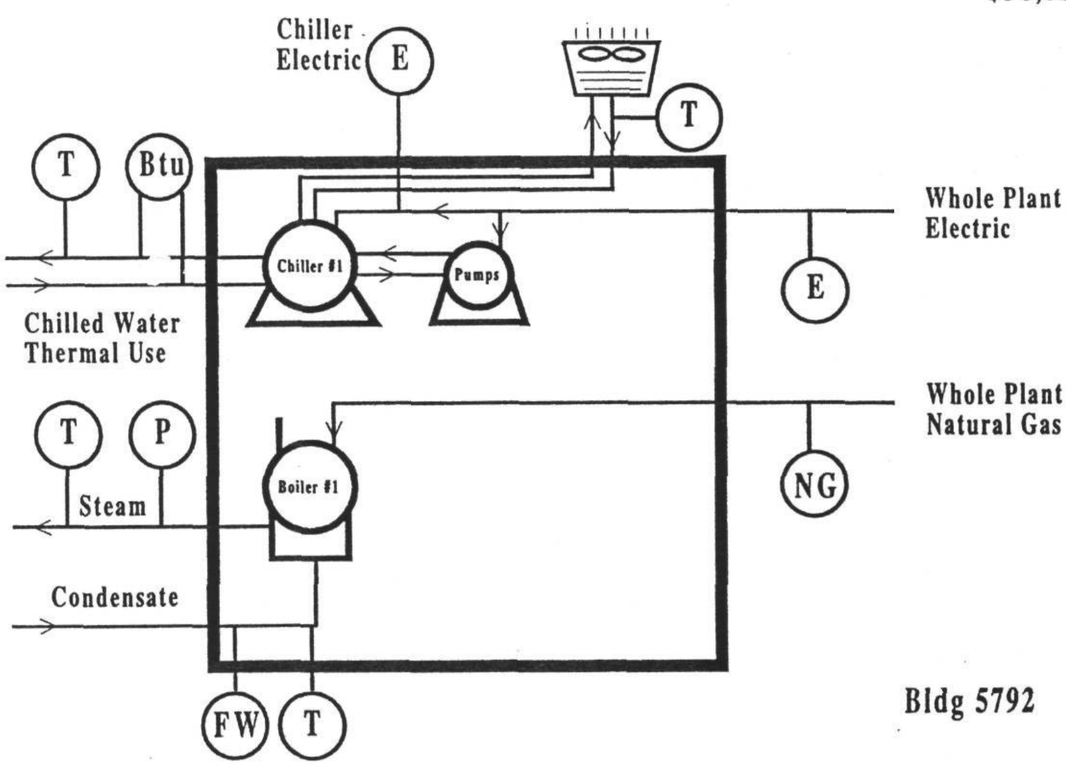
						$30,020



Bldg 5764

Monitoring Proposal for Ft. Hood: (P4)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
5792	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,020

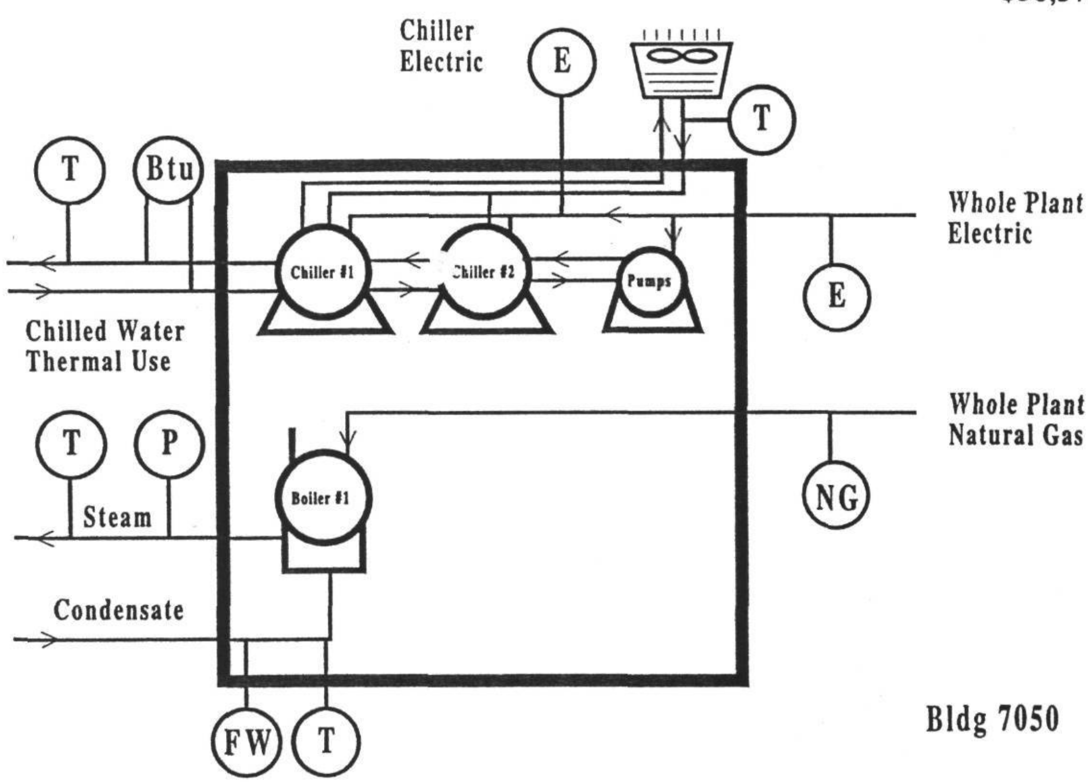


Bldg 5792

Monitoring Proposal for Ft. Hood: (P5)

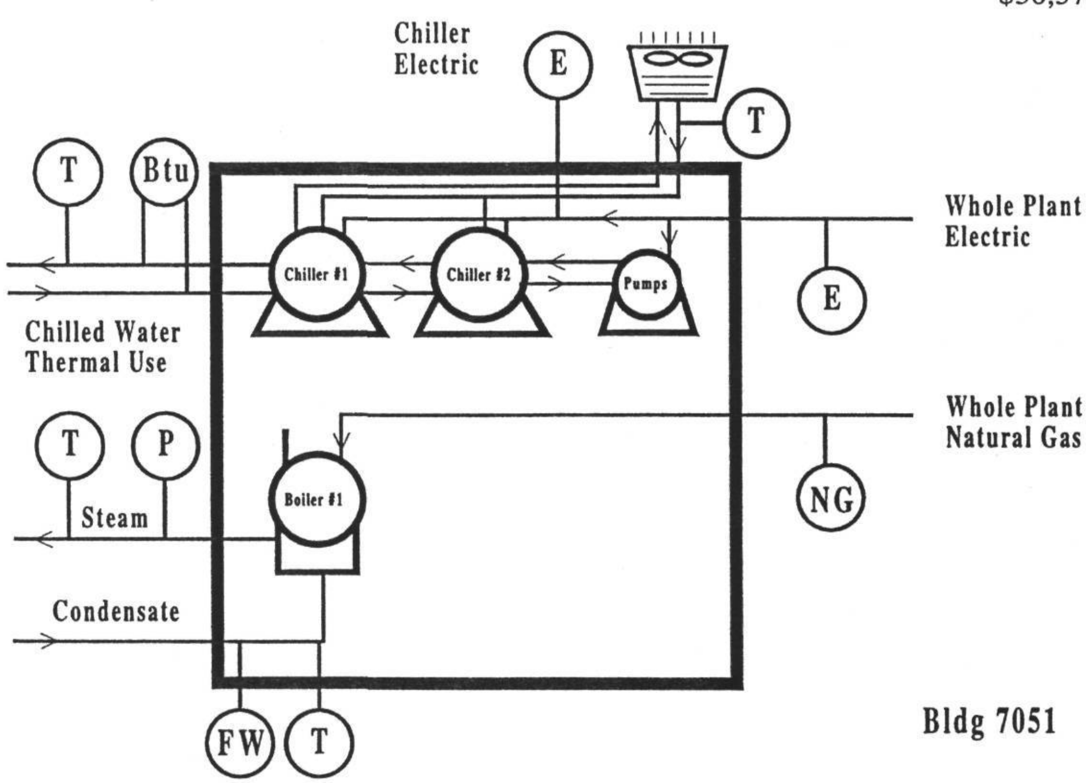
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
7050	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
		-------	---------	------	------	------------
	Logger Channels	1	7	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration					
	(10 days x 2 peo x 8 x $50)					$8,000

						$30,370



Monitoring Proposal for Ft. Hood: (P6)

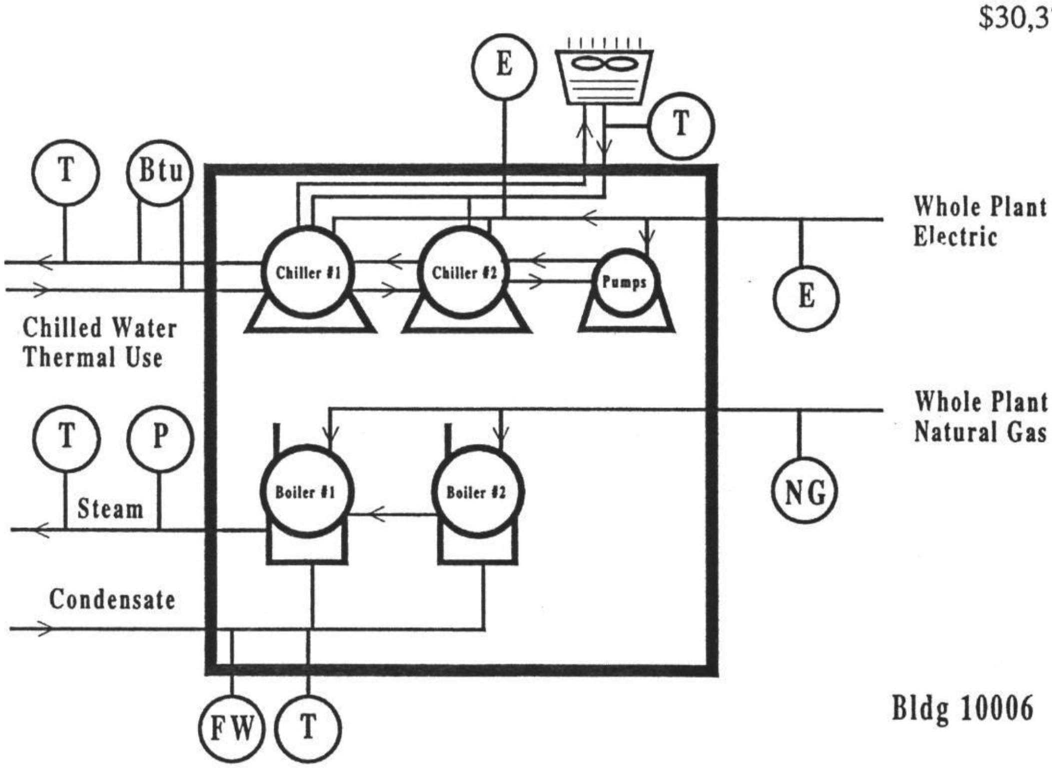
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
7051	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	7	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,370



Monitoring Proposal for Ft. Hood: (P7)

BUILDING	PTs	CTs	Dig	Ana.	Tot.Cost
10006 Whole-Plant Electric	1	3			$1,000
Whole-Plant Natural Gas			1		$3,000
Chiller #1 Electric		2			$350
Chiller #2 Electric		2			$350
Chilled Water Temperature				1	$500
Condensor Temperature				1	$500
Whole Plant Chilled Water Btu			1		$3,000
Boiler Feed Water Flow			1		$3,000
Steam Pressure				1	$1,000
Steam Temperature				1	$1,000
Condensate Temperature				1	$500
	-------	----------	------	------	-----------
Logger Channels	1	7	3	5	
Synergistics Logger & Modem	C-140E-A-N1				$3,170
Wiring, phone hook-up, misc.					$5,000
Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

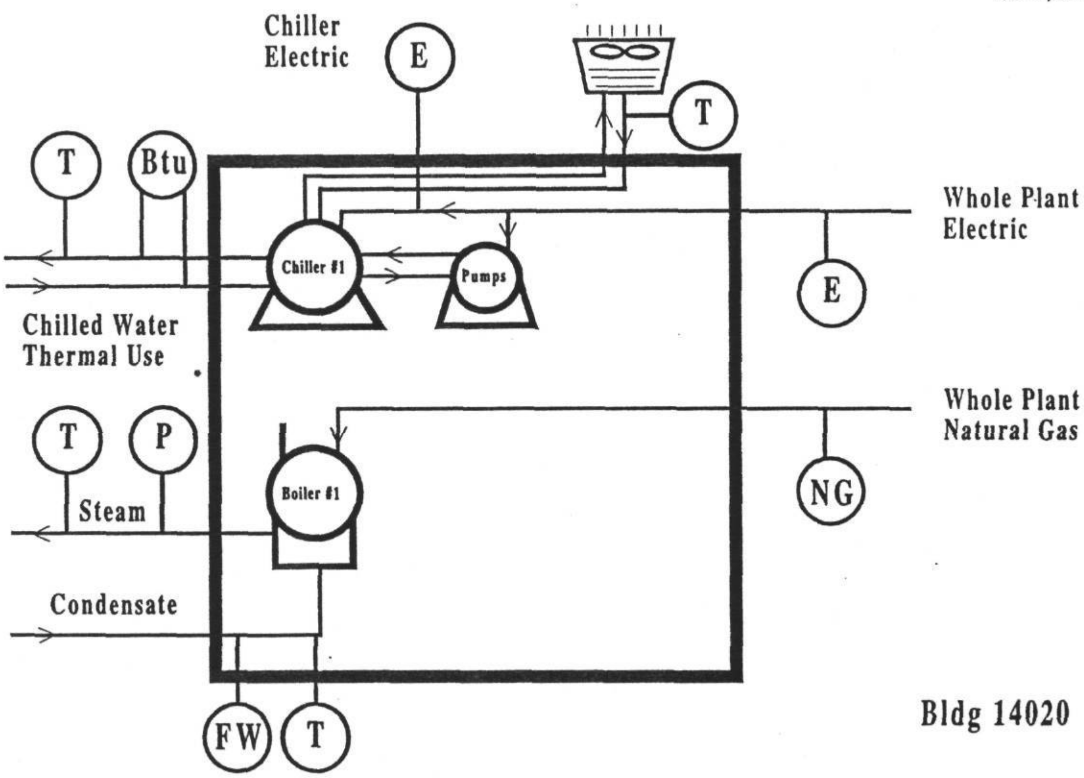
					$30,370



Bldg 10006

Monitoring Proposal for Ft. Hood: (P8)

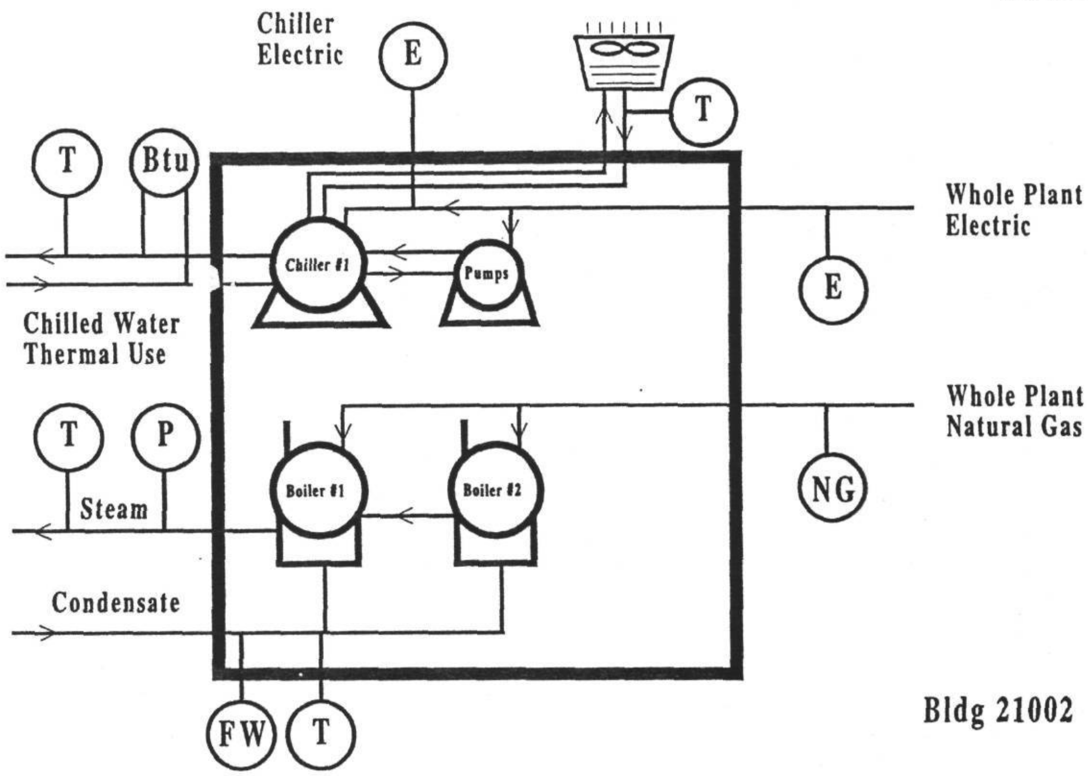
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
14020	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,020



Monitoring Proposal for Ft. Hood: (P9)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
21002	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	-------	---------	------	------	------------	
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

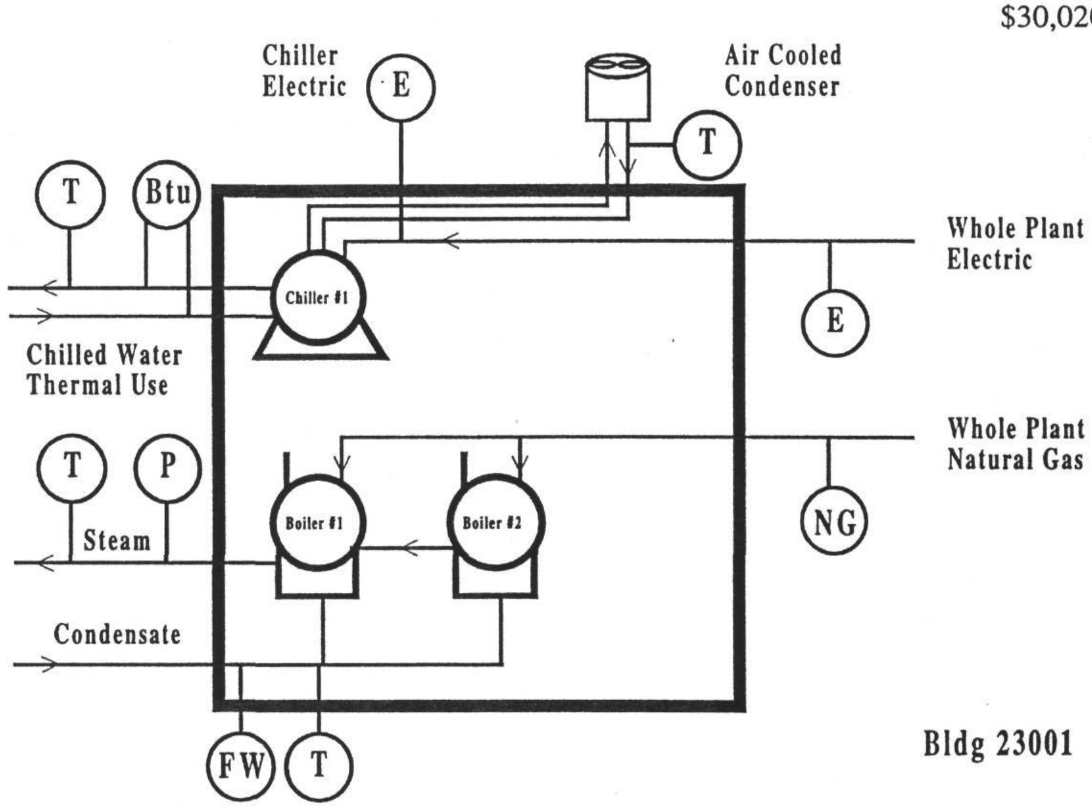
						$30,020



Monitoring Proposal for Ft. Hood: (P10)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
23001	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temp. (Refrigerant)				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
		-------	---------	------	------	------------
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

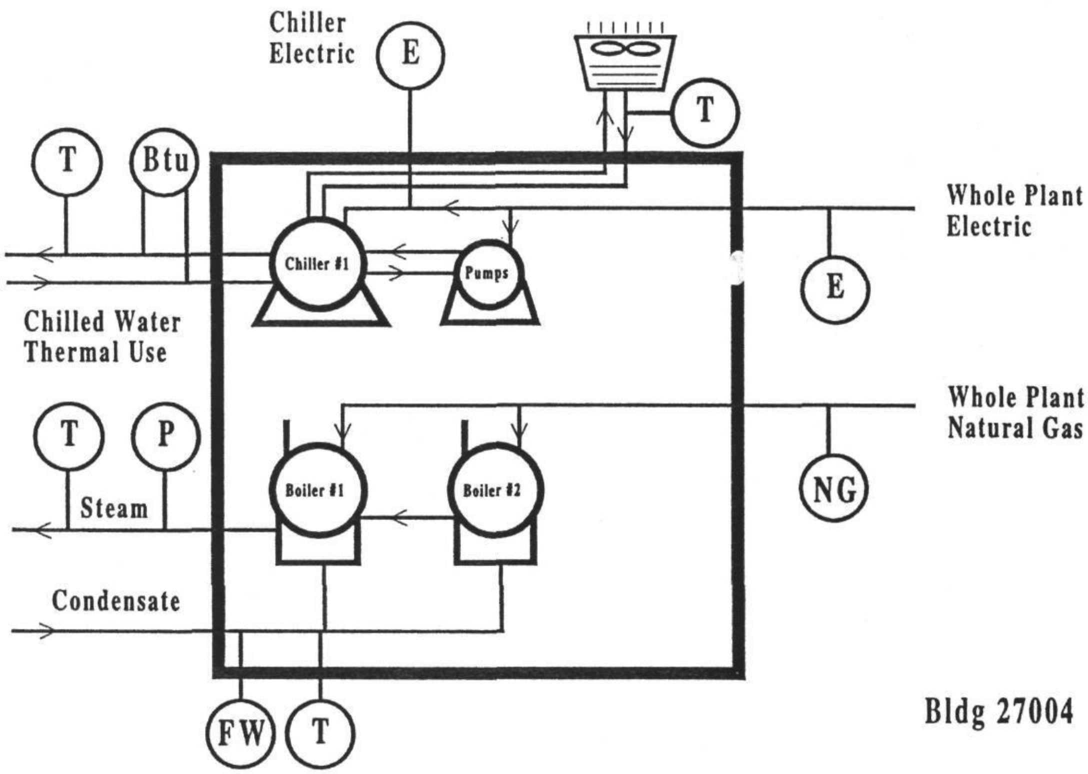
						$30,020



Monitoring Proposal for Ft. Hood: (P11)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
27004	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
		-------	----------	------	------	-----------
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

						$30,020

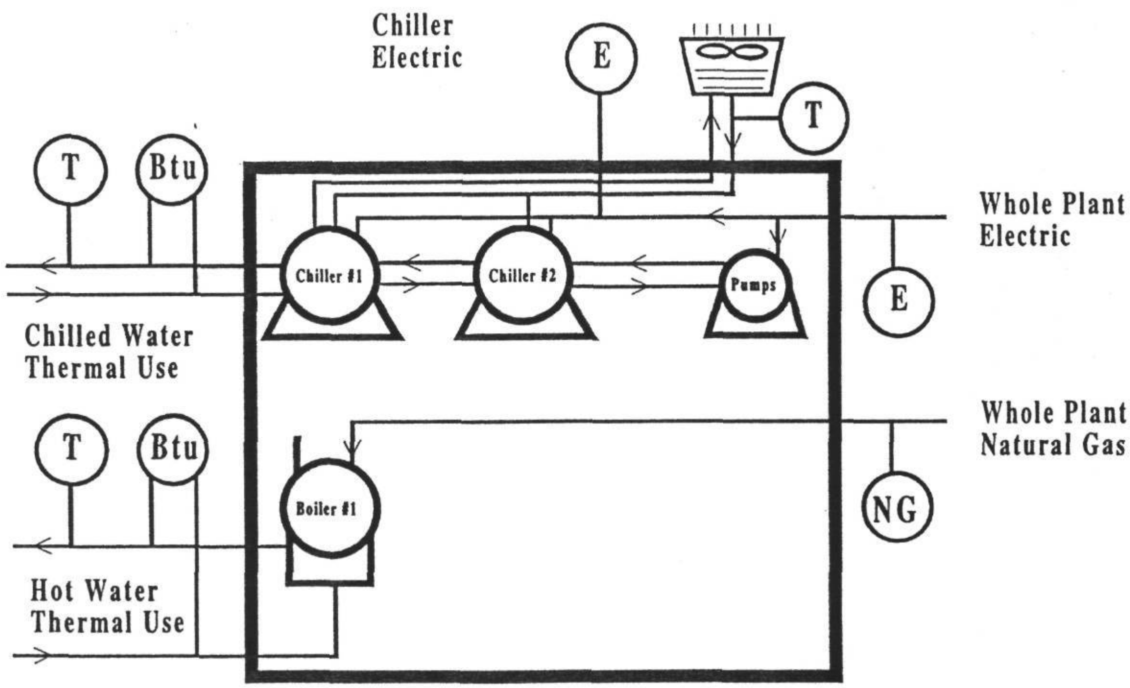


Bldg 27004

Monitoring Proposal for Ft. Hood: PLANT (P12)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
28000	Whole-Building Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$1,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				2	$1,000
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu			1		$3,000
		-------	---------	------	------	-----------
	Logger Channels	1	7	3	4	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

						$26,870

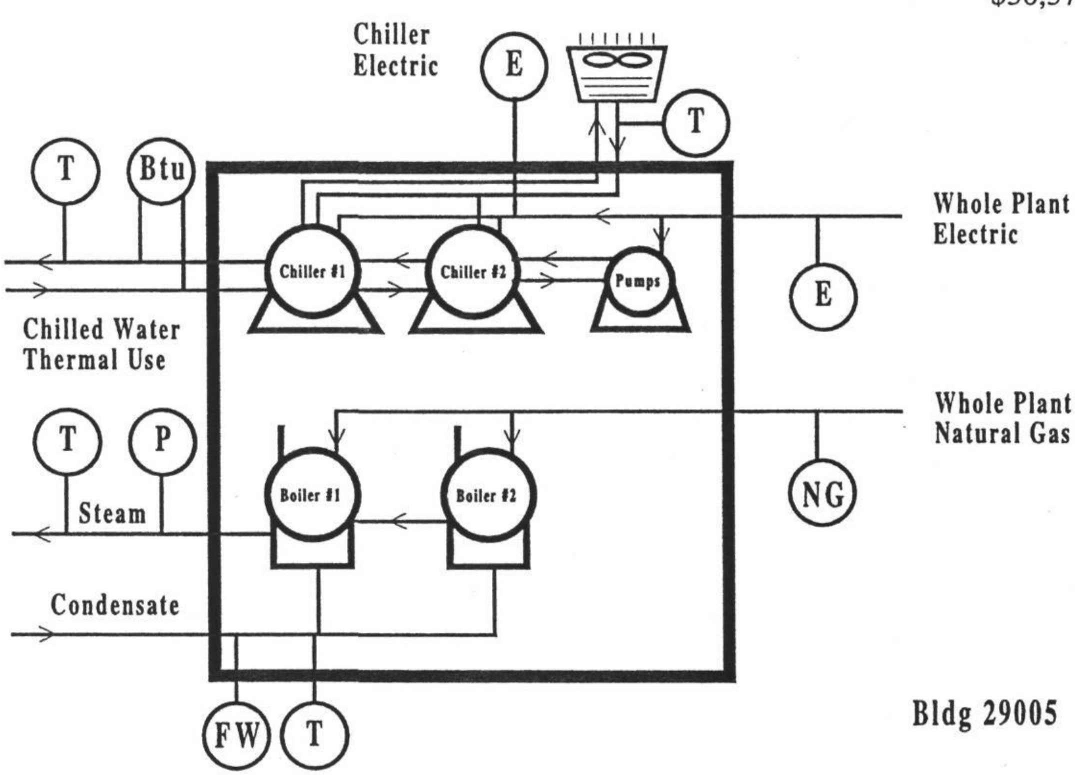


Bldg 28000

Monitoring Proposal for Ft. Hood: (P13)

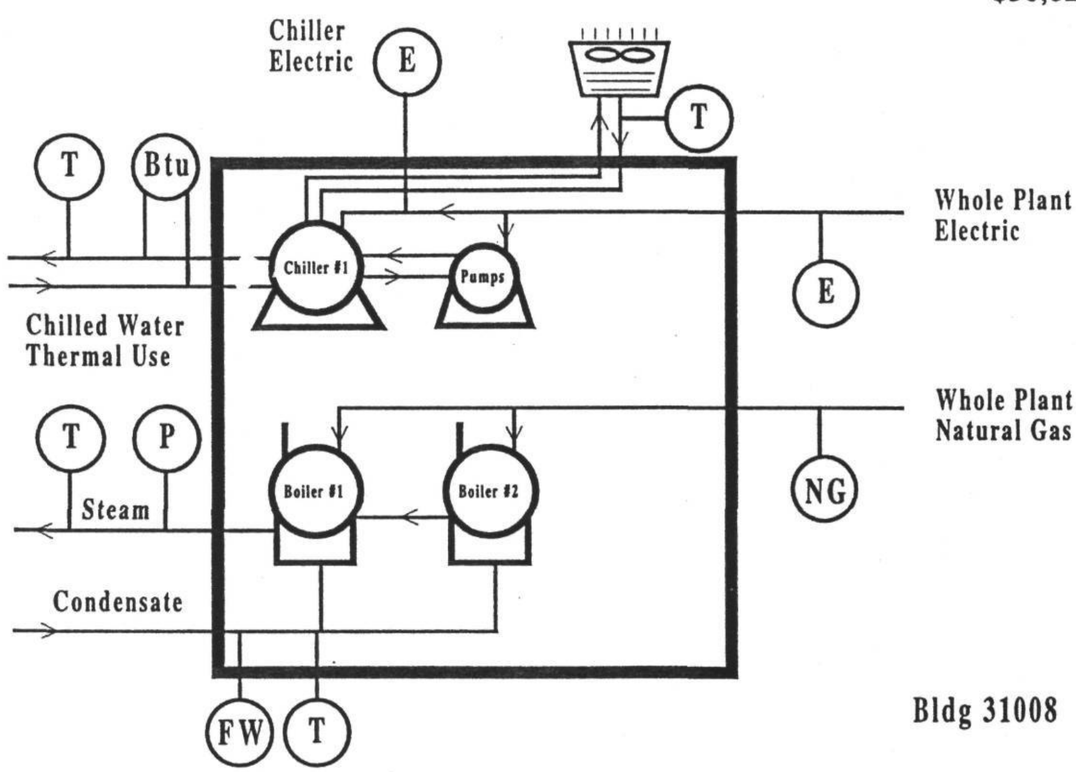
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
29005	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	-------	-------	---------	------	------	------------
	Logger Channels	1	7	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

						$30,370



Monitoring Proposal for Ft. Hood: (P14)

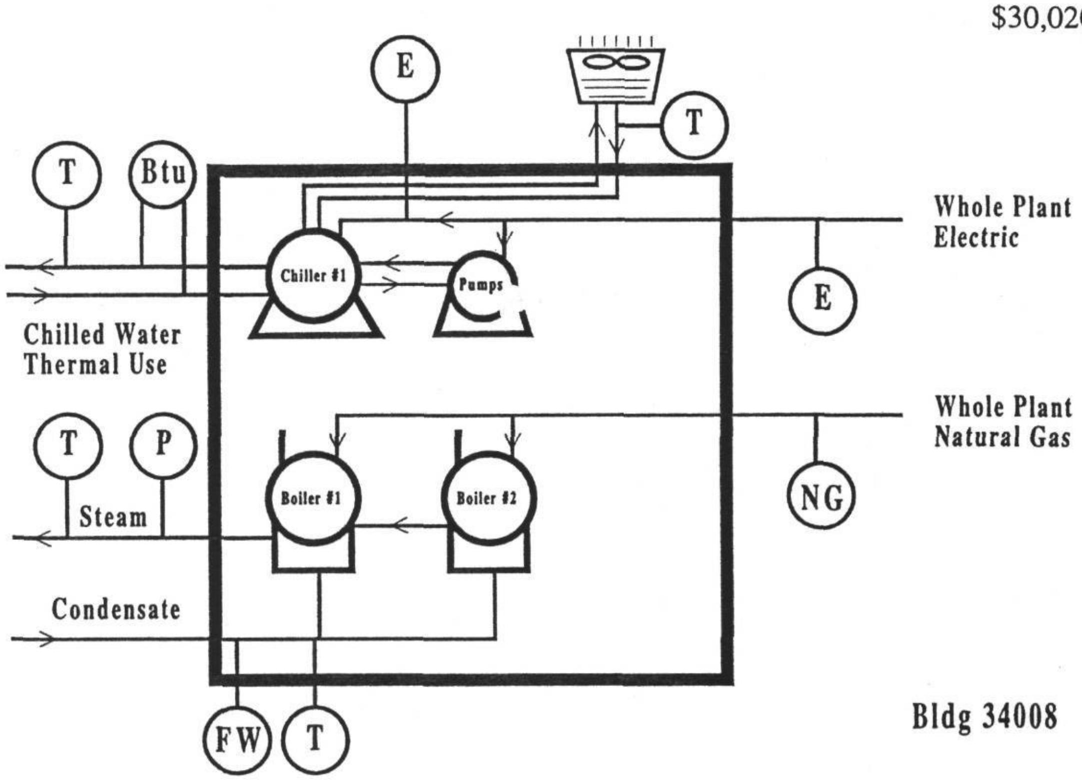
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
31008	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,020



Monitoring Proposal for Ft. Hood: (P15)

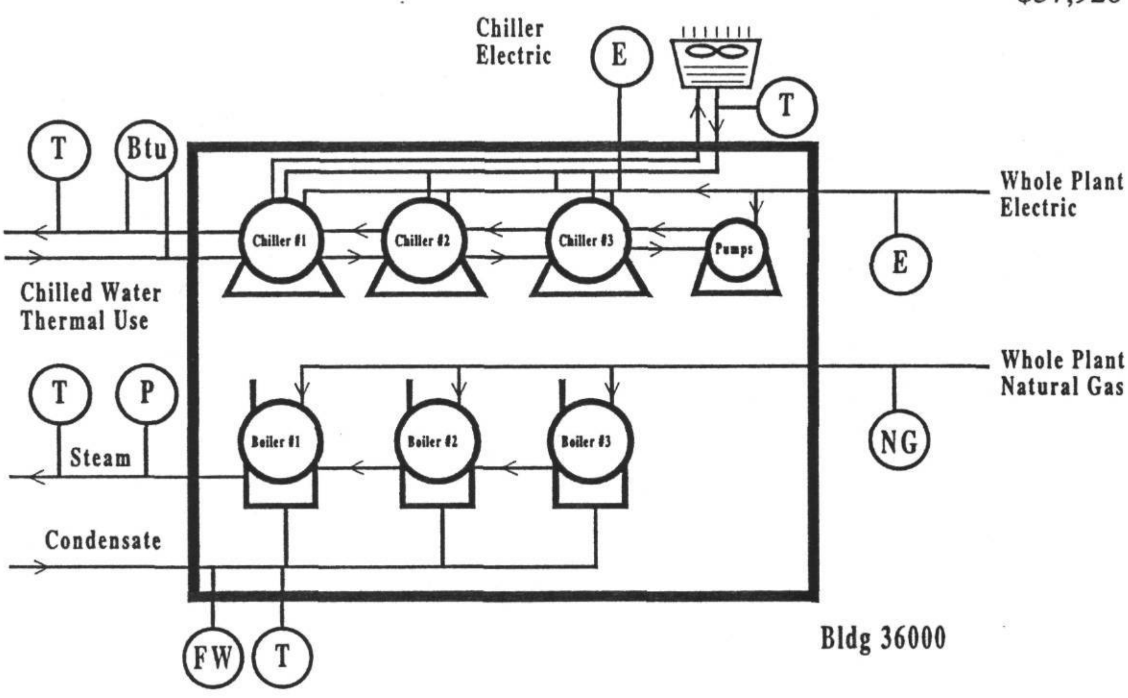
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
34008	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
		-------	----------	------	------	-----------
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

						$30,020



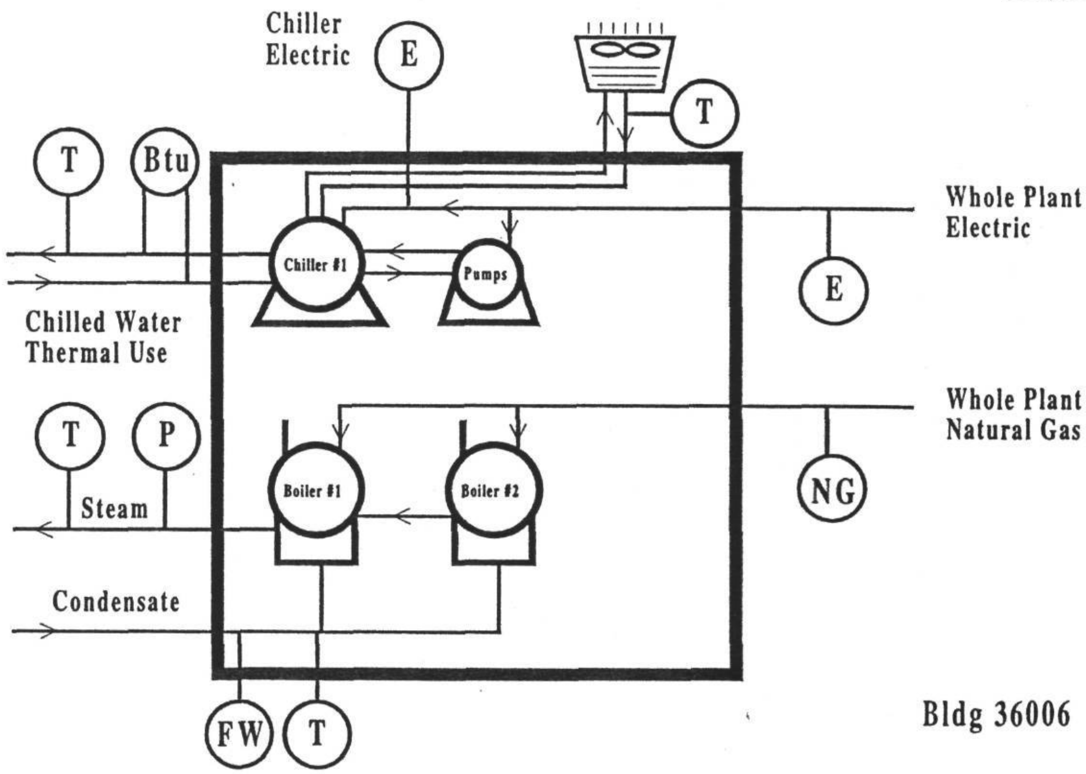
Monitoring Proposal for Ft. Hood: (P16)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
36000	Whole-Building Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$1,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chiller #3 Electric		2			$350
	Chilled Water Temperature				3	$1,500
	Condensor Temperature				2	$1,000
	Whole Plant Chilled Water Btu			3		$9,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	9	4	8	
	Synergistics Logger & Modem	C-160				$3,870
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (15 days x 2 peo x 8 x $50)					$12,000
						$37,920



Monitoring Proposal for Ft. Hood: (P17)

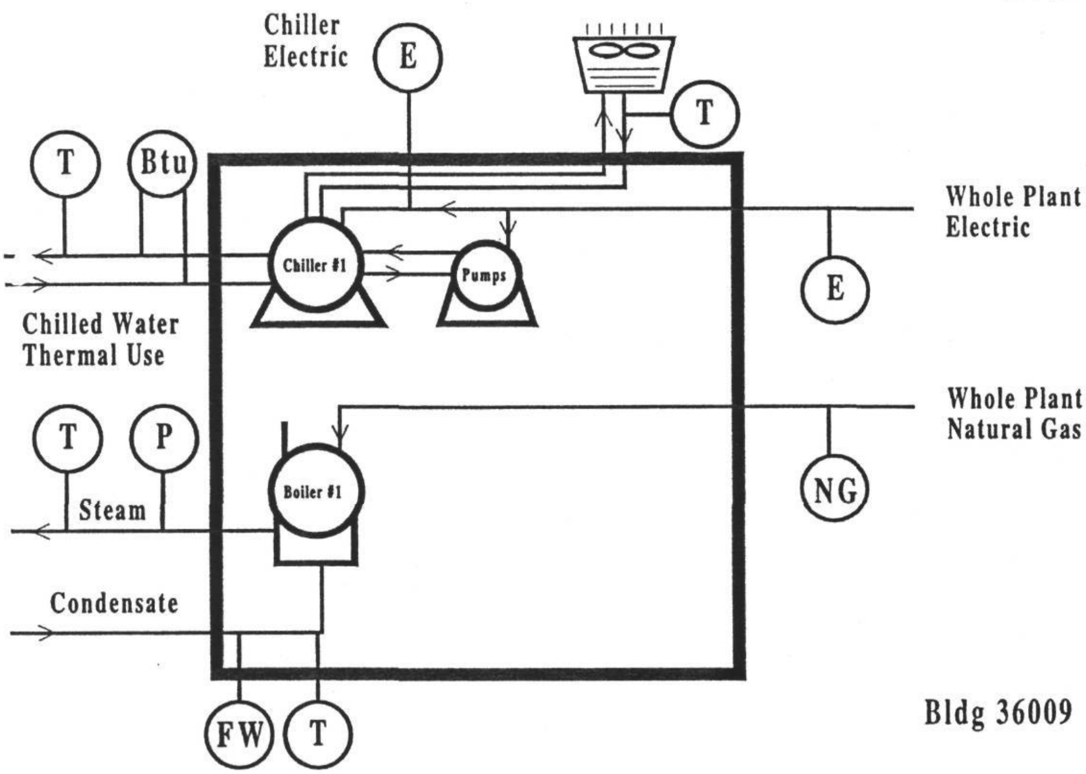
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
36006	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,020



Bldg 36006

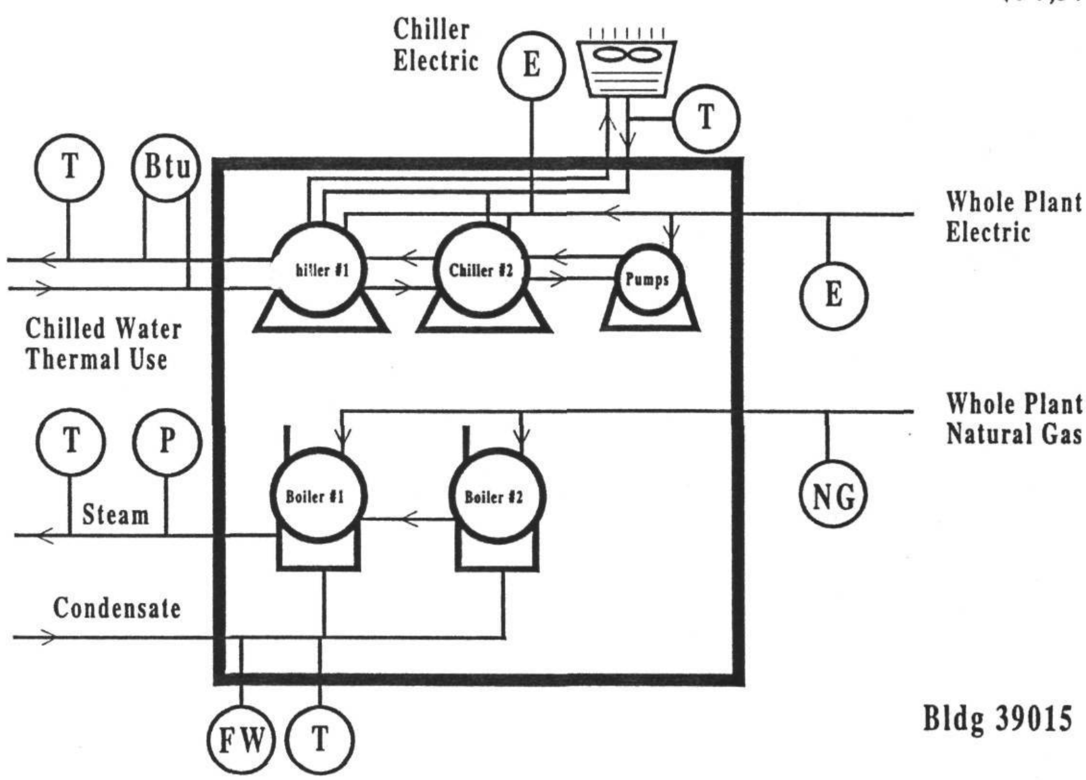
Monitoring Proposal for Ft. Hood: (P18)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
36009	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,020



Monitoring Proposal for Ft. Hood: (P19)

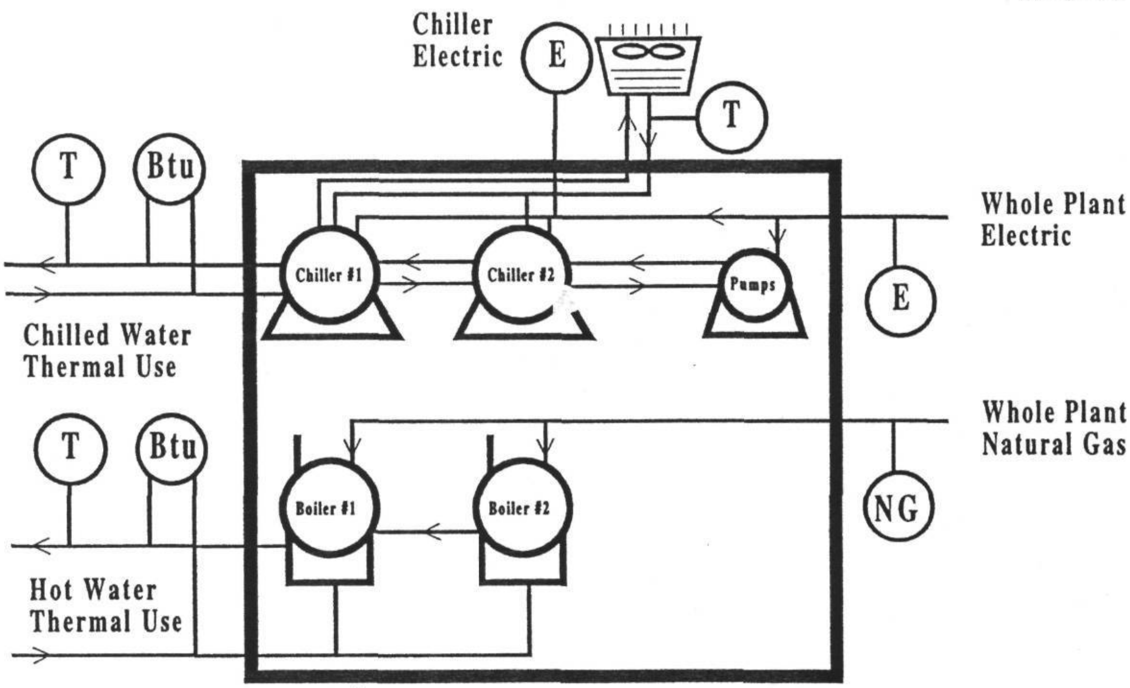
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
39015	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	7	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,370



Monitoring Proposal for Ft. Hood: (P20)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
39043	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu			1		$3,000
		-------	---------	------	------	------------
	Logger Channels	1	7	3	3	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

						$28,370

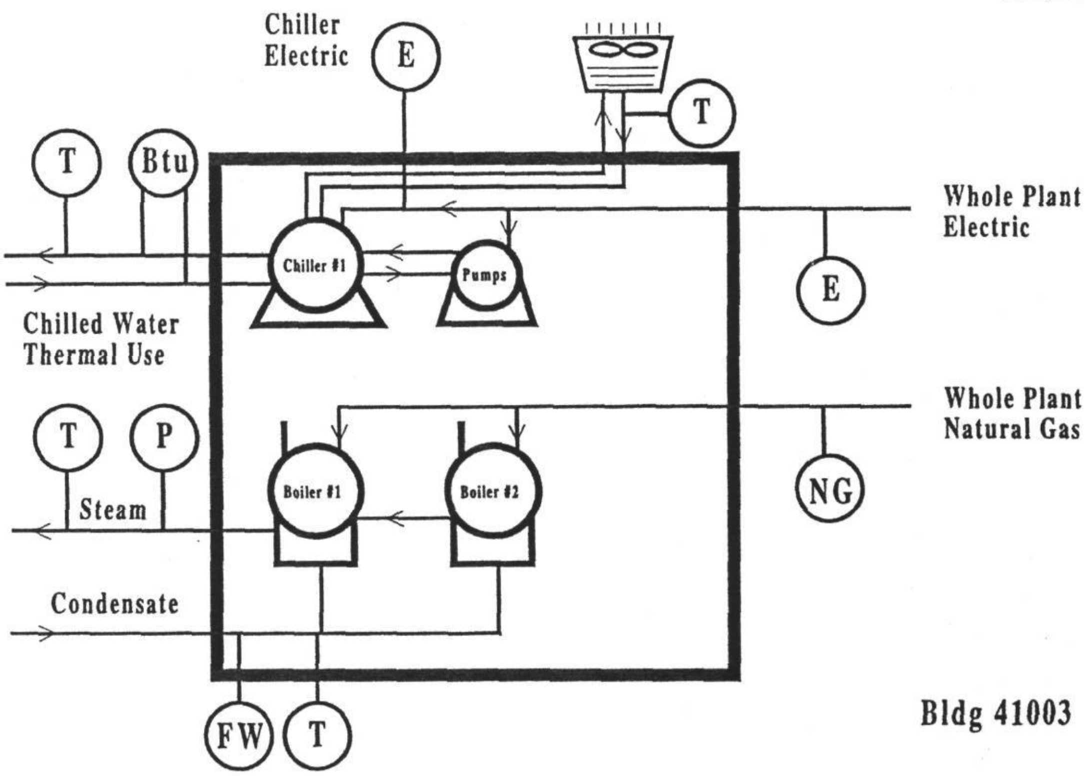


Bldg 39043

Monitoring Proposal for Ft. Hood: (P21)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
41003	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
		-------	---------	------	------	------------
	Logger Channels	1	5	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

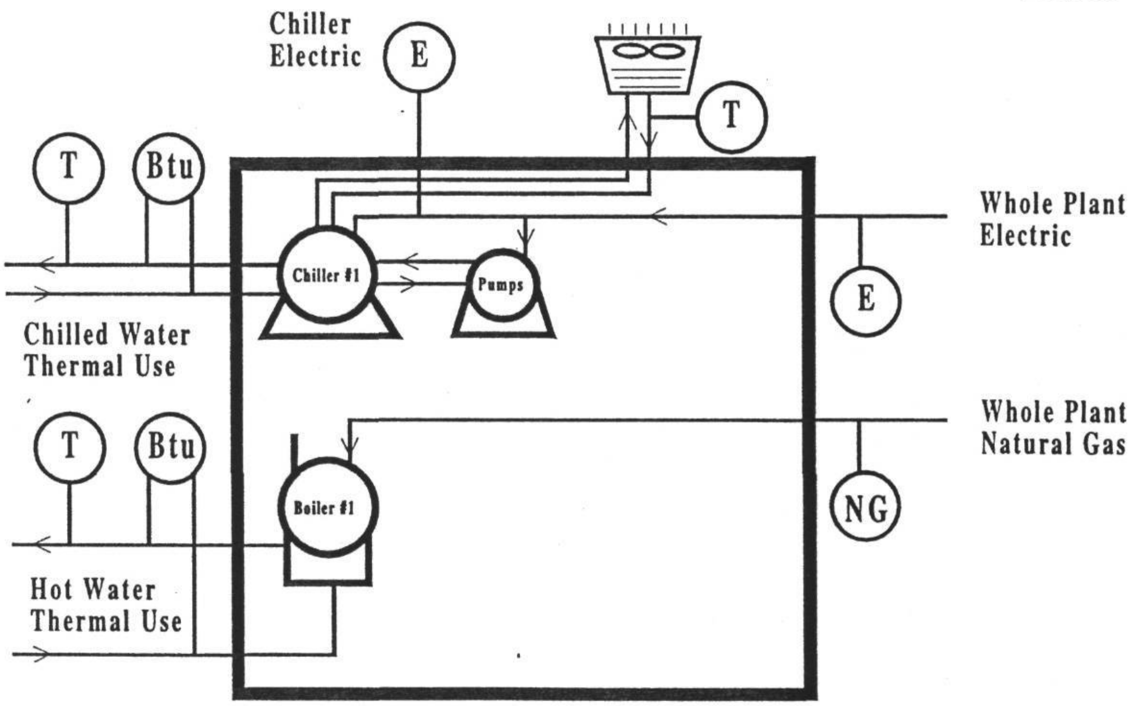
						$30,020



Monitoring Proposal for Ft. Hood: (P22)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
50001	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temp. (Refrigerant)				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu				1	$3,000
		-------	---------	------	------	------------
	Logger Channels	1	5	2	4	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

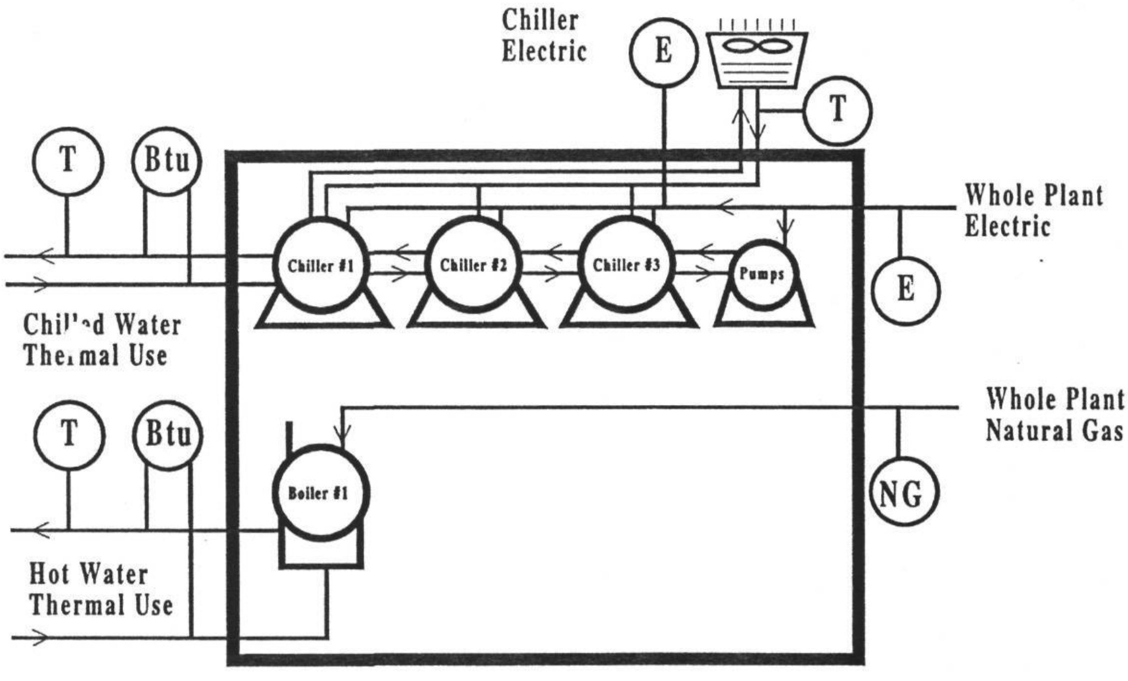
						$28,020



Bldg50001

Monitoring Proposal for Ft. Hood: (P23)

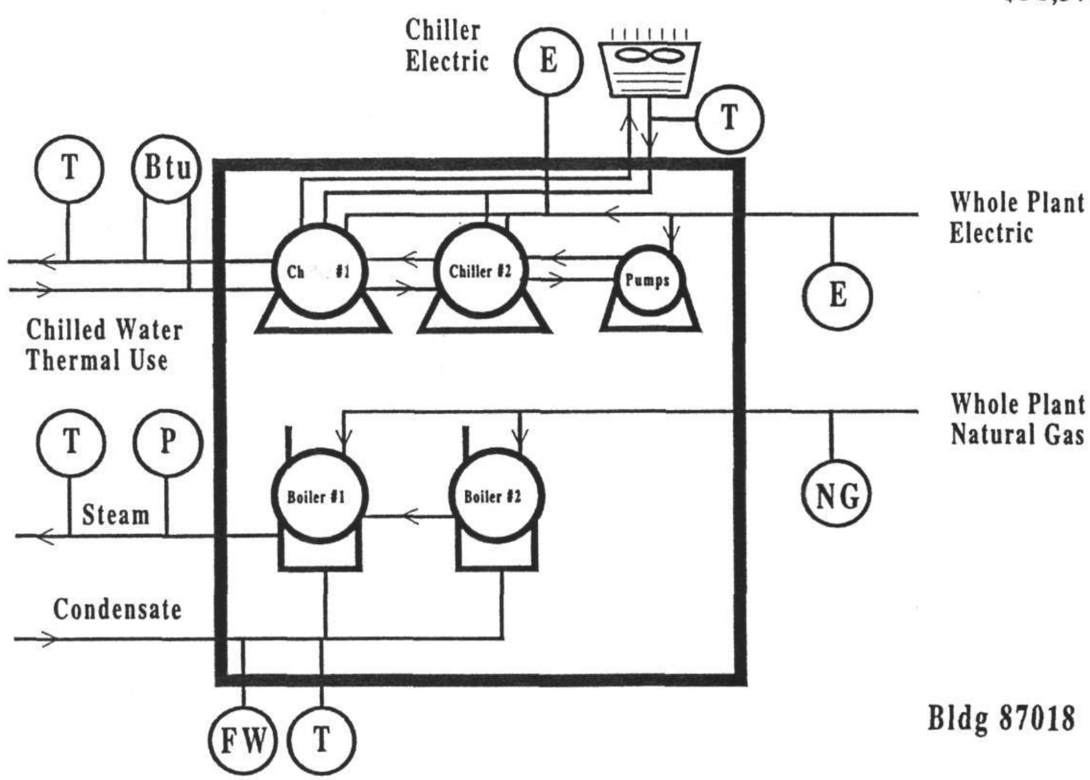
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
50004	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temp. (Refrigerant)				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu				1	$3,000
	Logger Channels	1	5	2	4	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$28,020



Bldg 50004

Monitoring Proposal for Ft. Hood: (P24)

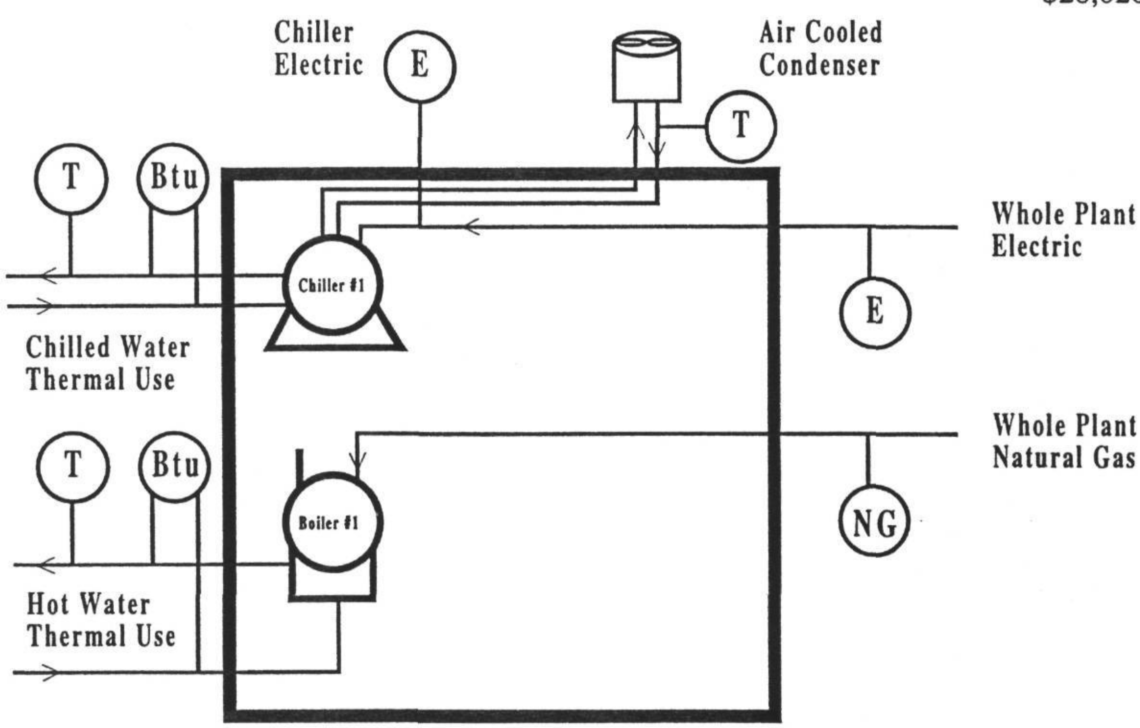
BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
87018	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chiller #2 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temperature				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Boiler Feed Water Flow			1		$3,000
	Steam Pressure				1	$1,000
	Steam Temperature				1	$1,000
	Condensate Temperature				1	$500
	Logger Channels	1	7	3	5	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000
						$30,370



Monitoring Proposal for Ft. Hood: (P25)

BUILDING		PTs	CTs	Dig	Ana.	Tot.Cost
91014	Whole-Plant Electric	1	3			$1,000
	Whole-Plant Natural Gas			1		$3,000
	Chiller #1 Electric		2			$350
	Chilled Water Temperature				1	$500
	Condensor Temp. (Refrigerant)				1	$500
	Whole Plant Chilled Water Btu			1		$3,000
	Hot Water Temperature				1	$500
	Whole Plant Hot Water Btu			1		$3,000
		-------	--------	-------	-------	-------------
	Logger Channels	1	5	3	3	
	Synergistics Logger & Modem	C-140E-A-N1				$3,170
	Wiring, phone hook-up, misc.					$5,000
	Installation & calibration (10 days x 2 peo x 8 x $50)					$8,000

						$28,020



Bldg 91014

APPENDIX C1

SYNERGISTIC LOGGERS INFORMATION

WIN YOUR BATTLES WITH ACCURATE, RELIABLE WEAPONS FROM THE SYNERGISTIC ARSENAL

Synergistic Control Systems is the leading supplier of meters/recorders that meet the accurate and intense data requirements of end-use/load research programs, performance evaluation, and measurement and verification of demand-side management programs. The product line integrates electric power, analog and digital measurements into a single, solid-state device, capable of internal calculations (including waveform analysis and Btu calculations) and storage of time-series data. It is ideally suited for data acquisition projects that require a correlation of thermal and electrical energy usage (e.g. chiller efficiency) or the relationship between environmental conditions (indoor/outdoor temperature and humidity) and energy consumption patterns.

The SYNERNET™ software package provides a pull-down menu format for meter initialization, viewing of real-time data, and retrieval of time-series data. Local and modem communications can manually or automatically collect and store data in formats compatible with popular spreadsheet and analysis packages. Using a PC, the user can download a parameter set to the meter which defines the operating parameters needed to collect the desired data. This parameter set includes items such as potential and current transducer ratios, scale factors and types of analog sensors, and selection of data and intervals for recording.

An important feature of the Synergistic data loggers is their ability to store data in a compressed format for later retrieval by a remote host computer. The data storage interval may be varied during the day so that frequent intervals can be selected during high-demand periods, while less frequent intervals can be used during off-peak times to conserve memory. The recorders can be configured with up to a megabyte of solid-state memory – enough to store months of data, depending on the data items and recording intervals selected.

The Harmonic Analysis Option allows the units to gather detailed waveform data that is used by SYNERNET™ to graphically display time/frequency-domain waveshapes, and to measure harmonic amplitudes, total harmonic distortion and other related information.

Model Numbers	Potential Inputs (3 phases)	Current Inputs	Digital Inputs	Analog Inputs *(optional)	Digital Outputs
C180E	2	16	16	* 15	8
C160E	2	16	8	8	-
C150E	2	16	8	8	-
C140E	2	8	8	*8	8
C120E	1	4	4	*4	4
B-40	-	-	4	-	-
B-80	-	-	8	-	-

SYNERGISTIC
CONTROL SYSTEMS, INC.
2700 Lake Villa Drive Suite 180
Metairie, LA 70002
(504) 885-8180 • (504) 885-1180 FAX

SYNERGISTIC CONTROL SYSTEMS, INC.

PRICE LIST
Effective September 1, 1994

MODEL C160E METER/RECORDER

Each Model C160E unit includes 2 potential transducer (PT) input channels (one PT is provided with each unit; an optional second PT is sold separately), 16 current transducer (CT) input channels (CTs are sold separately), 8 digital input channels, no digital output channels, 8 analog input channels, 128KB memory, a DC-loop/RS232 communication interface module and a 120VAC to 24VAC transformer for powering the unit.

Part Number	Description	Price
C160E-A-N1	MODEL C160E METER/RECORDER WITH ANALOGS, NEMA 1 Basic C160E (as described above; includes 8 analog input channels for monitoring 0-5VDC, 4-20mA or 1000-ohm RTD sensors) packaged in a 14"x12"x4" NEMA 1 enclosure.	3,595
C160E-A-N4	MODEL C160E METER/RECORDER WITH ANALOGS, NEMA 4 Same as C160E-A-N1 above, except packaged in a 14"x12"x6" NEMA 4 enclosure.	3,795

MODEL C160E OPTIONS

RAM-256K	MEMORY UPGRADE TO 256KB	200
RAM-512K	MEMORY UPGRADE TO 512KB	400
RAM-1024K	MEMORY UPGRADE TO 1024KB	800
MDM-2400	MODEM, HAYES-COMPATIBLE 1200/2400 BAUD Compact internal modem plugs into communication interface module.	275
PT-1	THREE-PHASE POTENTIAL TRANSDUCER Required only if the second three-phase voltage metering input is to be used.	175
HARM-1	HARMONIC ANALYSIS OPTION This option allows the Synergistic meter/recorder to gather detailed waveform data which is used by the Synernet PC-based software to graphically display voltage and current waveforms, and to compute and display harmonic amplitudes (fundamental frequency through 16th harmonic) and total harmonic distortion.	295
PCL-180	PROTOCOL OPTION This firmware option causes the meter/recorder to use the original C180 communication protocol; it is intended to support users of the original C180 whose host software may not yet have been upgraded to support the C180E protocol. Some features of the C180E, including cumulative KWH recording, harmonic analysis and automatic baudrate selection are not available if this option is selected; however, expanded memory is available.	N/C

Form PL9409-2

SYNERGISTIC
CONTROL SYSTEMS, INC.

PRICE LIST
Effective September 1, 1994

MODEL C140E METER/RECORDER

Each Model C140E unit includes 2 potential transducer (PT) input channels (one PT is provided with each unit; an optional second PT is sold separately), 8 current transducer (CT) input channels (CTs are sold separately), 8 digital input channels, 8 digital output channels, 128KB memory, a DC-loop/RS232 communication interface module and a 120VAC to 24VAC transformer for powering the unit.

Part Number	Description	Price
C140E-N1	MODEL C140E METER/RECORDER, NEMA 1 Basic C140E (as described above) packaged in a 14"x12"x4" NEMA 1 enclosure.	2,195
C140E-N4	MODEL C140E METER/RECORDER, NEMA 4 Same as C140E-N1 above, except packaged in a 14"x12"x6" NEMA 4 enclosure.	2,395
C140E-A-N1	MODEL C140E METER/RECORDER WITH ANALOGS, NEMA 1 Basic C140E plus 8 analog input channels for monitoring 0-5VDC, 4-20mA or 1000-ohm RTD sensors; packaged in a 14"x12"x4" NEMA 1 enclosure.	2,895
C140E-A-N4	MODEL C140E METER/RECORDER WITH ANALOGS, NEMA 4 Same as C140E-A-N1 above, except packaged in a 14"x12"x6" NEMA 4 enclosure.	3,095

MODEL C140E OPTIONS

RAM-256K	MEMORY UPGRADE TO 256KB	200
RAM-512K	MEMORY UPGRADE TO 512KB	400
RAM-1024K	MEMORY UPGRADE TO 1024KB	800
MDM-2400	MODEM, HAYES-COMPATIBLE 1200/2400 BAUD Compact internal modem plugs into communication interface module.	275
PT-1	THREE-PHASE POTENTIAL TRANSDUCER Required only if the second three-phase voltage metering input is to be used.	175
HARM-1	HARMONIC ANALYSIS OPTION This option allows the Synergistic meter/recorder to gather detailed waveform data which is used by the Synernet PC-based software to graphically display voltage and current waveforms, and to compute and display harmonic amplitudes (fundamental frequency through 16th harmonic) and total harmonic distortion.	295
PCL-180	PROTOCOL OPTION This firmware option causes the meter/recorder to use the original C180 communication protocol; it is intended to support users of the original C180 whose host software may not yet have been upgraded to support the C180E protocol. Some features of the C180E, including cumulative KWH recording, harmonic analysis and automatic baudrate selection are not available if this option is selected; however, expanded memory is available.	N/C

Form PL9409-4

SYNERGISTIC CONTROL SYSTEMS, INC.

MODEL C160E
METER / RECORDER

[Revised 01/03/94]

Product Description

The Model C160E is a multi-channel survey meter/recorder intended for use in residential, commercial, industrial and institutional energy metering and data collection. The C160E combines several metering subsystems which provide the capability to monitor many input signals from a variety of sources.

Inputs/Outputs

Power Metering - The C160E includes a complete electronic power metering subsystem that accepts 16 current transformers and 2 three-phase potential transducers. All electrical parameters (true-RMS volts, amps, real power, apparent power, power factor, energy) are computed directly from the voltage and current inputs; no additional watt transducers are required. For poly-phase metering, power and energy readings can be summed into a single aggregate value or computed individually for each phase.

Pulse/Run-Time - In addition to the electrical metering subsystem, the C160E also accepts up to 8 external dry contact closure signals; each input can be independently configured to accumulate either pulse counts or duration of contact closure (run-time).

Analog Sensors - In addition to the power metering and pulse metering subsystems, the C160E is configured with 8 analog inputs (i.e., RTD temperature sensors, 4-20ma transducers, 0-5VDC sensors, etc.) for monitoring temperature, humidity, wind speed, solar radiation, etc.

Time-Series Data

An important feature of the C160E is its ability to internally store time-series data in a compressed format for subsequent retrieval by a remote host computer. Time-series data can be used to determine totalized electrical energy (i.e., kWh, kVAh); average values of current, voltage, power and/or apparent power; average or instantaneous values of analog signals (temperature, etc.); totalized accumulator pulses; and/or contact duration (equipment runtime) during each integration period.

The C160E allows the data storage interval to be varied during the day so that frequent intervals can be selected during high-demand hours, while less frequent intervals can be used to conserve data memory during off-peak hours. The C160E can be configured with up to 1 megabyte of solid state memory, enough to store months of data. The precise storage capacity is dependent on amount of installed memory, the specific data items selected for recording, and the recording interval.

Harmonic Analysis

The C160E can be ordered with the Harmonic Analysis Option, which allows the unit to gather detailed waveform data that is used by the SYNERNET® software to graphically display time-domain and frequency-domain waveshapes, and to measure harmonic amplitudes, total harmonic distortion and other related information.

Programmability

The C160E's communication interface allows the user to "down-load" a parameter set which defines virtually all of the operating parameters of the unit. The parameter set includes items such as CT and PT ratios, selection of analog input sensor types and scale factors, selection of data to be recorded, selection of data recording intervals, etc. The Synergistic SYNERNET® software package for IBM PC-compatible computers provides a convenient, menu-driven user interface that allows configuration of all C160E operating parameters, viewing of instantaneous metered data, and manual or fully automated remote retrieval of time-series data.

Communication

The C160E provides an RS232 interface (for connection to a local PC) and a local area network interface (for multi-drop connection of up to 100 units on a single two-wire circuit). A modem option is available (1200/2400 baud) for remote communication via telephone line (land-based or cellular). Security is insured by use of a binary communication protocol which uses a cyclic redundancy check (CRC) code to verify all data packets, and password protection for any commands which can alter the internal operation or stored data of the C160E.

Data Integrity

Communication security is insured by a binary protocol which uses a cyclic redundancy check (CRC) code to verify all communications, and password protection for any commands which can alter the internal operation or stored data of the C160E. System integrity is further insured by internal self-test procedures which are continuously performed by the C160E to verify correct hardware and firmware operation. A long-life lithium battery keeps the real-time clock running and maintains all recorded data and user settings during power outages. The time and date of each power outage/recovery is recorded in the data memory.

Access to Data

The C160E includes an alphanumeric display and keypad that can be used to access real-time (instantaneous) values of all metered inputs. Both real-time and recorded data are accessible using SYNERNET® software from Synergistic (SYNERNET can export data in ASCII or WK1 spreadsheet formats). Recorded data is also accessible with MV90 software from Utility Translation Systems.

Model C160E Specifications

Packaging: NEMA 1 enclosure with hinged cover, door lock and conduit knockouts (optional NEMA 4 enclosure does not have lock or knockouts).

Size: 14" high x 12" wide x 4" deep; NEMA 4 enclosure is 6" deep.

Power metering subsystem:

Current: Up to 16 external current transducers, 0.333 VRMS output at rated full-scale current.

Voltage: 1 or 2 external potential transducers for single- or poly-phase electrical service up to 480 VRMS; low-voltage output.

Accuracy:

Amps, Volts:	±0.5% of full scale.
Power Factor:	±0.02 PF from 5% to 100% of full scale input.
kW, kWh:	±0.5% of reading from 1% to 100% of full scale input, unity to 0.5 PF, excluding CT error.

Contact Closure Inputs:

Type: 8 independent form "A" contact closures to system common.

Electrical pullup: +5 volt, 3.3 kOhm

Count rate: 10 Hz. maximum

Contact bounce: 20 mSec maximum

Analog Signal Inputs:

Type: 8 independent single-ended voltage inputs, all referenced to system common.

Input range: 0 to +5 volts DC

Input impedance: 10 Mohm minimum

Signal types:

- *Voltage*: 0 to +5VDC
- *Current loop*: 4-20mA
- *Resistance*: 2-wire resistance sensors, 0 - 1.33kOhm
- *Temperature*: Linearization is provided for 1000 ohm Platinum RTDs.

Accuracy: ±0.25% of full scale

Resolution:

Voltage:	1.0 mv
Resistance:	0.3 ohm
Temperature:	0.1 Deg C., using Platinum RTD sensor.

Power Supply:

24VAC or 24VDC, approx 15VA. Instrument transformer (120VAC to 24VAC) is provided with unit.

SYNERGISTIC
CONTROL SYSTEMS, INC.

MODEL C140E METER / RECORDER

[Revised 04/01/93]

Product Description

The Model C140E is a multi-channel survey meter/recorder intended for use in residential, commercial, industrial and institutional energy metering and data collection. The C140E combines several metering subsystems which provide the capability to monitor many input signals from a variety of sources.

Inputs/Outputs

Power Metering - The C140E includes a complete electronic power metering subsystem that accepts 8 current transformers and 2 three-phase potential transducers. All electrical parameters (true-RMS volts, amps, real power, apparent power, power factor, energy) are computed directly from the voltage and current inputs; no additional watt transducers are required. For poly-phase metering, power and energy readings can be summed into a single aggregate value or computed individually for each phase.

Pulse/Run-Time - In addition to the electrical metering subsystem, the C140E also accepts up to 8 external dry contact closure signals; each input can be independently configured to accumulate either pulse counts or duration of contact closure (run-time).

Analog Sensors - In addition to the power metering and pulse metering subsystems, the C140E can be optionally configured with 8 analog inputs (i.e., RTD temperature sensors, 4-20ma transducers, 0-5VDC sensors, etc.) for monitoring temperature, humidity, wind speed, solar radiation, etc.

Digital Outputs - The C140E also provides 8 digital outputs for driving relays or other devices. The first five outputs produce pulses proportional to kWh; one output provides an end-of-interval pulse; two outputs can be manually controlled via PC software.

Time-Series Data

An important feature of the C140E is its ability to internally store time-series data in a compressed format for subsequent retrieval by a remote host computer. Time-series data can be used to determine totalized electrical energy (i.e., kWh, kVAh); average values of current, voltage, power and/or apparent power; average or instantaneous values of analog signals (temperature, etc.); totalized accumulator pulses; and/or contact duration (equipment runtime) during each integration period.

The C140E allows the data storage interval to be varied during the day so that frequent intervals can be selected during high-demand hours, while less frequent intervals can be used to conserve data memory during off-peak hours. The C140E can be configured with up to 1 megabyte of solid state memory, enough to ·ore months of data. The precise storage capacity is dependent on amount of installed memory, the specific data items selected for recording, and the recording interval.

Harmonic Analysis

The C140E can be ordered with the Harmonic Analysis Option, which allows the unit to gather detailed waveform data that is used by the SYNERNET® software to graphically display time-domain and frequency-domain waveshapes, and to measure harmonic amplitudes, total harmonic distortion and other related information.

Programmability

The C140E's communication interface allows the user to "down-load" a parameter set which defines virtually all of the operating parameters of the unit. The parameter set includes items such as CT and PT ratios, selection of analog input sensor types and scale factors, selection of data to be recorded, selection of data recording intervals, etc. The Synergistic SYNERNET® software package for IBM PC-compatible computers provides a convenient, menu-driven user interface that allows configuration of all C140E operating parameters, viewing of instantaneous metered data, and manual or fully automated remote retrieval of time-series data.

Communication

The C140E provides an RS232 interface (for connection to a local PC) and a local area network interface (for multi-drop connection of up to 100 units on a single two-wire circuit). A modem option is available (1200/2400 baud) for remote communication via telephone line (land-based or cellular). Security is insured by use of a binary communication protocol which uses a cyclic redundancy check (CRC) code to verify all data packets, and password protection for any commands which can alter the internal operation or stored data of the C140E.

Data Integrity

Communication security is insured by a binary protocol which uses a cyclic redundancy check (CRC) code to verify all communications, and password protection for any commands which can alter the internal operation or stored data of the C140E. System integrity is further insured by internal self-test procedures which are continuously performed by the C140E to verify correct hardware and firmware operation. A long-life lithium battery keeps the real-time clock running and maintains all recorded data and user settings during power outages. The time and date of each power outage/recovery is recorded in the data memory.

Access to Data

The C140E includes an alphanumeric display and keypad that can be used to access real-time (instantaneous) values of all metered inputs. Both real-time and recorded data are accessible using SYNERNET® software from Synergistic (SYNERNET can export data in ASCII or WK1 spreadsheet formats). Recorded data is also accessible with MV90 software from Utility Translation Systems.

Model C140E Specifications

Packaging: NEMA 1 enclosure with hinged cover, door lock and conduit knockouts (optional NEMA 4 enclosure does not have lock or knockouts).

Size: 14" high x 12" wide x 4" deep; NEMA 4 enclosure is 6" deep.

Power metering subsystem:

Current: Up to 8 external current transducers, 0.333 VRMS output at rated full-scale current.

Voltage: 1 or 2 external potential transducers for single- or poly-phase electrical service up to 480 VRMS; low-voltage output.

Accuracy:

Amps, Volts:	±0.5% of full scale.
Power Factor:	±0.02 PF from 5% to 100% of full scale input.
kW, kWh:	±0.5% of reading from 1% to 100% of full scale input, unity to 0.5 PF, excluding CT error.

Contact Closure Inputs:

Type: 8 independent form "A" contact closures to system common.

Electrical pullup: +5 volt, 3.3 kOhm

Count rate: 10 Hz. maximum

Contact bounce: 20 mSec maximum

Digital Outputs:

Type: 8 independent open-collector relay drivers with clamp diodes.

Capacity: 0.2 Amp DC current sink; 35 volts maximum.

Analog Signal Inputs (optional):

Type: 8 independent single-ended voltage inputs, all referenced to system common.

Input range: 0 to +5 volts DC

Input impedance: 10 Mohm minimum

Signal types:

Voltage: 0 to +5VDC

Current loop: 4-20mA

Resistance : 2-wire resistance sensors, 0 - 1.33kOhm

Temperature: Linearization is provided for 1000 ohm Platinum RTDs.

Accuracy: ±0.25% of full scale

Resolution:

Voltage:	1.0 mv
Resistance:	0.3 ohm
Temperature:	0.1 Deg C., using Platinum RTD sensor.

Power Supply:

24VAC or 24VDC, approx 15VA. Instrument transformer (120VAC to 24VAC) is provided with unit.