ESL-TR-90/07-01

Texas LoanSTAR Monitoring and Analysis Program

Progress Reports

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

Energy Systems Laboratory
Mechanical Engineering
Texas A&M University
College Station, Texas

July 1990

TASK

REPORTS

JULY 1990

Texas LoanSTAR Monitoring and Analysis Program

Audit Review and Assignment

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

Angela J. Britton
Warren M. Heffington
Darin W. Nutter

Energy Systems Laboratory
Mechanical Engineering
Texas A&M University
College Station, Texas

July 1990

Task 1. Audit Review and Assignments
Progress Report for MARC Meeting

EXECUTIVE SUMMARY

Eleven audit reports have been accepted by the review staff at Texas A&M University. These eleven reports cover 3.8 million square feet of building space and two street-lighting projects. One engineer has been employed to work in the GEMC for the purpose of assigning audits, approving screening reports and reviewing overall auditing progress.

REPORT OF PROGRESS

Since January 1, 1989, energy audits of 19.6 million square feet of building space and 43 facilities or systems have been assigned to the nine consulting engineering firms which are contractors to the GEMC. Assignments include hospitals, office buildings, classroom buildings, central plants, and street lighting systems.

As of July 1, 1990, the consultants have screened 13.3 million square feet and 33 projects, and 3.8 million square feet and 11 reports are completely done and finally accepted. An average of five weeks elapses between assignment and receipt of the screening report (POSSR) and 12 weeks elapse between the POSSR and receipt of the first draft.

Review of the first draft takes about four weeks at Texas A&M, and about three weeks (included in the four weeks review time) are allowed for facility manager comments on the first draft. Subsequent drafts are not submitted to the agency for comment unless there are substantial changes to the projects.

Consultants spend an average of over four weeks revising unsuitable drafts, and Texas A&M spends an average of two weeks reviewing drafts beyond the first. The number of drafts required averages 2.6. An audit report review summary is periodically provided to the GEMC (see attached sample).

Problems encountered in the review process include careless proofreading, lack of understanding of consumer avoided costs, failure to document, and problems which defy description. In Draft 3 of one important report, the author stated:

> Approximately 10% (estimated from boiler log observation and information from operating personnel, see the following page) of the entire heating systems steam is wasted in leaking or stuck steam traps and its energy lost.

On the same page, about three inches below the above statement was: "Analysis of boiler logs shows that make-up water quantities do not indicate leakage problems." Three pages later, in the same ECRM, the author stated, "Normal blowdown procedures would easily account for a loss of this magnitude. Therefore, system leakage is not considered to be a problem."

In the next draft, the author eliminated the statement about 10% steam losses and stated, "Analysis of boiler logs shows that make-up water quantities do not indicate significant leakage problems." Losses were placed at 3% and well-documented with make-up water data. Unfortunately, blowdown still was neglected in the calculations, but the author wrote, "Normal blowdown procedures could easily account for a significant quantity of these losses."

This sort of engineering is, in our opinion, without excuse, and contributes significantly to review time and delays the whole audit procedure.

The guidelines and audit format are being rewritten to accomplish several aims: streamline the reporting process by requiring less ancillary descriptive material; provide a general descriptive section on maintenance and operation procedures; and better define acceptable documentation for implementation costs. A checklist of ECRMs (see attached "Possible Energy Cost Reduction Measures") has been generated for use at the screening stage in an attempt to assure that important projects are not overlooked.

In accordance with the LoanSTAR contract, an engineer was employed and officed with GEMC personnel, primarily to assign audits and review contracts.

Plans for the next 6-12 months include the report reviews, continuing to monitor and provide support for the guideline and audit format revision, and participation in workshop training for the auditors.

Other activities will include further support to the GEMC on personnel matters. The LoanSTAR engineer employed by the ESL for the GEMC may move to another position in the GEMC, or another position may be opened for someone to monitor audit activities. Our support consists of advertising, and interviewing and evaluating (particularly with regard to technical qualifications). A related workshop is scheduled for July 31 in Austin where we will make a presentation on building energy conservation tips.

AUDIT REPORT REVIEW SUMMARY July 2, 1990

FIRM	AGEN No.	FACILITY	BLDG No.	TOTAL SQ FT	DFT 1 PROJ.	DFT 1 RCD	COMMENTS	APPROVED FIN REP
TEES	N/A	CITY OF RICHARDSON			5/16/90	6/08/90	STREET LIGHTING	6/18/90
TEES	N/A	CITY OF DALLAS			5/23/90	5/21/90	STREET LIGHTING	6/18/90
ACR	7420	UT PERMIAN BASIN	3	330,600		11/07/89		3/13/90
TEES	7360	UT PAN AMERICAN	14	909,462		11/21/89		3/02/90
TEES	3030	SP&GSC - STARR	1	99,012		6/23/89		1/15/90
TEES	3030	SP&GSC - THOMPSON	1	73,272		6/23/89		11/13/89
TEES	3240	SP&GSC - JOHN H WINTER	1	503,000		7/06/89		11/10/89
ACR	3030	SP&GSC - TRAV AUS JOHN	3	1,269,200		6/13/89		10/24/89
TEES	3010	GOVERNOR'S MANSION	1	15,792		7/06/89		9/18/89
TEES	4010	ADJUTANT GENERAL	3	37,289		5/24/89		9/18/89
TEES	3030	SP&GSC - PARKING GAR	3	607,247		7/06/89		8/25/89
ENSY	6740	TDMHMR KERRV. ST HOS	9	281,412	2/12/90	6/22/90	HOSPITAL	
Y&H	7390	TT-HSC EL PASO	2	168,658	1/15/90	5/15/90	MEDICAL CLINIC	
Y&H	7390	TT-HSC ODESSA	1	70,000	1/15/90	5/15/90	MEDICAL CLINIC	
Y&H	7390	TT-HSC AMARILLO	2	111,000	1/22/90	5/15/90	MEDICAL CLINIC	
TEES	7540	SOUTHWEST TX ST UNIV	6	669,223	4/12/90	5/10/90		
BJI	5060	UT M.D. ANDERSON CC	1	500,000	3/19/90	4/13/90		
ACR	7430	UT AT SAN ANTONIO	3	592,108	1/22/90	4/04/90		
KINS	6690	TDMHMR LUFKIN ST SCH	27	243,721	2/12/90	3/05/90		
Y&H	7630	TX COLL OSTEOP MED	3	496,000		10/19/89		
Y&H	3030	SP&GSC - STATE CAP COM	7	723,166		5/22/89		
ACR	7440	UT HEALTH SC,HOUSTON	4	1,523,993	2/14/90			
EEA	7130	TARLETON STATE UNIV	5	159,615	3/05/90			
ENSY	6770	TDMHMR AUSTIN ST HOS	5	93,290	3/05/90		CENTRAL PLT & HOSP.	
TEES	7610	LAREDO STATE UNIV.	1	56,862	3/15/90			
KINS	7520	U OF NORTH TX SC RES	1	61,317	3/19/90			
Y&H	7390	TX TECH UNIV-LUBB,PHYS	1	0	3/29/90		CENTRAL HT&COOL PL 2	
Y&H	7390	TX TECH UNIV- HSC LUBB	1	811,131	4/12/90		LUBBOCK - HOSP,CLIN	
EBA	7600	CORPUS CHRISTI ST SC	11	501,879	5/16/90		NO START DATE/4/4/90	
KINS	6820	TDMHMR TERRELL ST HO	24	721,204	6/11/90		HOSPITAL	
ENSY	6780	TDMHMR AUSTIN ST SCH	29	319,158	7/10/90			
ACR	N/A	VICTORIA IND SCH DIS	11	935,098	7/17/90		ELEM & HIGH SCHOOLS	
Y&H	?	UNIV MED CENTER-LUBB	4	375,026	8/13/90		HOSPITAL	

Building area screened: 13,258,735
Building area completed: 3,844,874
Building area in progress: 9,413,861

Projects screened: 33
Reports completed: 11

Reports in review at TAMU: 3
Building area in review at TAMU: 520,070

POSSIBLE ENERGY COST REDUCTION MEASURES

Lighting
- Incandescent to fluorescent conversion
- Occupancy sensor
- Fluorescent 40W to 34W conversion
- Delamping
- Photocell control

Utility Bill
- Power factor correction
- Demand control
- Installation of discharge water meter to save on sewer charges
- Rate schedule change: gas, electric, steam, water, or sewage
- Thermal storage

AHU
- VAV conversion
- EMS control
- Time clock
- Addition of small dedicated units so large units can be turned off at night
- Improvement/repair of damper controls for OA, RA, and/or MA (includes economizers and OA reduction)

Pumps
- Variable/two speed
- Speed reduction

Boilers
- Insulation on boiler, steam lines, condensate lines, and equipment
- Summer shut down
- Steam trap repair/replacement
- Optimization
- Temperature reset

Chillers
- Temperature reset

Reduce Thermal Load
- Weatherstripping on doors and windows
- Solar screen on skylights and windows

Executive Summary - TASK 2

A total of five Data Acquisition System SubContractors (DASS) were selected to participate in the program for the pilot year. Four of the contractors signed contracts with TEES; MSE Inc., National Center for Appropriate Technology (Ncat), Architectural Energy Corporation (AEC), and ADM and Associates. Initial sites were assigned to the contractors in January and a total of 15 sites have been visited through June. The most troublesome aspect of the project thus far has been the slow progress of the installations caused by delays in approval of the project, coordination problems with the agencies, equipment delivery times, and initial organization/startup of the project.

Synergistics data acquisition systems (DAS) have been used exclusively thus far in the project. They are developing a line of "Datamate" loggers that come in 6 different configurations of analog and digital inputs and range from $600 to $1,500 in cost. Several other manufacturers are being evaluated (Task 4) but none have yet displayed a similar combination of cost and configuration. Synergistics Inc. has extended some special pricing to the program for this year and we are negotiating for additional discounts for next year. The DASS are submitting manufacturers' information on the different sensors to be installed at a given site. The MAC Resident Engineer (RE) reviews and approves these submittals. From this process an "approved" list of sensors will be generated for next year.

All sites assigned for this pilot year have been visited and are in various stages of site development. The PREMAP/SiteMAP process has been followed as originally planned. The DASS have submitted PREMAPs displaying varying degrees of effort and this portion of the monitoring plan development will be standardized for the coming year. To date, we have 4 sites under construction:

Site	# of Bldgs	# Chnls	Cost
U.T. Austin	16	156	$180,750
Capitol Complex	10	98	$130,000
U.T. Arlington	8	39	$56,240
U.T.H.S.C. Houston	1	12	$33,115

Three of the data acquisition systems (DAS) at the U.T. Austin campus are on-line and being polled and the Capitol Complex is to be completed during the first week of August. As the different sites progress to the "system verification" stage of installation, we will be able to prove our procedures for system testing and acceptance.

Texas LoanSTAR Monitoring and Analysis Program

Task 2 - Progress Report

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

Dennis L. O'Neal
John A. Bryant

Energy Systems Laboratory
Building Energy and Analysis Division
Mechanical Engineering
Texas A&M University
College Station, Texas

July 1990

Task 2. Monitoring Systems Selection and Installation

Purpose

This task ensures that adequate and reliable data are collected to monitor energy use in the buildings participating in the LoanSTAR program. Data collected from the buildings serves as the basis for determining the cost-effectiveness of different retrofits as well as providing indices of how well an individual building is performing. Thus, it is critical that the data are the best that can be collected given economic constraints.

Functions

The major functions in this task include: determination of metering requirements, management of data acquisition system subcontractor contracts, and installation and maintenance of systems.

Determination of Metering Requirements

The strategy of labeling the different levels of monitoring as Level 0 - 3 as originally envisioned has been modified during this pilot year. The label would be simple to apply in a post-installation evaluation, but in the PREMAP stage, the level of monitoring effort is not as easily defined nor of particular benefit. The following procedure has evolved to determine the metering level for a given site.

1. Initial Site Visit - This visit by the MAC resident engineer (RE) is conducted as soon as a site is assigned and the Agency notified. During this visit, the RE and a representative for the agency determine in a general way (CONMAP) what level of monitoring effort will be required for the ECRMs for that site. At the larger sites, the MAC RE has videotaped during the walk-through. The videotape helps identify the equipment that will be monitored and where transducers will be mounted. This tape is then sent to the DASS before their visit to the site. The CONMAP is the guiding philosophy for the DASS during the development of the PREMAP.

2. DASS Site Visit - This visit involves the Agency representative, the MAC RE, and the DASS. A thorough tour of the facility is conducted with emphasis on the buildings/systems to receive ECRMs under the LoanSTAR program. This visit usually lasts one half day to a whole day depending on the site complexity. The DASS takes careful notes during the visit and combines them with the CONMAP as provided by the RE develop the PREMAP.

3. PREMAP is submitted - Two to four weeks after the DASS site visit, a Preliminary Monitoring and Analysis Plan (PREMAP) is submitted to the MAC RE for review. It is at this point that

the first firm indication of the number of channels and the costs for the energy monitoring is presented. If warranted, the PREMAP will include diagrams of the proposed installation.

4. SiteMAP is developed - The PREMAP is submitted for internal review by Task 2 and 5 and results in the Site Monitoring and Analysis Plan (SiteMAP). The SiteMAP is the final stage of the monitoring plan development and an example of a completed SiteMAP is included in the appendix.

After the above steps are completed, the SiteMAP is sent to the GEMC for final approval. Upon final approval, a contract amendment is issued to the DASS to proceed with the installation.

Data Acquisition System Subcontractor Qualification and Selection

The process for qualification and selection of the DASS was executed as originally proposed. Five contractors were selected and four eventually signed their contracts. The contractors are;

1. National Center for Appropriate Technology (Ncat), Butte, MT. Under contract for $350,000 for the pilot year. Ncat is a non-profit organization and have been involved in numerous building energy use installations and studies. They have been assigned the majority of the sites thus far and have shown to be very capable and extremely resourceful with state funds.

2. McEver Systems Engineering Incorporated (MSE), Houston, TX. Under contract for $350,000 for the pilot year. MSE has been assigned the Capitol Complex and was to receive approximately 40% of the remaining projects for this year. Shortly after signing the contract amendment for the Capitol Complex, the president of MSE announced that he was taking an executive position with a former employer. Due to this development, MSE's participation in the LoanSTAR program has been limited to the Capitol Complex.

3. ADM Associates, Sacramento, CA. Under contract for $50,000 for the pilot year. ADM has been assigned the University of Texas Health Science Center in Houston. They were originally selected as an alternate for Ncat and MSE.

4. Architectural Energy Corporation (AEC), Boulder, CO. Under contract for $50,000 for the pilot year. AEC has been assigned the University of Texas Medical Branch and the Texas A & M campus both in Galveston. They were also selected as an alternate to Ncat and MSE.

All four DASS have been assigned sites this year so that we may evaluate them for continued participation in the program. Ncat has assigned an engineer to Texas and they now have a local office. They have shown considerable knowledge concerning the installation of monitoring equipment at the U.T. Austin site. This professionalism extends to their dealings with our contracts and accounts personnel. We are very pleased with their performance thus far and plan to continue and expand their contract for the next year. MSE has effectively withdrawn from the program. They will finish the Capitol Complex and provide maintenance at that site but will not do any additional work for the LoanSTAR program. ADM and AEC have just recently submitted their PREMAPs for their respective sites and have not yet begun installation. Their continued participation in the program will depend on the quality, cost, and timeliness of their monitoring installations. For the next year we intend to continue with Ncat as the primary DASS and utilize ADM and AEC as alternates.

Data Acquisition Systems Selection

Synergistics Controls has been the DAS supplier for this program to date. After discussions with Texas A & M in the Fall of 1989, Synergistics decided to start developing a new product line (Datamate) that will better match some of the needs of the LoanSTAR project. The 5 models range from a 4 digital input (DI) model priced at $695 to an 8 DI and 8 analog input (AI) model for $1,595. These systems will be compatible with the existing Synergistics hardware and software used by Texas A & M. Though we are evaluating other systems (Task 4), no other manufacturers offer the same combination of configuration and cost. Our DASS have been using the following transducers on the projects;

1. Electrical sensors

   Current Transformers (CT) - Two type of CTs have been used in two configurations; 1) shunted, solid and split, and 2) 1 or 5 amp solid. Fermitek has been the primary supplier and is claiming ± 2% for their CT accuracy. Voltage Transformers - Ohio Semitronics has been the primary supplier for these devices. They provide a pulse proportional to Kwh with 1 to 5 amp CT inputs from the load. These devices have a stated accuracy of ± 0.5%. Ohio Semitronics has expressed interest in manufacturing a transformer that would take shunted CT inputs.

2. Temperature sensors

   RTD - RTD assemblies for direct immersion have been the primary temperature sensing application. This has been applied to chilled water piping, hot water piping, and airflow in ductwork. In all cases the RTD is a 1000 ohm precision platinum type with a typical accuracy of ± 1.0 ^{o}F (Hy-Cal).

3. Humidity sensors

It has been found that the bulk polymer type relative humidity sensor as applied to our weather measurements, has rather severe limitations at an RH greater than 85%. We have decided to use chilled mirror dew point sensors (General Eastern Corp.) in areas with consistently high relative humidities. For air relative humidity in ductwork, we are using Hy-Cal CT-829-A RH sensors. These sensors have a stated accuracy of ± 2% for the range of 0 - 90% RH.

4. Differential pressure sensors

Differential pressure transducers are being used to monitor chilled water flow with existing flow meters and to monitor the differential pressures across fans. Robinson-Halpern and Mamac transducers are being used for these applications. The accuracies are + 0.5% F.S. and + 1.0% F.S. respectively.

5. Water flow/BTU meters

Several manufacturers were contacted during the search for a suitable BTU/flow meter for use in this project. We are now using BTUSA Corporation's precision BTU meter. This meter takes AD-590 temperature sensor inputs and flow input from a Flow Research Corp. insertion flow meter. The BTU meter produces two pulse signals; one proportional to the BTUs and one proportional to the GPM. These signals are KYZ type (Form C, SPDT) Mercury-wetted which are compatible with most EMS and with the Synergistics DI board.

6. Natural Gas meters

For the two types of gas meters encountered thus far (bellows and temperature/pressure compensating) digital pulse initiators are being installed. These units provide a KYZ type pulse proportional to the CFH as measured through the meter.

7. Solar/Wind sensors

Weather measurements include dry-bulb temperature, RH (dew-point), solar radiation, and wind speed. The latter measurements are being taken with a Licor LI-200SA pyranometer for solar and a Weathermeasure Model 2010 anemometer.

When possible, all analog transducers are required to provide a 4 - 20 ma signal to the DAS. Upon completion of the calibration facility (Task 3), a more complete evaluation can be made of the instrumentation being installed in the sites.

Installation and Maintenance of Systems

The only significant deviation from the original sequence is that installing a whole building electric meter prior to the installation of the complete monitoring system has proven to be unfeasible. There are two major reasons for this;

1) *Coordination.* The sites assigned thus far have all had numerous problems with coordination between the utility, the agency and the MAC. The Capitol Complex had major problems with asbestos removal, identification of existing meters (flow and electric), and the multi-layered physical plant bureaucracy. At this site, the pulse initiators for the existing electric meters were installed approximately 2 months after the site installation was begun. The U.T. Austin installation has experienced similar problems.

2) *Applicability of data gathered.* All of the sites for this year have been campus type, in that there are several buildings on the grounds and not all buildings are included in the ECRMs for a given site. The data gathered from the main campus meter (electric for instance) would not necessarily give any relevant information to evaluate the ECRM in question.

A major addition to the monitoring documentation has been the development of a comprehensive site form. This form is being completed for each building being monitored in the LoanSTAR program. A copy of the draft form is included in the Appendix. The purpose of the form is to thoroughly document the basic building characteristics, both architecturally and mechanically. Most of the answers are available from the agency Audit reports, with field visits required to answer the remaining questions. Additionally, there is an operator questionnaire being completed for each facility. This is a behavioristic research effort to evaluate occupational patterns of the HVAC mechanics and operators.

Innovations and Problems

With the first several site cost estimates it became apparent that the 3% level of funding was, in most cases, inadequate to cover a basic monitoring installation. The GEMC established a criteria that has proven very beneficial to the LoanSTAR program and to the Agencies. If the metering to be installed is of direct benefit to the Agency, then the Agency will pay for that metering through their loan from the GEMC. This has been applied to cases where we are installing whole building thermal and/or electric metering. In those cases the Agency pays (usually) the metering costs and the LoanSTAR pays for the installation labor. The pulse signals produced by these meters is immediately available to both the agency EMS and our data logger via a splitter/isolator. In all sites where we have used this method the Agencies have been very receptive. Having these costs paid by the Agency has essentially increased our monitoring budget from 3% to approximately 4% of the loan amount, and resulted in better instrumentation at the site.

Asbestos insulation has been identified in most of the sites for this pilot year. The coordination of the Agency, the abatement contractor and the DASS has proven to be difficult. The Agencies have been paying for this abatement with our DASS reinsulating the affected piping.

The Capitol Complex chilled water flow meter difficulties convinced us to install new insertion flow meters in subsequent sites. The existing meters have proven to be very difficult to identify and have required considerable effort to obtain flow coefficients. There are no assurances concerning the calibration of these meters. Most have been installed since the building was built and have never been calibrated nor serviced. At one site a venturi meter had been found to be partially blocked with a piece metal from a failed valve.

Most Agency directors and managers have been very enthusiastic and anxious to assist the installation program.

<u>Future Plans</u>

Task 2 plans for the next year include;

- the addition of an RE to provide more coverage of the field installations

- improvement in the PREMAP submittal process. This would include firm submittal dates and a more formal submittal "form"

- obtaining more channels of data for lower cost. This year, we are investigating the feasibility of using an existing EMS at two sites as our DAS. This would save the cost of a data logger and potentially provide much more information for our analysis task

- adding the ability to install a temporary DAS to collect some short term electrical data before the installation of the complete monitoring system.

TASK 2

APPENDIX I

Following is a list of projects assigned for the pilot year of the LoanSTAR program. Included is a series of GANTT charts depicting the scheduling for each of the sites.

Agency Name: State Purchasing (Capitol Complex)
Location: Austin
Number of Buildings: 10
Loan Amount: $3,338,585
Initial Site Visit: 12/04/89
DASS Site Visit: 1/11/90
PREMAP Submitted: 2/07/90
SiteMAP Submitted: 2/26/90
SiteMAP Approved: 3/07/90
Estimated Cost: $130,000
Installation Start: 3/07/90
Installation Completed: 8/06/90

Agency Name: Texas A&M
Location: College Station
Number of Buildings: 1
Loan Amount: $1,331,660
Initial Site Visit:
DASS Site Visit:
PREMAP Submitted:
SiteMAP Submitted:
SiteMAP Approved:
Estimated Cost: $31,000
Installation Start: 5/01/89
Installation Completed: 8/01/89

Agency Name: Texas Department of Health
Location: Austin
Number of Buildings: 4
Loan Amount: $289,174
Initial Site Visit: 6/23/90
DASS Site Visit: 6/23/90
PREMAP Submitted:
SiteMAP Submitted:
SiteMAP Approved:
Estimated Cost:
Installation Start:
Installation Completed:

Agency Name: MHMR Austin State Hospital
Location: Austin
Number of Buildings: 40
Loan Amount: $281,496
Initial Site Visit: 6/23/90
DASS Site Visit: 6/23/90
PREMAP Submitted:
SiteMAP Submitted:
SiteMAP Approved:
Estimated Cost:
Installation Start:
Installation Completed:

Agency Name:	MHMR Austin State School
Location:	Austin
Number of Buildings:	55
Loan Amount:	$254,175
Initial Site Visit:	6/23/90
DASS Site Visit:	6/23/90
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	
Installation Start:	
Installation Completed:	

Agency Name:	MHMR Terrell State Hospital
Location:	Terrell
Number of Buildings:	72
Loan Amount:	$914,507
Initial Site Visit:	6/24/90
DASS Site Visit:	6/24/90
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	
Installation Start:	
Installation Completed:	

Agency Name:	MHMR El Paso State Center
Location:	El Paso
Number of Buildings:	15
Loan Amount:	$42,510
Initial Site Visit:	4/15/90
DASS Site Visit:	
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	
Installation Start:	
Installation Completed:	

Agency Name:	U.T. Arlington
Location:	Arlington
Number of Buildings:	8
Loan Amount:	$1,281,822
Initial Site Visit:	2/13/90
DASS Site Visit:	3/21/90
PREMAP Submitted:	4/04/90
SiteMAP Submitted:	5/15/90
SiteMAP Approved:	6/15/90
Estimated Cost:	$56,240
Installation Start:	
Installation Completed:	

Agency Name:	Texas A&M - Galveston
Location:	Galveston
Number of Buildings:	8
Loan Amount:	$88,589
Initial Site Visit:	4/23/90
DASS Site Visit:	5/21/90
PREMAP Submitted:	7/13/90
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	$26,000
Installation Start:	
Installation Completed:	

Agency Name:	U.T. Austin
Location:	Austin
Number of Buildings:	16
Loan Amount:	$4,678,852
Initial Site Visit:	1/11/90
DASS Site Visit:	1/16/90
PREMAP Submitted:	3/09/90
SiteMAP Submitted:	4/02/90
SiteMAP Approved:	4/13/90
Estimated Cost:	$180,750
Installation Start:	4/13/90
Installation Completed:	10/90

Agency Name:	U.T. Medical Branch
Location:	Galveston
Number of Buildings:	8
Loan Amount:	$1,502,906
Initial Site Visit:	5/15/90
DASS Site Visit:	5/29/90
PREMAP Submitted:	7/13/90
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	$90,000
Installation Start:	
Installation Completed:	9/90

Agency Name:	U.T. Health Center - Dallas
Location:	Dallas
Number of Buildings:	4
Loan Amount:	$521,623
Initial Site Visit:	2/12/90
DASS Site Visit:	2/22/90
PREMAP Submitted:	6/21/90
SiteMAP Submitted:	6/26/90
SiteMAP Approved:	7/13/90
Estimated Cost:	$30,710
Installation Start:	
Installation Completed:	9/90

Agency Name:	U.T. Dallas
Location:	Dallas
Number of Buildings:	8
Loan Amount:	$766,201
Initial Site Visit:	2/12/90
DASS Site Visit:	2/22/90
PREMAP Submitted:	5/17/90
SiteMAP Submitted:	7/05/90
SiteMAP Approved:	
Estimated Cost:	$40,000
Installation Start:	
Installation Completed:	9/90

Agency Name:	Texas Tech Health Center
Location:	Lubbock
Number of Buildings:	1
Loan Amount:	$349,077
Initial Site Visit:	3/15/90
DASS Site Visit:	
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	$25,000
Installation Start:	
Installation Completed:	

Agency Name:	U.T. Health Center - Houston
Location:	Houston
Number of Buildings:	1
Loan Amount:	$1,748,639
Initial Site Visit:	2/29/90
DASS Site Visit:	3/20/90
PREMAP Submitted:	6/01/90
SiteMAP Submitted:	6/21/90
SiteMAP Approved:	7/10/90
Estimated Cost:	$30,115
Installation Start:	7/11/90
Installation Completed:	9/90

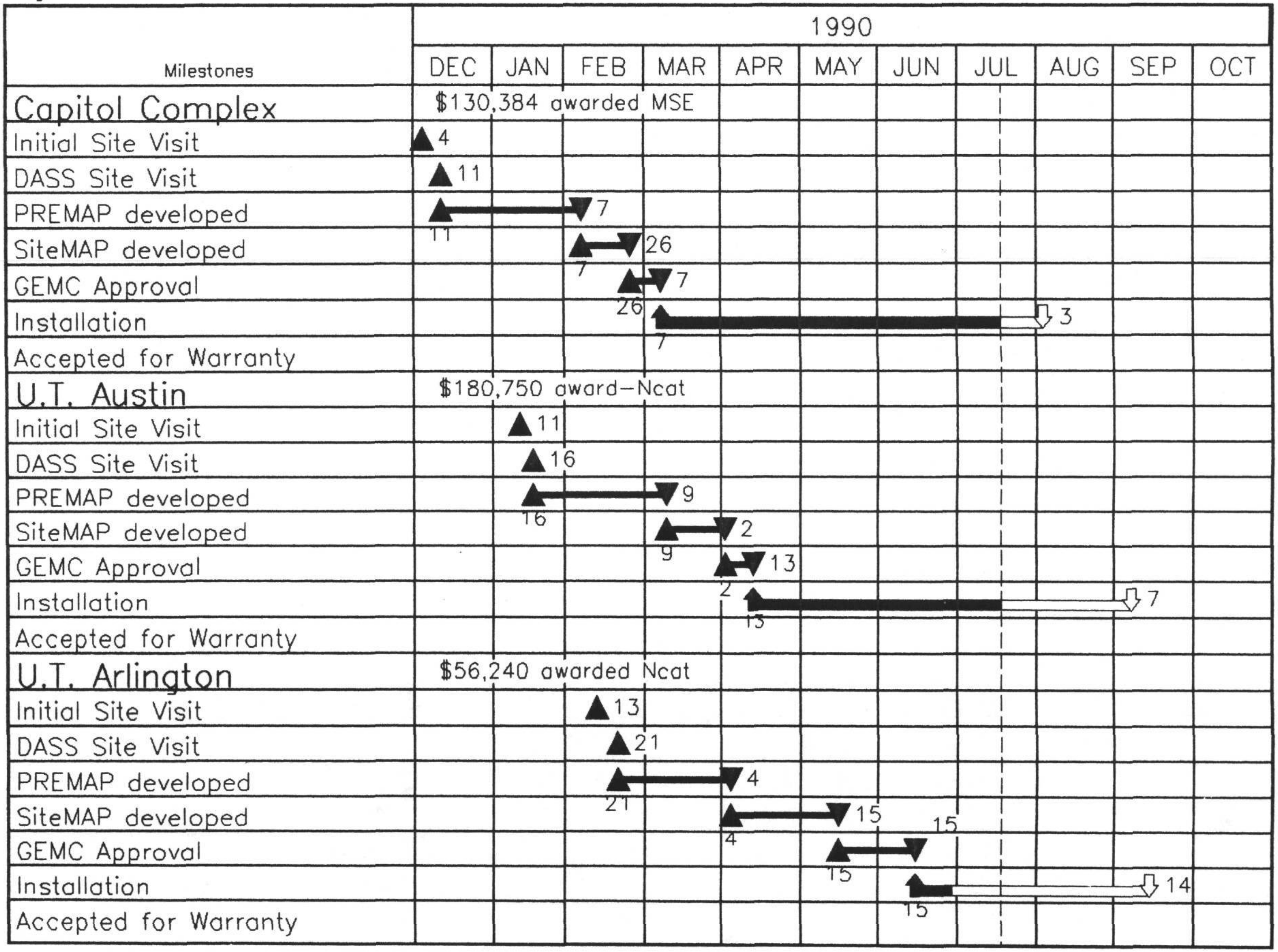
Agency Name:	U.T. Health Center
Location:	San Antonio
Number of Buildings:	2
Loan Amount:	$238,484
Initial Site Visit:	5/15/90
DASS Site Visit:	
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	$15,000
Installation Start:	
Installation Completed:	

Agency Name:	University of North Texas
Location:	Denton
Number of Buildings:	8
Loan Amount:	$145,116
Initial Site Visit:	3/24/90
DASS Site Visit:	6/24/90
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	$7,000
Installation Start:	
Installation Completed:	

Agency Name:	Texas School for the Blind
Location:	Austin
Number of Buildings:	
Loan Amount:	$125,765
Initial Site Visit:	
DASS Site Visit:	
PREMAP Submitted:	
SiteMAP Submitted:	
SiteMAP Approved:	
Estimated Cost:	$5,000
Installation Start:	
Installation Completed:	

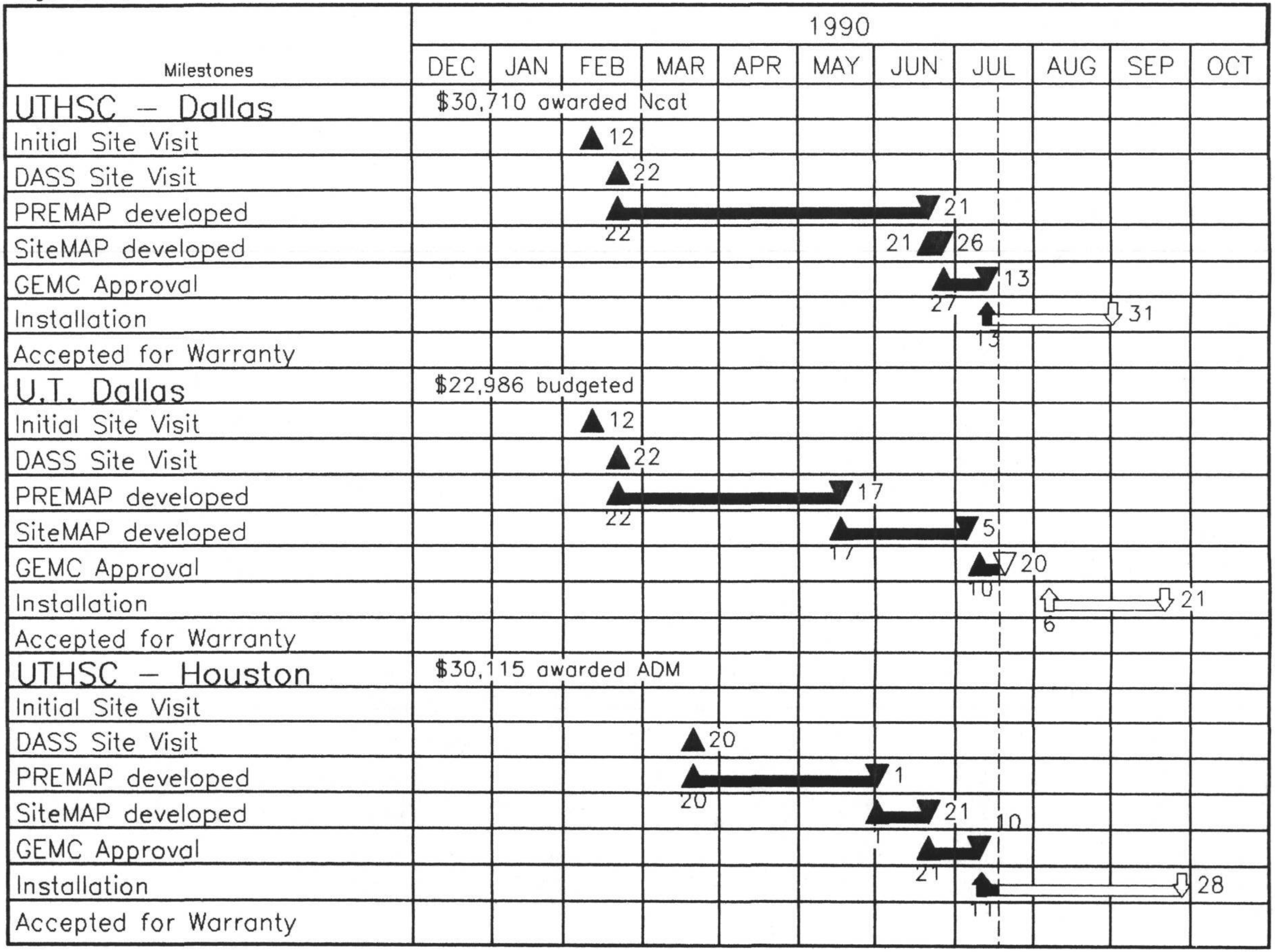
LoanSTAR Project Status

7/17/1990



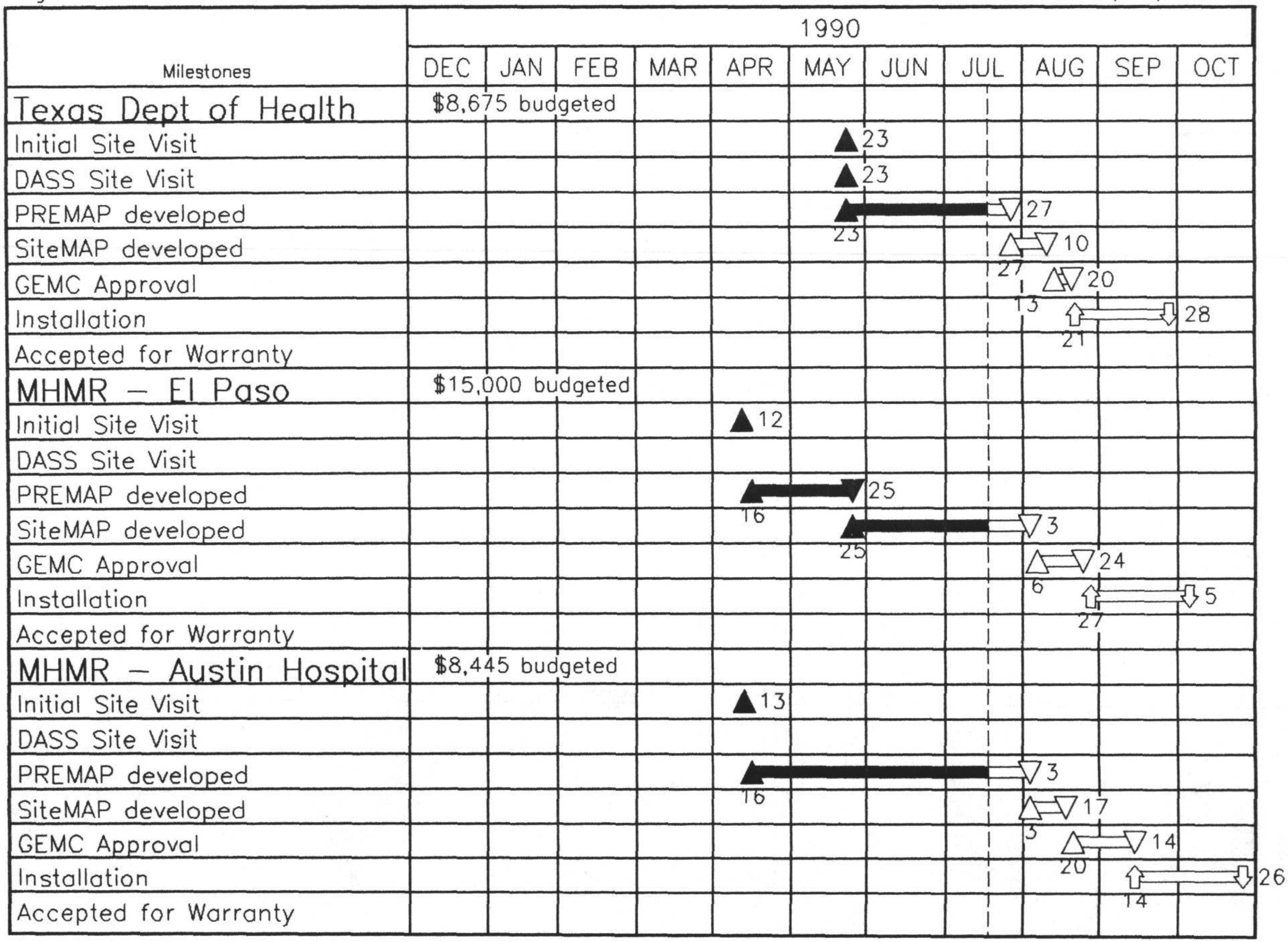
LoanSTAR Project Status

7/17/1990



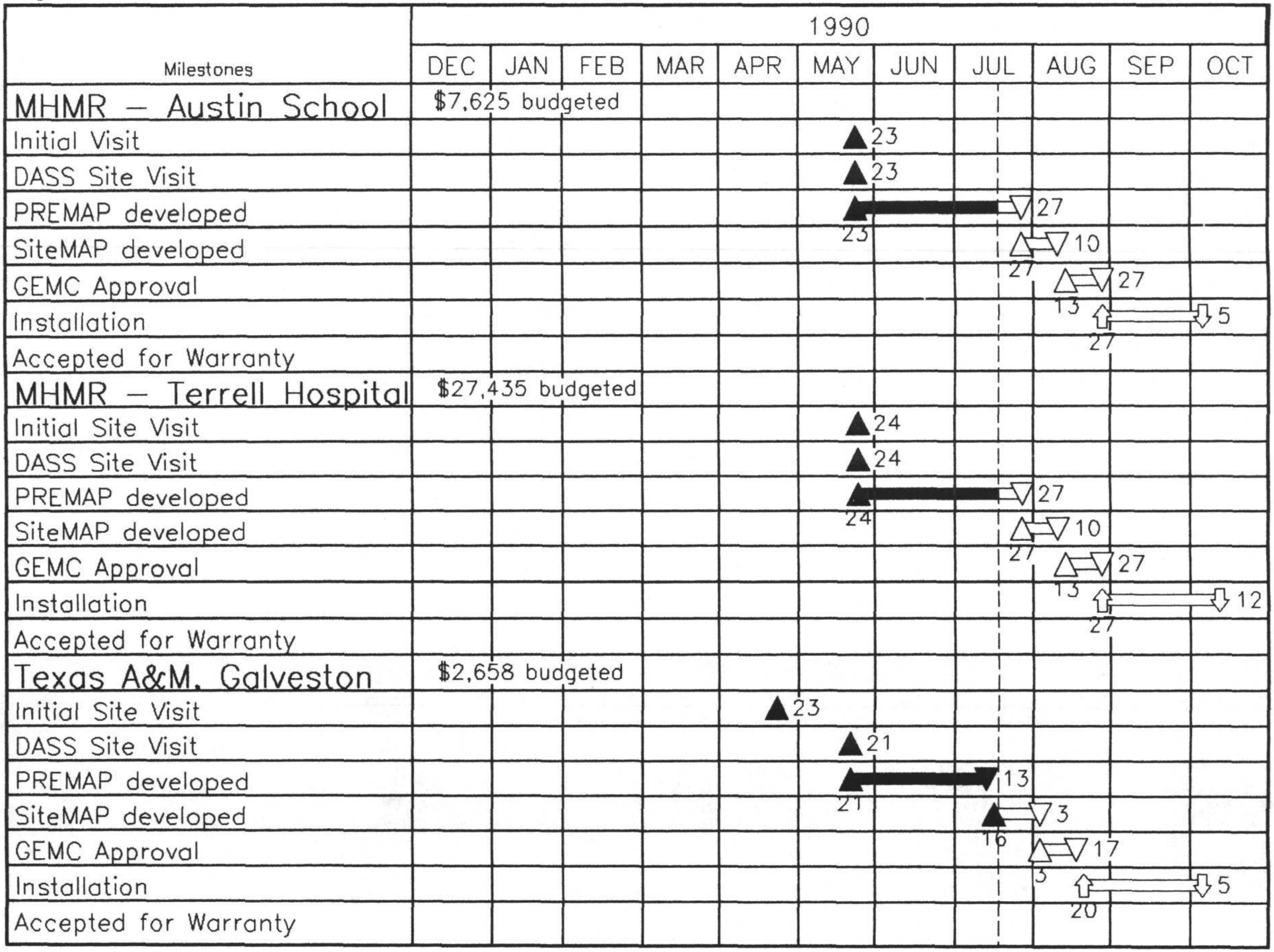
LoanSTAR Project Status

7/17/1990



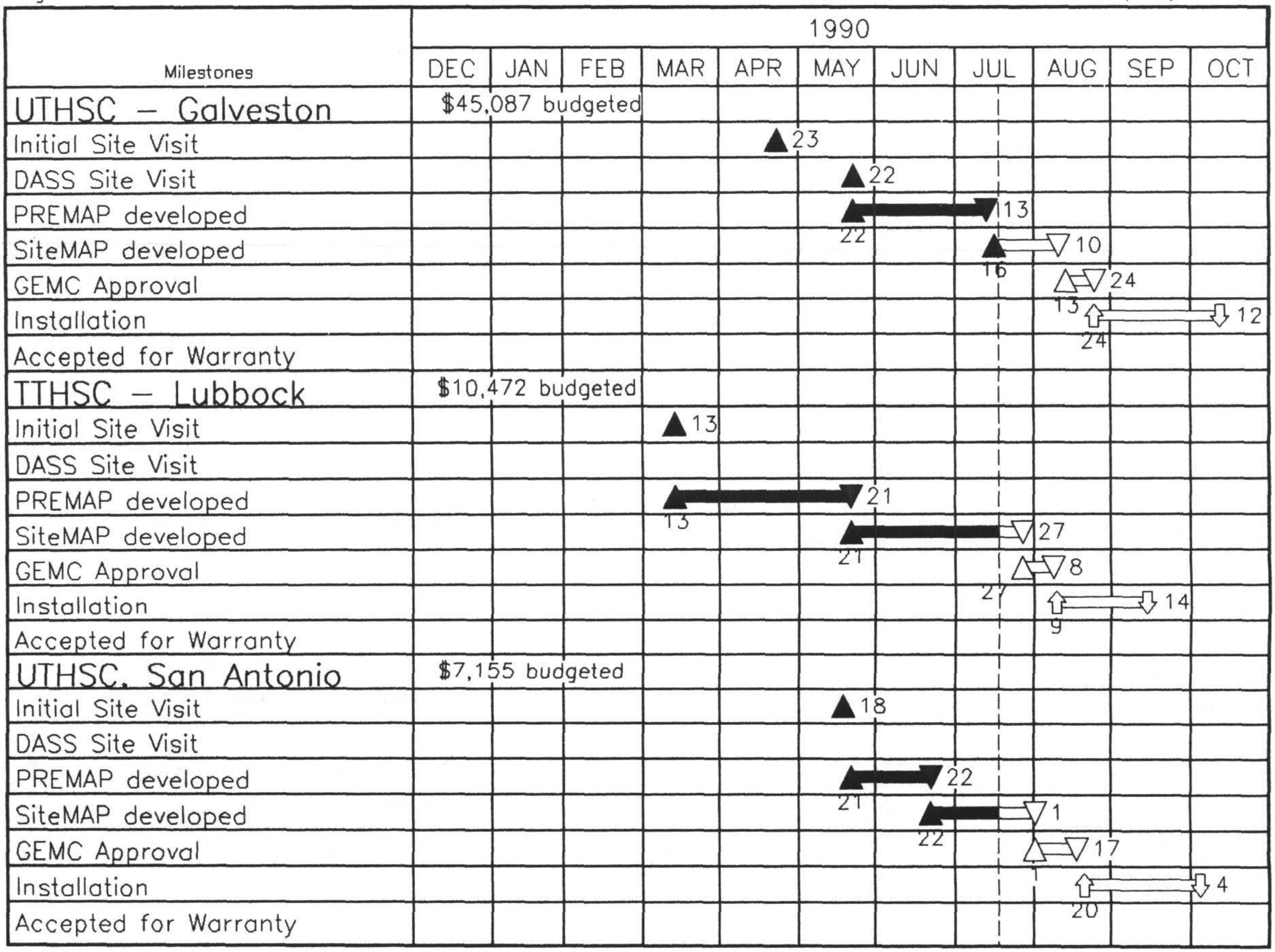
LoanSTAR Project Status

7/17/1990



LoanSTAR Project Status

7/17/1990



LoanSTAR Project Status

7/18/1990

Milestones	1989 DEC	1990 JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
U. of North Texas	$4,353 budgeted										
Initial Site Visit			▲ 12								
DASS Site Visit						▲ 24					
PREMAP developed						▲ 25			▽ 10		
SiteMAP developed									△ 13 – ▽ 27		
GEMC Approval									△ 26	▽ 14	
Installation										⇧ 17	⇩ 12
Accepted for Warranty											

Agency Name	Loan Amount	Approx. Funding	PREMAP Costs	BUDGETED Amount	Agency Costs
Texas A&M	$1,331,660	$39,950			
Texas Dept of Health	$289,174	$8,675	$650	*$15,000*	*$7,000*
MHMR - Total site	$4,408,687	$132,261	$1,700	*$130,000*	*$20,000*
MHMR - El Paso	$42,510	$1,275			
MHMR - Austin Hospital	$281,496	$8,445			
MHMR - Austin School	$254,175	$7,625			
MHMR - Terrell	$914,507	$27,435			
U. T. Arlington	$1,281,822	$38,455	$1,582	$56,240	$17,781
Texas A & M, Galveston	$88,589	$2,658	$500	$26,961	$24,303
U. T. Austin	$4,678,852	$140,366	$6,300	$180,750	$46,674
U. T. Medical Branch	$1,502,906	$45,087	$4,500	$87,343	$31,144
UTHSC, Dallas	$521,623	$15,649	$790	$30,910	$19,700
U. T. , Dallas	$766,201	$22,986	$790	$34,335	$16,850
TTHSC, Lubbock	$349,077	$10,472		*$15,000*	*$5,000*
UTHSC, Houston	$1,748,639	$52,459	$3,000	$32,655	$6,735
UTHSC, San Antonio	$238,484	$7,155		*$15,000*	*$8,000*
Univ. of North Texas	$145,116	$4,353	$700	*$7,000*	*$3,000*
Texas School ... Blind	$125,765	$3,773		*$4,000*	*$1,000*
Capitol Complex	$3,338,585	$100,158	$4,300	$130,384	$38,670
	$20,815,180	$624,455	$24,812	$765,578	$245,857

- Project costs update for 7/2/90. Costs in Budgeted Amount include the costs of the weather stations.
- Costs in italics are estimated amounts.

APPENDIX II

Following is a typical SiteMAP as completed for the U.T. Austin LoanSTAR site. This form lists some of the building characteristics as well as the ECRMs and the proposed monitoring points. Once the final SiteMAP has been generated, it is sent to the G.E.M.C. for approval.

AGENCY: U.T. Austin

BUILDING: Education
SIZE: (sq. ft.) 251,161
MONITORING BUDGET: $17,609.00

Building description: 5 floors, hours of operation 8:00-24:00, 2-75 hp CHW pumps, 8-50 hp fans, 8-30 hp fans, 8-20 hp fans, dual feed switchgear.

Proposed ECRMs	Cost ($)	Annual Savings
1. Replace incand. lights	$50,036.00	$38,220
2. occupancy sensors	$1,845.00	$1,199
3. variable air volume	$555,066.00	$116,071
4. variable speed pumping	$30,021.00	$7,665
Total Cost:	$636,968.00	$163,155

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 2 kyz units in ex. mtrs	1,2,3,4	$507.00
2. condensate flow HW meter & trap	3,4	$610.00
3. CHW flow 1 flow mtr, 1 BTU mtr	3,4	$846.00
4. total fan KWh 57 CTs & 3 KWh xducer	3	$2,369.00
5. study AHU KWh 6 CTs & 1 KWh xducer	3	$518.00
6. CHW pump KWh 9 CTs & 1 KWh xducer	4	$625.00
	Monitoring Costs:	$5,475.00

AGENCY: U.T. Austin

BUILDING: PCL
SIZE: (sq. ft.) 483,895
MONITORING BUDGET: $20,554.00

Building description: 6 floors, 2-60 hp CHW pumps, dual feed switchgear, 24 fans of 75 and 100 hp.

Proposed ECRMs		Cost ($)	Annual Savings
1. occupancy sensors		$3,250.00	$1,210
2. variable air volume		$706,764.00	$362,896
3. variable speed pumping		$25,129.00	$9,515
	Total Cost:	$735,143.00	$373,621

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 4 kyz units in ex. mtrs	1,2,3	$1,063.00
2. condensate flow 4 HW meters & traps	2,3	$2,452.00
3. CHW flow 1 flow mtr, 1 BTU mtr	2,3	$846.00
4. total fan KWh 90 CTs & 5 KWh xducers	2	$6,012.00
5. CHW pump KWh 9 CTs & 1 KWh xducer	3	$866.00
	Monitoring Costs:	$11,239.00

AGENCY: U.T. Austin

BUILDING: WELCH
SIZE: (sq. ft.) 243,000
MONITORING BUDGET: $21,943.00

Building description: 5 floors, 2-75 hp CHW pumps, dual feed switchgear 6-100 hp AHU, 5-30 hp AHU, 1-60 hp AHU.

Proposed ECRMs		Cost ($)	Annual Savings
1. replace incan. lights		$16,715.00	$3,184
2. variable air volume		$734,726.00	$276,494
3. variable speed pumping		$30,002.00	$23,757
	Total Cost:	$781,443.00	$303,435

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 2 kyz units in ex. mtrs w/monitoring 1929 bldg	1,2,3	$1,376.00
2. condensate flow HW meter & trap	2,3	$600.00
3. CHW flow 1 flow mtr, 1 BTU mtr	2,3	$846.00
4. total fan KWh 36 CTs & 3 KWh xducers	2	$2,961.00
5. CHW pump KWh 9 CTs & 1 KWh xducer	3	$863.00
	Monitoring Costs:	$6,646.00

AGENCY: U. T. Austin

BUILDING: UTC
SIZE: (sq. ft.) 152,690
MONITORING BUDGET: $10,488.00

Building description: 6 floors, 2-50 hp CHW pumps, dual feed switchgear 3-25 hp AHU, 2-20 hp AHU, 2-30 hp AHU, 1-15 hp AHU, 7-7.5 hp RAF.

Proposed ECRMs		Cost ($)	Annual Savings
1. 3 position light switch		$3,091.00	$9,996.
2. variable air volume		$328,820.00	$97,646
3. variable speed pumping		$34,344.00	$23,757
	Total Cost:	$366,255.00	$131,399

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh split kyz from exist.	1,2,3	$42.00
2. condensate flow HW meter & trap	2,3	$605.00
3. CHW flow 1 flow mtr, 1 BTU mtr	2,3	$846.00
4. total fan KWh 60 CTs & 5 KWh xducers	2	$4,909.00
5. CHW pump KWh 6 CTs & 1 KWh xducer	3	$758.00
	Monitoring Costs:	$7,160.00

AGENCY: U. T. Austin

BUILDING: J.J. COMM (CMA)
SIZE: (sq. ft.)
MONITORING BUDGET: $14,813.00

Building description: (CMA); 2-25 hp CHW pumps, 2-75 hp AHU. (CMB); various hp 5-40 AHUs, 1-75 hp CHW pump (CMC); 1-30 hp AHU, 1-15 hp CHW pump

Proposed ECRMs		Cost ($)	Annual Savings
1. lighting control		$4,111.00	$3,481
2. variable air volume		$404,874.00	$210,141
3. variable speed pumping		$68,502.00	$31,138
4. two speed AHU motors		$66,278.00	$10,765
	Total Cost:	$543,765.00	$255,525

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh (blg A,C) 2 kyz units in ex. mtrs	1,2,3,4	$510.00
2. condensate flow 1 HW meter & trap	2,3	$597.00
3. CHW flow 1 flow mtr, 1 BTU mtr	2,3	$846.00
4. total fan KWh 12 CTs & 2 KWh xducers	2,4	$1,496.00
5. CHW pump KWh 3 CTs & 1 KWh xducer	3	$639.00
1. total bldg KWh (blg B) 2 kyz units in ex. mtrs	1,2,3,4	$508.00
2. condensate flow 2 HW meters & traps	2,3	$1,227.00
3. CHW flow 1 flow mtr, 1 BTU mtr	2,3	$846.00
4. total fan KWh 36 CTs & 4 KWH xducers	2	$3,444.00
5. CHW pump KWh 6 CTs & 1 KWh xducer	3	$748.00
6. AHU B-6 KWh (2 spd) 6 CTs & 1 KWh xducer (pulled into #4 3/26/90)	4	$335.00

1.	AHU VAV KWh (blg C) 6 CTs & 1 KWh xducer	2	$752.00
2.	condensate flow 1 HW meter & trap	2,3	$593.00
3.	CHW flow 1 flow mtr, 1 BTU mtr	2,3	$846.00
4.	total fan KWh 6 CTs & 1 KWh xducer	2,4	$756.00
5.	CHW pump KWh 3 CTs & 1 KWh xducer	3	$648.00
		Monitoring Costs:	$14,791.00

AGENCY: U. T. Austin

BUILDING: WAGGENER
SIZE: (sq. ft.)
MONITORING BUDGET: $2,106.00

Building Description: 4 floors, 2-40 hp AHU, 1-5 hp CHW pump.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$86,852.00	$20,400
	Total Cost:	$86,852.00	$20,400

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 1 KWh meter w/kyz	1	$1,253.00
2. condensate flow 1 HW meter & trap	1	$1,000.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1	$846.00
4. total fan KWh 6 CTs & 2 KWh xducers	1	$1,285.00
	Monitoring Costs:	$4,384.00

AGENCY: U. T. Austin

BUILDING: BURDINE
SIZE: (sq. ft.)
MONITORING BUDGET: $3,548.00

Building description: 1-75 hp AHU, 1-100 hp AHU, 2-40 hp CHW pumps.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$122,966.00	$36,138
2. variable speed pumping		$11,993.00	$5,911
	Total Cost:	$134,959.00	$42,049

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 1 KWh meter w/kyz	1,2	$1,255.00
2. condensate flow 1 HW meter & trap	1	$598.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1,2	$846.00
4. total fan KWh 9 CTs & 2 KWh xducers	1	$1,490.00
5. CHW pump KWh 6 CTs & 1 KWh xducer	2	$746.00
	Monitoring Costs:	$4,935.00

AGENCY: U. T. Austin

BUILDING: GARRISON
SIZE: (sq. ft.)
MONITORING BUDGET: $2,124.00

Building description: 1-25 hp AHU, 1-30 hp AHU, 1-15 hp CHW pump.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$59,979.00	$9,066
2. variable speed pumping		$8,313.00	$1,419
3. connect to FMCS		$19,194.00	$9,401
	Total Cost:	$87,486.00	$19,886

Proposed Monitoring Points	ECRM affected		Cost ($)
1. total bldg KWh 1 KWh meter w/kyz	1,2,3		$1,252.00
2. condensate flow 1 HW meter & trap	1,3		$598.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1,2,3		$846.00
4. total fan KWh 12 CTs & 2 KWh xducers	1,3		$838.00
5. CHW pump KWh 3 CTs & 1 KWh xducer	2,3		$635.00
		Monitoring Costs:	$4,169.00

AGENCY: U. T. Austin

BUILDING: GEARING
SIZE: (sq. ft.)
MONITORING BUDGET: $3,864.00

Building description: 2-30 hp AHU, 2-25 hp AHU, 1-5 hp AHU, 1-2 hp AHU 1-15 hp CHW pump. convert 30 and 25 hp AHU to VAV.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$134,815.00	$24,280
2. variable speed pumping		$10,643.00	$2,087
	Total Cost:	$145,458.00	$26,367

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 1 KWh meter w/kyz	1,2	$1,254.00
2. condensate flow 1 HW meter & pop valve	1	$1,004.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1,2	$846.00
4. total fan KWh 18 CTs & 3 KWH xducers	1	$2,265.00
5. CHW pump KWh 6 CTs & 1 KWH xducer	2	$752.00
	Monitoring Costs:	$6,121.00

AGENCY: U. T. Austin

BUILDING: NURSING
SIZE: (sq. ft.)
MONITORING BUDGET: $4,675.00

Building description: 2-100 hp AHUs, 1-30 hp CHW pump.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$161,842.00	$38,441
2. variable speed pumping		$10,674.00	$2,795
	Total Cost:	$172,516.00	$41,236

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 2 kyz units on ex. mtrs	1,2	$505.00
2. condensate flow 1 HW meter & trap	1	$508.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1,2	$846.00
4. total fan KWh 6 CTs & 2 KWH xducers	1	$1,300.00
5. CHW pump KWh 3 CTs & 1 KWH xducer	2	$647.00
6. tennis court lights 6 CTs & 1 KWh xducer		$766.00
	Monitoring Costs:	$4,572.00

AGENCY: U. T. Austin

BUILDING: STEINDHAN
SIZE: (sq. ft.)
MONITORING BUDGET: $581.00

Building description: 1-40 hp AHU, 1-50 hp AHU, and 1-7.5 hp CHW pump.

Proposed ECRMs	Cost ($)	Annual Savings
1. hot and cold deck reset	$19,369.00	$5,768
Total Cost:	$19,369.00	$5,768

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 1 KWh meter w/kyz		$1,252.00
2. condensate flow 1 HW meter & trap	1	$597.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1	$846.00
	Monitoring Costs:	$2,695.00

AGENCY: U. T. Austin

BUILDING: W.C. HOGG
SIZE (sq. ft.)
MONITORING BUDGET: $1,815.00

Building description: 2-40 hp AHUs, 2-5 hp AHUs, and 1-25 hp CHW pump.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$64,700.00	$11,301
2. variable speed pumping		$9,675.00	$3,671
3. replace economizer AC-1		$2,790.00	$710
	Total Cost:	$77,165.00	$15,682

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 1 KWh meter w/kyz	1,2	$1,259.00
2. condensate flow 1 HW meter & trap	1,3	$605.00
3. CHW flow 1 flow mtr, 1 BTU mtr	1,2,3	$846.00
4. total fan KWh 12 CTs & 3 KWH xducers	1	$.00
5. CHW pump KWh 3 CTs & 1 KWH xducer	2	$.00
6. status pt on econ 1 status switch	3	$53.00
Note: items 4, 5, & 6 cut meeting 3/26/90.	Monitoring Costs:	$2,763.00

AGENCY: U. T. Austin

BUILDING: WIN
SIZE (sq. ft.)
MONITORING BUDGET: $5,854.00

Building description: 1-100 hp AHU, 1-50 hp AHU, 1-30 hp CHW pump, and 2-10 hp CHW pumps.

Proposed ECRMs		Cost ($)	Annual Savings
1. variable air volume		$178,157.00	$38,567
2. variable speed pumping		$33,655.00	$6,314
	Total Cost:	$211,812.00	$44,881

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 4 KWH meter w/kyz	1,2	$3,000.00
2. condensate flow 1 HW meter & trap	1	$599.00
3. CHW flow 2 flow mtrs, 2 BTU mtrs	1,2	$1,692.00
4. total fan KWh 36 CTs & 3 KWH xducers	1	$.00
5. CHW pump KWh 9 CTs & 2 KWH xducers	2	$.00
Note: items 4 & 5 cut meeting 3/26/90.	Monitoring Costs:	$5,291.00

AGENCY: U. T. Austin

BUILDING: PAINTER
SIZE (sq. ft.)
MONITORING BUDGET: $7,129.00

Building description: 6 floors, 2-40 hp AHUs, 1-50 hp AHU, 1-20 hp CHW pump, and 1-15 hp CHW pump.

Proposed ECRMs		Cost ($)	Annual Savings
1. cold deck control AC-1		$41,958.00	$10,374
2. occupancy control AC-2,3,4		$4,768.00	$4,805
3. VAV AC-1,5,6		$173,318.00	$18,994
4. replace AC-3,4		$34,267.00	$5,158
	Total Cost:	$254,311.00	$39,331

Proposed Monitoring Points	ECRM affected	Cost ($)
1. total bldg KWh 4 KWH meter w/kyz	2,3,4	$3,000.00
2. condensate flow 2 HW meters & traps	2,3,4	$1,217.00
3. CHW flow 2 flow mtrs, 2 BTU mtrs	1,3,4	$1,692.00
4. AC-2,3,4 KWh 9 CTs & 3 KWH xducers	2	$.00
5. AC-1 KWh 3 CTs & 1 KWH xducer	3	$.00
6. CHW pump KWh 6 CTs & 2 KWH xducers		$.00
7. AC-5,6 KWh 12 CTs & 2 KWH xducers	3	$.00
Note: items 4, 5, 6, & 7 cut meeting 3/26/90.	Monitoring Costs:	$5,909.00

	LoanSTAR 3% BUDGET	UT AUSTIN MAP ACTUAL	UT AUSTIN LOAN
Material Costs	$50,000	$86,150	$0.00
KWH Metering Costs	$8,000	$0.00	$18,036
Termal Metering Costs	$9,000	$0.00	$28,638
Project Engineering	$18,000	$36,000	$0.00
Direct Labor Costs	$40,000	$32,900	$0.00
Travel - per Diem Costs	$3,000	$5,850	$0.00
Data Logger Costs	$11,360	$15,850	$0.00
Misc. Material Costs	$1,000	$4,000	$0.00
TOTALS:	$140,360	$180,750	$46,674

APPENDIX III

Following is a draft version of the comprehensive Site Form. This type form will be completed for all buildings in the LoanSTAR program.

DRAFT

INSTRUCTION SHEET

I. General Data - Whole Section

get this information before you go (as much as possible)
verify @ site meeting

II. Building Description

3) get from drawings or ask @ meeting
5) brief description if more than one note

IV.

1) count light (in a few sample rooms) or get from plans
2) look @ equipment actually being used
3) note any large loads - mainframe computers, etc.

V. HVAC Systems Data

A) EMS System

6 Capabilities

- timing functions → time clocks / programmable timers / computers / lights, night set-back

- duty cycle functions
- demand control
- efficiency optimization (chiller, boiler)
- HVAC control - economizers enthalpy control
- single function vs. multi-function

DRAFT

Know before you Go

- name of personnel that you will be dealing with on site visit
- get @ least 2 yrs of utility data NOTE: the person who gives you this info will probably not be the same as the site visit guide
- ask for a floor plan (such as the one they give to fire dept) (make 5 copies for visit - see last 4 pages)
- get rate schedule from electrical utility
- if possible get a copy of as built plans SQ FT.

Tools for Site Visit

Camera (film, flash) - black & white better contrast (publications)
VHS camcorder (tape)
Light meter
Amp meter

DRAFT

Field Checklist - Site Visit

- Meet/greet   NOTE: names of people @ meeting

- Sit down if possible - discuss some upfront questions

- Verify any information received prior to visit
    - bring up any questions @ this time about that information
    NOTE: Record all this in field notebook

- ASK

    - when was bldg built?   SQ FT.

    - any modifications?
        if so when?
            what?

    - hours of operations? (M-F)/S&S
        tenant
        any exceptions? ____ how frequent

    - holiday schedule

    - # of people working on schedule above
        (M-F) ____ S/S
        Holidays

    - computer room?
        separate equipment ____________
        hours ____________

    - is the bldg zones for htg/cooling?
        set pt temperatures
        night setback? _____ hours _____
        if zoned - mark up a map

    - what type of equipment is out there?
    - what do they believe are the major energy users

    } background for walk through

DRAFT

During Walk through - (Escorted)

Name of Escort:

Note in field book

Room/Location
Equipment
get name plate data
What is it used for
if zoned which zone

If possible: roof top visit for inspection

Next part of walk through site visit
escorted/unescorted
NOTE: this part it is not necessary to have bldg personnel w/you

Walk through individual zones

- get lighting info
- get receptacle load info/note location of any major equipment
  - any biggies
    get nameplate data

} possibly do during lunch as to not disturb

Get info in bldg shell

- as built plans (not as drawn)
- verify construction
- glazing ___amt & type
- roof

Take pictures/video

MAR 0 3 1990 **DRAFT**

CONFIDENTIAL

I'm ________________________ a student at Texas A&M University. We are working on a project called LoanSTAR (loans to save taxes and resources) that will study a number of buildings throughout the state in hopes of targeting some measures that will reduce energy costs. As a part of this study we are also hoping to learn about building maintenance and operations so that others may learn from this. We would like to ask you some questions in our survey. We will not use your name and your answers will be held in confidence. Would you be willing to help us out?

________ yes ________ no ______ reasons?

<u>QUESTIONS</u>:

1. How is the building maintenance performed?
   - General? (i.e. windows, plumbing, etc)
   - Electrical/telephone/commercial/EMCs?
   - Boiler?
   - Chiller?

4. How many maintenance people?
   - What are the different crafts?

2. How have you obtained your work experience for this position? (formal training, O.J.T., none, etc.)

3. What training do the maintenance personnel have?
   - HVACR Training? ---K-12------college?-------License?

3. What experience do the maintenance personnel have?

5. How do maintenance personnel view their job?
   - a. Is your job "easy"?
   - b. Do you feel there is enough time to get the job done well?
   - c. Could you use more help? _
   - d. Do you feel you are making a contribution to the smooth running of the facility?
   - Recognized for good work?----Complaint driven?

6. Do maintenance personnel see the energy bills? _
   - a. If so, when? _
   - b. How often do they see them? (sporadically, end of year, etc.)
   - c. What, if any, information do they see? (total costs, demand, etc.)
   - d. Does it make sense?

7. Who makes decisions about equipment choice?_

HVAC systems? ---- Filters?

Lights? -------- Maintenance?

8. What equipment do you feel you need to accomplish your job?

9. What type equipment do you feel would be the most useful to this facility to improve building energy efficiency? (Lighting control systems, EMCS systems, microcomputers, etc.)

Why?

9. Do the maintenance personnel have PC's.?

Do they want them?-----For what?-----What are they helpful for?_

10. Do the maintenance personnel belong to any societies or professional organizations? To which do they belong?

If your fees were paid, would you want to participate in these type organizations?

11. Do the maintenance personnel receive any periodic trade or journal literature?

12. Have you heard about the about the Texas LoanSTAR program?

What do you think of it?_

13. What do the maintenance personnel expect from this program?

14. What would help the maintenance personnel do their job better?

15. Do they have any EMCS experience?

a. Where and how did you obtain this experience?

b. Who provided this training?

SITE ______________________________ BUILDING _________________________

INTERVIEWER ___________________________________ DATE _______________________

comments

GENERAL BUILDING DATA

I. GENERAL DATA:

1.Agency Name:____

2.Agency Address: ____

____

3.Agency Phone:______________ 4.Agency Fax#_________________

5.Building Name:____________________ 6. MAP ID #___________

7.SIC code__________________________ 8. GEMC ID #__________

9.Location/Address:____

10.Phone:___________________ 11.FAX_________________________

12.Building manager-operator name:__________________________

13.Address:_________________ 14.Phone:______________________

_________________ 15.FAX:___________________________________

16.Maintenance Contractor Name:_____________________________

17. Address:____

18. Contact:__________________ 19.Phone:____________________

20. Telephone Co.:______________ Address:____________________

21. Contact:____

II. BUILDING DATA:

1.Const. date:_________ 2.Remodel type/date(s):_____________

3.Conditioned Floor Area:_________4.Number of Stories:______

5.Building shell description:

Overall U-value:

____

____

____

6.Roof construction:

Overall U-value:

____

____

____

COMMENTS ____

____

____

____

____

7. Windows:

Mark	Type	Glazing	Size

8.

window	NORTH	EAST	SOUTH	WEST
square footage				

III.OCCUPANCY AND LIGHTS SCHEDULE DATA --(NOTE AM/PM)

Occupancy:

1.Zone #

DAYS	M	T	W	TH	F	S	S	HOL
HOUR OPEN								
HOUR CLOSED								
# OF PEOPLE								

2.Zone #

DAYS	M	T	W	TH	F	S	S	HOL
HOUR OPEN								
HOUR CLOSED								
# OF PEOPLE								

Lights

1.Zone #

DAYS	M	T	W	TH	F	S	S	HOL
HOUR ON								
HOUR OFF								

2.Zone #

DAYS	M	T	W	TH	F	S	S	HOL
HOUR ON								
HOUR OFF								

COMMENTS

5. Observed Holidays:

HOLIDAY/CLOSINGS	DATE	COMMENTS

IV. MISCELLENEOUS LOAD DATA

1. Estimated Lighting load (kW)______________________________

2. Estimated Receptacle load (kW):__________________________

3. Light Fixture:

MARK	# OF	WATTS	VOLTS	REMARKS

4. Misc. loads :

SOURCE	FUEL	LOAD	LOCATION/COMMENTS

COMMENTS

____

____

____

____

____

V. HVAC SYSTEMS DATA:

A. EXISTING DATA ACQUISITION/ENERGY MONITORING & CONTROL SYSTEM/S:

1. Manufacturer:____________________ 2. Model:____________________

3. Operator________________ 4. Year purchased__________________

5. Upgrades____

6. Extent of System/s and: Capabilities________________________________

____

____

____

____

B. HEATING AND COOLING

I.D.#	TYPE	H/C	FUEL	RATING (BTUH, TON)	CONTROL	COMMENTS

COMMENTS____

____

____

____

____

____

C. DISTRIBUTION

Air Handling Units

MARK	TYPE	TYPICAL FOR

FAN SECTION	CFM	OSA CFM	HP	VOLTS	PH

COOLING COIL	GPM	EWT	T	EAT	LAT	COOLING CAPACITY SENS/TOTAL (MBTUH)

HEATING COIL	GPM	EWT	T	EAT	CFM	HEATING CAP.(MBTUH

SCHEDULE:	HOUR ON	HOUR OFF

ZONES SERVED

Fan Coil Units

MARK	TYPE	TYPICAL FOR

FAN SECTION	CFM	OSA CFM	HP	VOLTS	PH

COOLING COIL	GPM	EWT	T	EAT	LAT	COOLING CAPACITY SENS/TOTAL (MBTUH)

HEATING COIL	GPM	EWT	T	EAT	CFM	HEATING CAP.(MBTUH

ELECTRIC REHEAT COIL	

SCHEDULE:	HOUR ON	HOUR OFF

ZONES SERVED

COMMENTS:

EXHAUST FANS:

MARK	TYPE	TYPICAL FOR

CFM	HP	VOLTS	PHASE	LOCATION

SCHEDULE:	HOUR ON	HOUR OFF

ZONES SERVED

PUMPS:

MARK		SERVICE	

HEAD	GPM	PH	VOLTS	MOTOR EFF.	PUMP EFF.

COMMENTS:

DRAFT

VI. HISTORICAL BUILDING ENERGY USE DATA

A. ELECTRICAL

1. Electric Utility Name: ______________________ 2. Contact ______________________

3. Phone : ______________ 4. Address: ______________________________

____

5. Electric Meter: Manufacturer: ______________________

6. Class: __________ 7. Voltage: ______________________

8. Wire #: __________ 9. Wye or Delta: ______________________

10. Meter Type: __________ 11. Form #: ______________________

12. Demand Register Yes/No Type: ______________________

______________ 13. Time Interval ______________

DATE START	DATE END	kWh	kW PEAK	kW BILLED	POWER FACTOR

ATTACH RATE SCHEDULE

DRAFT

B.NATURAL GAS

1.Gas Utility Name: ______________________________ 2.Contact______________________

3.Phone :______________________________

4.Address: ____

____

5.Natural Gas Meter: Manufacturer:______________________________

6.Model # ______________________________

7.Serial #______________________________

8.Natural Gas Use Data:

DATE START	DATE END	USAGE (CCF OR MCF)

ATTACH RATE SCHEDULE

COMMENTS

____

____

____

____

DRAFT

C. PURCHASED THERMAL ENERGY DATA

1. Thermal Energy Supplier Name:______________ 2. Contact________________

3. Address:__________________________________ 4. Phone :____________________.

____

5. Thermal Energy Meter: Type_________________________________

6. Manufacturer:______________________________

7. Model # ______________________________

8. Serial #______________________________

9. Thermal Energy Use Data: (circle one)

DATE START	DATE END	MBTUH HOT WATER LBS-STEAM TON-HR CHILLED WATER

COMMENTS

____

____

____

DRAFT

D.OTHER ENERGY DATA

1.Other Energy Supplier Name:________________2.Contact__________________

3.Address:______________________________4.Phone :__________.

_____________________________________.

5.Other Energy Meter: Type____

6.Manufacturer:_____________________________________

7.Model # ___________________________________

8.Serial #___________________________________

9.Other Energy Use Data:

WATER	OIL	COAL	STANDBY GAS	OTHER

COMMENTS

____

____

DRAFT

VII. SKETCHES

A. Sketch a Plan View of the Facility with; 1) meter/utility location/s for N.G., Elec., Water, & Telephone 2) show approximate locations of major electrical panels, and proposed retrofit/s.

DRAFT

B.Sketch a one-line diagram of the electrical distribution for the facility. Show major panels, meter location, and proposed1 retrofit location.

DRAFT

C.Sketch a one-line diagram of the main chilled/hot water/steam piping layout. Show locations for thermowells and flow stations.

DRAFT

D.Sketch a one-line diagram of the Natural Gas System. Show major gas loads, meter location and retrofit location.

Texas LoanSTAR Monitoring and Analysis Program

Calibration Laboratory

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

Mel Glass
W. D. Turner

Energy Systems Laboratory
Mechanical Engineering
Texas A&M University
College Station, Texas

July 1990

TASK 3 - Calibration Laboratory

Executive Summary

<u>Objective:</u>

To create a calibration test laboratory which will be used to calibrate sensors, validate their output prior to installation, calibrate Monitoring and Analysis Program (MAP) portable meters, and provide input signals for systems communications testing.

The calibration facility will include measurement of electrical energy, temperatures, air and liquid flow rates, humidity, air and hydraulic pressure, illumination levels solar energy measurement and other quantities likely to be used in building energy measurement. Contractor will use National Institute of Standards and Technology (NIST)-(formerly the National Bureau of Standards) certified equipment where possible, but shall as a minimum maintain NIST traceable hardware. Additionally this laboratory will be used to trouble-shoot problem sensors in the field. The contractors and vendors portable meters used in field measurements will also be calibrated and verified periodically at this facility.

<u>Current Status:</u>

The following is the current status of the test setups:

<u>Temperature:</u> All equipment needed for the temperature testing has been received and is operational.

<u>Humidity:</u> All equipment needed for the humidity testing has been received. The dew-point sensors have been sent for calibration and are due back the week of July 23, 1990.

<u>Pressure - Hydraulic:</u> All equipment needed for the pressure testing has been received and is operational.

<u>Pressure - Air:</u> All equipment needed for the air pressure testing has been received and is operational.

<u>Flow - Liquid:</u> All equipment needed for the liquid flow testing has been received except the weighing load cells. We are presently constructing the test setup and should be operational by August 31, 1990.

Air Velocity: All equipment needed for the air velocity testing has been received and will be operational by August 31, 1990.

Computer Programming: We are using Lotus 123 spreadsheet formats for the initial report generation. All data from the testing is manually entered into the appropriate spreadsheet format. We are in the evaluation stage of developing an automatic data acquisition and report generation.The techniques and procedures for calibration are being developed for each of the sensors based upon recommendations of existing calibrating standards.

TASK 3 - Calibration Laboratory

Calibration Laboratory:

The accuracy of the installed sensors is the key to a successful energy monitoring project. Data obtained for this project must be accurate to maintain confidence and reliability. In order to assure that accurate data are collected, a National Institute of Standards and Technology (NIST) traceable calibration laboratory is being established at the Energy Systems Laboratory (ESL) at Texas A&M University.

The objectives of the calibration laboratory are to: (1) construct a NIST-traceable facility which will be used to test sensors and verify their compatibility with selected energy monitoring systems; (2) establish a facility for troubleshooting faulty sensors found in the field; (3) construction and calibration of a portable calibration laboratory system for in-situ field testing, troubleshooting, calibration and validation; (4) have a facility to bench-test and pre-quality proposed sensors and hardware prior to approval for installation in the field; and (5) develop and test new and revised calibration procedures for in-situ field testing of sensors, and develop installation guidelines for the sensors.

This calibration laboratory will have the capability to measure dry-bulb, wet-bulb and dew-point temperatures; relative and absolute humidity; air and hydraulic pressure - absolute, gage and differential; air and liquid mass flowrates; air velocity; RPM; illumination levels; electrical - demand, energy and power factor; and solar energy. Figure 1 shows the test set-ups and their ranges, accuracy and calibration capacities. Typically this calibration laboratory's accuracy will be two to ten times more accurate than the sensors being tested (as recommended by nation calibration standards).

The calibration laboratory will be located at the ESL facility on the Texas A&M Riverside Campus. An expansion of these objectives follows:

1. The philosophy behind establishing the calibration laboratory is to be able to verify both sensor accuracy and compatibility with the monitoring systems before field installation. In too many cases, the field installation is the first check of the system compatibility. For example a recent installation at a Texas state facility took months before the system was operational, or at another facility the energy monitoring system was abandoned because of incompatibility of monitoring equipment.

2. Field installation problems likely will arise with faulty sensors or a faulty class of sensor. Since the DASS are required to maintain and verify periodic calibration of their systems in the field, the ESL calibration facility can be used to determine sensor problems and also resolve potential conflicts about incorrect sensor readings.

3. Calibrated portable instrumentation also will be developed for spot checks on the DASS installation. The DASS is responsible for installing the system and certifying proper operation, but a portable field unit will enable the MAC to verify proper system operation on-site. The unit also can be used for troubleshooting older installations when problems arise.

4. The accuracy of sensor calibration is key to the whole monitoring project. Data obtained from the DAS has to be accurate to maintain confidence in the project. To verify the accuracy of the sensors and to have a facility that the DASS will have confidence in, NIST-traceable calibration is absolutely necessary. The ESL will make the NIST-traceable services available to potential hardware suppliers, and will maintain an NIST-traceable facility for all common quantities (i.e., temperature velocity, flow RPM, etc.) that will be encountered in this project. It also anticipated that field sensors and systems will be rechecked periodically to verify their continued calibration.

5. Development of simple techniques for evaluating and calibrating in-situ sensors. For example, the facility could be used to simulate an in-field setup to develop the correct procedure for calibrating the sensor. A prime example of this is a flow meter installed too close to an elbow or some other obstruction which distorts the flow to produce incorrect readings. This setup can be duplicated at the lab and studied to develop the proper calibration procedure and correction factors to obtain the proper data.

<u>General Standards:</u>

* ASHRAE, 1985 Fundamentals Handbook, Chapter 13, "Measurement and Instruments";
* ISA, "Recommended Environments for Standards Laboratories";
* ASME; Standard PTC 19.1-85, "Measurement Uncertainty Instruments and Apparatus";
* "Measurement Systems Applications and Design", E. Doebelin, 4th Edition, McGraw Hill, NY, NY, 1990.

Work Plan:

The calibration laboratory is being constructed at the ESL facility, which is the certified fan test laboratory for the Home Ventilating Institute. When a fan performance curve is run on a fan, quantities such as RPM, power, and flow rates are normally measured. Thus, some of the facilities and instrumentation necessary for air flow and power measurements already exist. Where possible, existing facilities will be used or modified to meet the needs of the calibration laboratory. The construction of the calibration laboratory will be done in two phases due to the budget constraints of the project. The first phase will include the construction of the temperature; humidity; air and hydraulic pressure; air and liquid flow rates; and air velocity test setups. Figure 2 shows the present budget for phase one. The second phase will add RPM; illumination levels; electrical-energy, demand and power factor; and solar energy. The first phase is scheduled to be completed by August 31, 1990.

The Appendix A briefly describes each calibration test setup. The range of sensor calibration, types of sensor that can be calibrated, accuracy of calibration, applicable standards and simplified testing procedures are specified.

Future Plans

The following are the tentative plans for FY 1991:

Additional Calibration Test Setups:

Lighting: We will be adding a simple black box method of calibrating portable light meters using a comparison technique with a precision light meter.

Electrical: We will be developing three test setups for single and multi-phase electrical monitoring. These three test setups will be: (1) for calibrating electrical demand meters; (2) for calibrating electrical watt, volts and amp meters; and (3) for calibrating power factor. We are presently looking at both off the shelf and built-up systems.

Solar Radiation: We will be using a calibrated Eppley Precision Spectral Pyrometer as the "standard. The method used for evaluating and calibrating solar meters will be simple, side-by-side comparative testing outside using available solar radiation. Only global solar radiation will be measured, and cosine dependence will be determined.

Computer Programming: We will be modifying the existing manual data entry to an automatic entry system using a data acquisition system and computer interface. This data entry program will be either our own developed software, public domain software adapted for our needs, or a purchased laboratory information management system. Figure 3 shows the data to be associated with each test.

Portable Calibration Kit: We will be creating a traveling calibration kit that will be able to field-verify and calibrate temperature, humidity, air and hydraulic pressures, air velocity, amp, volts, watts and illumination levels. This kit will also be able to monitor sensor input to the field data loggers, download the data loggers and send known data steams to the down loading computer at the ESL facility.

CALIBRATION LABORATORY
Energy Systems Laboratory

Temperature
1990

Range:
-40°F to +400°F

Accuracy:
±0.2°F

Calibrate:
1. Thermometers
2. Thermocouple
3. RTD
4. Temperature portion of RH sensor

Humidity
1990

Range:
10% to 90% RH
Temperature:
(32 to 100)°F

Accuracy:
±1.5% RH
±0.2°F

Calibrate:
1. Dew Point Sensors
2. Relative Humidity Sensors
3. Dimensional Change Devices

Hydraulic Pressure
1990

Range:
0 to 500 PSI

Accuracy:
±0.5% Reading

Calibrate:
1. Pressure Gauges
2. Pressure Transducer

Air Pressure
1990

Range:
±0 to 24 in. WG

Accuracy:
±0.01 in. WG

Calibrate:
1. Manometer
2. Pressure Gauge

Liquid Flow
1990

Range:
5 to 600 GPM

Accuracy:
±1.0% of Flow

Calibrate:
1. Orifice
2. Venturi Tube
3. Flow Nozzle
4. Positive Displacement
5. Turbine
6. Vortex
7. Electro-magnetic
8. Ultrasonic
9. Mass-Coriolis
10. Mass-Thermal

Air Flow
1990

Range:
0 to 8,000 FPM

Accuracy:
±10 FPM

Calibrate:
1. Pitot Tube
2. Hot Wire Thermo-anemometer
3. Rotary Devices

Electrical

Voltage
1991

Range:
120/240/480
1 and 3 Phase

Accuracy:
±0.5% Reading

Calibrate:
1. Voltmeter
2. Multimeter

Amperes
1991

Range:
0 to 200 Amps

Accuracy:
±1.0% Reading

Calibrate:
1. Amp Meters

Wattage
1991

Range:
0 to 40 KW

Accuracy:
±1.5% Reading

Calibrate:
1. Watt Meter

Miscellaneous

Lighting
1991

Range:
1 to 10,000
Foot Candles

Accuracy:
±1.0% Reading

Calibrate:
1. Light Meter

Rotational Speed
1991

Range:
0 to 3,600 RPM

Accuracy:
±1 RPM

Calibrate:
1. Tachometers Contact & Noncontact

Solar
1991

Range:
0 to 500 Btu/ft^2

Accuracy:
±2% Reading

Calibrate:
1. Pyrometer

TASK 3 CALIBRATION FACILITY

Figure 2

COST ESTIMATE FOR CALIBRATION EQUIPMENT

DATE REVISED: JULY 16, 1990

EQUIP ITEM	EQUIP SUBSYSTEM	ORIGINAL GEMC COST ESTIMATE	PRESENT ESTIMATED COSTS	ACTUAL COSTS	ACTUAL COST SAVING FROM PRESENT EST	DATE ORDERED	DATE BID	DATE DUE	DATE REC'D	DATE OPERATION	COMMENTS
TEMPERATURE											
	THERM STORAGE RACK	$250.00	$220.00	$214.15	$5.85	11/29/89	---	01/25/90	01/25/90	05/15/90	THERMOMETERS SUPPORTS ARE COMPLETE
	MICROSCOPE	$250.00	$240.00	$238.36	$1.64	11/29/89	---	12/20/89	12/20/89	04/01/90	
	ICE BATH	$250.00	$160.00	$155.30	$4.70	11/29/89	---	12/14/89	01/05/90	04/01/90	
	CONST TEMP BATH	$3,350.00	$2,600.00	$2,571.00	$29.00	01/11/90	02/06/90	03/01/90	03/02/90		BATH ($2,216) + OIL ($355)
	DIST WATER CONTAINER	$200.00	$100.00	$83.81	$16.19	11/29/89	---	12/14/89	12/20/89	04/01/90	
	ICE SHAVER	$50.00	$50.00	$0.00	$0.00	02/12/90	---	05/15/90			
	ICE MAKER/STORAGE	$200.00	$175.00	$168.00	$7.00	11/29/89	---	12/08/89	12/15/89	04/01/90	
	ASTM THERMOMETERS	$1,500.00	$1,200.00	$1,168.99	$31.01	01/11/90	02/06/90	03/01/90	03/21/90	04/01/90	
	RTD THERMOMETERS	$1,000.00	$1,000.00	$819.50	$180.50	01/25/90	04/27/90	06/11/90	06/27/90		
	READING TELESCOPE	$200.00	$150.00	$136.33	$13.67	01/03/90	---	01/10/90	01/12/90	04/01/90	
	****SUBTOTAL****	$7,250.00	$5,895.00	$5,555.44	$289.56						
HUMIDITY											
erle	DEW POINT SENSORS	$7,300.00	$1,000.00	$0.00	$0.00	---	---	06/04/90	06/09/90		UNDERGOING CHECKOUT AND CALIBRATION
	FLOW METERS	$100.00	$100.00	$101.19	($1.19)	11/29/89	---	12/03/89	12/01/89		
	SALT BATH	---	$215.00	$0.00	$0.00		---				
	MISC TUBE & FIT	$100.00	$100.00	$0.00	$0.00		---				
	****SUBTOTAL****	$7,500.00	$1,415.00	$101.19	($1.19)						
PRESS-HYDR											
	DEAD WT TESTER	$1,780.00	$1,735.00	$1,735.00	$0.00	01/11/90	02/06/90	03/01/90	03/01/90	05/21/90	
	CARRYING CASE	$220.00	$100.00	$100.00	$0.00	01/11/90	02/06/90	03/01/90	03/01/90	05/21/90	
	****SUBTOTAL****	$2,000.00	$1,835.00	$1,835.00	$0.00						
PRESS-AIR											
	HOOK GAGE	$2,000.00	$2,200.00	$2,140.00	$60.00	01/11/90	02/06/90	03/01/90	03/20/90	05/15/90	
existing	PRESS BAROMETER	$250.00	$0.00	$0.00	$0.00	---	---	---	---	01/01/90	WILL USE EXISTING SYSTEM
	Q T VACUUM PUMP	$250.00	$125.00	$124.75	$0.25	11/30/89	---	12/14/89	12/12/89	05/15/90	
	****SUBTOTAL****	$2,500.00	$2,325.00	$2,264.75	$60.25						
FLOW-LIQUID											
	LOAD CELLS -4	$4,000.00	$6,000.00	$5,967.00	$33.00	02/20/90	03/21/90	07/16/90			
	STOR TANK 10K	$2,300.00	$2,200.00	$2,178.49	$21.51	01/25/90	02/20/90	03/19/90	03/26/90		
	REC TANK 10K	$2,300.00	$2,200.00	$2,178.49	$21.51	01/25/90	02/20/90	03/19/90	03/26/90		
	STEEL SUPPORT	$500.00	$2,275.00	$1,330.20	$944.80	04/18/90	---	05/20/90	05/14/90		Steel-$1,330.20+Unistrut-$x,xxx.xx
	PUMPS:										
	50 GPM	$750.00	$675.00	$670.49	$4.51	01/25/90	02/20/90	04/02/90	04/26/90		
	150 GPM	$1,500.00	$750.00	$737.80	$12.20	01/25/90	02/20/90	04/02/90	04/26/90		
donated	500 GPM	$3,000.00	$450.00	$450.00	$0.00	---	---	---	01/29/90		GIFT FROM DR MORRISON/REWOUND MOTOR
donated	RETURN	$0.00	$0.00	$0.00	$0.00	---	---	---	01/29/90		PICKED UP AT TAMU SURPLUS
	ELECTRICAL	---	$1,500.00	$0.00	$0.00		---				
	PIPING/VALVES	$1,000.00	$4,150.00	$4,104.90	$45.10	01/30/90	---	Various			Valves, Fittings, Piping, Stands
	****SUBTOTAL****	$15,350.00	$20,200.00	$17,617.37	$1,082.63						
AIR VELOCITY											
fan model	HOT WIRE THERM	$1,000.00	$0.00	$0.00	$0.00	---	03/30/90	07/17/90			USING UNIT FROM CEMR FAN MODELING
	ACRYLIC TUBING	$600.00	$150.00	$141.96	$8.04	12/01/89	---	12/05/89	12/15/89		
donated	INLET BELL	$50.00	$50.00	$0.00	$50.00	12/01/89	---	12/08/89	12/08/89		DONATED BY THE MANUFACTURER
	SWEGELOCK FITTINGS	$100.00	$50.00	$0.00	$0.00		---				
	****SUBTOTAL****	$1,750.00	$250.00	$141.96	$58.04						
	#####TOTAL#####	$36,350.00	$31,920.00	$27,515.71	$1,489.29						

SUMMARY OF EXPENDITURES

	Original	Present	Actual
Budgeted to GEMC	$36,350.00	$31,920.00	$31,920.00
Amount Not Yet Spent:			$4,404.29
TOTAL SPENT			$27,515.71

Figure 3

CALIBRATION LABORATORY INFORMATION MATRIX

TYPE OF TESTING

Test Type	Temperature		Humidity		Pressure				Flow				Electrical						Miscellaneous					
					Hydraulic		Air		Liquid		Air		Voltage		Amperes		Wattage		Lighting		Speed		Solar	
Input/Output	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	ut	In	Out	In	Out	In	Out
General																								
Technician Name	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Reviewer Name	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
ESL Heading	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
TEES Heading	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
Disclaimer	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
Copyright	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
Caution	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
G.I. Notes	M	H	M	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H	C	H
Ambient Tdb	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	–	–	–	–	–	–	–	–	–	–	M/A	H
Ambient Tdp	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	–	–	–	–	–	–	–	–	–	–	M/A	H
Barometric Pressure	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	–	–	–	–	–	–	–	–	–	–	M/A	H
Unit Information																								
Model Number	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S
Manufacturer	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S
Trade Name	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Serial Number	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Nameplate Data	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Test Number	M/C	H/S	M/C	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S
Test Standard	C	H	C	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Remove Location	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Reason for Removal	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H	M	H
Error Band																								
% Full Scale	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S
% Reading	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S	M	H/S

*Input (In): Manual(M); Automatic(A); Computer(C): Output (Out): Hard Copy(H); Screen(S)

Figure 3 Continued

CALIBRATION LABORATORY INFORMATION MATRIX

TYPE OF TESTING

Test Type	Temperature		Humidity		Pressure				Flow				Electrical						Miscellaneous					
					Hydraulic		Air		Liquid		Air		Voltage		Amperes		Wattage		Lighting		Speed		Solar	
Input/Output	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	Out	In	ut	In	Out	In	Out	In	Out
Temperature																								
Tdb	M/A	H/S	M/A	H/S			M/A	H/S	M/A	H/S	M/A	H/S											M/A	H/S
Twb	M/A	H/S	M/A	H/S			M/A	H/S	M/A	H/S	M/A	H/S											M/A	H/S
Tdp	M/A	H/S	M/A	H/S			M/A	H/S	M/A	H/S	M/A	H/S												
Tliq									M/A	H/S														
Humidity																								
RH			M/A	H/S																				
Tdp			M/A	H/S																				
Pressure																								
Hydraulic					M/A	H/S			M/A	H/S														
Static							M/A	H/S	M/A	H/S	M/A	H/S												
Total					M/A	H/S	M/A	H/S																
Velocity							M/A	H/S			M/A	H/S												
Different					M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S												
Velocity																								
Air											M/A	H/S												
Liquid									M/A	H/S														
Electrical																								
Voltage													M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S	M/A	H/S		
Amperes															M/A	H/S	M/A	H/S	M/A	H/S				
Wattage															M/A	H/S	M/A	H/S	M/A	H/S				
Phase Angle															M/A	H/S	M/A	H/S						
Number of Phases															M	H/S	M	H/S						
Power Factor															M/A	H/S	M/A	H/S	M/A	H/S				
kwh															M/A	H/S	M/A	H/S	M/A	H/S				
Lead/Lag															M/A	H/S	M/A	H/S	M/A	H/S				
Lumens																			M/A	H/S				
Foot candle																			M/A	H/S				
Rpm																					M/A	H/S		
Solar																							M/A	H/S

*Input (In): Manual(M); Automatic(A); Computer(C): Output (Out): Hard Copy(H); Screen(S)

APPENDIX A

TASK 3 - Calibration Laboratory

Subsystem: TEMPERATURE

Objective:

Develop and maintain a laboratory for calibrating liquid-in-glass thermometers and electronic temperature measuring systems to an accuracy of ± 0.2 °F (0.1 °C) over a range of -40 to 400 °F and have traceability to NIST.

Capacities:

a. Range of calibration: -40 °F to 400 °F (-40 °C to 200 °C)
b. Accuracy: ± 0.2 °F (± 0.1 °C); Traceable to NIST
c. Type of devices that can be calibrated
   1. Liquid-in-glass thermometers
      a) total immersion
      b) partial immersion
   2. Electronic temperature measuring systems
      a) thermocouple
      b) thermistors
      c) RTD

Standards:

* International Practical Temperature Scale of 1968
* ASHRAE Standard 41.1-86, "Standard, Method of Temperature Measurement";
* ASTM Standard E220-86, "Standard, Method for Calibration of Thermocouple by Comparison Techniques";
* ASTM Standard E644-86, "Standard, Method for Testing Industrial Resistant Thermometer";
* ASTM Standard E77-84, "Method for Verification and Calibration at Liquid-in-glass Thermometers";
* ASME Standard PTC 19.3-74, Part 3, "Temperature Measurement Instruments and Applications".

References:

* "Thermometer Calibration: A Model for State Calibration Laboratory", J.A. Wise, R.V. Soulen; National Bureau of Standards, Monograph 174, January 1986;
* "Liquid-in-glass thermometry", J.A. Wise, National Bureau of Standards, Monograph 150, 1975;
* Calibration of Temperature Measurement Systems Install in Buildings", W. Hurley, NBS Building Science Series 153, January 1984.

Equipment:

* Thermometer storage rack
* Southern Precision Instrument Microscope - 20-X power
* Thermoflask Ice Bath with necessary accessories
* Cole-Parmer Polystat Model 1194-00 Constant Temperature Bath (-40 °F to 400 °F)
* Distilled water storage container (20 gallons)
* Ice shaver
* General Electric Ice Freezer/storage
* Kessler #1298C Primary set of ASTM thermometers (NIST traceable)
* 3 JMS Southeast PT thermistors (NIST traceable) with digital read outs (0.01 °F)
* Specwell 10-X Power Reading Telescope
* Power Supply for Thermocouple

Simplified Testing Procedure:

a. Physical examination of temperature measuring device for flaws under microscope;
b. Measurement in a prepared ice bath against primary thermometer and the 3 Pt thermometers;
c. Measurements in prepared constant temperature bath (10 points) against primary thermometer and the 3 Pt thermometers;
d. Generation of test report including graphs.

Subsystem: HUMIDITY

Objective:

Develop and maintain a laboratory for calibrating relative humidity sensors, dew-point sensors to an accuracy of ±1.5% over a range of 10 to 90% R.H., an temperature range of 32°F to 100°F and have traceability to NIST.

Capacities:

a. Range of calibration: 10% to 90%
: 32°F to 100°F

b. Accuracy = ± 1.5% R.H., traceable to NIST

c. Type of devices that can be calibrated
   1. psychrometer
   2. Dewpoint meters
   3. Dimensional change devices

Standards:

* ASHRAE Standard, 41.1-86, "Standard Method for Measurement of Moist Air Properties";
* ASTM Standard E337-62, "Standard Method for Determining Relative Humidity by Wet and Dry Bulb Psychrometer";
* ASME Standard PTC 19.3-74, Part 3, "Temperature Measurement, Instruments and Apparatus", Revised 1985.

References:

* "Humidity and Moisture: Measurement and Control in Science and Industry", 1963 International Symposium on Humidity and Moisture, Washington D.C., 1963, Published by Reinhold Publishing Corp. NY, NY;
* "Electric Hygrometers", A. Wexlan, NBS Circular 586, 1957;
* "General Guidelines for the On-site Calibration of Humidity and Moisture Control Systems in Buildings", R. Hyland, NBS Building Science Series 1157, September 1983.

Equipment:

* 3 E.G.G. Model 660 Precision Dew Point Sensors with Vacuum Pumps
* 3 Dwyer Rate Master Flow meters rated at 0 to 5 SCFH
* Associated Environmental Systems Temperature Humidity Chamber
* Vaisala Humidity Meter Calibrator Salt Bath one bath rated at 11% R.H. and other rated at 95% R.H.

Simplified Testing Procedure:

a. Physical Examination of Humidity Sensor;
b. Installation of Humidity Sensor in Low R.H. salt bath, if applicable;
c. Installation of Humidity Sensor in Temperature Humidity Chamber for a 10 point test;
d. Repeat c. at varying dry-bulb temperatures, if required;
e. Installation of Humidity Sensor in High R.H. salt bath, if applicable;
e. Generation of test report including graphs.

Subsystem: PRESSURE - HYDRAULIC

Objective:

Develop and maintain a laboratory for calibrating at absolute, differential and gauge pressure gage and transducers to an accuracy at ± 0.5% over a range of 0 to 500 psi and have traceability to NIST.

Capacities:

a. Range of Calibration: 0 to 500 psi
b. Accuracy: ± 0.5%, traceable to NIST
c. Types at Devices that can be calibrated
   1. Pressure transducers
   2. Pressure gauges

Standards:

* ASME Standard PTC 19.2-87, Part 2, "Pressure Measurement Instruments and Apparatus";
* ISA Standard 537.6-7.6, "Potentiometric Pressure Transducer, Spec and Test of", (Revised 1982);
* ANSI B-40.1, "American Standard for Indicating Pressure and Vacuum Gages; Round Dial Type with Elastic Pressure Chamber", 1939.

References:

* "Precision Pressure Gages"; Instrument and Control Systems, Vol. 34, No. 6, pp 1057-1063, June 1961.

Equipment:

* Omega Model DWT 1305 Dead Weight Tester

Simplified Test Procedures:

a. Physical examination of test pressure sensor;
b. Installation of test pressure sensor for 10 point test starting at lowest pressure to rated pressure;
c. Generation of test report including graphs.

Subsystem: PRESSURE - AIR

Objective:

Develop and maintain a laboratory for calibration of manometer, and air pressure, and draft gauges to an accuracy of ±0.01 inch W.G. over a range of 0 to 24 inch W.G. and have traceability to NIST.

Capacities:

a. Range of calibration: 0 to 24 inch W.G.
b. Accuracy : ± 0.01 inches W.G.
c. Types at Devices that can be calibrated
   1. Manometers
      a) inclined
      b) micromanometer
      c) U tube
   2. Pressure gauge

Standards:

* ASME, Standard PTC 19.2-37, Part 2, "Pressure Measurements Instruments and Apparatus";
* ISA Standard RP2.1-62, "Manometer Tables Recommended Practices".

References:

* ANSI/AMCA, Standard 210-85, "Laboratory Methods of Testing Fans for Ratings";
* "Fan Engineering", R. Jorgenson, Buffalo Forge Company, Buffalo, NY, 1970.

Equipment:

* Dwyer Instrument Model 1425 Hook Gage
* 2 Merian Model 34FB2-TM Micro manometers
* Precision Barometer
* Ralston Instruments Quick Test Vacuum Pump

Simplified Test Procedure:

a. Physical Examination of test equipment;
b. Calibration of micro manometer against Hook gage;
c. Install test equipment and the micro manometer and run a 10 point test starting at lowest point;
d. Generation of test report including graphs.

Subsystem: FLOW - LIQUID

Objective:

Develop and maintain a Laboratory for calibrating liquid flow meters to an accuracy of ± 1% of rate over a range of 5 to 650 gpm, meter from 1" to 6" in size and have traceability to NIST.

Capacities:

a. Range of calibration: 5 to 650 gpm
b. Pipe sizes: 1 to 6 inches
c. Accuracy ± 1% of rate
d. Type of devices that can be calibrated
    1. Orifice
    2. Venture Tube
    3. Flow Nozzle
    4. Positive Displacement
    5. Turbine
    6. Vortex
    7. Electro-magnetic
    8. Ultrasonic
    9. Mass-Coriolis
    10. Mass-Thermal

Standards:

* ASHRAE, Standard 41.8-78, "Standard Method of Measurement of Flow of Fluid - Liquids;
* ASME. Standard PTC 19.5-72, "Application Part III of Fluid Flowmeter";
* ANSI/ASME, Standard MFC-1M-1979, "Glossary of Terms Used in the Measurement of Fluid Flow in Pipes";
* ANSI/ASME, Standard MFC-2M-1983, "Measurement of Uncertainty for Fluid Flow in Conduits";
* ANSI/ASME, Standard MFC-3M-1985, "Measurement of Fluid Flow in Pipes using Orifice, Nozzle and Venturi";
* ANSI/ASME, Standard MFC-6M-1987, "Measurement of Fluid Flow in Pipes using Vortex Flow Meters";
* ANSI/ASME, Standard MFC-9M-1988, "Measurement of Liquid Flows in Closed Conduits by Weighing Methods".

References:

* "Flow Measurement Engineering Handbook", R.W. Miller, McGraw Hill, NY, NY, 1983;
* "Methods of Calibrating Flowmeter with Liquids - A Comparative Survey", ASHRAE Transaction Paper 3.77, 1976;
* "On-site Calibration of Flow Metering Systems Installed in Buildings", D. Baker, NBS Building Science Series 159, Jan.1984;
* "Introduction to Liquid Flow Metering and Calibration of Liquid Flow Meters", L. Olsen, NBS Institute of Basic Standards, NBS, June 1974.

Equipment:

* 4 Howe Richardson Load Cells rated at 25,000 lb each
* L.F. Manufacturing 10,000 Gallon Storage tank
* L.F. Manufacturing 10,000 Gallon Receiving tank
* Steel supports
* Flow pumps:
  - 50 gpm: Armstrong Model 4030 BF 1.5x1x8
  - 150 gpm: Armstrong Model 4030 BF 3x1.5x8
  - 500 gpm: Dean Hill Model 105952
* Piping and Valves
* Electrical Equipment

Simplified Testing Procedure:

a. Physical examination of flowmeter;
b. Install the flowmeter in the flow loop and run a 10 point test from highest to lowest flow rates;
c. Generation of test report including graphs.

Subsystem: AIR VELOCITY

Objective:

Develop and maintain a laboratory for calibrating pitot tube and hot wire thermoanemometer to an accuracy of ± 10 FPM over a range of 100 to 8,000 FPM and have traceability to NIST.

Capacities:

a. Range of calibration: 100 to 8,000 FPM
b. Accuracy: ± 10 FPM
c. Type of devices that can be calibrated
   1. Pitot tube
   2. Hot wire thermoanemometer
   3. Rotary Devices

Standards:

* ASHRAE, Standard 41.7-84, "Standard Method for Measurement of Flow of Gas";
* ASTM; Standard D3796-79, Calibration of Type S Pitot Tube, Practice for";
* ASME, Standard PTC 19.2-87, Part 2, "Pressure Measurement-Instruments and Apparatus";
* ISA RP 2.1-62, "Manometers Tables, Recommended Practices".

References:

* "Flow Measurement Engineering Handbook", R.W. Miller, McGraw Hill, NY, NY, 1983.

Equipment:

* TSI Model 1054 B1 1-D Hot wire thermoanemometer
* Acrylic tubing
* Inlet bell
* Swedgelock fittings

Simplified Testing Procedure:

a. Physical examination of sensors;
b. Installation of sensor in test chamber (10 points);
c. Generation of test report including graphs.

Texas LoanSTAR Monitoring and Analysis Program

Task 4 - Progress Report

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

Jeff Haberl
Srinivas Katipamula
Dean Willis
Kristel Weber
Jennie Matson
Murthy Rayaprolu
Udaya Subramanian

Energy Systems Laboratory
Mechanical Engineering
Texas A&M University
College Station, Texas

July 1990

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. EXECUTIVE SUMMARY

Task 4 is responsible for ensuring that the LoanSTAR MAP Net can communicate with the instrumentation installed in each building, developing public domain software for communicating with selected data acquisition systems, and developing a procedure to test the accuracy of the data being collected by the data acquisition systems.

In order to accomplish these tasks we have established a testbench facility and have obtained software licensing agreements from the DAS vendors participating in the program which will allow us to develop our own software using a Data Recorder Unified Management System (DRUMS).

We have also found that managing the data we are collecting for the sites is a daunting task. So we are looking into the feasibility of translating our records into a relational data base in order to speed the organization and access to data.

In this report we provide a typical data path to help explain the process of acquiring data from a site, translating these data to a common format and preparing the data for graphic presentation, etc. Plots and appendices are also provided which contain the details of such a process.

In the section concerning our future work we discuss our continued work with the licensing agreements, acquiring weather data from the National Weather Service, continuing the develop of the testbench & DRUMS, exploring the feasibility of EMCS monitoring, and exploring the use of portable monitoring equipment. Appendices with the necessary supporting material are also provided.

2. OVERVIEW

This task is responsible for: 1) ensuring that the LoanSTAR MAP Net can communicate with the instrumentation installed in each building; 2) developing public domain software for communicating with selected data acquisition systems; and 3) developing a procedure to test the accuracy of the data being collected by the data acquisition systems.

In order to facilitate these objectives the following sub-tasks have been set up, including: 1) negotiating licensing agreements with manufacturers in order to obtain proprietary communications protocols for developing the LoanSTAR software;
2) establishing a communications testbench for testing the data acquisition systems;
3) polling of the data acquisition systems with manufacturer's software;
4) translation of data to common archive format using manufacturer's software; and
5) development and testing of Texas LoanSTAR software to poll the data acquisition systems using the LoanSTAR MAP Net.

This report describes the communications testbench and software which has been developed and the work to be accomplished in the following year. The data path for the Zachry Engineering Center (ZEC) is provided as an example to help describe the software we have developed. Appendices are provided with more detailed information about the communications testbench and software.

3. COMMUNICATIONS TESTBENCH

A communications testbench has been established in the Wisenbaker Engineering Research Center on the main campus of Texas A&M University. Several major milestones have been accomplished in the pilot year. First, we have obtained legal consent from three of the six manufacturers which will allow us to proceed with the development of the LoanSTAR polling software.

Second, we have broken-up the effort into two primary phases: Phase I where we poll and translate with the manufacturer's software; and Phase II where we develop our own software for polling and translating.

This has allowed us several advantages. First, we were able to take advantage of the software that is available which allowed us to immediately begin polling systems and retrieving data. Second, it gave us time to develop our own software for polling a number of different vendors DASs.

All six of the manufacturers participating in the LoanSTAR program have passed Phase I polling and translation. Three of the manufacturers have signed the licensing agreement and delivered their protocols and hence the development of

Phase II polling and translation is under way for these vendors.

We have provided a schematic diagram of the Communications Testbench in Figure 1. The testbench is used to verify the accuracy of the data acquisition systems (DAS) used in the LoanSTAR program and to develop the polling software. Three PCs are being used in the testbench; one to generate a pre-programmed signal; a second PC to communicate with the DAS; and a third PC to analyze the communications between the polling computer and the DAS. Currently, we have the testbench set up, have received and tested the software that we will be using and have initiated the early stages of testing with the Synergistics C180 recorder.

4. SOFTWARE DESIGN

4.1. Polling the Data Acquisition Systems (DASs)

In order to receive the data from the field we have dedicated several PCs to the task of polling the data acquisition systems via modem. This is performed weekly, with some interim checks to assure that the systems are still operational between weekly pollings. Each week when we call the data acquisition systems we perform several tasks, including: a check to see if the clock is still on time, resetting the clock if necessary, and the data to the MAP Net.

We have found it quite helpful to be able to poll the data acquisition systems with the software that the vendors supply during this pilot year. Excluding the down-loading Scientific unit (their protocols are published in the manual that accompanies their unit), all the vendors have provided us with an evaluation copy of their software for this purpose. Each recorder was put through a battery of test to assure us that it operated in a satisfactory fashion and that we could translate the data to an ASCII format for further processing. All of the vendors have passed this stage of the evaluation, as shown in Table 1.

In order for us to automatically poll the computer we needed to develop one program that can call several different manufacturers' systems and collect that data, . However, before we could proceed to this stage it was necessary that we obtained a licensing agreement from each of the vendors to protect their proprietary software and assure us that we would have continuing access to their software protocols.

4.1.1. Obtaining a Licensing Agreement

Currently, equipment manufactured by six vendors is being evaluated for use in the LoanSTAR program. In general, we have found the vendors to be eager to participate in the program. Early on, several of the manufacturers insisted on some type of legal mechanism to protect their proprietary software and communications protocols, and still allow them to participate in the LoanSTAR program.

In order to facilitate the development of public domain software and to protect the rights of the manufacturers participating in the program, a Data Recorder Unified Management System (DRUMS) was conceived. This software approach encapsulates the proprietary communications protocols and translation into compiled software drivers, thus protecting the manufacturers' rights and still allowing for the development of public domain software.

Data acquisition systems from six vendors are being evaluated at the testbench as shown in Table 1. Three of these manufacturers have signed licensing agreements with the Texas Engineering Experiment Station (TEES - Office of Contracts and Grants), and a fourth vendor has agreed in principle.

Copies of the TEES contracting requirements, confidentiality agreement, and LoanSTAR "dream machine" are included in Appendix A. The description of the LoanSTAR "dream machine" was circulated to the vendors to encourage the development of special equipment that would meet the monitoring needs of the LoanSTAR program. This description incorporates the best characteristics of all the data acquisition systems that we have looked at for the LoanSTAR program.

4.1.2. The Data Recorder Unified Management System (DRUMS)

Figure 2 illustrates the conceptual structure of the DRUMS. The DRUMS will perform several functions, including: programming of the data acquisition systems, scheduling the polling calls, and translation of commands and data records for different manufacturer's recorders.

Common-format data from the DRUMS are then passed onto the storage processing systems where permanent on-line storage will be a Relational Data Base Management System (RDBMS) to facilitate easy retrieval of the heterogeneous data.

4.2. Implementing the Shared Unix Data Base

Figure 7 illustrates the amount of hourly information that we have collected at the Zachry building and the College Station High School during the first year. For each agency participating in the LoanSTAR program we have found it necessary to gather the following information:

Point-in-time Information: such as engineering data, survey information, one-time measurements, interviews, site descriptions, etc.

Time-Sequenced Information: including monthly utility billing data, daily minimum-maximum weather data, hourly energy consumption data, etc.

Influencing Parameters: such as ambient temperatures, humidity, solar and wind speed, scheduling information, etc.

System Requirements: such as design information, environmental quality requirements, comfort requirements, lighting conditions, etc.

We have found that organizing and accessing such heterogeneous information is a daunting task, for several reasons. First, we have several types of information that are being captured for each site. For example, we have consumption data that requires a starting point, an ending point, and links to corresponding weather information for the same time periods -- otherwise known as periodic data. We also have data that requires only one time stamp -- point-in-time data and site description information.

To accomplish this task we have turned to data bases that allow for relationships to be captured in the data base -- otherwise known as relational data base management systems (RDBMS). Our next step with the MAP Net is to evaluate RDBMS packages, select a package and design a system for containing the diverse LoanSTAR data base.

4.3. Typical Data Path for LoanSTAR Agency

In order to rapidly facilitate the development of software for the LoanSTAR project we decided to use a modular approach, and as much as possible, canned graphic programs and statistics routines that allow us string together numerous small modules, or "filters" to accomplish a larger task. Figure 3 is an example of our programming. Appendices C, D, E, and F contain additional details concerning the process.

Appendix C is a listing of the data channels for the Synergistics C180 DAS in the Zachry building. Data from the Zachry building are weekly to the MAP Net computers and processed.

Appendix D is a listing of the ARCHIVE channel table for the Zachry building. ARCHIVE is a data translation down-loaded from Princeton University which was written especially for manipulating columnar data. We have found the ARCHIVE program to be tremendously helpful and plan to process all data collected by the MAP Net with it. At a minimum, ARCHIVE allows us to turn channels on/off, add a decimal date to each data record, perform various calculations with each channel, check for hi/low limits, and produces a log report (.LOG) that is filed away with the data that are collected each week.

Appendix E is an example of the log reports that are produced with ARCHIVE each week. We have also found it helpful to reduce the several pages of log reports using the Microtxt program as indicated.

Appendix F is the "batch" file that is used to process the data from the Zachry building each week. Figure 3 diagrams the data flow in the batch file. As one can see polling the "raw" data from the data acquisition is just one part of a long chain of events that eventually lead to finished graphs and log reports.

Appendix G contains a listing of the software that we have chosen for use in the LoanSTAR MAP Net.

To give you an example of the amount and type of pre-processing that must be performed for each site we have included Figure 3 and listings of the batch routine in Appendix F.

Briefly, here are some of the steps that are performed: The first step is to remove non-processible characters from the Synergistics data. The data from the Synergistics C180 contains "/", ":", and "A-Z" characters as well as numbers in "-123E-10" format. In order to process this with the ARCHIVE software we have had to do some preliminary pre-processing to remove these extraneous characters from each record. This is performed by the RAW2DAT.AWK routine, an awk script.

Next we pass the data stream to the ARCHIVE program (with the appropriate channel table) and produce log reports and columnar ASCII data that is almost ready for archiving on the Unix hard disk. One additional step with the MISSING.AWK program inserts a "missing" character (i.e., -99) for whole records of data that are not contained in the original files. Data are now ready for loading onto the Unix hard disk (via the ethernet) or can continue on for additional processing.

The remainder of the flowchart contains four additional processing threads that produce derived weather channels and pre-process the data for plotting. The processing thread heading directly down from the .ACS file through the RHTRIM.PAS procedure produces a relative humidity that is trimmed at 99.9999 whenever the incoming data register 100.5 -- an indication of a saturated humidity sensor.

The thread that passes down through AIR.PAS calculates enthalpy and absolute humidity given dry bulb temperature and relative humidity. This stream is then recombined with the original weather channels and stored on disk for each site.

The threads that pass through PLUCK.AWK and through AHU.DAT generate plotting information for the weekly inspection plots.

Figure 4 is an example of the weekly data inspection plots that are produced to view each of the respective channels. For the most part each of the graphs represents one channel or one channel plotted against another.

Figure 5 is an example of a derived graph that we have found helpful to view on a regular basis. This graph contains one month of hourly whole-building, sub-metered and derived electricity data from 12 channels. The upper line represents the whole-building electricity data recorded at the main service panel in the building. The lowest line represents the electrical energy use of the large computer center in the Zachry building and the next line up represents the electricity used by the motor control centers (primarily motors in the air-handling units). The second line from the top is a derived channel which is representative of all other electricity consumption in the building, for the most part lights and electrical receptacle loads.

Figure 6 is an example of a derived plot that displays the daily hot water use plotted against the average daily ambient temperature. Clearly, the amount of hot water consumed increases with decreasing ambient temperature.

4.4. Availability of LoanSTAR Software

Our two primary objectives with developing the LoanSTAR software are to:
1) collect, analyze, archive and distribute energy consumption data for those agencies participating in the LoanSTAR program; and 2) develop and make available public domain building energy analysis tools that perform such processing.

With this in mind we have made provisions for licensing and distributing software through the Texas Engineering Experiment Station (TEES) Office of Contract and Grants. Software produced will be Public Domain and will be available for a modest distribution fee.

The following modules have been produced as part of our work during this first year and will be prepared for distribution:

1. A columnar-to-matrix pre-processor for 3-D plots.
2. Automatic macro routines for processing the 3-D plots with the Lotus 123 program.
3. An hourly ASCII data extraction program for DOE-2.
4. A file handling batch routine for PRISM runs that utilizes multiple weather stations.

5. Psychrometric routines for calculating absolute humidity and enthalpy given dry bulb temperature & relative humidity.
6. A "missing data" add-on awk script for ARCHIVE.
7. A "cleaning" awk script pre-processor for ARCHIVE that removes "/", ":", etc., from Synergistics C180 data.
8. Procedures for preparing Sangamo data for ARCHIVE.

We feel that there is a need for such public domain routines to be provided to building energy analysts. At the recent ASHRAE Conference in St. Louis a Seminar presentation on LoanSTAR generated 18 requests for software from participants in the audience. Appendix G contains a listing of those persons inquiring about the LoanSTAR software, and our response to them.

5. FUTURE WORK

The future work for Task 4 during the 1990/91 year will evolve around securing additional Software Licensing Agreements, determining the feasibility of acquiring hourly weather data over the Internet from the National Weather Service, continuing with the development of the testbench and DRUMS, developing the relational data base for the Unix server, exploring the feasibility of monitoring building energy usage with Energy Management and Control Systems, and taking a closer look at using portable monitoring systems.

5.1. Licensing Agreement

As we have seen, the vendors who are supplying us with data acquisition systems are eager to participate in the LoanSTAR program yet want to protect their investments in the polling software they have developed for their machines. Hence, we will continue to pursue the licensing of software protocols for the LoanSTAR program in order to provide the best equipment for monitoring energy usage in the State agencies participating in the program.

5.2. Acquiring Hourly Weather Data from the N.W.S.

We are very lucky to have the State Meteorology Department located at the Texas A&M Campus. We are also lucky to have Mr. Kelly Kissock, a resourceful graduate student, who has determined that it is possible to obtain hourly weather information from 30 sites around the state of Texas (also sites from around the country) through the same Ethernet that connects our MAP Net. With such information we can be assured of accurate cross-checks for our LoanSTAR weather stations. With the help of our programming staff we will be developing the routines to capture and record this information in the next year.

5.3. Communications Testbench and DRUMS Software

Now that the equipment has been purchased and installed for the communications testbench, we will be proceeding at full pace with the development and testing of the LoanSTAR polling routines for the hardware we are using in the program.

5.4. Continue Development of the Shared Unix Data Base

As mentioned earlier, we have found that organizing and access to the heterogeneous information we are collecting to be a daunting task. To accomplish this task we have turned to data bases that allow for relationships to be captured in the data base -- otherwise known as relational data base management systems (RDBMS).

In the next year we will be evaluating RDBMS packages, selecting a package and designing a system for containing the diverse LoanSTAR data base. Currently, there is very little guidance in the literature concerning the use of relational data bases and building monitoring information. So, we feel that we will be breaking some new ground in this area.

5.5. Explore the Feasibility of Monitoring with E.M.C.S.

In the coming year we will be exploring the feasibility of collecting our monitoring data with Energy Management and Control Systems (EMCS). We are currently evaluating systems at two facilities with the help of Dr. Hashem Akbari at L.B.L. These systems include a Landis Gyr system at the University of Texas, and a Johnson Controls system at the Prairie View Texas A&M Campus.

We also will be looking into the feasibility of extending this to a Honeywell system, and the possibility of using the Honeywell ServiceNet monitoring system.

The use of and EMCS for monitoring could present considerable savings in the instrumentation costs for the LoanSTAR program. However, each system must be looked at separately and requires close cooperation with the manufacturer.

5.6. Explore the Feasibility of Monitoring with Portable DASs

We had hoped to be able to use Level 1 monitoring immediately at many of the sites and then incorporate it into the permanent monitoring for that site. Task 2 personnel have reported to us that this is difficult to accomplish in most buildings because of the added expense of extra meetings, inspections, telephone lines, etc.

In the coming year we hope to improve our ability to begin monitoring immediately at the first site visit through the use of portable "clip-on" monitoring equipment.

Currently, none of the manufacturers of portable monitoring equipment have expressed any interest in cooperating with us (i.e., sharing their protocols). In light of this we may have to develop some creative alternatives that will allow us to accomplish the portable monitoring while still providing public domain software.

Table 1: LoanSTAR DAS Vendor Status

This table displays the status of the vendors that are participating in the LoanSTAR program. A copy of the legal agreement is contained in Appendix A.

VENDOR	LEGAL AGREEMENT	PHASE I POLLING	PHASE I TRANS.	PHASE II
Synergistics C-180	Signed	Passed	Passed	Underway
Campbell 21X	Signed	Passed	Passed	Underway
Process Systems Sentry 200	Signed	Passed	Passed	Underway
Sangamo ST-DS111	Tentative	Passed	Passed	Waiting
Landis Gyr DataGyr 100	Waiting	Passed	Passed	Waiting
Rustrak Ranger II	Refused	Passed	Passed	None

NOTE:

1. EMCS vendors contacted who have indicated an interest in participating in the LoanSTAR program include: Honeywell, Johnson Controls, Teletrol, Andover, American Auto-Matrix, Landis Gyr Powers, and Trane.

2. Honeywell has also indicated a willingness to provide monitoring data using their ServiceNet system.

Figure 1: The Communications Testbench

This figure illustrates the communications testbench that has been established in the WERC. The testbench is used to verify the accuracy of the data acquisition systems (DAS) used in the LoanSTAR program and to develop our polling software. Three PCs are being used in the testbench; one to generate a preprogrammed signal; a second PC to communicate with the DAS; and a third PC to analyze the communications.

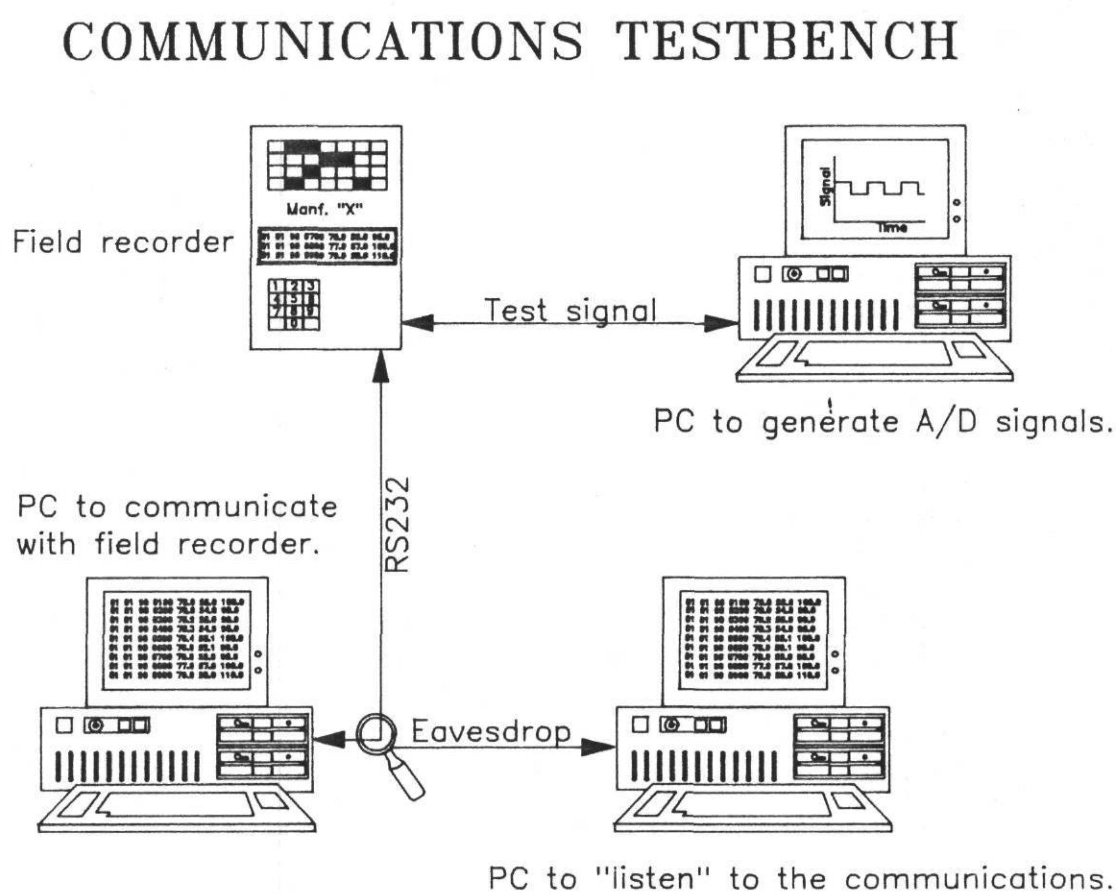


Figure 2: The Data Recorder Unified Management System (DRUMS)

A schematic figure of the DRUMS is shown here. Data are retrieved periodically from various sites via modem using the appropriate manufacturer's driver. Once the data are translated to a common format they are then stored for analysis and reporting in a Relational Data Base Management System (RDBMS).

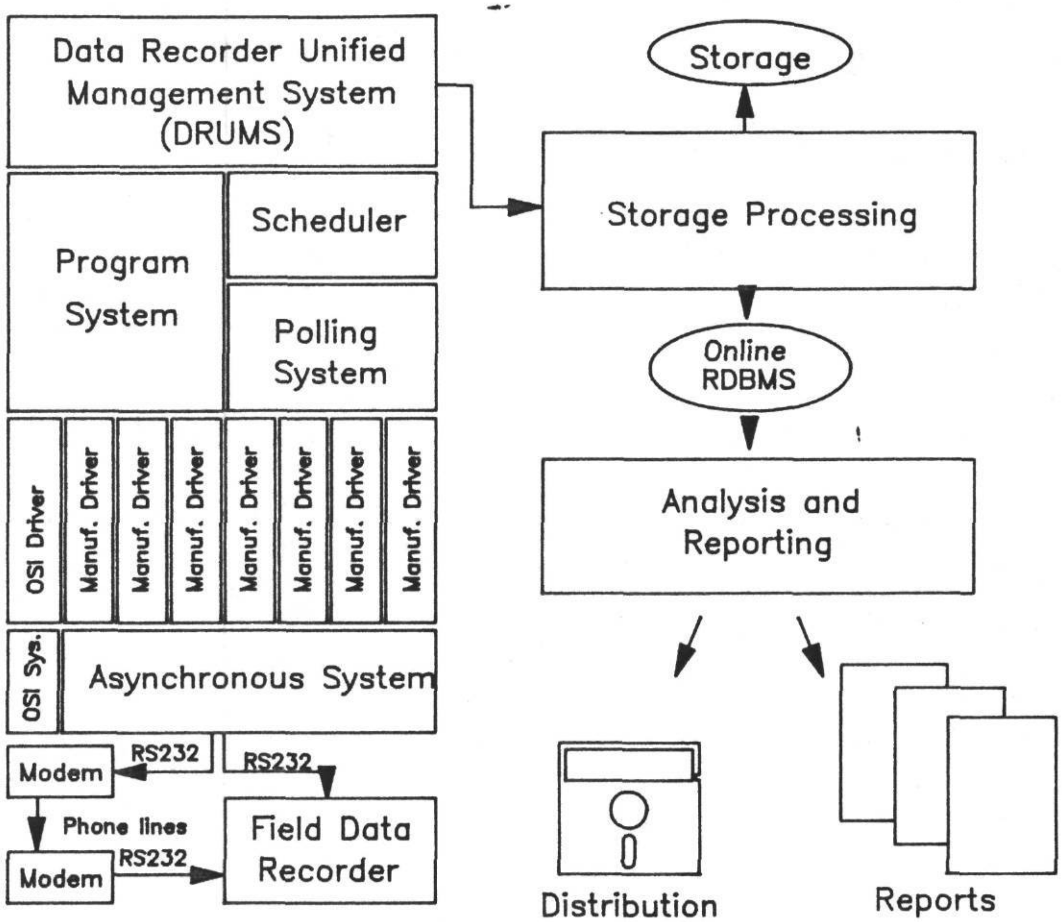


Figure 3: Data Path for the Zachry Engineering Center (Z.E.C.)

This figure is an example of the data path for the Z.E.C. Data are polled once per week and archived in both raw and processed format. Various modules have been developed for removing extraneous characters, checking for missing data, calculating derived weather channels, and producing various graphs.

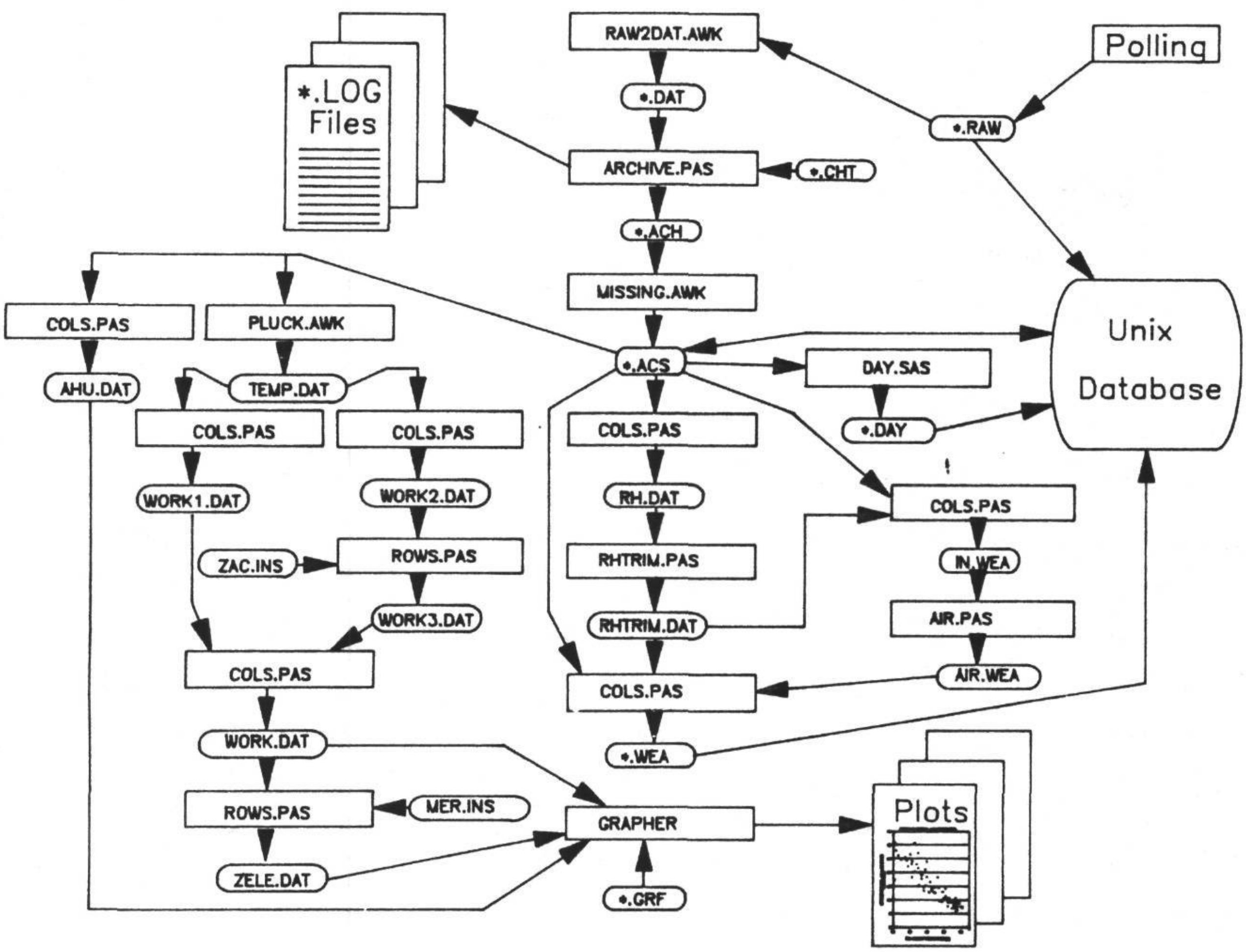


Figure 4: Weekly Verification Plots for Zachry Engineering Center

This figure is an example of the weekly verifications plots for the Z.E.C. Each graph represents a channel of information plotted in time-series or versus another channel of information. These graphs are used for visually inspecting the data that are coming from the sites.

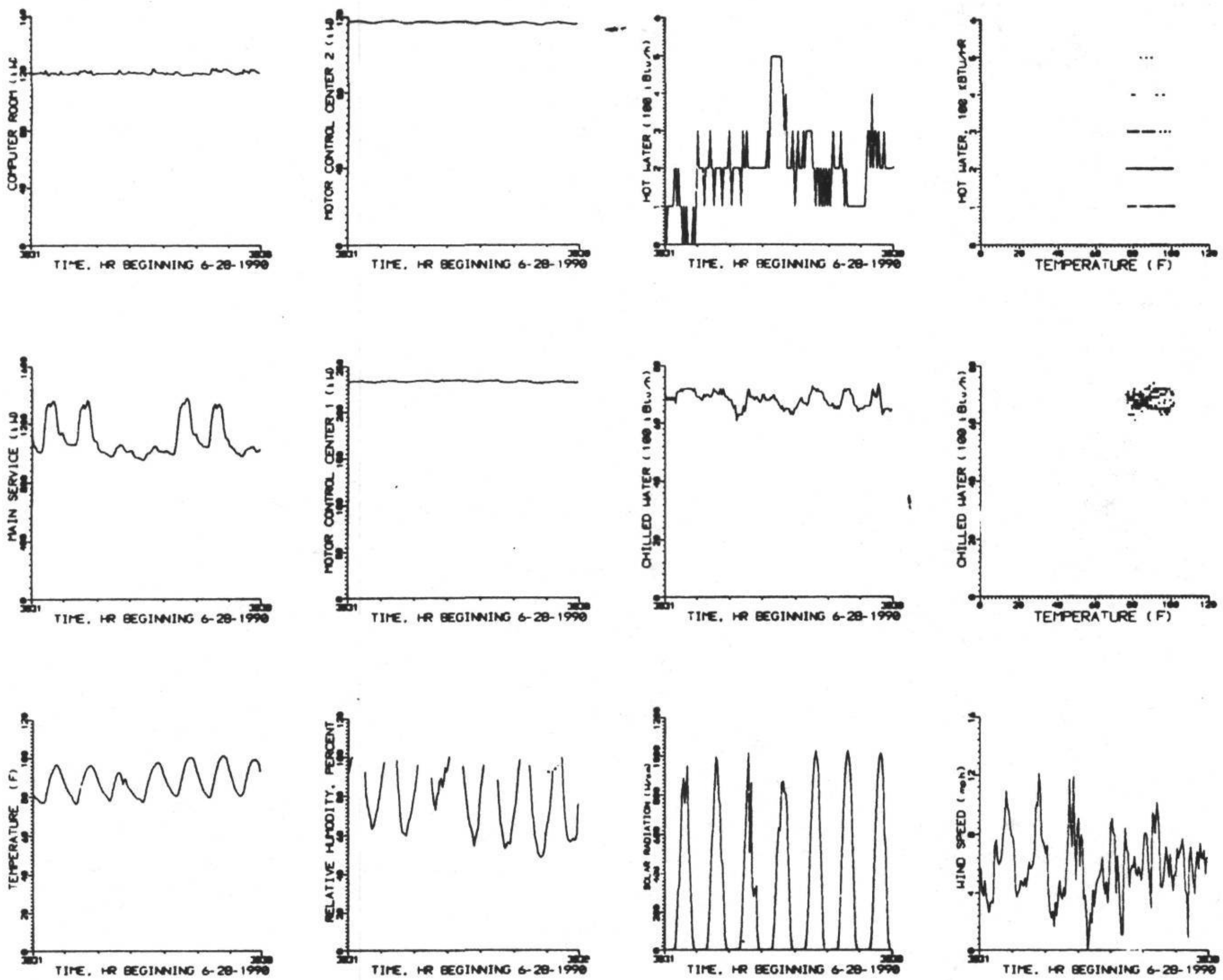


Figure 5: Derived Electricity Plot for Zachry Engineering Center

This figure displays whole-building, sub-metered and derived electricity consumption for the Z.E.C. Starting from the top, the upper line represents the whole-building electricity use, the next line represents energy use that is not being sub-metered at the motor control center or at the computing center, the third line represents energy used by large electric motors, and the lowest line represents energy used by the computing center.

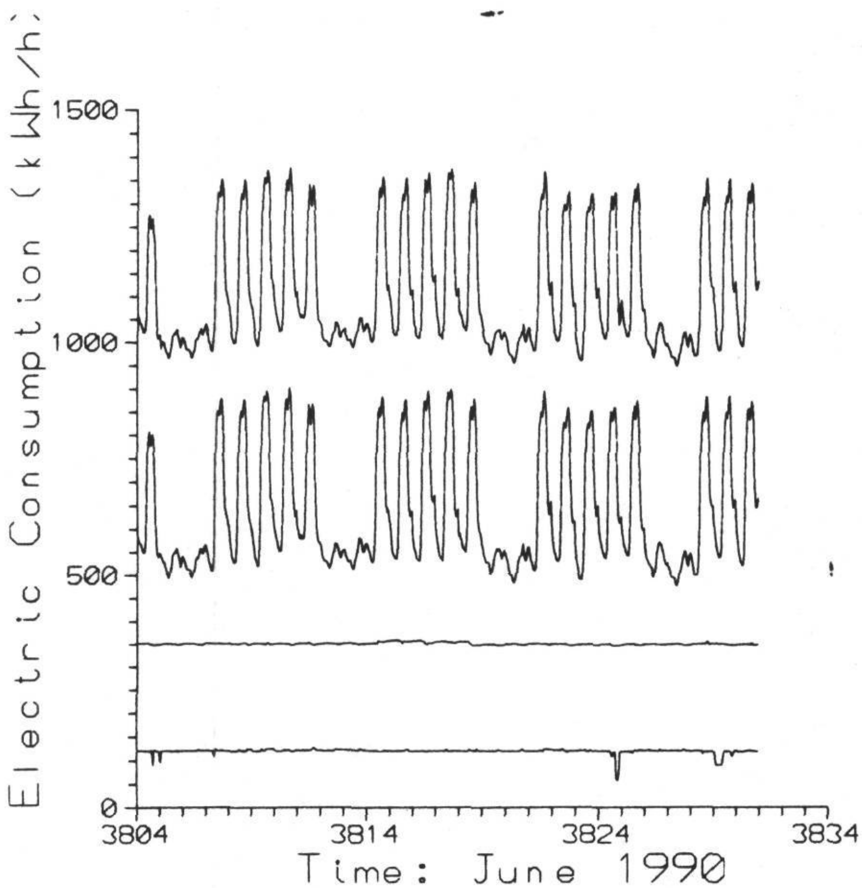


Figure 6: Daily Hot Water Use vs. Ambient Temperature for Z.E.C.
This figure displays the total daily hot water use against the average ambient temperature for the Z.E.C. during the period September, 1989 through May, 1990. The data labels represent the day of the week (e.g., S = Saturday, s = Sunday).

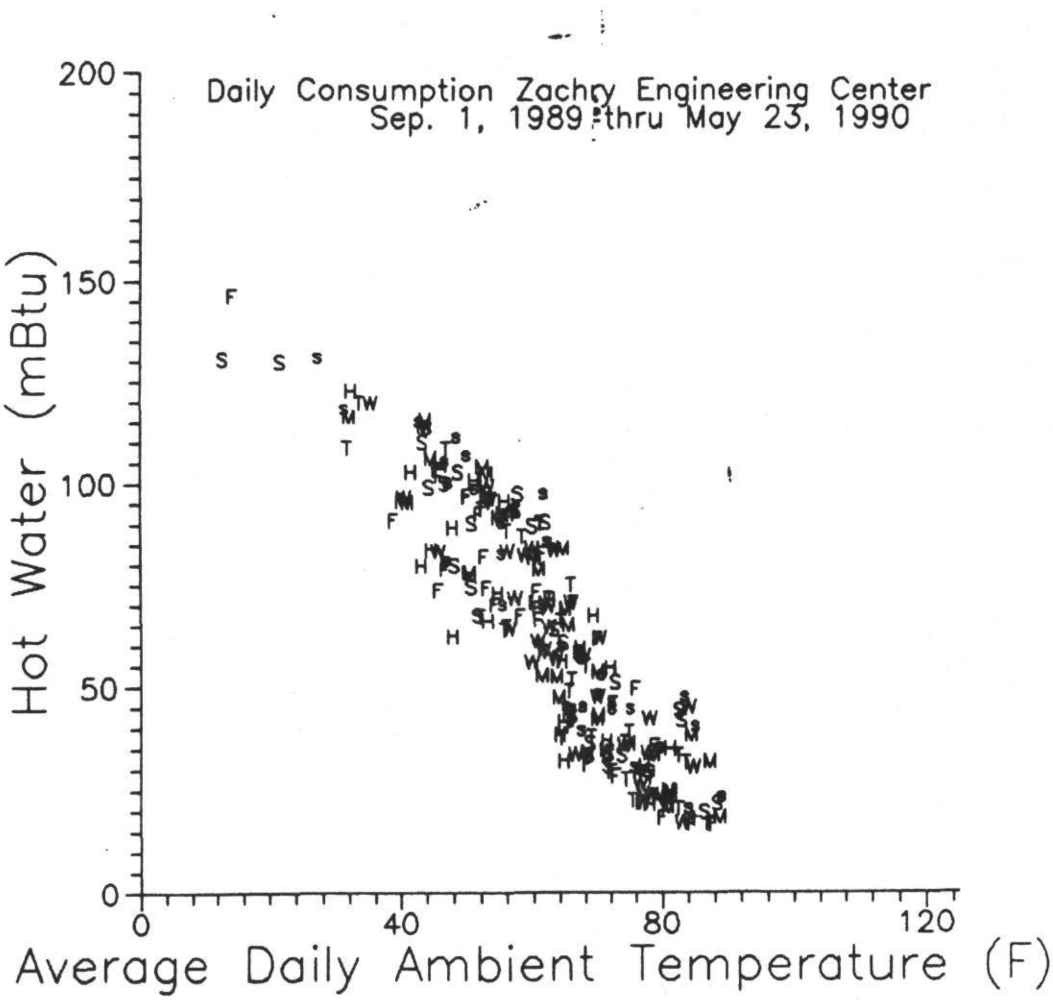
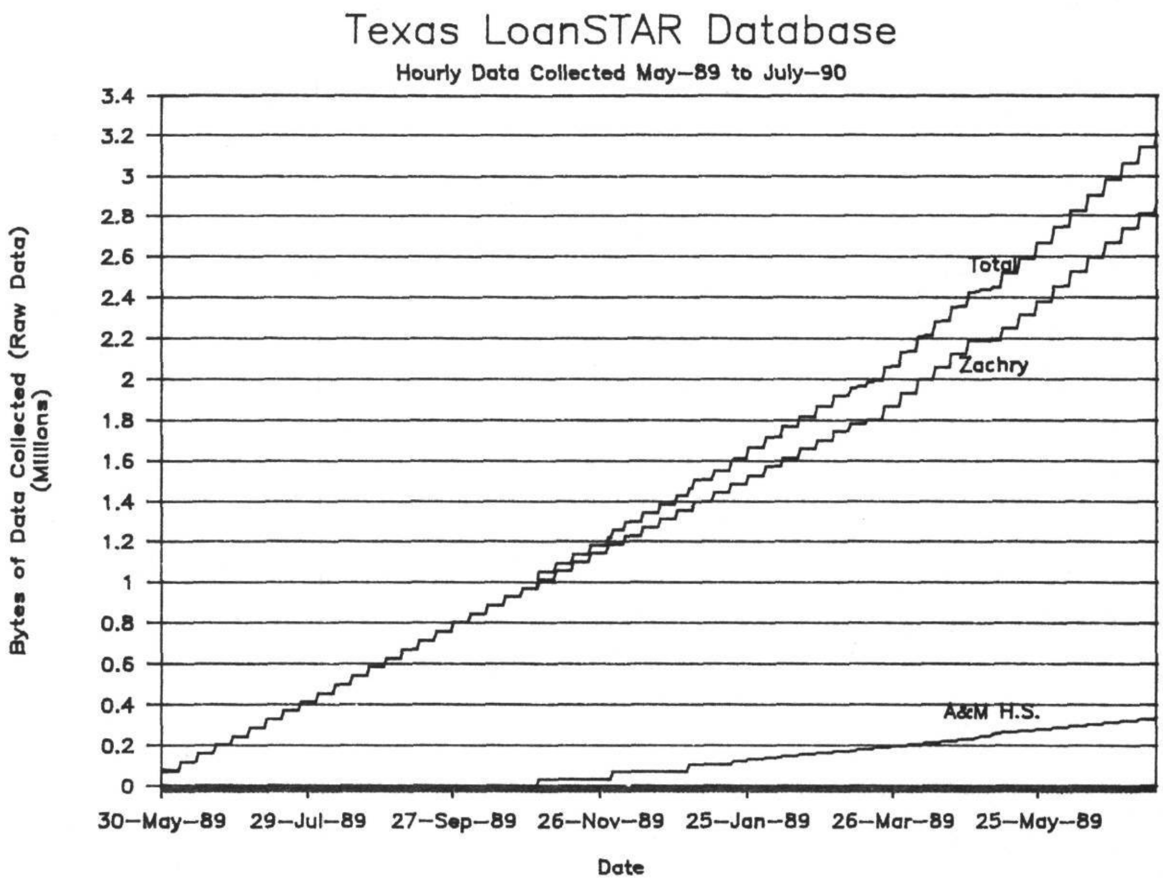


Figure 7: Data Collection Summary Statistics

This shows the accumulation of data for the LoanSTAR project. Roughly 3,200,000 bytes of raw data have been accumulated for the first two buildings in the LoanSTAR project, the Zachry Engineering Center and The A&M Consolidated High School. Both the amount and the rate of accumulation will increase dramatically as more buildings are brought on-line.



APPENDIX A - T.E.E.S. LICENSING AGREEMENT

This appendix contains a copy of the TEES licensing agreement that was issued to all manufacturers participating in the LoanSTAR program. Also included is a copy of the LoanSTAR "dream machine" which is our best thoughts about the ultimate data acquisition system.

ENERGY SYSTEMS LABORATORY
Department of Mechanical Engineering
Texas Engineering Experiment Station
Texas A&M University
College Station, Texas 77843
(409) 845-6402, or
(409) 845-1251

MEMORANDUM

Mar. 19, 1990

To:

From: Srinivas Katipamula
(409)845-9212

Subject: Evaluation of unit:

Attached to this memo are:

(i) A letter written by our contracting agency the TEES (Texas Engineering Experiment Station), which outlines our requirements.

(ii) A Confidentiality Agreement. This is an agreement to protected your proprietary information.

(iii) Our specification for the LoanSTAR "Dream Machine" data acquisition system (DAS).

We are sending these three documents to all vendors participating in the LoanSTAR program. Our thoughts concerning the LoanSTAR "Dream Machine" DAS have evolved from numerous conversations with the program participants. Such a DAS, in our opinion, should contain the features we feel are needed by our program. We would appreciate if you could reply as soon as possible so we can continue with our evaluation.

If you have any questions feel free to call me. We appreciate your participation in the LoanSTAR program.

APPENDIX A - T.E.E.S. LICENSING AGREEMENT (cont.)

Texas Engineering Experiment Station • The Texas A&M University System • College Station, Texas 77843-3124 • 409/845-1264 • FAX 409/845-9643

TEES
Contracts & Grants

March 22, 1990

RE: TEES Project 27370 ME

Dear Mr.

In 1988, the Governor's Energy Management Center (GEMC) of the state of Texas received approval from the U. S. Department of Energy to establish a statewide retrofit demonstration program, the LoanSTAR (Loan to Save Taxes and Resources) Program. The LoanSTAR Program is designed to demonstrate commercially available, energy-efficient retrofit technologies and techniques in several hundred buildings.

This program is a multi year project. Many state agencies, state institutions, public schools and local governments are targeted for retrofits. The GEMC has contracted the Energy Systems Laboratory (ESL), a division of Texas Engineering Experiment Station, Texas A & M University System to monitor and analyze the energy consumption of all sites targeted. Typical retrofits include: lighting, HVAC systems, building shell, electric motors, energy management and control systems, boilers and thermal energy recovery systems.

One of the tasks of the monitoring project is to conduct bench-mark communications testing of field data acquisition systems and qualify them for installation in the targeted sites. We are required to test the data acquisition systems and qualify them for installation in the targeted sites. This includes testing the data acquisition systems with software developed by the LoanSTAR programmers/analysts. Therefore, before your recorder can be qualified for installation at any LoanSTAR sites, a complete description of the information specific to your recorder is needed to develop an application which will communicate with your recorder for purposes of polling and programming that recorder. This description must include, but is not limited to, the following items:

(i) Line settings, including speed, parity, and the number of data, stop and start bits.

(ii) If protocol is packet-based, format of packet including header, length, and integrity check.

APPENDIX A - T.E.E.S. LICENSING AGREEMENT (cont.)

March 22, 1990
Page 2

(iii) Method used for calculating any checksum or cyclic redundancy checks.

(iv) All command, message and response codes or the equivalents thereof.

(v) Sequence of commands and responses for normal operation.

(vi) Layout and definition of all memory areas and registers within the data recorder which are to be manipulated.

Additionally, we would require a contact within your organization who will be responsible for providing additional details as needed. Source code of example programs and testing software or data acquisition software would be appreciated.

Our state contract requires that we perform our work in the public domain. To facilitate this we will embed sensitive or proprietary protocols into compiled modules to be licensed to approved organizations or individuals. Source code which contains sensitive or proprietary information, developed by ESL, will not be released to organizations or individuals without the prior consent of all parties involved. If necessary, we will be willing to enter into a confidentiality agreement to insure the protection of sensitive data.

Please send the requested materials as soon as possible as we have already begun reviewing protocols for several units. At the end of the review, reports produced by ESL will be available upon request.

We appreciate your participation in the LoanSTAR program. We are anticipating your cooperation in the success of this program.

If you have any questions concerning the technical aspects of this request, please contact Dr. Jeff Haberl at (409)845-6065. Administrative or contractual questions may be directed to me at (409)845-1264.

Sincerely,
Sharon Brooks
Sharon K. Brooks
Sr. Contract Administrator

Enclosures

cc: J. Haberl
S. Katipamula
T. Young

APPENDIX A - T.E.E.S. LICENSING AGREEMENT (cont.)

CONFIDENTIALITY AGREEMENT

CONFIDENTIALITY AGREEMENT between Texas Engineering Experiment Station (hereinafter referred to as "TEES") and a corporttion having a place of business (hereinafter referred to as VENDOR).

WITNESSETH THAT:

WHEREAS, TEES desires to obtain from VENDOR proprietary protocol to communicate with and program the :vey Meter/Recorder unit as required to complete work associated with Texas Engineering Experiment Station Project Number 27370 ME; and

WHEREAS, VENDOR regards the protocols as confidential information; and

WHEREAS, VENDOR desires to disclose to TEES such confidential information;

NOW, THEREFORE, the parties agree as follows:

TEES understands that in making the disclosure referred to above, VENDOR may be revealing information of a confidential nature. Therefore, any information which TEES receives that is designated "confidential" by VENDOR at the time of disclosure will be received and accepted in confidence. TEES will not disclose such information to anyone except officers and employees in its organization, who shall be informed of the confidential nature of the information, and subject only to the provisions given below. TEES will use the information only for the purpose of developing an application to program and communicate with VENDOR's data acquisition system.

Notwithstanding the provisions of the paragraph above:

(a) For the purpose of keeping confidential information derived from VENDOR, TEES shall protect such information in the same manner and to the same extent as it protects is own confidential information.

(b) TEES shall include confidential information in its application sofware which shall be placed in public domain. However, TEES shall protect protocol designated as "confidential" by embedding the protocol into compiled modules to be licensed to organizations or individuals. The contents of the compiled modules shall not be made known by TEES to persons outside its organization without the express written consent of VENDOR.

APPENDIX A - T.E.E.S. LICENSING AGREEMENT (cont.)

(c) TEES shall not be obligated to keep as confidential information received from VENDOR if TEES can show that any such information:

(1) appears in printed publications, or

(2) becomes generally known to the public, or

(3) is already known to it at the time of receipt or is disclosed to it by sources independent of VENDOR and not bound by this Agreement, or is independently developed by personnel who did not have access to such information.

This agreement shall be governed by the laws of the State of Texas

ACCEPTED:	ACCEPTED:
TEXAS ENGINEERING EXPERIMENT STATION	
BY:____________________	BY: ____________________
TITLE:____________________	TITLE: ____________________
DATE:____________________	DATE: ____________________

APPENDIX A - T.E.E.S. LICENSING AGREEMENT (cont.)

Specification for the LoanSTAR "Dream Machine" Data Acquisition System

(i) Should accept four, eight, or sixteen on-board current inputs and four or eight potential inputs to measure real and apparent power.

(ii) Programmable sliding window demand five, ten, fifteen, thirty, ... etc., minutes.

(iii) Modular four, eight, or sixteen 4-20 millamp and/or -5 to +5 vdc analogue channels.

(iv) Modular four, eight, or sixteen digital channels.

(v) Power factor monitoring.

(vi) Time averaging, run time summation and special functions (square root, etc,).

(vii) On-Board Calculation of Btus given delta P and delta T.

(viii) Complete description of information needed to develop an application to communicate with your recorder for polling and programming.

(ix) Interconnectivity to the following:
* Local Area Network
* Digital F.M.
* Cellular phone connection
* Meteor burst communication
* Error correcting on-board modem, 1200, 2400 baud
* RS-232 serial port
* IEEE 488 port
* Optical port

(x) Regulated (12 vdc) power supply for external devices

APPENDIX B - LoanSTAR DAS VENDORS

The table shown is our summary of the performance and price of the data acquisition system under evaluation for the LoanSTAR program. The cost information reflects prices offered by the vendors to the program.

List of Data Acquistion Systems for Bench Test

Manufacturer	Unit	kW	Digital	Analogue	Cost
Synergistics Control Inc.	Datamate 10@ (Level 1)	-	Four	-	$695
	Datamate 20@ (Level 1)	-	Eight	-	$795
	Datamate 30@ (Level 2)	-	-	Eight (4-20ma) (0-5vdc)	$995
	Datamate 40@ (Level 2)	-	Four	Four (4-20ma) (0-5vdc)	$1,295
	Datamate 50@ (Level 2)	-	Eight	Eight (4-20ma) (0-5vdc)	$1,595
	C-140@ (Level 2)	Six	Six	Six (4-20ma) (0-5vdc)	$1,995
	C-180 (Level 3)	Sixteen	Sixteen	Fifteen (4-20ma) (0-5vdc)	$4,000
Campbell	21X (Level 3)	-	Four	Eight/ Sixteen Number of options*	$2,000
Campbell	CR10@ (Level 2)	-	One/Two	Six/ Twelve Number of Options*	$800
Rustrak	Ranger II (Level 2)	-	Four	Four	$1,200
Intek	dl-714	-	-	mA, mV, PT100 RTD thermocouple	$1,800

* Doesn't include 4-20ma

@Proposed

Srinivas Katipamula 7/18/90

APPENDIX B - LoanSTAR DAS VENDORS (cont.)

List of Data Acquistion Systems for Bench Test

Manufacturer	Unit	Status	Digital (Pulse)	Control	Cost
Landis & Gyr	DataGyr 100 (Level 1)	Four	Four (2/3 wire)	Two/Four	$850
Process System Inc.	Sentry 200 (Level 1/2)	Four	Four 3 wire Eight 2 wire	Four	$900
Sangamo Systems	ST-DS111 (Level 1)	-	One/Two/Four	-	$800

Srinivas Katipamula 7/18/90

APPENDIX C - SYNERGISTIC C180 CHANNEL TABLE

This table is the channel table for the Synergistics C180 data logger in the Zachry Engineering Center. The C180 has 3 types of monitoring capabilities, electrical power monitoring, digital channels and analog channels.

ARCHIVE CHANNEL TABLE ZEC (As of April, 1990)

Channel	Description	Type	Units
1	Month of the Year	Internal	-
2	Day of the Month	Internal	-
3	Year	Internal	-
4	Julian Date Representation	-	-
5	Julian Decimal Date Representation	-	-
6	Hour of the Day	Internal	h
7	Main Service - Leg 1	kW	kW
8	Main Service - Leg 2	kW	kW
9	Main Service - Leg 3	kW	kW
10	Motor Control Center I - Leg 1	kW	kW
11	Motor Control Center I - Leg 2	kW	kW
12	Motor Control Center I - Leg 3	kW	kW
13	Motor Control Center II - Leg 1	kW	kW
14	Motor Control Center II - Leg 2	kW	kW
15	Motor Control Center II - Leg 3	kW	kW
16	Computers - Leg 1	kW	kW
17	Computers - Leg 2	kW	kW
18	Computers - Leg 3	kW	kW
19	Air Handling Unit 10 - Leg 1	kW	-
20	Air Handling Unit 10 - Leg 2	kW	kW
21	Air Handling Unit 10 - Leg 3	kW	kW
22	Blank		-
23	Ambient Dry-Bulb Temperature	Analog	F
24	Ambient Relative Humidity	Analog	%
25	Horizontal Solar Radiation	Analog	W/sq.m

APPENDIX C - SYNERGISTIC C180 CHANNEL TABLE (cont.)

ARCHIVE CHANNEL TABLE ZEC (As of April, 1990)

Channel	Description	Type	Units
26	Wind Speed	Analog	mph
27	Chilled Water Consumption (Synergistics)	Digital	100kBtu/h
28	Hot Water Consumption (Synergistics)	Digital	100kBtu/h
29	Hot Deck Temperature (AHU10)	Analog	F
30	Cold Deck Temperature (AHU10)	Analog	F
31	Cold Deck Relative Humidity (AHU10)	Analog	%
32	Mixed Air Temperature (AHU10)	Analog	F
33	Mixed Air Relative Humidity (AHU10)	Analog	%
34	Return Air Temperature (AHU10)	Analog	F
35	Return Air Relative Humidity (AHU10)	Analog	%
36	Air Flow Rate (AHU10)	Analog	cfm
37	Pressure Drop Across Fan (AHU10)	Analog	in
38	ON-Time Cold Water Pump I	Digital	%
39	ON-Time Cold Water Pump II	Digital	%
40	ON-Time Hot Water Pump I	Digital	%
41	ON-Time Hot Water Pump II	Digital	%
42	Gallons of Hot Water	Digital	x GPM
43	Hot Water Consumption (BTUSA)	Digital	x Btu
44	Gallons of Chilled Water	Digital	y GPM
45	Chilled Water Consumption (BTUSA)	Digital	y Btu

APPENDIX D - Z.E.C. ARCHIVE CHANNEL TABLE

This is the Z.E.C. ARCHIVE channel table used by Princeton's ARCHIVE program to translate the raw data into final archive format.

Date MM/DD/YY (YY DDD)	Time HH:mm	Raw-Data lin pos	Raw-Data coln pos	Arch coln pos	Name of Channel	Archive Units	Arch Format	Conv'n Code	Conv'n Constants	Error Code	Error Constants	Channel Description
#4												
03/12/90	00:00	1	0	0	Begin	Zachry						Beginning date
03/12/90	00:00	1	1	1	Mon-Raw	MM	I3	1		0		Month
03/12/90	00:00	1	2	2	Mon-Raw	DD	I3	1		0		Day
03/12/90	00:00	1	3	3	Mon-Raw	YY	I3	1		0		Year
03/12/90	00:00	1	3	4	Greg-Jul	MMDDYY	I5	24	1 2	0		Gregorian Date to Julian
03/12/90	00:00	1	4	6	Time	HH mm	I5	16	5	0		Time
03/12/90	00:00	1	3	5	Greg-Dec	DDD.frac	F10.4	28		0		Gregorian Date to Jul.Decmal
03/12/90	00:00	1	6	7	Main#1	F9.3	F9.3	1		1	200 600	Main Service Leg #1 (kW)
03/12/90	00:00	1	7	8	Main#2	F9.3	F9.3	1		1	200 600	Main Service Leg #2 (kW)
03/12/90	00:00	1	8	9	Main#3	F9.3	F9.3	1		1	200 600	Main Service Leg #3 (kW)
03/12/90	00:00	1	9	10	MCC1#1	F9.3	F9.3	1		1	30 120	MCC #1 Leg #1 (kW)
03/12/90	00:00	1	10	11	MCC1#2	F9.3	F9.3	1		1	30 120	MCC #1 Leg #2 (kW)
03/12/90	00:00	1	11	12	MCC1#3	F9.3	F9.3	1		1	30 120	MCC #1 Leg #3 (kW)
03/12/90	00:00	1	12	13	MCC2#1	F9.3	F9.3	1		1	20 80	MCC #2 Leg #1 (kW)
03/12/90	00:00	1	13	14	MCC2#2	F9.3	F9.3	1		1	20 80	MCC #2 Leg #2 (kW)
03/12/90	00:00	1	14	15	MCC2#3	F9.3	F9.3	1		1	20 80	MCC #2 Leg #3 (kW)
03/12/90	00:00	1	15	16	Cry#1	F9.3	F9.3	1		1	0 200	Crystal Palace #1 (kW)
03/12/90	00:00	1	16	17	Cry#2	F9.3	F9.3	1		1	0 200	Crystal Palace #2 (kW)
03/12/90	00:00	1	17	18	Cry#3	F9.3	F9.3	1		1	0 200	Crystal Palace #3 (kW)
03/12/90	00:00	1	18	19	Blank	F9.3	F9.3	1		0		Blank
03/12/90	00:00	1	19	20	AHU#1	F9.3	F9.3	1		1	0 50	AHU Fan Leg #1 (kW)
03/12/90	00:00	1	20	21	AHU#2	F9.3	F9.3	1		1	0 50	AHU Fan Leg #2 (kw)
03/12/90	00:00	1	21	22	Blank	F9.3	F9.3	1		0		Blank
03/12/90	00:00	1	22	23	OA DB	F9.3	F9.3	1		1	-10 150	Rooftop Dry Bulb (F)
03/12/90	00:00	1	23	24	OA RH	F9.3	F9.3	1		1	0 101	Rooftop Relative Hum. (%)
03/12/90	00:00	1	24	25	Solar	F9.3	F9.3	1		1	-10 1100	Rooftop Global Solar (W/m2)
03/12/90	00:00	1	25	26	Wind	F9.3	F9.3	1		1	0 130	Rooftop Wind Speed (mph)
03/12/90	00:00	1	35	27	CWtot	F9.3	F9.3	1		1	20 100	Whole Bldg. CW (100kBtu)
03/12/90	00:00	1	36	28	HWtot	F9.3	F9.3	1		1	0 60	Whole Bldg. HW (100kBtu)
03/12/90	00:00	1	26	29	HDTMP	F9.3	F9.3	1		1	60 180	Hot Deck Temperature (F)
03/12/90	00:00	1	27	30	CDTMP	F9.3	F9.3	1		1	35 70	Cold Deck Temperature (F)
03/12/90	00:00	1	28	31	CDRH	F9.3	F9.3	1		1	0 100	Cold Deck Relative Humidity (%)
03/12/90	00:00	1	29	32	MATMP	F9.3	F9.3	1		1	50 100	Mixed Air Temperature (F)
03/12/90	00:00	1	30	33	MARH	F9.3	F9.3	1		1	0 100	Mixed Air Relative Humdity (%)
03/12/90	00:00	1	31	34	RATMP	F9.3	F9.3	1		1	60 90	Return Air Temperature (F)
03/12/90	00:00	1	32	35	RARH	F9.3	F9.3	1		1	0 100	Return Air Relative Humidity (%)
03/12/90	00:00	1	33	36	Flow	F9.3	F9.3	1		1	0 25000	Air Flow Rate (SCFM)
03/12/90	00:00	1	34	37	Diff P	F9.3	F9.3	1		1	0 10	Pressure Drop Across the fan (in)
03/12/90	00:00	1	37	38	HPMP1	F9.3	F9.3	1		1	0 100	Percent ON time Hot Water Pump
03/12/90	00:00	1	38	39	HPMP2	F9.3	F9.3	1		1	0 100	Percent ON time Hot Water Pump
03/12/90	00:00	1	39	40	CPMP1	F9.3	F9.3	1		1	0 100	Percent ON time Cold Water Pump
03/12/90	00:00	1	40	41	CPMP2	F9.3	F9.3	1		1	0 100	Percent ON time Cold Water Pump
03/11/91	23:00	1	0	0	End	zachry						

APPENDIX E - Z.E.C. ARCHIVE LOG FILES

This is an example of the log file that the ARCHIVE program produces for the Z.E.C. data that are polled once per week. The standard output has been reduced with the Microtxt program.

```
                         Microtext Page 1
Log of Archive, version: 1.41 of 18 June 1987,        processed
on 18 Feb 1990

Files:

        RAW DATA 00190046.dat

    CHANNEL TABLE c:\zach\00189001.cht

         ARCHIVE 00190046.ach

              LOG 00190046.log

Archive delimiter is " ".
Missing or bad data values are replaced by the value -99.000 .

Line errors: are identified by their line number in the raw
data file.
Data errors: are identified by the channels name, line and
position
                within the case: "name  "(line in case/position
in line).
Line numbers in raw data file are shown as |number| or as
#number#
                |number| indicates a line of data, #number# is
a comment line.

First case on raw data: 90 039 00:00

-----------------------------------------------------------------
-----------------
BeginDate: 89 238 00:00                           First output
case: 90 039 00:00
- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - -

Data Error:
|4|  2  8 90    3  0   320.0  330.0  334.3  79.81  79.76  78.34
 38.24  36.24  32.62  43.17  41.99 31.971  -0.19100  1.168
1.370  0.009000  63.44 101.10    0.6  4.672  80.00  32.00
Value out of bounds: "DA RH   "(1/23);

Data Error:
|5|  2  8 90    4  0   318.7  326.8  330.8  79.71  79.76  78.29
 38.29  36.29  32.68  43.08  41.92 31.996  -0.19000  1.160
1.362  0.009000  63.33 101.20    0.7  4.602  80.00  31.00
Value out of bounds: "DA RH   "(1/23);

Data Error:
-----------------------------------------------------------------
```

```
                                          Microtext Page 2
| |6|  2  8 90    5  0   318.7  327.8  330.3  79.81  79.86  78.19
|  38.26  36.27  32.62  43.25  42.09 32.097  -0.19000  1.147
| 1.385  0.008000  63.27 101.20    0.6  5.464  80.00  33.00
| Value out of bounds: "DA RH   "(1/23);
|
| Data Error:
| |7|  2  8 90    6  0   318.0  327.2  331.8  79.41  79.46  78.04
|  38.24  36.27  32.62  43.00  41.92 32.097  -0.18900  1.142
| 1.348  0.009000  62.96 101.50    0.6  4.998  81.00  31.00
| Value out of bounds: "DA RH   "(1/23);
|
| Data Error:
| |8|  2  8 90    7  0   329.0  342.1  340.8  79.86  79.61  78.14
|  38.21  36.21  32.57  43.02  41.74 31.996  -0.18900  1.129
| 1.339  0.009000  63.08 101.70    0.6  3.904  80.00  32.00
| Value out of bounds: "DA RH   "(1/23);
|
| Data Error:
| |9|  2  8 90    8  0   384.1  368.7  374.2  79.86  80.07  78.14
|  38.24  36.44  32.58  42.98  41.94 31.444  -0.19000  1.149
| 1.311  0.009000  63.40 101.70    3.8  4.079  80.00  33.00
| Value out of bounds: "DA RH   "(1/23);
|
| Data Error:
| |10|  2  8 90    9  0   401.3  409.6  418.4  79.76  80.62
| 78.44  38.19  36.82  32.47  43.42  42.44 31.218  -0.19400
| 1.204  1.343  0.011000  63.71 101.80   84.6  3.180  80.00
| 29.00
| Value out of bounds: "DA RH   "(1/23);
|
| Data Error:
| |11|  2  8 90  10  0   433.7  437.2  443.3  79.11  80.27
| 74.99  38.11  36.89  32.47  43.48  41.77 30.992  -0.19000
| 1.298  1.413  0.010000  66.09 101.80  118.8  6.004  82.00
| 28.00
| Value out of bounds: "DA RH   "(1/23);
|
| Data Error:
| |12|  2  8 90  11  0   442.8  449.3  449.3  78.96  80.17
| 74.94  34.41  38.91  31.97  43.60  41.82 31.243  -0.19100
| 0.000 -0.001  0.006000  67.90 101.10  139.8  7.982  83.00
| 24.00
| Value out of bounds: "AHU02   "(1/20); "DA RH   "(1/23);
|
| Data Error:
| |34|  2 10 90    5  0   328.0  326.5  336.0  79.31  79.96
| 78.19  39.08  40.28  36.29  43.80  43.32 31.820  -0.19700
| 9.362  9.110  0.009000  82.88 101.30    1.4  6.180  83.00
| 46.00
| Value out of bounds: "DA RH   "(1/23);
-----------------------------------------------------------------
```

```
                    Microtext Page 3

Data Error:
|58|  2 10 90    6  0   327.7  328.2  337.3  79.41  80.07
78.24  39.08  40.28  36.29  43.17  42.97 31.921  -0.19600
9.368  9.110  0.009000  81.80 101.30    1.8  6.380  82.00
42.00
Value out of bounds: "DA RH   "(1/23);

Data Errors.
|81|  2 11 90    8  0   317.4  318.7  329.0  79.71  80.47
78.39  39.30  40.61  36.44  43.20  42.72 31.748  -0.19200
9.484  9.161  0.009000  48.87  61.88   36.7 -0.059  47.00
42.00
Value out of bounds: "Wind    "(1/28);

Data Error:
|129|  2 13 90    8  0   363.7  362.2  383.8  79.11  80.37
74.84  38.98  40.46  38.91  44.08  42.82 31.243  -0.19800
9.098  8.746  0.009000  58.95 101.10   23.1  5.088  86.00
40.00
Value out of bounds: "DA RH   "(1/23);

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
- - - - - - - - - -
EndDate:   99 365 24:00                           Last output
case: 90 046 00:00
-----------------------------------------------------------------
-----------------

STATISTICS:

 169 lines read from beginning of raw data file.
 169 lines processed between Begin and End dates.
   (including 0 comments and 0 all-blank lines)
  0 line errors detected.

  14 data errors, and 0 missing data detected, itemized below:

  Arc  Channel    Error  Missing
  pos   name      count   count
  21   AHU02        1       0
  24   DA RH       12       0
  26   Wind         1       0
-----------------------------------------------------------------
```

```
                                          Microtext Page 4
```

APPENDIX F - Z.E.C. DATA REDUCTION "BATCH" FILE

This appendix contains the batch file instructions for producing the weekly inspection plots for the Z.E.C. The instructions in this batch file are outlined in Figure 3 of the report.

```
**********************First batch file commands*****************

cd \site\%1                                      ! set current dir to
                                                 ! \site\%1
                                                 ! %1 --> site number

gawk -f \sys\raw2dat.awk < raw\%1%2.raw > %1%2.dat ! convert *.raw to *.dat
                                                 ! filter non-numeric elements
                                                 ! %1 --> site number
                                                 ! %2 --> julian date

archive %1%2.dat %1%3.cht                        ! add decimal date string
                                                 ! check high/low bounds on
                                                 !  all channels
                                                 ! %1 --> site number
                                                 ! %2 --> julian date
                                                 ! %3 --> julian date for the
                                                 !    channel table file

gawk -f \sys\missing.awk < %1%2.ach > acs\%1%2.acs ! replace missing records
                                                 !  with -99.0 for all channels
                                                 ! %1 --> site number
                                                 ! %2 --> julian date

call util\%1graph %1 %2 %4 %5                    ! calls batch file to generate
                                                 ! qualitative plots

**********************Second batch file commands****************

gawk -f util\pluck.awk <acs\%1%2.acs >\temp\temp.dat  ! Pluck out two blank channels

cols <\temp\temp.dat 1:28 >\temp\work1.dat ! Extract first 26 channels for weekly plots

cols <\temp\temp.dat 7:18 >\temp\work2.dat ! Extract electric consumption channels

rows <\temp\work2.dat >\temp\work3.dat zac.ins go ! Sum individual legs for total
                                                 !  consumption for each end-use

cols ^\temp\work1.dat ^\temp\work3.dat a1:6 b1 a8:9 b2 a11:12 b3 a14:15 b4 a17:26 >\temp\work.dat
                                                 ! merge total consumption for end-use
                                                 ! with the other channels

rows <\temp\work.dat >\temp\zele.dat mer.ins go  ! Seperate the electric end-use
                                                 ! to: total, motor contro center,
                                                 !    lights and equipment, and
                                                 !    computer usage

 **** GENERATE A WEATHER FILE FOR ZACHRY ****

cols <acs\%1%2.acs 24 >rh.dat                    ! get the relative humidity
                                                 ! values from *.acs file (24th col)
```

APPENDIX F - Z.E.C. DATA REDUCTION "BATCH" FILE (cont.)

```
util\rhtrim                                     ! trim any value above 100.5%

cols ^acs\%1%2.acs ^rhtrim.dat a5 a23 b >in.wea  ! get decimal time, and
                                                ! dry-bulb temp. form *.acs file

util\air                                        ! generate other psychrometric
                                                ! properties of air from
                                                ! dry-bulb temp., and relative humidity

cols ^acs\%1%2.acs ^air.wea a1:6 b2:5 a25:26 >wea\%1%2.wea
                                                ! create a *.wea file for College Station

 **** GENERATE DATA FILE FOR PLOTTING AHU ****

cols <acs\%1%2.acs 5 29 >hd.out
cols <acs\%1%2.acs 5 30 31 >in.wea
util\air
copy air.wea cd.out

cols <acs\%1%2.acs 5 32 33 >in.wea
util\air
copy air.wea ma.out

cols <acs\%1%2.acs 5 34 35 >in.wea
util\air
copy air.wea ra.out

cols ^hd.out ^cd.out ^ma.out ^ra.out ^wea\%1%2.wea a1:2 b2 c2 d2 e7 b5 c5 d5 e10 >\temp\ahu.dat

  **** This section changes the X-Axis label and start/end time for the weekly graphs *****

gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\ztemp.grf > \temp\ztemp.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zmain.grf > \temp\zmain.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zcomp.grf > \temp\zcomp.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zrela.grf > \temp\zrela.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zmcc1.grf > \temp\zmcc1.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zmcc2.grf > \temp\zmcc2.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zsola.grf > \temp\zsola.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zchil.grf > \temp\zchil.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zhot.grf  > \temp\zhot.grf
gawk -v var1=%3 -v var2=%4 -f util\chgrf.awk graph\zwind.grf > \temp\zwind.grf

copy graph\ztecw.grf \temp\ztecw.grf
copy graph\ztehw.grf \temp\ztehw.grf

gawk -v var1=%3 -f util\chdate.awk graph\zahu0.grf > \temp\zahu0.grf
gawk -v var1=%3 -f util\chdate.awk graph\zahu1.grf > \temp\zahu1.grf
gawk -v var1=%3 -f util\chdate.awk graph\zmer.grf  > \temp\zmer.grf

cd \temp
for %%i in (*.grf) do grapher %%i  ! generate plot files for all the weekly graphs
cd site\%1

copy graph\1.plt + \temp\ztemp.plt + graph\2.plt + \temp\zmain.plt \temp\tempgrf1.plt
copy graph\3.plt + \temp\zcomp.plt + graph\4.plt + \temp\zrela.plt \temp\tempgrf2.plt
copy graph\5.plt + \temp\zmcc1.plt + graph\6.plt + \temp\zmcc2.plt \temp\tempgrf3.plt
copy \temp\tempgrf1.plt + \temp\tempgrf2.plt + \temp\tempgrf3.plt \temp\plotgrf1.plt

copy graph\7.plt + \temp\zsola.plt + graph\8.plt + \temp\zchil.plt \temp\tempgrf4.plt
```

APPENDIX F - Z.E.C. DATA REDUCTION "BATCH" FILE (cont.)

```
copy graph\9.plt + \temp\zhot.plt + graph\10.plt + \temp\zwind.plt \temp\tempgrf5.plt
copy graph\11.plt + \temp\ztecw.plt + graph\12.plt + \temp\ztehw.plt \temp\tempgrf6.plt
copy \temp\tempgrf4.plt + \temp\tempgrf5.plt + \temp\tempgrf6.plt \temp\plotgrf2.plt

copy \temp\plotgrf1.plt + \temp\plotgrf2.plt first.plt

copy graph\a1.plt + \temp\zahu0.plt + graph\a2.plt + \temp\zahu1.plt + graph\a3.plt + \temp\zmer.plt second.plt

plot first.plt /b
plot second.plt /b
```

APPENDIX G - SOFTWARE USED IN THE TEXAS LoanSTAR PROGRAM

This appendix contains a listing of some of the software that is currently being used in the LoanSTAR program. Also included are a list of the persons inquiring about the software at the June 1990 ASHRAE Meeting held in St. Louis, MO.

ENERGY SYSTEMS LABORATORY
Department of Mechanical Engineering
Texas Engineering Experiment Station
Texas A&M University

College Station, Texas 77843
(409) 845-6402 or
(409) 845-1251

July 9, 1990

TO:

Persons inquiring about software mentioned in the June 1990 ASHRAE Seminar "Measured Energy Performance Data Analysis and Presentation: Pitfalls, Problems & Solutions".

FROM:

Jeff Haberl

SUBJECT:

Software used in the Texas LoanSTAR Program.

Here are some of the software packages in use at Texas A&M for the Texas LoanSTAR Program. We currently are using both MSDOS and Unix platforms tied together with an ethernet.

We intend to have several useful PC-based monitoring modules ready for release in the near future.

Please do not hesitate to call me should you have additional questions.

SOFTWARE IN USE:

VOYAGER: Data Exploration Software., Lantern Corporation, 63 Ridgemont Drive, Clayton, MO, 63105 (requires MS Windows).
--> We use this for browsing through the data soup.

Intex Solutions: 3D Graphics., Intex Solutions, 161 Highland Ave., Needham, MA, 02194, (requires Lotus 123).
--> This is used for 3D surface plots. One needs to convert columnar data to a matrix form.

"ARCHIVE: Software for Management of Field Data", Daniel Feuermann and Willett Kempton, Center for Energy and Environmental Studies - Report No. 216, Princeton University, Princeton, New Jersey.
--> This is used to process all incoming data from our field recorders. It has hi/low limit checks, date stamps, etc.

APPENDIX G - SOFTWARE USED IN THE TEXAS LoanSTAR PROGRAM (cont.)

"Tony's Tools", Tony Lovell, (comes with ARCHIVE), Center for Energy and Environmental Studies - Report No. 216, Princeton University, Princeton, New Jersey.
--> An extremely useful toolkit that attaches to ARCHIVE output.

"Art's Tools", Art McGarrity, (comes with ARCHIVE), Center for Energy and Environmental Studies - Report No. 216, Princeton University, Princeton, New Jersey.
--> Another useful toolkit that attaches to ARCHIVE output.

Surfer, Golden Software, 809 14th Street, P.O. Box 281, Golden, Colorado, 80402-0281.
--> This is used for production 3D surface plots.

Grapher, Golden Software, 809 14th Street, P.O. Box 281, Golden, Colorado, 80402-0281.
--> This is used for other production plots.

GAWK, A PC-based version of AWK by Diane Close, Richard Stallman, Paul Rubin, Arnold Robbins, Free Software Foundation (GNU implementation of AWK - a Unix toolkit by Aho, Kernighan & Weinberger), 675 Massachusetts Ave., Cambridge, MA, 02139.
--> Another useful toolkit for handling columnar data.

PC SAS, SAS Institute, SAS Circle, Box 8000, Cary, NC, 27512-8000.
--> Our mainstream statistical package. Also has great graphics.

JSH July 9, 1990 P.2

APPENDIX G - SOFTWARE USED IN THE TEXAS LoanSTAR PROGRAM (cont.)

TEXAS A&M UNIVERSITY'S ENERGY SYSTEMS LABORATORY **FILE COPY**

---------->M E M O R A N D U M<---------

PERSONS INQUIRING ABOUT SOFTWARE USED IN THE TEXAS LOANSTAR PROGRAM FROM THE JUNE 1990 ASHRAE MEETING.

Mr. Raj Gopal
The Anco Group
231 W. Michigan Ave. #P141
Milwaukee, WI 53203
414-221-4831

Mr. Robert Tyls
AT&T Contract Services
One Oak Way Rm. 3Wc135
Berkeley Heights, NJ 07922
201-771-4224

Mr. Dominick Chirico
Stone & Webster Engineering
250 w. 34th Street
New York, N.Y. 10119
212-290-6743

Mr. James Elleson P.E.
Dorgan & Associates
5610 Medical Cir. #31
Madison, Wisconsin 53719-1227
608-273-0044

Mr. Lew Harriman
Mason-Grant Company
P.O.Box 6547
Portsmouth, N.H. 03801
603-431-0635

Mr. Robert Hough P.E.
The Fleming Group
6310 Fly Road
East Syracuse, New York 13057
315-437-1869

Dr. Hiroshi Yoshino
Department of Architecture
Tohoku University
AOBA SENDAI 980 JAPAN

Mr. Ernie Freeman
U.S.D.O.E.
1000 Independence S.W.
Washington, D.C. 20585
202-586-6784

Dr. Lester Shen
Underground Space Center
Civil & Mineral Engr. Bldg.
500 Pillsbury Dr. S.E.
University of Minn.
Minneapolis, Minn. 55455
612-624-9501

Mr. Charles Cromer P.E.
Florida Solar Energy Center
300 State Road #401
Cape Canaveral, FL 32920-4099
305-783-0300

Mr. Harry Misurello
The Fleming Group
1511 K. Street N.W. #331
Washington, D.C. 20005
202-347-9500

Mr. William Mixon
O.R.N.L. MS 6070
P.O.Box 2008 Bldg. 3147
Oak Ridge, Tenn. 37831-6070
615-576-7323

Mr. Robert McDowall P.E.
Physical Plant
89 Freedman Crescent
Winnipeg, Manitoba CANADA
Canada R3T 2N2
204-474-6289

Mr. David Saum
Infiltec
P.O.Box 1533
Falls Church, VA 22041
703-820-7696

Mr. Robert Briggs
Battelle PNL
Battelle Boulevard
Richland, Washington 99352
509-375-3854

Mr. William Fleming
The Fleming Group
6310 Fly Road
East Syracuse, New York 13057
315-437-1869

FROM THE DESK OF JEFF S. HABERL July 9, 1990 7:50 AM
PAGE 2

APPENDIX G - SOFTWARE USED IN THE TEXAS LoanSTAR PROGRAM (cont.)

TEXAS A&M UNIVERSITY'S ENERGY SYSTEMS LABORATORY
---------->M E M O R A N D U M<----------

FILE COPY

Ms. Julie Oliver
U.S.D.O.E.
1000 Independence
Washington, D.C.20585

Mr. Richard Mazzucchi
Battelle PNL
Battelle Boulevard
Richland, Washington 99352
509-375-3854

Dr. Jan Kreider
JCEM/CEAE
University of Colorado
Boulder, CO 80309-0428
303-492-7315

FROM THE DESK OF JEFF S. HABERL July 9, 1990 7:50 AM
PAGE 3

Texas LoanSTAR Monitoring and Analysis Program

Progress Report

Task 5

ANALYSIS AND PLANNING

Submitted to

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

David E. Claridge
Jeff Haberl
Srinivas Katipamula
Dennis O'Neal
David Ruch*
Lu Chen*
Tia Heneghan
Sharon Hinchey
Kelly Kissock*
Jinran Wang

Energy Systems Laboratory
Mechanical Engineering Department
Texas A&M University
College Station, Texas 77843-3123

July 1990

*Supported by Texas ERAP Project #227.

EXECUTIVE SUMMARY

Task 5 is responsible for selecting and developing analysis techniques, developing necessary software and performing the analysis needed to determine retrofit savings from the measured consumption data and meet other needs of the Monitoring and Analysis Program. It is also responsible for coordinating the planning and reporting for the MAP.

During the first ten months of the program, the draft Monitoring and Analysis Plan was written, reviewed at the first MARC Meeting and the Plan was subsequently revised.

Task 5 was also responsible for design and implementation of a local area network known as the LoanSTAR MAP Net to handle the data archiving and analysis needs of the MAP. This effort is documented in a separate report.

The analysis effort during this time has emphasized selection and development of baseline analysis techniques to cover the range of buildings expected in the LoanSTAR Program. PRISM has been adopted as the baseline technique for buildings which are appropriate for treatment with one-, three- and five- parameter segmented linear change-point models. Data from buildings now available indicates that two- and four- parameter linear segmented change point models are also needed. Taken together, the one-, two-, three-, four- and five- parameter change-point models are expected to be suitable for at least preliminary analysis of monthly and daily data for all the buildings in the Program. Regression analysis with hourly scheduling will be used for baseline hourly analysis.

A substantial effort has been devoted to exploratory analysis intended to refine the analysis performed with the baseline techniques. Work to date has centered on investigation of Principal Component Analysis, an improved goodness-of-fit-indicator, and calibrated simulation modeling. A substantial part of the exploratory effort has been funded by a complementary project funded by the Texas Higher Education Coordinating Board through its Energy Research and Applications Program.

Data from five buildings is used to explain and illustrate the baseline analysis techniques and the exploratory work conducted.

OUTLINE

TASK 5

ANALYSIS AND PLANNING

OVERVIEW

This task is responsible for selecting and developing analysis techniques, developing the necessary software and analyzing collected data to:

1. determine the energy and dollar savings of the retrofits.
2. reduce energy costs by identifying operational and maintenance improvements at retrofitted facilities. Operator interviews are a part of this subtask as well as communication of needed changes to appropriate agency and operating personnel.
3. identify the savings of individual retrofits as feasible to help improve retrofit selection in future rounds of the LoanSTAR Program.
4. develop an end-use database of energy use for commercial/institutional buildings located in Texas.

The task is also responsible for coordinating the preparation and updates of the overall plan for the Monitoring and Analysis Program.

Data analyses will be performed in several phases for each monitored site. These include:

- verification/modification of audit assumptions
- pre-retrofit analysis
- preliminary post-retrofit analysis
- detailed post-retrofit analysis
- interaction and feedback to agencies and operators
- reports

During the pilot year, a local area network of computers, named the LoanSTAR MAP Net, has been designed and assembled to archive data and conduct analyses. A separate report describes this effort. Analysis effort has emphasized the development and testing of a set of procedures and analysis techniques needed to implement the phases noted above.

The three different types of models selected and implemented during the first year are described in this report, followed by a summary of the exploratory analysis performed to identify and develop improved analysis techniques. Data from five buildings was available for the analyses performed to date. These buildings and data sets are described along with the "pre-retrofit" models developed for these buildings. Results of the exploratory analysis are given and future directions of this task are outlined. Appendices are provided with more detailed information about the buildings and analysis performed.

ANALYSIS STRUCTURE

The analysis procedures which are currently regarded as sufficiently tested for immediate use as baseline analysis techniques can be categorized as:

PRISM
Extended Change-Point Regressions
Regression with Hourly Schedule

Exploratory analysis is being conducted to identify and develop techniques which extend and refine the capabilities of the baseline analysis.

PRISM

The versions of PRISM which are available or under development handle the one-, three- and five- parameter segmented regressions with change points as shown in Figure 1.

The one- parameter model is typical of monthly electrical use when heating and cooling influences are absent . It is also typical of daily electrical data from many buildings expected in the LoanSTAR Program after sorting into weekday/weekend data since heating and cooling is often supplied by a central system.

The three-parameter models represent the classic PRISM HO and PRISM CO models and have been used with some success on three of the five buildings for which data is currently available.

The five- parameter model represents the PRISM HC model which is operational at Princeton and will provide a better model for two of the current buildings.

Extended Change-Point Regressions

The two-parameter and four-parameter change point lines shown in Figure 2 represent additional change point types which we expect will be highly useful with the LoanSTAR buildings, based on our examination of preliminary data.

The two-parameter model can be used to represent the hot water or chilled water consumption of buildings with conventional reheat systems, typified by the Zachry Engineering Center at A&M.

The four-parameter model provides a better fit to consumption than the three-parameter model for some buildings which exhibit a change point, but show a non-zero slope on both sides of the change-point. This will be illustrated by electrical data from a grocery store.

Regression with Hourly Schedule

Hourly data is very useful for identifying scheduling changes, equipment failures, etc. This is particularly true when use is predicted with a model which includes a basic schedule of the electricity use plus a temperature regression, if appropriate. Hourly data, combined with hourly predictions can be conveniently displayed as a comparative plot. This approach will be used routinely on buildings for which hourly consumption data is available.

Exploratory Analysis

Exploratory analysis is currently underway in three areas:

Principal Component Analysis
Improved Measures for Goodness-of-Fit
Calibrated Simulation Models

We have concluded that there is such strong intercorrelation between daily influencing parameters that simple multiple linear regression may be of limited value in developing predictive models because the intercorrelated parameters overdetermine the prediction. Consequently, we are examining the effectiveness of Principal Component Analysis (PCA) for this purpose. PCA is attractive because it uses the influencing parameters to create orthogonal (independent) "components" which may be interpreted to have physical significance. Other techniques which will be investigated include: 1) change-point PCA models; 2) Singular Valued Decomposition; and 3) the use of switching models to isolate the influence of individual influencing parameters.

Goodness-of-fit has generally been evaluated primarily in terms of the correlation coefficient, R^2, when regression has been used in energy analysis. This is generally a useful measure when the model involves a single slope (e.g. PRISM CO or HO). A different method is needed when a four-parameter change point model is used. We are currently examining the use of an approach which minimizes the variance for the entire data set to located the change point for a four parameter model. We also intend to examine this approach for locating the change point for three- and five-parameter models (with a zero slope region) as well.

Calibrated simulation models also hold promise for use in determining retrofit energy savings. We have developed a procedure which can be used to create a partially calibrated DOE-2 input deck and have used this procedure to estimate the savings of the planned VAV retrofit of the Zachry Engineering Center at A&M. We are currently examining the effects of zoning on calibration. We are beginning to create such a procedure for ASEAM, using the A&M Consolidated High School as a test case.

DATA AVAILABLE

Data have been available for analysis from only one building, the Zachry Engineering Center, which has been audited and is scheduled for a retrofit under the LoanSTAR Program. Consequently, data from four other buildings has been analyzed and is presented in this report since it is relevant to Task 5 of the MAP. Additional buildings for which data will be presented and analyzed are: the A&M Consolidated High School in College Station, the Kroger Store in College Station, the Four Seasons Nursing Home in Temple and the Four Seasons Nursing Home in Austin. The data from the Kroger Store and the Nursing Homes has been acquired and analyzed under sponsorship from the Texas Energy Research and Applications Program. Data from these sites is presented, not because it is part of the LoanSTAR Program, but because it is representative in many ways of data we anticipate in the LoanSTAR Program. It allows us to present more effectively the analysis techniques we plan to use. Data are available for these sites as follows.

Zachry Engineering Center

The following hourly data are available from August, 1989 through July, 1990, generally with minor gaps:

Whole-building electric
Motor Control Centers (fans)
Computer Center
Chilled Water Consumption (Btus and gallons)
Hot Water Consumption (Btus and gallons)
Dry Bulb Temperature
Relative Humidity (calibration problems)
Global Horizontal Solar Radiation

Additional channels measure several air handler quantities and other information which is not used in the baseline pre-retrofit analysis. The complete channel table is presented in a Task 4 Appendix.

A&M Consolidated High School

Monthly electric consumption demand data are available for May 1985 through April 1987 and May 1989 through June 1990. In addition, hourly electric consumption is available since September 30, 1989.

College Station Kroger Store

Fifteen-minute electric consumption is available since 1988.

Austin and Temple Four Seasons Nursing Centers

Monthly utility gas consumption data is available since September 1987 for Austin and since June 1987 for Temple. Utility electric demand and consumption data are available since October 1988 for Austin and Temple with consumption data from January 1988 for Temple.

DATA ANALYSIS AND PRE-RETROFIT MODELS

Zachry Engineering Center

The Zachry Engineering Center (ZEC) is a four-story (plus basement parking level) building on the A&M campus with approximately 324,400 gross square feet of floor area. It is a heavy structure with 6-inch concrete floors with heating and cooling supplied by a constant volume dual duct system. Hot water and chilled water are supplied by the central campus plant. Major uses of the building include: 1) offices, 2) class rooms, 3) computer rooms, and 4) laboratories. The building also includes hallways and a large atrium area which serves as a common space.

Electrical Consumption

The electrical consumption for ZEC from July 1989 through May 1990 is shown in Figure 3. The figure shows hours of the day from front-to-back, Julian day of the year from right-to-left and hourly electricity use on the vertical axis. The building is open seven days a week, 24 hours a day, and the HVAC systems are operated continuously. The electrical consumption shows a diurnal pattern which varies from a minimum level near 1 MW to a peak of 1.5 MW on weekdays with a slightly lower minimum and much lower peak on weekends. Some gross characteristics of the data are evident in the figure. Proceeding from right to left, consumption is seen to be lower during the break period just before Autumn Semester begins. Christmas vacation period is very evident as the "canyon" near the middle of the figure. The other "canyons" in the left half of the figure represent missing data which occurred when a technician fried an IC in the data logger. The weekday/weekend split is even more obvious in Figure 4 which shows a time plot of daily electric consumption with days of the week indicated by single letters.

The data were used to define an hourly schedule for weekdays and for weekends when school is in session as shown in Figure 5(b). This may be compared with the actual consumption for February 1990, shown in Fig. 5(a). The positive residuals and absolute values of the negative residuals are shown in Figs 5(c) and 5(d). The residual plots indicate that : 1) the electrical use is generally well-described by this simple model (+/- 100 KW out of 1500 KW); 2) consistent underuse of electricity can be seen on Friday afternoons (days 32,29,46 and 53 of Fig. 5(d)); and Saturday consumption is sometimes higher than Sundays (days 40 and 54 of Fig. 5(c)).

Chilled Water Consumption

The chilled water consumption for ZEC depends primarily on the ambient temperature as can be seen in Figure 6. There appears to be a slight difference between weekdays and weekends - physically we expect this difference to be due to the lower electrical consumption on weekends. Table 1 shows our pre-retrofit model for chilled water consumption in ZEC, determined using SAS. Models are shown which depend on temperature (T) only and which depend on temperature, T, as well as electrical consumption for lights and equipment, LE. The second model explains slightly more of the chilled water consumption, though the difference is not statistically significant. We will use the second model, since it is physically preferred.

Note that the chilled water consumption does not show a change-point. It simply decreases as temperature decreases. It <u>might</u> show a change point at sufficiently low temperatures, but the available data includes some of the coldest weather ever experienced in College Station, so the two- parameter model without a change point seems most appropriate. We plan to examine the relationship between chilled water consumption and electricity consumption using a switching model and possibly a lagged hourly model.

	$CW = \alpha + \beta T$	$CW = \alpha + \beta_t T + \beta_e LE$
R^2	0.86	0.87
Intercept	221.8	35.5
Slope	16.4	β_t=16.2; β_e=0.01;
Statistical Significance	good	β_t = good; β_e= fair;

Table 1 - Model parameters and statistics for two models of chilled water consumption at Zachry Engineering Center.

	$HW = \alpha + \beta T$	$HW = \alpha + \beta_t T + \beta_e LE$
R^2	0.87	0.90
Intercept	1808.8	2178.3
Slope	-19.5	β_t=-19.2; β_e=-0.03;
Statistical Significance	good	β_t = good; β_e= good;

Table 2 - Model parameters and statistics for two models of hot water consumption at Zachry Engineering Center.

Hot Water Consumption

The hot water consumption is similar to the chilled water consumption, except that the temperature dependence is negative as would be expected. This behavior is shown in Figure 7. The data again appears to exhibit a slight dependence on the electrical consumption for lights and equipment as shown in Table 2. In this case the dependence on electrical use is somewhat stronger than for chilled water, and is statistically significant, according to the SAS analysis.

A&M Consolidated High School

A&M Consolidated High School is a 209,605 sq.ft. two-story facility in College Station. Electricity dominates energy cost at the school as shown in the table below which presents data for October 1988 through November 1989:

ENERGY CONSUMPTION DATA

Energy Source	Amount	Cost
Electricity		$ 189,841
Consumption	2,853,600 Kwh	(87,945)
Demand - peak mo.	1,112 KW	(101,896)
Natural Gas	23,343 CCF	$ 10,439

It is estimated that approximately 20 percent of the natural gas is used for water heating with the remainder used for space heating. An ASEAM simulation of the building provides the following breakdown of electricity use:

Estimated Electricity Consumption by End Use

End Use	Consumption
Heating	3.1%
Cooling	36.7%
Lighting	16.5%
Fans	15.0%
Misc. Equipment	25.8%
Pumps	3.0%

The electricity use of the building can best be described as erratic. Consumption for October 1988 through September 1989 is shown in Figure 8. The consumption is relatively constant and changes appear to be dominated more by scheduling and operation than by ambient temperature. PRISM analysis of the data is consistent with these conclusions. Analysis of monthly data for three different 12-month periods produced R^2 values of

0.35, 0.71 and 0.29. Analysis of the daily data including sorting data into weekday/weekend subsets produced R^2 values between 0.10 and 0.25.

At least part of the reason for this erratic behavior is evident in Figure 9 which plots the hourly electric consumption. Night shut-off of fans and HVAC systems has been very erratic as evidenced by early morning consumption in the 200 Kw range for much of the Autumn of 1989. Consumption during much of February shows abnormally high night-time use and low daytime use suggesting the possibility of a metering problem. A dramatic drop in both nighttime and daytime consumption over the Christmas break period is clearly evident.

Further analysis of the data using daily and hourly totals for "normal" data periods will be used in an attempt to better model and understand consumption at the high school.

Kroger Store
(Analysis supported by ERAP)

The Kroger store analyzed is a 40,000 square-foot supermarket located in College Station, Texas. The building is a rectangular (160 ft x 250 ft) single-story structure with 16 ft ceilings. The front 35,000 ft^2 is used for display and the rear 5,000 ft^2 is occupied by the space conditioning equipment, the walk-in coolers and the meat and product storage and preparation areas.

The store has the electrical energy-using systems typical of a modern supermarket. The systems and their estimated contribution to peak electrical demand are: refrigeration cases and compressors (44.3%), air conditioning (24.6%), lighting (15.8%), food preparation (12.6%), point-of-sale registers (1.2%), and miscellaneous uses (1.5%). Almost all of the heating for the store is provided by heat reclaim from the refrigeration compressors. Natural gas is used for an oven in the bakery, supplemental heating in very cold weather, and for a 40 gallon hot water heater. The natural gas cost is less than two percent of the electricity cost for the store, so it has been ignored in the model reported here.

The store is open 24-hours per day and is closed only on Christmas and part of Thanksgiving day.

Electrical Consumption and Demand

Monthly electrical consumption and demand of the supermarket for August, 1988 through July, 1989 is shown in Figure 10. The consumption and demand both show weather (or season) dependence. A simple analysis of the data shown in the figure indicates that 16% of the consumption is weather dependent which basically corresponds to the air conditioning load, with a small part of the variation due to changing efficiency of the refrigeration system as a function of temperature. Demand varied by 129 KW (25%) throughout the year from 383 KW in February to 512 KW in September. The average demand was 445 KW and the average consumption was 258,381 kWh per month. Electricity cost $201,150 for the period with demand charges accounting for $48,096.

The variation follows a general seasonal pattern, but deviates by peaking in September while December seems too low and January too high. The September peak probably is related to the influx of customers at the beginning of the school year, while the December dip may reflect Christmas break and the closing of the store on Christmas Day.

Electrical Consumption Analysis

Electrical consumption is recorded at 15-minute intervals and read weekly via modem by the local utility. The 15-minute data has been aggregated to provide hourly and daily total consumption for analysis. The average consumption for each day, expressed in kWh/h or KW is shown in Figure 11 as a function of average daily ambient temperature. There appear to be two essentially linear regions of the data which meet at 62 F (called the change point). Physically, the consumption appears to drop slowly with temperature (below 62 F) due to the increasing COP of the refrigeration compressors. As the temperature increases above 62 F, the COP of the compressors continues to drop, but air conditioning also becomes necessary, resulting in a sharp increase in the slope of the consumption.

Consequently, the data were divided into that collected when the ambient temperature (as recorded at the local airport) was above 62 F and that collected when the temperature was at or below 62 F. Each set was then regressed against the dry bulb temperature to obtain a unique slope and change-point electricity consumption.

This process resulted in a four-parameter model for the daily average electric consumption: (1) slope for the heating regime, (2) slope for the cooling regime, (3) change-point temperature and (4) consumption at the change point temperature. Hence the daily average electric consumption, E_d, can be expressed as:

$$E_d = E_{TC} + B_h*(T_d-T_C) \qquad T_d <= 62 \text{ F}$$

$$E_d = E_{TC} + B_c*(T_d-T_C) \qquad T_d > 62 \text{ F}$$

where T_d is the average daily temperature, E_{TC} is the electricity consumption at the change point of 62 F and B_h and B_c are the slope coefficients. The model parameters obtained are:

E_{TC} = 310 Kwh/h

B_h = 0.868 Kwh/h/F

B_c = 4.976 Kwh/h/F

The ability of the daily predictor model to estimate consumption is shown in Figure 12. The measured daily average consumption is shown for April 1 through April 29, 1989 by the asterisks near the top of the figure. The model prediction for each day is shown by the diamonds while the residual (measured minus predicted) consumption is shown by the line near the bottom of the figure. Excluding anomalies on April 4, 8 and 9, the average residual consumption is 8.6 kWh or 1.7% of the total. A more extensive discussion is provided in the Appendix.

Four Seasons Nursing Homes
(Analysis supported by ERAP)

The Four Seasons Nursing Homes in Austin and Temple are being analyzed as part of the ERAP Program. They are discussed here since electrical data from these buildings is suitable for analysis with PRISM.

The Temple facility is a 100 bed nursing home that is currently 80 per cent occupied. Approximately 40 staff members are present during the day and about 20 during the night. The facility operates 24 hours per day, year round. Full food and laundry service are provided. The single story, slab on grade building was built in 1970 and has an approximate floor area of 31,000 square feet.

Space conditioning is provided by eight roof-top air conditioning units and six small heat pumps. Two of the roof-top units provide heat using electrical resistance heaters and six of the units use natural gas for heating. Direct expansion cooling is used by all units.

The Austin facility is nearly twice as large: it is a two-story building with approximately 58,000 square feet of floor area. Operational schedules and characteristics are similar. Space conditioning is primarily provided by 16 roof-top air conditioning units. Some small window air conditioners and heat pumps supplement the roof-top units. All roof top units provide electrical resistance heating and direct expansion cooling.

Electrical-Use Analysis

Energy use at both facilities has been analyzed using PRISM while that at Temple has also been examined using ASEAM and an equipment inventory with name plate data. The ASEAM simulation results in the following end-use estimates:

HVAC	50%
Kitchen & Laundry	24%
Lighting	26%

PRISM Analysis: The electricity billing data for both facilities are shown in Figure 13. Since some heating is present in both facilities, the PRISM cooling only model was used with winter data omitted. The Temple data provides R^2 of 0.88 with a cooling balance temperature of 66.8 F while the Austin data provides $R^2 =$ 0.96 with a balance point of 74.2 F. Electricity consumption vs cooling degree days for these facilities is shown in Figure 14.

Additional data on these facilities is provided in the Appendix.

EXPLORATORY ANALYSIS

Principal Component Analysis (PCA)
(Work Sponsored by ERAP)

Numerous investigators have attempted to use multiple linear regression analysis to develop improved models of building energy consumption. These attempts have often been frustrated by the significant collinearity between the predictors used. While simulation models clearly separate the influences of temperature, solar gain, occupant gains, humidity, scheduling, etc. as inputs, the inverse problem of determining the influence of these and other factors is complicated by the level of diurnal correlation between such factors and even the annual correlation which often exists.

Principal Component Analysis has been used to tackle similar problems for some time by climatologists and more recently was used by Hadley and Tomich to examine influences on heating energy consumption. PCA forms orthogonal vectors as combinations of the "independent" variables which exhibit some collinearity. The data is then regressed using these orthogonal vectors or "principal components" as the new independent variables to obtain regression coefficients for each "principal component." The less significant "components" may then be dropped to obtain a set of components which provide more stable coefficients for the physical variables. This approach appears to hold promise as a way of combining physical models and insight with measured data to achieve improved models for determining retrofit savings.

The effort to date has been primarily directed toward developing software to implement PCA and beginning exploratory analysis. The method has been applied to data for the Kroger store for June 19, 1989 through June 19, 1990 considering temperature, specific humidity and global horizontal solar radiation as important influencing parameters. The daily energy use, E_p, predicted using standard regression is

$$E_p = 2550 + 77.7*T + 19918*w + 1.56*I_h \qquad T > 62\text{ F}$$

$$E_p = 6016 + 20.5*T + 42501*w + 0.77*I_h \qquad T <= 62\text{ F}$$

where T and w are the daily average temperature and specific humidity respectively and I_h is the daily total horizontal solar radiation. The model found using PCA and dropping the third component is

$$E_p = 4179 + 46.7*T + 47216*w + 3.27*I_h \qquad T > 62\text{ F}$$

$$E_p = 6029 + 19.9*T + 44140*w + 0.82*I_h \qquad T <= 62\text{ F}$$

This process changed the model very little at low temperatures, but approximately doubles the apparent importance of solar and humidity at high temperatures. However, humidity and solar radiation each still account for only 8 percent of the electrical consumption on a typical June day. Additional coefficients are shown in the appendix.

Improved Goodness-of-Fit-Indicators
(Work Sponsored by ERAP)

As noted above, the most appropriate model for the daily electric consumption for the Kroger store is a four parameter, segmented linear model. The results shown in the figures are based on selection of the change-point by visual estimate. A more rigorous procedure has been developed which determines the change-point to minimize the variance with respect to the segmented model. The algorithm for calculating the optimal model is complete. A program which carries out the algorithm is operational, fast, and easy to use. The user provides the data set and reasonable upper and lower bounds for the change-point temperature. The program, which runs on a PC, will compute the models parameters and various relevant statistics in less than one minute using several years of daily data.

The program, run on a full year of data (June 1989 - June 1990), yields a change-point temperature of 59.5 F. This may be compared with the visual estimate of 62 F; the difference of 2.5 F is significant and supports the need for a precise method for calculating the change-point temperature.

An algorithm complementary to that described above has been written to determine the reliability of the parameter estimates. The computer program implementing this algorithm will be finished soon.

Calibrated Modelling

Calibrated input decks for simulation programs offer an approach for examining the expected sensitivity of individual measurement points to the retrofits installed. They also may provide improved estimates of the savings which should be expected from retrofits on individual buildings.

A procedure was defined and tested for preparing a first order calibrated input deck for DOE-2. This process identified several time-consuming software issues which had to be resolved before the procedure could be implemented. A ten-zone input deck of the ZEC was prepared for DOE-2 and important system parameters were adjusted until the measured hot water and chilled water consumption approximated the predicted consumption, using data taken with ambient temperatures between 65 F and 95 F. This input deck was then changed to incorporate a VAV system to provide an update on the expected retrofit savings. Savings indicated were 14,300 MMBtu hot water 30,500 MMBtu chilled water and 3,150,000 Kwh electricity.

We are now examining the sensitivity of the simulation results to the zoning assumptions. The original model highlighted the need for better air handler data which is now being incorporated.

Calibration procedures for ASEAM are now being examined. A&M Consolidated High School has been simulated with ASEAM, and when sufficient four-channel data is available, calibration procedures will be developed and tested.

FUTURE PLANS

During the coming months, effort will be devoted to:

1. Analysis of data from the large number of new buildings which are now coming on line, using PRISM, extended change-point analysis and/or regression models with hourly schedules as appropriate.

2. Retrofit savings analysis will begin.

3. The reliability of parameter estimates for the extended change point analysis will be investigated.

4. Exploratory analysis will continue in the following areas:

   a) The investigation of the sensitivity of ZEC to zoning assumptions will be completed.

   b) DOE-2 calibration procedures will be further developed using data from the Travis Building in Austin as well as ZEC.

   c) ASEAM calibration procedures will be developed.

   d) PCA analysis will continue.

   e) Utility of switching models will be examined.

   f) Application of indices such as those developed by Haberl and Komor (e.g. w/ft^2, ELF, OLF, % unoccupied, etc.) will be examined.

Figure 1. One-, three-, and five- parameter models of energy use as implemented in PRISM.

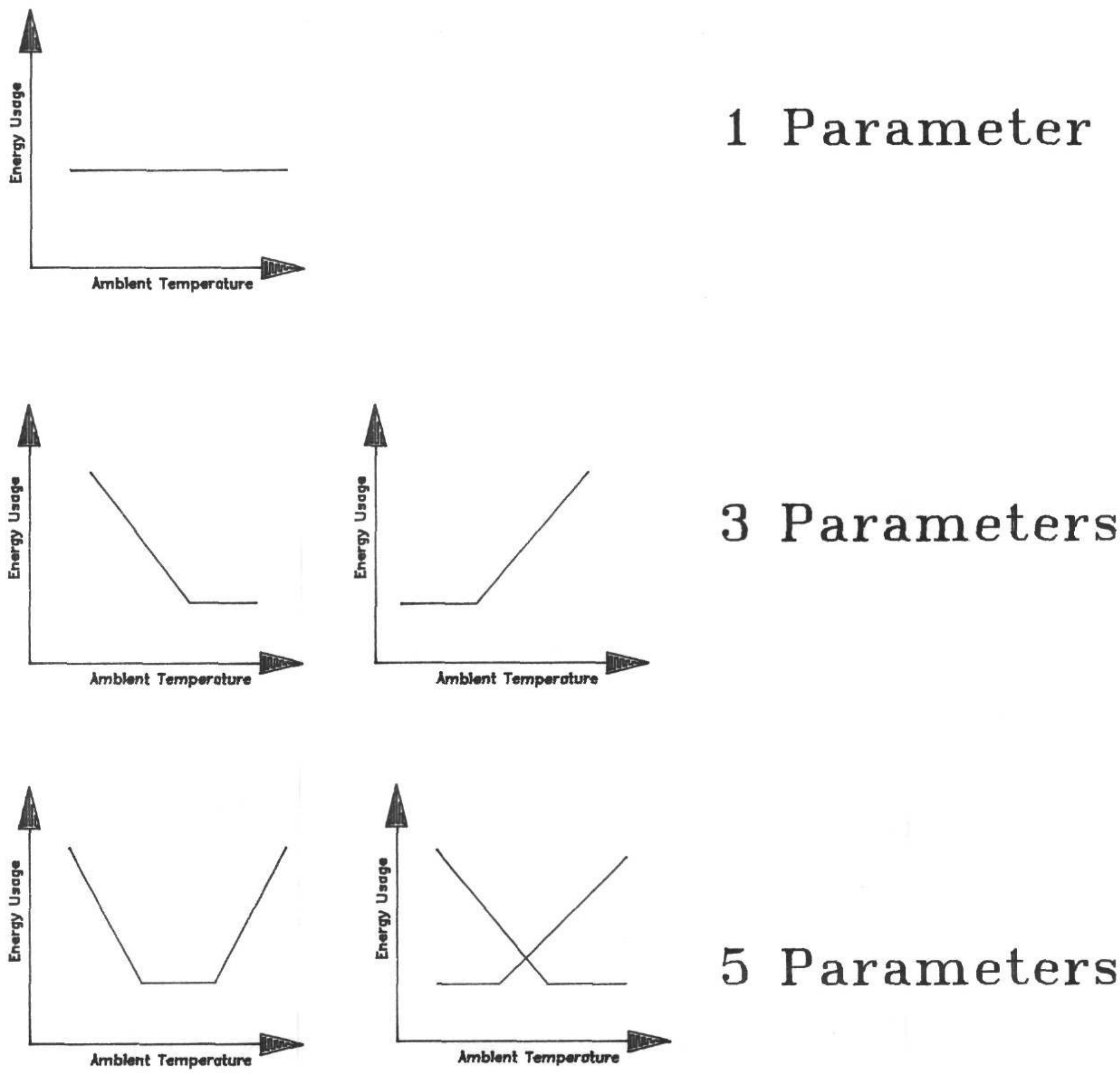


Figure 2. Two- and four- parameter models of energy use described as "extended change-point regressions" in this report.

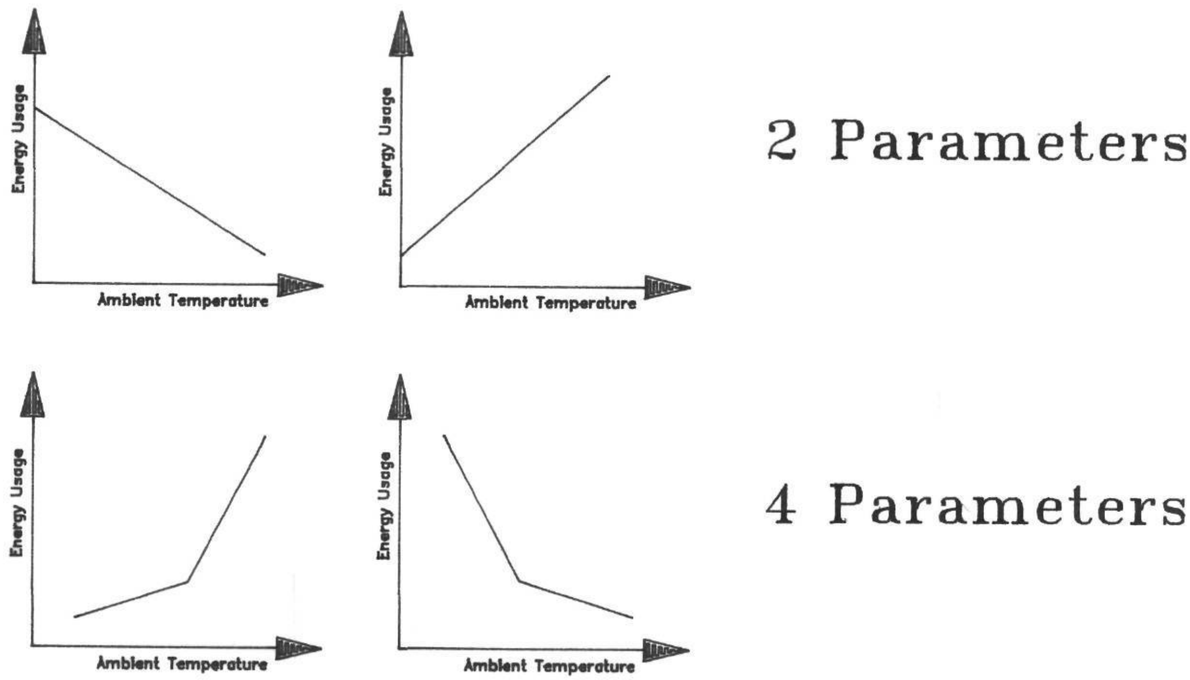


Figure 3. Hourly electricity consumption for Zachry Engineering Center from July 1989 through May 1990.

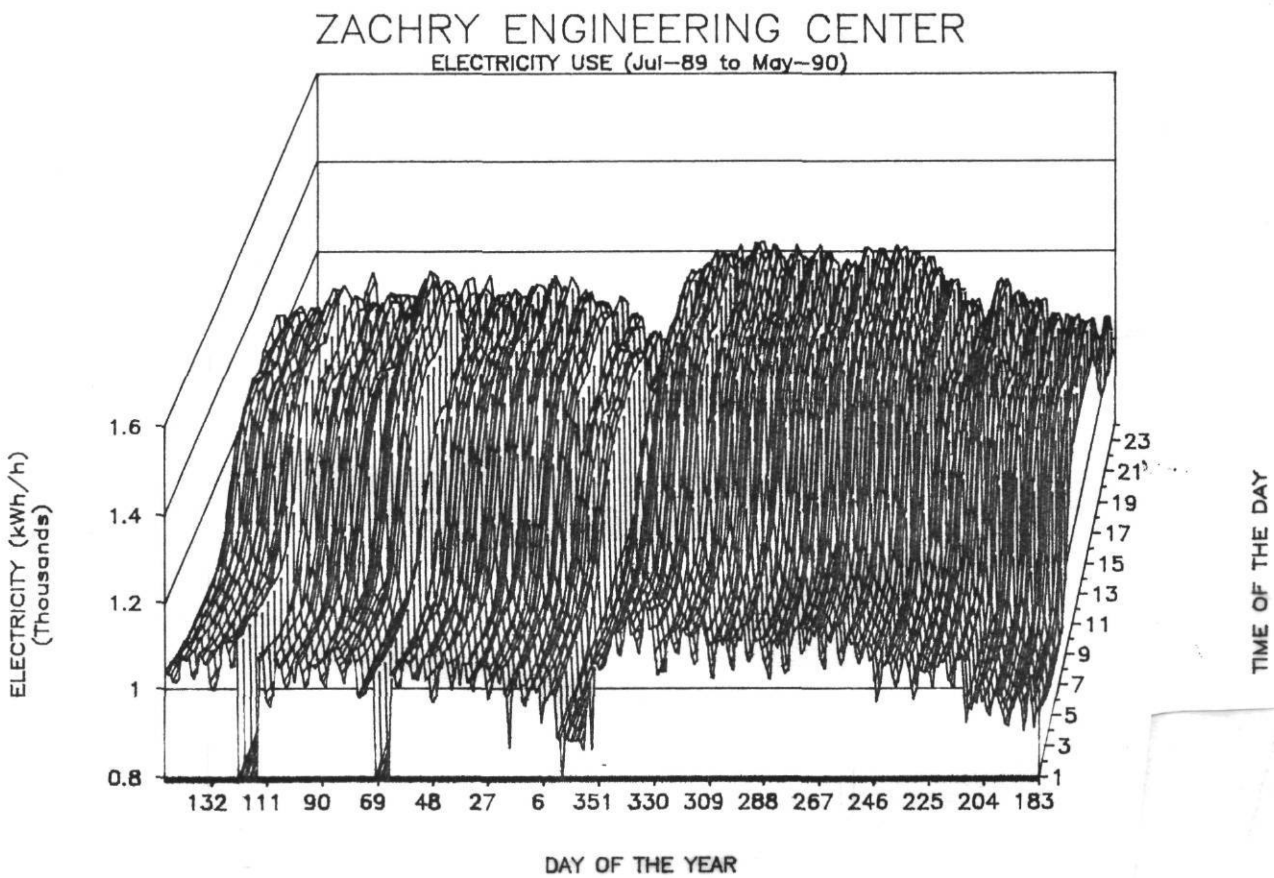


Figure 4. Daily electricity consumption for lights and equipment at the Zachry Engineering Center for May 15, 1989 through May 23, 1990 with the days of the week denoted by the letters s,M,T,W,T,F,S for Sunday through Saturday, respectively.

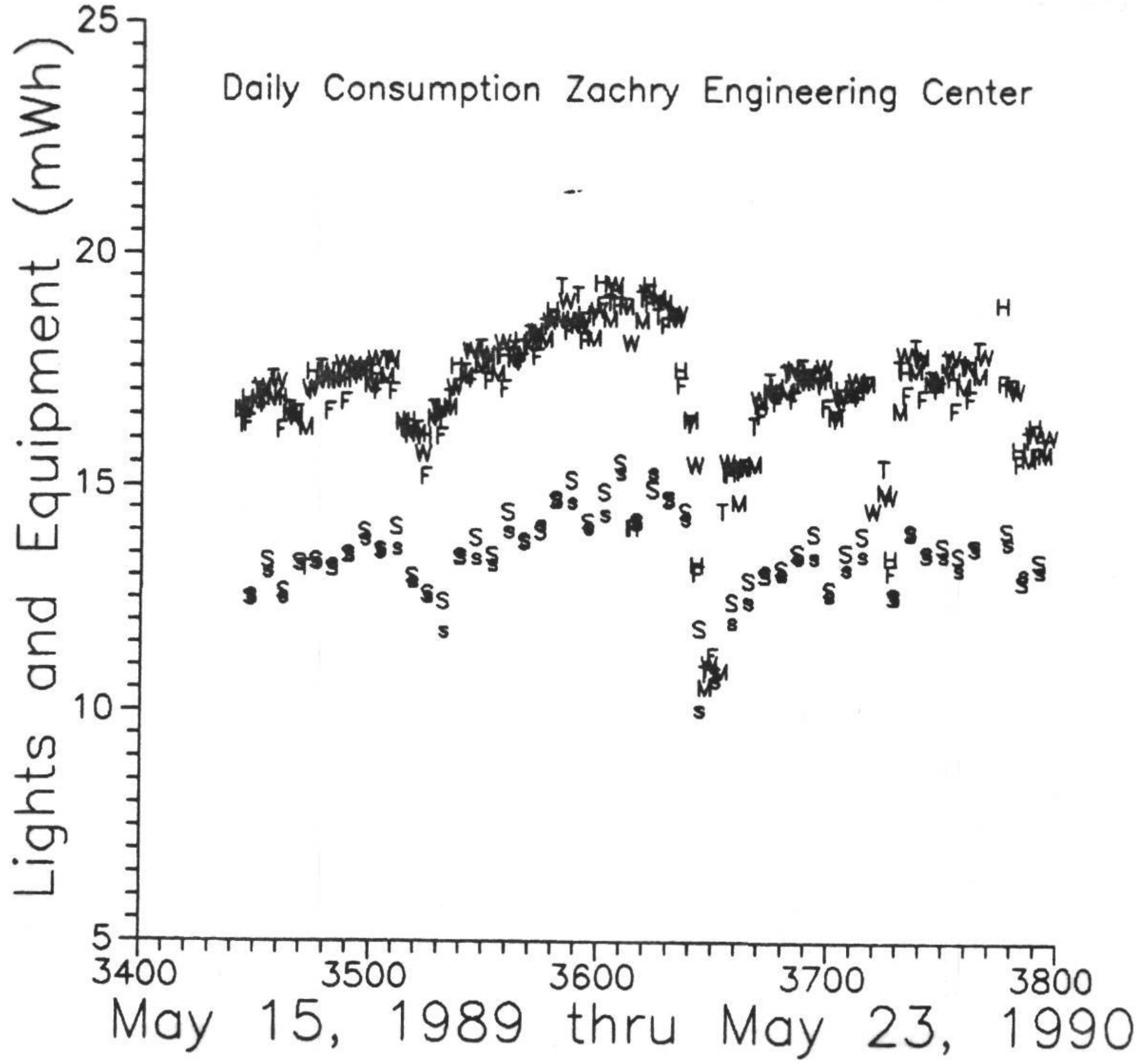


Figure 5. Zachry Engineering Center electricity use and residuals for February, 1990. (a) Measured electricity use. (b) Scheduling model of electricity use. (c) Positive residuals (measured minus predicted) of electricity use. (d) Absolute values of negative residuals of electricity use.

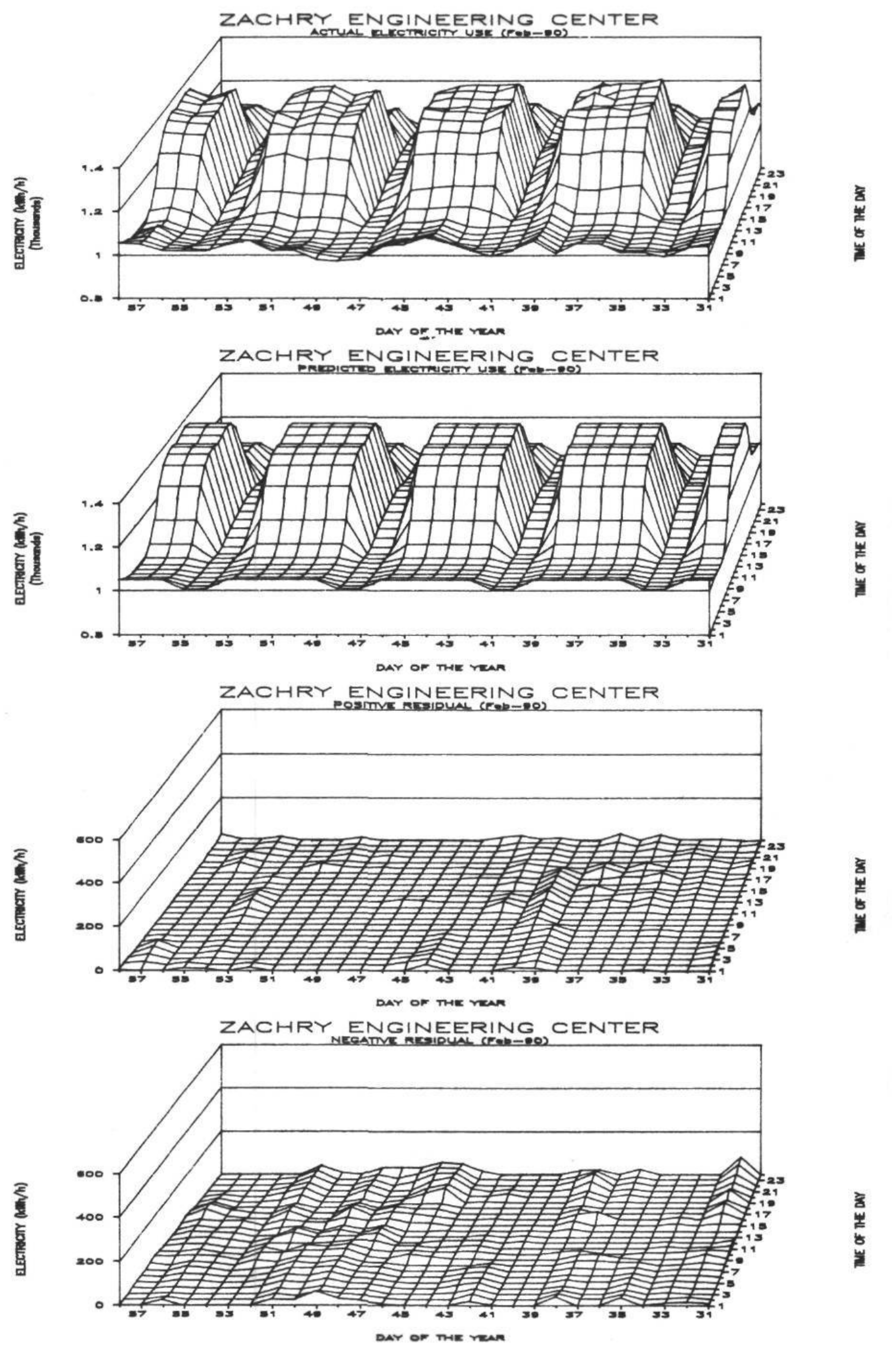


Figure 6. Chilled water consumption at Zachry Engineering Center plotted as a function of ambient temperature using data for September 1, 1989 through May 23, 1990.

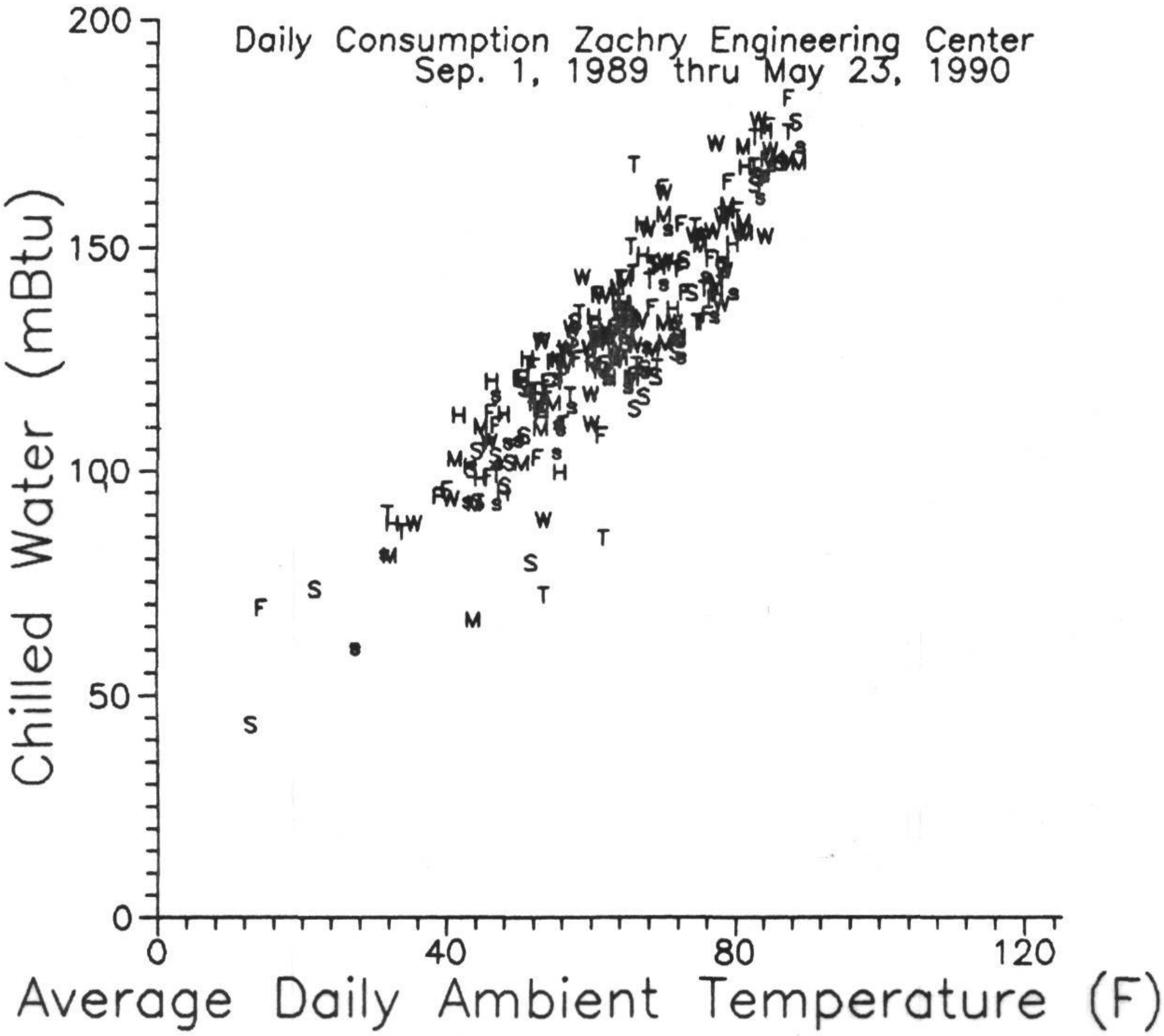


Figure 12. Measured, predicted and residual average daily electric use at the College Station Kroger Store for April 1989.

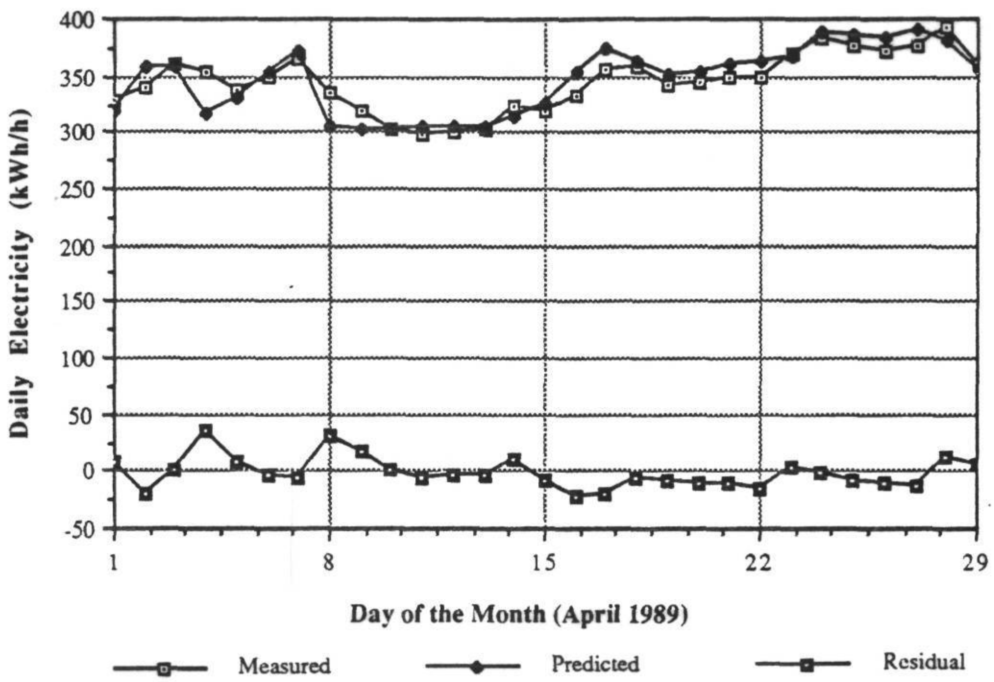
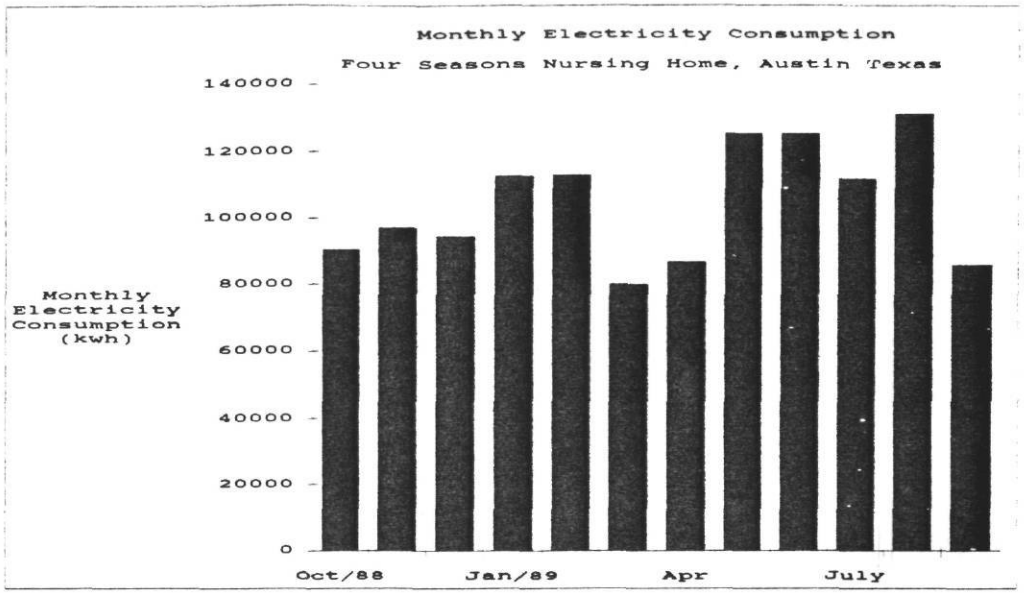


Figure 13. Monthly electrical consumption for Austin and Temple Four Seasons Nursing Homes.



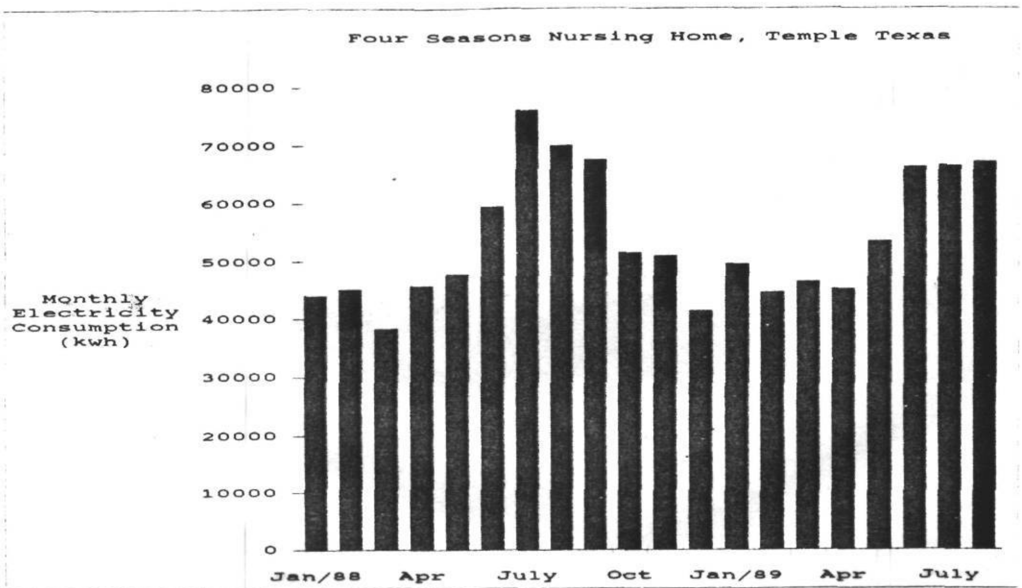
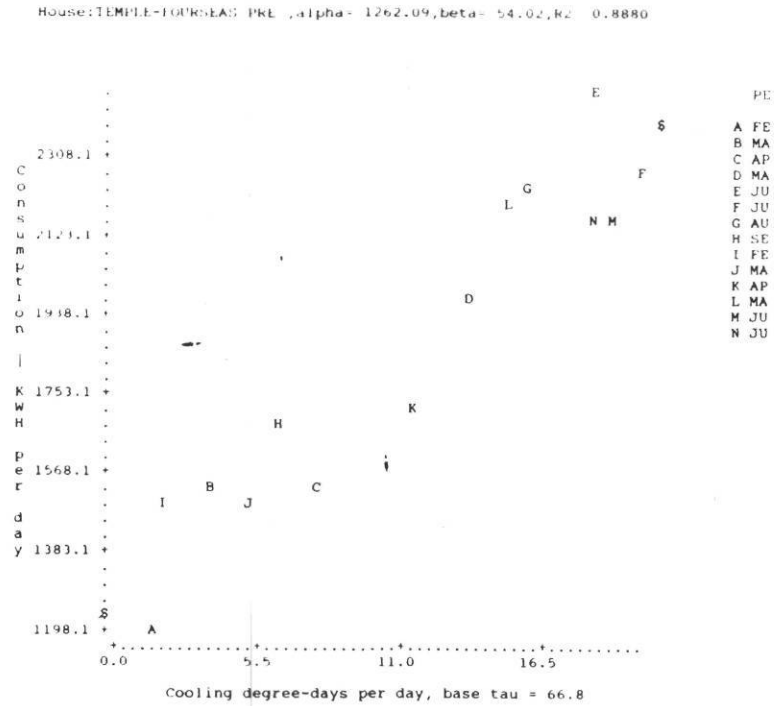
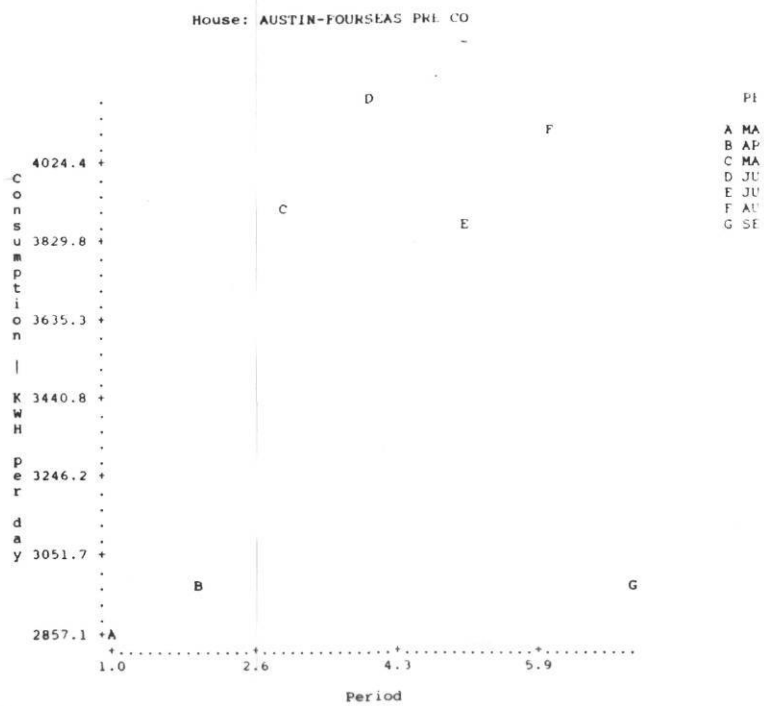


Figure 14. PRISM plots of monthly electricity use versus cooling degree-days for Austin and Temple Four Seasons Nursing Homes.





TASK 5

APPENDIX

a. A&M Consolidated High School

b. Four Seasons Nursing Homes

c. Kroger Grocery Store

d. PCA Results

A.

A&M CONSOLIDATED HIGH SCHOOL

GENERAL BACKGROUND

A&M Consolidated High School is located in College Station, TX. The 209,605 sq.ft. two-story educational facility was originally built in 1970. The original building has grown to its present size with two major additions (including renovations) in 1979 and 1982. Since the building is a result of various additions, the HVAC system has multiple components. The following heating and cooling combinations exist within the structure:

1. Roof Top Units for cooling with electrical resistive heaters.
2. Constant Volume Reheat system using centrifugal chillers with natural gas boiler heating.
3. Constant Volume Reheat system using centrifugal chillers with electrical resistive heaters.

The high school is a concrete structure with 3 inch face brick. The R-value of the outside walls vary slightly throughout the facility from 10-11 ft^2 hr ºF/Btu. During the 1982 renovation the high school was re-roofed and insulation added which resulted in an R-value of 14.3.

HVAC EQUIPMENT

The current structure is divided into eight heating and cooling zones. The components of the HVAC and other major equipment are controlled by a Johnson control system. The purpose of the controller is to turn on the equipment at 6 am then turn it off at 5 pm for a standard Monday through Friday operation. There is a manual override available for special functions in the evenings and on weekends.

Originally built with electric resistance heaters and roof tops air conditioning units, modifications occurred with each addition. During the first addition in 1977 the only noticeable change to the HVAC system was the addition of wall insulation. However, in 1982 the second additional major improvements were made. Two centrifugal chillers (200-ton each) with four 25 horsepower compressors were added and a single duct control volume reheat system was installed. The chillers service five of the eight zone areas, while the other three zones have their own roof top units totaling 70 tons. Also added in 1982 was a natural gas boiler to meet some of the heating load. The boiler serves only four zones, the other four use electric resistance heaters. In two of the four heating zones served by the boiler there are some rooms using electric heaters.

The kitchen's hot water is supplied by a 1000 gallon natural gas domestic hot water heater. This unit also supplies hot water to other parts of the school although there are two smaller units for the Home Ec area and the showers in the new gym.

MONITORING and ANALYSIS

The overall electrical consumption at A&M Consolidated High School has been monitored by the City of College Station in previous years using a Sangamo Data Star Recorder (DSR) with four channels. Since the DSR had available channels, three major electrical users were identified to be monitored along with the overall consumption. The four channels will be on line in the near future.

The three major electrical consumers identified were:

- two 200-ton chillers
- 21 Air handling units (AHUs)
- kitchen equipment

The properly sized monitoring equipment was installed for each of the above using current transformations (CTs) and watt transducers [1] with a pulse output to the Sangamo DSR. Currently, there is a communication problem between the DSR and the watt tranducers that is being resolved.

------**more here on friday----!!!**

Figure 7. Hot water consumption for Zachry Engineering Center as a function of ambient temperature for September 1, 1989 through May 23, 1990.

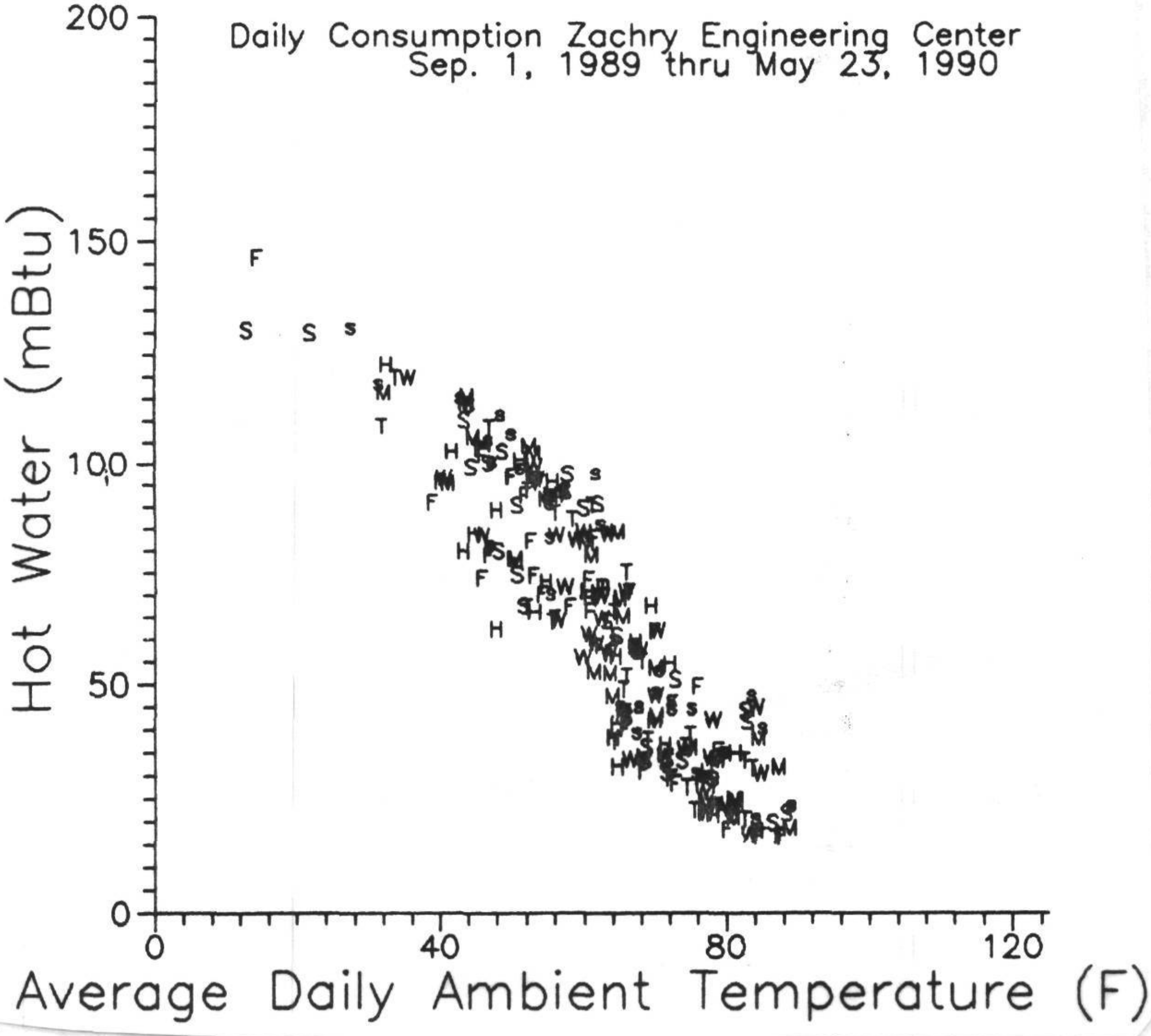


Figure 8. Monthly electricity use at A&M Consolidated High School for October 1988 through September 1989.

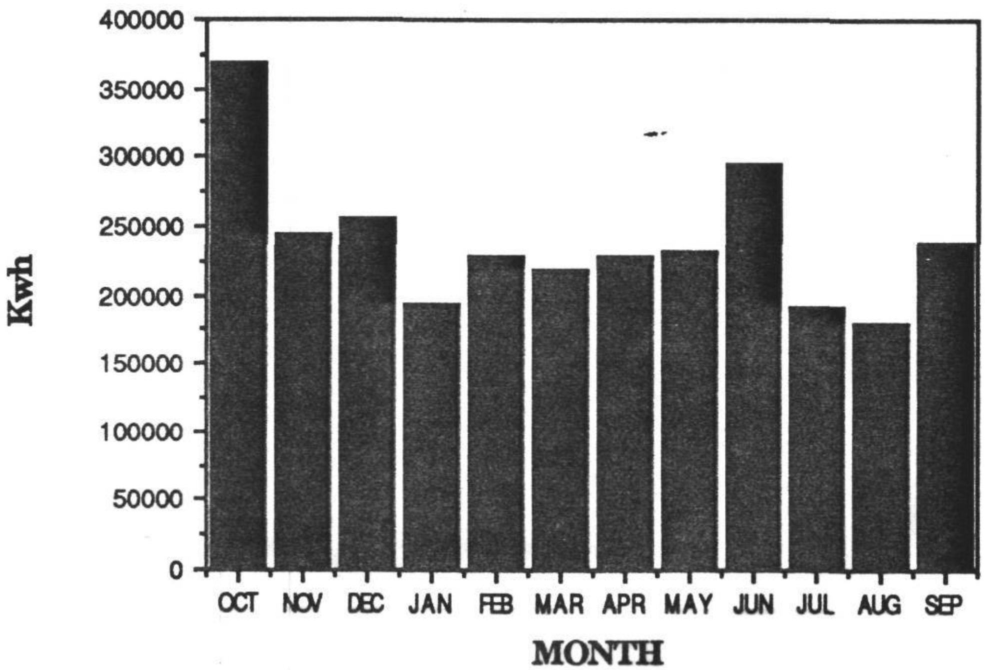
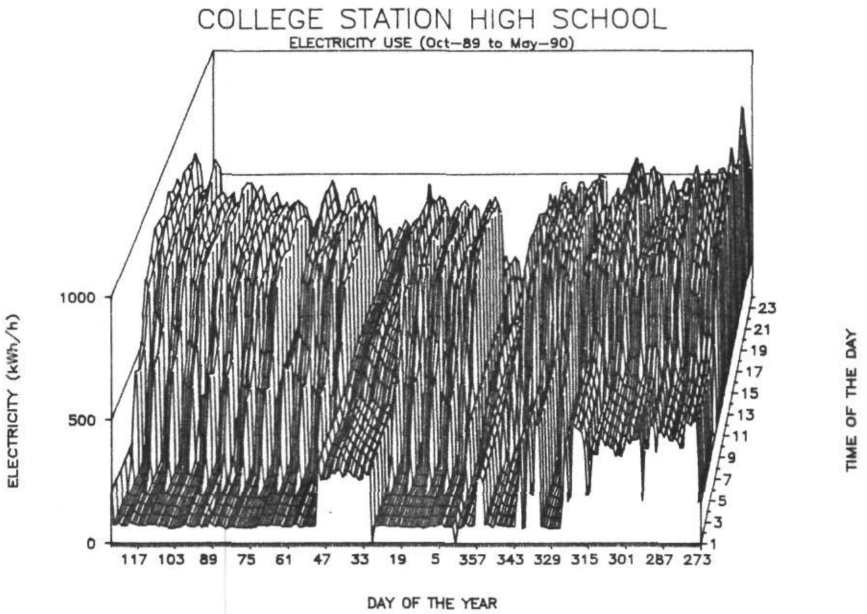


Figure 9. Hourly electricity consumption at A&M Consolidated High School for October 1989 through May 1990.



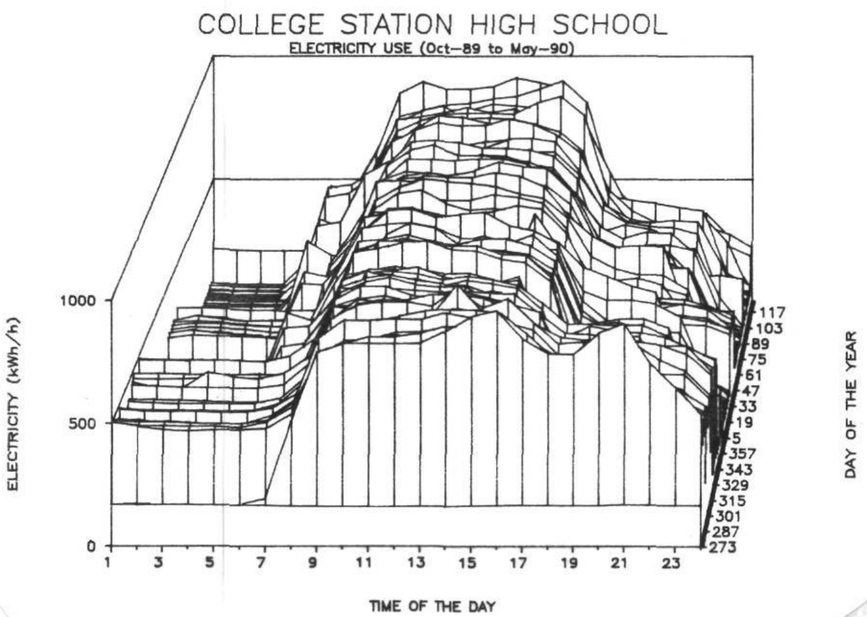


Figure 10. Monthly billed electric use (kWh) and demand (KW) at the College Station Kroger Store for August 1988 through July 1989.

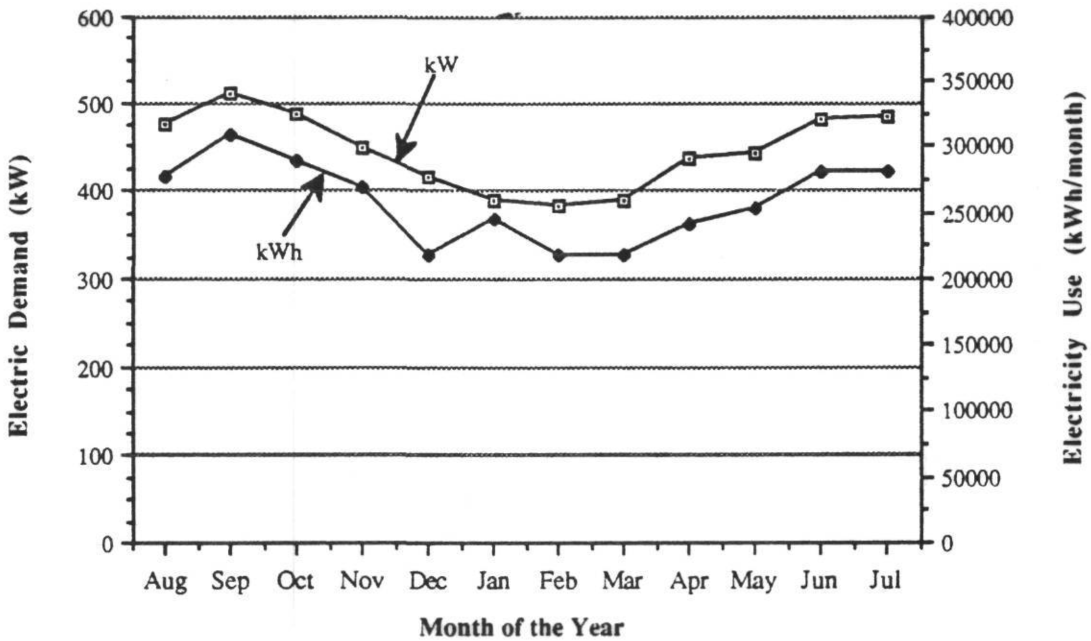
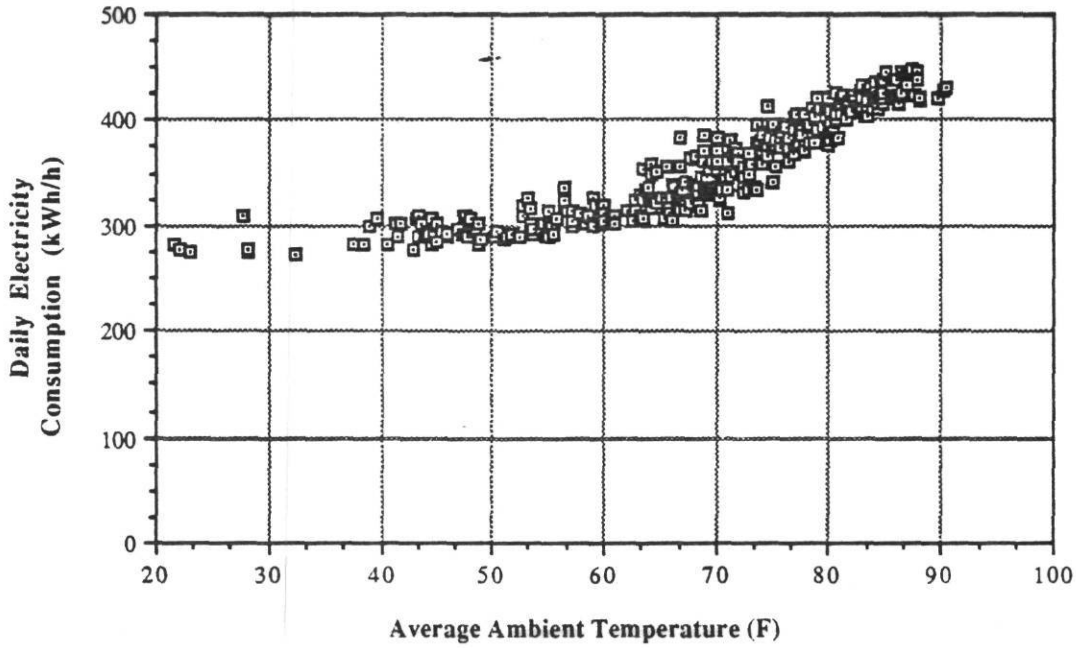


Figure 11. Average daily electricity use at the College Station Kroger Store for March 1988 through April 1989.



The data interval frequency is every 15 minutes. The data is averaged over hourly and daily periods. These average output files are then meshed with corresponding weather data files. The graphical output from these combined data files for the following periods:

- October , 1989 through March ,1990
- April ,1990 through May 8,1990

are attached. Further in depth analysis using various techniques, such as principal component analysis, will be done in the future.

B.

Introduction

This report summarizes preliminary efforts to understand energy use at two Texas nursing homes. The nursing homes, Four Seasons Nursing Home in Temple and Four Seasons Nursing Home in Austin, are part of a chain of elderly care centers operated by Manor HealthCare Corporation.

In addition to these preliminary energy modeling efforts, a data acquisition system is scheduled to be installed at the Temple facility in the next month.

Building Description: Four Seasons Nursing Home, Temple, Texas

Four Seasons Nursing Home in Temple, Texas is a 100 bed facility that is currently about 80% occupied. Approximately 40 staff members are present during the day and about 20 during the night. The facility operates 24 hours per day, year round. Full food and laundry service are provided.

The single story, slab on grade building has an approximate floor area of 31,000 square feet. It was built in 1970. Exterior walls consist of an eight foot lower section and a four foot upper section (Figure 1). The lower wall section has a stone and concrete exterior, with no insulation. The upper section is uninsulated stucco. The upper section creates an overhang beginning directly above the windows and provides some shading. The windows are double grazed, gray glass and cover about 15% of gross wall area. The building has a flat roof with built-up roofing and six inches of fiberglass batt insulation (Figure 2). The long axis of the building runs east-west.

Space conditioning is provided by eight roof-top air conditioning units and six small heat pumps. Two of the roof-top units provide heat using electric resistance heaters and six of the units provide heat by burning natural gas. Direct expansion cooling is used by all units. No outside air is introduced into the building by the units, but the air circulation fans run continuously. All supply and return air is vented through ducts in the plenum area between the roof and suspended ceiling. Temperature is controlled by eight standard thermostats set at 72 F in the summer and 74 F in the winter with no night setback. Hot water is provided by three one hundred gallon, natural gas heated, hot water tanks.

Six 1/6 HP bathroom exhaust fans run continuously. A 2 HP exhaust/intake kitchen fan runs whenever the kitchen is in use.

The kitchen provides three meals per day, every day, and is generally in use from 6 AM to 8 PM. It is equipped with two soda machines, an ice maker, two refrigerators, two freezers, 5 plate warmers, a heated serving table, gas stove and oven, and a dish washing machine.

The laundry is operational seven days per week from 8 AM to 5 PM. It is equipped with two commercially sized washing machines and three commercially sized, gas heated, clothes dryers.

The primary source of light in the building is 40-watt fluorescent tube lamps. The client wings, lobby, and corridors are illuminated by four-lamp, unvented luminaries. The kitchen and laundry areas are illuminated by two-lamp unvented luminaries. The dining room is illuminated by chandeliers containing 25-watt incandescent bulbs.

Building Description: Four Seasons Nursing Home, Austin Texas.

The Austin facility is two stories tall and has a floor area of approximately 58,000 square feet. It was built in 1969. It operates 24 hours per day, year round, and provides laundry and meal service. The laundry is located in a separate building on the facility grounds.

The walls are brick facade with no insulation. The standard window has an area of 30 square feet with both fixed and operable sections of roughly equal area. The fixed section is single glazed, gray glass and the operable section is double glazed. Overhangs are provided only on the front, second story windows. The roof is flat, with built-up roofing and suspended ceilings.

Space conditioning is primarily provided by 16 roof-top air conditioning units. Some small window air conditioners and heat pumps supplement the cooling. All roof-top units provide heat using electric resistance heaters and cool with direct expansion cooling. Each roof-top unit has a manually controlled economizer that is closed shut in the winter and summer and open in the autumn and spring. Temperature is controlled by 16 Honeywell thermostats with night setback capability. The temperature is normally set at 78 F in the winter and 74 F in the summer with manual override. Hot water is provided for the main building by three gas heated, hot water tanks kept at 140 F, 140 F, and 180 F.

Ten 2.5 HP, bathroom exhaust fans run continuously. Air is exhausted from and introduced to the kitchen by a 3 HP fan which operates whenever the kitchen is in use.

The laundry is operated from 5 AM to 5 PM seven days per week and is housed in a separate building. Hot water for the laundry is provided by two gas heated, hot water heaters kept at 180 F. The laundry is equipped with three commercially sized washing machines and four commercially sized, gas heated dryers. The laundry has a separate electric meter from the main building.

Energy Use Analysis:

Energy use at the Temple facility has been analyzed using equipment inventories and name plate data, ASEAM computer simulation software, and the PRISM score-keeping method computer software. The results from each analysis are presented below.

Equipment Inventory Method: The energy used by end-use groups can be estimated from an inventory of energy using equipment and energy use data from manufacturer's specifications. These estimates should correspond with measured electricity demand and consumption. The average peak demand for the cooling season months May through September is 135 kw. The average electricity consumption during these months is 64,152 kwh per month. The table below details energy use estimates by end-use groups during the cooling season.

Equipment	Quantity	Rated Capacity (Btu/hr)	COP or PF*	Estimated Demand (kw)
Dining Room AC	1	90,000	2.3	11.5
200 Wing AC	1	90,000	2.3	11.5
300 Wing AC	1	90,000	2.3	11.5
400 Wing AC	1	90,000	2.3	11.5
500 Wing AC	1	120,000	2.3	15.3
Lobby AC	1	60,000	2.3	7.6
Kitchen AC	1	90,000	2.3	11.5
Laundry AC	1	48,000	2.3	6.1
				86.5
Clothes Dryers	3	115 V, 8 A	0.8	2.2
Washing Machine	1	208 V, 13 A	0.8	2.1
Washing Machine	1	208 V, 13 A	0.8	2.1
Freezers	2	208 V, 14.8 A	0.8	4.9
Refrigerators	2			4.0*
Plate Warmers	4	120 V, 7.5 A	1.0	3.6
Pellet Warmer	1	208 V, 13.5 A	1.0	2.8
Dish Washer	1	12 kw		12.0
				33.7
200 Wing Installed Lighting				6.1
300 Wing Installed Lighting				5.1
400 Wing Installed Lighting				4.0
500 Wing Installed Lighting				4.4
Lobby Installed Lighting				6.0
Dining Installed Lighting				3.7
Laundry & Kitchen Installed Lighting				1.0
				30.4

The total maximum demand estimated by summing the power required by individual pieces of equipment is 150.6 kw. This is 10 % greater than the measured average peak demand during cooling months of 135 kw. It is expected that demand calculated from an equipment inventory will be greater than measured demand since it is improbable that every piece of inventoried equipment is in use at the same time. Thus, the estimate of demand from an energy inventory appears close enough to provide some rough numbers about how energy is used by the nursing home.

Demand Breakdown By End-Use Function:

HVAC	57%
Kitchen & Laundry Functions	22%
Lighting	20%
	100%

Demand Breakdown By Building Zones:

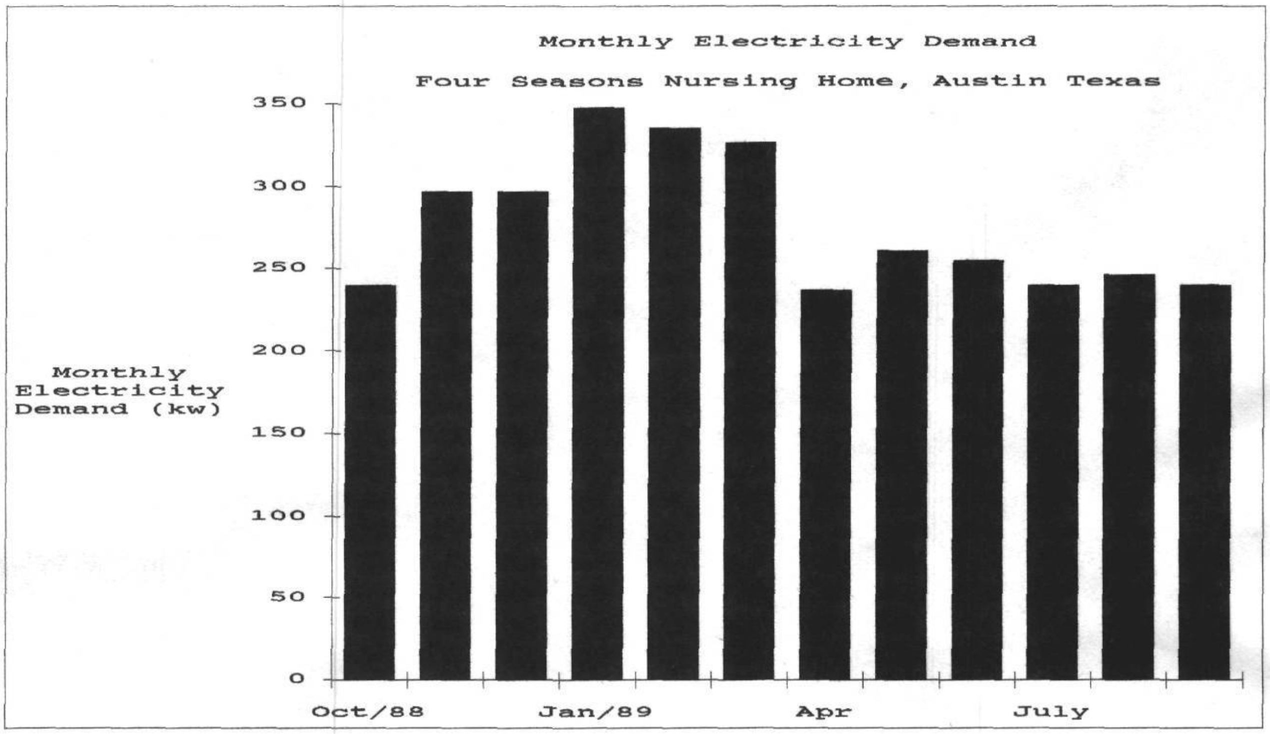
Resident Wings	46%
Lobby & Dining Room	19%
Kitchen & Laundry	34%
	100%

ASEAM Simulation: Energy consumption was simulated using A Simplified Energy Analysis Method (ASEAM) software which is based on the modified bin method of energy analysis. Predicted monthly energy consumption deviates from measured consumption by an average of 19% and shows similar seasonal variation. The ASEAM simulation estimates annual energy consumption to be divided between HVAC, kitchen and laundry equipment, and lights as:

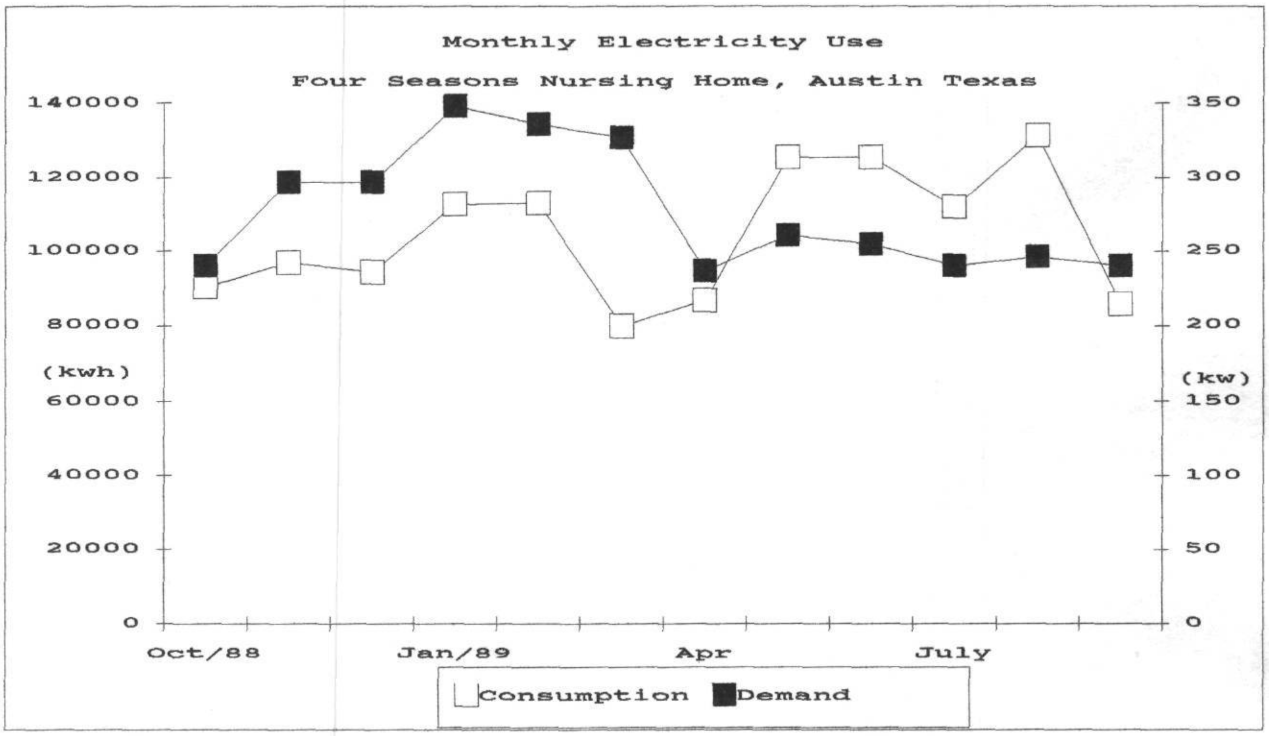
Consumption Breakdown By End-Use Function:

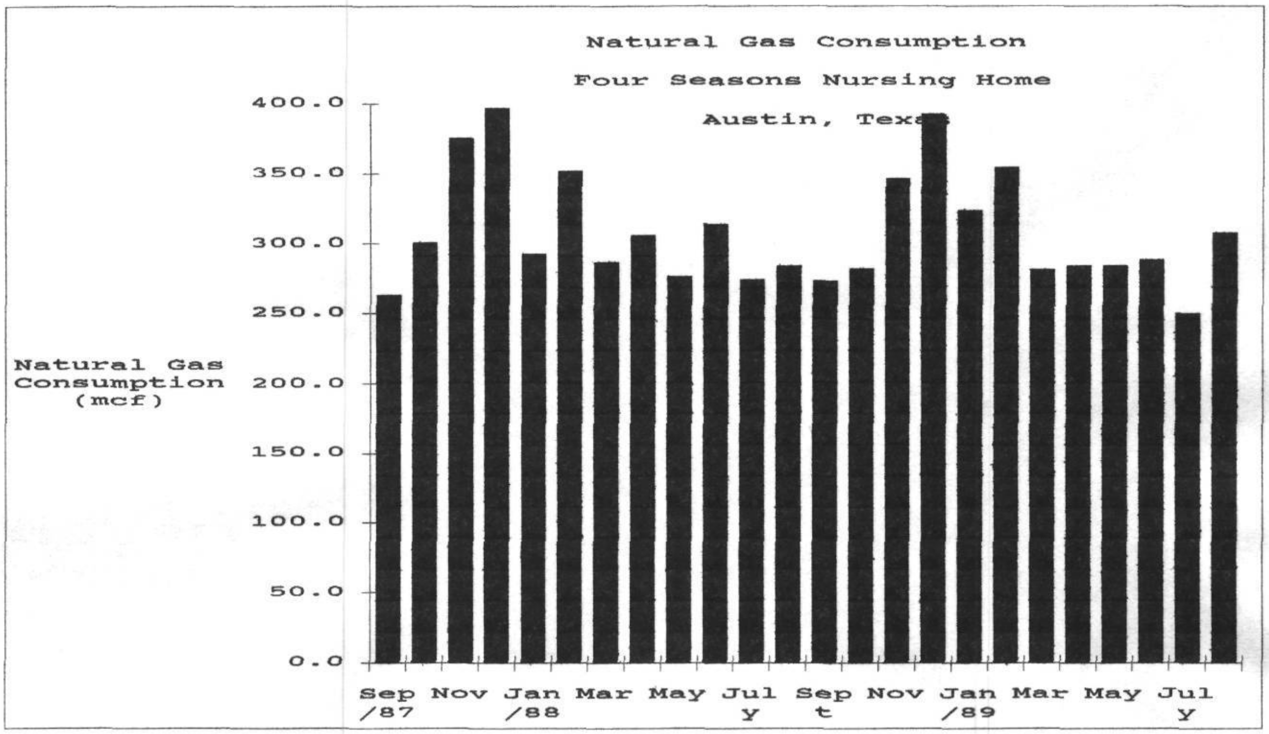
HVAC	50%
Kitchen & Laundry Functions	24%
Lighting	26%
	100%

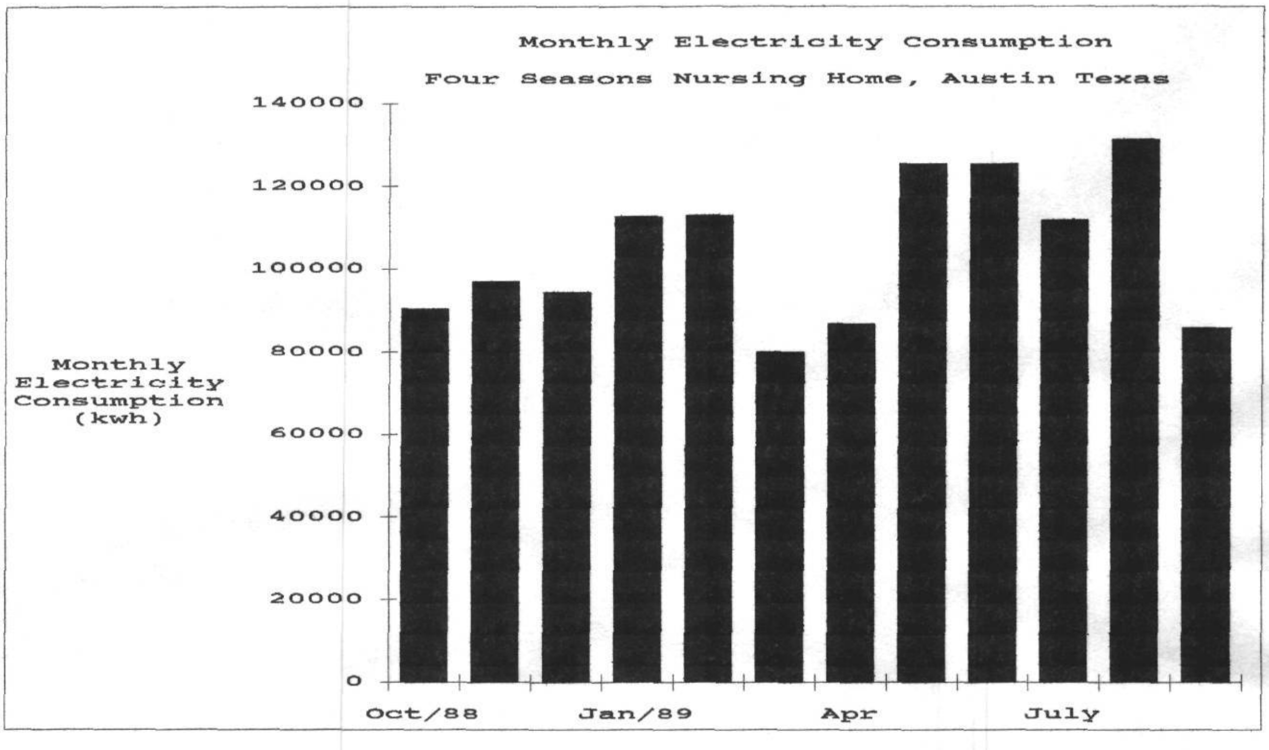
Prism Simulation: The Temple and Austin facilities were also modelled using Princeton Scorekeeping Method (PRISM) software. This software plots electricity consumption against cooling degree days and estimates a balance temperature for the building. The cooling only model appears to simulate energy consumption at both facilities very well as shown by a R square fit of .88 at Temple and .96 at Austin if heating months are removed from the data set. The cooling balance point is computed as 66.8 F at Temple and 74.2 F at Austin. Graphs of the electricity consumption verse cooling degree days are included.

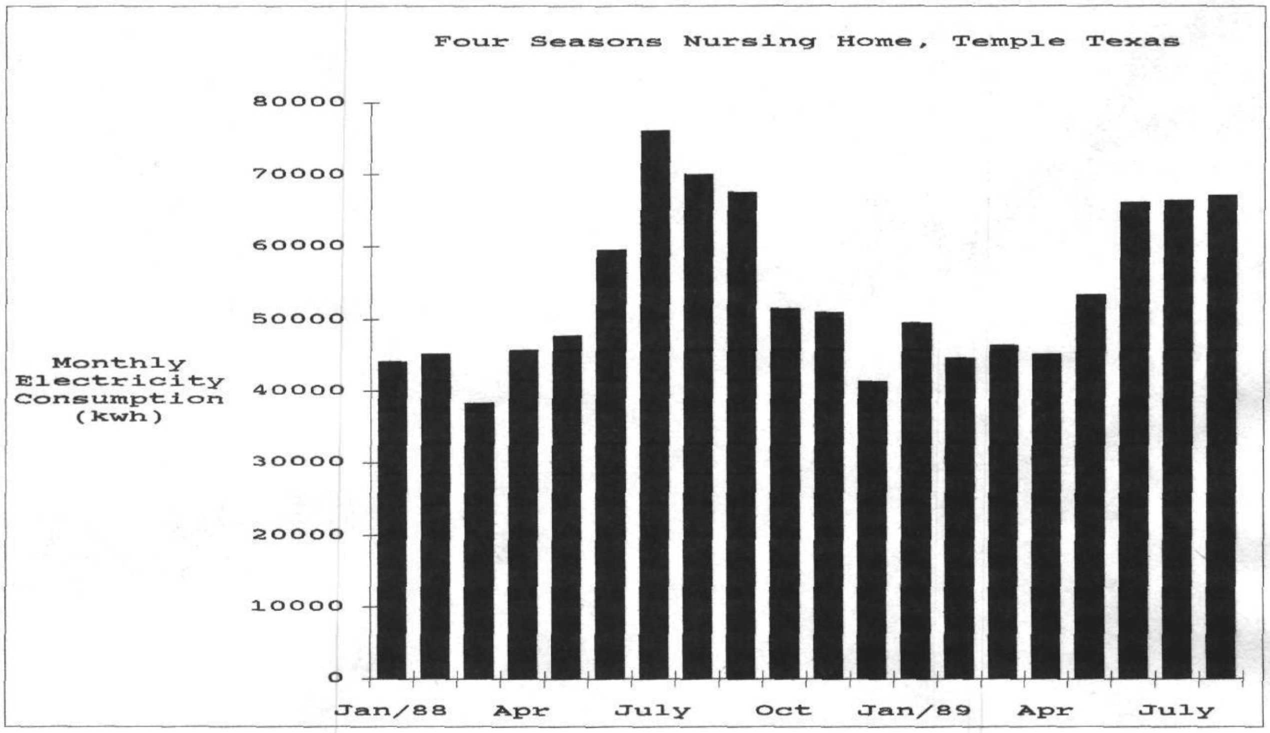


Monthly Electricity Demand
Four Seasons Nursing Home, Austin Texas
Monthly Electricity Demand (kw)
350
300
250
200
150
100
50
0
Oct/88
Jan/89
Apr
July

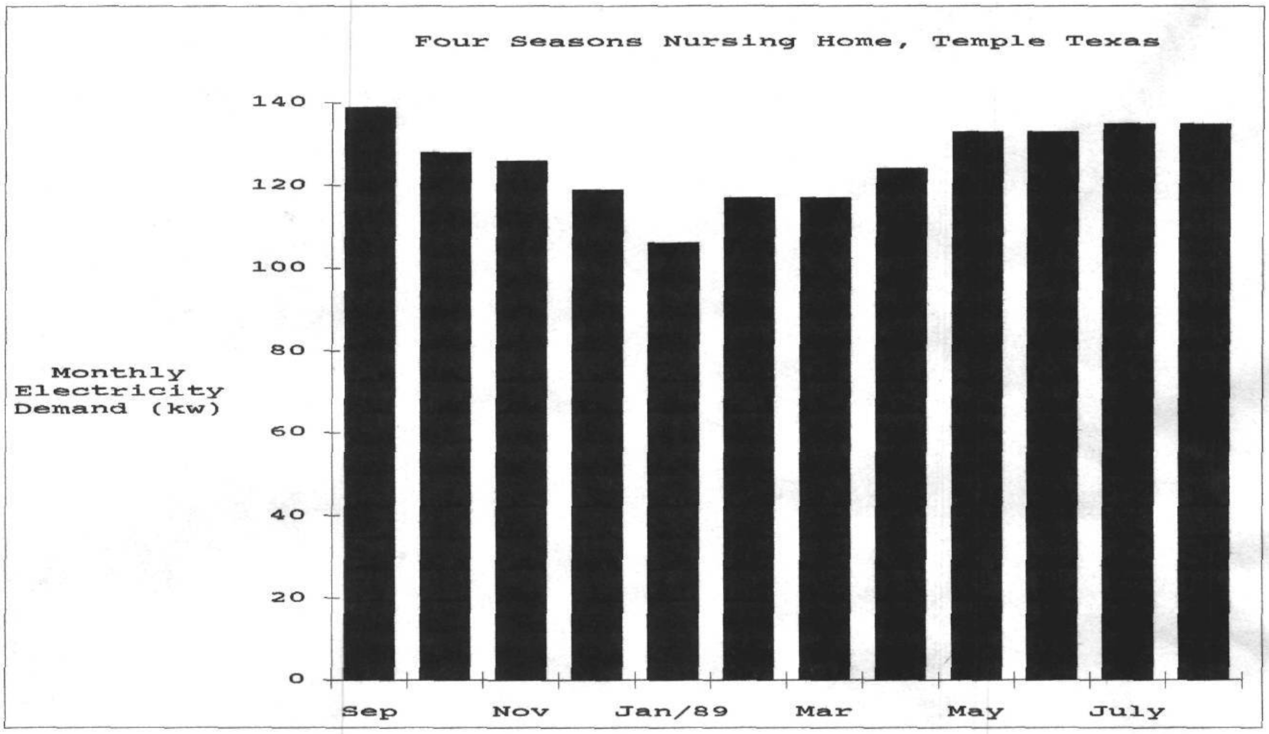

Monthly Electricity Use
Four Seasons Nursing Home, Austin Texas
140000
120000
100000
80000
(kwh)
60000
40000
20000
0
350
300
250
200
(kw)
150
100
50
0
Oct/88
Jan/89
Apr
July
Consumption
Demand


Natural Gas Consumption
Four Seasons Nursing Home
Austin, Texas
Natural Gas Consumption (mcf)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Sep /87
Nov
Jan /88
Mar
May
Jul y
Sep t
Nov
Jan /89
Mar
May
Jul y


Monthly Electricity Consumption
Four Seasons Nursing Home, Austin Texas
Monthly Electricity Consumption (kwh)
140000
120000
100000
80000
60000
40000
20000
0
Oct/88
Jan/89
Apr
July

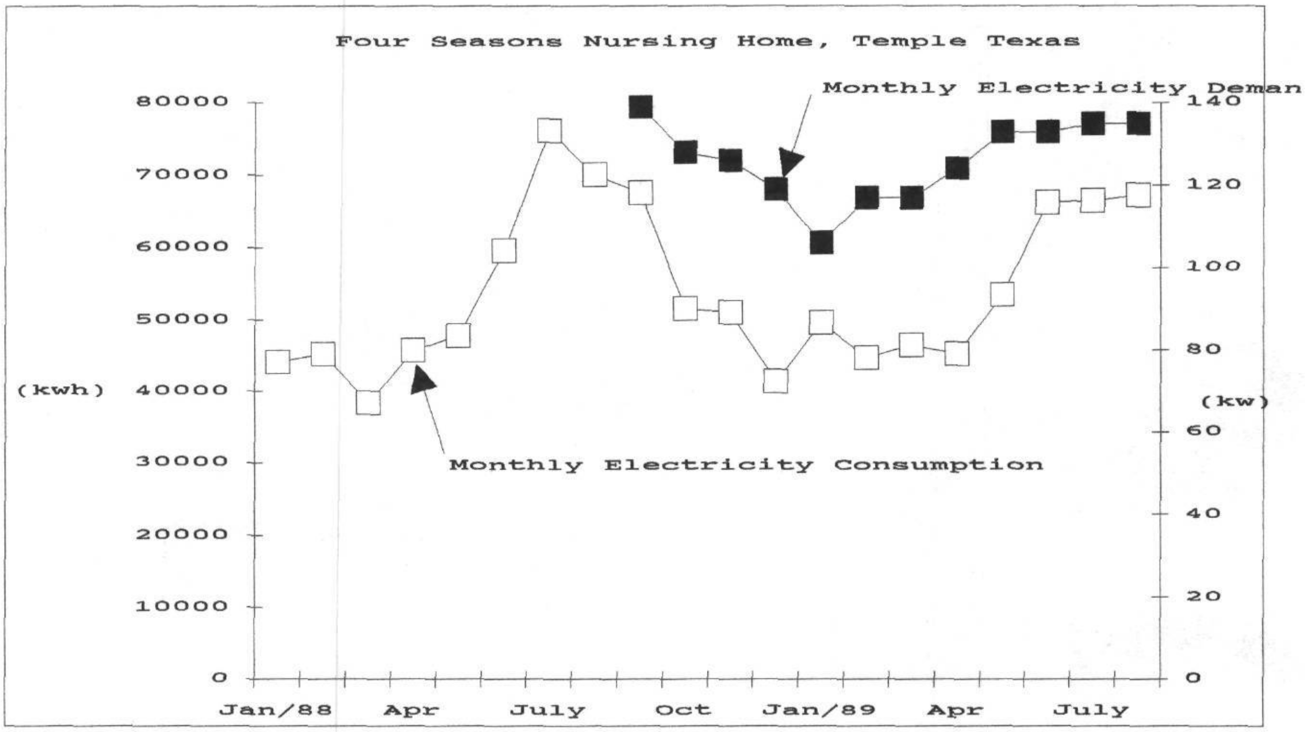


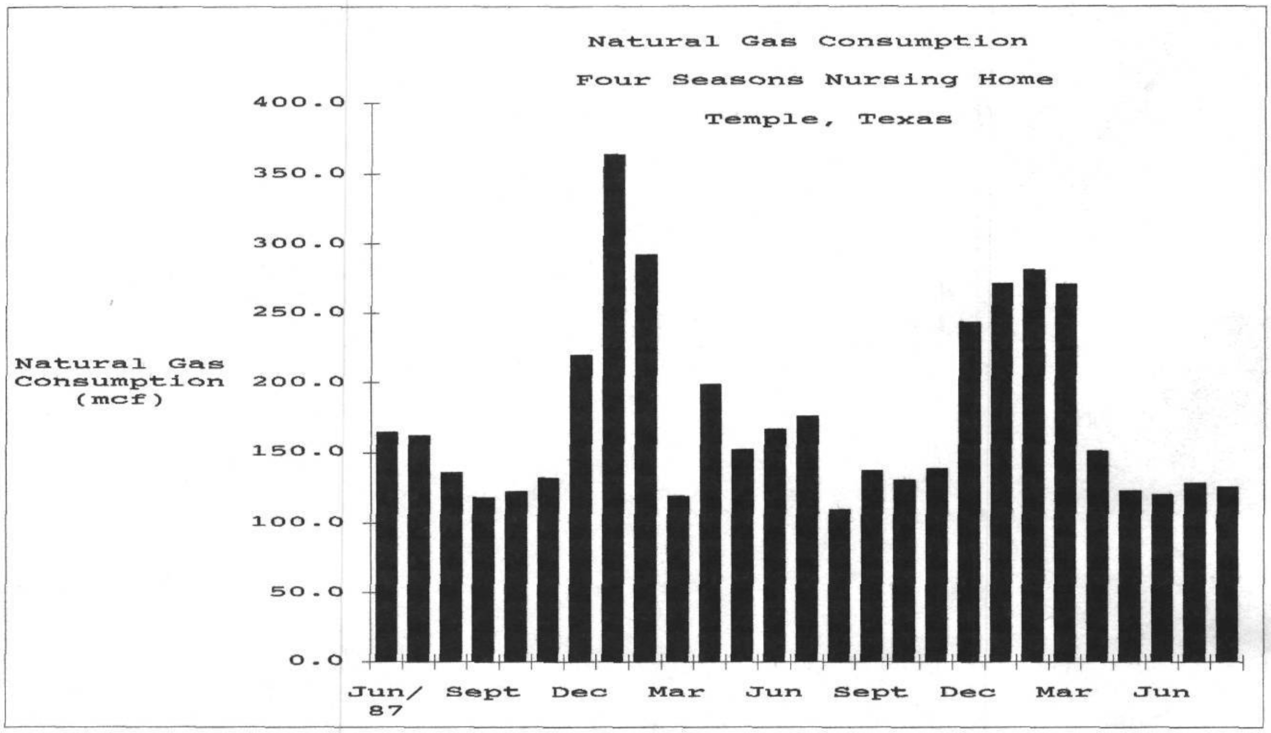
Avg All year = 53856
Avg May-Sept = 64152



Avg May-Sept = 135   Avg all year = 126

Avg


Four Seasons Nursing Home, Temple Texas
Monthly Electricity Deman
Monthly Electricity Consumption
(kwh)
(kw)
80000
70000
60000
50000
40000
30000
20000
10000
0
140
120
100
80
60
40
20
0
Jan/88
Apr
July
Oct
Jan/89
Apr
July



Natural Gas Consumption
Four Seasons Nursing Home
Temple, Texas
Natural Gas Consumption (mcf)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
Jun/ 87
Sept
Dec
Mar
Jun
Sept
Dec
Mar
Jun

******************** PRISM--Cooling Only (CO)****************************

ESTIMATION FOR HOUSE TEMPLE-FOURSEAS , PERIOD: FEB 28, 1988 TO AUG 31, 1989
PREPOST=PRE LABEL=CO UNITS=KWH

	REFERENCE TEMPERATURE	COOLING SLOPE	BASE LEVEL	NORM ANNUAL CONSUMPTION	R-SQUARE	NUM OF OBS
ESTIMATES:	66.79	54.0250	1262.0872	607250.0000	0.8880	14
(STD ERRS)	(5.13)	(9.9983)	(163.1399)	(21060.8359)		
(CV%)	(----)	(18.5%)	(12.9%)	(3.5%)		

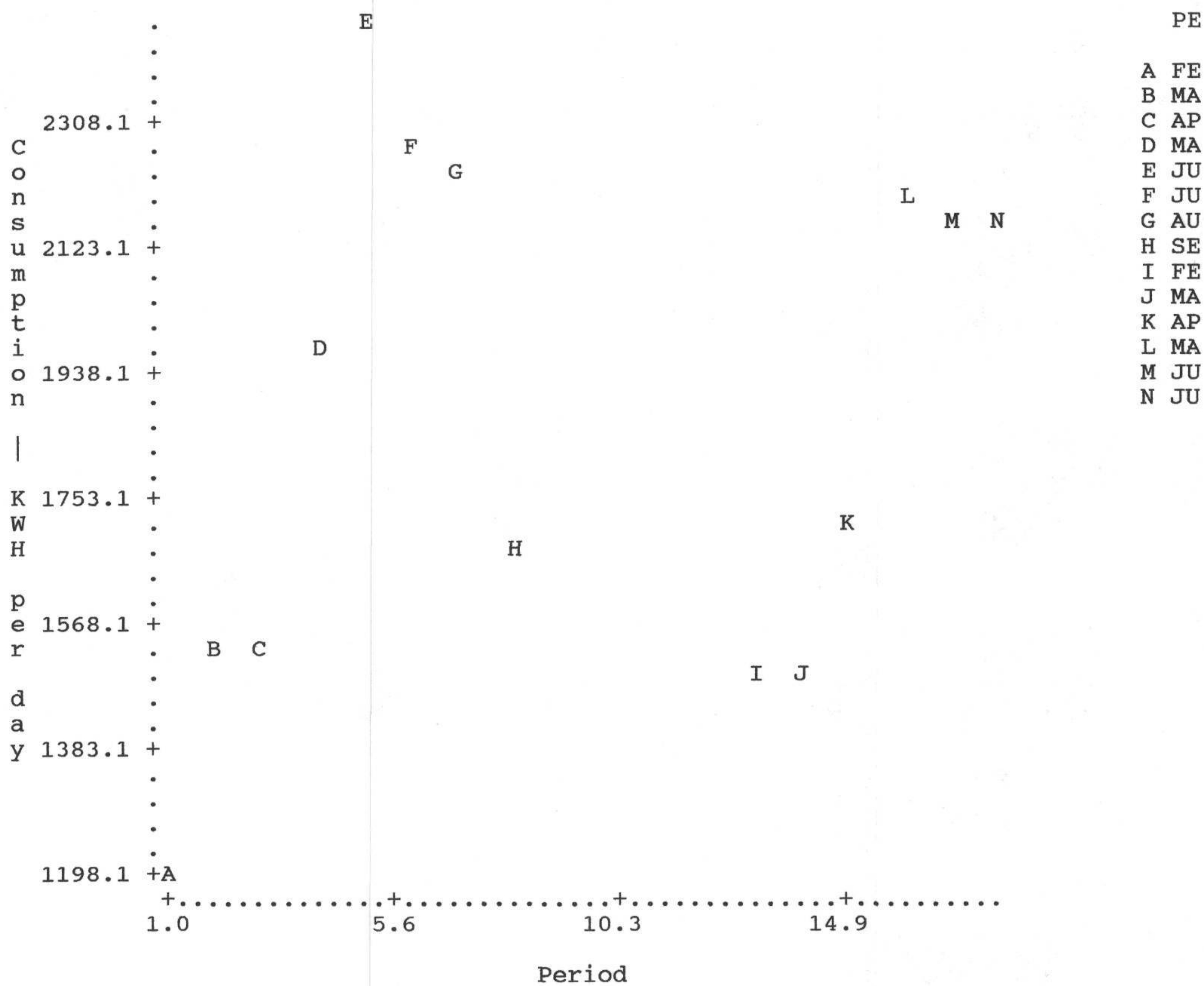
COOLING PART OF NAC: 146272.6719 (42130.2422) % OF NAC: 24.1
(CV%) (28.8%)

TECHNICAL CODES: J NUMBER OF ITERATIONS: 3

OCT
NOV
DEC
JAN
Removed FOR "CO" MODEL

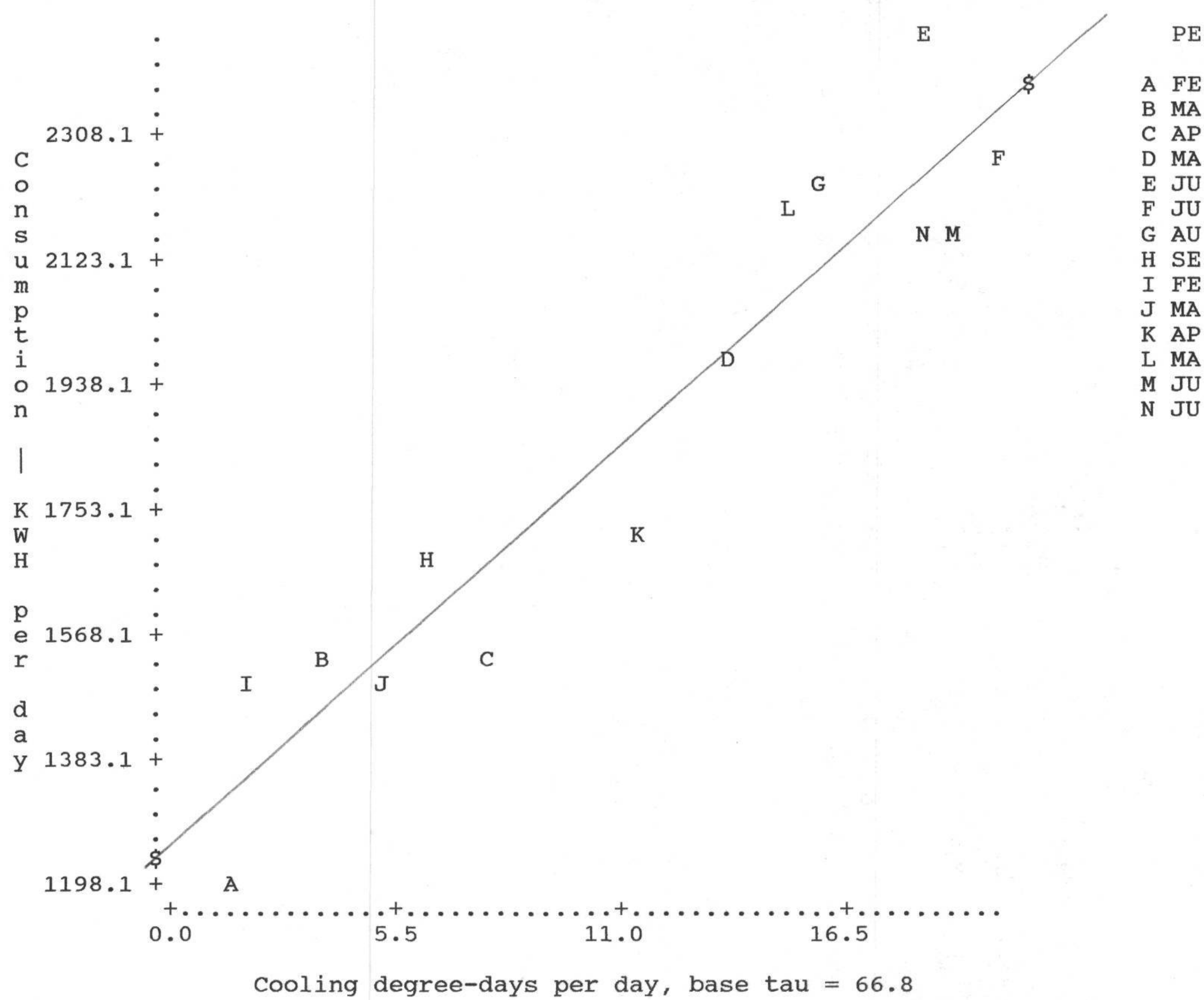
METER.TP2

House: TEMPLE-FOURSEAS PRE CO

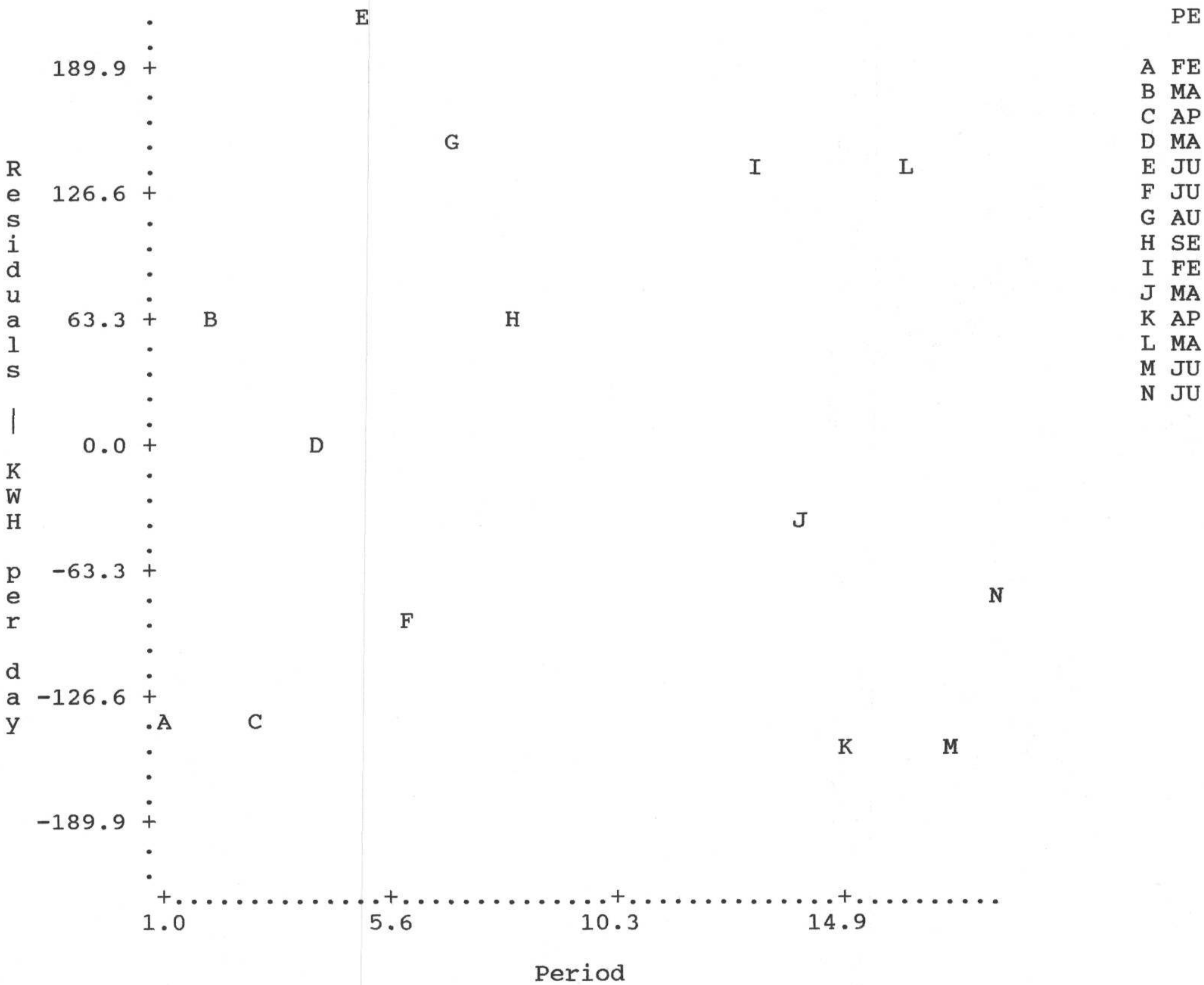


1

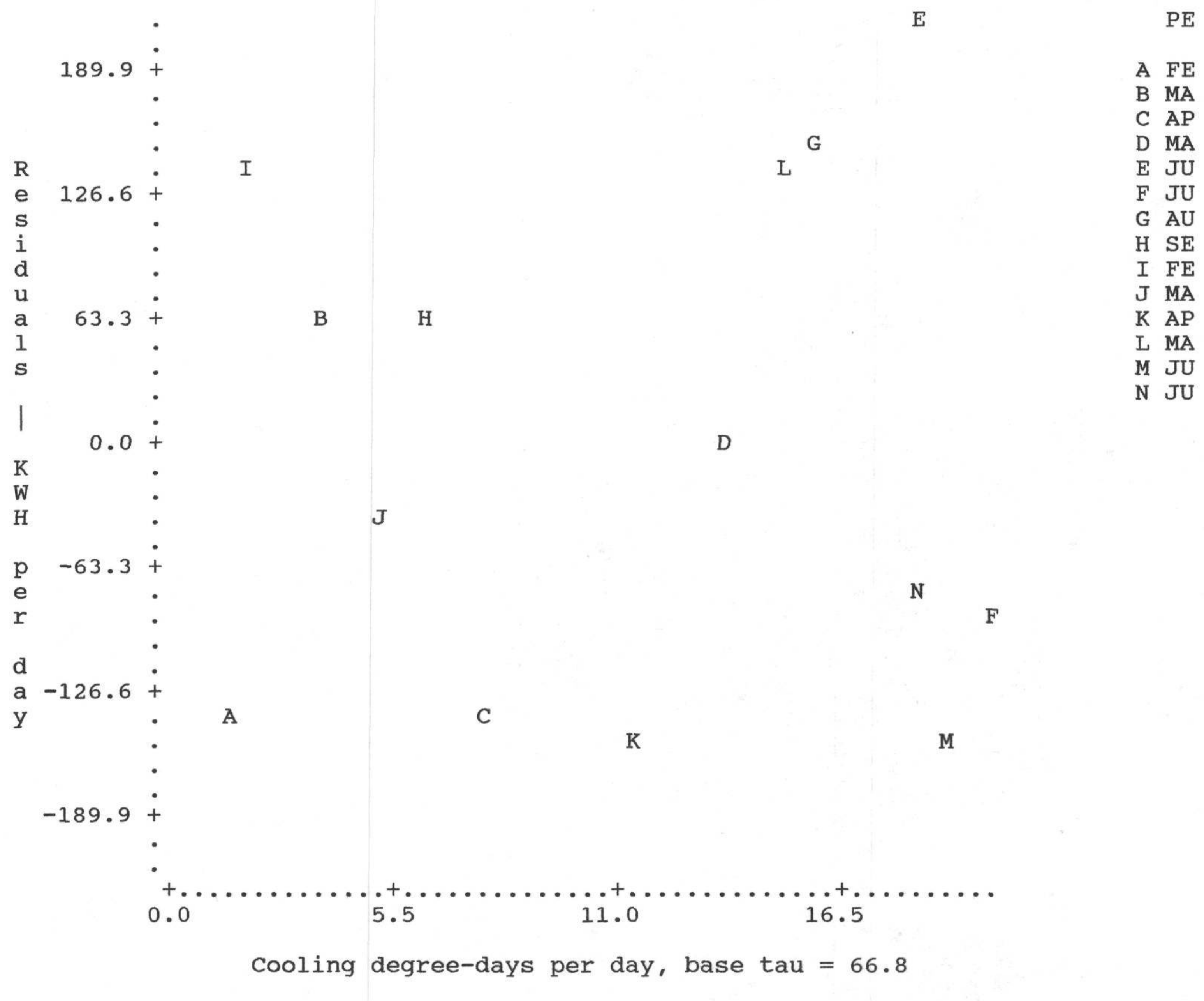
House:TEMPLE-FOURSEAS PRE ,alpha= 1262.09,beta= 54.02,R2= 0.8880



House: TEMPLE-FOURSEAS PRE CO



House: TEMPLE-FOURSEAS PRE CO

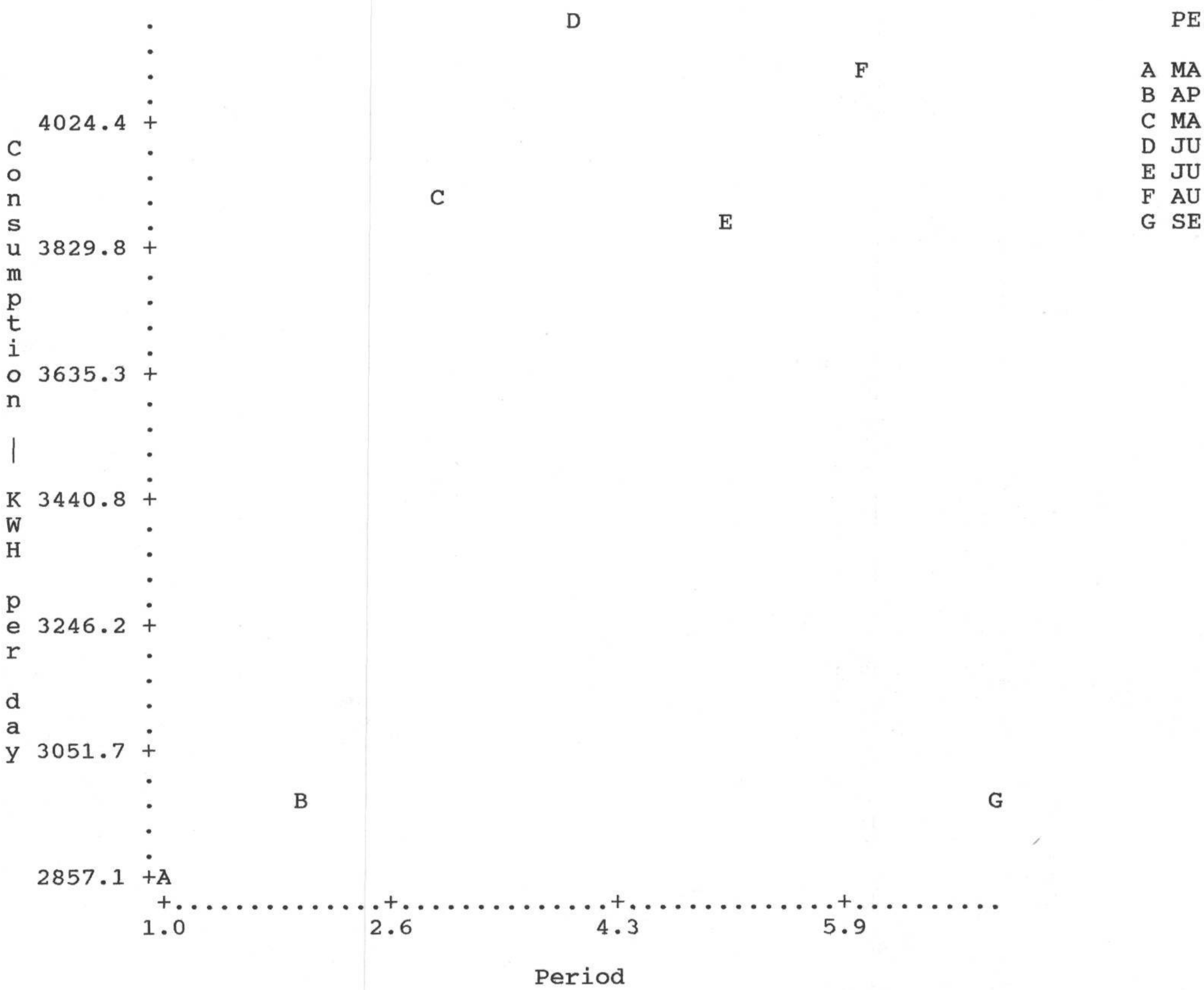


```
********************* PRISM--Cooling Only (CO)***************************

ESTIMATION FOR HOUSE AUSTIN-FOURSEAS , PERIOD: MAR 22, 1989 TO OCT 17, 1989
                     PREPOST=PRE LABEL=CO UNITS=KWH

           REFERENCE        COOLING    BASE       NORM ANNUAL   R-SQUARE   NUM
           TEMPERATURE      SLOPE      LEVEL      CONSUMPTION              OF OBS

 ESTIMATES:    74.17       125.8308 2762.1321   1172688.3750    0.9663     7
(STD ERRS)     (3.16)      (27.5006)(162.9856)   (29658.0137)
  (CV%)        (----)      (  21.9%)(     5.9%)   (         2.5%)

COOLING PART OF NAC:   163819.6250 (33309.6992)      % OF NAC:  14.0
  (CV%)                            (       20.3%)

TECHNICAL CODES:                NUMBER OF ITERATIONS:   5
```

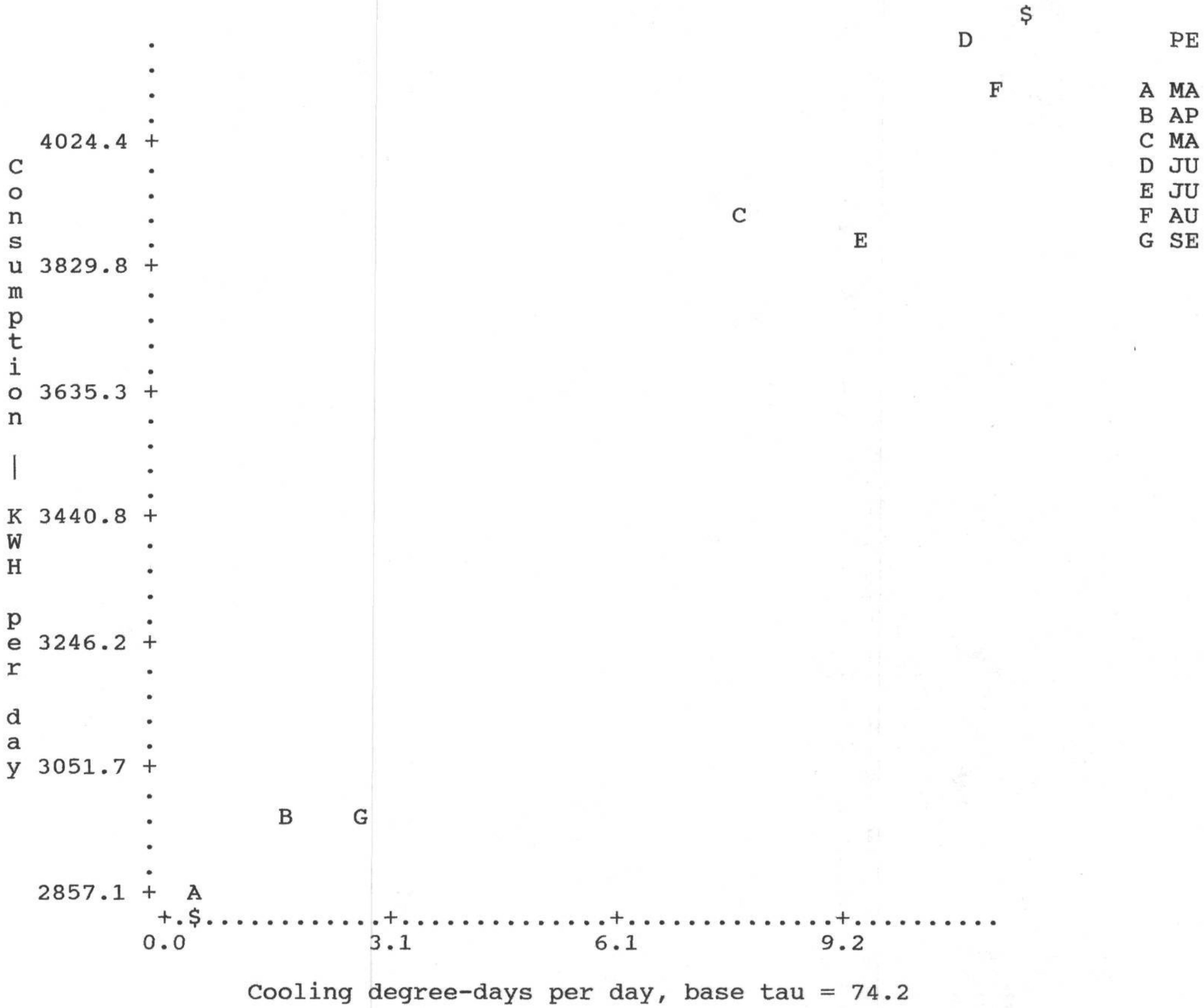
OCT
NOV
DEC
JAN
FEB
Removed for "CO" Model

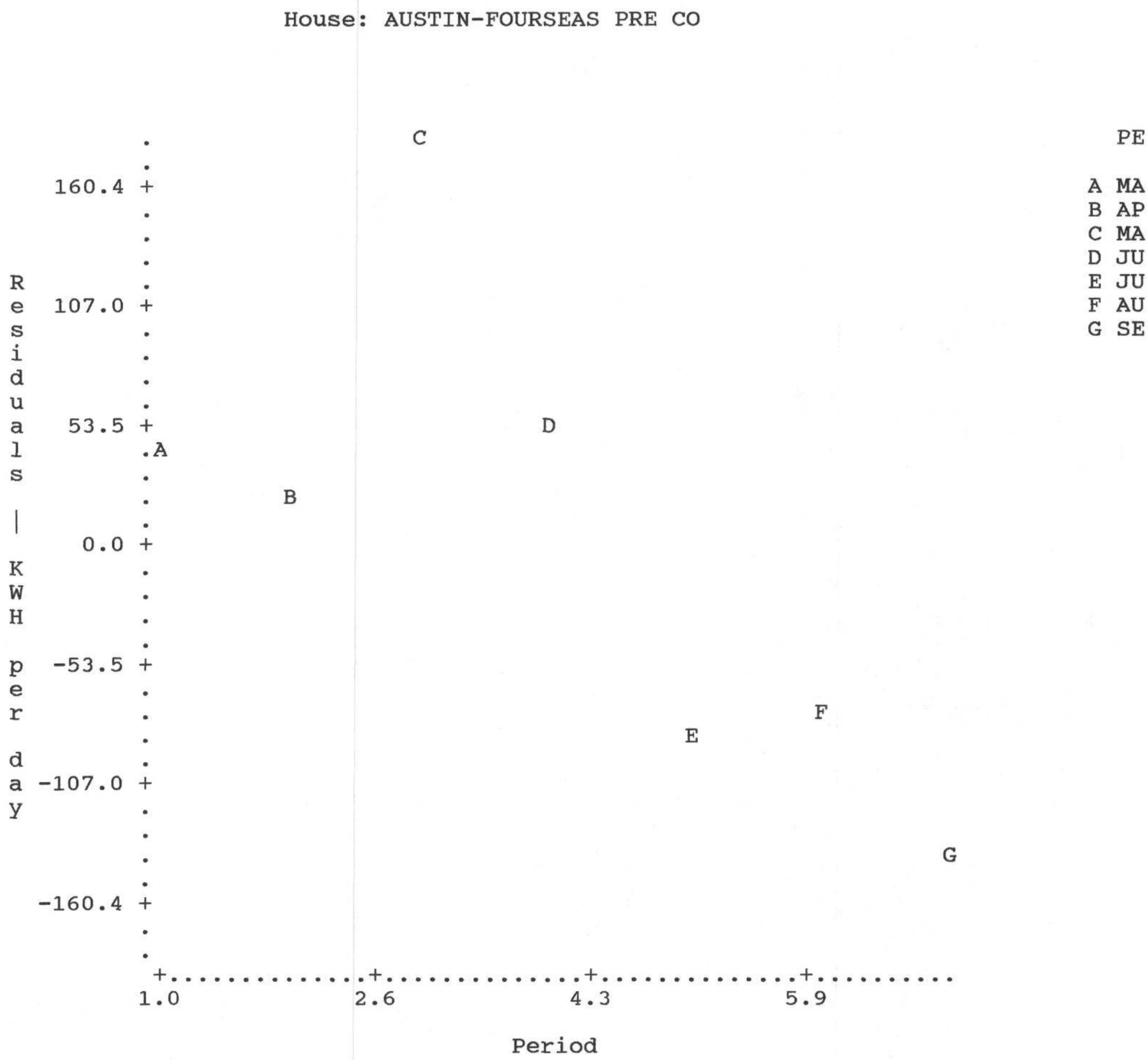
METER.AU3

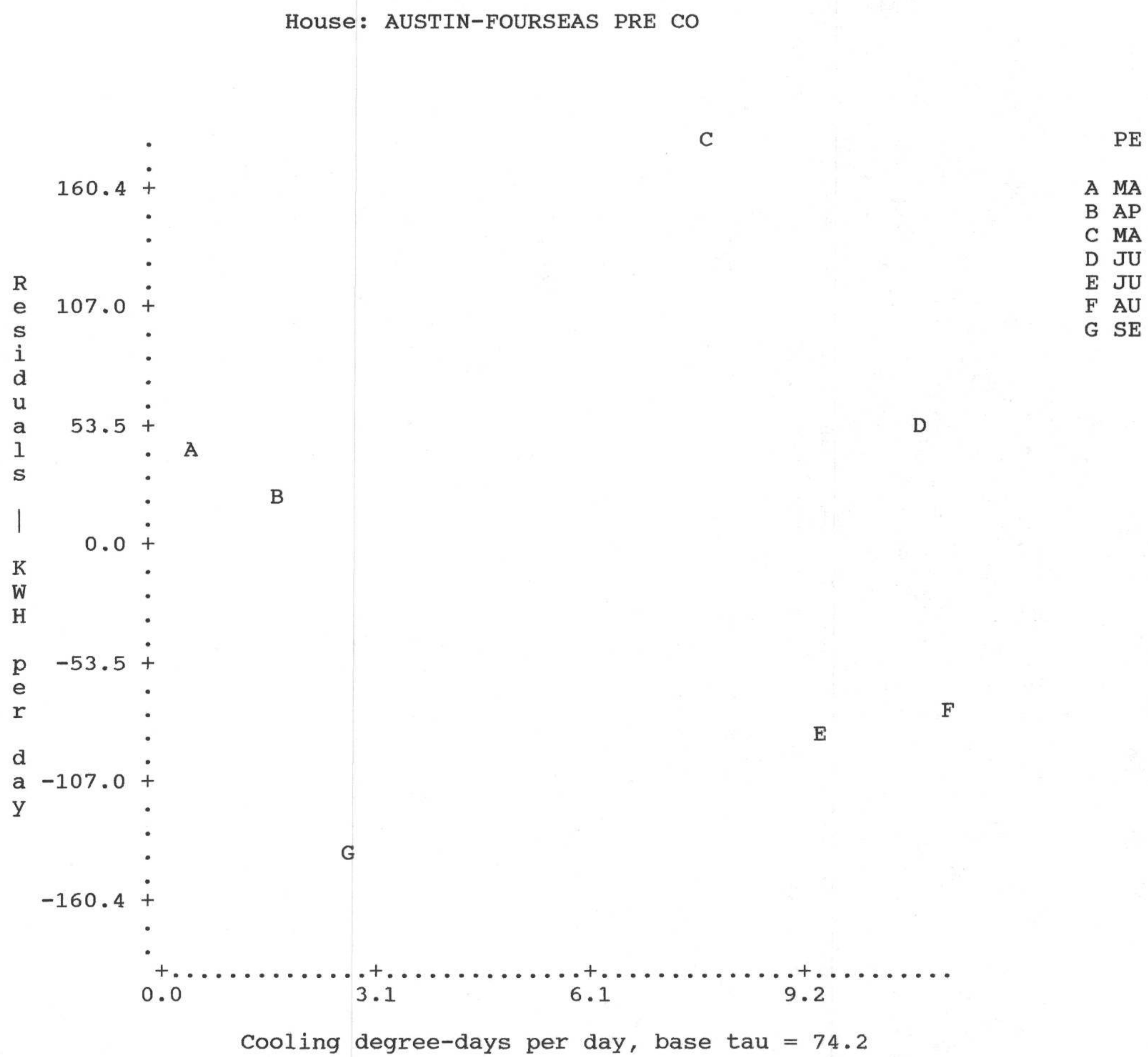
House: AUSTIN-FOURSEAS PRE CO



House:AUSTIN-FOURSEAS PRE ,alpha= 2762.13,beta= 125.83,R2= 0.9663




House: AUSTIN-FOURSEAS PRE CO
Residuals | KWH per day
160.4
107.0
53.5
0.0
-53.5
-107.0
-160.4
1.0
2.6
4.3
5.9
Period
A
B
C
D
E
F
G
PE
A MA
B AP
C MA
D JU
E JU
F AU
G SE


House: AUSTIN-FOURSEAS PRE CO
Residuals | KWH per day
160.4
107.0
53.5
0.0
-53.5
-107.0
-160.4
A
B
C
D
E
F
G
0.0
3.1
6.1
9.2
Cooling degree-days per day, base tau = 74.2
PE
A MA
B AP
C MA
D JU
E JU
F AU
G SE

C.

PREDICTING ELECTRICAL USE IN A SUPERMARKET

Derek W. Schrock
Graduate Student

David E. Claridge
Associate Professor

Energy Systems Laboratory
Mechanical Engineering Department
Texas A&M University
College Station, Texas 77843-3123

ABSTRACT

A change-point regression model for predicting the hourly and daily electrical use of a supermarket is described. The model predicts daily use within 2 percent for the data examined, except when abnormal use occurs. The model can identify high usage and is helpful in explaining and correcting the causes of excess consumption.

INTRODUCTION

Multiple linear regression of electrical and other energy consumption data from buildings has been used by several investigators to identify key parameters causing variation in use [1-4]. The models used in this paper, which differ from those used in previous studies, are change-point multiple regression models with different slopes for the heating and cooling regimes. The basic temperature dependence of the electrical consumption has been determined using daily consumption data from a single supermarket. The model is then used to predict the hourly consumption and the predicted consumption is compared with the metered consumption using residual analysis. The hourly residuals are examined and used to identify and help explain unnecessary consumption.

CASE STUDY BUILDING

The building data used to develop the model described in this paper was collected from a 40,000 square-foot supermarket located in College Station, Texas. The building is a rectangular (160 ft x 250 ft) single-story structure with 16 ft ceilings. The front 35,000 ft^2 is used for display and the rear 5,000 ft^2 is occupied by the space conditioning equipment, the walk-in coolers and the meat and product storage and preparation areas.

The store is located in a small shopping mall with eight other businesses. Customer parking is available in the front (with lighting provided by the store) and deliveries are generally made in the rear. The store shares party walls with other businesses on the northwest and southwest sides. However, the adjacent northwestern space is currently unconditioned. The walls are constructed of 6-inch poured concrete, 3.5 inches of interior batt insulation and interior drywall. The only glazing is a 60 ft by 16 ft section of glass on the southeast wall. The roof is constructed of a lightweight metal deck which supports a 1-1/2-inch layer of foam insulation, a 2-inch concrete slab and a built up roof covered with light colored aggregate.

The store has the electrical energy-using systems typical of a modern supermarket. The systems and their estimated contribution to peak electrical demand are: refrigeration cases and compressors (44.3%), air conditioning (24.6%), lighting (15.8%), food preparation (12.6%), point-of-sale registers (1.2%), and miscellaneous uses (1.5%). Almost all of the heating for the store is provided by heat reclaim from the refrigeration compressors. Natural gas is used for an oven in the bakery, supplemental heating in very cold weather, and for a 40 gallon hot water heater. The natural gas cost is less than two percent of the electricity cost for the store, so it has been ignored in the model reported here.

The store is open 24-hours per day and is closed only on Christmas and part of Thanksgiving day.

FACILITY ELECTRICAL CONSUMPTION AND DEMAND

Monthly electrical consumption and demand of the supermarket for August, 1988 through July, 1989 is shown in Figure 1. The consumption and demand both show weather (or season) dependence. A simple analysis of the data shown in the figure indicates that 16% of the consumption is weather dependent which basically corresponds to the air conditioning load, with a small part of the variation due to changing efficiency of the refrigeration system as a function of temperature. Demand varied by 129 KW (25%) throughout the year from 383 KW in February to 512 KW in September. The average demand was 445 KW and the average consumption was 258,381 kWh per month. Electricity cost $201,150 for the period with demand charges accounting for $48,096.

The variation follows a general seasonal pattern, but deviates by peaking in September while December seems too low and January too high. The September peak probably is related to the influx of customers at the beginning of the school year, while the December dip may reflect Christmas

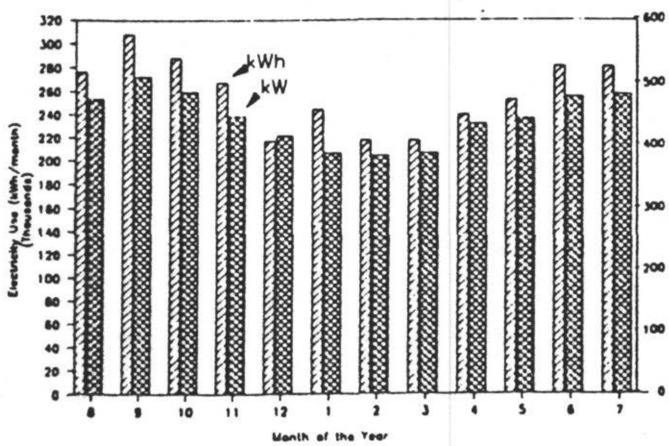


Figure 1 Monthly billed electric use (kWh) and demand (kW) for August 1988 through July 1989

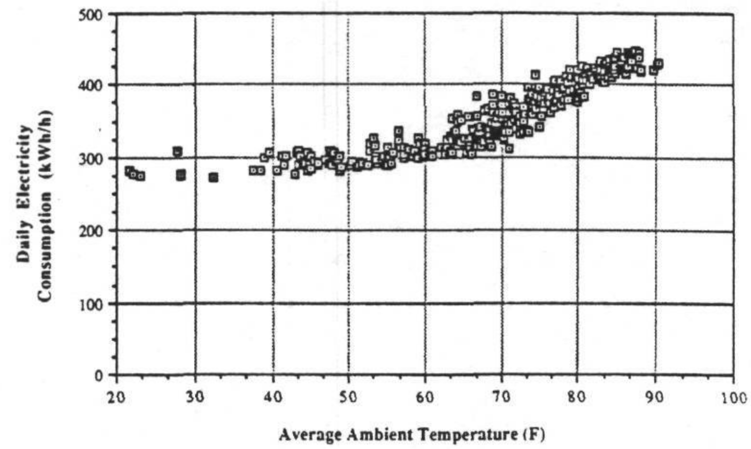


Figure 2 Average daily electricity use for March 1988 through April 1989

break and the closing of the store on Christmas Day.

ELECTRICAL CONSUMPTION ANALYSIS

Electrical consumption is recorded at 15-minute intervals and read weekly via modem by the local utility. The 15-minute data has been aggregated to provide hourly and daily total consumption for analysis. The average consumption for each day, expressed in kWh/h or KW is shown in Figure 2 as a function of average daily ambient temperature. There appear to be two essentially linear regions of the data which meet at 62 F (called the change point). Physically, the consumption appears to drop slowly with temperature (below 62 F) due to the increasing COP of the refrigeration compressors. As the temperature increases above 62 F, the COP of the compressors continues to drop, but air conditioning also becomes necessary, resulting in a sharp increase in the slope of the consumption.

Consequently, the data were divided into that collected when the ambient temperature (as recorded at the local airport) was above 62 F and that collected when the temperature was at or below 62 F. Each set was then regressed against the dry bulb temperature to obtain a unique slope and intercept.

This process resulted in a five parameter model for the daily average electric consumption: (1) slope for the heating regime, (2) intercept for the heating regime, (3) slope for the cooling regime, (4) intercept for the cooling regime, and (5) change-point temperature. Hence the daily average electric consumption, E_d, can be expressed as:

$$E_d = B_{0,h} + B_{1,h} * T_d \quad T_d <= 62 \text{ F}$$

$$E_d = B_{0,c} + B_{1,c} * T_d \quad T_d > 62 \text{ F}$$

where T_d is the average daily temperature, $B_{0,i}$ are the intercept coefficients and $B_{1,i}$ are the slope coefficients. The coefficients obtained are:

Region	B_0	B_1
Heating	256.878	0.868
Cooling	1.2449	4.976

The ability of the daily predictor model to estimate consumption is shown in Figure 3. The measured daily average consumption is shown for April 1 through April 29, 1989 by the asterisks near the top of the figure. The model prediction for each day is shown by the diamonds while the residual (measured minus predicted) consumption is shown by the line near the bottom of the figure. Excluding anomalies on April 4, 8 and 9 which will be discussed later, the average residual consumption is 8.6 kWh or 1.7% of the total.

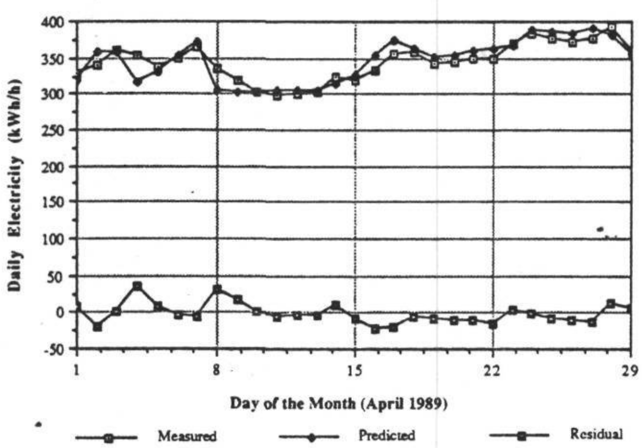


Figure 3 Measured, predicted and residual average daily electric use for April 1989

The hourly consumption data were regressed against temperature to develop an hourly predictor model, but effects of equipment cycling, thermal lags, etc. were quite pronounced. Consequently, the predictor equations above (based on daily data) were then used with hourly temperature data to predict hourly consumption. The hourly consumption and predictions can best be seen in three-dimensional plots.

The measured hourly electrical consumption for April 1 through 29, 1989 is shown in Figure 4. In general, it can be observed that

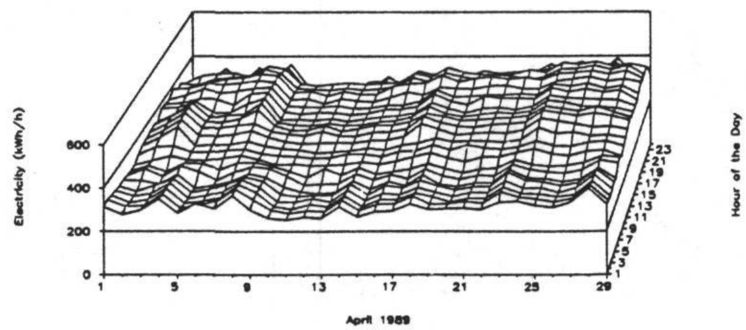


Figure 4 Surface plot of measured hourly electric use for April 1989

consumption is lowest during the early morning hours toward the front of the figure, peaking in the afternoon or evening. Figure 5 shows the predicted hourly consumption for the same period using temperature as the predictive variable. Here the consumption peaks more predictably during the afternoon. The period of relatively flat consumption during the second week of the month is even more evident, indicating several days of cloudy weather and near constant temperatures.

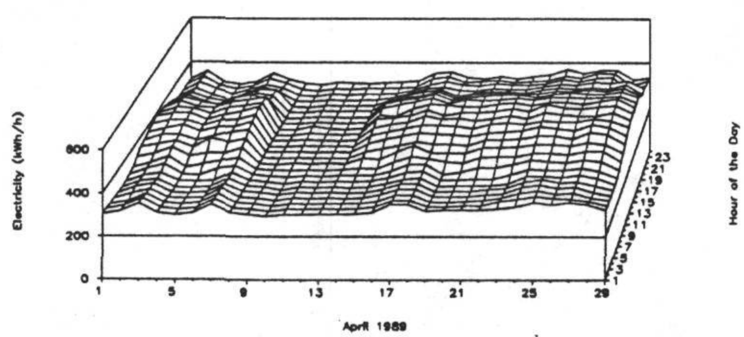


Figure 5 Predicted hourly electric use for April 1989

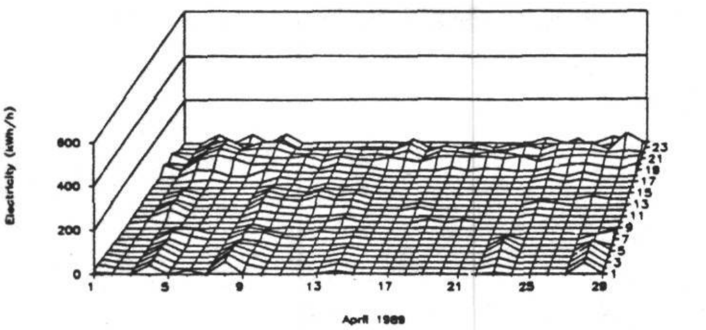


Figure 6 Residual hourly electric use for April 1989

The positive residuals (measured minus predicted use) are shown in Figure 6. Negative residuals have been suppressed since we are more interested in unusually high consumption. The figure shows that most of the occasions when consumption exceeds the model predictions occur during the early morning hours before 8 am or after 8 p.m.

Observation at the store and discussions with the manager indicated that approximately 30 KW of lighting is manually turned off in the store from approximately 11 p.m. until 7 a.m. The predictive model was modified to include this day/night switching. The positive residuals resulting when the model with switching is used are shown in Figure 7. They are now concentrated more heavily in the early morning and evening hours. Most of the early morning residuals (e.g. April 4,8,9,14,23, and 28 reflect occasions when the night manager forgot to turn off the lights as instructed. The late night residuals generally reflect defrosting of freezer cases (a non-weather effect not included in the model) and some excess lighting.

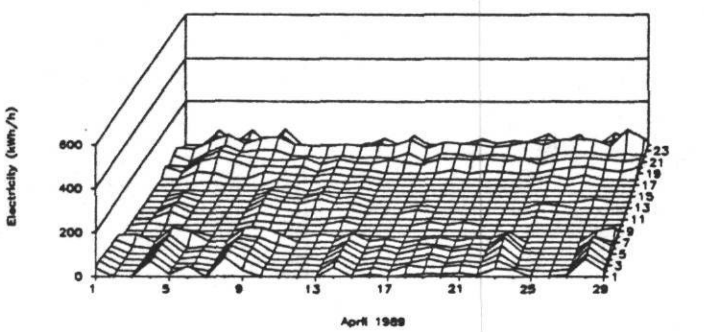


Figure 7 Residual hourly electric use for April 1989 for model with day/night switch

Further investigation showed that the defrost schedules for the freezer cases are not set to avoid contributing to peak demand since the technicians and store manager were unaware that defrost could add up to $712 per month to demand charges. For the 29 days shown in the plots, excess consumption identified due to failure to turn off lights as scheduled amounted to about $65.

SUMMARY

A change-point regression model for predicting daily and hourly electrical use in a supermarket which also incorporates daily scheduling information is described. Use of this model has identified potential monthly savings of $777 from minor scheduling changes.

ACKNOWLEDGEMENTS

Funding by the Energy Systems Laboratory Industrial Consortium at Texas A&M University and the Texas Higher Education Coordinating Board through ERAP is gratefully acknowledged. We also thank Jeff Haberl and the store engineering staff, managers and maintenance personnel for their cooperation and assistance.

REFERENCES

1. Claar, C., Mazzucchi, R. and Heidell, J. 1985. "The Project on Restaurant Energy Performance--End-Use Monitoring and Analysis", Pacific Northwest Lab. Rpt. PNL-5462, May.

2. Palmiter, L., and Hanford, J., 1986. "Relationship Between Electrical Loads and Ambient Temperature in Two Monitored Commercial Buildings", ASHRAE Trans., Part 1A, Vol. 92.

3. Leslie, N. Aveta, G., and Sliwinski, B., 1986. "Regression Based Process Energy Analysis System", ASHRAE Trans., Part 1A, Vol. 92.

4. Haberl, J. and Claridge, D., 1987. "An Expert System for Building Energy Consumption Analysis: Prototype Results", ASHRAE Trans., Pt 1, Vol. 93.

D,

SUMMARY OF THE PCA FOR DATA 06/19/89--0619/90

There are 366 points total. 214 points are above 62F. 104 points are below 62F. There are also 48 bad points(-99 values).

****

For PCA for the above 62F, the principal components are

$$P1 = 0.673953*Z1+0.557052*Z2+0.485264*Z3 \quad (1)$$
$$P2 = -0.038158*Z1-0.629725*Z2+0.775880*Z3 \quad (2)$$
$$P3 = -0.737788*Z1+0.541424*Z2+0.403149*Z3 \quad (3)$$

where

Z1, Z2, Z3 are the normalized original variables.

The prediction model is

$$\begin{aligned} Yp &= 9223.77+547.41*P1-11.28*P2-333.18*P3 \\ &= 9223.77+614.90*Z1+131.65*Z2+122.57*Z3 \\ &= 2552.80+77.75*temp+19918.15*hmdty+1.56*solar \quad (4) \end{aligned}$$

The R-square for eq(4) is 0.8366, adjusted R-square 0.8343.

The first component explains 63.25% of the total variances.
The second component explains 28.36% of the total variances.
The third component explains the rest (8.39%) of the total variances.

If drop out the third component, the prediction model eq(4) becomes

$$\begin{aligned} Yp &= 9223.79+547.42*P1-11.29*P2 \\ &= 9223.79+369.37*Z1+312.05*Z2+256.883*Z3 \\ &= 4179.05+46.70*temp+47216.07*hmdty+3.27*solar \quad (5) \end{aligned}$$

The R-square for eq(5) is 0.7975, the adjusted R-square is 0.7955.

By using conventional regression, the prediction model is

$$\begin{aligned} Yp &= 9223.77+615.18*Z1+131.65*Z2+122.57*Z3 \\ &= 2550.05+77.72*temp+19918.15*hmdty+1.56*solar \quad (6) \end{aligned}$$

The R-square for eq(6) is 0.8366, adjusted R-square 0.8343.

****

For PCA for the below 62F, the principal components are

$$P1 = 0.604429*Z1+0.734548*Z2-0.308391*Z3 \quad (7)$$
$$P2 = 0.531690*Z1-0.083668*Z2+0.842796*Z3 \quad (8)$$
$$P3 = -0.593271*Z1+0.673379*Z2+0.441123*Z3 \quad (9)$$

The prediction model is

$$\begin{aligned} Yp &= 7332.52+198.12*P1+142.39*P2-7.36*P3 \\ &= 7332.52+199.82*Z1+128.66*Z2+55.66*Z3 \\ &= 6016.43+20.45*temp+42501.32*hmdty+0.77*solar \quad (10) \end{aligned}$$

The R-square for eq(10) is 0.4819, adjusted R-square 0.4664.

The first component explains 54.48% of the total variances.
The second component explains 37.41% of the total variances.
The last component explains the rest (8.11%) of the total variances.

If drop out the third component, the prediction model eq(10) becomes

$$\begin{aligned} Yp &= 7332.52+198.12*P1+142.39*P2 \\ &= 7332.52+194.82*Z1+133.62*Z2+58.91*Z3 \\ &= 6028.77+19.94*temp+44139.80*hmdty+0.82*solar \quad (11) \end{aligned}$$

The R-square for eq(11) is 0.4819, adjusted R-square 0.4716.

using conventional regression, the prediction model is

$$\begin{aligned} Yp &= 7332.52+199.82*Z1+128.66*Z2+55.67*Z3 \\ &= 6016.43+20.45*temp+42501.32*hmdty+0.77*solar \quad (12) \end{aligned}$$

The R-square for eq(12) is 0.4819, adjusted R-square 0.4664.

Texas LoanSTAR Monitoring and Analysis Program

Network Concept and Implementation

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:

Dean Willis
Emily Hogg
Jeff Haberl

Energy Systems Laboratory
Mechanical Engineering
Texas A&M University
College Station, Texas

July 1990

The LoanSTAR MAP Net

General Concept

A local area computer network has been established to handle the data acquisition, archiving, computational, word processing and graphics needs of the LoanSTAR Monitoring and Analysis Program (MAP). Based on a high-performance Data General UNIX server and industry-standard Ethernet cabling, the network includes both UNIX workstations/terminals and personal computers. A general layout of the MAP Net is shown in Figure 1. The units denoted by IK have been provided to the network by other projects at A&M.

The design of the MAP Net is complicated by the wide range of tasks to be performed. The functional requirements for the network include a diverse mixture of engineering, communication, and office automation tasks, including but not limited to:

1) Collection of data from remote (field) data recorder units.
2) Storage and retrieval of collected building energy data.
3) Statistical and mathematical analysis of collected data.
4) Preparation of reports, documents, and other written communications.
5) Preparation of presentation graphics and analytical graphs.
6) Electronic messaging and file transfer, including remote sites.
7) Support for collaborative work and shared information.
8) Secure backup of collected data and other critical files.

Furthermore, environmental needs, economic issues, and anticipated growth requirements imposed additional selection criteria:

1) Connectivity to existing university TCP/IP Ethernet network.
2) Support for Internet-style electronic mail.
3) Effectively unlimited growth potential -- many gigabytes of data.
4) Connectivity with existing TAMU systems, including PCs and VAX minicomputers.

In order to meet these criteria, the Energy Systems Lab staff solicited input from academia, industry, and other sources including the MARC and systems vendors. The resulting network computer system combines traditional PC-DOS based personal computers with advanced UNIX based engineering workstations through the use of industry-standard software and networking protocols.

Personal Computers

The current LoanSTAR MAP Net includes twenty-four IBM-compatible personal computers, not including shop-floor systems at the ESL main lab. These systems range from original XT-class machines to high speed models using the 80386 processor. All systems currently operate under MS-DOS, many with the Microsoft Windows graphical user interface. There are four major classes of units on the MAP Net:

1) Analysis and Development Systems:
   - 80386SX or 80386 CPUs at 16 to 25 Mhz.
   - 4Mb of R.A.M.
   - 40-100Mb disk
   - Extended VGA color graphics

2) General Analysis and Student Systems:
   - 80286, 80386 or 80386sx CPUs at 8 to 16 Mhz.
   - 1 to 4Mb of R.A.M.
   - 40-80Mb disk
   - Assorted graphics, including EGA and VGA

3) Administrative and Secretarial Systems:
   - 80386sx at 16 Mhz.
   - 2Mb of R.A.M.
   - 40 Mb disk
   - Paper-white VGA monochrome graphics

4) Polling and Test Bench Systems:
   - 8086 or 8088 at 7 to 8 Mhz.
   - 640Kb R.A.M.
   - 20Mb disk

UNIX SYSTEM

The system installed uses a Data General AV-4000 UNIX server with 16 Mb of dynamic R.A.M., a 662 Mb SCSI hard disk and a 150 Mb cartridge tape (which can be used for backup). Currently, the system can support two directly connected users and several dozen network connected users. Up to 512 concurrently processes can be active at one time on the server, with additional processes running at each workstation.

In addition to the UNIX server on the system, the MAP Net includes two Data General AV-300 workstations, two Data General AV-30x terminals, and one DG D216+ simple terminal used as the operator's console for the AV-4000. The AV-300 workstations and AV-30x terminals use the OSF/Motif graphical user interface running in conjunction with MIT's X Window System. Each AV-300 contains its own RISC central processing unit (a Motorola 88100) as well as 8Mb of local memory.

ADDITIONAL CAMPUS SYSTEMS

Texas A&M maintains a large number of mainframe and minicomputers, as well as workstations and personal computers, which are available for research and academic purposes. Connectivity to the TAMU systems is provided via the campus network. Two of these university systems are being used to a significant extent by the MAP project. THOR, a VAX cluster centered on an 8650 is used for BITNET mail, TeX typesetting, DOE-2 runs and large FORTRAN systems. AIM, an HP-9000 UNIX cluster containing model 835 and model 825 processors, is used for large SAS applications. Both systems are maintained by TAMU Academic Computing Services and are available on a chargeback basis financed by the ESL. A Cray Y-MP supercomputer is available for future computationally intensive tasks.

PRINTING FACILITIES

The network currently includes nineteen assorted printers. Specifically, four laser printers, six Hewlett-Packard Deskjet+ printers, a portable ink-jet printer (for use at remote sites) and eight assorted impact printers are attached.. Several of the printers are connected to printer-sharing devices, allowing them to be accessed by multiple users. One laser printer, a Texas Instruments model 2108, is connected directly to the AV-4000 server and can be accessed from all Ethernet-connected network nodes.

FUNCTIONS

The MAP Net is connected using the 10 Mbps campus Ethernet. Network routing facilities provided by TAMU provide for connection to the defense/academic Internet via the Texas Sesquicentennial Network (Sesquinet). Sesquinet is provided by a joint effort of Rice University and the National Science Foundation. Electronic mail and file transfer are operational, and allow communication with Internet and Usenet sites worldwide. Standard telephone lines provide dial-out access for polling of data recorders.

The system is currently used for polling remote data acquisition units, data storage, software development, word processing, advanced graphics, numerical analysis and administrative support.

SOFTWARE

Much of the functionality of any computer system is provided by the software programs which drive the hardware to do useful work. Some of the software, and associated functions, include:

File Transfer:

File transfer over Ethernet is via TCP/IP using the FTP program. FTP is built into DG/UX. FTP and Telnet (remote terminal emulation) for PCs are provided at no charge by the National Center for Supercomputing Activities (NCSA). File transfer over modem lines is via Kermit, which is provided at no charge by Columbia University.

Electronic Mail:

Internet-style electronic mail is provided by the Data General systems. PCs access mail by logging into the server. Electronic mail can be exchanged with approximately 30 million users at ten million sites worldwide.

Data Storage:

Collected data from monitored sites is transmitted from PCs via FTP to the AV-4000, where it is available in its entirety for on-line retrieval and/or analysis.

Software Development:

DG systems currently support development in C, assembly, and awk.
PCs provide C, C++, awk, Pascal, FORTRAN, assembly, and SAS.

Word Processing:

DG systems support word processing using nroff, troff, and Framemaker.
PCs support Word 5.0, Windows Word 1.0, and some WordPerfect 5.1 users.

Advanced Graphics:

Graphical presentation of data in 2 and/or 3 dimensions is on the PCs using SAS, Golden Software's Grapher and Surfer packages, Intex Solutions, Excel, Lotus 1-2-3, Quatro Pro, and Freelance.

SAS (running on AIM) provides graphical presentation for DG.

Numerical Analysis:

Worksheet numerical analysis is being done on PCs using Excel, Quatro Pro, and Lotus 1-2-3. Statistical and mathematical analyses are being performed with SAS and PRISM. Specialized tools such as change point analysis are being developed in-house for both PC and UNIX systems.

Administrative Support:

Borland's Reflex database is used for list and inventory management. We also have specialized software for processing official forms.

Specialized Data Analysis:

Many specialized tools are being used for data analysis tasks, including Voyager, Archive, Tony's Tools, Art's Tools, awk, L, and micropage.

FUTURE PLANS

As the number of remote sites providing data rapidly increases in coming months, additional capability will be required. Planned expansion includes the following:

662 Mb additional server storage.
16 Mb additional server R.A.M.
R.A.M., disk and tape additions to workstations.
Four to six additional PCs.
Automated polling cluster, either PC or server based.
Relational (or object-oriented) database system.
SAS statistical analysis software on Data General.
X terminal capability for network-attached PCs.

The configuration of the 1990-1991 MAP Net is shown in Figure 2. As outlined, the major changes will be additional memory and disk space to handle the greatly increased data acquisition function and analysis, additional software, and additional PCs, primarily to increase computer availability for the graduate students and staff working on the project.

Figure 1: The Texas LoanSTAR MAP Net (1989/90)

This figure illustrates the current configuration of the Texas LoanSTAR MAP Net. The MAP Net has been established to handle data acquisitin, archiving, computational, word processing and graphics needs. It is based on a Unix server, Ethernet cabling and both Unix and PC-based workstations.

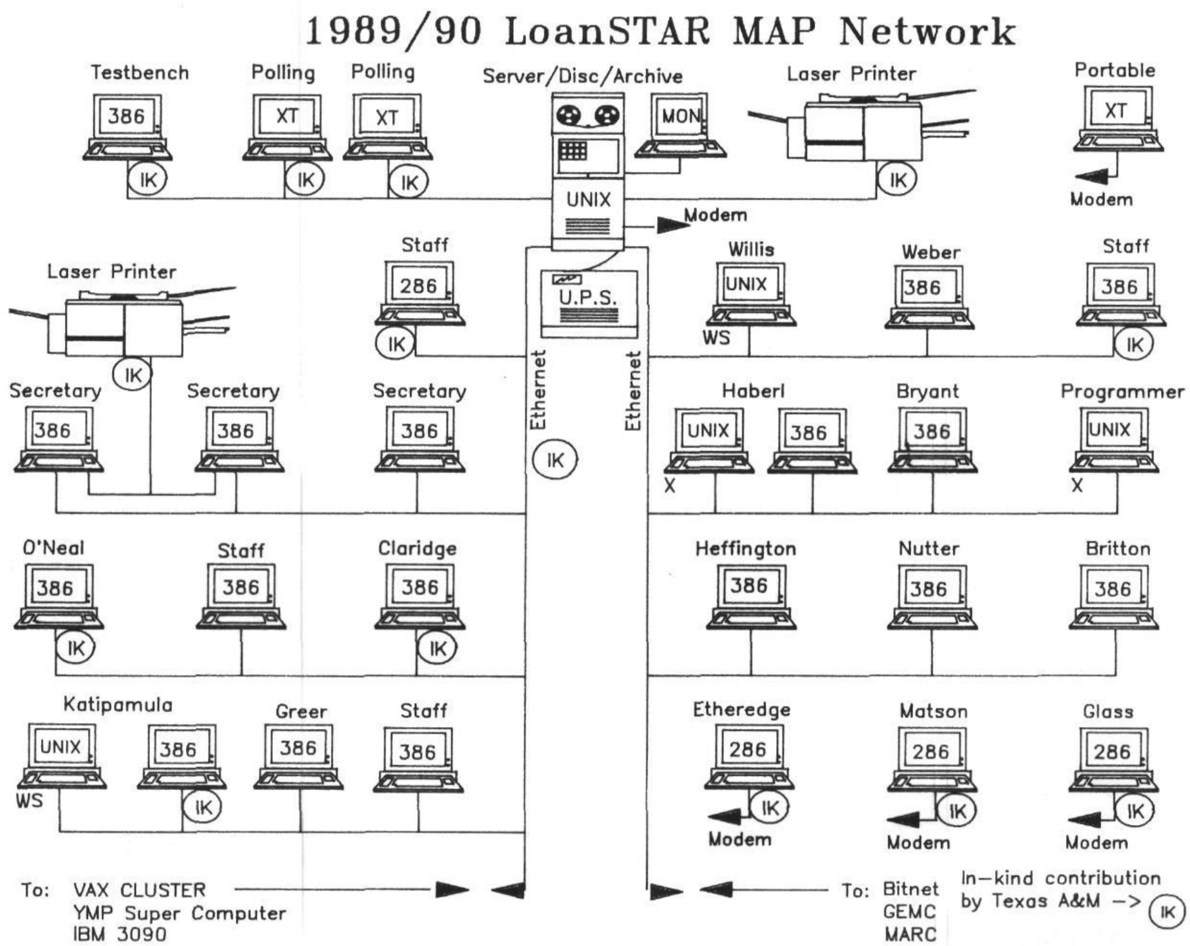
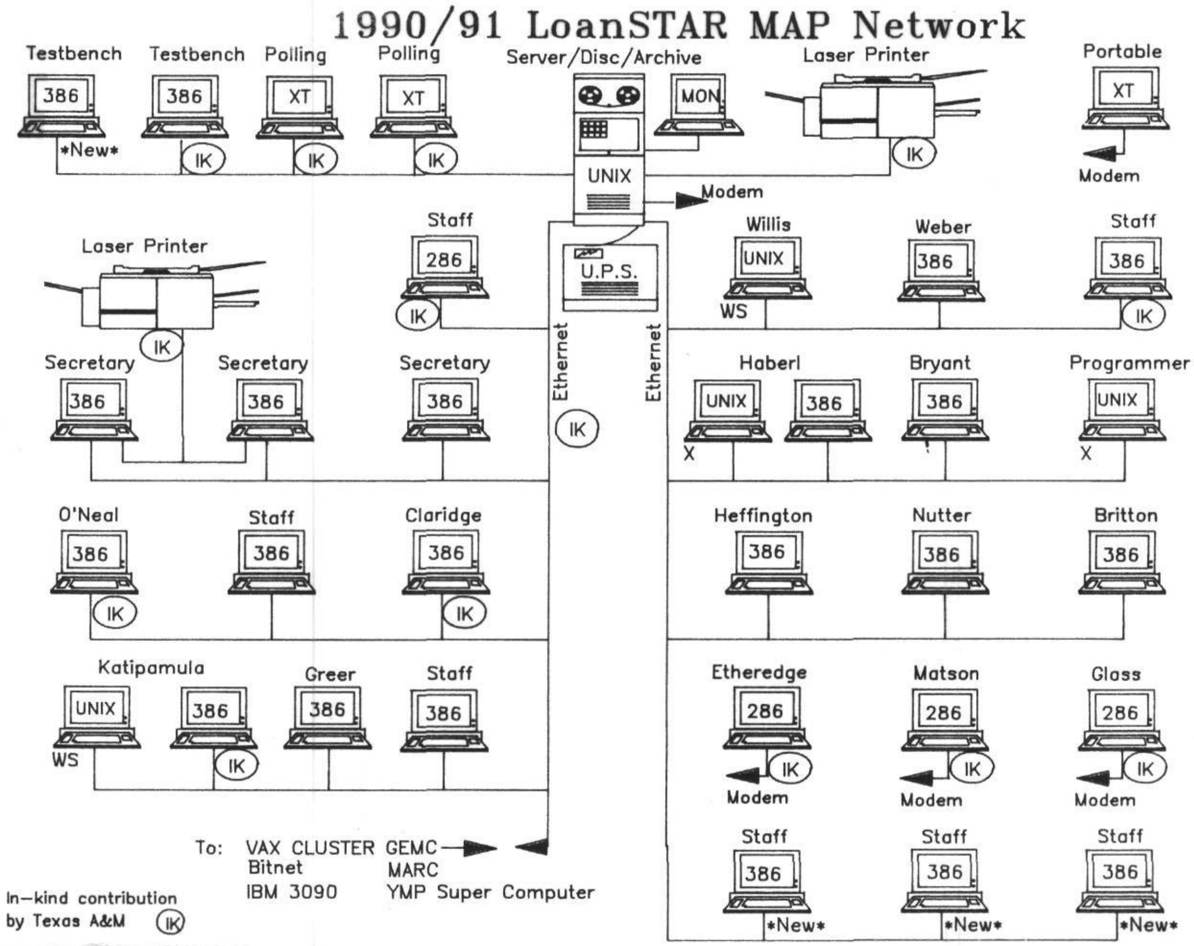


Figure 2: The Texas LoanSTAR MAP Net (1990/91).

This planned extension to the LoanSTAR MAP Net is shown in this figure. In addition to the configuration shown in Figure 1, in 1990/91 the MAP Net will be expanded to included at least 4 additional PC-based workstations, memory enhancements and other modifications to allow for improved processing capabilities.



SUPPORT

MATERIAL

TEXAS LOANSTAR
MONITORING AND ANALYSIS PROGRAM

Submitted to:

Energy Management Center
Office of the Governor
State of Texas

Submitted by:
David E. Claridge
Jeff Haberl
Warren Heffington
Dennis O'Neal
W. D. Turner
John Bryant
Rusty Etheredge
Melvin Glass

Energy Systems Laboratory
Texas A&M University
College Station, Texas

July, 1990

Contents

EXECUTIVE SUMMARY

Major objectives of the LoanSTAR Monitoring and Analysis Program (MAP) are to:

- Verify energy and dollar savings of energy conservation retrofits in state, school and local government buildings
- Reduce energy costs by identifying operational and maintenance improvements at facilities receiving retrofits.
- Improve retrofit selection in future rounds of the LoanSTAR program.
- Initiate a detailed data base of energy use in commercial/institutional buildings in Texas.

The Monitoring and Analysis Program is being conducted by:

- Monitoring and Analysis Contractor (MAC)--the Energy Systems Laboratory at Texas A&M University.
- Data Acquisition System Subcontractors (DASS).
- Monitoring Advisory and Review Committee (MARC).

Monitoring and data analysis will be conducted at three primary levels:

- Facility/whole building utility data.
- Facility/whole building short-term demand and consumption data.
- Sub-metered building systems data.

The major tasks of the monitoring and analysis contractor are to:

- Develop a comprehensive monitoring and analysis program plan.
- Coordinate a workshop at which the monitoring advisory and review committee outlines modifications to the program
- Specify data reporting format.
- Test sensors and systems to be used in the program.
- Develop an approved list of monitoring equipment for use in the MAP and negotiate quantity discounts, with assistance from the Governor's Energy Management Center (GEMC).
- Qualify three to six firms as data acquisition system subcontractors and supervise their performance.
- Design and implement a system to archive data collected.
- Analyze data to determine savings realized by retrofits.
- Analyze data and examine facilities to determine whether further retrofits and operational savings are practical.

- Conduct training for facility operators to implement findings of the MAC that will improve the efficiency of building operation.

The data acquisition system subcontractors will:

- Assist the MAC in design of an instrumentation plan for each monitored site.
- Provide data/guarantee data to the MAC.
- Maintain hardware for the duration of the monitoring in each building.
- Periodically recalibrate sensors and report on hardware condition.

The monitoring advisory and review committee will:

- Provide input and expertise from national monitoring and analysis efforts to preclude costly MAP errors and needless duplication of effort.
- Participate in a workshop to refine and improve the comprehensive MAP Plan.
- Meet at six- to twelve- month intervals to review progress of the monitoring and analysis program, to ensure that it fully integrates appropriate input from other monitoring projects and to recommend future directions of the program.

Chapter 1

INTRODUCTION AND BACKGROUND

In 1988, the Governor's Energy Management Center (GEMC) of Texas received approval from the U.S. Department of Energy to establish a $98.6 million statewide retrofit demonstration program, the LoanSTAR (Loan to Save Taxes And Resources) Program. The LoanSTAR Program is designed to demonstrate commercially available, energy-efficient retrofit technologies and techniques.

The program will use a revolving loan financing mechanism to fund energy-conserving retrofits of state, public school and local government buildings. Retrofit projects will be identified by energy audits conducted according to the guidelines of the Texas State Energy Conservation Program (SECP). Each retrofit will compete for funds on the basis of the estimated payback period, ability to repay the loan through energy savings, engineering assessment of the viability of the retrofit, and the GEMC's ability to monitor the project effectively. The projects will apply the latest cost-effective energy saving technologies for commercial and institutional buildings.

The LoanSTAR Program will be implemented in two phases. Phase I targets state agencies and institutions that received energy audits conducted by engineering firms for the GEMC through the Texas Energy Cost Containment Program (TECCP). Capital intensive energy-conserving improvements recommended by the TECCP auditors are candidates for funding in this phase. Loan recipients will repay the loan from energy savings projected from the retrofit projects.

Public schools and local governments are targeted for Phase II of LoanSTAR. Previous engineering audits of these facilities conducted under the Institutional Conservation Program (ICP) revealed potential energy savings similar to those in state buildings.

The projects funded by LoanSTAR primarily will include retrofits to lighting, HVAC systems, building shell, electric motors, energy management and control systems (EMCS), boilers and thermal energy recovery systems. Other retrofits using alternative or renewable energy systems and load management also will be considered.

LoanSTAR will establish a monitoring and analysis project to measure energy and cost savings at selected sites and to increase the effectiveness and savings from the program. Because the program is expected to involve eventually hundreds of retrofits (and monitoring installations) in buildings throughout the state, it is extremely important to prepare a plan that provides overall direction to the monitoring and analysis component of the LoanSTAR Program. Failure to do so could result in unnecessary metering and added program cost.

This document is intended as a work plan for a comprehensive monitoring program that will serve the purposes of the GEMC, the institutions receiving retrofits, building researchers and others involved in LoanSTAR. Chapter 2 describes the purpose, objectives and benefits of the monitoring and analysis program. Chapter 3 discusses organization, with a brief overview of each major task. Chapter 4 discusses the major monitoring and analysis tasks in more detail, including specific sub-tasks. This plan emphasizes the first year of the monitoring program. It will be updated in subsequent years as needed.

Chapter 2

OBJECTIVES OF THE MONITORING PROGRAM

The monitoring program is a an innovative and essential feature of LoanSTAR that will serve the different needs of many interested parties. The monitoring program has four primary purposes:

1. Verify energy and dollar savings of the retrofits.
2. Reduce energy costs by identifying operational and maintenance improvements at facilities receiving retrofits.
3. Improve retrofit selection in future rounds of the LoanSTAR program.
4. Initiate a detailed data base of energy use in commercial buildings located in Texas.*

Money for each retrofit financed by LoanSTAR must be repaid to the GEMC on the basis of energy savings estimated during energy audits of the building. Thus, the monitoring program's first purpose is to determine whether retrofits save as much as estimated in audits. Monitoring plans must be developed for retrofitted facilities to verify savings. Verification of savings will include measurement of consumption data before and after the retrofit, and analysis of the data to account for weather, changes in operation of the building, etc. This is a quality assurance method to ensure that agencies purchasing retrofits receive real savings from the LoanSTAR Program. All large retrofit projects will have savings verified. Budget constraints will preclude the necessary metering and analysis on some small projects.

The second objective of monitoring is to reduce the energy costs of a building by studying its energy-using characteristics. Experiences at the University of Colorado, Princeton University and the U. S. Department of Energy have demonstrated how monitoring identifies specific energy use of a building. Monitoring can provide a precise breakdown of how much energy is used for cooling, lighting, heating and other applications.

These data enable identification of retrofits that are not performing as expected and why, so "non-performers" can be dropped for future phases of the program. The

---

*"Commercial" buildings as used in this document refers to any state owned building, school, or local government building included is the LoanSTAR program. No distinction in made between "institutional" buildings and other "commercial" buildings.

data (with interpretation) also will be made available to the building operator to help identify ways to improve daily operation of the facility. In addition, data from monitoring can also show how changes in occupancy, weather, equipment, etc. have effected the energy use of a building. The savings realized from this activity may pay for the entire monitoring program.

The data and subsequent analysis will measure the cost effectiveness of different types of retrofits in Texas buildings. Some retrofits will prove more cost effective and others less cost effective than expected.This knowledge will enable engineers who perform future audits to make more cost-effective recommendations. Hence, the third objective is to increase the cost-effectiveness of future rounds of the LoanSTAR Program by reducing the number of ineffective retrofits installed.

The final major objective of monitoring is the establishment of a detailed, commercial building, end-use data base for buildings in Texas. Several large data collection programs in the U.S., including one at the Pacific Northwest Laboratory and another at the Lawrence Berkeley Laboratory, provide building scientists with data bases for analysis of building energy use and development of better analytical tools for predicting energy use. None include a large number of buildings in hot and humid climates, and none have been established for evaluation of the effectiveness of retrofits. Thus, the data base initiated by the LoanSTAR Program will be unique and provide building scientists with invaluable data for future analysis.

Chapter 3

ORGANIZATION

The Monitoring and Analysis Program (LoanSTAR MAP) will be conducted by the Energy Systems Laboratory (ESL) at Texas A&M University, which will act as the Monitoring and Analysis Contractor (MAC), by Data Acquisition System Subcontractors (DASS), and a Monitoring Advisory and Review Committee (MARC), with other subcontractors as needed. The MAC will oversee monitoring, design the database and write software, conduct analyses, interface with building operators and conduct educational programs for building operators. The MAC wrote this comprehensive plan to achieve the objectives described in Chapter 2. The plan has been refined with input from the Governor's Energy Management Center (GEMC) and the MARC. The MARC also will provide ongoing contact with other monitoring and analysis efforts to ensure incorporation of applicable techniques and results from those efforts. The data acquisition system subcontractors are installing and maintaining the monitoring equipment under the supervision of the MAC. Other subcontracts with Battelle Pacific Northwest Laboratory, Oak Ridge National Laboratory, Lawrence Berkeley Laboratory, Massachusetts Institute of Technology, Princeton University and the University of Texas at Austin are planned to supplement the expertise of the MAC.

Monitoring and Analysis Contractor

The monitoring and analysis contractor is responsible for carrying out the overall monitoring and analysis program. Major duties include:

- Preparing this plan for the metering and analysis needed to achieve program objectives.
- Selecting and supervising performance of the data acquisition system subcontractors.
- Preparing a list of approved hardware (after testing for compatibility), including updates.
- Designing and implementing a system to archive the data collected.
- Selecting, developing and refining procedures for determining retrofit savings.
- Analyzing data to determine savings realized by retrofits.
- Reporting results to the GEMC and building owners.
- Assigning audits to audit contractors.
- Reviewing audit reports.
- Developing a facility for calibration of sensors and instrumentation.
- Analyzing data and examining facilities to determine whether further retrofits and operational savings are practical.

- Training facility operators to implement operational procedures that improve efficiency of building operation.

The duties of the MAC have been divided into five major tasks as shown in Figure 1. The tasks are described below.

Task 1. Audit Review and Assignments: provide independent engineering review of all audits submitted to the GEMC; assign buildings to the consulting engineering teams selected to conduct audits for the LoanSTAR Program.

Task 2. Monitoring Systems Selection and Installation: ensure collection of adequate and reliable data by determining metering requirements, selecting data acquisition systems, and selecting and supervising the DASS who will install and maintain monitoring equipment.

Task 3. Calibration Laboratory: maintain NIST-traceable instrumentation to bench-test and prequalify different types of sensors and other hardware for use in the MAP; also calibrate portable instrumentation used to check field installations.

Task 4. Systems Communications Testing and Development: bench-test hardware systems types before they are accepted for use in the MAP and develop software for use in polling and archiving data.

Task 5. Monitoring Plans, Analysis and Reports: develop/select analysis procedures and analyze monitored data from LoanSTAR buildings and report the savings and O&M measures identified to the GEMC and agencies that own or operate individual buildings.

Figure 2 illustrates the interaction of the MAC and each task with a typical LoanSTAR building. After the agency applies for an audit, Task 1 assigns the audit team and subsequently reviews the audit report before it is accepted. The GEMC then reviews the application for a loan and approves it. Task 2 assigns the building to a DASS and participates in development of a monitoring plan, selection of data acquisition equipment for the site and oversees installation of monitoring equipment in the building. Task 4 collects and archives the data which is then analyzed by Task 5 to determine retrofit energy savings and cost savings and identify additional O&M measures which should be implemented at the site. These results are then reported to the GEMC, the agency and/or the building operators as appropriate.

While this figure illustrates interaction with a typical building, it omits several important functions of the MAC, including selection of the DASS, approval and calibration of sensor types used in the program, testing of data acquisition systems approved for use in the program, development of software for polling and archiving data, and selection and development of techniques and software for analyzing data and communicating with building operators and owners. Buildings receiving low-cost retrofits will have an appropriately abbreviated monitoring and analysis activity.

Data Acquisition System Subcontractors

Data acquisition system subcontractors are required to install and maintain data acquisition equipment in the buildings monitored. The DASS will prepare the metering installation plan for each building, with the cooperation of and subject to the approval of the MAC (and the agency); select hardware from the approved list; and install the system. The DASS will also calibrate the system (including periodic recalibration) and provide maintenance as necessary to ensure that at least 90 percent of the data collected is usable. Calibration procedures must be approved by the MAC.

Monitoring Advisory and Review Committee

The monitoring advisory and review committee is composed of representatives from nine organizations with experience in monitoring and analyzing data from buildings. The MARC met initially and developed recommendations for this comprehensive monitoring and analysis plan, using the MAC draft plan as the starting point. The committee will meet in the future at six- to twelve-month intervals to review progress of the program, ensure that the monitoring and analysis fully integrate appropriate input from other monitoring projects and recommend future directions of the program. Members of the MARC come from national laboratories, universities, a federal agency a utility and a utility research organization.

Figure 1. Monitoring and Analysis Contractor tasks and Principal Investigators.

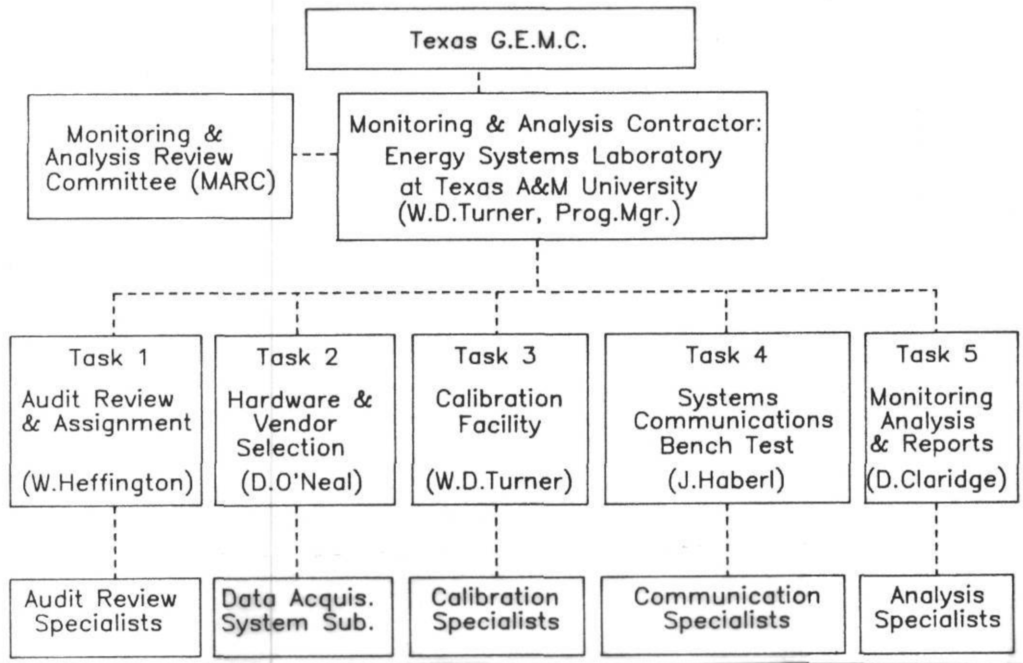
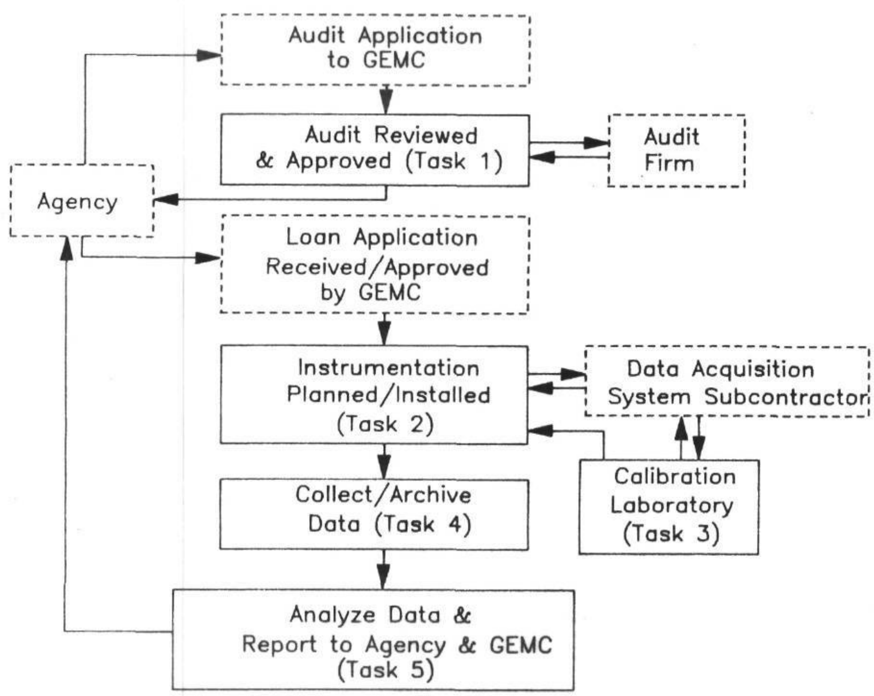


Figure 2. Interaction of each MAC task with a typical agency and building. Solid blocks represent MAC tasks and dashed blocks represent other organizations.



Chapter 4

TASK PLANS

The previous chapters have described the purposes and organization of the monitoring and analysis program in broad outline. This chapter provides detailed descriptions of the tasks of the monitoring advisory and review committee and the monitoring and analysis contractor.

Monitoring Advisory and Review Committee

The first meeting of this committee was held December 14-15, 1989 in Austin, Texas. Comments from this meeting were used to modify and refine the draft and develop this Comprehensive Monitoring and Analysis Plan. This mechanism enables the MAC to utilize the experience of other major monitoring programs to minimize problems and avoid duplication of effort. Historically, large-scale monitoring programs have taken two- to five- years from inception until significant data was acquired. One of the goals of the LoanStar Program is to reduce this costly front-end requirement.

The two-day workshop was structured to use the draft plan as a starting point and refinements were added by the committee.

Work Plan

<u>Date</u>	<u>Action</u>
Year 1:	
December 1989	Planning Workshop
Summer 1990	Review Meeting
Year 2:	
Winter 1991	Review Meeting
Summer 1991	Review Meeting
Successive years:	
Winter	Review meeting
Summer	Review Meeting

Monitoring and Analysis Contractor

Task 1. Audit Review and Assignments

Purpose

This task requires an independent review of all energy audit reports submitted by the eight consulting engineering firms under contract to the GEMC. Reports will be reviewed for use of appropriate technology, conceptual correctness, accuracy of energy rates, adequacy of implementation cost data, numerical accuracy and compliance with program guidelines. Recommendations on improved audit procedures and forms will be provided to the GEMC based on experience with the review process and interaction with Tasks 2-5.

Another purpose is to assign audits at a pace the keeps approximately fifteen engineering teams reasonably busy and on schedule completing the audits.[1] These audit assignments likely will be made by personnel of the GEMC, including a Texas A&M engineer officed in the GEMC. This task is responsible for advertising, interviewing and hiring for the engineering position.

Functions

Conduct desk-top audit reviews for consulting engineers' reports. All reports in the draft stage will be reviewed to assure they are accurate, propose the use of suitable retrofit technologies, are conceptually correct, have adequate implementation data, are numerically correct and are in compliance with guideline and format requirements. This task involves final approval of the audit reports, which triggers certain payments to the firms. It is the primary function of Task 1.

Assign audits.[2] Agencies desiring audits apply to the GEMC. The audit requests must be reviewed and assigned to the consulting engineering firms in a timely manner.

---

[1]Presently there are 16 million square feet of state agencies for which audits have been requested. A limited number of local governments have requested audits.

[2]These functions are contractual obligations of Texas A&M; however, they will be performed by a Texas A&M engineer office in the GEMC in Austin and directed by personnel of the GEMC.

Review preliminary on-site screening reports (POSSRs).[2] Facilities are screened by an assigned engineering firm to identify projects and eliminate poor audit candidates at an early stage. The screening results in a tentative list of projects and a proposed audit cost by Energy Cost Reduction Measure (ECRM) that must be reviewed and aaproved.

Conduct meetings of the consulting firms, agency and GEMC.[2] In conjunction with the POSSR review, a meeting between representatives of the consulting firm, agency and GEMC must be conducted to finalize the tentative ECRM projects in the POSSR.

Negotiate audit prices.[2] Audit prices proposed by the contractors are given close scrutiny and are subject to negotiation when it is in the interest of the state to do so.

Participate in audit format training workshop. TAMU has already participated in a one-day workshop to train auditors on the audit guidelines and format, and will do so on an as-needed basis.

Provide information to other Tasks' Personnel. Other MAP personnel must be kept abreast of auditing progress, and the data from final reports will be made available for use in tasks 2, 4 and 5. particularly.

Update audit format. This task will explore ways to improve the quality of the energy audit process. Recommendations on modified audit procedures will be provided when warranted and training will be modified accordingly. Wholesale modification of the energy audit process, and accompanying revision of the guidelines and format will require significant effort and is not anticipated without contractual authorization. However, upgrading of the audit procedure is a long-term objective of Task 1.

Work Plan

Date	Action
Year 1	Employ engineer to be officed in the GEMC to: assign audits; review POSSRs; conduct meetings of the consulting firms, agency and GEMC; and negotiate audit prices.
	Participate in audit format training workshop. This was accomplished October 13, 1989.

Year 1 - Year 4	Conduct desktop audit reviews of consulting engineers' reports. This has been ongoing since contract initiation and will continue until approximately four to six months after the last audit. The review procedure used is described below. Provide information to other tasks.

Audit Report Review Procedure

The following procedures are followed in the detailed desktop audit review process at Texas A&M University. Audit report drafts are sent to the GEMC, the agency, and Texas A&M. When a draft is received at Texas A&M, it is logged in and comments are solicited from the agency energy manager. The draft is routed to a review assistant (graduate student or staff engineer) who reviews it in detail for numerical correctness and agreement with the POSSR, format and guidelines. Insofar as possible, the review assistant comments on the concepts employed and the technology recommended. A copy also is sent to the cost analyst (a professional cost estimator from the Department of Construction Science) who reviews the implementation cost data.

The draft then proceeds to a professional engineer in the Mechanical Engineering department who discusses identified problems with the review assistant or cost analyst, reviews unusual aspects of the report, including new ECRMs and questionable procedures and independently reviews the report for overlooked problems. The engineer then merges the comments of the agency energy manager, GEMC and Texas A&M reviewers. The other is kept as a record copy at Texas A&M. Occasionally, the draft procedure is repeated. When the final report is received at Texas A&M, it is compared to the record copy and any problems are reconciled prior to acceptance.

Task 2. Monitoring Systems Selection and Installation

Purpose

This task ensures that adequate and reliable data are collected to monitor energy use of the buildings participating in the LoanSTAR program. Data collected from the buildings will serve as the basis for determining the cost-effectiveness of different retrofits as well as providing indices of how well an individual building is performing. Thus, it is critical that the data are the best that can be collected, given economic constraints.

Functions

The major initial functions of this task were to qualify and select data acquisition subcontractors. The major ongoing functions of the task include: determination of metering requirements, systems design/selection for each site, and installation and maintenance of systems. These functions are outlined in Table 1 and described in detail in this section.

<u>Determination of Metering Requirements.</u>

The monitoring program is intended to verify savings, ensure that retrofits operate properly and identify additional measures to reduce energy costs. Sufficient data must be collected to achieve these objectives, but monitoring and analysis expense must not undermine the cost-effectiveness of the LoanSTAR Program.

Evidence from LBL, Princeton, the U. S. DOE, the University of Colorado and elsewhere shows the cost-effectiveness of sub-metering large buildings with major retrofits. However, savings achieved in smaller buildings do not generally justify the expense of sub-metering. Such buildings will have whole-building energy consumption analyzed, sometimes with monthly data and sometimes with 15-minute or hourly demand data.

Four levels of systems have been developed for the monitoring program. These accommodate the necessary data requirements with the money available for monitoring retrofitted buildings. The levels also are compatible with different hardware available on the market. As the project progresses beyond the prototype year, the definition of the levels and associated hardware requirements is expected to change.

Level 0. Facility/whole building(s) utility data: These data will vary from monthly consumption data, based on utility bills, to weekly or daily data collected by utility meters. It is useful for separating consumption into heating, cooling, water heating and other non-weather related consumption. A substantial portion of retrofits in the schools and local governments are expected to fall within this category.

Level 1. Whole-building and limited sub-metered hourly data: Ongoing work at Texas A&M, Princeton, and LBL shows that use of hourly data permits a more detailed analysis of end-use patterns and identification of major individual operating parameters within buildings than does the use of monthly or daily data; for example, whether lights or air conditioners are being turned off as scheduled. This level will utilize one to four channel data acquisition systems and is also a viable option for buildings of intermediate size. Portable meters may sometimes be used to collect such data for a one- to two- month period.

Level 2. Moderate sub-metered hourly data: This level has all the capabilities of the first two levels and also enables more detailed analysis for identifying the savings from specific retrofits and pinpointing building operational problems. The moderate sub-metered data acquisition systems will be simple four to twenty channel systems. Sub-metering in some small all-electric buildings can be accomplished with smaller systems to obtain adequate data at minimum cost.

Level 3. Detailed sub-metered hourly data: These systems typically include at least 20 channels of data. Given current costs for these systems, they are expected to be cost-effective only in large buildings with retrofits valued at more than $500,000. Large buildings constitute about half of the expenditures expected in Phase I of the LoanSTAR program. These systems also will be required in selected smaller installations (such as schools and local government buildings) to "calibrate" the simpler levels (i.e., daily or monthly manual watt-hour readings) of monitoring for different building types in Texas. Portable systems may be used for one- to two-month periods in some of these buildings as well.

The feasibility of using an agency's existing energy management control system (EMCS) to gather some or all of the required data will be explored during this first year. Cost reductions are possible if it is feasible to use EMCS systems for data acquisition.

Data Acquisition System Subcontractor Qualification.

Subcontractors will be required to install and maintain data acquisition equipment in monitored buildings. The DASS will prepare a metering installation plan for each monitored building, with the cooperation and approval of the MAC (and the agency). Then the DASS will select hardware from the approved list and install the system. The DASS also will calibrate the system (including periodic recalibration) and provide maintenance as necessary to ensure that data collected during the monitoring period are usable.

The MAC will qualify three to six engineering firms to work as subcontractors during this first year. The number of qualified DASS may be changed if problems arise concerning installation quality or project scheduling.

Data Acquisition System Subcontractor Selection.

DASS selection will be based on guidelines in the Request for Qualifications (RFQ) that were sent to interested subcontractors in September 1989. The selection committee consisted of several staff and principal investigators of the MAC and GEMC. Committee members were given copies of each respondent's RFQ and evaluated according to the following criteria:

general knowledge of data acquisition systems	(15%)
knowledge of hardware and software	(15%)
knowledge of calibration requirements	(15%)
ability to staff project	(15%)
quality of prior work	(25%)
geographical location(s) in the state	(15%)

The committee's evaluations were collated and the final list of subcontractors forwarded to the GEMC for approval.

Data Acquisition Systems Selection.

Data acquisition systems include both the data-logging hardware and transducers which measure electrical power, temperature, pressure, etc. The selection process will continue throughout the duration of the project. As new hardware is qualified, it will be included on an approved hardware list from which the DASS may make purchases.

A list of data logging equipment appropriate for each level of monitoring has been developed by the MAC (Table 1). The equipment must have an open communications protocol so the MAC can incorporate it into the LoanSTAR MAP network (MAP NET). A sample of each of the vendors' systems is undergoing evaluation by the MAC to ensure compatibility with data transmission protocols and any other equipment it must interface with before being listed.

Table 1 - Data logging hardware being evaluated by the MAC.

Level	Manufacturer
1	Landis and Gyr/Synergistics Controls/ RustRak/Sangamo/Process Systems
2	Campbell/Synergistics Controls
3	Synergistics Controls

The MAC has arranged quantity discounts with these manufacturers which will reduce the purchase price of data loggers and some transducers by 10% to 25% of retail prices.

Estimating the savings due to a retrofit will require accurate estimates of end-use energy in many of the buildings. End-use measurements require a variety of transducers. Listed below are the transducers that are anticipated:

1. electrical sensors
   - current transducers
   - wattmeters
   - voltage transformers
2. temperature sensors
   - RTD
   - thermocouple
   - IC
3. humidity sensors
   - relative humidity
   - dew point
4. airflow meters
   - hot wire
   - pitot-static
   - turbine
5. waterflow meters
   - turbine
   - venturi
6. pressure transducers
   - differential
   - total
7. anemometers
8. Btu meters
9. pyranometers

<u>Installation and Maintenance of Systems</u>

The installation of a monitoring system at a site require several steps as outlined in Table 2 and described in this section.

Development of a conceptual metering and analysis plan (CONMAP)

Once the agency loan is approved by the GEMC, the MAC will conduct a survey of the building(s) to determine the relevant information to monitoring the building.

Table 2. Sequential outline of system design installation activities performed by Task 2.

1. Loan approved by GEMC
2. TEES notified of loan approval.
3. DASS assigned to the site
4. Site visited by TEES (optional)
5. Conceptual monitoring and analysis plan developed (ConMAP)
6. DASS visit to site
7. Detailed preliminary monitoring and analysis plan (preMAP) prepared by DASS
8. TEES reviews/revises preMAP into site monitoring and analysis plan
9. GEMC approves siteMAP
10. DASS contracted for installation
11. System installed/verified
12. System maintained/recalibrated

These data include building description, utility billing history, utility serving the building, EMCS system information, type of retrofit, estimated savings of the retrofit, and availability of local climatological data. Some of the building and retrofit data will come from the audit report with the person at the agency responsible for the buildings(s) and utility personnel. A data form which includes detailed building, equipment, and equipment operator profiles will be developed and used as an aid in gathering important data necessary to make decisions on the level of monitoring and aid in the eventual analysis of the building(s).

Availability of weather data will be an important consideration in the development of the CONMAP. Many of the Texas electric utilities collect weather data or subscribe to a private weather service for major metropolitan areas. However, these data will probably not be available to the MAC in a timely manner for analysis of monitoring data on a building. For a new site in a large metropolitan area, a weather station will be included in the CONMAP for that site. This weather station will be used for analysis of all of the buildings that have monitoring equipment installed in that metropolitan area.

The primary purpose of the CONMAP is to develop an initial monitoring plan that is consistent with the budget constraints and the metering requirements from Task 5. The output of the CONMAP will be a description of the data points needed to monitor for a site and the level of metering. These data will be provided to the DASS assigned to the site.

Development of a preliminary site metering and analysis plan (PREMAP)

Once the CONMAP is completed, the next milestone will be the development of a preliminary site metering and analysis plan (PREMAP) for the building(s). The PREMAP will include options for hardware (specified by brand name), drawings which provide monitoring equipment locations in the building, data provided by the monitoring system in engineering units, data format, and estimates of engineering, hardware and installation costs. These data will be provided by the DASS.

The first step in the PREMAP process will be the assignment of a DASS to a site based on the site's monitoring requirements and geographical location. The DASS will be chosen from the list previously approved by the MAC and the GEMC. When the DASS is chosen, its representative will meet with the MAC and review the CONMAP for the site to ensure the DASS understands the monitoring required by the MAC. During the prototype year, the MAC also may have more than one DASS visit the same site to aid in developing site plans and identifying potential field installation problems.

The second step in the PREMAP process for a building will be an initial visit to the site by the DASS. The MAC will assist the DASS in arranging meetings with the responsible personnel from the affected agency. A representative from the MAC will be designated as the site relations person (SRP) for the particular site. For the larger monitoring sites, the SRP from the MAC will accompany the DASS during coordination or technical problem visits to the site. Also, the MAC will make a video record of the site. This video record can be used by the DASS for assistance in designing the monitoring system once they are away from the site. The video will be used by the MAC for acquainting the analysts with the equipment to be monitored and for familiarizing the team that will recalibrate transducers with the location of transducers in the facility.

For all levels of monitoring, a priority will be to obtain whole building electrical and gas metering (Level 0), if feasible, during the initial visit by the DASS. For some buildings, the data will be available from the local electric or gas utility. In those cases, the local utility will be contacted and asked to provide at least a year of consumption data on the building. However, for the buildings located on a large campus which is centrally metered, the DASS could install Level 0 metering during the initial visit(s) to the site. Initiation of Level 0 data collection would provide the MAC with several months of data before a complete level 1, 2, or 3 system is installed. It may also be cost effective to install a Level 3 meter in a site during the initial visit of the DASS at those sites where a Level 3 meter will be to be used. The Level 3 meter will be used initially to get whole building data. Later, when the site is completed, additional data points could be connected to the previously installed Level 3 data recorder.

The DASS will develop a PREMAP for this initial site visit. The PREMAP is analogous to the preliminary on-site screening report of the audit program in Task 1. The PREMAP will include options for hardware (specified by brand name), communications recommendations, major energy using equipment (air handlers, chillers, etc.), locations, detailed drawings of the proposed monitoring installations, data to be provided, data format, and estimates of hardware and installation costs. The MAC will be responsible for developing procedures that the DASS must follow in completing the PREMAP.

Development of a site monitoring and analysis plan (SITEMAP)

The PREMAP will be submitted to the MAC by the DASS. The MAC will then review the monitoring options specified in the PREMAP for completeness in meeting budgetary constraints and specific metering requirements from Task 5.

Then MAC will develop a SITEMAP that contains the final recommendations for the type of monitoring system to install, locations, costs, etc. The agency receiving the monitoring system must concur with the SITEMAP to ensure that the proposed installation does not interfere with their desires for the system. The agency's concurrence also is important because the money for the monitoring system is paid by the agency out of its retrofit loan. The SITEMAP will be submitted to the GEMC for final approval.

System Verification:

Data verification is performed immediately after the monitoring equipment is installed. The data will be compared with past utility data, auditor estimates of consumption and any other information available to verify that the data acquisition system and sensors are providing reasonable values. This is followed by checks of most sensor outputs. Such checks must be preformed periodically for data quality assurance. The system verification will occur within the first sixty days after the system is installed. The DASS will be required to correct any equipment problems at the site during this period as part of the installation contract. At the end of the prototype year a system installation/verification manual will be developed based on the experiences of the first year.

Maintenance of monitoring system:

The contract documents and specifications cover warranty items, routine maintenance and unscheduled or emergency repairs to the data acquisition system. Continuing maintenance of the equipment must be provided in a timely manner to assure that usable data is delivered to the MAC at least 90 percent of the time.

Work Plan

Date	Action
Sept-Oct 1989	Initial selection of pilot year data logging systems.
Sept 16, 1989	RFQs sent out to potential contractors.
Oct 16, 1989	RFQ deadline for submissions.
Nov 1989	Final approved list of DASS distributed.
Dec 1989	DASS visits to pre-selected site to develop site plan methodology.
Jan 1990	Initial list of approved LoanSTAR sites assigned to DASS.
Jan-Aug 1990	Continue DASS site assignments and follow-up on completed installations.

Task 3. Calibration Laboratory

Purpose

The purposes of the Calibration Laboratory are:

1. Construct an NIST-traceable facility which can be used to test sensors and verify their compatibility with selected monitoring systems.

2. Establish a facility to troubleshoot faulty sensors found in the field and to check the difference between bench tests and field sensor installations.

3. Verify portable instrumentation which can be used for field testing and validation.

4. Establish a facility to bench-test and pre-qualify proposed hardware systems prior to installation in the field, which means close interaction with Task 4, Systems Communications.

5. Develop field calibration techniques and error analysis to verify insitu systems.

The calibration laboratory will be located at the Energy Systems Laboratory on the Texas A&M Riverside Campus.

An expansion of these purpose statements follows:

1. The philosophy behind establishing the calibration laboratory is to be able to verify both sensor accuracy and compatibility with the monitoring systems before field installation. In too many cases, the field installation is the first check of system compatibility. For example, a recent installation at a Texas state facility took months before the system was operational.

2. Field installation problems likely will arise with faulty sensors or a faulty class of sensor. Since the DASS are required to maintain and verify periodic calibration of their systems in the field, the ESL calibration facility can be used to determine sensor problems and also resolve potential conflicts about incorrect sensor readings.

3. Calibrated portable instrumentation also will be developed for spot checks on the DASS installation. The DASS is responsible for installing the system and certifying proper operation, but a portable field unit will enable the MAC to verify proper system operation on-site. The unit also can be used for trouble-shooting older installations when problems arise.

4. The accuracy of sensor calibration is the key to the whole monitoring project. Data obtained from the DASS has to be accurate to maintain confidence in the project. To verify the accuracy of sensors and to have a facility that the DASS will have confidence in, NIST-traceable calibration is absolutely necessary. The ESL will make NIST-traceable services available to potential hardware suppliers and will maintain an NIST-traceable facility for all the common quantities (i.e., temperature, velocity, flow, rpm, etc.) that will be encountered in this program. It is also anticipated that field sensors and systems will be rechecked periodically to verify their continued calibration. When sensor drift is detected the sensor will be recalibrated, but the lab also will develop recommended procedures for correcting past data from sensors that have drifted.

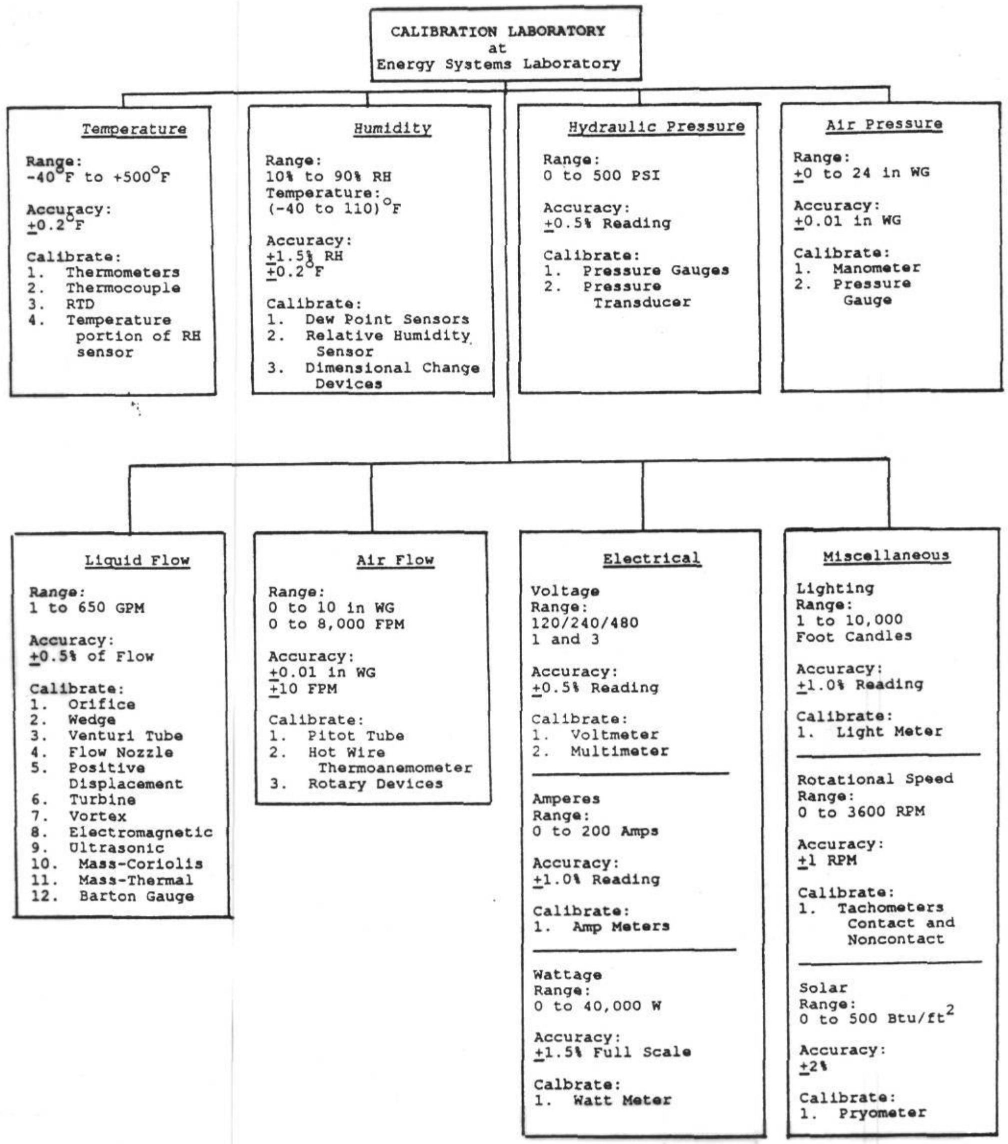
5. Operational guidelines will be developed for sensors and hardware. Initially, the DASS will follow the manufacturer's installation instructions for sensor installation, calibration and maintenance procedures. However, over the course of time, the Calibration Laboratory may need to be verified every three months while others may be valid for two years. This type of data will not be known until experience is gained with the hardware under controlled test conditions. This calibration laboratory can provide invaluable date for manufacturers and installers of instruments.

Functions to be Performed

The calibration facility will include the capability to measure electrical energy, power factor, electrical demand, temperature, air and liquid flow rates, humidity, pressure, solar radiation, light levels, air velocity and rpm. Services available from local utilities for a nominal fee will be used for calibration of electrical meters and gas meters. It is not cost effective to perform independent calibration with less than 100 sites per year.

The Energy Systems laboratory will use National Institute of Standards and Technology (NIST) certified instrumentation where practical, but as a minimum, will maintain NIST-traceable instrumentation. Periodic calibration will be maintained for both primary- and secondary- standard hardware. The calibration capability being developed is shown in Figure Three and described in the Work Plan which follows.

Figure 3. LoanSTAR Calibration Laboratory. This figure describes the calibration facilities being developed for checking the accuracy of instruments and sensors used in the LoanSTAR Program.



Work Plan

The calibration laboratory will be constructed at the Energy Systems Laboratory, a test laboratory certified by the Home Ventilating Institute for air flow testing of fans. When a performance curve is run on a fan, quantities such as rpm, power and flow rates normally are measured. Thus, some of the facilities and instrumentation necessary for air flow and power measurements already exist. Where possible, existing test facilities will be used or modified to meet the needs of the calibration laboratory.

The facility is scheduled for completion in July 1990. Testing will be conducted as needed thereafter.

The following briefly describes facilities needed to calibrate temperature, humidity, liquid flow, air velocity, and pressure sensors. The range of calibration, types of sensors calibrated, accuracy of calibration and applicable standards are specified.

Temperature

Objective:

Develop and maintain the capability to calibrate and test liquid-in-glass thermometers and electronic temperature measuring systems to an accuracy of +/- 0.2°F (0.1°C) over a range of -40°F to 500°F (-40°C to 250°C) and have traceability to NIST.

Capacities:

1. range of calibration: -40°F to 500°F (-40°C to 250°C)
2. accuracy: +/- 0.2°F (+/- 0.1°C) and have traceability to NIST
3. type of devices that can be calibrated:
    a. liquid-in-glass thermometer
        - total immersion
        - partial immersion
    b. electronic temperature measuring systems
        - thermocouples
        - thermistors
        - RTD
        - integrated circuit sensors
        - temperature portion of relative humidity sensor

Standards:

1. International Practical Temperature Scale of 1968
2. ASHRAE Standard 41.1-86, Standard, Method of Temperature Measurement
3. ASTM Standard E220-86, Standard, Method of Calibration of Thermocouples by Comparison Techniques
4. ASTM Standard E64-86, Standard, Method for Testing Industrial Resistance Thermometer
5. ASTM Standard E77-84, Method of Verification and Calibration at Liquid-in-Glass Thermometers
6. ASME Standard PTC 19.3-74 Part 3, Temperature Measurement Instruments and Applications

Equipment:

- thermometer storage rack
- microscope (15 to 20-X power)
- ice bath with necessary accessories
- constant temperature bath (-40°F to 500°F)
- distilled water storage container (20 gallons)
- ice shaver
- ice maker/storage
- primary set of ASTM thermometers (NIST traceable)
- 3 pt thermistors (NIST traceable) with digital readouts (0.01°F)
- 10X power reading telescope

Simplified Testing Procedure:

1. physical examination of temperature measuring device for flaws under microscope
2. measurement in a prepared ice bath against primary thermometer and the platinum RTDs
3. measurements in prepared constant temperature bath (three tests with a minimum of 10 points each
4. measurement in a thermocouple well or duct, if required
5. generation of test report including graph

Humidity

Objective:

Develop and maintain a laboratory for calibrating relative humidity sensors and dewpoint sensors to an accuracy of +/- 1.5 percent over a range of 5-99 percent R.H. and have traceability to NIST.

Capacities:

1. range at calibration: 5 to 99 percent
2. accuracy +/- 1.5% R H, traceable to NIST
3. type of devices that can be calibrated:
   a. psychrometer
   b. dewpoint meters
   c. dimensional change devices

Standards:

1. ASHRAE Standard, 41.1-86, Standard Method for Measurement of Moist Air Properties
2. ASTM Standard E337-62, Standard Method for Determining Relative Humidity by Wet and Dry Bulb Psychrometer
3. ASME Standard PTC 19.3-74 Part 3, Temperature Measurement, Instruments and Apparatus, Revised 1985

Equipment:

- 3 precision dew point sensors
- 3 vacuum pumps
- 3 flow meters - cubic feet of air per hour
- temperature/humidity chamber (obtained from a DOE Program)
- 4 salt bath solutions - one at 11 percent R,H., one at 35 percent R.H., one at 75 percent R.H., and one at 95 percent R.H.

Simplified Testing Procedure:

1. physical examination of humidity sensor
2. installation of humidity sensor in low R.H. salt bath
3. installation of humidity sensor in temperature humidity chamber and run three times with a minimum of 9 points each time
4. installation of humidity sensor in high R.H. salt bath
5. generation of test report including graph

Hydraulic Pressure

Objective:

Develop and maintain a laboratory for calibrating absolute, differential and gauge pressure transducers to an accuracy of +/- 0.1 percent of reading over a range of 0-500 psi and have traceability to NIST.

Capacities:

1. range of calibration: 0 to 500 psi
2. accuracy: +/- 0.1 percent of reading, traceable to NIST
3. types of devices to be calibrated:
   a. pressure transducers
   b. pressure gauges

Standards:

1. ASME Standard PTC 19.3-87, Part 2 Pressure Measurement Instruments and Apparatus
2. ISA Standard 537.6-7.6 Potentiometric Pressure Transducer, Spec and Test of (Revised 1982)
3. ANSI B-40.1, American Standard for Indicating Pressure and Vacuum Gauges, Round Dial Type with Elastic Pressure Chamber, 1939

Equipment:

- dead weight tester

Simplified Testing Procedures:

1. physical examination of test pressure sensor
2. install test pressure sensor on test stand and perform three tests with a minimum of 10 points each starting at lowest pressure to rated pressure
3. generate test report including a graph

Air Pressure

Objective:

Develop and maintain a laboratory for calibration of manometer, air pressure and draft gauges to an accuracy of +/- 0.01 inch W.G over a range of 0-24 inches W.G. and have traceability to NIST.

Capacities:

1. range of calibration: 0-24 inches W.G.
2. accuracy: +/- 0.01 inch W.G.
3. types of devices that can be calibrated:
   a. manometers
      - inclined
      - micro manometer
      - regular
      - U tube
   b. pressure gauge

Standards:

1. ASME, Standard PTC 19.2-37, Part 2, Pressure Measurements-Instruments and Apparatus
2. ISA Standard RP2.1-62 Manometer Tables Recommended Practices

Equipment:

- hook gauge
- 2 Merian micro manometers
- precision barometer
- quick test vacuum pump

Simplified Testing Procedure:

1. physical examination of test equipment
2. calibration of micro manometer against Hook gauge
3. installation of test equipment against micro manometer with three tests with a minimum of 10 points each starting at lowest point to the rated pressure
4. generation of test report including graph

Liquid Flow

Objective:

Develop and maintain a laboratory for calibrating liquid flow meters to an accuracy of +/- 0.5 percent of rated flow over a range of 1-650 gpm, meter from 1/2-6 inches in size and have traceability to NIST. Flow in excess of 650 gpm will be calibrated under subcontract.

Capacities:

1. range of calibration: 1.0-650 gpm
2. accuracy: +/- 0.5 percent of rated flow
3. type of devices that can be calibrated:
   a. orifice
   b. wedge
   c. venturi tube
   d. flow nozzle
   e. positive displacement
   f. turbine
   g. vortex
   h. electro magnetic
   i. ultrasonic
   j. mass-coriolis
   k. mass-thermal

Standards:

1. ASHRAE, Standard 41.8-78, standard Method of Measurement of Flow of Fluid - Liquids
2. ASME, Standard PTC 19.5-72, Application Part III of Fluid Flowmeter

Equipment:

- 3 liquid manometers
- 10,000 gallon storage tank
- piping and valving
- 10,000 gallon receiving storage tank
- screening material
- P & T ports
- flow pumps: 650 gpm, 150 gpm and 50 gpm

Simplified Testing Procedure:

1. physical examination of flowmeter
2. installation of flowmeter in appropriate flow test stand and run test points (10 points) from highest to lowest points
3. generate test report including graph

Air Velocity

Objective:

Develop and maintain a laboratory for calibrating pitot tube, hot wire thermoanemometer and rotary devices to an accuracy of +/- 0.1 inch W.G. or +/- 10 fpm over a range of 10 to 8,000 fpm and have traceability to NIST.

Capacities:

1. range of calibration: 0.0 to 10.0 inches W.G.
   0 to 8,000 fpm
2. accuracy: +/- 0.01 inch W.G., +/- 10 fpm
3. type of devices that can be calibrated:
   a. pitot tube
   b. hot wire thermoanemometer
   c. rotary devices

Standards:

1. ASHRAE, Standard 41.7-84, Standard Method of Measurement of Flow of Gas
2. ASTM, Standard D3796-79, Practice for Calibration of Type S. Pitot Tube
3. ASME, Standard PTC 19.2-87, Part 2 Pressure Measurement-Instruments and Apparatus
4. ISA RP2.1-62 Manometers Tables, Recommended Practices

Equipment:

- 1-D Hot wire thermoanemometer with digital readout
- acrylic tubing
- inlet bells
- swedgelock fittings

Simplified Testing Procedure:

1. physical examination of sensor
2. install sensor in test chamber and run 3 tests with a minimum of 10 points each starting from the lowest point up to the rated point
3. generate test report including graph

Electric (KW and KWH) and Gas Utility Meters (MCF)

Calibration to be conducted under subcontract to local electric and gas utilities.

Light Levels

Portable light meters will be compared to an existing NIST-traceable light meter at the Energy Systems Laboratory.

Solar

Portable meters will be compared to an existing NIST traceable solar meter.

Task 4. System Communication Testing

Purpose

The purpose of this task is to conduct bench-mark communications testing of all field data acquisition systems for the LoanSTAR MAP. This includes testing the compatibility of sensors, DAS and the host computer. Public domain software, using open communications protocol, will be developed by the ESL for each system. DAS types that adequately satisfy ESL testing will then be accepted (certified) for use in the LoanSTAR MAP.

Functions

The primary functions of system communications testing are: 1) communications benchtest, and 2) software design.

Communications Benchtest

The communications benchtest facility will ensure that the local area network polling computers have access through open communications protocols to the instrumentation installed in each building. Each type of data acquisition system selected for a LoanSTAR building must be tested and certified for compatibility with MAP software. This testing will be conducted at the ESL.

The LoanSTAR MAP Net will facilitate side-by-side testing with ESL benchtest equipment. MAC will establish a battery of tests, including: public domain modem function under automatic answering/automatic dialing (AA/AD), hardware/software implementations, catastrophic loss of power/power up cycles, bit error detection and remediation, redial on busy or loss of connection, password sign-on/sign-off, recording interval set/reset, clock set/reset, status check/recheck, bit stream protocol for handshaking identification, initialization, audit trail capabilities and emergency operating procedures. The open protocol requirement is essential.

MAC can and will require source code in order to establish communications protocols and procedures. In such cases, non-disclosure agreements will be signed in order to obtain those portions of the code that contain vital information. MAC must have ready access to address codes and bit stream password construction of all field installations. These protocol requirements will reside encrypted on the database, linked to each respective installation.

Software Design

A necessary subtask of the system communications testing and development is the development of software to poll, archive, analyze and report the energy savings of agencies participating in the Texas LoanSTAR. Important aspects of the software development process include the database design, approach and functional tasks of the LoanSTAR MAP database. A description of a typical data path for a Texas LoanSTAR agency or building also is provided.

Database Design

The conceptual design of the database for the LoanSTAR MAP is illustrated in Figure 4. The four primary functions of the database are shown in the screen of the workstation. A set of typical files is shown to illustrate the complexity of the different types of information needed to make decisions about energy usage.

Typical information for a given site will depend on the level of monitoring installed at each site, the availability of historical metered information, and information obtained from the agencies and from the energy audits. Typical information will include the following types of files:

1. Hourly data. Electronically polled data in columnar format consisting of 1 to 50+ channels of data.

2. Monthly utility billing data. Manually entered data from utility billing data.

3. Weather data. Electronically polled weather data in columnar format representative of the weather conditions at that site.

4. Site description information. Information gathered from each site which describes such things as square footage, type of exterior envelope, etc.

5. Cost information. Manually entered cost data which accurately reflects the appropriate $/CCF, $/kWh, etc., for that site.

6. Log notes. Notations concerning change-out of equipment, changes in functional usage, polling procedures, etc.

Database design approach

The software engineering approach will include: 1) system engineering and analysis, 2) software requirements analysis, 3) design, coding and testing of software, and 4) maintenance and upgrades.

1. System engineering and analysis (Product: software plan). This task will identify user requirements; define the analysis to be performed and specify products to be produced; survey other organizations to see what systems are currently being used; identify proprietary software packages that may or may not be performing similar tasks; and perform a formal literature search concerning work performed in this area.

2. Software requirements analysis (Product: software requirements specification). Once the software plan has been established, the next task is to develop the software requirements specification. This document will define data inputs/outputs, and software packages/languages to be used during the codification process. Specialty proprietary statistical, database and graphing packages also will be evaluated for inclusion in the software design.

3. Design, coding and testing (Product: preliminary and detailed design, coding and testing). This task comprises the formal development, coding and testing of software modules. It includes proper documentation and insertion of completed code into the system architecture. Available public domain software will be used (when appropriate) to reduce coding requirements.

4. Maintenance upgrades and software releases. This task entails the maintenance and upgrades of software produced in the previous three tasks. Maintenance and upgrades are important functions for any software project. Unlike hardware, computer software requires continual upgrading and maintenance to assure that problems (or "bugs") are resolved and new features incorporated into the system as rapidly as possible.

Once the necessary software for the LoanSTAR MAP Net has been developed, tested and documented, the software will be released as public domain software. Software developed for the LoanSTAR project will be copyrighted by Texas A&M. Code and data from the LoanSTAR program will be released "as is" without support or warranty.

Functional Tasks for the LoanSTAR MAP Database

Primary functions of the LoanSTAR MAP include: 1) data entry, retrieval, polling and editing, 2) database structure and relationship, 3) data retrieval, reports, graphs, browsing, and transfer, and 4) database documentation, help and training.

1. Data entry/retrieval/polling/edit. Data will enter the MAP database from one of several paths: by entry into pre-formatted screens, retrieval from archive files, and from polling of field units. All data will be systematically checked for errors, stored in the appropriate archive format and loaded into the relational file for on-line access.

2. Data structure/relationships. An important aspect to develop is the database structure and relationship to other data records in the database. This task involves

development of database formats that will hold the diverse data needed for analysis of energy consumption data. An outline of anticipated database information requirements is shown in Figure 4. For example, the information required for a typical building easily could include: hourly consumption data and analog inputs, daily data, monthly data, annual data, site description information, schedule information, engineering information, log notes from site visits and interviews, weather information, predicted or simulated consumption, utility billing data and utility rate information. Such information then will be properly cataloged and maintained by the database management system.

3. Data retrieval, graphs, reports, browsing and transfer files. The primary product of the LoanSTAR MAP network will consist of reports and graphs that document energy savings for the GEMC. Transfer files containing detailed information will allow for export/import of the data product for comparative study.

4. System documentation/help/training. System documentation and help and training manuals also will be developed to assure transferability of the information and institutional memory of the source code.

Typical Data Path for the LoanSTAR Agency

Data entering the LoanSTAR MAP can originate from three primary sources: 1) electronically polled data, 2) manually entered data, and 3) data transferred from existing databases. The paths for the different data are listed below.

1. Electronically polled data.
   a. Poll site, check for transmission errors, test for dead telephone line, no answer, etc. -- archive raw data.
   b. Translate to common data format, conduct additional error checking (i. e., pre-established high-low bounds), archive translated data.
   c. Prepare data for insertion into on-line relational database.
   d. Use multi-generation archive of on-line relational database.
   e. Analyze data and prepare reports and graphs.

This procedure is illustrated in Figure 5.

Figure 4. Texas LoanSTAR MAP Database Information Requirements. This figure shows the information requirements for the LoanSTAR MAP database. The four primary functions of the database are shown in the screen of the workstation. A set of typical files is shown to illustrate the complexity of the different types of information needed to make decisions about energy consumption usage.

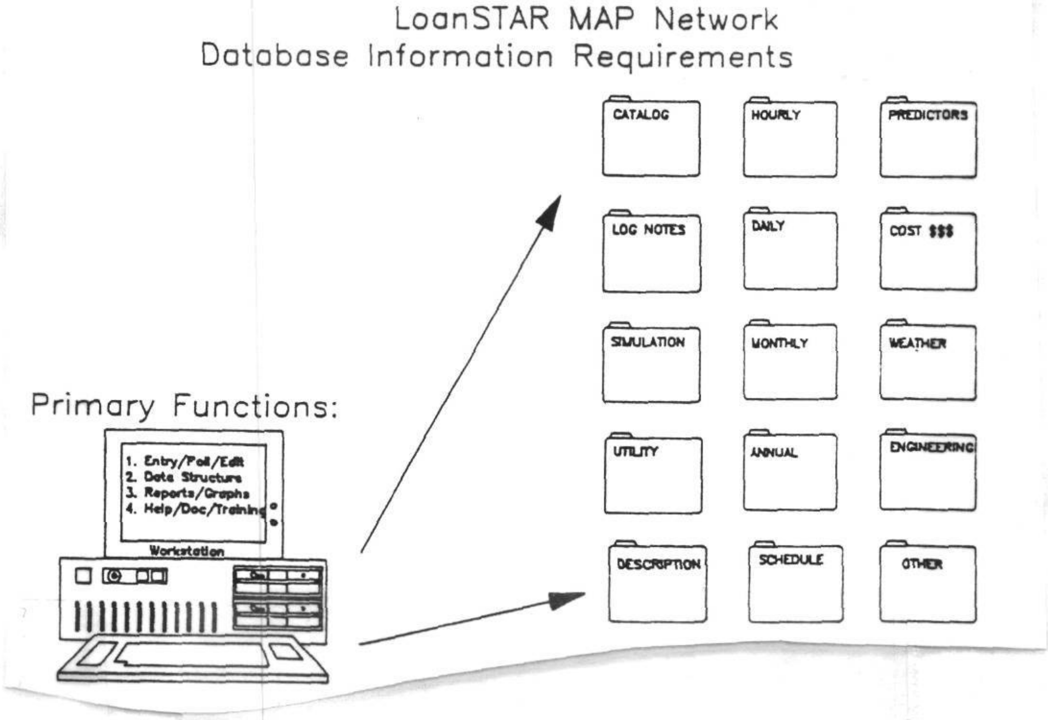
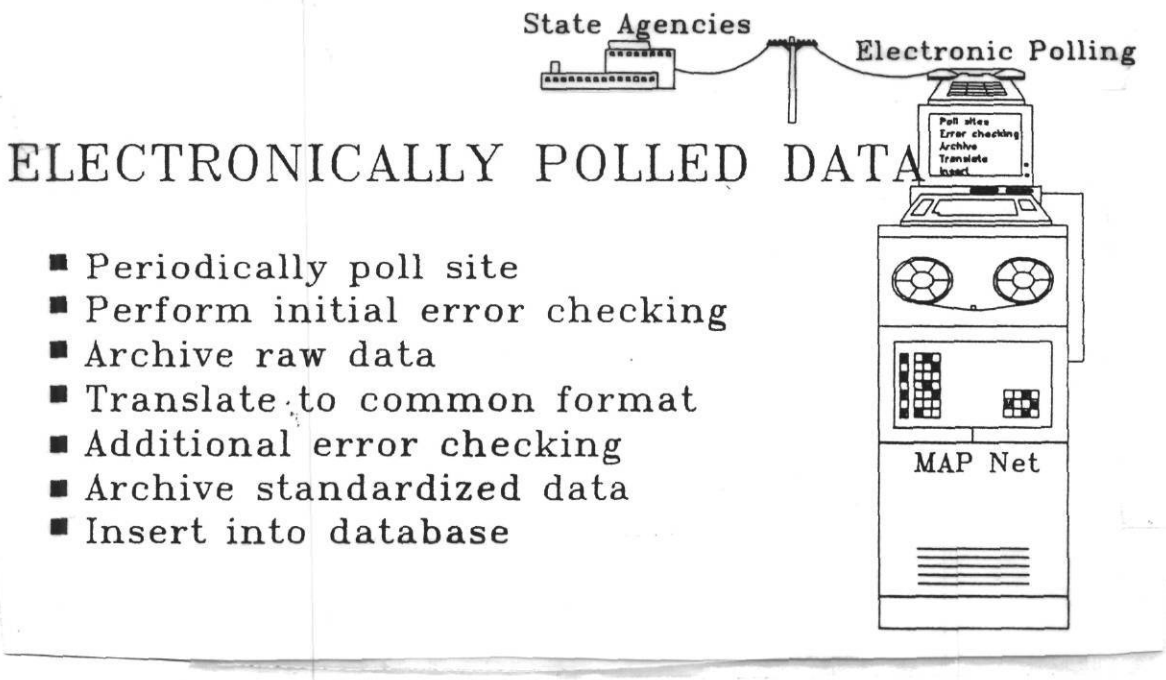


Figure 5. Electronic polling procedure.



2. Utility-type manual data.
   a. Transcribe data using data entry screens, archive raw data.
   b. Prepare data for insertion into on-line relational data base.
   c. Use multi-generation backup of on-line relational database.
   d. Analyze data and prepare reports and graphs.

3. Data transferred from existing records.
   a. Transfer data using appropriate transfer routines.
   b. Prepare data for insertion into on-line relational data-base.
   c. Use multi-generation backup of on-line relational database.
   d. Analyze data and prepare reports and graphs.

Work Plan

The following tentative schedule has been set for delivery of Task 4 sub-tasks.

Date	Action
June 1990	System engineering and analysis Deliverable: Software Plan
July 1990	Software requirements analysis Deliverable: Software Requirements Specs
Jan - Aug 1990	Design, coding and testing Deliverable: Preliminary & Detailed Design
Continuous	Maintenance and upgrades

Task 5. Monitoring Plans, Analysis and Reporting

Purpose

This monitoring and analysis task is responsible for selecting/developing analysis techniques, developing necessary software and analyzing data to:

1. Determine the energy and dollar savings of the retrofits.
2. Reduce energy costs by identifying operational and maintenance improvements at retrofitted facilities. Operator interviews are part of this subtask, as well as communication of needed changes to appropriate agency and operating personnel.
3. Identify the savings of individual retrofits as feasible to help improve retrofit selection in future rounds of the LoanSTAR Program.
4. Initiate an end-use database of energy use for commercial/institutional buildings located in Texas.

Functions

This task will be conducted in two major phases: the pilot year and subsequent analysis with refinements added. During the pilot year, a local area network of computers, named the LoanSTAR MAP Net, will be assembled to archive data and conduct analysis. Data analyses will be performed in several phases for each monitored site. These include:

- verification/modification of audit assumptions
- pre-retrofit analysis
- preliminary post retrofit analysis
- detailed post-retrofit analysis
- interaction and feedback to agencies and operators
- reports

The pilot year will be devoted to developing and testing a set of procedures and analysis techniques needed to implement these activities for each site. Refinements to the procedures will be added throughout the program. Subsequent analysis will streamline and automate such procedures to enable analysis of the increasing number of buildings in the program. During the second year and subsequent years, an end-use database for commercial and institutional buildings in Texas will be assembled and described, based on data available in the database.

<u>MAP Net Hardware Design</u>

The MAP Net will receive data from field instrumentation, analyze the data and produce reports from the analysis. This network is being configured to archive raw data, process working data files on a large server disc, automatically back up all data transactions on tape, and produce hard copy. The network includes multiple work stations for engineering analysis, software development and secretarial duties. Data received from buildings will be linked to a number of parametric files that contain information about building design, operational characteristics, weather, engineering constants and relationships, reports and recommendations, etc. The hardware configuration of the LoanSTAR MAP Net is shown in Figure 6.

Information from field installations will be received on the file server via modem communications controlled by XT-class PCs. A portable XT-class PC will be deployed as needed to spot-check instrumentation function and integrity.

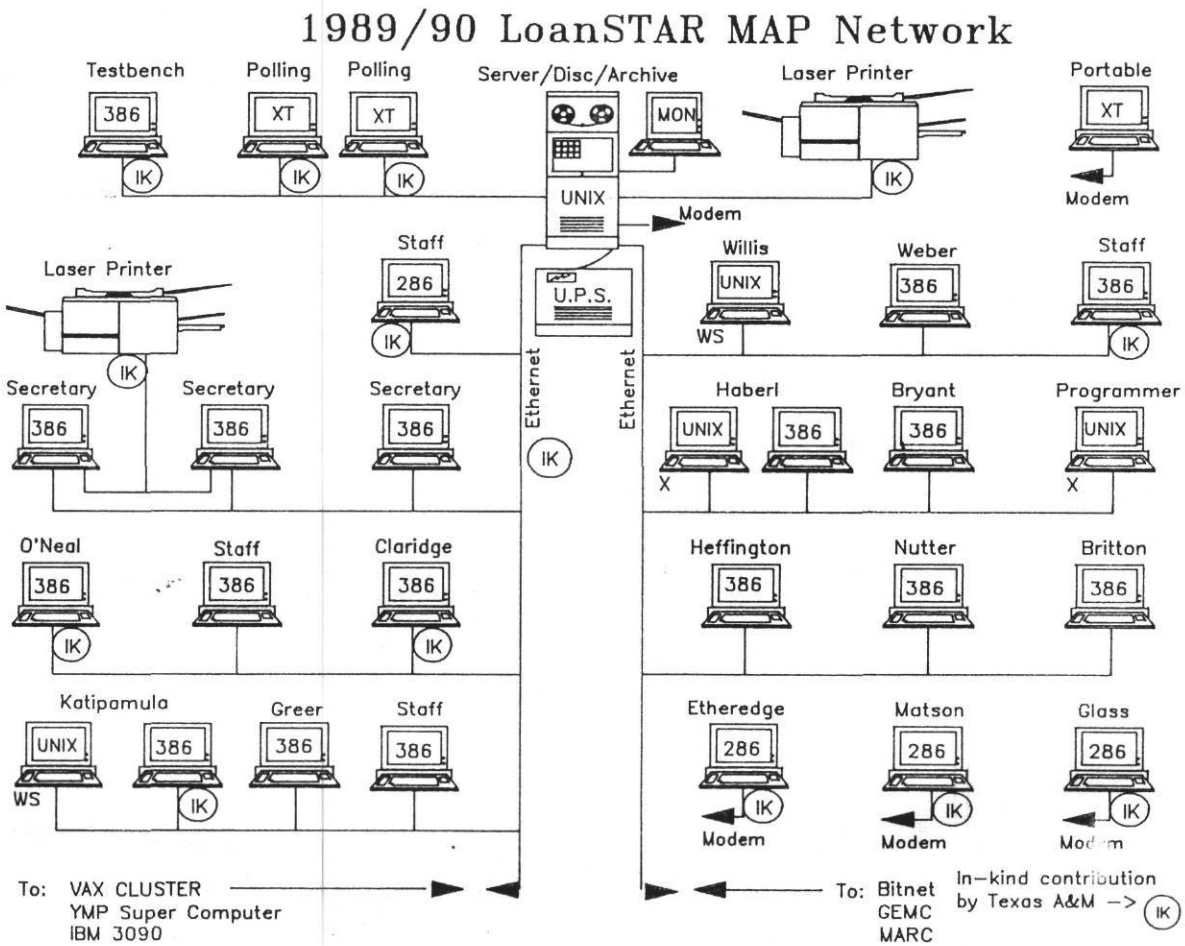
The file server is a dedicated UNIX-based Ethernet processor. As such, it contains relevant hardware and software to amass the data coming from field instrumentation; to insure protection of the data system; and to back up automatically all data on a frequent schedule. Besides network workstations, the file server maintains a working disc for software residence and file manipulation, cassette tape backup and a laser printer. There are two kinds of workstations on the network: 80386 clones and UNIX workstations. These machines are distributed across three primary uses: secretarial workstations, engineering workstations and staff workstations. The LoanSTAR MAP Net will reside on the TAMU Ethernet backbone. This connectivity ensures LAN access to the IBM and Amdahl mainframes, the VAX clusters and the Cray YMP supercomputer on campus. This connectivity also puts the LAN on national networks such as BitNet, etc.

System Operation

The primary function of the LoanSTAR MAP Net is to acquire and archive data, analyze data and report the results to the project monitor and others. The hardware discussion above outlines the physical configuration of the network. This section briefly develops the network functions for each of several groups of people associated with various kinds of data in the database, and the relevant processing by each group. The methods by which the data acquisition archival, analysis and reporting are accomplished are not task independent. The primary function of data acquisition and archival is augmented by data processing all along the task alignment of the program. The operation of the LoanSTAR MAP Net will proceed according to task assignment as previously diagrammed, and as summarized below.

The approved audit reports and recommendations from Task 1 will reside on the database with an identifier for each report. The identifier will indicate the level of monitoring this site receives, and linkages to the data that come from this site.

Figure 6. Texas LoanSTAR MAP Network. This figure shows the Texas LoanSTAR MAP Net to be configured at Texas A&M. The MAP Net will utilize a UNIX-based AN server amd workstations connected with an existing Ethernet.



Information transmitted to the file server via polling computers from each field installation will enter the database with an appropriate identifier. Pertinent to each field site is other information relating building population and use parameters, operation and maintenance practices, architectural parameters and meteorological parameters. Each of these classes of data will enter the database with an identifier to link it to the polled information. The information in the database subsequently is processed at the engineering and staff workstations. The results and reports thus produced will reside on the database with an identifier that links all the raw and processed data files.

Overview of Analysis/Feedback Process

The analysis process takes different types of data collected before and after the retrofit to determine the savings due to the retrofit. The savings are compared with the audit estimate and feedback is provided to the owners and operators. This process is illustrated in Figure 7.

The data used can be listed in four categories. Point-in-time information is collected one time and assumed to be constant unless changed by a specific action such as the retrofit. The energy consumption data in aggregate or sub-metered form is collected as time-sequenced data. Data on the parameters which directly influence energy use such as temperatures, schedules, etc., is also necessary as well as information on the comfort needed and other system requirements. This data is all used in a before-after analysis to determine the energy savings.

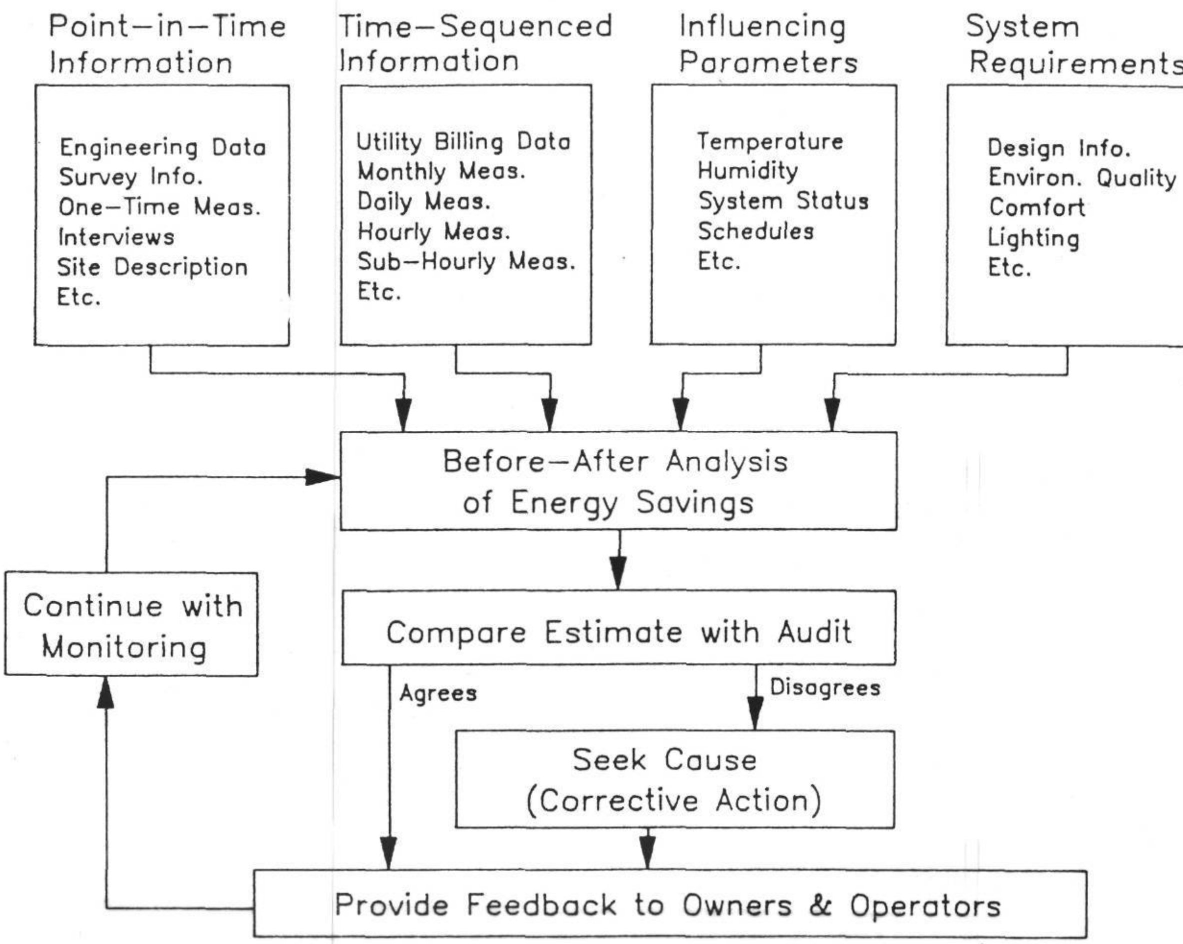
The savings measured are compared with the audit estimate. If similar, this is reported to the owners and operators. If there is a significant difference, the cause must be determined so corrective action can be taken.

This overall process is detailed in the sections which follow.

Verification /Modification of Audit Assumptions

The engineering savings estimates for the LoanSTAR retrofit measures rely on numerous assumptions made by the auditors. Some of the most crucial estimates are the electrical gains, building schedules, lighting schedules, etc. Data obtained from initial monitoring of buildings will be used (when practical) to check audit assumptions. In some cases this may lead to recalculated savings estimates. A procedure will be developed for "calibrating" the inputs used by energy calculation tools for use in these checks. Such a procedure is currently being developed for use with the DOE-2 building simulation program. Since this program is large and time-consuming to use, it must be restricted to certain very large installations. Similar "calibration" procedures for less detailed programs, such as ASEAM, also will be investigated.

Figure 7: Before-After Analysis of Energy Conservation Retrofit Savings. This flowchart illustrates the before-after analysis of retrofit savings. For each site before-after point-in-time and time-sequenced information, influencing parameters, and system requirements are evaluated to determine if energy savings match those of the audit estimates. Corrective measures (if needed) and feedback to owners and operators are also provided.



Analysis-Approach

The primary objectives which will influence the analysis methods used are the need to determine

1) overall cost savings due to the retrofits, and
2) the savings and effectiveness of individual retrofits.

These objectives lead to a requirement for different levels of analysis methods and tools.

Determination of overall cost savings implies a need for a standard evaluation technique which can be applied to all buildings. Since data will be limited from many buildings, methods which require only whole-building data, such as PRISM, will be evaluated for use as the standard evaluation technique.

More sophisticated approaches will be explored when the available data warrants or as required to adequately determine overall savings.

The savings due to individual retrofits will sometimes require very little analysis when adequate submetered data is available. Other cases will require the use of more sophisticated analysis techniques which incorporate a more inclusive set of influencing parameters and building characteristics. Models which incorporate simplified scheduling, extensive weather data and techniques such as principal component analysis and single -valued decomposition will be investigated for these applications. The use of calibrated inputs for predictive programs such as DOE-2 and ASEAM also will be considered.

Pre-retrofit Analysis

Pre-retrofit analysis will utilize energy-use data collected from the building before retrofit measures are installed. This analysis will develop a preliminary model of energy use in the building that will be used to determine energy savings and cost savings due to the retrofit. The quality of such models depends on the amount and type of data available. This will vary from a few months of monthly whole-building data toa year of hourly sub-metered data. Additional information that will be used includes the audit reports and data, the DASS site plans and finalized measurement site plans, supplemented in some cases by interviews with building operators.

During the pilot year, procedures will be developed for using this pre-retrofit data to develop a suitable empirically-based model (with physically meaningful parameters) for predicting energy use. Different levels of model complexity will be used for different levels of data, e. g. a sequence of monthly data likely will permit use only of temperature (using PRISM) as a predictive variable. Daily data would permit incorporation of additional predictive parameters (e. g. scheduling, solar radiation, etc.)

Hourly data on energy use, weather, occupancy, etc. will make possible evaluation of models which incorporate hourly schedules, weather data, etc.

Pre-retrofit data also will be examined to determine if submetering installations accurately measure the response of the building and particular end-uses to the planned retrofits. In some cases, the analysis might indicate a need for changes in the monitoring systems installed.

The procedures developed during the pilot year will be evaluated and updated in later years to incorporate refinements based on experience gained with the Texas LoanSTAR buildings.

Preliminary Post-Retrofit Analysis

Preliminary post-retrofit analysis will be conducted to provide initial savings estimates based on measured data and to compare these estimates with the audit savings estimates. This analysis may lead to corrective measures if the retrofits are not performing as planned.

Measured consumption following the retrofit will be compared with the consumption predicted by the model developed in the pre-retrofit analysis. This will indicate whether the retrofit measures are performing as planned. If retrofit measures do not perform to design expectations, further analysis (sometimes in conjunction with site visits) will attempt to determine whether there is a modeling problem, an installation error or an incorrect audit estimate of savings. These findings will be used to correct or update the model or audit estimates of savings when necessary.

When installation errors are detected, the retrofit contractor will be contacted and asked to correct the installation. Correction of such problems will increase savings of the retrofit and may prove to be a significant benefit of the monitoring and analysis program. Anticipation of such cases necessitates development of a procedure to resolve conflicts between retrofit contractors and Texas A&M as the monitoring and analysis contractor.

Detailed Analyses

Following pre-retrofit analysis and preliminary post-retrofit analysis, the building models will be refined as additional energy-use and other data are collected. Thus, as information is obtained about building schedules, system operating parameters, etc., it will sometimes be possible to update the pre-retrofit energy-use data. The refined "pre-retrofit models" will be used then to provide better estimates of retrofit savings.

In some installations, "on-off" testing will be used to determine the impact of retrofits such as lighting. This will be particularly valuable if the pre-retrofit data is inadequate.

While all three phases of the analysis effort will seek operational improvements to produce additional energy or cost savings, it is expected that the majority of that effort will occur during this phase. Identification of O&M measures typically will require significant interaction with building operators. This activity is experimental; it has been applied in a couple dozen individual buildings, but it has never been applied before to a large number of buildings. So significant effort will be required to develop an efficient approach to finding, communicating and measuring the impact of these O&M measures.

This portion of the analysis effort also will identify the savings attributed to specific retrofit measures when practical. This information will go to the GEMC to improve the measures selected for future loans.

Feedback to Building Owners and Operators

The MAP will differ from all previous large-scale monitoring programs by its emphasis on interaction with building operators so they will better understand operating practices and provide subsequent suggestions for improving operating practices. Evaluation of current research practices will be based on an examination of whole-building and submetered consumption data as well as discussions with building operators. The experience of earlier research projects suggests that an interactive process will be most effective. Some features of the operation are obvious from the consumption data, but others require observation of the data and discussion with building operators. However, an important part of this task is attention to the behavioral aspects of communicating with the operators so they will feel they are an important part of the team, and hence want to see the O&M measures implemented and succeed.

An initial meeting with the building operators will review the preliminary data collected, familiarize them with system capabilities and solicit their input on specific operating problems which may be apparent in the data. The emphasis will be on benefits to both MAC personnel and the operators. The program will make them look better as operating personnel and enable them to learn more about their buildings. Subsequent meetings will be held when analysis shows a need for operator input or leads to recommendations for operational changes. Written recommendations will be sent to the agency and research will be devoted to determining the most effective written, verbal and graphical communication formats.

Considerable planning will be required to develop efficient and effective procedures for identifying O&M measures to building operators and agencies. It is likely that workshops for building operators will eventually be developed from this effort. Feedback to operators and owners may eventually become a separate task.

The successful implementation of operating improvements will be enhanced greatly if the GEMC and the agencies can provide significant financial (or other) incentives for key operating personnel in buildings that have or achieve highly efficient operation.

Reporting

The findings from this program will be reported in four ways:

- regular written summaries.
- technology transfer workshops.
- feedback (written and oral) to building owners and operators.
- public domain polling, archive and analysis procedures.

Regular Written Summaries. Regular summaries from this program will take several forms. For the GEMC and the agency involved, both of which are interested in monitoring the success of a retrofit, summaries will be provided quarterly. These summaries will include details of energy use and dollar savings by end-use (when monitored.) Additional reports will be provided for buildings/facilities which perform below expectations. The fourth quarter report will be an annual report that summarizes major advances in analysis techniques, methods for identifying O&M measures and effective ways of communicating and implementing findings. The reports for this task normally will be incorporated within the overall report for the project, though topical reports and papers will be produced.

Technology Transfer Workshops. As the data from this program are analyzed and new techniques developed for estimating retrofit energy savings, the MAC will organize workshops to transfer this technology to engineering auditing firms, building operators, etc. The first workshop is planned for the second year of the MAP. Some of these workshops will be incorporated into the annual building symposium that is hosted by TEES and sponsored by the GEMC.

End-Use Database

An energy end-use database for the buildings in the LoanSTAR Program will be assembled and described based on the data archived. This database will be useful to state agencies for defining appropriate energy-use indices, planning and budgeting for energy costs of new construction, etc. It also will be useful to utility companies within the state. Support from utilities will be sought to broaden and enhance the value of this database. A more detailed plan for this database will be provided in the plan for Year 2.

Subcontracts

Four subcontracts have been negotiated under this task to provide support to the entire project. They are:

1. Lawrence Berkeley Laboratory: consultation on the metering, monitoring and analysis tasks and work with the EMCS system on a specific building to investigate the necessary system communication protocols and incorporate data from the EMCS system into the remote monitoring program;
2. Massachusetts Institute of Technology: consultation on development of calibration procedures, data acquisition hardware and software support; and advice on the metering, monitoring and analysis tasks.
3. Pacific Northwest Laboratory: to provide consultation on monitoring hardware, building monitoring software, analysis and handling of the data.
4. Princeton University: to provide PRISM and behavioral support work, and consultation on the metering, monitoring and analysis tasks.

Work Plan

During the first year of the project, this task will emphasize development of procedures while carrying out analysis on the buildings for which retrofits are planned. This will result in application of less refined analysis tools and methods to some buildings than will be used later. During the following years, implementation of the procedures will proceed on larger numbers of buildings with research effort aimed at refining and improving the techniques used.

Listed below is a set of subtasks that will be implemented:

Year 1

- Analyze data and develop model for prototype building with Level 3 system (Zachry Engineering Center, TAMU.)

- Collect and analyze data and develop model for prototype building with Level 1 system (A&M Consolidated High School, College Station.)

- Calibrate DOE-2 model of Zachry Engineering Center and evaluate its usefulness.

- Work on calibration procedure for use of DOE-2.

- Begin calibration of ASEAM to A&M Consolidated High School.

- Work on calibration procedures for use with ASEAM.

- Analyze data from Zachry Engineering Center and attempt to identify O&M changes.

- Develop pre-retrofit models for Zachry Engineering Center,A&M Consolidated High School and other buildings for which adequate data becomes available.

- Analyze data from A&M Consolidated High School and attempt to identify O&M changes.

- Collect and examine data from buildings approved for retrofit during first year of LoanSTAR Program.

<u>Year 2</u>

- Collect and analyze data from buildings retrofitted during year 1 of LoanSTAR.

- Collect and analyze data from buildings retrofitted during year 2 of LoanSTAR.

- Develop preliminary methodology for identifying O&M measures using measured data and operator interviews.

- Refine models developed during Year 1 and apply to buildings for years 1 and 2.

<u>Year 3</u>

- Refine procedures developed during years 1 and 2.

- Collect and analyze data from all appropriate buildings.

- Additional tasks to be defined.

<u>Year 4</u>

- Same as year 3 with additional buildings on line.

The Design of Field Experiments and Demonstrations.

Jeff S. Haberl*, David E. Claridge*, David T. Harrje**

* Energy Systems Laboratory, Mechanical Engineering Department, Texas A&M University, College Station, Texas

** Center for Energy and Environmental Studies, Princeton University, Princeton, New Jersey

1. KEYWORDS

EXPERIMENT, EXTENT, TEST-REFERENCE, DESIGN, ERROR ANALYSIS, WHOLE-BUILDING, TYPES, ON-OFF, SUB-METERING, BENEFACTOR, BEFORE-AFTER, SIMULATED OCCUPANCY

2. ABSTRACT

Experiments that monitor energy use and environmental conditions in commercial buildings depend on the purpose of the data collection and analysis, the uses of the data and the analysis, the type of analysis to be performed, the experiment design, the budget available, and the extent of monitoring and data gathering required. Designing the right monitoring program for a specific project requires a skilled balancing of these options.

This paper discusses the design of data gathering experiments used in commercial building energy use and environmental monitoring projects. First, a general overview highlights the purpose, benefits, types, design, extent of monitoring and relatedness. Then we discuss the analysis of methodological errors.

3. INTRODUCTION

This paper presents an overview of the design of experiments that monitor energy and conditions in commercial buildings. We find that such experiments depend on the purpose of the data collection and analysis, the uses of the data and the analysis, the type of analysis to be performed, the experiment design, the budget available, and the extent of monitoring and data gathering required. First, a general overview highlights the purpose, benefits, types, design, extent of monitoring and relatedness. Then we discuss equipment calibration and the analysis of methodological errors.

February 1990. To be published in the Proceedings of the IEA Field Monitoring Workshop, Gothenburg, Sweden, April 2-5, 1990.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 2 (26)
Title: The Design of Field Experiments and Demonstrations.

3.1. BENEFIT, TYPE, DESIGN, AND EXTENT OF MONITORING

3.1.1. Who Benefits From Monitoring Buildings?

Information from building monitoring projects is of little value unless it is used by those making energy-related decisions, including:

Local, State, and Federal Agencies. Energy use in buildings is of interest to public agencies such as local, State, and Federal planning agencies. Unfortunately, data on energy use are not collected in a consistent format, and are not easily accessible to policy makers and public sector analysts. Olsen et al. (1988) reviewed data sources on energy use in small commercial buildings and showed that data are not readily accessible to public agencies or policy analysts who depend on it.

Utilities and Fuel Suppliers. Utilities can benefit from several types of building energy consumption data. Accurate energy use and demand data by building sector and type is essential for planning purposes. End- use data is needed for demand-side programs such as thermal storage incentive programs. Data is also needed to determine the effect of demand reduction actions such as correcting simple operation and maintenance problems. A recent study by Haberl and Komor (1989) showed that operation and maintenance problems could be responsible for as much as 8% of peak summertime electric demand and can be eliminated for as little as $56/kW.

Building Energy Analysts. An important beneficiary of energy-related information is the building energy analyst or energy auditor. Current building audit procedures may not be providing as much useful information as other analysis techniques. Such audit procedures could be improved by incorporating an interactive procedure whereby the energy analysts can diagnose problems by first making use of an analysis of metered data and then following-up with on-site measurements. Such procedures can address major concerns of the occupants, such as, comfort, lighting and environmental quality issues which are normally ignored in commercial building audits.

Manufacturers and Contractors. The building service contractor is yet another potential beneficiary of information extracted from metered data. Typically, contractors are actively involved in various aspects of the building. Preliminary observations indicate that they do not have any data on energy use, and that their only sources of information are complaints by occupants and inspections of equipment (Haberl and Komor 1989).

The Energy Consumer. As retrofit decisions are usually made by the building occupant or owner, improved energy information must be in a form that is useful and understandable to occupants or owners if it is to have any effect on energy use. Building operators often do not see the energy bills and thus have no way of assessing the impact of their day-to-day actions. Often, commercial property is remodeled without the necessary consideration given to the implications on the energy consumption. With the passage of time engineering records, as-builts, system descriptions, etc. become unavailable. Sometimes information about energy use may not be in a format that is easily understood. Early results from field tests performed with building occupants have shown that significant improvements can be made in the way metered data is packaged and presented to the occupants or building owners (Komor et al. 1989).

3.2. APPROACHES TO THE PROBLEM

The following sections of this paper present an overview of the design of experiments that monitor energy use and conditions in commercial buildings. First, we discuss the types of monitoring programs followed by a discussion of experiment design. Then, we discuss the extent to which information and data are gathered for typical experiments and finish this section with some comments about balancing the benefit, type, design, and extent of monitoring. The paper concludes with a discussion of equipment calibration and error analysis.

4. MONITORING ENERGY AND CONDITIONS IN BUILDINGS

4.1. PRIMARY TYPES OF MONITORING PROGRAMS

Monitoring the field performance of building energy systems is fast becoming the standard method for making decisions about energy use in commercial buildings. Data gathered from such studies are diverse and depend to some extent on the purpose for performing the study and the type of monitoring program. Some examples of the types of energy monitoring programs include consumption planning and load forecasting, evaluating end- use energy data, monitoring energy savings from retrofits, determining system efficiencies, evaluating environmental quality issues, analyzing the human factor, and diagnosing operational and maintenance problems.

Gathering information and measuring data about energy use and conditions in buildings depends to a large extent on the purpose and objective for performing the work (MacDonald and Wasserman 1989). The following are the categories that we feel represent the building monitoring programs.

4.1.1. Consumption Planning and Load Forecasting

Energy use data is most frequently collected as an aid in planning and forecasting energy consumption. For the most part such programs are performed by local or regional utility suppliers and serve as a basic tool for assessing system growth, geographic distributions, load characteristics, etc. local, State, and Federal agencies also perform such studies which are used for the purpose of regulating the utility suppliers. To a lesser extent energy analysts, engineers and manufacturers also perform such studies to assess market potential, and analyze trends.

4.1.2. Evaluating End-use Energy Data

End-use energy data has become an important tool for ascertaining how energy is being used by consumers. With such information (for a statistically significant sample) utilities and regulating agencies can better determine the answers to such complex issues as rebate and bounty programs or third-party conservation financing programs.

4.1.3. Monitoring Energy Savings From Retrofits

Recently, with the advent of affordable, high-powered microprocessors, researchers have begun to unravel the complexities of determining the energy savings from a large number of retrofits by electronically measuring the important parameters of individual retrofits. Actual measured savings from individual building conservation retrofits has, until recently, been too expensive to justify for all but the largest projects. In its place, the energy analyst has had to rely on utility billing data, energy usage estimates, simulations, or rules-of-thumb to calculate the energy savings. Most often, energy conservation retrofits are installed and forgotten with no monitoring or only a cursory look at raw monthly data.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 4 (26)
Title: The Design of Field Experiments and Demonstrations.

Programs which monitor the energy savings from individual retrofits are fast gaining acceptance by utilities, government agencies, and energy analysts. The energy consumer also can benefit from such programs since they will gain (or lose) the most from the purchase of energy efficient appliances.

4.1.4. Determining System Efficiencies

The evaluation of system or individual components is important to manufacturers, contractors, engineers, utility suppliers, and ultimately consumers. Government agencies can also benefit from improved information about the performance of energy systems and appliances, especially when it is derived from long-term measured data (versus one-time laboratory tests).

4.1.5. Environmental Quality Issues

With increasing awareness of environmental quality (both inside and outside), the monitoring of indoor environments has become an issue. Whether it relates to the monitoring of contaminants, lighting conditions, thermal conditions, or other health and safety issues, it is becoming as important to measure why energy is consumed as how much is consumed. Since many measurement programs make before-after measurements of energy consumption, it is equally important to measure the before and after states of the interior environmental conditions since the two are often directly related.

For example, the installation of lighting reflectors into existing fixtures has caused considerable discussion. Vendors claim that such devices deliver nearly the same illumination to the work plane as the existing non-reflective fixtures with a considerable savings in the energy consumption. Such systems are usually installed at no initial cost to the owner. The vendor receives an agreed-upon fixed dollar payment based on the calculated lighting-cost savings for several years. Such a program may or may not be in the best interests of the consumer.

A better way to compensate the vendor would be to measure the actual cost savings which would include the a credit for the electricity savings, a credit for the reduced cooling load, a credit for the reduced maintenance (there are fewer lamps to re-lamp), a penalty for the increased heating load, a penalty for possible increases in cleaning requirements, and a careful photometric analysis to determine if the proper lighting levels are being maintained (especially over the duration of the program when the surface of the reflector becomes dirty). A well designed monitoring experiment could easily accomplish this.

4.1.6. Analyzing the Human Factor

One important consideration that has eluded most energy studies is the human factor. A recent study by Komor et al. (1989) showed that consumers, contractors and even engineers may not be receiving enough useful energy consumption information to make the most basic determination: e.g. is a new system performing as expected? In many instances, consumers do not understand electric demand, and therefore do not have the basis to understand whether a proposed retrofit will save them money. In one instance, even the engineer who designs such systems did not understand how to calculate the electric demand savings.

Building occupants also govern the quality of the indoor environment. Although much has been accomplished in laboratory comfort measurements field studies seldom measure anything but the most elementary comfort parameters. Energy studies may measure indoor air temperature, sometimes humidity, and only in rare instances ventilation rates or indoor pollutant levels. With improved low-cost measurement and analysis techniques, building scientists are beginning to unravel the complex interactions that link energy use, comfort, and the indoor environmental quality issues.

4.1.7. Diagnosing Operational and Maintenance Problems

Inefficient operation of HVAC systems wastes valuable resources, can be difficult to track and rarely receives the attention necessary from understaffed building operators Building operators have a need for focused, timely energy information that is not being met in most facilities. Current trends that rely only on increased monitoring of energy usage may not be the best answer because they require constant attention by building personnel who seldom have the training or the resources to make full use of the data at hand. Building operators rarely see the energy impact of their day-to-day actions, and even if they did, without incentives, it is doubtful that they would go that extra mile to save energy. (Haberl et al. 1989).

Another issue poised on the horizon for building researchers is the application of real-time energy consumption data to operational problems. Which variables should be displayed? What intervals and which graph types are most effective? Can operators who have been trained with traditional "action-response" methods be retrained to fully utilize abstract computerized control displays (Zuboff 1988)? Will facility managers use such data as a weapon to punish operators who are not fulfilling their quota of repair tasks? These critical people-oriented issues and many more like them remain to be answered in the coming years.

4.2. IDENTIFYING THE EXPERIMENTAL PARAMETERS

The design of the monitoring experiment should measure and evaluate both the ingredients and products of the process under consideration. Figure 1 illustrates the three primary categories which represent building monitoring experiments.

4.2.1. Defining the System Requirements

The system requirements are the products or value that the mechanical and electrical systems provide to the building, and should include: 1) some measure of what the original design requirements were; 2) an assessment of any special requirements (e.g., clean rooms, computer rooms); 3) an analysis of environmental quality issues; 4) a measurement of the comfort conditions to be maintained; and 5) a measurement of the lighting environment.

4.2.2. Measuring the Energy Consumption

Measuring the energy consumption should include: 1) a measurement of the electricity use and demand profiles; 2) measurements of natural gas, fuel oil and other fossil fuel consumptions; 3) measurements of thermal energy consumptions; and 4) measurements of energy consumed from renewable sources (i.e., solar, wind, geothermal, economizers).

4.2.3. Measuring the Influencing Parameters

The Influencing Parameters represent significant parameters that influence energy consumption. These parameters are grouped as: 1) environmental parameters; 2) system parameters; and 3) operational parameters. Wind, ambient temperature, sunlight, and cold water temperature are examples of environmental parameters that can easily be recorded at the site or transferred from a nearby weather station. Operational parameters are occupant related and vary hourly or daily. Typical parameters include occupancy, operating hours, and custodian schedules. System parameters are characteristics that define the installed equipment (e.g., AHU damper settings, thermostat set-points, etc.). System parameters and operating parameters are similar except system parameters are directly related to each subsystem and operational parameters are only indirectly related. Operational parameters tend to change at least daily, while system parameters change less frequently, if at all.

5. DESIGNING THE EXPERIMENT

There are many different ways of designing an experiment to measure the energy efficiency of an HVAC component or to compare one building to another (Harrje 1982; Frascatero and Lyberg 1983; Lyberg 1987; Ternes 1987; MacDonald 1989; ASHRAE 1987). Most experimental designs can be categorized according to whether they are on-off experiments, before-after experiments, simulated occupancy experiments, or test-reference experiments. Most experiments rely either on the measurement of energy consumed directly at the device (sub-metering) or at the whole-building boundary.

5.1. ON-OFF EXPERIMENTS

On-off experiments measure the efficiency improvement of a component or system by simply turning a device on-off and measuring the impact upon the variable of interest. Such experiments, in effect, use the building or system as its own reference. On-off experiments require that the component or system can easily be turned on-off and are therefore limited to systems that can meet this criteria. Extended on-off experiments can be performed by attaching a simple runtime meter to a device, measuring the duration of on-time versus off-time over a given period and relating it to a one-time measurement of power or energy required to turn the device on.

When on-off measurements are being considered for systems or groups of systems in a whole-building configuration the measurement period should either be greater than the time constant for the building or the experiment should be structured to allow measurement of interactions. For example, when considering a lighting retrofit that involves a considerable reduction in the electrical energy consumption it may be necessary to consider the interaction of the lighting system with the heating and cooling requirements of the HVAC system that serves the area. In this case an on- off experiment using hourly measurements (taken on weekends) can provide valuable insight into such interactions and may give an estimate of additional savings attributable reduced cooling loads (or increased heating loads).

Kimura and Stephenson (1968) observed that such a relationship can be deduced by a simple curve fit of an exponential decay relationship to a step change in conditions. This idea has been confirmed both experimentally and by computer simulations (Treado and Bean 1988; Treado 1988).

5.2. BEFORE-AFTER EXPERIMENTS

Before-after experiments (which are one-time only on-off experiments), are usually used when trying to monitor the effects of a permanent change to a building. Before-after experiments are also used when on-off cycling is impossible, for example, when measuring the impact of additional roof insulation.

Since before-after experiments are usually a one-time event, careful surveys and planning must take into account system requirements and previous energy consumption characteristics. Appropriate influencing parameters must be identified since before-after experiments usually require normalization for environmental, system and occupancy effects.

5.3. SIMULATED OCCUPANCY EXPERIMENTS

Simulated occupancy experiments measure the occupant effect on building energy consumption by varying specific control parameters during an experiment (Sonderegger 1978a). Simulated occupancy experiments can use on-off or before-after measurement techniques and usually require some type of physiological indices (e.g., comfort, illumination). One example of a simulated occupancy experiment is the use of co-heating units which follow a control pattern that is representative of anticipated occupant behavior.

5.4. TEST-REFERENCE EXPERIMENTS

Test-reference experiments involve the comparison of a building to either a similar building, a normalized data base or to a simulated building. Test-reference experiments can be applied to most retrofits.

5.4.1. To a Similar Building

Test-reference experiments using a similar building require access to two buildings, usually in the same or a similar climate. Construction characteristics, interior environmental conditions and operational parameters must be carefully considered. Such experiments are usually performed when one building has a retrofit applied and one does not. Measurements must identify similarities and differences in the buildings both before and after the experiment.

5.4.2. To a Normalized Data Base

Test-reference experiments that utilize a normalized data base are another way to compare energy usage between a building and what is considered to be normal usage. Such experiments seek to measure the impact of a change by comparing the results to those published in a normalized data base. Typically, buildings used for comparison must have similar functions (or system requirements), energy consumption (i.e., fuel type), and influencing parameters. Sometimes on-off or before-after experiments are also added to account for varying conditions during the period of the test.

5.4.3. To a Calibrated Model

Test-reference experiments using a calibrated model (e.g., DOE-2, BLAST, ASEAM) are essentially on-off experiments that utilize a simulation model to turn systems on-off and then measure the effect as simulated by the model. Test-reference experiments can use forward models, inverse models or component-based models. Forward models are building simulation programs that model energy use using engineering principals (and varying solutions schemes) and are based on a given set of descriptive building characteristics (i.e., wall U-value, wall area and orientation, HVAC system type, etc.). Forward models typically have a set number of system types and allow the user to input different values for the control variables. Inverse modeling, a type of system parameter identification, simulates a building's energy consumption (or other variable of interest) by identifying a simplified (or aggregate) model from actual performance records (Sonderegger 1978; Rabl 1988; Subbarao 1988, Reddy 1989). Component-based models simulate the transient behavior of individual components and allow the user to assemble a system that is representative of portions or all of the system under consideration (Clark 1985; Klein et al. 1976; Sowell et al. 1986).

Each modeling technique has its strengths and weaknesses. Forward models (i.e., DOE-2, BLAST) are most commonly used in such experiments but can present insurmountable problems during the calibration effort (Hsieh et al. 1989) and are limited in the types of systems that can be simulated. Inverse models are simpler to use, but require measured energy consumption data and measurements of the primary influencing parameters. In some instances inverse models require formulating an appropriate model, deriving a basic set of equations, solving the equations and codifying the solution into an algorithm for each site. Component-based models are the most powerful simulation tool available but, in their current form, are more difficult to master than forward models and can require enormous computational resources. This may change however, if current research by Haves and Trewhella (1988) is any indication of things to come. Their research showed that it is possible to develop a user-friendly front-end preprocessor to a component-based. Such a program would dramatically improve the utility of such models.

6. WHOLE-BUILDING OR SUB-METERING MEASUREMENTS

The measurement of building energy consumption primarily involves two categories; whole-building measurements and sub-metering or component-based measurements. Each has its advantages and disadvantages.

6.1. WHOLE-BUILDING MEASUREMENTS

Whole-building measurements are usually accomplished by taking periodic readings at the building boundary. Such measurements can be manually taken on a monthly or even daily basis and the values transcribed into a computer program for analysis. Alternatively, utility meters (gas and electric) can be modified to generate a pulse or analog signal that can then be recorded by a microcomputer at a pre-specified interval (usually hourly) and analyzed with a variety of methods.

6.2. INTRUSIVE SUB-METERING MEASUREMENTS

Whole-building measurements can provide a wealth of information about a building's energy consumption. They can show relationships to parameters such as temperature, scheduling, et cetera, that can lead to a useful predictive model. However, information is often required on specific components or systems which requires sub-metering. Traditional sub-metered measurements have been performed by expensive "hardwiring" of sensors to a dedicated computer where the information can be captured and recorded for later analysis.

Recent developments have introduced new methods for connecting sensors to their attendant computer, including: powerline carrier, twisted pair wiring, coaxial cable, infrared, low power radio and fiber optics. The Electronic Industries Association is developing a Consumer Electronics Bus (CEBUS) which is an open protocol, hierarchical, multi-media, "plug and play" communications media that will greatly reduce the amount of hardwiring necessary to obtain sub-metered information (EIA 1989). The

Smart House concept, involving combined communication and power cabling, may also provide an improved technique for gathering information about individual component consumption (Gilmore 1988). The potential for direct digital FM communications between field monitoring equipment and a centralized data base have also recently been announced (WSJ 1990). Such systems would substitute for telephone modem communications and might prove advantageous where connection by phone is prohibitively expensive. Cellular-phone computer communications have also been proposed for certain applications where such services are available and prove to be a cost effective alternative to the traditional "hard-wired" phone line.

6.3. NON-INTRUSIVE SUB-METERING MEASUREMENTS

Some recent developments have shown that certain sub-metered information can be coaxed from a whole-building signal using high resolution measurements and a continuous statistical analysis, referred to as non-intrusive sub-metering (Hart 1985). Basically, this type of metering consists of a dedicated microprocessor that attaches to the main electrical service to a building and scans the power consumption at a very high sampling rate. The on-off time of individual devices can then be determined by analyzing their high-resolution signature. When combined with individual component consumption characteristics such measurements can provide sub- metered information about buildings without having to install expensive hardwiring. Currently, this technique has been shown to be effective for residential buildings and is being extended to small commercial buildings (Norford 1990).

7. EXTENT OF MONITORING

The design of building energy monitoring experiment must determine the types of data, the variables to be measured, and the time intervals at which variables are recorded. The primary types of data available include: data-base information, point-in-time information, and time-sequenced measurements.

7.1. DATA-BASE INFORMATION

Data-base information is primarily information that is archived in various forms and kept by different types of organizations and agencies. Data-base information can consist of printed material, charts, graphs, engineering drawings, and specifications. Traditionally it has not been readily accessible in a common computerized format. However, recent trends in the computer hardware industry that have dramatically reduced the cost of electronic storage media may hasten the era of the integrated data base for building energy information.

Data-base information consists of data from several sources, including: engineering data, as-builts, specifications, utility billing data, customer survey records, and other heterogeneous forms of information.

7.1.1. Engineering Data, As-Builts, et cetera

Data-base information in the form of engineering data, as-builts, and specifications are often needed to confirm the types of systems which exist in a building, locate wiring runs, and identify control schemes, etc. Such information is commonly used in experiments that are concerned with evaluating systems, analyzing environmental quality, analyzing human interactions and assessing operation and maintenance problems. Information obtained from such documents is usually very helpful to the design of a monitoring experiment and can save many hours of effort tracing wires, and inspecting electrical panels.

7.1.2. Utility Billing Data

Data-base information in the form of utility billing data typically contains monthly consumption and demand data, and sometimes an identifier for the geographical location of the site and SIC code. When combined with daily weather data from a nearby weather station and analyzed with PRISM, the Princeton Scorekeeping Method (Fels 1986), billing data can be used to separate environment-related energy use into five basic categories: 1) heating plus base level, 2) cooling plus base level, 3) heating and cooling plus base level, 4) absence of heating and cooling -- a flat consumption profile, and 5) absence of heating and cooling -- erratic consumption (Haberl and Komor 1989). General indicators, or figures of merit, can also be developed for a set of buildings by analyzing Electric Load Factors, electric demand profiles, etc.

Utility billing data is relatively inexpensive to obtain, is usually easily obtained for a given building, and can provide a general sense of how a building is performing. When combined with a simple phone survey such information can yield a comparative index (i.e., W/ft2) that can be used to compare a buildings performance with similar buildings in similar climates.

7.1.3. Heterogeneous Data Bases

Useful data for certain types of monitoring experiments can often be found in disparate data bases (Olsen et al. 1988). Such heterogeneous data bases often take the form of publicly available data such as that from municipal records, state planning data, and local, state and national surveys. Sometimes such data can be found in privately maintained (often unpublished) data bases in the form of aggregate utility billing data, utility surveys, and aggregate energy audit results. Most often, such data include monthly consumption and demand information, building description information, and usually are indexed by geographical location, and to a lesser extent, SIC code. For the most part, such data can be obtained for a modest retrieval cost, once the energy analyst knows where to obtain the records of interest.

7.2. POINT-IN-TIME INFORMATION GATHERING

Point-in-time information generally refers to "snapshot" information gathered about a building that can be used to describe "before" and "after" conditions (MacDonald et al. 1989). Usually, point-in-time information is used to gather information about the building description, building occupants, building schedule, system characteristics and control modes, and information concerning recent changes to the building or energy consuming sub-systems. Point-in-time information can be obtained from preliminary surveys or detailed surveys and may include one-time measurements, utilize customer surveys, interviews, and sometimes follow-up surveys.

7.2.1. Preliminary Surveys

Preliminary surveys are typically quite brief, often using phone calls or mail-in responses. Information from preliminary surveys can include details about operating schedules, installed equipment, square feet of conditioned space, and occupant concerns. At best, preliminary surveys can provide rough estimates of such information since many building occupants are usually unaware of the type of heating or air conditioning system in their building, and information obtained may be incorrect (Komor, et al. 1989).

7.2.2. Detailed Surveys

Detailed surveys take the form of the traditional energy audit utilizing information (when available) from previous studies. Typically, such surveys include an instrumented walk-through where information is gathered about the building, its occupants, the energy consuming sub- systems, building zone information, and schedule and occupancy information.

7.2.3. One-Time Measurements During the Survey

Such detailed surveys should, at least, utilize a minimum of instrumentation, including, a camera, a light meter, a thermometer, and a relative humidity meter. In this fashion, existing or "before" conditions can be documented and measured to allow for a comparison to "after" conditions to determine if there has been in improvement (or degradation) of the interior environmental conditions. Often, in the case of low-cost (or moderate cost) energy conservation retrofits, one-time energy measurements can be taken before and after installation of the retrofit and combined with a simple runtime meter to determine the total energy savings. Manual runtime meter readings can then be multiplied by the one-time before-after measurements to determine the energy savings. One example where this would yield suitable results would be the measurement of a lighting replacement retrofit for parking lights operated on a photo-cell.

7.2.4. Customer Surveys and Interviews

Often, customer awareness, attitudes about energy consumption, or knowledge of energy information can play an important role in discovering opportunities for energy conservation. Such information can be obtained by a simple mail-in or phone survey. However, an interview is often necessary to determine a detailed accounting of such information. Survey techniques vary widely depending on the cost, medium for distribution, intended data entry and analysis method and audience. Interview techniques can also vary considerably. One technique which has gained favor among energy researchers is the ethnographic interview. Ethnographic interviews differ from a strictly "guided" interview in that the informant is allowed to partially guide the discussion and elaborate on the points they discuss (DeCicco and Kempton 1987; Agar 1980).

7.2.5. Follow-up Surveys and Interviews

Obviously, an important aspect of surveys and interviews involves the follow-up survey (or interview). Often, such information can provide completely new insight as why (or why not) an energy conservation retrofit has succeeded (or failed). Usually, it is best if the initial and follow-up survey can ask the same (or similar) questions in order to ascertain whether or not conditions or perceptions have changed.

7.3. TIME-SEQUENCED MEASUREMENTS

Time-sequenced measurements, or time-dependent data, represent data that changes often enough to warrant a time-series recording. Such measurements can be derived from existing utility billing data, and measured data. Measured time-series data can be accumulated at monthly, daily, hourly or sub-hourly intervals. Such records can then be merged with similar recordings of weather data, operating schedules, etc. at the time of analysis. New research has shown that high resolution data and special purpose data also provides useful information about how a building is consuming energy or whether or not the required environmental conditions are being maintained.

7.3.1. Monthly Data

The most common time-sequenced measurement consists of monthly consumption data. Often, such data is readily available in the form of utility billing information. In certain instances, special meters must be installed, read (either manually or electronically) and the information transcribed and prepared for analysis. Monthly data usually must be adjusted for differences in the length of the period of measurement.

7.3.2. Daily Data

Daily time-sequenced measurements have gained some acceptance as a useful means of tracking and diagnosing operation problems . Such measurements often utilize whole-building utility billing meters, and can be summaries of electronically recorded hourly data or can be read manually and transcribed into a spreadsheet template for analysis.(Haberl and Vajda 1988; Haberl and Claridge 1987). In large institutional complexes, daily measurements have also proven to be helpful in improving boiler efficiencies by providing operators with immediate feedback regarding boiler efficiency, make-up water percentages, and predictions of anticipated loads -- information that previously took hours of hand calculations and yet was provided at a fraction of the cost of a fully computerized system (Haberl et al. 1989).

7.3.3. Hourly and Sub-Hourly Data

As more powerful, inexpensive microprocessors have become available, the cost of microprocessor-based data acquisition equipment, polling computers and analysis software has also dropped. As a consequence, time- sequenced measurements which consist of hourly and sub-hourly data (5, 10, or 15-minute intervals) are becoming more available to answer detailed questions about all aspects of building operation.

With hourly data nearby weather data can often be obtained and merged with the site information at the time of analysis. In most locations, local utilities can install a utility load-monitoring recorder (for a nominal fee), monitor a site, and transcribe the data to an ASCII format for transfer to the analysts computer for later consideration.

The size of the data set can become a problem with hourly or shorter measurement intervals when the experiment duration is several months or longer. For a one year period data files of several megabytes in size for are common. A good set of data preparation tools, or toolkits are very valuable. The public-domain ARCHIVE program developed by Feuermann and Kempton (1987), and the attendant toolkits are examples of excellent software tools for manipulating data in columnar format. With the use of such tools, data-reduction, data-merging, data-filtering, error- checking, and graph preparation can be reduced to a single key-stroke on most commonly available microcomputers -- a tremendous time saver.

7.3.4. High Resolution Data

The traditional hardwiring of a building to obtain end-use energy data can be expensive and disruptive to the building occupants; even when advanced FM transmitters or powerline carrier systems are used. Recently, as mentioned previously, an alternative approach has been developed at MIT that eliminates the need for hardwiring (Hart 1985). The basic concept extracts end-use data from high resolution measurements of whole building electricity usage by using statistical analysis to identify on-off times which can then be combined with one-time consumption measurements to calculate end-use energy consumption.

Early results have shown this to be an effective alternative for certain types of end-use experiments. Specifically, those where the components being monitored have a constant energy usage pattern. This technology was originally developed for residential applications and is now being extended into commercial buildings. Commercialization is expected within a few years. Since installation costs can easily represent 2/3 and more of the total monitoring costs this technology could dramatically reduce the cost of obtaining certain types of end-use energy data.

7.3.5. Special Purpose Data

Another approach to obtaining end-use energy data is to determine which device is running by "listening" to audio signals from a mechanical room and then calculating the energy use in a similar fashion to that used by the MIT high resolution approach. A technique developed by Miller (1989) has been shown capable of calculating the simultaneous on-off status of several devices using artificial neural networks for classifying the different acoustic signals. This technique also has potential for diagnosing operation and maintenance problems. Although still in its early stages, the concept of using acoustic pattern recognition (or for that matter visual pattern recognition) opens up an entirely new area of study for building energy analysts.

8. BALANCING THE BENEFIT, TYPE, DESIGN, AND EXTENT OF MONITORING

Experiments that monitor energy and conditions in commercial buildings must carefully consider who will benefit from the analysis to be performed, the type of program being developed, how the experiment will be designed, and the extent of monitoring to be undertaken. Designing the right monitoring program for a specific project requires a skilled balancing of these options. One way to visualize the interactions is with the help of relationship matrices. This section describes four relationship matrices that we have found to be helpful, namely: a benefactor versus type-of program matrix (Figure 2), an extent-of-monitoring versus type-of-program matrix (Figure 3), an extent-of-monitoring versus design-of-experiment matrix (Figure 4), and a type-of-program versus design-of-experiment matrix (Figure 5).

8.1. BENEFACTOR VS. TYPE OF EXPERIMENT

A benefactor versus type-of-experiment matrix (Figure 2) illustrates the potential for benefits according to benefactor groups. For example, conservation planning and forecasting programs are usually conducted by utility and fuel suppliers, local, State, and Federal agencies, sometimes by engineering concerns, manufacturers, contractors, building energy analysts, and rarely by consumer groups.

8.2. EXTENT OF MONITORING VS. TYPE OF EXPERIMENT

An extent-of-monitoring versus type-of-experiment matrix (Figure 3) shows the extent of monitoring used by different types of monitoring programs. For example, monitoring of energy retrofit savings usually makes use of utility billing data, heterogeneous data-base information, preliminary and detailed surveys, one-time measurements, monthly, daily and hourly measured data. In some instances, engineering data, customer surveys and interviews, and follow-up surveys can provide useful information. Special purpose and high resolution data are rarely required for monitoring retrofit energy savings.

8.3. EXTENT OF MONITORING VS. DESIGN OF EXPERIMENT

An extent-of-monitoring versus design-of-experiment matrix (Figure 4) illustrates the extent of monitoring used to accomplish a particular experiment design. For example, an on-off experiment design should make use of engineering data, as-builts, preliminary surveys, detailed surveys, and one-time measurements. It may sometimes use utility billing data, customer surveys and interviews, follow-up surveys and measurements, high resolution data, and special purpose data. The asterisk indicates that utility billing data can be used as a means of cross-checking whole-building and sub-metered experiments.

8.4. TYPE OF EXPERIMENT VS. DESIGN OF EXPERIMENT

A type-of-experiment versus design-of-experiment matrix (Figure 5) shows the relationships between the type of monitoring program and the design of the experiment. For example, diagnosing operation and maintenance problems usually requires some sort of whole-building measurements, hardwired sub-metering, and in some cases can take advantage of test- reference experiments to similar buildings, test-reference experiments to a normalized data-base, and non-intrusive sub-metering.

9. ANALYSIS OF METHODOLOGICAL ERRORS

One underlying concern with the collection of data from an experiment is whether the data truthfully portrays what happened. To provide assurance that this indeed is the case there must be a systematic procedure for calibrating instruments and analyzing for errors. In the strictest sense (and assuming no budgetary constraints), all measurements should use the finest laboratory instruments. However, since this is rarely the case, not only should procedures be developed to measure the accuracy (i.e., calibration, and recalibration); methods should also be employed to determine the precision of the measurements. In other words, the size of the errors that are known to exist should be determined (Bevington 1969).

The precision of any experiment is a critical parameter. This is especially so in building energy monitoring experiments since normalized measurements of before and after conditions are often used to determine energy savings. To measure the savings the signal must be larger than the known error levels (i.e., the background noise). Sometimes, this is easier said than done.

9.1. REQUIREMENTS FOR ACCURACY OF THE MEASUREMENTS

Any analysis based on measured data relies on the accuracy of the measurements and how well they portray the true events that transpired. Measurements taken in buildings are no exception to this condition. In fact, since monitoring programs can extend over several years, calibration and recalibration of the instruments and sensors used in the experiments becomes an important aspect of the experimental design.

9.1.1. Calibration of the Instrumentation

In contrast to the computer industry (where new and better equipment is introduced almost daily), the methods for calibrating instruments commonly used in building monitoring experiments have changed little over the years. A significant body of literature documents standard methods for calibrating instruments. A list of documents describing such procedures is included in the bibliography. Any serious monitoring program should use the procedures described by a certified standards institute, for example, those published by the National Institute of Standards and Technology (formerly the National Bureau of Standards) or should at least have access to such a facility where instruments can be periodically sent for calibration.

9.1.2. Recalibration of Instrumentation

Instrumentation should also be recalibrated periodically. Unfortunately, this can add substantially to the cost of a monitoring program. Several helpful rules-of-thumb are: 1) When in doubt...calibrate. 2) Calibrate those sensors that are measuring the most critical variables more often (i.e., large thermal flows, whole-building watt-hour meters, weather-monitoring sensors, etc.). 3) Use as many redundant sensors and sum-checks as your budget will permit. 4) Periodically recalibrate your calibration instruments. A more rigorous treatment of the calibration issue is available in the literature listed in the bibliography.

9.2. ANALYZING METHODOLOGICAL ERRORS

Like death and taxes, errors we will always have with us. However, with a concerted effort, the most damaging (and potentially embarrassing) ones can be avoided.

9.2.1. Blunders and Mistakes

Even the best experimenters make mistakes and occasionally a major blunder. Such occurrences are usually apparent from results that are not even reasonably close to the expected value. A simple range check will often suffice to catch most blunder-type errors. Occasionally, slightly more complicated statistical measures (i.e., mean, standard deviation, or goodness of fit) need to be employed.

9.2.2. Systematic Errors

Systematic (often called "bias" errors) are not always detected by simple range checks or other statistical measures. Often systematic errors result from instruments or sensors that have drifted out of calibration. One method for trapping systematic errors is to compare current measurements to estimated values. Corrections to the data that compensate for systematic errors can be made once the type and extent of error are known. The experimental accuracy is therefore dependent on how well systematic errors are controlled.

9.2.3. Random Errors

Random errors represent differences in the measured and true values that cannot easily be removed. They are generally due to sensor or other instrument limitations. Such fluctuations should be minimized within the available budget. The size of the remaining errors must be found to determine the experiment precision. Random errors can be reduced by carefully planning the experiment and by repeating the experiment and comparing the results. Bendat and Piersol (1986) has a lengthy treatment of random error analysis as well as additional definitions of random data (e.g., stationary, non-stationary, ergodic, non-ergodic, et cetera).

9.2.4. Procedures for Analyzing Data

Procedures for automatically analyzing data can be divided into two primary categories: procedures for analyzing individual records, and procedures for analyzing a collection of records (Bendat and Piersol 1986). Some individual record procedures which we have found helpful include simple static range checks, dynamic range checks, and comparisons to expected values. Procedures for analyzing collections of records are considerably more complex and typically involve measurements of central tendency and dispersion, measurements of periodicity, and frequency or spectral analysis. At a minimum, all records should be checked against static range checks.

9.2.5. What About Missing Data?

Missing data can present problems. Often, when one finds individual or groups of records that do not meet prescribed error criteria the simplest thing to do is to declare it to be "missing data" and replace those records with the appropriate indicator (we prefer to use -99). Although this is the safest way to assure that the data base is not contaminated with bad data the practice can present problems during the analysis phase. For example, relative humidity sensors are notorious for drifting out of calibration. Some sensors have a tendency to measure 100.01 percent relative humidity during conditions of 100.00 percent relative humidity. Our first inclination was to throw-out those readings. However, this significantly reduced our data set for calculations involving enthalpy, etc. Since we still wanted to have a high-end static limit of 101.00 percent we decided to convert readings in the range of 100.01 to 100.99 percent to 99.9999 percent. In this fashion we embedded a replacement value for the 100.01+ percent relative humidity that would reveal itself upon close inspection of the records (no measurements would ever obtain 99.9999) and yet pass through the analysis routines, plots, etc. as 100 percent humidity.

In general missing data can be dealt with by: 1) throwing it out, 2) embedding a replacement value, 3) interpolation, and 4) replacing it with a synthesized or calculated value. Regardless of which method is chosen, always keep the raw data and the instructions necessary for recreating any embedded or estimated values.

10. DISCUSSION

The intention of this paper has been to present an overview of the design of experiments that monitor energy and conditions in commercial buildings. Such experiments depend on the purpose of the data collection and analysis, the uses of the data and the analysis, the type of analysis to be performed, the experiment design, the budget available, and the extent of monitoring and data gathering required. The analysis of methodological errors as they relate to the types of data that are used by building energy researchers is also discussed.

Throughout this paper additional literature is referenced where one may obtain a detailed discussion of the concepts that are important to the design of monitoring experiments in buildings. As such we were limited to those references that were contained on our combined shelves (and the shelves of others who so generously allowed us to borrow their books), and therefore apologize in advance for not including many other references that can also provide useful information, especially those not written in English or originating across the Atlantic.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 17 (26)
Title: The Design of Field Experiments and Demonstrations.

11. REFERENCES

Agar M. 1980. The Professional Stranger: An Informal Introduction to Ethnography, Academic Press, New York, ISBN-0-12-043850.

ASHRAE 1987. Handbook of HVAC Systems and Applications, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, Georgia, Chapter 48 - Energy Management.

Bendat, J. S., and Piersol, A. G. 1986. Random Data Analysis and Measurement Procedures, John Wiley and Sons, New York, ISBN-0-471-04000-2.

Bevington, P. R. 1969. Data Reduction and Error Analysis, McGraw-Hill, New York.

Clark, D. R. 1985. "HVACSIM+ Building Systems and Equipment Simulation Program", User's Guide and Reference Manual, National Bureau of Standards - Reports No. NBSIR-84-2996 and NBSIR-85-3243.

DeCicco, J. M., and Kempton, W. 1987. "Behavioral Determinants of Energy Consumption in a Centrally-Heated Apartment Building", Energy Systems and Policy, Vol. 11.

EIA 1989. Consumer Electronics Bus (CEBus) - Home Automation Standard, Electronic Industries Association, 2001 Eye Street, N.W., Washington, D.C., 20006.

Fels, M. (ed.) 1986. "Special Issue Devoted to Measuring Energy Savings, The Scorekeeping Approach," Energy and Buildings, Vol. 9, Nos. 1 and 2.

Feuermann, D., and Kempton, W. 1987. "ARCHIVE: Software for Management of Field Data", The Center for Energy and Environmental Studies - Report No. 216, Princeton University, Princeton, New Jersey, June.

Fracastoro, G. V., and Lyberg, M. D. 1983. Guiding Principles Concerning Design of Experiments, Instrumentation and Measuring Techniques, International Energy Agency and the Swedish Council for Building Research, Stockholm, Sweden.

Gilmore, V. E. 1988. "Smart House", Popular Science, August, (An article that describes the Smart House project being developed by the Smart House Limited Partnership, Washington, D.C.).

Haberl, J., and Claridge, D. 1987. "An Expert System for Building Energy Consumption Analysis: Prototype Results", ASHRAE Transactions, Vol. 93, Part 1.

Haberl, J., Englander, S., Reynolds, C., Nyquist, T., and McKay, M. 1989. "Whole Campus Performance Analysis Methods: Early Results from Studies at the Princeton Campus", Proceedings of the 6th Annual Symposium on Improving Energy Efficiency in Hot and Humid Climates, Texas A&M University, Dallas, Texas, October.

Haberl, J., and Komor, P. 1989. "Investigating an Analytical Basis for Improving Commercial Building Energy Audits: Early Results from a New Jersey Mall", Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings IV, ASHRAE/DOE/BTECC/CIBSE, Orlando, Florida, December.

Haberl, J., Norford, L., and Spadaro, J. 1989. "Diagnosing Building Operational Problems: Intelligent Systems for Diagnosing Operational Problems in HVAC Systems", ASHRAE Journal, June.

Haberl, J., and Vajda, J. 1988. "Use of Metered Data Analysis to Improve Building Operation and Maintenance: Early Results From Two Federal Complexes", Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in Buildings, Volume 3.

Harrje, D. T., 1982. "Monitoring Energy Use - What is Needed?", Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings, August.

Hart, G. 1985. "Non-Intrusive Appliance Load Data Acquisition", Proceedings of the International Load Management Conference, Section 40, Sponsored by the Electric Power Research Institute - Report No. EPRI-EM4643, Palo Alto, Calif.

Haves, P., and Trewhella, D. 1988. "Towards an Environment for HVAC Control System Evaluation", Proceedings of the USER-1 Building Simulation Conference, Society for Computer Simulation, September.

Hsieh, E. H., Norford, L. K., and Socolow, R. H. 1989. "Calibrated Computer Models to Track Building Energy Use: The Role of the Tenant and Operator Decisions.", Energy and Buildings, in preparation.

Klein, S. A., Beckman, W. A., and Duffie, J. A. 1976. "TRNSYS - A Transient Simulation Program", ASHRAE Transactions, Vol. 82, Pt. 2.

Komor, P., Kempton, W., and Haberl, J. 1989. "Energy Use, Information, and Behavior in Small Commercial Buildings," Center for Energy and Environmental Analysis - Report No. 240, Princeton University, July.

Lyberg, M. D. (ed.) 1987. Source Book For Energy Auditors, Volume 1 and 2, International Energy Agency and the Swedish Council for Building Research, Stockholm, Sweden.

MacDonald, J. M., Sharp, T. R., and Gettings, M. B. 1989." A Protocol for Monitoring Energy Efficiency Improvements in Commercial and Related Buildings", Oak Ridge National Laboratory Report ORNL/CON-291, September.

MacDonald, J. M. and Wasserman, D. M. 1989. "Investigation of Metered Data Analysis Methods for Commercial and Related Buildings", Oak Ridge National Laboratory Report No. ORNL/CON-279, May.

Miller, R. C. 1989. "Identification of Acoustic Signals Using Artificial Neural Networks", Master's Thesis, Marquette University, Milwaukee, Wisconsin, December.

Norford, L. 1989. M.I.T., Department of Architecture, personal communication, December.

Olsen, K., Komor, P., and Fels, M. 1988. "Development of a Data Base to Characterize the Small Commercial Sector: A New Jersey Example", Proceedings of the ACEEE 1988 Summer Study on Energy Efficiency in buildings, Volume 10.

Rabl, A. 1988. "Parameter Estimation in Buildings: Methods for Dynamic Analysis of Measured Energy Use", ASME Journal of Solar Energy Engineering, Vol. 110.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 19 (26)
Title: The Design of Field Experiments and Demonstrations.

Reddy, T. A. 1989. "Application of Dynamic Building Inverse Models to Three Occupied Residences Monitored Non-Intrusively", Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings IV, ASHRAE/DOE/BTECC/CIBSE, Orlando, Florida, December.

Sonderegger, R. C., 1978a. "Movers and Stayers: The Resident's Contribution to Variation Across Houses in Energy Consumption for Space Heating", in Saving Energy in the Home, Robert Socolow (ed.), Ballinger Publishing Co.

Sonderegger, R. C. 1978b. "Diagnostic Tests Determining the Thermal Response of a House." ASHRAE Transactions, Vol. 84, Part 1, pp. 691-702.

Sowell, E. F., Buhl, W. F., Erdem, A. E., and Winkelmann, F. C. 1986. "A Prototype Object-Based System for HVAC Simulation", Proceedings of the Second International Conference on System Simulation in Buildings, Liege, Belgium.

Subbarao, K. 1988. "PSTAR- Primary and Secondary Terms Analysis and Renormalization: A Unified Approach to Building Energy Simulations and Short-term Monitoring", Solar Energy Research Institute - Report No. SERI/TR-254-3175.

Ternes, M. P. 1987."Single-Family Building Retrofit Performance Monitoring Protocol: Data Specification Guideline", Oak Ridge National Laboratory Report ORNL/CON-196.

Treado S. J., and Bean, J. W. 1988. "The Interaction of Lighting, Heating and Cooling Systems in Buildings - Interim Report", National Institute of Standards and Technology, NISTIR 88-3860, December.

Treado, S. J., 1988. "Experimental Plan for Investigation of Lighting and HVAC Interactions", National Institute of Standards and Technology, NISTIR 87-3656, February.

WSJ 1990. "IBM, Motorola Plan Radio Link for Computers", The Wall Street Journal, January 30, Tuesday.

Zuboff, S. 1988. In the Age of the Smart Machine: The Future of Work and Power, Basic Books, New York, N.Y.

12. BIBLIOGRAPHY

ASHRAE 1989. Handbook of Fundamentals, American Society of Heating, Refrigeration and Air-Conditioning Engineers, Atlanta, Georgia, Chapter 13 - Measurement and Instrumentation.

Baker, D. W., and Hurley, C. W. 1984. "On-Site Calibration of Flow Metering Systems Installed in Buildings", N.B.S. Building Science Series 159, January.

EEI 1981. Handbook for Electricity Metering, Edison Electric Institute, Washington, D.C., ISBN-0-931032-11-3.

Harrje, D. T. 1977. "Heat Pump Performance Measured Using Ten Residential Units Operating in the Northeastern United States," Energy Use Management - Proceedings of the International Conference, Pergamon Press, Vol. 1, pp. 447 - 456.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 20 (26)
Title: The Design of Field Experiments and Demonstrations.

Harrje, D. T. 1981. "Energy - A brief Overview of Trends in Low Energy Buildings," Presented at the First International Energy Agency (IEA) Conference on New Energy Conservation Technologies and Their Commercialization, West Berlin, April, Vol.1, pp. 1079-1082.

Harrje, D. T., Grot, R. A., Gadsby, K. J. 1981. "Levels of Energy Monitoring in Houses", Proceedings of the Conference of Comparative Experimentation of Low Energy Houses. Liege: University of Liege, pp. II-1 to II-27.

Harrje, D. T., Persily, A. K., and Linteris, G. T. 1981. "Instrumentation and Techniques in Home Energy Analysis," Proceedings of the Energy Audit Workshop. Copenhagen: Danish Building Research Institute.

Harrje, D. 1984. "Monitoring Energy Use - What is Needed?", Proceedings of the Second ACEEE Conference, Washington, D.C.

Harrje, D. T., and Gadsby, K. J. 1984. "Diagnostics of Energy-Related Building Problems Using Today's Technologies", 11th Energy Technology Conference, Washington, D.C., March.

Harrje, D. T., Kirkpatrick, D. L., Norford, L. K., and Seroussi, R. E. 1984. "Data Collection and Analysis Hardware for Measuring Building Energy Use", Doing Better Setting an Agenda for the Second Decade, ACEEE, Vol. C, pp. 177-192, August.

Harrje, D. T., DeCicco, J. M., and Kirkpatrick, D. 1985. "Optimizing Building Control Strategies Using Short-Term Energy and Comfort Monitoring", Clima 2000, VVS Kongres - VVS Messe, Copenhagen, pp. 7-12.

Harrje, D. T., Gadsby, K. J., and Grot, R. A. 1986. "Alternative Methods to Acquire Energy Usage and Occupancy Data," Proceedings of the Field Data Acquisition for Building and Equipment Energy-Use Monitoring Workshop, ORNL Publication No. CONF-8510218, pp. 67-70.

Harrje, D. T. 1986. "Obtaining Building Energy Data, Problems and Solutions", Proceedings of the Field Data Acquisition for Building and Equipment Energy-Use Monitoring Workshop, ORNL Publication No. CONF- 8510218, pp. 205-209.

Hyland, R. W., and Hurley, C. W. 1983. "General Guidelines for the On-Site Calibration of Humidity and Moisture Control Systems in Buildings", N.B.S. Building Science Series 157, September.

Hurley, C. W., and Schooley, J. F. 1984."Calibration of Temperature Measurement Systems Installed in Buildings", N.B.S. Building Science Series 153, January.

ISA 1976. Recommended Environments for Standards Laboratories, Instrument Society of America - Recommend Practice, Research Triangle Park, North Carolina.

Olsen, L. 1974. "Introduction to Liquid Flow Metering and Calibration of Liquid Flowmeters", N.B.S. Technical Note 831.

Ramboz, J. D. and McAuliff, R. C. 1983. "A Calibration Service for Wattmeters and Watthour Meters", N.B.S. Technical Note 1179.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 21 (26)
Title: The Design of Field Experiments and Demonstrations.

Tufte, E. R. 1983. The Visual Display of Quantitative Information, Graphics Press, Cheshire, Connecticut.

Wise, J. A., and Soulen, R. J. 1986. "Thermometer Calibration: A Model for State Calibration Laboratories", N.B.S. Monograph 174, January.

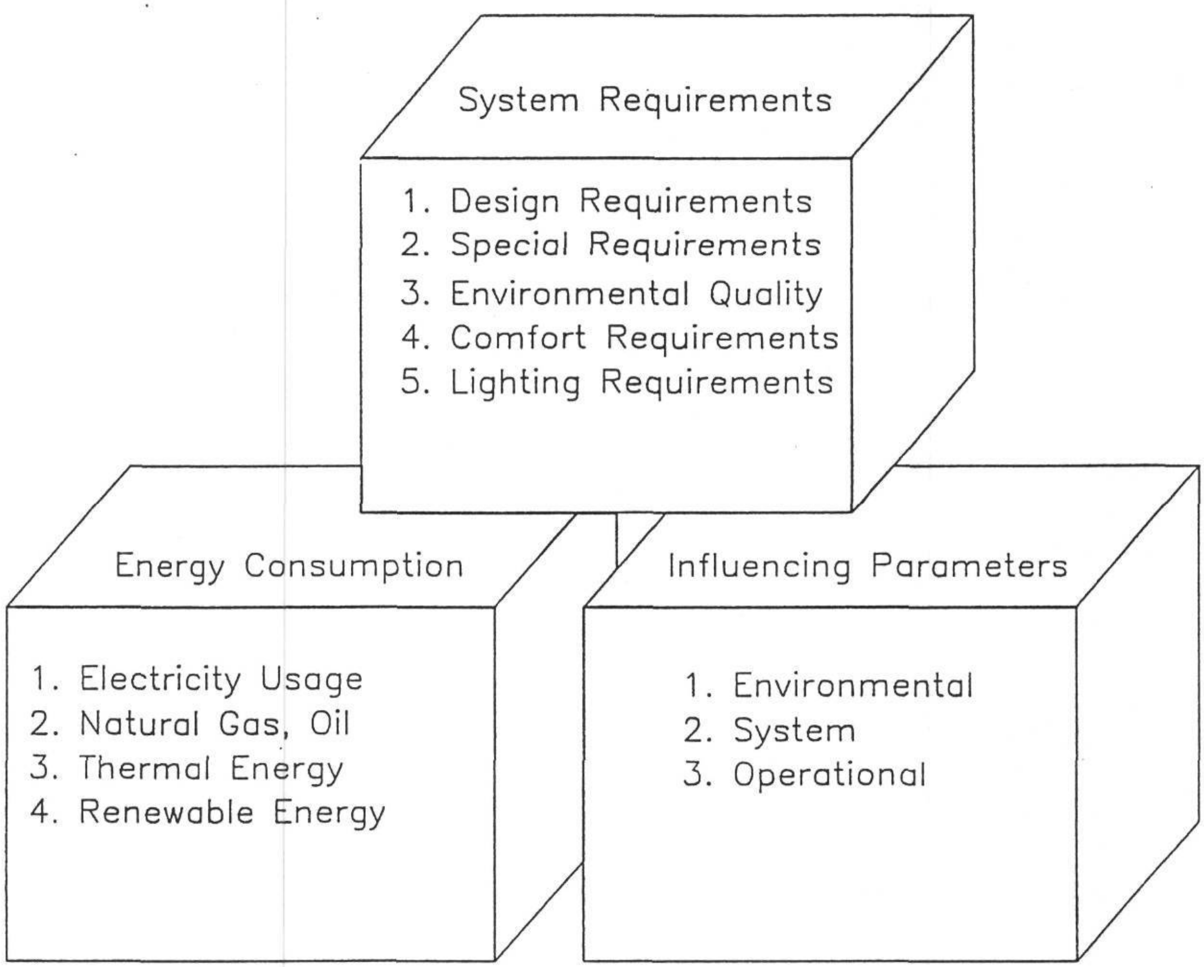
Wise, J. A. 1976 "Liquid-In-Glass Thermometry", N.B.S. Monograph 150, January.

13. ACKNOWLEDGMENTS

This work was funded through the Texas Governor's Energy Management Center at Texas A&M's Energy Systems Laboratory and through the New Jersey Energy Conservation Laboratory (NJECL) at Princeton's Center for Energy and Environmental Studies (CEES). We would like to thank our fellow researchers for helpful comments in preparing this paper.

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 22 (26)
Title: The Design of Field Experiments and Demonstrations.

FIGURE 1 Primary experimental parameters. This figure lists the primary experimental parameters to be considered for the system requirements, energy consumption monitoring, and influencing parameter measurements.



Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 23 (26)
Title: The Design of Field Experiments and Demonstrations.

FIGURE 2 Benefactors versus the types of programs. This relationship matrix illustrates the potential for benefits according to benefactor groups. For example, conservation planning and forecasting programs are usually conducted by utility and fuel suppliers, local, State, and Federal governing agencies, sometimes by engineering concerns, manufacturers, contractors, building energy analysts, and rarely by consumer groups.

The Energy Consumer	Engineers, Manufacturers & Contractors	The Energy Analyst	Utility and Fuel Suppliers	Local, State, and Federal Agencies	
	○	○	●	●	Conservation Planning & Forecasting
○	○	○	●	●	End–Use Energy Data
●	○	●	●	●	Retrofit Energy Savings
●	●	●	●	○	System & Component Evaluation
●	●	●	●	●	Environmental Quality Issues
○	●	●	●	●	Analyzing the Human Factor
●	●	○	○	○	Operation & Maintenance Problems

FIGURE 3 Extent of monitoring versus the type of program. This matrix shows the extent of monitoring used by different types of monitoring programs. For example, monitoring of energy retrofit savings usually makes use of utility billing data, heterogeneous data-base information, preliminary and detailed surveys, one-time measurements, monthly, daily and hourly measured data. In some instances, engineering data, customer surveys and interviews, and follow-up surveys can provide useful information. Rarely are special purpose and high resolution data required for the monitoring of retrofit energy savings.

Special Purpose	High Resolution	Hourly Measurements	Daily Measurements	Monthly Measurements	Follow-up Survey & Meas.	Customer Survey & Interview	One-Time Measurements	Detailed Survey	Preliminary Survey	Heterogeneous Data Base	Utility Billing Data	Engineering Data, As-Builts, etc.	
○	●	●	●	●		○	○	●	●	●	●	○	Conservation Planning & Forecasting
○	●	●	○		○	○	●	●	●		○		End–Use Energy Data
		●	●	●	○	○	●	●	●	●	●	○	Retrofit Energy Savings
○	●	●	●	●	●	○	●	○	○		○	●	System & Component Evaluation
●	●	●	○	○	●	●	●	●	●	○		●	Environmental Quality Issues
●	●	●	●	○	●	●	●	●	●	○	○	●	Analyzing the Human Factor
○	●	●	●	●	●	●	○	○	○	○	●	●	Operation & Maintenance Problems

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 25 (26)
Title: The Design of Field Experiments and Demonstrations.

FIGURE 4 Extent of monitoring versus the design of the experiment. This matrix illustrates the extent of monitoring used to accomplish a particular experiment design. For example, an on-off experiment design should make use of engineering data, as-builts, preliminary surveys, detailed surveys, one- time measurements, and sometimes utility billing data, customer surveys and interviews, follow-up surveys and measurements, high resolution data, and special purpose data. The asterisk indicates that utility billing data can be used as a means of checking whole-building and sub-metered experiments.

	Special Purpose	High Resolution	Hourly Measurements	Daily Measurements	Monthly Measurements	Follow-up Survey & Meas.	Customer Survey & Interview	One-Time Measurements	Detailed Survey	Preliminary Survey	Heterogeneous Data Base	Utility Billing Data	Engineering Data, As-Builts, etc.
On-Off	○	○				○	○	●	●	●		○	●
Before-After	○	○	●	●	●	●	●	○	●	●	●	●	●
Simulated Occupancy			●	●	●	●	○	○	●	○		○	●
Test-Ref. Similar Building	○	○	●	●	●	●	○	●	●	●		●	●
Test-Ref. Normalized Data Base	○	○	●	●	●	●	○	●	●	●	●	●	●
Test-Ref. Calibrated Model			●	●	●	●	○	●	●	●			●
Whole Building Energy & Conditions	●	●	●	●	●	●	●	●	●	●		*	●
Hardwired Sub-Metered	●	●	●	●	●				●	●		*	●
Non-Intrusive Sub-Metered	●	●	●	●	●				●	●		*	●

Paper 2. Authors: J. Haberl, D. Claridge, D. Harrje 26 (26)
Title: The Design of Field Experiments and Demonstrations.

FIGURE 5 Type of program versus the design of the experiment. This matrix shows the relationship between the type of monitoring program and the design of the experiment. For example, diagnosing operation and maintenance problems usually requires some sort of whole-building measurements, hardwired sub-metering, and in some cases can take advantage of test- reference to similar buildings, test-reference to a normalized data-base and non-intrusive sub-metering.

Human Factor	Environmental Issues	O & M Problems	System Evaluation	Retrofit Studies	End-Use Energy Studies	Conservation Planning	
	○		●	●		○	On-Off
	●		●	●		○	Before-After
●	●		○	●		○	Simulated Occupancy
○	○	○	●	●		○	Test-Ref. Similar Building
○	○	○	●	●		○	Test-Ref. Normalized Data Base
○	○		●	●		○	Test-Ref. Calibrated Model
●	○	●	○	●		●	Whole Building Energy & Conditions
●	●	●	●	●	●	●	Hardwired Sub-Metered
○	○	○	○	○	●	●	Non-Intrusive Sub-Metered

MONITORING $98 MILLION IN ENERGY EFFICIENT RETROFITS THE TEXAS LOANSTAR PROGRAM

Malcolm Verdict, Texas Governor's Energy Management Center,
Jeff Haberl, David Claridge, Dennis O'Neal,
Warren Heffington, W. Dan Turner, Texas A&M University

SYNOPSIS

This paper discusses the development of a large statewide energy conservation revolving loan program, including an overview of the program structure, energy monitoring effort, metering equipment installation procedures, calibration efforts, data analysis, and lessons learned to date.

ABSTRACT

The Texas LoanSTAR program is an eight year, $98 million revolving loan program for energy conservation retrofits in Texas state, local government and school buildings funded by oil overcharge dollars. The program began in 1988. Public sector institutions participating in the program must repay the loans according to estimated energy savings in four years or less. This paper provides an overview of the loan program, a discussion of the program structure, energy monitoring effort, equipment installation procedures, calibration efforts, data analysis, and lessons learned.

As part of this program, a statewide energy Monitoring and Analysis Program (MAP) has been established. The major objectives of the LoanSTAR MAP are to: 1) verify energy and dollar savings of the retrofits, 2) reduce energy costs by identifying operational and maintenance improvements, 3) improve retrofit selection in future rounds of the LoanSTAR program, and 4) initiate a data base of energy use in institutional and commercial buildings in Texas.

Currently, the program is monitoring hourly data from over two dozen buildings using public domain polling procedures that collect information from microcomputer-based field recorders supplied by several manufacturers. Future efforts will include investigating the feasibility of reducing energy monitoring costs by utilizing Energy Management and Control Systems (EMCS)-based monitoring and expand the program into additional sites.

Malcom E. Verdict is the LoanSTAR Program Manager at the Texas Governor's Energy Management Center, Austin, Texas. Jeff S. Haberl Ph.D, P.E. (Research Engineer), David E. Claridge Ph. D. (Associate Professor), Dennis O'Neal Ph.D., P.E. (Associate Professor) Warren M. Heffington Ph.D., P.E (Associate Professor), and W. Dan Turner Ph.D., P.E. (Associate Dean) are with Texas A&M University's Energy Systems Laboratory, College Station, Texas.

June 1990 (to be published in the Proceedings of the ACEEE 1990 Summer Study on Energy Efficiency in Buildings, August 26-September 1, 1990, Asilomar, CA.)

1. INTRODUCTION

1.1. Background

In 1988, the Governor's Energy Management Center (GEMC) of Texas received approval from the U.S. Department of Energy to establish a $98.6 million statewide retrofit demonstration revolving loan program, the LoanSTAR (Loan to Save Taxes and Resources) program. The LoanSTAR program uses a revolving loan financing mechanism to fund energy-conserving retrofits in state, public school and local government buildings. Retrofit projects are identified by energy audits conducted by engineering teams under contract to the GEMC. Each retrofit competes for funds on the basis of the estimated payback period, ability to repay the loan through energy savings, engineering assessment of the viability of the retrofit, and the feasibility of metering the project effectively.

1.2. Program Overview

The LoanSTAR is being implemented in two phases. Phase I targets state agencies and institutions that received energy audits in 1984-86. Capital intensive energy-conserving improvements totaling $40 million are candidates for funding in this phase. Public schools and local governments are targeted for Phase II of the LoanSTAR program. Previous engineering audits of these facilities conducted under the Institutional Conservation Program (ICP) revealed potential energy savings similar to those in state buildings.

The projects funded by LoanSTAR primarily include retrofits to lighting, HVAC systems, building shell, electric motors, energy management and control systems, boilers, and thermal energy recovery systems. Retrofits using alternative or renewable energy systems and load management also are considered.

The maximum loan amount to a local government or independent school district is $1.2 million. The maximum loan for state agencies and universities is $4.8 millions. Repayments are made semi-annually at an annual interest rate of 4.04 percent. The length of the loan is determined by the combined estimated simple payback of the project(s). Loan proceeds are used to pay for the retrofits, engineering and design, and installation expenses. The cost of the on-site metering and energy analysis is paid from the interest-income derived from the program. A breakdown of the program costs by task is given in Table 1. Total metering costs must not exceed three percent of all retrofit costs.

1.3. Objectives of the Monitoring and Analysis Program

The LoanSTAR Monitoring and Analysis Program (MAP) was designed to serve the differing needs of the many participants in the LoanSTAR revolving loan program. The energy monitoring program's first objective is to determine whether retrofits save as much as estimated in audits. When necessary, a monitoring plan is developed for each retrofitted facility to verify savings. Verification of savings includes measurement of consumption data before and after the retrofit, and analysis of the data to account for weather, changes in operation of the building, and so on. This is a quality assurance measure to insure that agencies purchasing retrofits receive real savings from the LoanSTAR retrofits.

The second objective of the MAP is to reduce energy costs of a building by evaluating its energy-using characteristics. Previous experience at several universities and at a large federal office building in Washington, D.C., has demonstrated that continuous energy monitoring and analysis can lead to changes in operation and maintenance that can substantially reduce energy use in a building (Haberl and Claridge 1987; Haberl and Vajda 1988; Haberl and Komor 1989).

Some retrofits may prove more effective and others less effective than expected. This knowledge enables engineers who perform future audits to make more cost-effective recommendations. Hence, the third objective is to increase the cost-effectiveness of future rounds of the LoanSTAR program by screening out ineffective retrofits.

The final major objective of energy monitoring is the establishment of an end-use data base for institutional and commercial buildings in Texas. The number and types of buildings in LoanSTAR for which detailed data will be available will be limited, so data should be considered a supplement to existing data bases, such as ELCAP, BECA, and EIA. It will include data to evaluate retrofit effectiveness in a large number of buildings in hot and humid climates. These data can be used by utility planners, building research scientists, and government policy makers. A more detailed description of the energy monitoring and analysis program is available in the report by Claridge et al. (1989).

2. THE MONITORING AND ANALYSIS PROGRAM

2.1. Organization

The LoanSTAR MAP is administered through the Governor's Energy Management Center (GEMC) and conducted primarily at the Energy Systems Laboratory at Texas A&M University. A Monitoring and Analysis Review Committee (MARC) has been established to provide ongoing contact with other energy monitoring and analysis efforts to ensure incorporation of applicable techniques and results from those efforts. Organizations with participants on the MARC include DOE, EPRI, LBL, ORNL, Princeton, MIT, the University of Texas, and a Texas utility.

2.2 Tasking

The primary work for the MAP has been divided into five tasks (Figure 1), which include audit review and assignments, hardware and vendor selection, a calibration facility, systems communications bench test, and energy monitoring analysis and reporting. Each of the five primary tasks utilizes subcontractors as needed to complete the work in a timely fashion.

2.21. Task 1: Audit Review and Assignment

The GEMC has contracted with eight engineering consulting firms to conduct audits for the LoanSTAR program. An audit firm is assigned to each building based on expertise, geographical location and workload. Task 1 personnel then conduct an independent review of all energy audit reports submitted by the consulting engineering firms under contract to the GEMC. Reports are reviewed for use of appropriate technology, conceptual correctness, adequacy of implementation cost data, numerical accuracy, and compliance with program guidelines. The major functions of this task include: review of preliminary on-site screening reports, desktop audit reviews, conducting meetings with the engineering consulting firms, and the development of audit format training workshops.

Table 2 lists the approved retrofits to be implemented in the first year of the program. The estimated $4.2 million implementation costs will generate a $1.2 million annual savings, for an estimated 3.5 year simple payback. Roughly 40 buildings containing 5.1 million square feet of conditioned space will have been effected by various retrofits ranging from variable speed drives to lighting replacements. Typically, it takes 6 months from the time an agency applies for an audit until a loan is approved.

2.2.2. Task 2: Selection and Installation of Monitoring Systems

This task ensures that adequate, reliable and affordable data are collected to monitor energy use of the buildings participating in the LoanSTAR program. Data collected from the buildings will serve as the basis for determining the cost-effectiveness of different retrofits as well as providing indices of how well an individual building is performing. The major functions in this task include: determination of metering requirements, data acquisition system subcontractor qualification and selection, and installation and maintenance of metering systems.

Four levels of metering systems have been developed for the energy monitoring program. These accommodate the necessary data requirements with the funds available for monitoring retrofits. The levels also are compatible with different hardware available on the market. As the project progresses, the definition of the levels and associated hardware requirements are expected to change. Table 3 contains guidelines for the energy monitoring levels.

Level 0: Facility/Whole-building(s) Utility Data. These data range from monthly consumption data, based on utility bills, to weekly or daily utility metered data. Such data are useful for separating consumption into heating, cooling, and non-weather related consumption (e.g. water heating). A substantial portion of retrofits in schools and local government buildings are expected to fall within this category.

Level 1: Whole-building and Limited Sub-metering Hourly Data. Level 1 utilizes one to four channel Data Acquisition Systems (DAS), and will capture hourly whole-building thermal and electric measurements. In some cases, limited sub-metering will also be included. It is anticipated that portable equipment will also be used to collect hourly data for a one- to two-month period as needed for short-term energy monitoring.

Level 2: Moderate Sub-metered Hourly Data. This level has all the capabilities of the first two levels and also enables more detailed analysis for identifying the savings from specific retrofits and pinpointing building operational problems. Moderate sub-metered DASs are simple four to twenty channel systems.

Level 3: Detailed Sub-metered Hourly Data. These systems typically include at least 20 channels of data. Given current costs for these systems, they are expected to be cost-effective only in large buildings and groups of smaller buildings.

Table four presents progress statistics from the first-year energy monitoring effort. About 410 channels of hourly information are being collected from 26 sites encompassing 2,750,000 square feet of conditioned space at an average cost per channel of about $1500. Thermal metering and large aggregations of electrical panels tend to dramatically increase the price per channel. Typical installation time is about 6 to 10 weeks from the approval of the loan and metering plan by the GEMC to the collection of the first hourly records.

Ongoing work at the DOE's National Laboratories and several universities shows that use of hourly data permits a more detailed analysis of end-use patterns and identification of major individual operating parameters within buildings than does the use of monthly or daily data (Reiter 1986; Akbari et al. 1988; Anderson et al. 1989; Haberl and Vajda 1988; Haberl and Komor 1989; MacDonald and Wasserman 1989; Schrock and Claridge 1989).

2.2.3. Task 3: Calibration Laboratory

The accuracy of the installed sensors is key to a successful energy monitoring project. Data obtained for this project must be accurate to maintain confidence and reliability. In order to assure that accurate data are collected, a National Institute of Standards and Technology (NIST) traceable calibration laboratory is being established at the Energy Systems Laboratory at Texas A&M University.

The objectives of the calibration laboratory are to: (1) construct a NIST-traceable facility which will be used to test sensors and verify their compatibility with selected energy monitoring systems; (2) establish a facility for troubleshooting faulty sensors found in the field; (3) construct a portable calibration system for in-situ field testing, troubleshooting, calibration, and validation; (4) have a facility to bench-test and pre-qualify proposed sensors and hardware prior to approval for installation in the field; and (5) develop improved calibration procedures for in-situ field testing.

This calibration facility will include the capability to measure dry-bulb, wet-bulb, and dew-point temperature, humidity, air and hydraulic pressure, air and liquid mass flow rates, air velocity, RPM, illumination levels, electrical energy, power factor, and solar radiation. Typically the calibration accuracy will be 2 to 10 times more accurate than the sensors being tested (as recommended by national calibration standards).

2.2.4. Task 4: Testing of Systems Communications

The purpose of this task is to conduct bench-mark communications testing of all field Data Acquisition Systems (DASs) for the LoanSTAR MAP. This includes testing the compatibility of sensors, DAS and the host computer. Public domain software, using open communications protocol, will be developed for polling, translating and analyzing the field data. Data acquisition systems that adequately satisfy the testing will then be approved for use in the program. The primary functions of this task include: the communications bench-test, and the software design, development, and testing.

In order to facilitate communications with any given manufacturer's field data recorder, the LoanSTAR program is developing a public domain Data Recorder Management System (DRMS). The DRMS will perform several functions, including: (1) remote programming of DASs, (2) scheduling the polling calls, and (3) translating the commands for and data records from any given manufacturer's DAS.

2.2.5. Task 5: Monitoring Plans, Analysis and Reports

This task analyzes collected data in order to determine the energy and dollar savings of the retrofits and reduce energy costs by identifying operational and maintenance improvements. This task also includes development of improved analysis methods, preparation of the overall project monitoring plan, the development of a LoanSTAR MAP computer network to conduct the analysis, the verification of audit assumptions through the analysis of energy use and site data, and the interaction and feedback to agencies and operators through ongoing analysis of the data.

2.3. Analysis Approach

The engineering savings estimates for the LoanSTAR retrofit measures rely on numerous assumptions made by the auditors. Most audits rely on estimates of electrical gains, building schedules, and lighting schedules. Reliable data obtained from monitored retrofits can be used to verify audit assumptions. In some cases this may lead to recalculated savings estimates. A procedure is being developed for "calibrating" the inputs used by the DOE-2 building simulation program. Since this program is large and time-consuming to use, it is being restricted to certain large installations. Similar "calibration" procedures for less detailed programs, such as ASEAM (ACEC 1987), are also being investigated.

The primary objectives which will influence the analysis methods used are the nee to determine: (1) the overall cost savings due to the retrofits and (2) the savings and effectiveness of individual retrofits. These objectives lead to a requirement for different levels of analysis methods and tools.

Determination of overall cost savings implies a need for a standard evaluation technique which can be applied to all buildings. Since data from many buildings will be limited, a method which requires only whole-building data and weather data, such as PRISM (Fels 1986) will be used as the standard evaluation technique. More detailed approaches will be explored when the available data warrants or as required to adequately determine overall savings.

The savings due to individual retrofits can vary from simple on-off tests to other cases which require the use of more sophisticated analysis techniques that incorporate a more inclusive set of influencing parameters and building characteristics. Models which incorporate simplified scheduling, extensive weather data and techniques such as principal component analysis (Hadley and Tomich 1986) or single-valued decomposition (Press et al. 1986; Anderson et al. 1989) are being investigated for these applications.

2.4. Measuring the Retrofit Savings

There are many ways of designing a procedure to measure the energy savings from energy conservation retrofits (Fracastoro and Lyberg 1983; Haberl et al. 1990). Because of the diversity of the types of retrofits being monitored in the LoanSTAR program, each building will have its own metering and analysis plan. The plans can be categorized according to whether they are on-of, before-after, simulated occupancy, or test-reference. In general, the energy monitoring will rely either on the measurement of energy consumed directly at the device (sub-metered) or at the whole-building level. The types of data, variables to be measured, and frequency of measurement will be determined for each site. The primary types of data to be collected include point-in-time information and time-sequenced information, each of which can be obtained from data-base information or measured at the site.

2.5. Use of a Before-After Procedure to Measure Savings

Many of the retrofits in the LoanSTAR program will use before-after measurements to evaluate their effectiveness. Figure 2 shows a flowchart of the information required by a before-after experiment used to compare measured energy savings from a retrofit to audit estimates. Point-in-time and time-sequenced information, measurements of influencing parameters, and evaluations of system requirements all are necessary to determine before-after differences in the energy consumed, products delivered (e.g., comfort levels and illumination levels), and influencing variables. Before-after consumption, normalized for environmental, operational and system parameters in then compared to audit estimates to determine if the retrofit is operating as intended.

If there is a disagreement between measured and audit estimates, corrective action can be taken immediately to assure that the retrofit functions properly so as not to effect the projected payback. Periodically, feedback reports will be provided to building operators and agency managers to determine possible O&M savings opportunities. Over time, the data collected will serve to improve audit estimates by providing measured energy savings for various classes of energy conservation retrofits, and will provide a valuable data base for energy decision makers.

3. SUMMARY

3.1. General

This paper presents an overview of the Texas LoanSTAR program by outlining the program structure, energy monitoring efforts, equipment installation and calibration procedures, and analysis techniques. Throughout this paper publications are references that provide additional information on the design and implementation of large scale monitoring programs. Detailed reports concerning the LoanSTAR program, availability of metered data, and software developed can be obtained from the authors.

3.2. Lessons Learned to Date and Potential for Transferability

The first year's experience of undertaking a large-scale energy monitoring project has taught us many lessons. Most importantly, the original cost and time estimates were difficult to arrive at and probably should have been twice as large. Here are some additional issues:

<u>Building energy audits.</u> (1) There is a building energy audit learning curve foe the Architect-Engineer (A-E) firms and agencies. We found that the quality of recent audits improved substantially over previous audits performed in the 1984-86 energy audit cycle.
(2) Implementation of consistent audit reporting formats is important. We recommend at least some standard reporting be incorporated in each audit. Standardized calculations have proven to be helpful in comparing recommendations from one audit to another.
(3) There is a need for ongoing energy auditor training classes. All too often, auditors over-use "use of thumb"

without adequate justification, and in some cases improperly use the building simulation programs to arrive at savings estimates.

Site description information, field energy monitoring equipment and calibrating sensors. (1) Published monitoring protocols (e.g., DOE, ASHRAE, IEA) are inconsistent, do not collect the information necessary to specify field data acquisition equipment, and require too many man-hours for data collection. Hence, we developed a simplified version for the LoanSTAR program.
(2) Most buildings do not have current as-built drawings. The existing condition of equipment must be obtained from site inspections.
(3) The use of existing electric utility meters, gas meters and certain thermal meters is not always feasible. Often it is less expensive to install new equipment than to trace down manufacturer's calibration constants, modify the transducers, recalibrate, etc.
(4) There are very few experienced, affordable DAS installation contractors. Nationwide, we identified only about two dozen firms, and selected four firms to participate in the LoanSTAR program.
(5) A considerable amount of time was spent coordinating site visits, agency contracts, and visits by A-Es. The geographical distance in Texas also increased the travel budget substantially beyond our expectations.
(6) Large thermal flows can be expected at most university campuses that have centralized utility distribution systems. Monitoring large thermal flows is expensive, and is compounded by the fact that very few DAS installers have previous experience with such metering. Costs for similar equipment from different manufacturers can vary dramatically.
(7) Buildings are not always well-suited for end-use electricity measurements. Power measurements across multiple panels can increase costs dramatically.
(8) We see a definite need to develop better procedures for calibrating in-situ electrical and large thermal load measurements.

Electronic communications, the LoanSTAR MAP Net, and developing energy analysis procedures. (1) Many DAS manufacturers are hesitant to release their communication protocols. Without such protocols analysts are locked-in to proprietary software and data formats that may not be suitable for their analysis.
(2) There is a need to develop affordable, public domain data analysis toolkits that are powerful, flexible and can be applied to any data streams.
(3) There is little agreement among experts on calibrating computer simulation models (i.e., DOE-2, ASEAM). This becomes an issue when one recognizes that many consultants frequently use computer simulations to estimate retrofit energy savings.
(4) There is also little agreement concerning empirical modeling procedures for commercial and institutional buildings. Even less agreement is evident on how to resolve intercorrelated influencing parameters.
(5) A large (i.e., multi-tasking, or Unix-based) data storage system is needed to monitor hundreds of hourly channels and routinely prepare reports for dozens of buildings. DOS-based systems can suffice, and are easier to implement, but quickly run out of memory and disk space, and end up costing about the same as a Unix system.

4. REFERENCES

ACEC 1987. ASEAM 2.1: A Simplified Energy Analysis Method, Version 2.1, American Consulting Engineering Council Research and Management Foundation, Washington, D.C.

Akbari, H., Heinemeier, K., LeConiac, P., and Flora, D. 1988. "An Algorithm to Dis-aggregate Commercial Whole-Building Hourly Electricity Load into End Uses," Proceedings of the 1988 ACEEE Summer Study on Energy Efficiency in Buildings, Volume 10.

Anderson, D., Lincoln, G., Reinert, W., Kreider, J., and Dow, J. 1989. "A Quasi-Real-Time Expert System for Commercial Building HVAC Diagnostics," ASHRAE Transactions, Vol. 95, Part 2.

Claridge, D., Haberl, J., Heffington, W., O'Neal, D., Turner, W.D., 1989. Texas LoanSTAR Monitoring and Analysis Program Work Plan, Submitted to the Texas Governor's Energy Management Center by Texas A&M's Energy Systems Laboratory.

Fels, M. 1986. "Special Issue Devoted to Measuring Energy Savings, The Scorekeeping Approach," Energy and Buildings, Vol. 9, Nos. 1 and 2.

Fracastoro, G. V. and Lyberg, M. D. 1983. Guiding Principles Concerning Design of Experiments, Instrumentation and Measuring Techniques, International Energy Agency and the Swedish Council for Building Research, Stockholm, Sweden.

Haberl, J., and Claridge, D. 1987. "An Expert System for Building Energy Consumption Analysis: Prototype Results," ASHRAE Transactions, V. 93.

Haberl, J., Claridge, D., and Harrje, D. 1990. "The Design of Field Experiments and Demonstrations," Proceedings of the 1990 Field Monitoring Workshop, Gothenburg, Sweden, April.

Haberl, J., and Komor, P. 1989. "Investigating an Analytical Basis for Improving Commercial Building Energy Audits:Early Results from a New Jersey Mall," Proceedings of the Thermal Performance of the Exterior Envelopes of Buildings IV, Sponsored by ASHRAE, DOE, BTECC and CIBSE, December.

Haberl, J. and Vajda, J. 1988. "Use of Metered Data Analysis to Improve Building Operation and Maintenance: Early Results From Two Federal Complexes," Proceedings of the ACEEE 1988 Summer Study, Vol. 3.

Hadley, D. and Tomich, S. 1986. "Multivariate Statistical Assessment of Meteorological Influences on Residential Space Heating," Proceedings of the ACEEE 1986 Summer Study, Vol. 9.

MacDonald, J. M. Sharp, T. R., and Gettings, M. B. 1989. "A Protocol for Monitoring Energy Efficiency Improvements in Commercial and Related Buildings," Oak Ridge National Laboratory Report ORNL/CON-291.

MacDonald M. and Wasserman, D., 1989. "Metered Data Analysis Methods for Commercial and Related Buildings, "Oak Ridge National Laboratory Report ORNL/CON-279.

Press, W. Flannery, B., Teukkolsky, S. and Vetterling, W. 1986. Numerical Recipes: the Art of Scientific Computing, Cambridge, MA, Cambridge University Press.

Reiter, P. 1986. "Early Results From Commercial ELCAP Buildings: Schedules as a Primary Determinant of Load Shapes in the Commercial Sector," ASHRAE Transactions, V. 91, Pt. 2.

Schrock, D., and Claridge, D. 1989. "Predicting Energy Usage in a Supermarket," Proceedings of the Sixth Annual Symposium on Improving Energy Efficiency in Hot and Humid Climates, Texas A&M University

Ternes, M. P. 1987. "Single-Family Building Retrofit Performance Monitoring Protocol: Data Specification Guideline," Oak Ridge National Laboratory Report ORNL/CON-196.

5. ACKNOWLEDGEMENTS

The Texas LoanSTAR program is funded through the Texas Governor's Energy Management Center using oil overcharge funds. We would like to thank our fellow researchers and staff at the Energy Systems Laboratory, including: Srinivas Katipamula, John Bryant, Dean Willis, Melvin Glass, Darin Nutter, Kristel Weber, Angela Britton, Jenny Matson, and an energetic cadre of graduate and undergraduate researchers.

Table 1: Budget Breakdown for First Year Monitoring Program

Task	(Man-months)	Personnel ($)	Travel, Supplies, Etc. ($)	Total ($)
1	29	$103,000	$2,500	$105,500
2	37	$103,000	$4,500	$107,500
3	14	$44,000	$30,000	$74,000
4	21	$59,000	$21,000	$80,000
5	65	$166,000	$105,000	$271,000
TOTAL	166	$475,000	$163,000	$638,000

NOTE: (1) Additional first year costs to establish the MARC were $110,000.
(2) Includes $81,000 for computer hardware and software, plus a 50% in-kind computer hardware, and software contribution by Texas A&M.
(3) Estimated hardware to monitor $26 million in retrofits is $780,000.

Table 2: Approved Retrofits for First Year Implementation

Category Type	# Buildings Effected	Conditioned Square Footage	Type of Retrofit
Office	12	2,610,745	Lighting, outside air mods, EMCS, Variable Freq. Drives (VFD), motion sensors, pump shutdown, rate schedule mods, 2-speed motor, hot water reset, HVAC mods, eddy current VSD, pump & motor mods.
Multipurpose	6	630,307	VAV, fan shutdown, timeclocks, motion sensors, lighting mods, Variable Frequency Drives.
Parking	3	607,247	Lighting, timeclocks, photocells.
Library	3	362,723	Motion sensors, lighting mods, air handler mods, VFD, pump shutoff, night setback.
Classroom	4	344,663	Add chiller, expand EMCS, VFD, lighting mods, motion sensors, outside air mods.
Gymnasium	2	139,063	Lighting, VFD.
Laboratory	1	125,000	Heat recovery.
Dormitory	3	116,408	Motion sensors, lighting mods, VFD, thermostats, add chiller.
Phys. Plant	3	19, 636	Add chiller, DDC, EMCS, renovate pump system, steam shut-down, replace boiler.
Other	2	92,450	Outside air mods, VFD, replace rooftop unit w/ new chiller.
	----	---------	
TOTAL	40	5,064,040	

Total Estimated Savings = $1,209,221 (Combined payback 3.5 years)

Total Estimated Cost = $4,241,667

Table 3: Guidelines for First Year Monitoring Costs

Monitoring Level:	Retrofit Amount:	Annual Energy Costs:	Monitoring Costs:
Level 0: (Utility data)	$20k - $50k	$10k - $30k	$0
Level 1: (1 - 4 channels)	$50k -$100k	$30k - $60k	$3k
Level 2: (4 - 20 channels)	$100k - $300k	$60k- -$200k	$10k
Level 3: (20+ channels)	$300k+	$500k+	$30k+

Table 4: First-Year Monitoring Estimates

Level	Number Channels (@ site)	Number of Buildings	Total Sq.ft.	ECRMS Being Monitored
1	1 to 6	14	1,750,000	VAV, lighting, Variable Speed Pumps, economizers, EMCS.
2	8 to 16	4	250,000	VAV, lighting, VSP.
3	30 to 50	8	750,000	VAV, boiler mods, chiller mods, VSP, EMCS.
TOTAL	410	26	2,750,000	

NOTE: (1) The average cost per channel is about $1500. The thermal metering and large aggregation of electrical panels can raise the price per channel significantly.
(2) Typical installation time is about 6 to 10 weeks from the approval of the loan by the GEMC.

Figure 1: LoanSTAR Monitoring and Analysis Task Planning

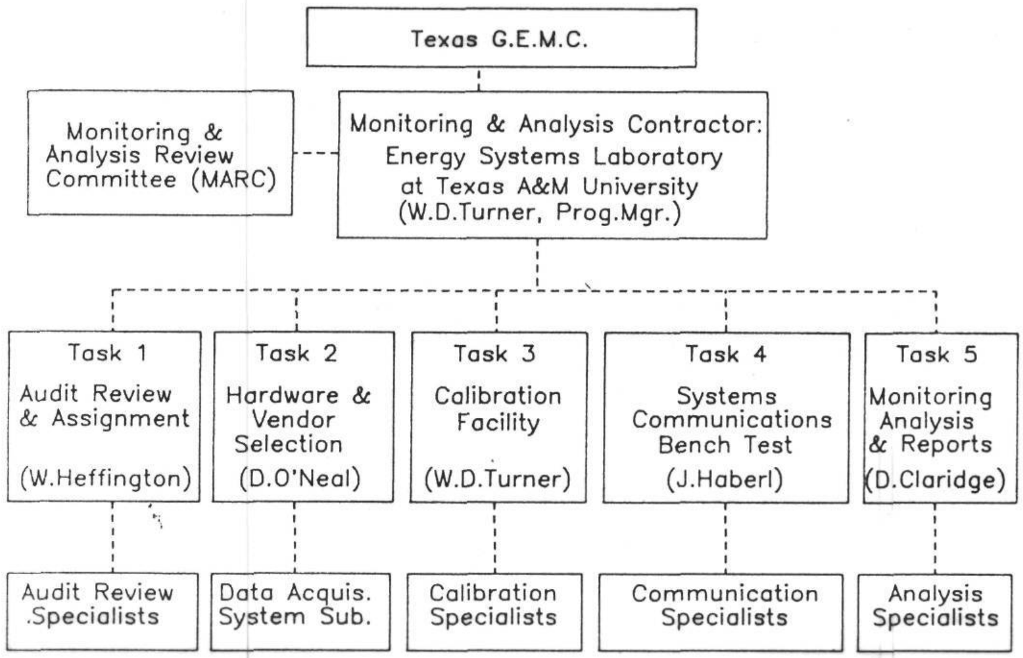
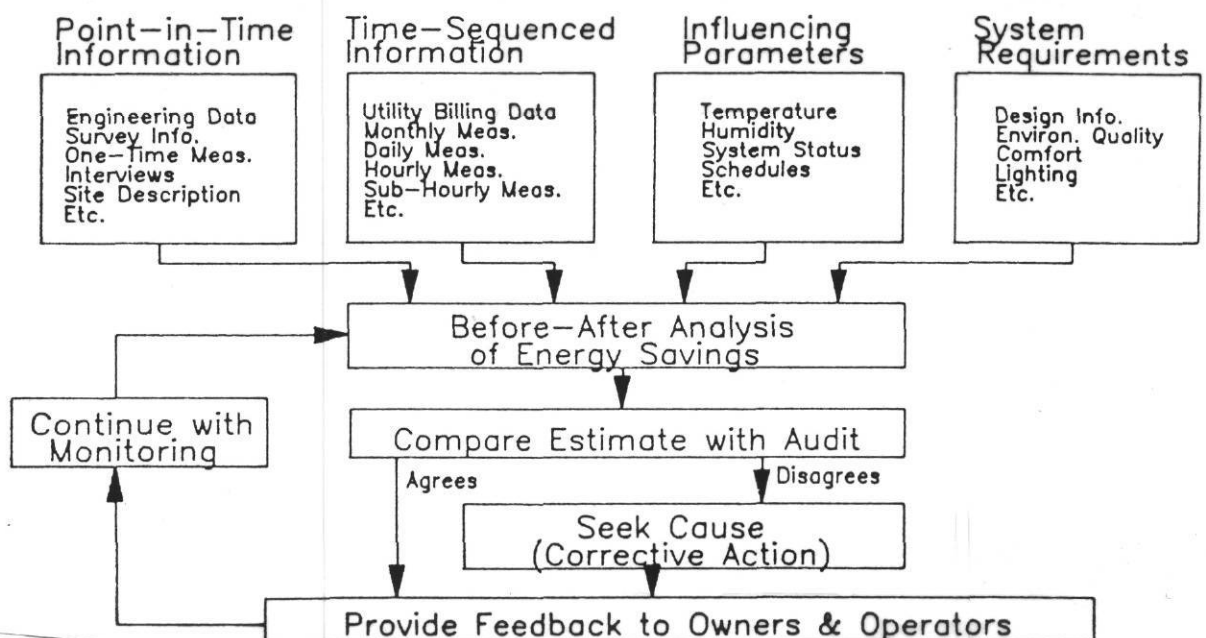


Figure 2: Before-After Analysis of Energy Conservation Retrofit Savings



RESEARCH NEWS

Research news will include the following topics:

- Current Activities
- New Releases
  - Publications, Software, and Databases
- People in Research
- National and Laboratory Research Plans
- News from Other Societies

Current Activities

The Texas LoanSTAR Monitoring and Analysis Program: A Brief Introduction

Jeff Haberl, David Claridge, Dennis O'Neal, Warren Heffington, W. Dan Turner, Texas A&M University; Malcolm Verdict, Texas Governor's Energy Management Center

The Texas LoanSTAR program is an eight year, $98 million revolving loan program for energy conservation retrofits in Texas state, local government and school buildings funded by oil overcharge dollars. Public sector institutions participating in the program must repay the loans according to estimated energy savings in four years or less. As part of this program a statewide Monitoring and Analysis Program (MAP) has been established.

The major objectives of the LoanSTAR MAP are to: 1) verify energy and dollar savings of the retrofits, 2) reduce energy costs by identifying operational and maintenance improvements, 3) improve retrofit selection in future rounds of the LoanSTAR program, and 4) initiate a data base of energy use in commercial and institutional buildings located in Texas.

In 1988, the Governor's Energy Management Center (GEMC) of Texas received approval from the U.S. Department of Energy to establish a $98.6 million statewide retrofit demonstration revolving loan program, the LoanSTAR (Loan to Save Taxes and Resources) Program. The LoanSTAR program uses a revolving loan financing mechanism to fund energy-conserving retrofits of state, public school and local government buildings. Retrofit projects are identified by energy audits conducted by engineering teams under contract to the GEMC. Each retrofit competes for funds on the basis of the estimated payback period, ability to repay the loan through energy savings, engineering assessment of the viability of the retrofit, and the staff's ability to monitor the project effectively.

The projects funded by LoanSTAR primarily include retrofits to lighting, HVAC systems, building shell, electric motors, energy management and control systems (EMCS), and boilers and thermal energy recovery systems. Retrofits using alternative or renewable energy systems and load management are also being considered.

The LoanSTAR MAP is administered through the Governor's Energy Management Center (GEMC) and conducted primarily at the Energy Systems Laboratory at Texas A&M University. A Monitoring and Analysis Review Committee (MARC) has been established to provide ongoing contact with other monitoring and analysis efforts to ensure incorporation of applicable techniques and results from those efforts.

The primary work for the MAP has been divided into 5 tasks which include: Task 1) the audit review and assignments, Task 2) hardware selection and installation, Task 3) a calibration facility, Task 4) systems communications bench test, and Task 5) monitoring analysis and reporting.

Table 1 presents monitoring progress statistics through April 1990. About 245 channels of hourly information are scheduled for installation to record data from 30 sites encompassing 4,250,000 square feet of conditioned space.

In order to facilitate communications with any manufacturer's field data recorder the LoanSTAR program is developing a public domain Data Recorder Management System (DRMS). Figure 1 illustrates the conceptual structure of the Data Recorder Management System (DRMS). The DRMS will perform several functions, including: programming of field recorders, scheduling the polling calls, and translation of commands and data records for different manufacturers' recorders. Common-format data from the DRMS are then passed into the storage processing system where permanent and on-line storage are maintained. The on-line storage will be a SQL-based Relational Data Base Management System (RDBMS) to facilitate easy retrieval of the heterogeneous data.

The engineering savings estimates for the LoanSTAR retrofit measures rely on numerous assumptions made by the auditors. Some of the most crucial estimates are the electrical gains, building schedules, and lighting schedules. One way to improve energy audit assumptions is through the use of calibrated computer models. A procedure is being developed for "calibrating" the inputs used by the DOE-2 building simulation program to actual buildings. Similar "calibration" procedures for less detailed programs, such as ASEAM, are also being investigated.

The design of the monitoring program is meant to measure and evaluate the ingredients (fuels being consumed), products (comfort, illumination, etc.), and influencing parameters (weather, schedules, etc.) of a building's energy usage.

There are many different ways of designing an experiment to measure the energy savings from an energy conservation retrofit. Because of the diversity of the types of experiments being monitored in the LoanSTAR program, each building will have its own experiment plan. In general the experiments will rely either on the measurement of energy consumed directly at the retrofit device (sub-metered) or at the whole-building boundary.

Figure 2 illustrates a typical before-after analysis of retrofit savings. For each site before-after, point-in-time, and time-sequence information measuring the influencing parameters and system requirements are evaluated to determine if energy savings match those of the audit estimates. Corrective measures, if needed, and feedback to owners and operators is also planned.

Detailed reports concerning the LoanSTAR program, availability of metered data, and software developed can be obtained from the authors. The first year efforts include the monitoring of hourly data from over two-dozen buildings using microcomputer-based field recorders supplied by several different manufacturers. Future efforts include investigating the feasibility of utilizing EMCS-based monitoring and data-sharing with the HVAC service industry to reduce monitoring costs and expanding the program into additional sites.

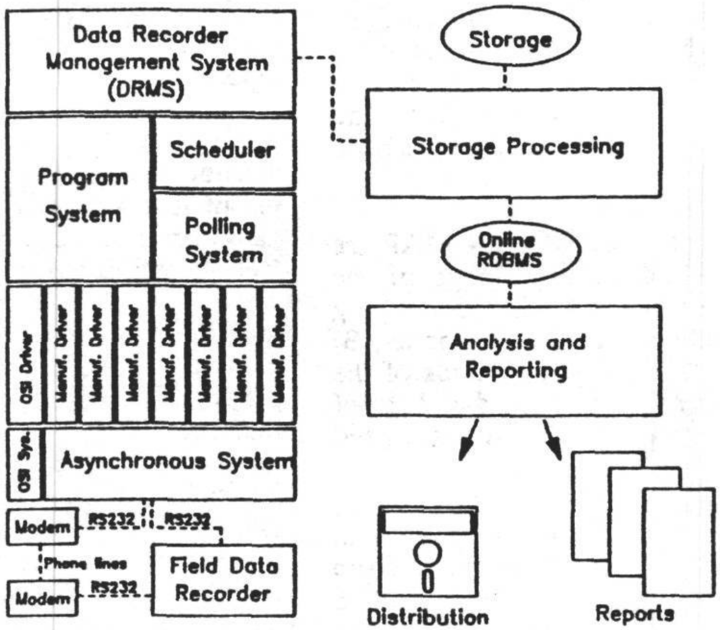


Figure 1. LoanSTAR Data Recorder Management System (DRMS). A schematic figure of the Data Recorder Management System is shown in this figure. Data are retrieved periodically from various field recorders via RS232 or modem using the appropriate manufacturer's driver. Once the data are translated to a common format they are then stored for analysis and reporting in a Relational Data Base Management System (RDBMS).

Table 1. LoanSTAR MAP First-Year Monitoring Estimates.

This table contains figures for the monitoring efforts through April 1990. The number of channels represents the approximate number of channels being recorded at each site. The square footage is the total for each monitoring level.

Monitoring Level	Number of Channels	Number of Buildings	Total Sqft.	ECRMs Being Monitored.
1	1 to 6	14	2,450,000	VAV, lighting, Variable Speed Pumps, economizers, EMCS.
2	8 to 16	12	1,050,000	VAV, lighting, VSP.
3	30 to 50	4	750,000	VAV, boiler mods, chiller mods, VSP, EMCS.
TOTAL	245	30	4,250,000	

NOTES:
1. The average cost per channel is about $1,300. Thermal metering and large aggregations of electrical panels can raise the price per channel significantly.
2. Typical installation time is about 6 weeks from the approval of the loan by the GEMC.

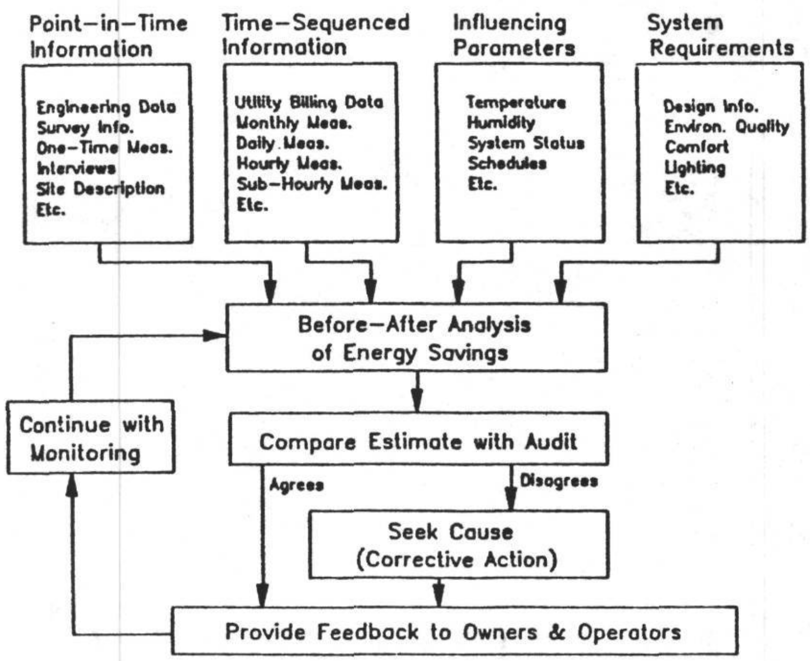


Figure 2. Before-After Analysis of Energy Conservation Retrofit Savings. This flowchart illustrates the before-after analysis of retrofit savings. For each site before-after point-in-time and time-sequenced information, influencing parameters, and system requirements are evaluated to determine if energy savings match those of the audit estimates. Corrective measures (if needed) and feedback to owners and operators is also provided.